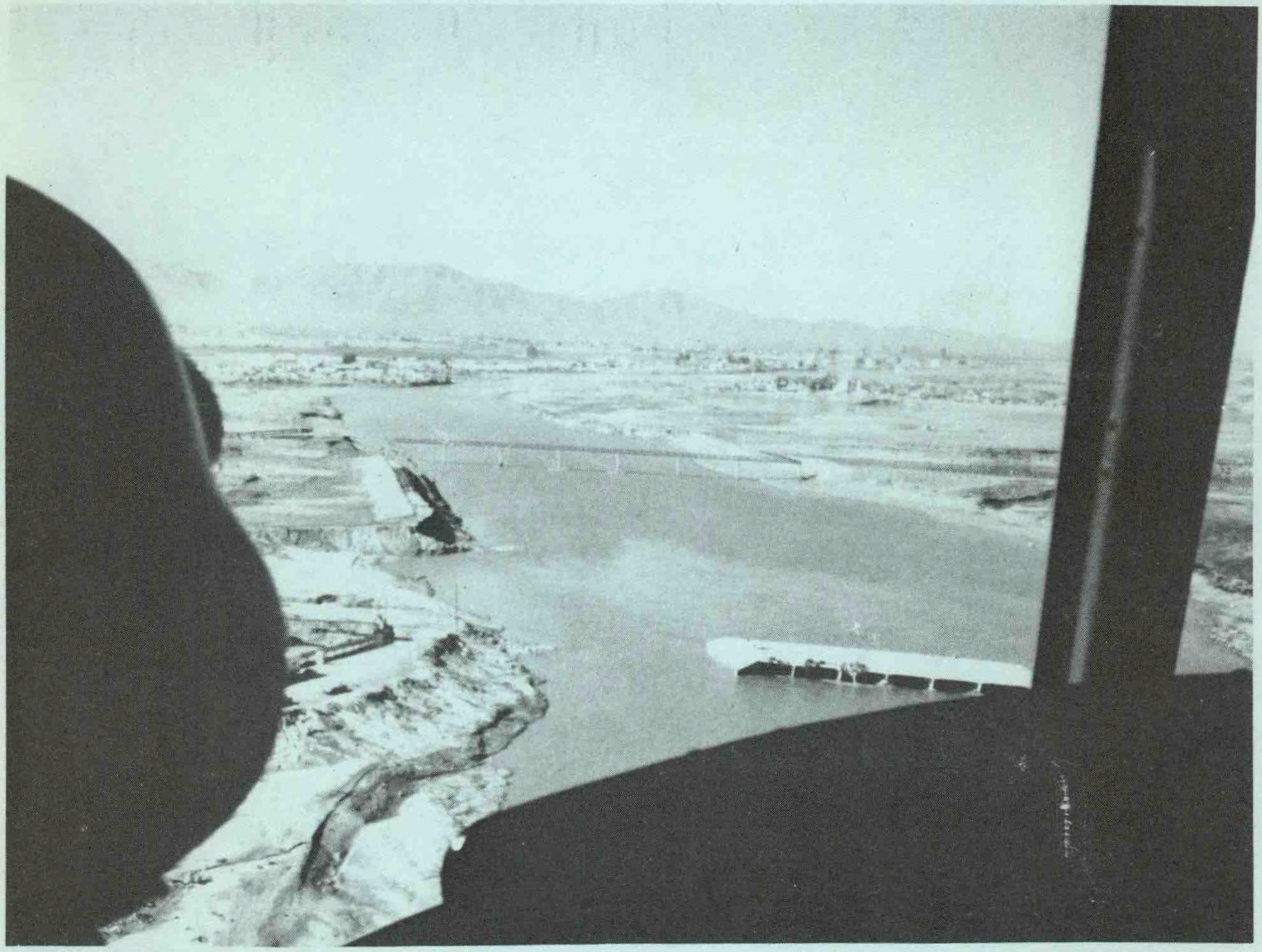
Natural Disaster Survey Report NWS-81-1

The Disastrous Southern California and Central Arizona Floods, Flash Floods, and Mudslides of February 1980

A Report to the Administrator



U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Md.

March 1981

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

COVER
Aerial view of the flood aftermath from the flooded Salt River showing a washed-out section of one of the principal bridges crossing the Salt River in Phoenix. (Photo taken from Army National Guard Helicopter.)

NATURAL DISASTER SURVEY REPORT NWS 81-1

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A REPORT TO THE ADMINISTRATOR

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U. S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
James P. Walsh, Acting Administrator

National Weather Service
Richard E. Hallgren, Director

FOREWORD

The National Weather Service (NWS) is one of the major line components of the Oceanic and Atmospheric Services of the National Oceanic and Atmospheric Administration (NOAA). The Congressional Organic Act of October 1, 1890, and subsequent reorganizations, assigned to the Weather Bureau the duties of "...the forecasting of weather, the issuing of storm warnings, the display of weather and flood signals for the benefit of agriculture, commerce, and navigation, the gauging and reporting of rivers..." The NWS, the successor to the Weather Bureau, has made great strides since 1890 in developing a comprehensive Weather and Flood Warning System for the Nation. However, since no system ever reaches perfection, it is important that we continue to search for ways to improve the NWS System so that the ever-increasing requirements of the future can be met. Under NOAA policy a survey team will be formed to review major weather related disasters and produce a written report of findings along with recommendations for correcting any deficiencies.

A survey team was dispatched to the affected areas as recovery operations were underway in Southern California and Central Arizona following the disastrous floods, flash floods, and mudslides of February 1980. The team was to review all aspects of the Weather and Flood Warning System, from the acquisition of data inputs to the dissemination of the warnings. (Even the best of warnings is of no value if it is not disseminated and acted upon.)

The success of any warning system depends on the full cooperation of the local officials, the broadcast media, and the public. I would like to thank the numerous individuals in each of these groups in Southern California and Central Arizona who participated in vital dissemination and response functions during the storms. Many of these same people also assisted the survey team members in carrying out their evaluation of the Warning System. The findings and recommendations of the survey team will contribute significantly to identifying areas which need improvement in the future.

Richard E. Hallgren, Director
National Weather Service

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES AND TABLES

Figures

LIST OF FIGURES AND TABLES

Tables

ABBREVIATIONS AND ACRONYMS

AFFIRMS	Automated Forest Fire Information Retrieval and Management System
AFOS	Automation of Field Operations and Services
AHOS/S	Automatic Hydrologic Observation Station/Satellite Interrogated
AHOS/T	Automatic Hydrologic Observation Station/Telemetered
AMOS	Automatic Meteorological Observing Station
AP	Airport
ARTC	Air Route Traffic Control
ARTCC	Air Route Traffic Control Center
AUTOB	Automatic Observation Station
BDT	Binary to Decimal Transmitter
BRNC2	Call-Letter Identifier for Boron, California (FAA ARTC Radar)
CAHDMA	Central Arizona Hydrometeorological Data Management Association
CDES	Civil Defense and Emergency Services
CENTREX	Central Exchange (Mountain Bell Telephone Company)
cfs	Cubic feet per second
CLETS	California Law Enforcement Telecommunication System
COE	Corps of Engineers
DARDC	Device for Automatic Remote Data Collection
DEMS	Department of Emergency and Military Services
DIFAX	Digital Facsimile
DMIC	Deputy Meteorologist-in-Charge
DPS	Department of Public Safety
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Administration
FLG	Call-Letter Identifier for Flagstaff, Arizona
FP1	Message Header Identifier for State Forecast

FSS	Flight Service Station
FTS	Federal Telephone System
FWO	Flood Warning Office
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
HPB	Heavy Precipitation Branch
HSA	Hydrologic Service Area
INW	Call-Letter Identifier for Winslow, Arizona
KCRT	Keyboard Cathode Ray Tube
kn	Knots -- nautical miles per hour
LAS	Call-Letter Identifier for Las Vegas, Nevada
LAWRS	Limited Aviation Weather Reporting Station
LAX	Call-Letter Identifier for Los Angeles, California
LFM	Limited Fine Mesh
LVGN2	Call-Letter Identifier for Las Vegas, Nevada (FAA ARTC Radar)
LWR	NWS Local Warning Radar
MARS	Marine Reporting Station
mb	Millibar
MHz	Megahertz
MIC	Meteorologist-in-Charge
MLAC1	Call-Letter Identifier for Mt. Laguna, California (FAA ARTC Radar)
MND	Mass News Disseminators
MNM	Mass News Media
MOS	Model Output Statistics
msl	Mean sea level
MST	Mountain Standard Time
NAFAX	National Facsimile
NAWAS	National Warning System

NESS	National Environmental Satellite Service; now called National Earth Satellite Service
nm	Nautical miles
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
NWR	NOAA Weather Radio
NWS	National Weather Service
NWWS	NOAA Weather Wire Service
OES	Office of Emergency Services
PE	Primitive Equation Atmospheric Model
PHX	Call-Letter Identifier for Phoenix, Arizona
PMD	Call-Letter Identifier for Palmdale, California
POP	Probability of Precipitation
PROC1	Call-Letter Identifier for Paso Robles, California (FAA ARTC Radar)
PVA	Positive Vorticity Advection
QPB	Quantitative Precipitation Branch
QPF	Quantitative Precipitation Forecast
RAFAX	Radar Facsimile
RAMOS(MED)	Remote Automatic Meteorological Observation Station with Manual Entry Device
RAWARC	Radar and Warning Coordination Circuit
RFC	River Forecast Center
SAC	Call-Letter Identifier for Sacramento, California
SAN	Call-Letter Identifier for San Diego, California
SAWRS	Supplementary Aviation Weather Reporting Station
SCS	Soil Conservation Service
SELS	Severe Local Storms
SFO	Call-Letter Identifier for San Francisco, California

SFSS	Satellite Field Services Station
SIM	Satellite Interpretation Message
SLC	Call-Letter Identifier for Salt Lake City, Utah
SMX	Call-Letter Identifier for Santa Maria, California
SNOTEL	Snow Survey Telemetry (SCS Data System)
SPEC1	Call-Letter Identifier for San Pedro, California (FAA ARTC Radar)
SRP	Salt River Project
STC	Sensitivity Time Control
UNIFAX	Trade name for digital facsimile machine used to receive GOES satellite pictures
USAF	United States Air Force
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USMC	United States Marine Corps
USN	United States Navy
WPRS	Water and Power Resources Service
WSFO	Weather Service Forecast Office
WSO	Weather Service Office
WSO(R)	Weather Service Office attached to FAA ARTCC for weather radar support

PREFACE

From February 13 through 21, 1980, a series of heavy rainstorms produced flash floods and widespread flooding in many areas of Southern California and Central Arizona. Southern California also was plagued by mudslides caused by the persistent heavy rains. A disaster survey team, formed on February 21, visited the affected areas during the week of February 24 to review the NOAA Weather and Flood Warning System. The purpose of the review was to determine the effectiveness of the NOAA System and to recommend improvements for the future if deficiencies were found. All aspects of the System, ranging from data acquisition to user response, were to be considered. This report describes the results and findings assembled by the survey team.

The survey team was comprised of the following members:

Michael D. Hudlow, Team Leader and Deputy Director, Hydrologic Research Laboratory, NWS Headquarters, Silver Spring, Maryland

Richard I. Coleman, Assistant Team Leader for Southern California and Warnings Program Leader, NWS Headquarters, Silver Spring, Maryland

Donald E. Witten, NOAA/NWS Public Affairs Officer, NWS Headquarters, Silver Spring, Maryland

Richard J. Hutcheon, Assistant Chief, Meteorological Services Division, NWS, Western Region Headquarters, Salt Lake City, Utah

Herbert P. Benner, Executive Officer, NWS Western Region Headquarters, Salt Lake City, Utah

George R. Miller, Chief, Data Acquisition Division, Western Region Headquarters, Salt Lake City, Utah

Gerald Williams, Hydrologist-in-Charge, NWS Colorado Basin River Forecast Center, Salt Lake City, Utah

Ira Bartfeld, Flash Flood Hydrologist, NWS California-Nevada River Forecast Center, Sacramento, California

Claire D. Jensen, Meteorologist-in-Charge, National Weather Service Forecast Office, Phoenix, Arizona

Carlos Garza, Jr., Deputy Meteorologist-in-Charge, National Weather Service Forecast Office, Los Angeles, California

H. James Owen, Principal, Flood Loss Reduction Associates, Palo Alto, California

The team was divided into two groups so that the diverse geographic areas could be covered in the allotted time. One group, composed of Hudlow, Miller, Williams, and Jensen, concentrated on Central Arizona; the other team members concentrated on Southern California. The two groups coordinated their reviews by telephone. Benner and Witten also visited the Phoenix area on the last 2 days of the survey. Most members of both groups arrived in time to begin their reviews on February 25. Both groups devoted the early part of the survey period to reviewing the forecasts and warnings issued by the Weather Service Forecast Offices, to discussions and interviews with relevant parties, and to surveys of damage in the greater metropolitan areas of Los Angeles and Phoenix. Actions were initiated also to acquire, for postanalyses, additional rain-gage data from various existing sources that may not have been reported previously, although no attempt was made to conduct comprehensive "bucket surveys," which would have included retrieval of data from unofficial recorders such as buckets, jars, etc.

Visits to Weather Service Offices and selected sites affected by the series of storms outside the metropolitan areas took place later in the week. For example, the Central Arizona group took a field trip by automobile on February 27 to survey damage, to interview citizens in the Oak Creek Canyon area, and to review operations at the Flagstaff Weather Service Office. The onsite review of the field activities by both groups was completed on February 29. However, substantial followup was required by correspondence and telephone to assemble and verify all of the information needed for this report.

The consensus of the survey team was that the NOAA Weather and Flood Warning System performed well overall, but several deficiencies were identified. The sucessful features of the System, as well as recommended improvements in System deficiencies, are discussed in subsequent sections of this report.

Mike Hudlow

Michael D. Hudlow
Team Leader

EXECUTIVE SUMMARY

REPORT ON THE DISASTROUS SOUTHERN CALIFORNIA AND CENTRAL ARIZONA FLOODS, FLASH FLOODS, AND MUDSLIDES OF FEBRUARY 1980

For 9 days during mid-February 1980, the southwestern United States was battered by a series of heavy rainstorms. Meteorological conditions from February 12 to 21 produced a strong zonal flow of moist air from the coast of Asia to California. The jetstream persisted far south, with the strongest associated atmospheric instabilities lying between latitudes 25°N and 35°N. Storm centers were continually generated on the polar side of the jetstream in the 35°N to 42°N latitude belt. Sometimes as many as three significant organized cloud masses, lined up in sequence off the coast of California, could be seen on the satellite pictures. These storms moved rapidly eastward toward the coast and across Southern California and Central Arizona. The long fetch over the warm ocean at low latitudes resulted in storm systems that were warmer and more moist than normal.

Cloud masses associated with widespread convection caused extended periods of heavy rainfall. Over the 9-day period from February 13 through 21, 5 inches or more of rain fell over most of Southern California's coastal valleys, and the coastal mountains received considerably more as a result of orographic lifting, with totals exceeding 15 inches over many areas. Some areas of the San Gabriel and Laguna Mountains received locally heavy rainfall amounts in excess of 25 inches. For example, rainfall accumulations for the 9-day period from February 13 through 21 at the Mt. Wilson station and at Lytle Creek near Mt. San Antonio were 30.71 and 30.86 inches, respectively. The month of February 1980 was described as one of the wettest Februarys in Southern California's history.

Rainfall amounts from February 13 through 21 in Central Arizona ranged from 1 to over 16 inches. Crown King, Arizona received a <u>9-day total</u> of 16.63 inches, which was only 0.32 inches less than the highest <u>monthly total</u> of record for any site in Arizona. This heavy rainfall followed two extremely wet years. As a result, most reservoirs in Arizona were nearly full at the beginning of the sequence of storms and could not store all the runoff.

The large rainfall amounts produced floods and flash floods in many areas of Southern California and Central Arizona. The antecedent soil moisture conditions and extended rain periods led to runoff amounts that significantly exceeded stream, levee, and reservoir capacities. In addition to widespread flooding, mudslides caused by the persistent heavy rains were a major problem in Southern California.

Overall, the NOAA warning systems worked well in both California and Arizona. The Los Angeles Weather Service Forecast Office (WSFO) issued watches, warnings, and statements well in advance of flooding, flash flooding, and mudslides. The Phoenix WSFO also issued timely flood/flash-flood watches, warnings, and statements. The issuances from both offices were well worded and contained specific action statements. All indications are that the NOAA services contributed significantly to reducing property losses and probably deaths. Nevertheless, 21 people died as a <u>direct</u> result of flooding, flash flooding, and mudslides; and total property damage in the two states topped $400 million.

Part of these losses might have been prevented if, in some cases, more effective action had been taken on the part of the public. One factor that apparently contributed to citizen inaction during this disaster, as well as in several previous disasters associated with heavy convective rainfall, was the inability to give, in the warning statements, a more precise description of the rainfall in space and time. This was a problem especially in the heavily populated foothills of the Los Angeles suburbs, where complexity of the terrain (for example, narrow canyons) made it impossible, within the present state of the art, to pinpoint the localized heavy rainfall accurately enough to issue timely warnings for individual sites.

Steps can and should be taken to improve rainfall observing networks. Some of these are discussed in subsequent parts of this report. It may be some time before completely adequate rainfall measurements and accurate site-specific rainfall forecasts become available. Therefore, it is critical that comprehensive preparedness/response plans provide for action to be taken when a significant potential for disaster exists somewhere within a general area even though site-specific information may not be available.

The February 1980 disaster episodes provide the opportunity to evaluate the emergency preparedness structures in two complex urban environments having similarities as well as distinct differences: 1) a very large megalopolis (Los Angeles), and 2) a large metropolitan area (Phoenix). As a result of onsite inspections, interviews, and postanalyses, the Survey Team arrived at several specific findings and recommendations pertaining to various aspects of the total warning/response systems, including the emergency preparedness components. Many of the findings and recommendations pertain not only to the Los Angeles and Phoenix urban areas, but also to other parts of Southern California and Central Arizona. Findings and recommendations, which are based on material in chapters 4 through 6 and expand on the general observations discussed above, follow in sequential order.

FINDINGS AND RECOMMENDATIONS

Findings and Recommendations Pertaining to:

Quality of Forecasts and Office Operations

Finding 4.1: The Numerical Weather Prediction (NWP) guidance products from the National Meteorological Center (NMC) in Camp Springs, Maryland, generally were very useful. Deficiencies, especially in the Limited Fine Mesh (LFM) model guidance, appeared to result primarily from boundary and initial condition problems.

Recommendation 4.1: The NMC should continue to give high priority to improving procedures for specifying initial and boundary conditions for the LFM model in the eastern Pacific.

Finding 4.2: The NMC Probability of Precipitation (POP) guidance derived from Model Output Statistics (MOS) was of mixed usefulness.

Recommendation 4.2: The POP products for this series of storms should be further evaluated in light of all other information to determine why the guidance was not of consistent quality throughout the series of storms and why, although areas of higher POP probabilities generally were significantly correlated with main rain areas, the probabilities usually were much too low during crucial parts of the rainy periods.

Finding 4.3: Quantitative Precipitation Forecasts (QPF's), issued by the Quantitative Precipitation Branch (QPB)* of the NMC, provided useful guidance to the forecast offices on when to expect significant rainfall events and on the general area of rainfall coverage. However, because of orographic and other local influences, the predicted quantitative amounts often differed considerably from the actual amounts. Realizing the likelihood of such a disparity, the lead forecasters at the Weather Service Forecast Offices (WSFO's) integrated information from all other available sources and, sometimes in consultation with the QPB, applied their personal knowledge in arriving at localized QPF's. Combined use of centrally prepared QPF guidance and QPF's tailored to the specific areas by the local forecaster will continue to be the preferred mode of operation.

Recommendation 4.3: None

Finding 4.4: One of the significant problems faced by the QPB of NMC in improving their QPF's, especially in the West, is a severe lack of rainfall observations. Another problem, affecting the accuracy of the excessive rainfall potential outlooks, was the lack of adequate flash-flood guidance values.

Recommendation 4.4: It is recommended that the Office of Hydrology and the QPB, working with other NOAA components including Western Region elements of the NWS, develop the required mechanisms to "build" a near real-time rainfall file on the NOAA central computer facility. This National file, which should include data for time intervals of six hours or shorter when available, would be accessible by the River Forecast Centers (RFC's) and the QPB as well as by other users. Also, investigations should be made of ways to improve the physical basis of flash-flood guidance criteria and to standardize the format of flash-flood guidance values, which would facilitate development of consistent and meaningful guidance criteria for various sections of the country.

Finding 4.5: Satellite data from the western Geostationary Operational Environmental Satellite (GOES) were fundamental to the production of high-quality forecasts by both the Los Angeles and Phoenix WSFO's. However, forecasters at both locations stated that, while the satellite pictures were indispensable, an even better understanding of the synoptic situation could have been achieved with animated satellite imagery.

Recommendation 4.5: The NWS should proceed to acquire satellite-display equipment that provides the forecaster with the capability of displaying GOES images in time-lapse sequence and of overlaying other graphics and observations on the satellite imagery.

Finding 4.6: The quality of the forecasts and advisories issued by the Los Angeles and Phoenix WSFO's was exceptionally good. A steady flow of statements from both forecast offices was a major factor in keeping the media abreast of changing conditions. The public and specialized users were advised of the threat of rain at least 2 days in advance. This advice was updated as it became clear that heavy rain would occur over a long span of time. Generally, both offices issued many well-worded statements providing citizens and public officials in the affected area with as much information as was available. In a few instances, however, the statements could have

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*Now called the Heavy Precipitation Branch (HPB).

been further improved by the use of simpler, non-technical words and shorter phrases and by placing the most important informational and action sentence(s) immediately after the lead sentence, i.e., news-style writing is generally more readily comprehended.

Recommendation 4.6: Clear, succinct news-style writing should be employed consistently.

Finding 4.7: Overall operational performance (including quality of forecasts and adherence to established operational procedures) of the NWS forecast offices in the affected areas was very good. Personnel at the Santa Maria and San Diego Weather Service Offices (WSO's) in California, and the Flagstaff and Winslow WSO's in Arizona, also performed effectively throughout the storm.

Recommendation 4.7: See Recommendation 4.11.

Finding 4.8: The Los Angeles WSFO, which has Hydrologic Service Area (HSA) responsibility for Southern California, did issue numerous flash flood statements and watches and also issued flash flood warnings as conditions dictated. However, no advisories explicitly concerning river conditions were issued during the storm series. While flood forecasting procedures have been developed by the Sacramento RFC* for most major Southern California rivers, lack of real-time rainfall data has prevented their operational implementation. In pursuit of ways to enhance the river forecast services in Southern California, the Sacramento RFC has worked extensively with Ventura County since the 1978 floods to provide a real-time flood warning system in that area.

Recommendation 4.8: The Sacramento RFC should continue, in cooperation with State and local agencies, the development of flood forecasting procedures and warning systems for critical streams and rivers in Southern California so that forecasts of flow rates and/or stages can be provided to the Los Angeles WSFO and other NWS offices as appropriate. This information should enable advisories to be issued by the Los Angeles WSFO (and other offices when appropriate) on conditions of specific rivers during future flood events.

Finding 4.9: The Palmdale WSO(R) provided excellent assistance to NWS offices with warning responsibility by providing information and advice based on data from the Federal Aviation Administration's (FAA) Air Route Traffic Control (ARTC) radars.

Recommendation 4.9: See Recommendation 4.11.

Finding 4.10: Flood advisories issued by the Salt Lake City RFC** were timely and accurate. Users were advised well in advance that near-record or record flooding would occur. For a few of the issuances, however, the formats were at variance with proper forecast format. For example, incorrect or incomplete header and identification information appeared in a few instances.

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*Now called the California-Nevada RFC.

**Now called the Colorado River Basin RFC.

Recommendation 4.10: The NWS offices should ensure that all forecasters are instructed to adhere carefully to proper forecast format, even when the pressure is great to disseminate a forecast quickly.

Finding 4.11: Coordination among offices in the affected areas was very good. As evidenced by logs kept at the offices, frequent coordination occurred between WSFO's and WSO's, WSFO's and RFC's, and WSFO's and the Satellite Field Services Station (SFSS) in San Francisco. There was coordination also between the WSFO's and the QPB.

Recommendation 4.11: In view of Findings 4.6 through 4.11, NWS offices in the affected areas should be appropriately commended for their actions.

Finding 4.12: The FAA ARTC radar-scope depictions of the affected storm areas were extremely valuable in delineating areas of significant rain. Excellent cooperation was received from the FAA controllers and the technicians at the FAA radar sites in providing optimum weather detection capability with the FAA radars whenever possible.

Recommendation 4.12: A letter of commendation should be sent to the FAA by the Director of the NWS.

Finding 4.13: The QPF's derived by the Phoenix WSFO were extremely valuable as inputs to the hydrologic forecast procedures used by the Salt Lake City RFC. The QPF's could have been of even greater utility had they been more geographically specific and at a finer time resolution. (Daily values generally were provided.)

Recommendation 4.13: QPF's should be made as geographically specific as the state of the art allows and should be generated for durations shorter than 24 hours. (Six-hourly QPF's are recommended to provide compatibility with the basic computational time step currently used by the RFC's.)

Finding 4.14: The river forecasts issued by the Salt Lake City RFC generally predicted the flood crests to occur somewhat later than they actually did.

Recommendation 4.14: The Salt Lake City RFC should determine more precisely how much of the error in the "timing" of the crest predictions can be attributed to errors in the mean areal precipitation inputs. Also, the hydrologic model and its calibration should be reevaluated in light of the latest flood events to determine whether a portion of the "timing" error might be attributable to the model.

Finding 4.15: The QPF's provided to the Salt Lake City RFC by the Phoenix WSFO were remarkably accurate for several of the days. However, in some instances, decisions were made to alter the QPF's based on evaluation of outputs from the hydrologic model and/or on other physical (hydrometeorological) evidence. The ability to perform such evaluations expeditiously, using computerized techniques, could be even more critical in future storms for those situations with large inherent errors in the QPF's.

Recommendation 4.15: NWS personnel involved in the derivation and use of QPF's should work together to develop software for implementing computerized procedures whereby certain physical consistency checks can be made before the final QPF values are released. For example, significantly overestimated magnitudes and/or spatially smeared QPF values may be identified because they can result in runoff amounts that would produce physically impossible or unrealistic streamflow estimates.

Findings and Recommendations Pertaining to:

Data Acquisition and Communication

Finding 5.1: Only a very limited amount of feedback as to actual mudslide and flash flood conditions was available to the Los Angeles WSFO during the series of storms, mainly from the Mass News Disseminators (MND).

Recommendation 5.1: The Los Angeles WSFO should accelerate its effort to recruit and train additional HAM radio operators and flash-flood spotters and should continue the development of interfaces with local and county officials, which will assure additional direct feedback during disasters.

Finding 5.2: The failure of some residents, particularly in the Los Angeles area, to recognize the danger of imminent flooding was due in part to the lack of site specificity in the NWS warnings. This resulted primarily from a lack of sufficient real-time rainfall data and from the limits imposed by the state of the art of quantitative precipitation forecasting.

Recommendation 5.2: See Recommendations 5.3, 5.4, 5.8, 5.10, and 5.11.

Finding 5.3: The Los Angeles District of the Corps of Engineers (COE) routinely collects real-time hydrometeorological data from various locations. Although the interrogation system used has some limitations for applications in quick-response watersheds, such as many of those in Southern California, the availability of the data at the Los Angeles WSFO would have been useful and may have enabled greater geographic specificity in warnings for some areas. The equipment needed for receiving these data was in place at the NWS and COE offices, but the computer software required at the COE office to relay the data to the NWS offices was not available.

Recommendation 5.3: The NWS should complete arrangements for access to these data so that their utility can be evaluated before the next major floods occur.

Finding 5.4: Event-reporting radio rain gages in Ventura County, California, installed as part of an automated flood recognition system, provided excellent real-time data to county officials in affected areas of that county and allowed for effective action to be initiated on the part of local officials to protect life and property. However, data from these gages were not available to the forecasters at the Los Angeles WSFO, because a terminal suitable for accessing the computer data base was not available.

Recommendation 5.4: The Los Angeles and Phoenix WSFO's and the Salt Lake City RFC, with the assistance of Western Region Headquarters, should ensure that all real-time data collected by other agencies are identified, and should obtain the hardware and software necessary for acquiring all existing real-time data. Other non-Federal parties should be encouraged to install automated sensors similar to the ones in Ventura County, provided that such sensors are advantageous and that simpler flood recognition systems will not suffice. Especially important are locations highly vulnerable to flash flooding. This general recommendation should not preempt Recommendation 5.3, which pertains to a specific problem to be pursued by NWS.

Finding 5.5: In Arizona, as was the case for many areas in Southern California, the density of real-time rain-gage reports was very inadequate throughout the series of storms. The shortage of data was aggravated by the fact that some of the existing "real-time" rainfall and river gages malfunctioned, were late in reporting, or reported erroneous data at critical times. Consequently, fewer than 20 rainfall reporting stations were available in real time to cover more than 65,000 square kilometers in Central Arizona. The sparsity of data led to unrepresentative estimates of basin average rainfall for many of the headwater areas that contributed to the flooding. The data sparsity problem would become even more acute if the forecast time-step is shortened below 6 hours in the future. Fortunately, for this series of storms, the QPF's produced by the Phoenix WSFO were very useful for supplementing and projecting the limited rainfall observations.

Recommendation 5.5: The Salt Lake City RFC, the Phoenix WSFO, and the Western Region Headquarters [through cooperation with and contributions of the United States Geological Survey (USGS), the United States Department of Agriculture (USDA), the Army COE, the Water and Power Resources Service (WPRS)*, the State of Arizona, the Salt River Project (SRP) Headquarters, the Maricopa County offices, the city of Phoenix, and other interested agencies] should continue development of an improved automated data network for Arizona. This should be achieved through the recently formed Central Arizona Hydrometeorological Data Management Association (CAHDMA) to the maximum extent possible. Sufficient redundancy in the network is required to ensure adequate watershed coverage during storm periods, when some communication links may fail or be garbled. This is especially important in the rugged, inaccessible, mountainous areas of Arizona.

Finding 5.6: Data collected from cooperative observers in Arizona via telephone calls made by the newly formed Flood Warning Office (FWO) attached to the Phoenix WSFO were generally irregular and not at time intervals compatible with current procedures for river forecast preparation.

Recommendation 5.6: The Phoenix WSFO and surrounding WSO's should establish timely collection schedules, attempt to have the cooperative observers report the data in a format suitable for automatic processing at the Salt Lake City RFC, and, where feasible, expand the cooperative observer and flash-flood spotter network in data-sparse regions.

Finding 5.7: At the Salt Lake City RFC, handling and preparation of the data from both the automatic and manual systems, for input to the hydrologic forecast procedures, were hampered by the lack of a data collection ("gateway") computer and adequate data management software.

Recommendation 5.7: The Salt Lake City RFC, as well as other RFC's, should be equipped with a "gateway" computer capable of automatically retrieving data from various sources, of performing various data management functions, and of relaying the data to the larger computer system, where additional data editing and preprocessing functions are performed. Improved data management software also is needed so that the data can be rapidly assimilated and data quality can be checked prior to input into the forecast procedures. This software should be versatile enough to permit use of data from "stranger" stations that may be available for non-standard times or locations.

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*Now called Bureau of Reclamation.

Finding 5.8: The GOES satellite imagery was extremely useful in ascertaining the timing and extent of rain areas. However, quantitative satellite rainfall estimates based on objective numerical procedures were not made available to any of the forecast offices.

Recommendation 5.8: NWS Headquarters and the Western Region should encourage the National Environmental Satellite Service (NESS)*, through cooperation with the Office of Hydrology, the Weather and Flood Warnings Coordination Office, and the QPB, to continue the development of satellite rainfall estimation methodology and to implement the procedures required for making the estimates operationally available to the affected field offices.

Finding 5.9: The unique FAA ARTC radar monitoring system, which provides the capability to monitor several radar systems remotely at the Palmdale and Albuquerque WSO(R)'s, was especially helpful for tracking and reporting weather activity over the large area affected by the storms. The communication capability provided by the network also facilitated interchange and coordination with the numerous involved offices of the NWS.

Recommendation 5.9: See Recommendation 4.12.

Finding 5.10: The NWS local warning radar (LWR) at Los Angeles was considered by the Los Angeles staff to be ineffective on numerous occasions during the sequence of storms due to attenuation caused by heavy rainfall on the radome. Blocking mountain ranges and, perhaps, anomalous propagation in the coastal areas and the Los Angeles basin also contributed to the difficulties in the detection of precipitation echoes. The radar was monitored during the storm and used as much as possible when propagation was considered normal, but there seemed to be a general lack of confidence in the rainfall information from the LWR at Los Angeles.

Recommendation 5.10: Western Region Headquarters should work closely with the Los Angeles WSFO to evaluate: 1) the performance of the LWR, 2) the level of operator training, and 3) the operating procedures during storm events. Operating procedures should be established, which include first-order intensity corrections where feasible, to partially compensate for data degradation resulting from wet-radome attenuation and other attenuation and propagation effects. As necessary, WSFO staff should receive more training on the interpretation and use of radar data in conjunction with rain-gage data for hydrologic applications.

Finding 5.11: The NWS LWR at Phoenix functioned well throughout the storm. Radar staffing was adequate and the radar data were used effectively to augment surface network data. A radar repeater scope at the Salt River Project (SRP) Headquarters also was used effectively to provide rainfall-distribution information to SRP personnel for input to their decisions on reservoir operations, but SRP staff expressed a strong need for provisions for real-time computer processing of digital radar data. Also, high-resolution rainfall estimates derived from computer processed radar data should provide valuable inputs to the hydrologic forecasting procedures used by the Salt Lake City RFC.

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*Now called the National Earth Satellite Service.

Recommendation 5.11: The NWS and Western Region Headquarters should investigate means for providing the necessary resources (including additional manpower and/or training, if required) to equip NWS radars at critical locations -- for example, the LWR's at Los Angeles, Las Vegas, and Phoenix -- with suitable digital radar-data processing systems. Real-time processing, communication, and display of the radar rainfall estimates by such systems would provide substantial improvements in the real-time availability of site-specific rainfall information. The radar-data processors also would provide the means of achieving the highest degree of accuracy because the data could be quality controlled by computer, and first-order correction procedures could be applied which incorporate telemetered rain-gage data to partially compensate for data degradation from such effects as radome attenuation.

Findings and Recommendations Pertaining to:

Dissemination of Forecasts and Warnings and User Reponse

Finding 6.1: All communication interfaces and equipment used for dissemination functioned satisfactorily with the exception of the NOAA Weather Radios (NWR's) at Santa Barbara and San Diego, which went off the air during the height of the storm because of transmitter power failures.

Recommendation 6.1: The NWS should pursue funding for emergency power for all NWR systems.

Finding 6.2: Some non-Federal governmental agencies, with emergency-related responsibilities, lacked knowledge of or access to NWR, and only a small fraction of the general public was aware of NWR.

Recommendation 6.2: The NWS should accelerate efforts to ensure that county and local officials are aware that NWR offers an inexpensive means of enhancing the speed and reliability of warning dissemination among non-Federal governmental emergency services, and efforts should be increased to inform the general public of NWR.

Finding 6.3: Most of the general public received watches and warnings through the mass news media (MNM). In general, the MNM announced warning messages fully and accurately.

Recommendation 6.3: The vital role of radio and television in the dissemination of urgent weather messages must continue to be emphasized. The NWS should continue efforts to assist the media, through workshops, etc., to perform this vital functio and should strive to identify the most effective methods of disseminating watches and warnings over the electronic media.

Finding 6.4: Personnel from the radio and television stations in the Los Angeles area frequently called or came to the WSFO for information and special interviews, requiring extensive staff time to meet their needs and creating the potential for minor differences in announcements, which could have caused confusion.

Recommendation 6.4: Provision should be made for dissemination of information to the MNM through press conferences scheduled on a regular basis for long-duration emergencies such as this one. One person on station should be assigned the duties of Public Information Officer to handle inquiries of press, etc., so the forecasters will not be diverted from their primary tasks and so the media can be kept fully informed.

Finding 6.5: Some evidence exists that a significant proportion of the Hispanic population in Los Angeles and surrounding areas is not sufficiently fluent in English to ensure comprehension of urgent warnings that are broadcast only in English. A similar, but less acute, situation exists in Phoenix, as well as in other areas of the Southwest where large Hispanic populations live.

Recommendation 6.5: The public service and warning components of NWS Headquarters, in cooperation with NWS regional offices, should explore alternatives for ensuring that at least the most critical watches and warnings receive multilingual dissemination in those areas where significant proportions of the population do not understand English. A significant part of the solution to this problem can result from closer ties being established between WSFO staff and personnel of radio and TV stations that broadcast in a foreign language. Suggestions to initiate multilingual broadcasts over NWR are not feasible, since the logistical problems and increased resources required to maintain multilingual NWR broadcasts would be prohibitive.

Finding 6.6: Although flash flood watches and warnings issued by the NWS offices contained specific precautionary statements and recommended actions, they often were not sufficiently site specific. This problem was especially prevalent in several of the canyon areas of the Los Angeles suburbs and resulted in many people taking no action because they did not recognize the direct threat to them. The lack of site specificity was in large part due to the sparsity of rainfall information, which prevented pinpointing the heavy rainfall areas. Therefore, the statements generally were as specific as available information and state of the art permitted.

Recommendation 6.6: To the extent that available information and the state of the art will allow, statements with greater site specifity should appear early in the text of the watches and warnings.

Finding 6.7: The majority of the people interviewed in the affected area knew the difference between a watch and a warning, and knew approximately the correct definition.

Recommendation 6.7: The NWS should continue to use watch/warning terminology.

Finding 6.8: In a large megalopolis like Los Angeles, with multiple county governments and municipality structures, it is difficult to initiate a comprehensive emergency preparedness program that uniformly and effectively covers all of the seven million people involved. Conversely, it has been possible to establish a very effective disaster preparedness system in the Greater Phoenix area, where the strong influence of a single county government (Maricopa) dominates. Primarily because of the lack of funds and personnel, the staff at the Los Angeles WSFO have been unable to cover the scope of activities required for achieving optimal input to the disaster preparedness planning and response of the local agencies and communities. Los Angeles WSFO personnel find they do not have sufficient time, and in some cases lack specialized training, to provide technical assistance to local governments in flood preparedness planning. Participation by the Los Angeles WSFO has been limited largely to presentations and briefings explaining NWS products. In summary, it seems clear that the larger number of interfaces required in the greater Los Angeles area to establish an effective total emergency preparedness system, and the limited resources available to accomplish these interfaces, contributed to the fact that many of the individual local-government preparedness plans lacked formal implementation and cohesiveness and resulted in poor public response to the warnings.

Recommendation 6.8: The Meteorologist-in-Charge (MIC) at the Los Angeles WSFO should pursue ways of enhancing the WSFO's active participation in community preparedness programs. NWS Headquarters should assist the Los Angeles WSFO (and other WSFO's) with their community preparedness interactions by ensuring that the Memorandum of Understanding between NOAA and the Federal Emergency Management Administration (FEMA) clearly enumerates the responsibilities of the various parties in providing guidance and assistance to local governments in the establishment and maintenance of emergency preparedness systems. Also, NWS Headquarters should assist in identifying other resources necessary for the NWS field offices to fully carry out their specific emergency preparedness liaison functions.

CHAPTER 1

BACKGROUND -- THE SOUTHERN CALIFORNIA AND CENTRAL ARIZONA FLOODS, FLASH FLOODS, AND MUDSLIDES OF FEBRUARY 1980

For 9 days during mid-February 1980, the southwestern U.S. was battered by a series of heavy rainstorms. The meteorological situation leading to the series of rainstorms can be traced to a strengthening of the subtropical westerly air flow resulting in the westerlies "breaking under" the blocking high pressure, which simultaneously weakened, over the Gulf of Alaska on February 11. From February 12 to 21, a strong zonal flow existed from the coast of Asia to California. The jetstream persisted far south, with the strongest associated atmospheric instabilities lying between latitudes 25°N and 35°N. Storm centers were continually generated on the polar side of the jetstream in the 35°N to 42°N latitude belt. Sometimes as many as three significant organized cloud masses, lined up in sequence off the coast of California, could be seen on the satellite pictures. The long fetch over the warm ocean at low latitudes resulted in storm systems that were warmer and more moist than normal.

Cloud masses associated with widespread convection caused extended periods of heavy rainfall. Over the 9-day period from February 13 through 21, 5 inches or more of rain fell over most of Southern California's coastal valleys, and the coastal mountains received considerably more as a result of orographic lifting, with totals exceeding 15 inches over many areas. Some areas of the San Gabriel and Laguna Mountains received locally heavy rainfall amounts in excess of 25 inches. For example, rainfall accumulations for the 9-day period from February 13 through 21 at the Mt. Wilson station and at Lytle Creek near Mt. San Antonio were 30.71 and 30.86 inches, respectively. This month of February was described as one of the wettest Februarys in history.

Rainfall amounts from February 13 through 21 in Central Arizona ranged from 1 to over 16 inches. Crown King, Arizona received a 9-day total of 16.63 inches, which was only 0.32 inches less than the highest monthly total of record for any site in Arizona. This heavy rainfall followed two extremely wet years. As a result, most reservoirs in Arizona were nearly full at the beginning of the sequence of storms and could not store all the runoff. Inflow volume on the Salt and Verde River systems exceeded 1.5 million acre-feet during the series of storms, whereas available storage on February 15 was less than 0.5 million acre-feet.

The large rainfall amounts produced floods and flash floods in many areas of Southern California and Central Arizona. The antecedent soil moisture conditions and extended rain periods led to runoff amounts that significantly exceeded stream, levee, and reservoir capacities. In addition to widespread flooding (Fig. 1.1), Southern California was plagued by mudslides caused by the persistent heavy rains (Fig. 1.2). At least 21 deaths and millions of dollars worth of property damage were associated with these heavy rains. Eighteen people are known to have died in Southern California as a direct result of flooding, flash flooding, and mudslides. Three people died in Arizona, a surprisingly low number considering the magnitude of the damage. Table 1.1 details causes of the deaths.

In Southern California, estimates of losses due to mudslides, flash floods, and floods topped $325 million. Destruction exceeded $100 million in both Los Angeles and San Diego Counties. Some of the hardest hit areas were neighborhoods tucked

Figure 1.1--Aerial view of San Diego River and flooded expanse of Mission Valley facing West near Taylor Street Exit. (Courtesy of the San Diego County Flood Control District; photograph taken by Don Carlson; pilot, Carey Stevenson.)

Figure 1.2--This home is one of many in the Los Angeles area severely damaged by mudslides. It was impacted by many tons of mud from the hillside in the background. This was the second time in 2 years that the homeowner lost his house to mudslides.

Table 1.1-Deaths in Southern California and Central Arizona as a direct result of flooding, flash flooding, and mudslides

	SOUTHERN CALIFORNIA
February 15	Man in Chino died when his auto ran off highway into flooded wash.
	Man with history of heart trouble collapsed and drowned in his backyard in Wildomar, south of Lake Elsinore.
February 16	Man, 25, died in Cucamonga, when he tried to cross a swollen creek in his car.
	Boy, 8, was swept into storm drain at Rancho Cucamonga and drowned.
	Boy, 11, drowned in a drainage ditch near San Dimas.
	Woman drowned in Mandeville Canyon when water and mud swept into her home.
	Woman drowned near Covina when she drove her automobile off road into wash.
	Man killed near Perris when his automobile slid off highway into a bridge abutment.
	Woman drowned in Tapia Park (Malibu Canyon) when she was swept into rising creek.
	Two people died after being swept down Malibu Creek.
	Man suffocated when buried in mud in Malibu Creek.
	Woman, 44, killed when automobile skidded off highway into swollen storm drain.
February 17	Woman, Lime Valley, drowned while attempting to wade through a swollen creek.
	Man drowned attempting to rescue young boy from rain-swollen Los Angeles River at Atwater; boy survived.
February 18	Woman electrocuted when she stepped into a puddle into which power lines had fallen on Del Rey Avenue in Los Angeles.
	Woman fell from car and drowned near her home in Desert Hot Springs.
February 19	Man died of apparent heart attack trying to drive his pickup truck through swollen Santa Clara Creek.

CENTRAL ARIZONA

February 15	Two men, 33 and 74, both of Prescott, died after their car plunged into Granite Creek.
February 16	Man, 26, of Flagstaff, drowned in swollen Oak Creek when his rubber raft overturned.

away in the exclusive canyon areas of Los Angeles. Brush fires during the summer and fall of 1979, and the year before, removed many of the shrubs needed to anchor soil to hillsides. In a typical scenario in the Los Angeles area, rains washed soil and houses down to canyon bottoms and onto homes located there. Minor flooding is a problem in the canyons almost every year, but with the very persistent rainfall of mid-February the effects were disastrous. Eighty-eight houses in Los Angeles County alone were destroyed by flooding and mudslides. Another 200 were heavily damaged. Overall in Southern California, 1,600 homes were destroyed or suffered major damage. More than 350 commercial buildings had major structural damages.

Several major San Diego County reservoirs reached their highest levels since 1941. Overflow from the reservoirs resulted in the flooding of 2,000 homes by the morning of February 21. Considerable damage occurred in the Mission Valley shopping and hotel area. High water levels also occurred in reservoirs in other parts of Southern California. For example, figure 1.3 illustrates the high level of water in the Littlerock Reservoir in Los Angeles County.

In Ventura County, extensive damage occurred at Point Mugu Pacific Missile Range, where approximately 500 families were evacuated February 17th after a levee broke allowing Calleguas Creek to flood the base's housing area. Navy officials estimated personal property damage at $5-$8 million. Several thousand acres of agricultural land were under water in Ventura County with crop losses estimated at $42 million; of this total, $12 million were citrus losses and $8 million were celery losses. Land and sod losses were estimated at $15 million.

Other Southern California counties also reported heavy economic losses in the public and private sectors.

Southern California coastal sections also suffered damage from pounding surf. During the night of February 20, the surf tore out a large section of the Imperial Beach municipal pier, and a number of houses along the Pacific Coast Highway fell victim to the continued assault from associated high tides. Complicating the problem of high surf were power outages that shut down the Tapia Sewage Treatment Plant, allowing raw sewage to flow down Malibu Creek, which forced closure of beaches from Pt. Dume to Marina del Rey.

Mudslides closed the Pacific Coast Highway and isolated many canyons. Mandeville Canyon streets were impassable because of mud. Malibu Canyon remained tenuously connected to the outside world, but only by one slide-endangered road.

Damage in Arizona was estimated at approximately $82 million. The greatest damage occurred to bridges and low-water crossings, estimated at $25 million. (See coverphoto.) Another $18 million worth of damage was done to utilities. Lost wages accounted for $14 million. Agricultural losses were estimated at $12 million, while damages to homes and non-agricultural businesses were estimated at $6 million. An additional $7 million was attributed to miscellaneous damages. Maricopa County sustained the majority of the damages, particularly to bridges and utilities. Approximately 10,000 people were evacuated before and during the flooding. The Phoenix metropolitan area was virtually cut in half by the flooding when all but two crossings over the Salt River were closed or declared unsafe (cover photo).

Los Angeles, Orange, Riverside, San Bernardino, Santa Barbara, Ventura, and San Diego Counties in California; Gila, Mohave, Yavapai, and Maricopa Counties in

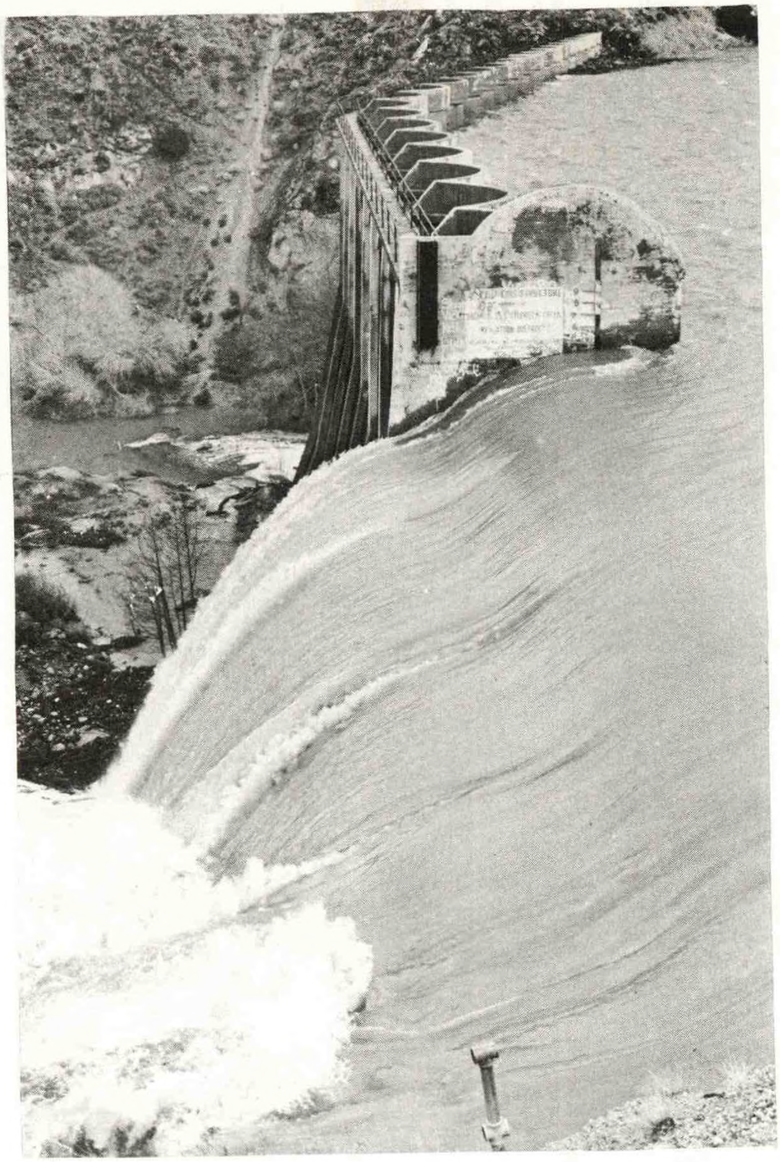

Figure 1.3--High water levels over the spillway of the Littlerock Dam as illustrated by a photograph appearing in the *Daily Ledger-Gazette* on February 22, 1980. The water level reached the 9-foot mark on the spillway apron earlier.

Arizona; and San Carlos and White Mountain Indian Reservations in Arizona were declared Federal disaster areas.

The Southern California and Central Arizona floods, flash floods, and mudslides of February 1980 join an ever-growing series of disasters associated with heavy rainfall that have resulted in large losses in property and life. The chapters that follow will discuss the various aspects of the February 1980 events in some detail. The following topics are considered: the hydrometeorological conditions; the operations of the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA); the data sources; the roles of the media, NWS personnel, and other public officials in dissemination of NWS forecasts; and the response of the public.

CHAPTER 2

METEOROLOGICAL ANALYSIS

On February 11, 1980, a 500-mb ridge of high pressure existed over southeast Alaska with a low pressure trough extending from about 45°N (latitude), 150°W (longitude) to 30°N, 135°W (Fig. 2.1). A strong zonal flow extended across most of the Pacific from the coast of Asia to about 160°W. The jetstream, located about 30°N, penetrated beneath the Alaskan ridge on February 12 (Fig. 2.2) bringing six short-wave troughs and associated cloud systems over the southwestern United States during the next 9 days. These six storms, which were identified to the public by number, brought heavy rains, floods, flash floods, and mudslides to parts of the Southwest. The storms are numbered on the sequence of satellite pictures taken from the western Geostationary Operational Environmental Satellite (GOES), figures 2.3-2.10.

The first storm was identified on February 11 as a wave developing on a frontal band about 32°N, 142°W (Fig. 2.3). This wave moved eastward and sheared off from the front, spreading rain over Southern California on February 13. Three vorticity commas (A, B, and C) were associated with this system (Fig. 2.4). The last of the three comma clouds (C) moved inland on the morning of February 14 and across Arizona during the day (Fig. 2.5).

The second and third storms in the series were first identified near 145°W and 165°W latitudes, respectively, on February 13. Similarly to the first storm, storm #2 underwent significant development near 32°N, 140°W (Fig. 2.5) early on February 14 and resulted in the advection of an elongated band of tropical high level moisture into Southern California during the day. The band merged with the front associated with approaching storm center #2, while the main center of rotation curved northeast into central California on the afternoon of the 14th and the morning of the 15th (Fig. 2.6).

Storm #3 developed like the earlier storms, with a center of rotation forming at 31°N, 148°W on February 15. High, cold clouds of subtropical origin (Fig. 2.6) between 25°N and 32°N preceded the storm center, which tracked northeastward to northwestern California on February 16, while the eastward-bulging portion of the storm, with its deep subtropical moisture, moved into California and Baja California (Fig. 2.7). The "lumpy" pattern in the satellite pictures indicated imbedded thunderstorms and heavy rain. Late on February 16, storm center #3 crossed the coastline and the rain in Southern California decreased in intensity and abated during the night. The rain diminished in Arizona on the morning of the 17th.

The center of storm #4 became visible on the satellite pictures on February 16 near 34°N, 148°W (Fig. 2.7). It moved eastward along the jetstream, reaching the coast on the afternoon and night of February 17, with accompanying heavy rain (Fig. 2.8). The rain ended in Southern California during the morning of the 18th; however, as the short-wave trough moved into Arizona on the same day, the storm system appeared to have more subtropical moisture than was available with the previous storms. The heavy rain, combined with a rise (to nearly 10,000 feet above msl) in the level at which the precipitation became predominantly snow, produced rapid rises in rivers and creeks in Central Arizona.

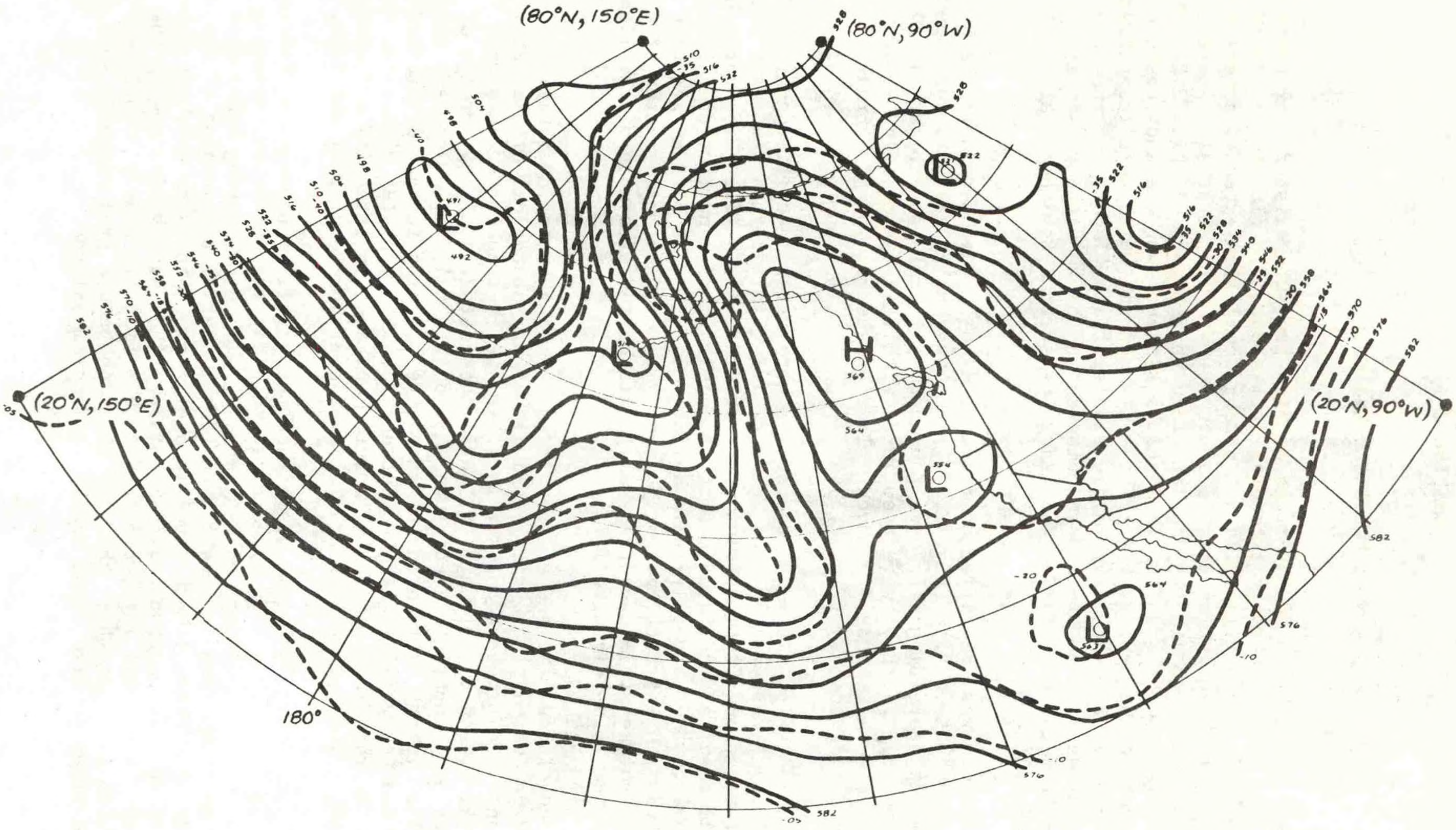

Figure 2.1--Sectional hemispheric chart of 500-mb height and temperature analyses, 1200 GMT, February 11. The isoheights are in hundreds of meters and the isotherms are in degrees Celsius.

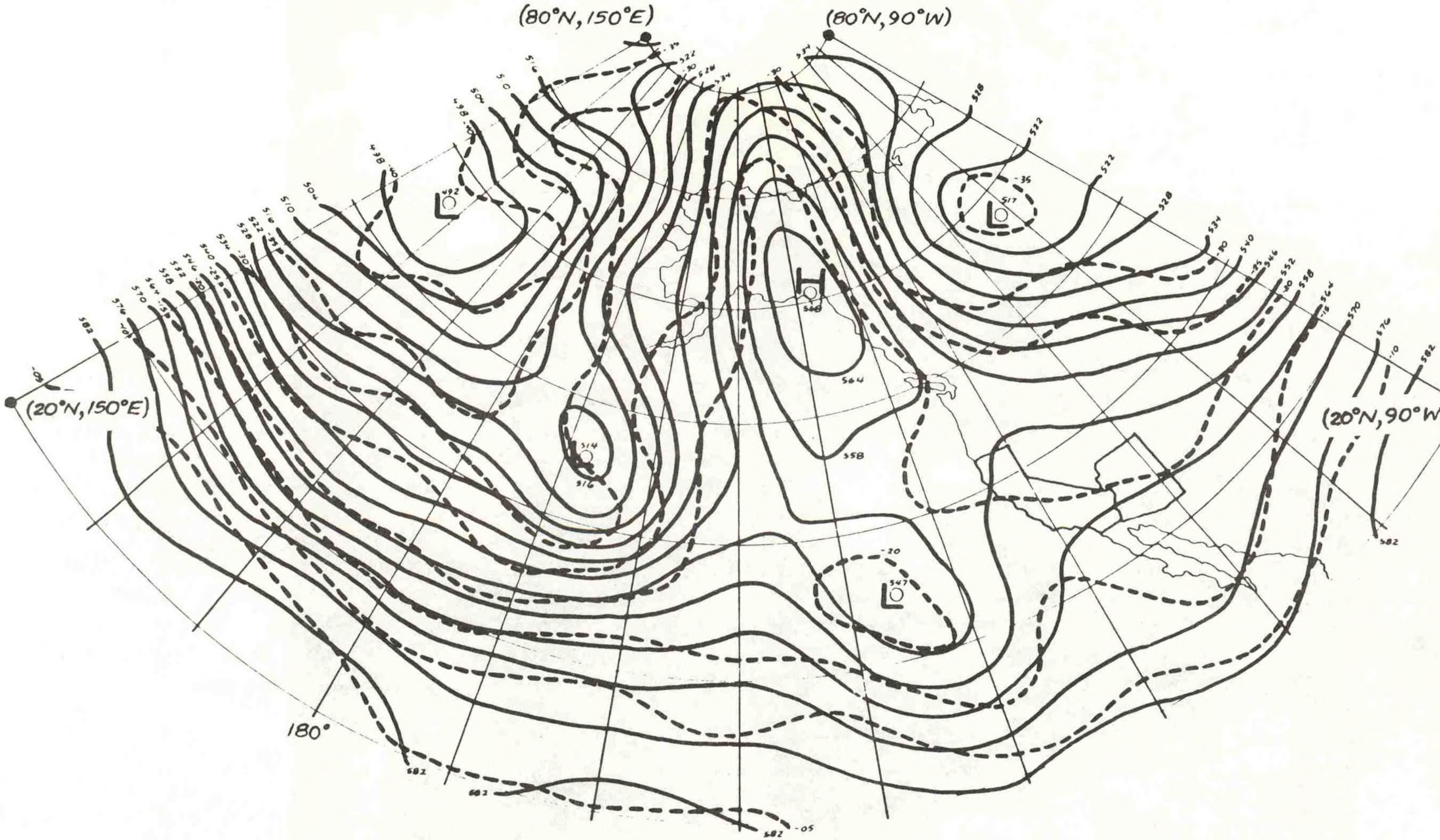

Figure 2.2--Sectional hemispheric chart of 500-mb height and temperature analyses, 1200 GMT, February 12. The isoheights are in hundreds of meters and the isotherms are in degrees Celsius.

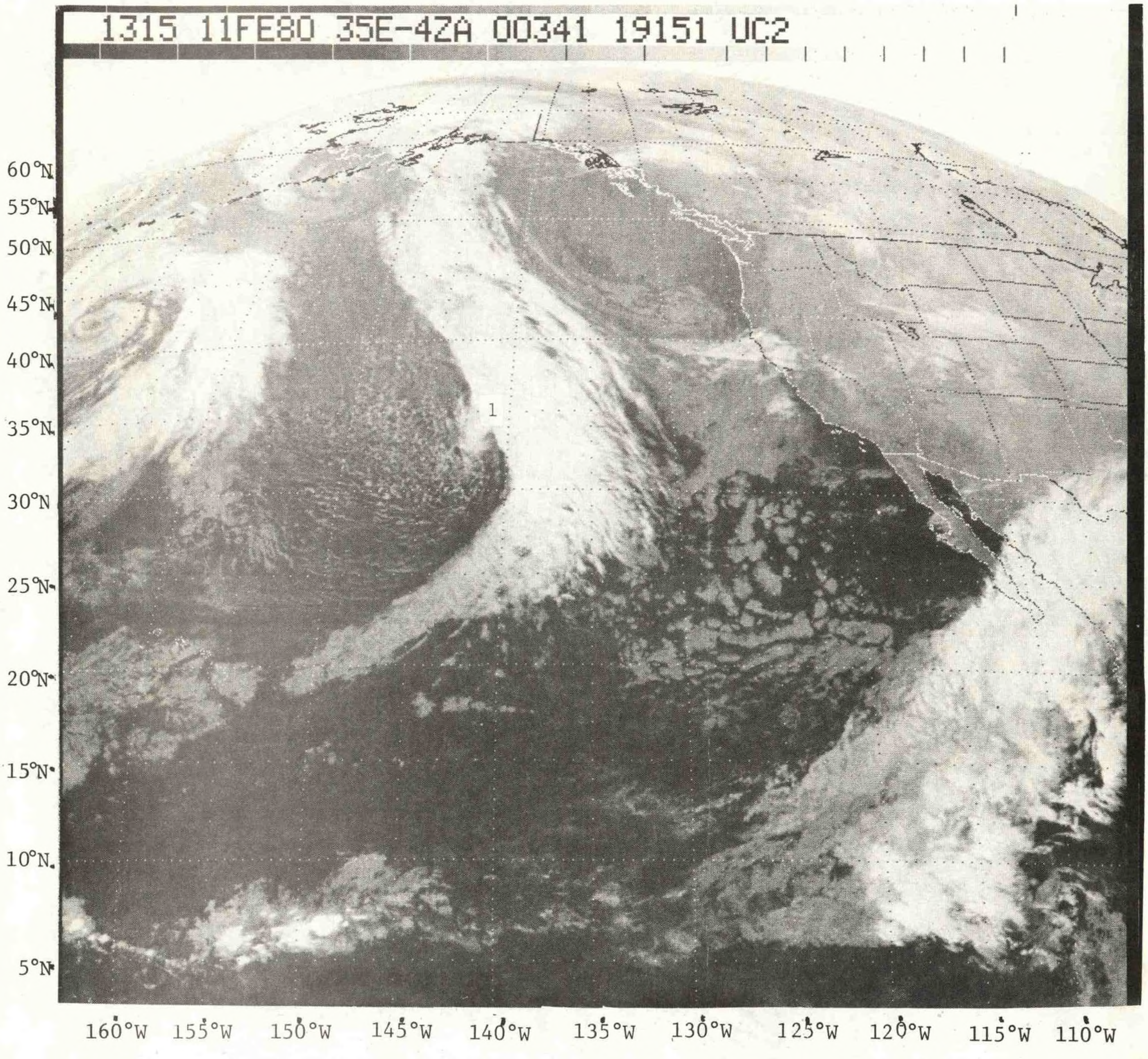

Figure 2.3--Infrared imagery from GOES west satellite, 1315 GMT, February 11.

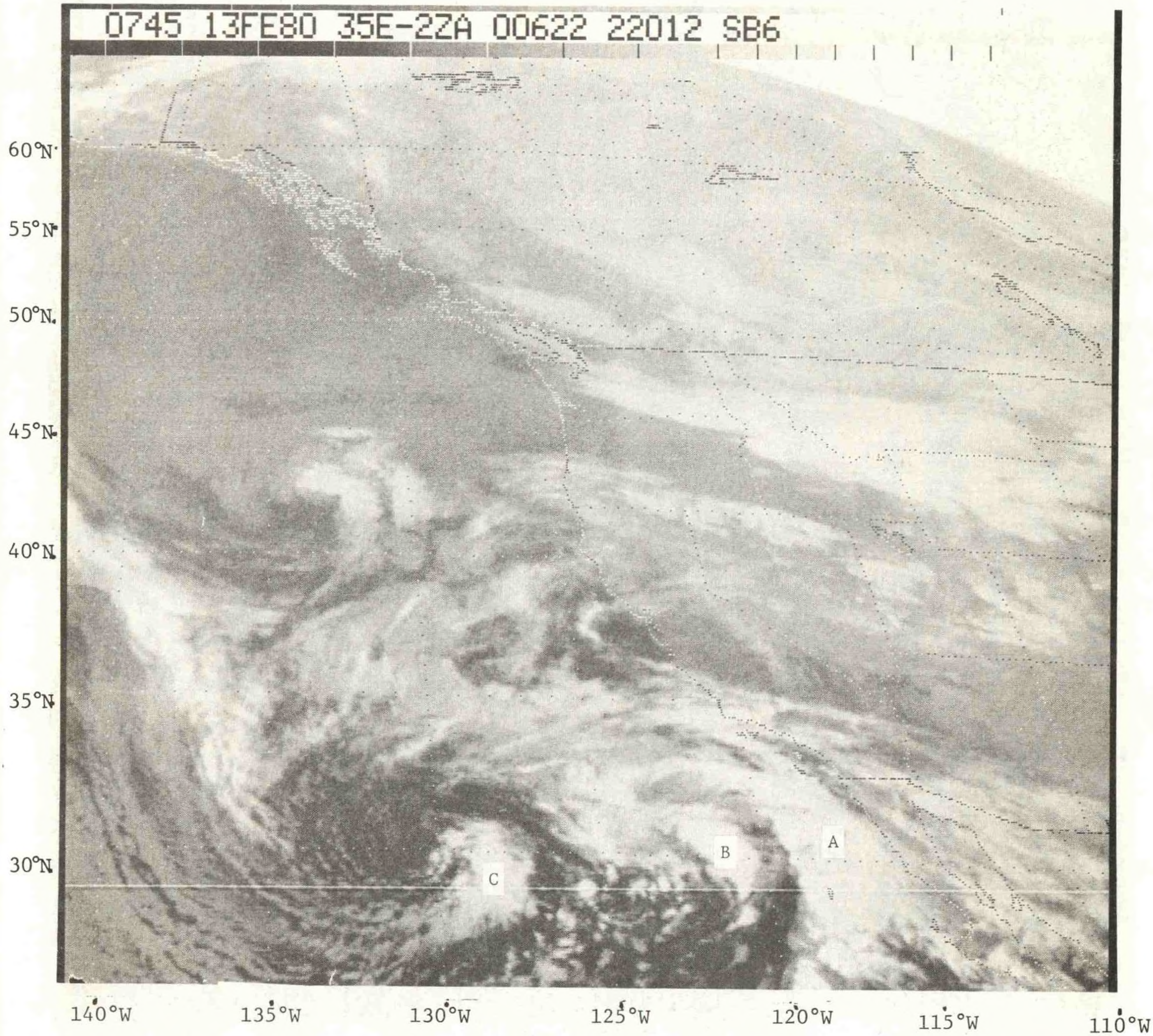

Figure 2.4--Infrared imagery from GOES west satellite, 0745 GMT, February 13.

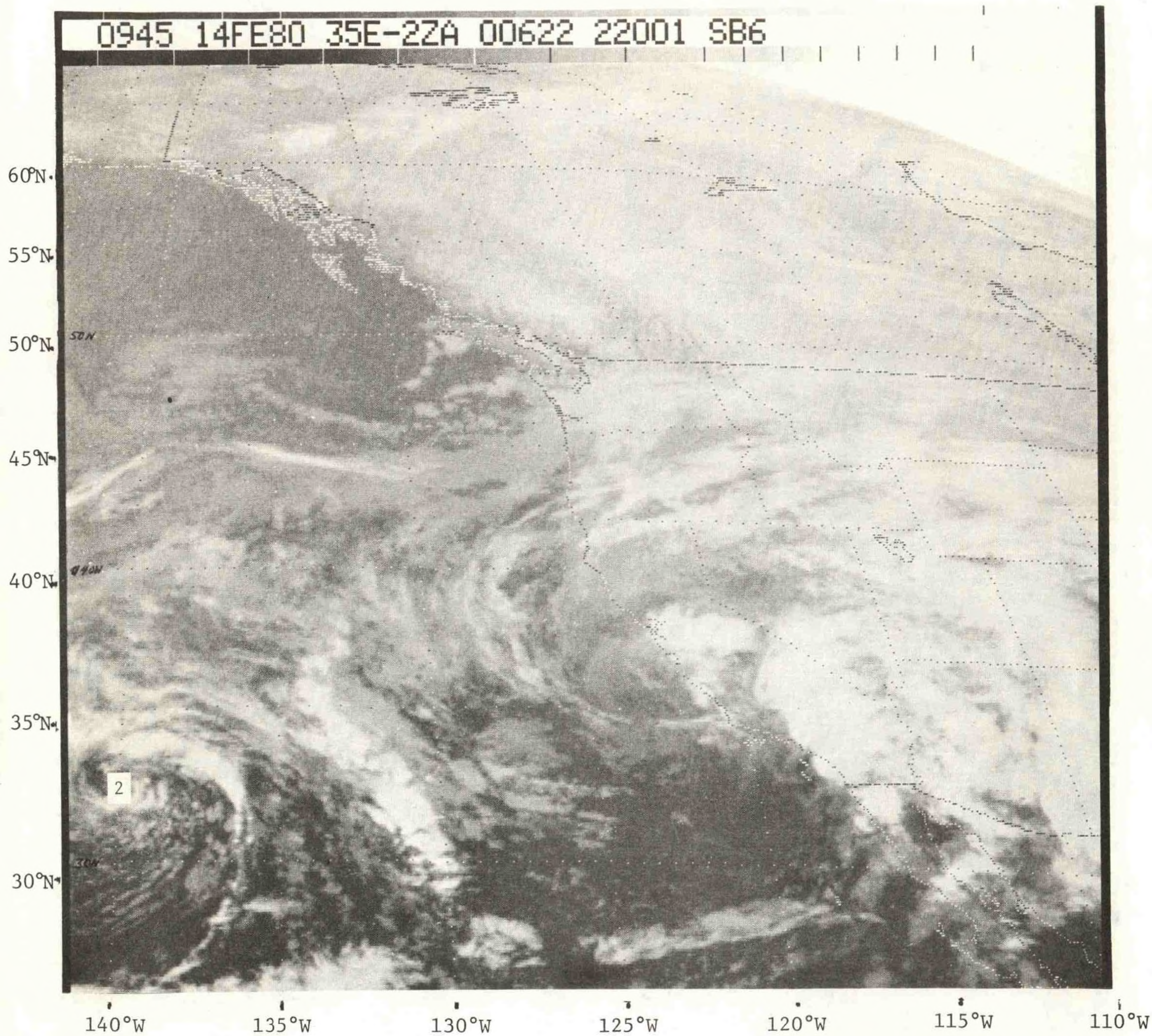

Figure 2.5--Infrared imagery from GOES west satellite, 0945 GMT, February 14.

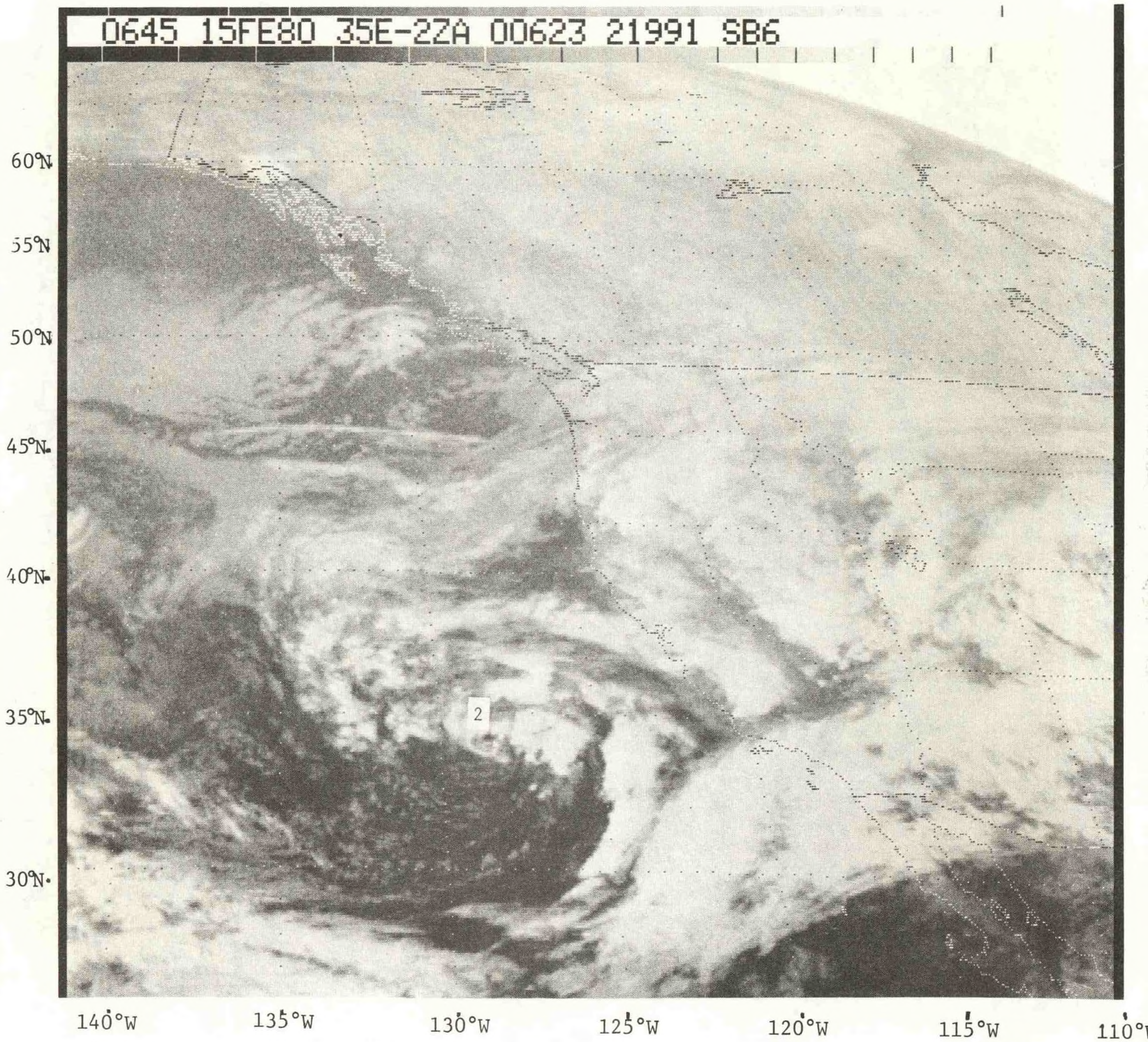

Figure 2.6--Infrared imagery from GOES west satellite, 0645 GMT, February 15.

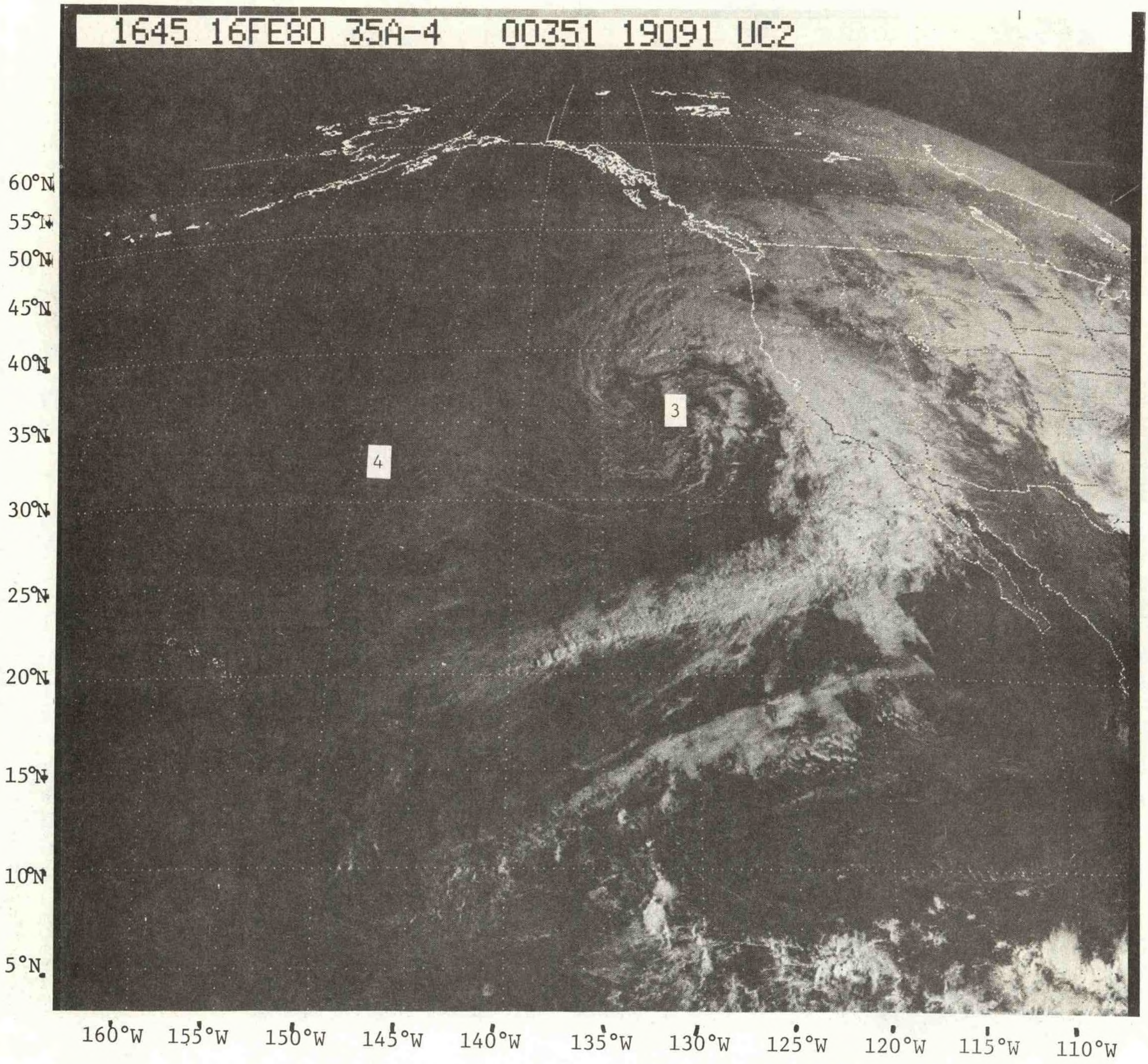

Figure 2.7--Infrared imagery from GOES west satellite, 1645 GMT, February 16.

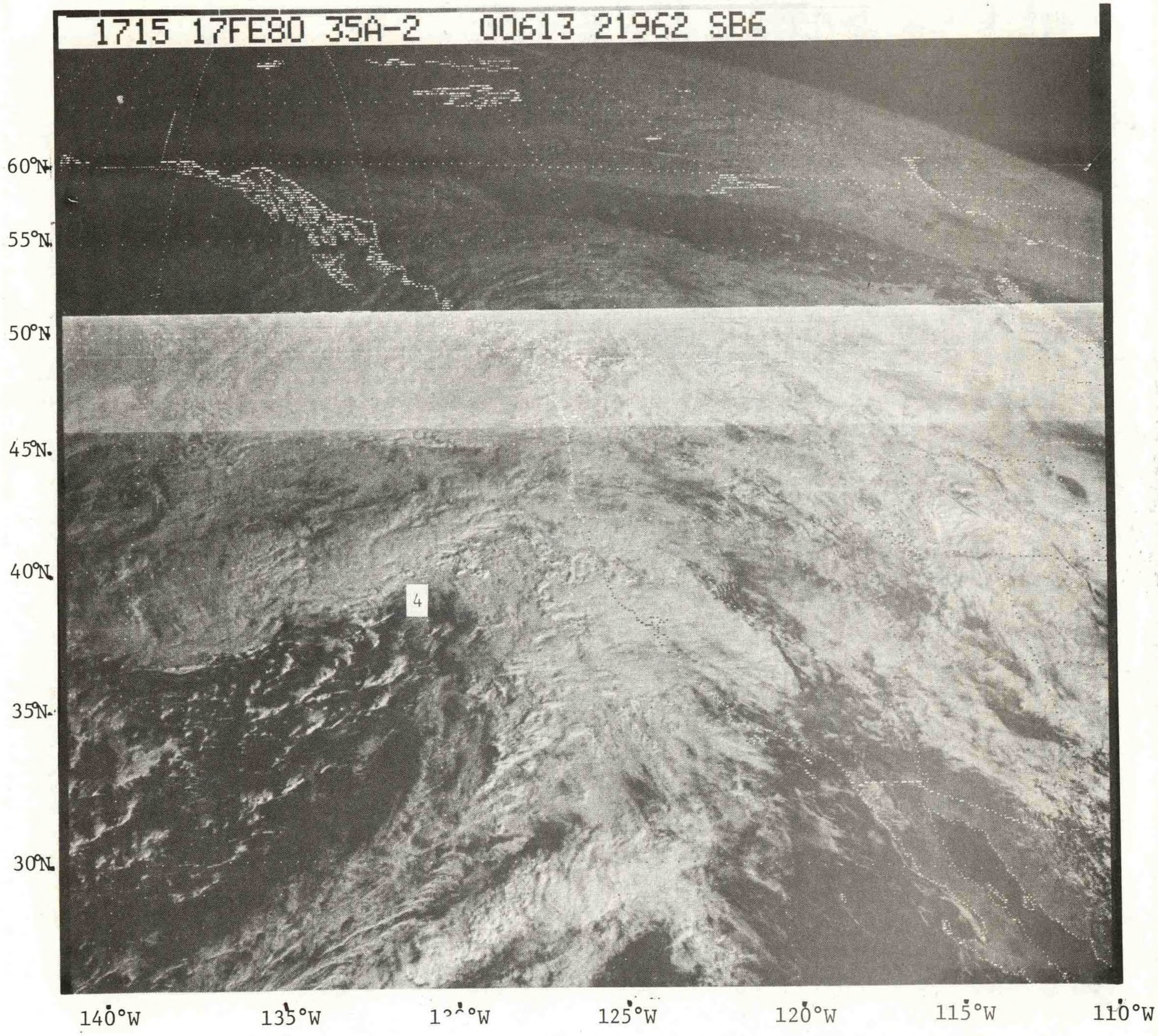

Figure 2.8--Infrared imagery from GOES west satellite, 1715 GMT, February 17.

Storm #5 organized north of Hawaii on February 17. It was first visible on the satellite pictures as a small comma cloud that moved eastward at about 50 knots between 30°N and 35°N on February 18, with a cloud cluster containing embedded cumulonimbi stretching 1,000 miles behind it (Fig. 2.9). The main cluster went into northern California on the night of the 18th. Of significance to Southern California was the enhancement of the trailing end of storm #4 (Fig. 2.9) between northwest Mexico and 20°N, 130°W as storm #5 reached the coast. The "lumpy" character of the satellite images in this area indicated that unstable moist tropical air still existed there. The area appeared to merge with storm #5 to the north and, more important, a well defined vorticity center developed which was associated with showers and thunderstorms over Southern California and Arizona on February 19.

Storm #6 was a breakoff from a center of cyclonic rotation 1,000 miles north of Hawaii on February 19. Again, the familiar pattern of a large eastward bulge was evident. However, during the night of February 19, the bulge became disorganized and was seemingly dissipated by the westerly jet along 35°N, with only scattered areas of cold, high-top clouds remaining. One of these cold cloud-top areas intensified over a period of a few hours and gave the appearance of a cumulonimbus anvil blowing off in an eastward direction. It enlarged rapidly (Fig. 2.10), moving faster than 60 knots, and the effects of the storm reached the coast during the afternoon and evening of February 20. From the evening of February 20 through the morning of the 21st, moderate-to-heavy rain was reported over much of Southern California, with showers extending into the evening of the 21st.

This last storm of the series did not entrain as much moist subtropical air as did the other storms. The strong zonal flow that had persisted across the Pacific since February 11 ended on February 21 as a ridge of high pressure developed over the Central Pacific, deflecting subsequent storms on a more northerly path.

Early recognition of the approaching storms, while they were still far out at sea, was accomplished through the use of satellite information. The GOES satellite pictures, normally received each 30 minutes on the GOES facsimile recorder, and the Satellite Interpretation Messages (SIM's), routinely received each 6 hours from the San Francisco Satellite Field Services Station (SFSS) of the National Environmental Satellite Service (NESS)*, proved invaluable to the Los Angeles and Phoenix Weather Service Forecast Offices (WSFO's). The satellite information was not only critical to remaining abreast of the synoptic situation and to identifying the individual meteorological systems moving in from the Pacific Ocean, but also was extremely useful in ascertaining the timing and extent of rain areas. Appendix 1 illustrates the type of satellite information that was contained in the SIM's.

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*Now called the National Earth Satellite Service

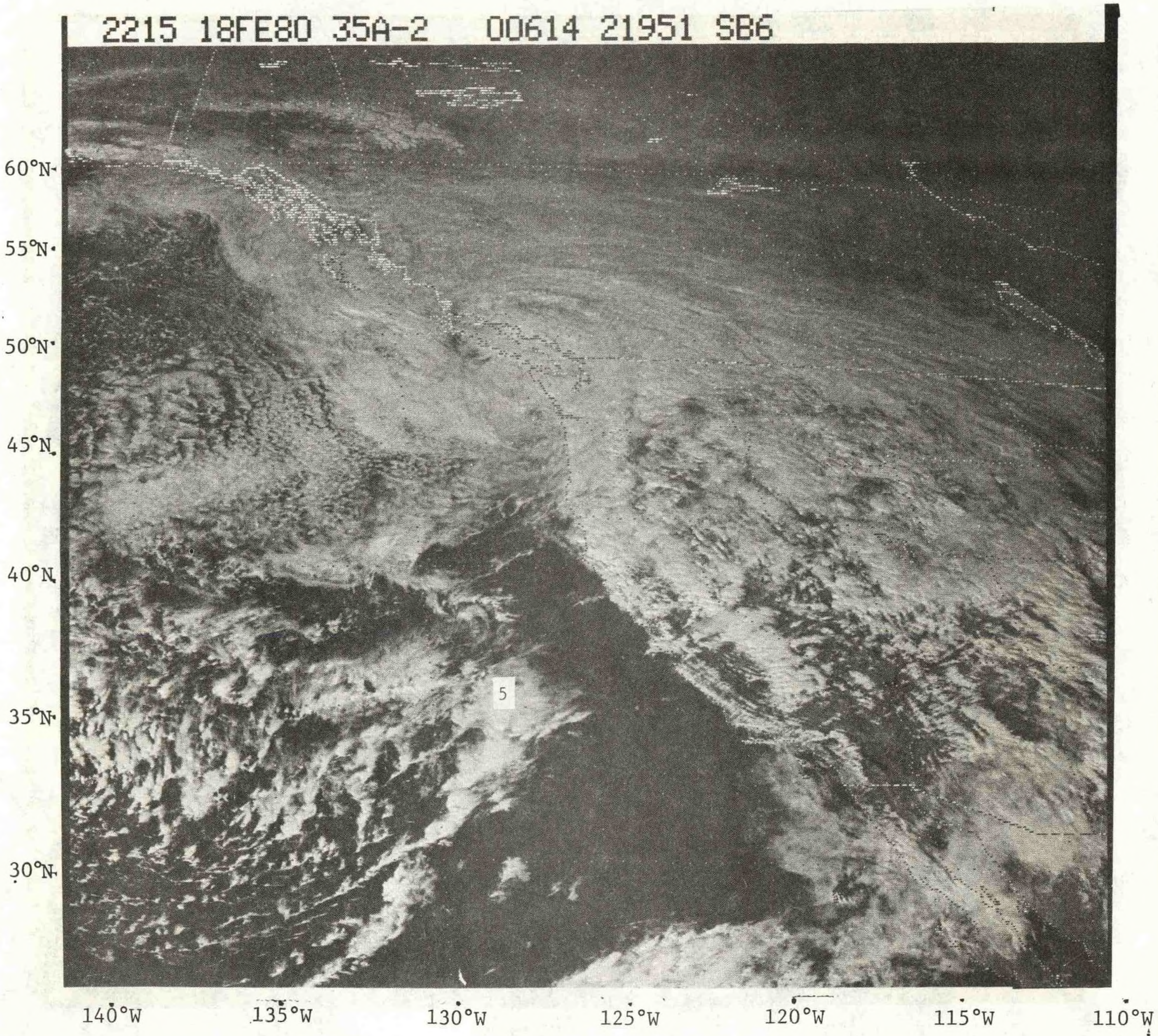

Figure 2.9--Infrared imagery from GOES west satellite, 2215 GMT, February 18.

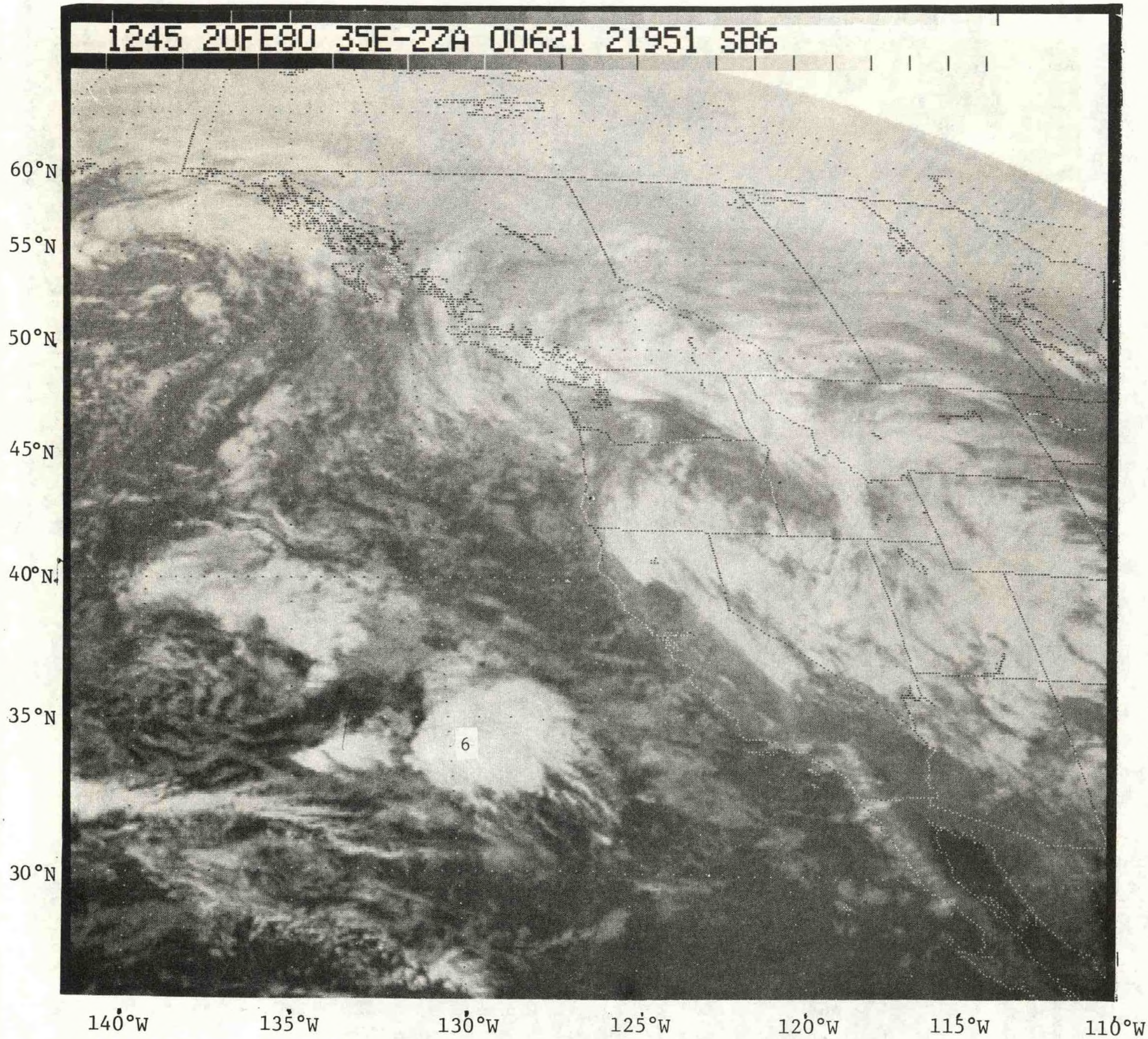

Figure 2.10--Infrared imagery from GOES west satellite, 1245 GMT, February 20.

CHAPTER 3

HYDROLOGICAL SITUATION

Southern California

As described in chapters 1 and 2, a series of six storms crossed the coast of California during the 9-day period from February 13 to 21, 1980, causing extended periods of heavy rain over Southern California and Central Arizona. Figure 3.1 gives the daily distributions of rainfall for one selected mountain and one selected coastal station -- Mt. Wilson and Los Angeles Airport, respectively. The large amounts and extended durations of rainfall produced extremely wet soil moisture conditions early in the series of storms, and the persisting rains quickly produced volumes of water which exceeded stream, levee, and reservoir capacities. By the end of the period, the capacities of several structures in a general vicinity often were being exceeded concurrently. For example, in the San Jacinto area, a levee burst along the raging San Jacinto River; water was pouring over the top of Lake Skinner Dam; Vail Lake was overflowing; and a levee broke open on a small lake southwest of the community of Elsinore.

Figure 3.2 is an isohyetal analysis of the rainfall accumulations for the total 9-day period. The rain gage stations and data used for the isohyetal analysis are contained in appendix 2. A significant orographic effect is apparent as illustrated by the correspondence between the heaviest rainfall areas and the major ridge lines shaded in figure 3.2. For example, areas of the San Gabriel and Laguna Mountains received locally heavy rainfall amounts in excess of 25 inches. These large rainfall amounts were typically funneled down the mountain slopes into canyon bottoms and the inhabited areas below, often causing mudslides and some flash floods.

Although the Los Angeles WSFO has Hydrologic Service Area (HSA) responsibility for Southern California, it provided no advisories explicitly on river conditions during the storm series. This was due to several factors, including the following: 1) generally, insufficient data have been available to support development of reliable river forecasting systems; 2) accordingly, while flood forecasting procedures have been developed by the Sacramento River Forecast Center (RFC)* for most major Southern California rivers, lack of real-time rainfall data has prevented their operational implementation; 3) many streams would not warrant routine forecasting, because they are quite small and are not perennial; and 4) there has been less than enthusiastic interest expressed by some Southern California communities for this type of information. Because of the interest in water supplies in California, the Sacramento RFC has emphasized the development of water supply forecasting procedures. In the West, advance knowledge of the general water supply outlook a month or two ahead is, in many respects, at least as important as production of accurate forecasts of stages and flows for immiment flooding situations. Optimally, both types of information should be available, and the Sacramento RFC will be expanding its services in Southern California with the goal in mind of providing both.

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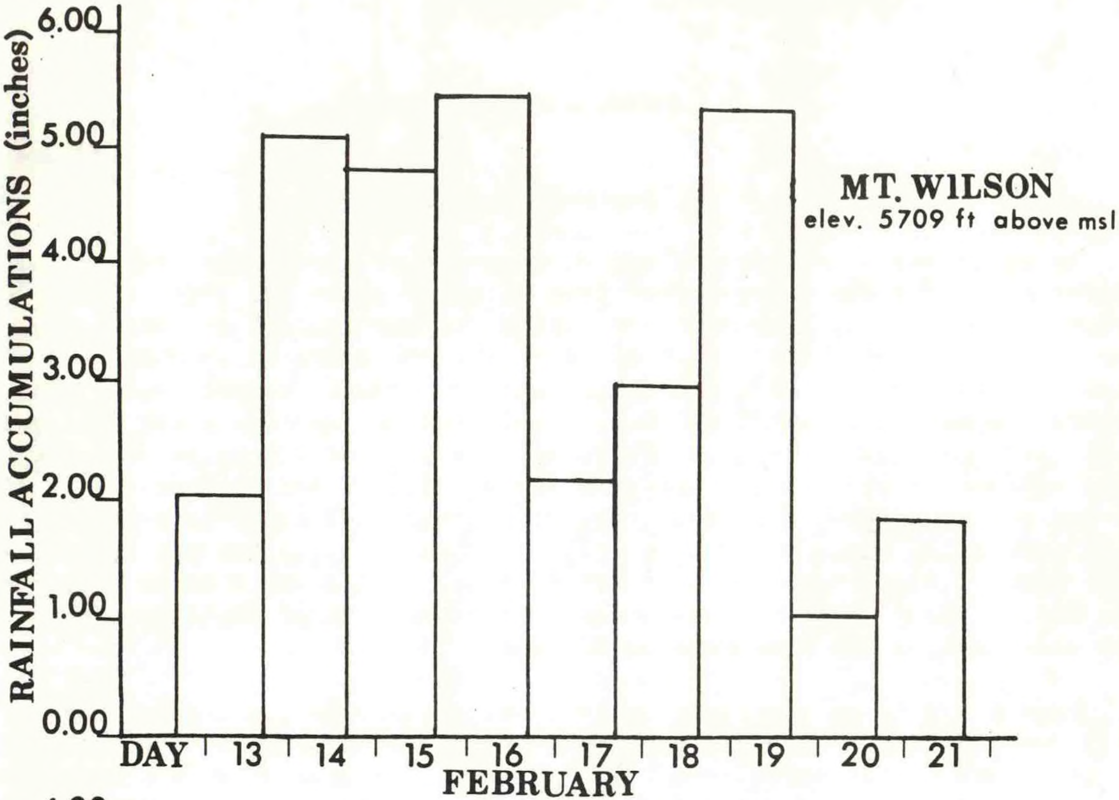
*Now called the California-Nevada RFC.



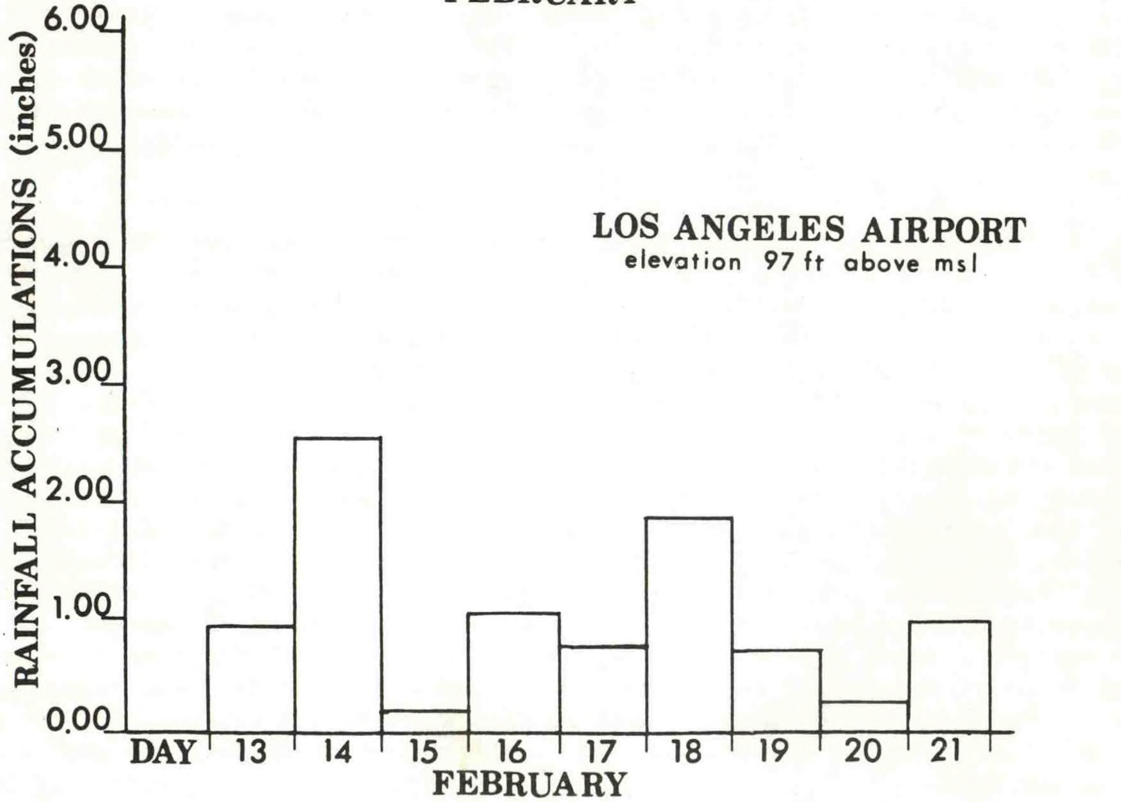


Figure 3.1--Daily accumulations of rainfall at two Southern California stations.

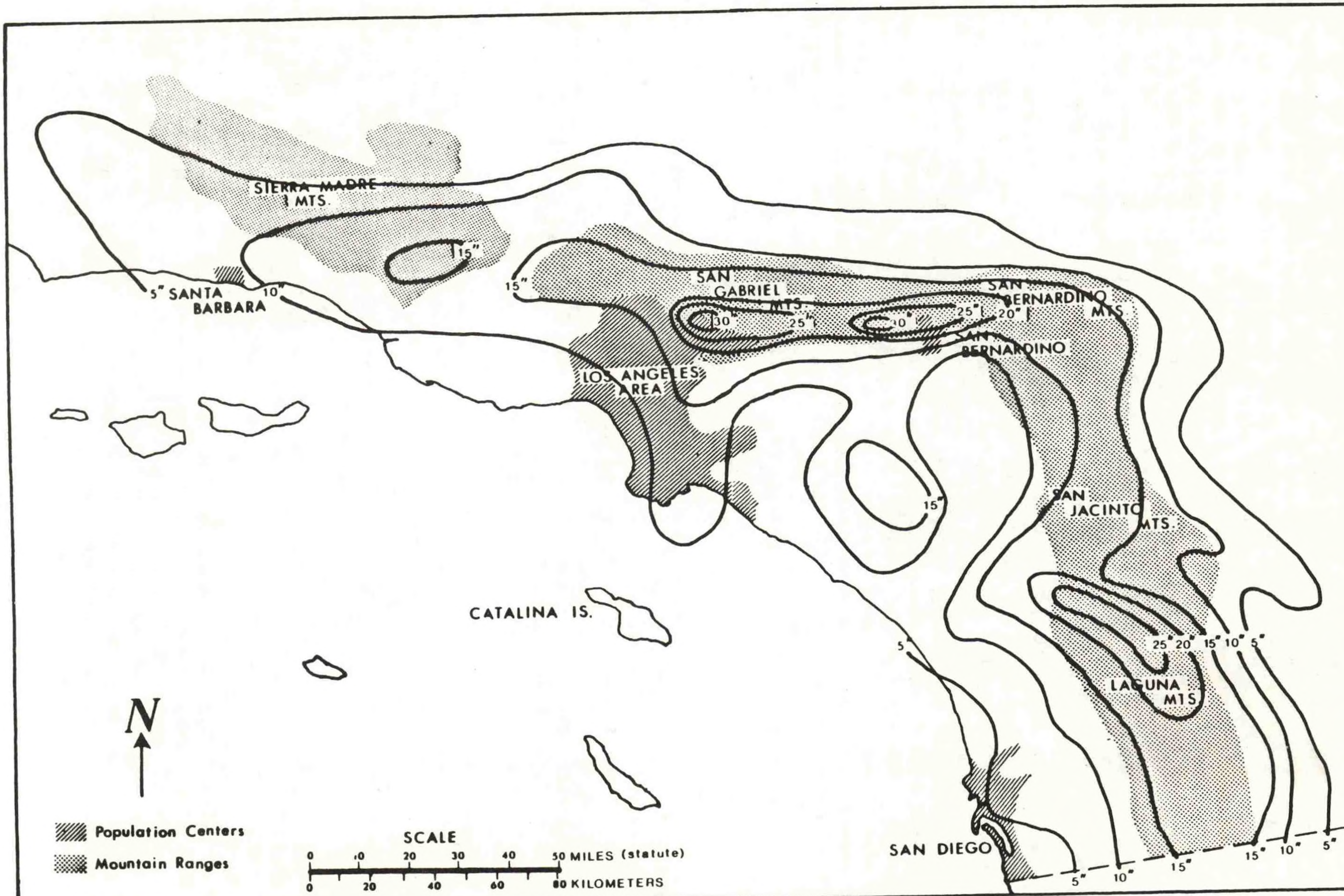


Figure 3.2--Isohyetal analysis of rainfall accumulations (inches) greater than 5 inches in Southern California for total period of rainfall, approximately 1400 GMT, February 13 through 0800 GMT, February 22.

One way that the Sacramento RFC will be able to expand the river forecast services provided in Southern California is through cooperation with other organizations in the implementation of real-time flood warning systems. For example, the Sacramento RFC has worked extensively with Ventura County to provide a real-time flood warning system in that area. A system of event-reporting radio rain gages was installed by the county after flooding in 1978. Analysis of the rainfall data from these gages was performed each 6 hours during the mid-February 1980 storms by the Sacramento RFC, and forecast advisories were input into the Ventura County computer. This system worked very successfully, which illustrates the potential improvements in services that may be realized through other such cooperative efforts in Southern California as well as other parts of the country.

Most of the damage in the Southern California area resulted from mudslides and some flash flooding. The Los Angeles WSFO did issue numerous flash flood statements and watches and also issued flash flood warnings as conditions dictated. (See chapter 4 and appendix 3.) These issuances were very effective in keeping the public informed of anticipated heavy rainfall and of the potential for flash flood conditions in specified counties and within other specified geographic boundaries. The value of the information in some instances, however, would have been significantly improved if the issuances could have been more site-specific with regard to precisely which streams, canyons, etc. were involved. The inability to achieve greater site specificity largely resulted from the lack of adequate real-time rainfall data and from the limits imposed by the state of the art in quantitative precipitation forecasting. (See chapters 4 and 5.)

Central Arizona

The February 1980 series of Pacific storms followed two extremely wet years in Arizona. As a result, reservoirs in Arizona were nearly full and could not store all the runoff. Inflow volumes into the Salt and Verde River Reservoir Systems exceeded 1.5 million acre-feet during the series of storms, exceeding storage available on February 15 by more than 1 million acre-feet. The Central Arizona flood potential was further compounded by intermittent antecedent rainfall which occurred for a month-long period immediately preceding the heavy rainfall and high-altitude snowmelt storm sequence of February 13-21, 1980.

Snowmelt apparently did not contribute significantly to the flooding that occurred in Central Arizona. GOES satellite data indicated that the Verde River basin was 14 percent snow-covered before the storm and 16 percent afterward, and the corresponding numbers for the upper drainages of the Salt River were 19 and 15 percent, respectively, indicating that only a small amount of snowmelt probably occurred at the periphery of the pack in the latter case.

The Soil Conservation Service (SCS) Snow Survey Telemetry (SNOTEL) data system available in the Verde basin showed that, before the series of storms, 8.3 to 11.5 inches of snow water content existed above 7,000 feet along the east rim of the Verde drainage, decreasing to 0.0 inches at the Sugar Loaf site at an elevation of 6,200 feet. SNOTEL readings before the sequence of storms for sites in the Salt River drainage above 7,000 feet ranged from 5.3 to 11.1 inches, and for the Gila (all stations 8,000 feet or greater) from 0.6 to 10.2 inches. The SNOTEL data further support the probability that only small amounts of runoff resulted from snowmelt, as only one station had less snow water content after the storm sequence than before, and the reduction at this station, McNary, was only 0.1 inches.

Further analysis of the data suggests that when rain fell upon the snowpack much of it moved directly through or replaced melt, with a net effect of little snowmelt contributing to runoff. It is possible that snow at lower elevations in the basin, where the pack was only 4 to 8 inches in depth, may have melted early in the storm series and might have been replenished later in the period as the snow level lowered and precipitation was in the form of snow.

The antecedent rains, and those occurring early in the storm series, added significantly to the soil moisture so that potential for absorption of additional rain was relatively low. Figure 3.3 gives the daily distributions of rainfall at Phoenix (a valley site) and Crown King (the mountain station receiving the greatest 9-day accumulation). To illustrate the effect of the wet antecedent conditions, consider the storm of February 14-15, which produced a peak flow in the Verde River of 96,000 cfs. If this storm had occurred at the beginning of a winter rainfall season with seasonably dry soil conditions, and if reservoirs had been at normal elevations, a runoff peak near half of this magnitude probably would have occurred.

Throughout the flooding, the Salt Lake City RFC generated peak flow and volumetric forecasts at 33 different forecast sites; however, forecasts for only five primary downstream points were disseminated (Fig. 3.4). In addition to these forecasts, which were transmitted to the Phoenix WSFO over the Radar and Warning Coordination Circuit (RAWARC), instantaneous forecasts to provide more points on the hydrographs were furnished via telephone directly to the Salt River Project (SRP) Office and the Flood Warning Office (FWO) for the State of Arizona attached to the Phoenix WSFO. The forecasts sent to the SRP and FWO, normally issued at 7:00 a.m. and 4:00 p.m. MST daily, usually consisted of flow estimates for each 6 hours of the subsequent 2½-day period.

The primary forecast points were: Agua Fria River -- inflow to Lake Pleasant Reservoir (2,925 km^2 drainage area); Verde River -- inflow to Horseshoe Lake (15,202 km^2 drainage area); Tonto Creek near Roosevelt Reservoir (1,748 km^2 drainage area); Salt River near Roosevelt Reservoir (11,132 km^2 drainage area); and Gila River at Calva -- inflow to San Carlos Reservoir (29,695 km^2 drainage area).

In addition, stage forecasts were provided to the Winslow Weather Service Office (WSO) when the Little Colorado River reached bankfull on February 20 in the vicinity of Holbrook and Winslow.

The most extensive area of flooding in Arizona was below Granite Reef Dam, extending into the metropolitan Phoenix area. The suburb of Holly experienced extensive residential damage. Elsewhere most damage was to public properties such as bridges and highways.

The confluence of the Salt River drainages (16,310 km^2) and the Verde River drainage (17,086 km^2) is above Granite Reef Dam. These two river systems have reservoir structures with total storage capacities of approximately 1.75 million acre-feet and 318,000 acre-feet, respectively. These reservoirs were approximately 90% full at the time and could not adequately handle the extreme flood flows experienced. Painted Rock Reservoir below Phoenix, with a total storage capacity exceeding 2 million acre-feet, contributed significantly to reducing the flows below Painted Rock Dam.

The highest flows on the Verde River occurred between Oak Creek and the East Verde River, and on the Salt River drainage from Tonto Creek eastward to

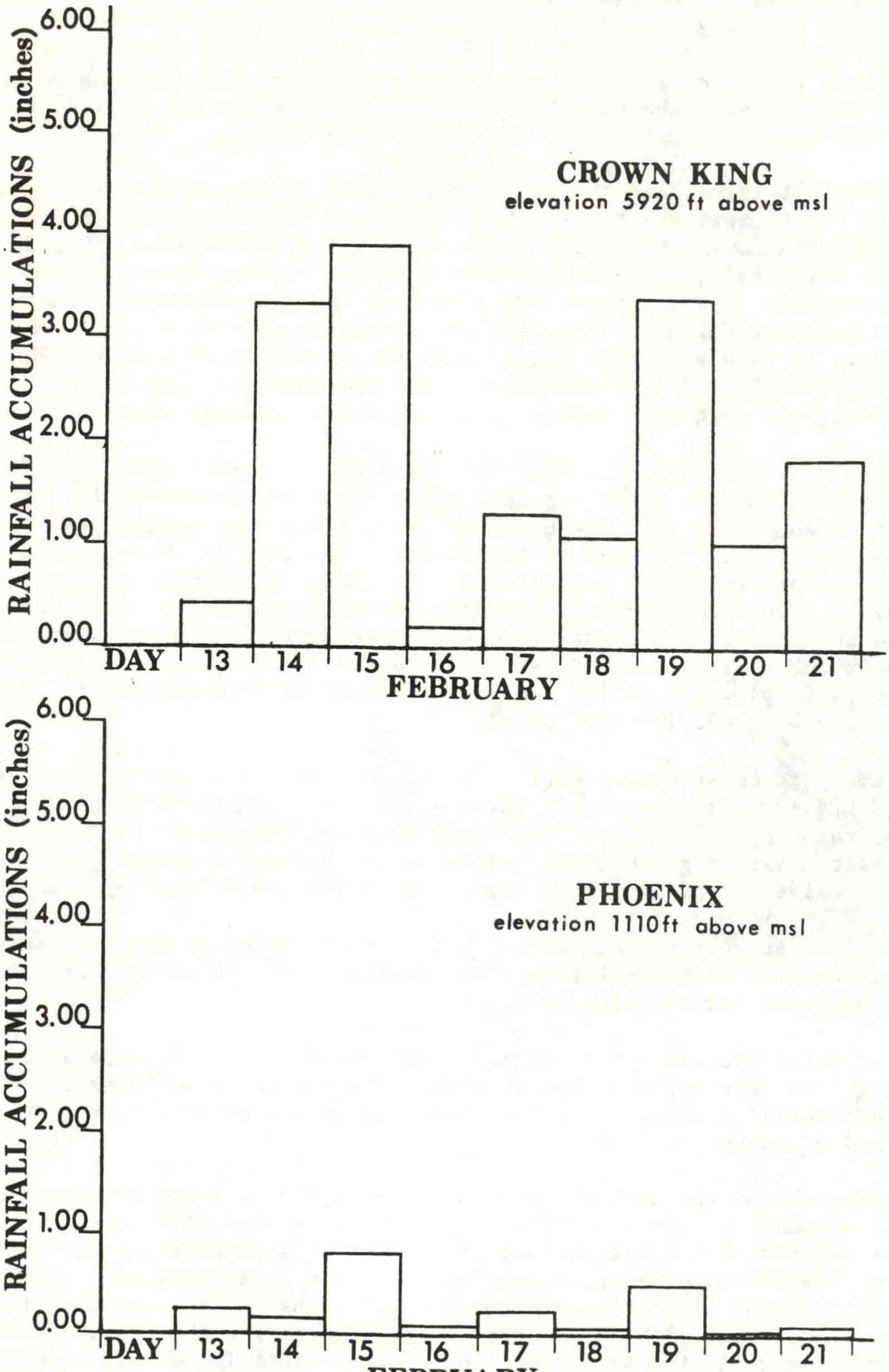


Figure 3.3--Daily accumulations of rainfall at two Central Arizona stations.

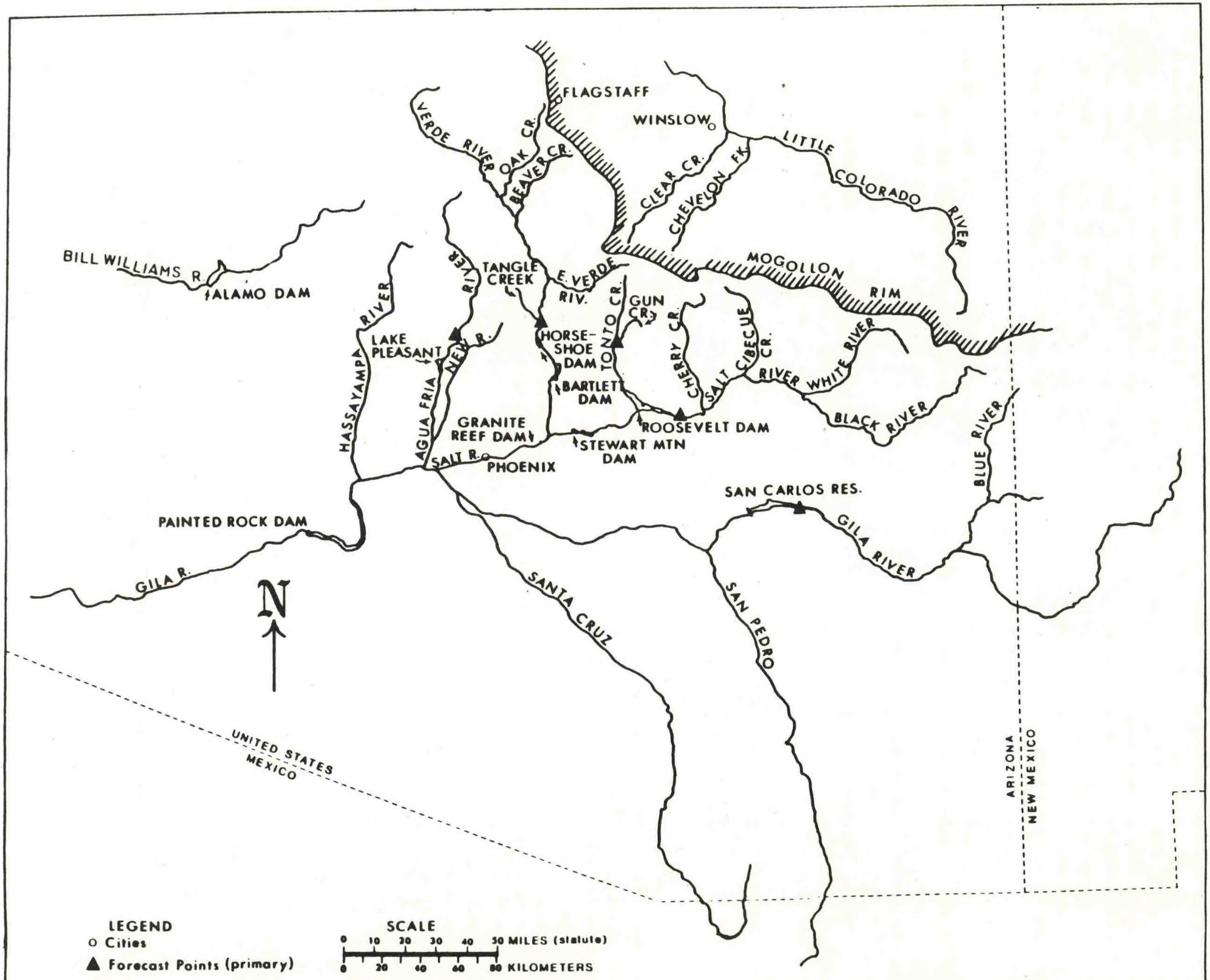


Figure 3.4--River systems of Central Arizona.

Cibecue Creek. The isohyetal analyses (Figs. 3.5-3.7) show a "ridge" of heavy precipitation over headwater areas of these drainages.

Preliminary data indicate that a record flow occurred on the Verde River below Tangle Creek, and the record flow on Tonto Creek near Roosevelt Dam was equalled. (See table 3.1.) Also, near-record flows with minor flooding were reported on the Agua Fria River, Hassayampa River, Bill Williams River, Clear Creek, Chevelon Creek, and the Little Colorado River in the vicinity of Winslow. Many of the headwater areas where the heaviest rainfall occurred are located on United States Department of Agriculture (USDA) Forest Service land, which is sparsely populated. Flood damage in these areas generally was confined to bridges, roads, and a few summer homes.

Although some high flows were reported in the upper reaches of the Blue River drainage, flows throughout most of the Gila Basin above the confluence of the Salt River were <u>not</u> damaging and were, for the most part, typical of a storm of moderate-to-light intensity for this time of year.

Total inflow to San Carlos Reservoir on the Gila River during the storm period was about 26,000 acre-feet, most of which was impounded. This completely filled the reservoir's storage capacity of nearly 1 million acre-feet.

Streamflow on the Santa Cruz and San Pedro Rivers was minimal.

Summary

In summary, the hydrological situations in Southern California and Central Arizona differed in the sense that flash flooding and mudslides produced <u>most</u> of the damage in Southern California while major river flooding caused <u>most</u> of the destruction in Central Arizona. This, of course, is not to say that flash flooding and major river flooding did not cause significant damage in the converse areas, but only that they did so to lesser relative extents. One common denominator to both areas was the persistent heavy rains that led to the destructive hydrologic phenomena. The forecasts issued in both areas were very valuable in providing information that certainly led to significant reductions in the economic and human losses resulting from these extreme hydrologic conditions. In some instances, however, the forecasts could have been improved. Subsequent sections of this report examine the effectiveness of the overall forecast system and provide recommendations on how forecasts for such hydrologic phenomena can be improved in the future.

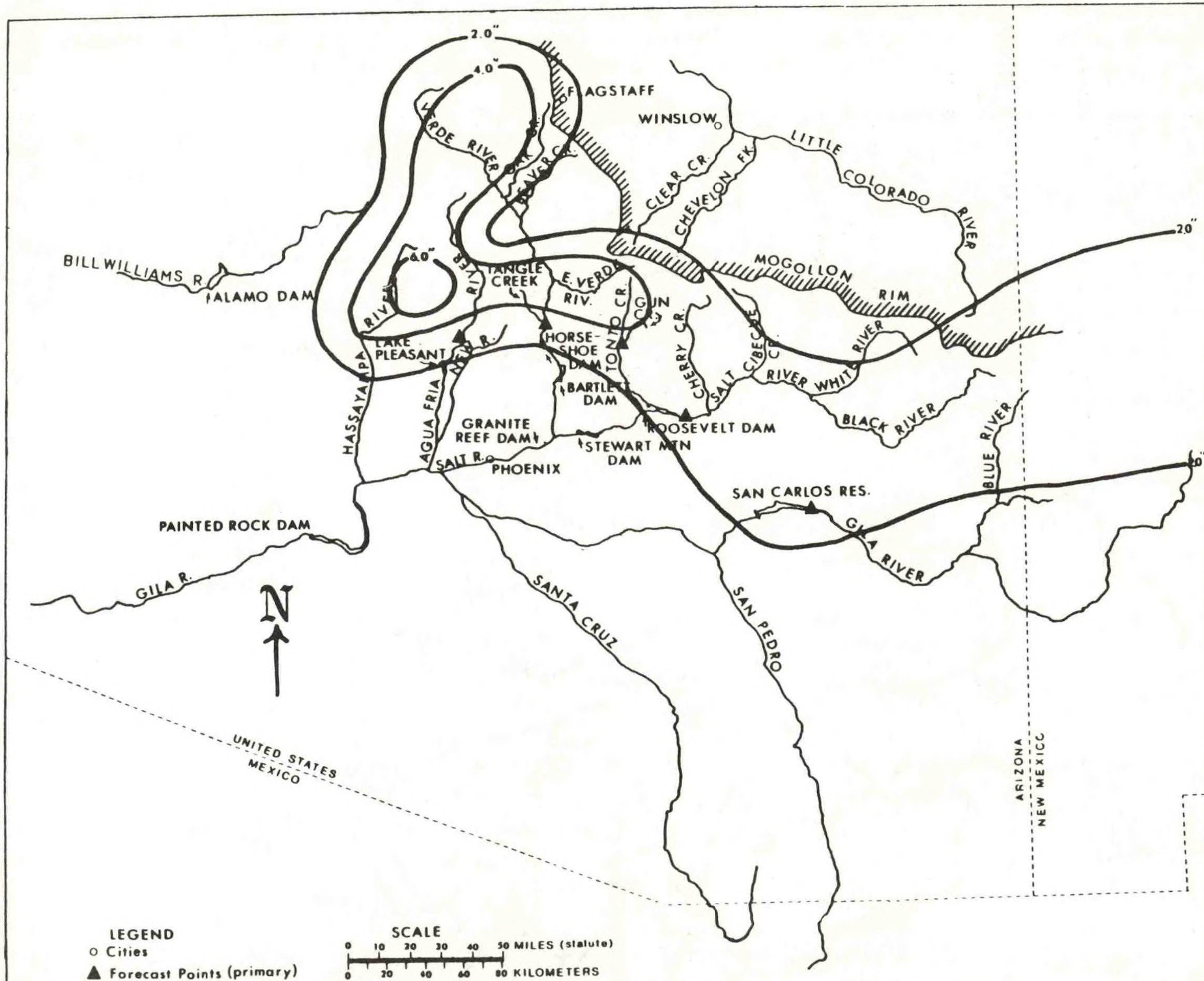


Figure 3.5--Isohyetal analysis of rainfall accumulations (inches) greater than 2 inches for Central Arizona, approximately 0300 GMT, February 14 through 0300 GMT, February 16. Only those gages available operationally in real time (approximately 20 gages) were used for this analysis.

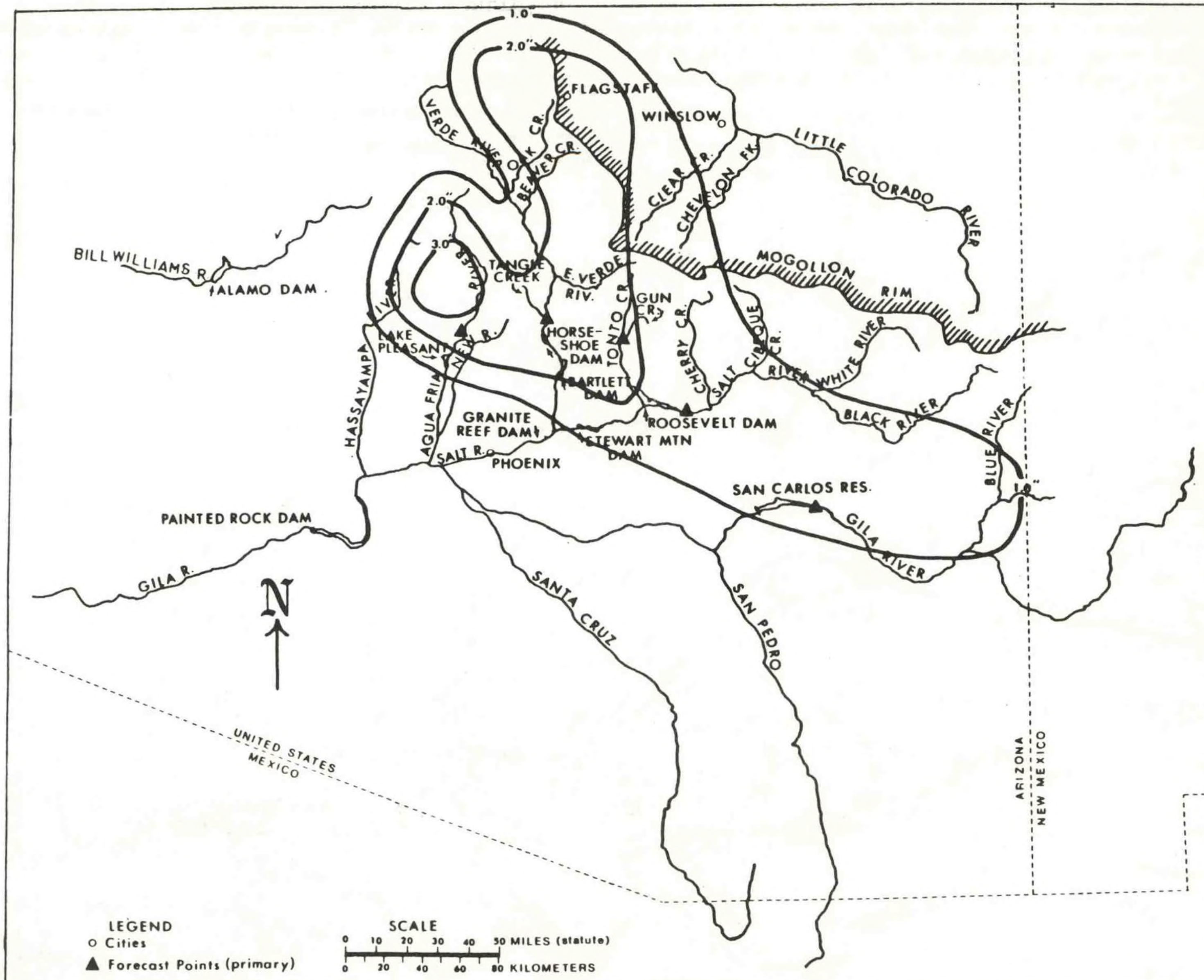


Figure 3.6--Isohyetal analysis of rainfall accumulations (inches) greater than 1 inch for Central Arizona, approximately 1600 GMT, February 19 through 1600 GMT, February 20. Approximately 90 of the 192 gages in Arizona and New Mexico listed in appendix 2 were used in this analysis.

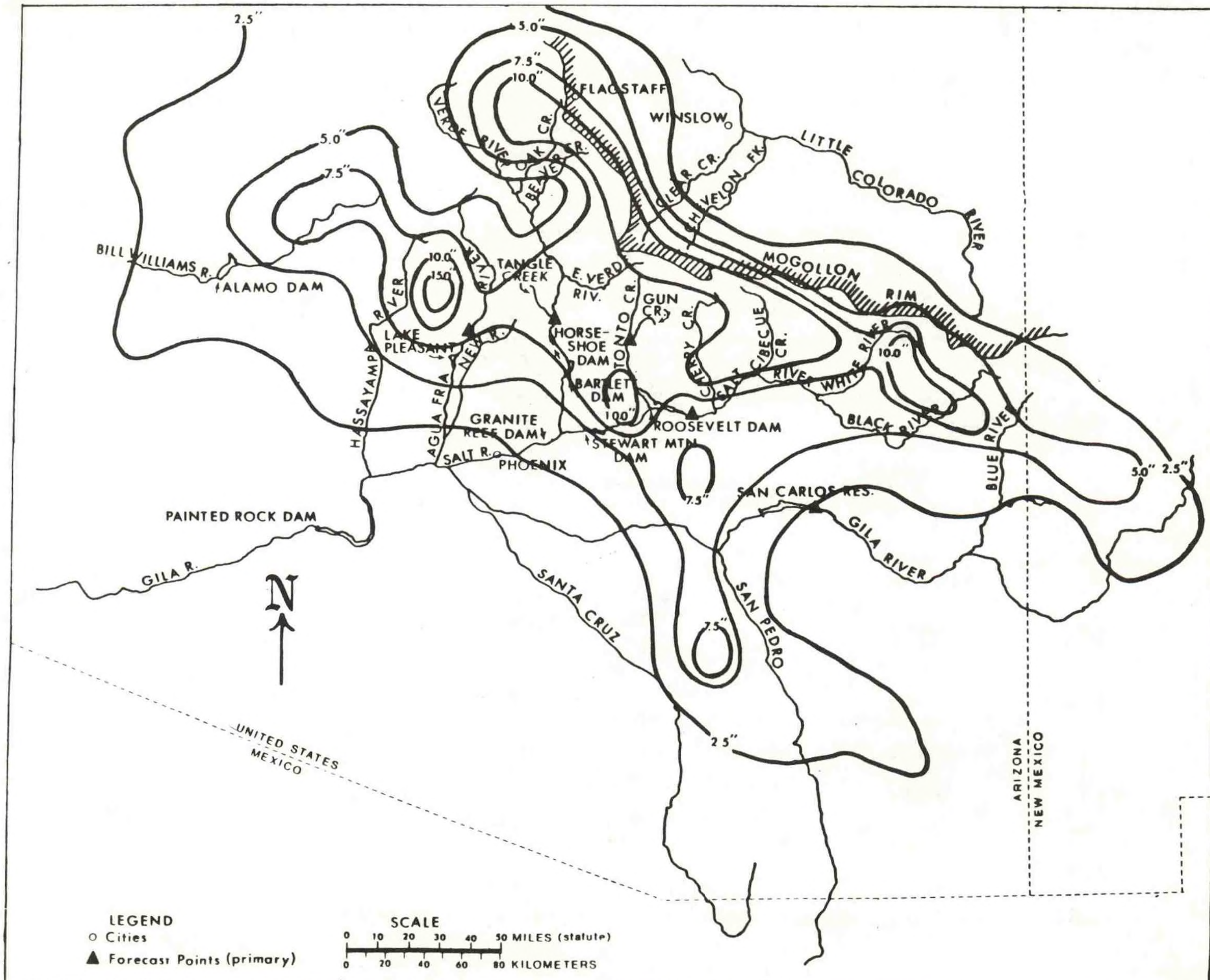


Figure 3.7--Isohyetal analysis of rainfall accumulations (inches) greater than 2.5 inches based on all data contained in appendix 2 for Central Arizona for total period of rainfall, approximately 1300 GMT, February 13 through 0700 GMT, February 22.

Table 3.1 Some preliminary streamflow data[1] for the storm period February 13 through 21, 1980 in Central Arizona

Stream	Drainage Area Above Forecast Point (km^2)	Peak Flow[2] (cfs)	Time of Peak	Previous Record (cfs)	Forecast Peak (cfs)	Forecast Time of Peak	Remarks
Agua Fria River; Inflow to Lake Pleasant Reservoir	2,925	25,500 42,300 73,000[3]	2/14 6 p.m. 2/15 noon 2/20 2:30 a.m.	105,000[4] Jan 1916	20,000 45,000 60,000	2/14 9 a.m. 2/15 2 p.m. 2/20 4 a.m.	
Verde River; Inflow to Horseshoe Lake	15,202	96,000 67,150	2/15 6 p.m. 2/20 8 a.m.	94,000 Dec 1978	85-100,000 50,000	2/16 6 a.m. 2/20 6 p.m.	Precip occurred earlier than expected
Tonto Creek above Gun Creek near Roosevelt Reservoir	1,748	55,800 52,300	2/15 3 p.m. 2/19 midnight	55,800 Jan 1979	35,000 25,000	2/15 6 p.m. 2/19 midnight	
Salt River near Roosevelt Reservoir	11,132	81,000 40,100	2/15 8 p.m. 2/20 6 a.m.	117,000 Mar 1941	75,000 50,000	2/16 noon 2/20 midnight	Precip occurred earlier than expected
Gila River at Calva; Inflow to San Carlos Reservoir	29,695	Reservoir filled	2/24	Filled one other time since construction in 1928	Reservoir[5] will be filled	2/25	

[1]The observed peak flow data are preliminary (from gage heights) and were provided on a provisional basis by the USGS.

[2]The maximum peak flows at each location are either record or near record. The total volumes are very close to the largest volumes that have occurred since 1891. The extended durations of high water levels, as well as the large peak flows, intensified the flood problems.

[3]Lake Pleasant Reservoir reached its maximum holding capacity on February 20, 1980.

[4]This estimated old record was established before the dam was built in 1927.

[5]Insufficient rain occurred in the San Carlos headwater areas to produce flood level flows, but the reservoir was predicted to fill since it was near maximum holding capacity when the rain began.

CHAPTER 4

RAIN AND FLOOD PREDICTIONS AND WARNINGS

Levels of Responsibility

Southern California

Forecast and warning responsibility for Southern California is shown in figure 4.1. The Los Angeles WSFO has forecast responsibility for the area of California roughly east and south of a line connecting the crest of the southern Sierra Nevada range, the Tehachapi Mountains, and the southern extremity of the coastal range. The Santa Maria WSO, a 16-hour station, has warning responsibility for San Luis Obispo and Santa Barbara Counties. Nighttime back-up warning responsibility for the Santa Maria WSO belongs to the WSFO (Los Angeles or San Francisco) for the county or portion of the county in its forecast area. The San Diego WSO has warning responsibility for San Diego and Imperial Counties. The Los Angeles WSFO has warning responsibility for Ventura, Los Angeles, Orange, Riverside, and San Bernardino Counties. It also has the HSA responsibility for California south of the Tehachapi Mountains.

Central Arizona

The meteorological forecast responsibility for the entire State rests with the Phoenix WSFO (Fig. 4.2). In addition, the Phoenix WSFO has HSA responsibility for the Colorado River and tributaries in the State of Arizona with the exception of the Virgin River. This includes responsibility for flash flood warnings. The Salt Lake City RFC* provides flood forecasts and warnings for the major river systems in Arizona (primarily disseminated via the Phoenix WSFO) and it also provides water-supply forecasts for this area.

Forecasts and Guidance from the NMC

Significant use was made of various guidance products received via facsimile and teletype from the NWS's National Meteorological Center (NMC) in Camp Springs, Maryland. The Numerical Weather Prediction (NWP) guidance from NMC (prognoses of 12 to 72 hours) generally was good and helpful. The major deficiency was failure to forecast more accurately the persistence of west-southwesterly flow over the ocean to the west and southwest of California as migratory short-wave troughs moved over Southern California and Arizona. This deficiency was most pronounced in the guidance from the Limited Fine Mesh (LFM) model and is believed to be associated with boundary conditions and initial analyses which are limited by the present state of the art.

The guidance based on Model Output Statistics (MOS) was not exceedingly useful overall. The Probabilities of Precipitation (POP's) from MOS generally were much too low (i.e., less than 50%) during crucial parts of the rainy periods. The POP's early in the storm sequence on February 13 and 14 were of the order of

*Now called the Colorado River Basin RFC.

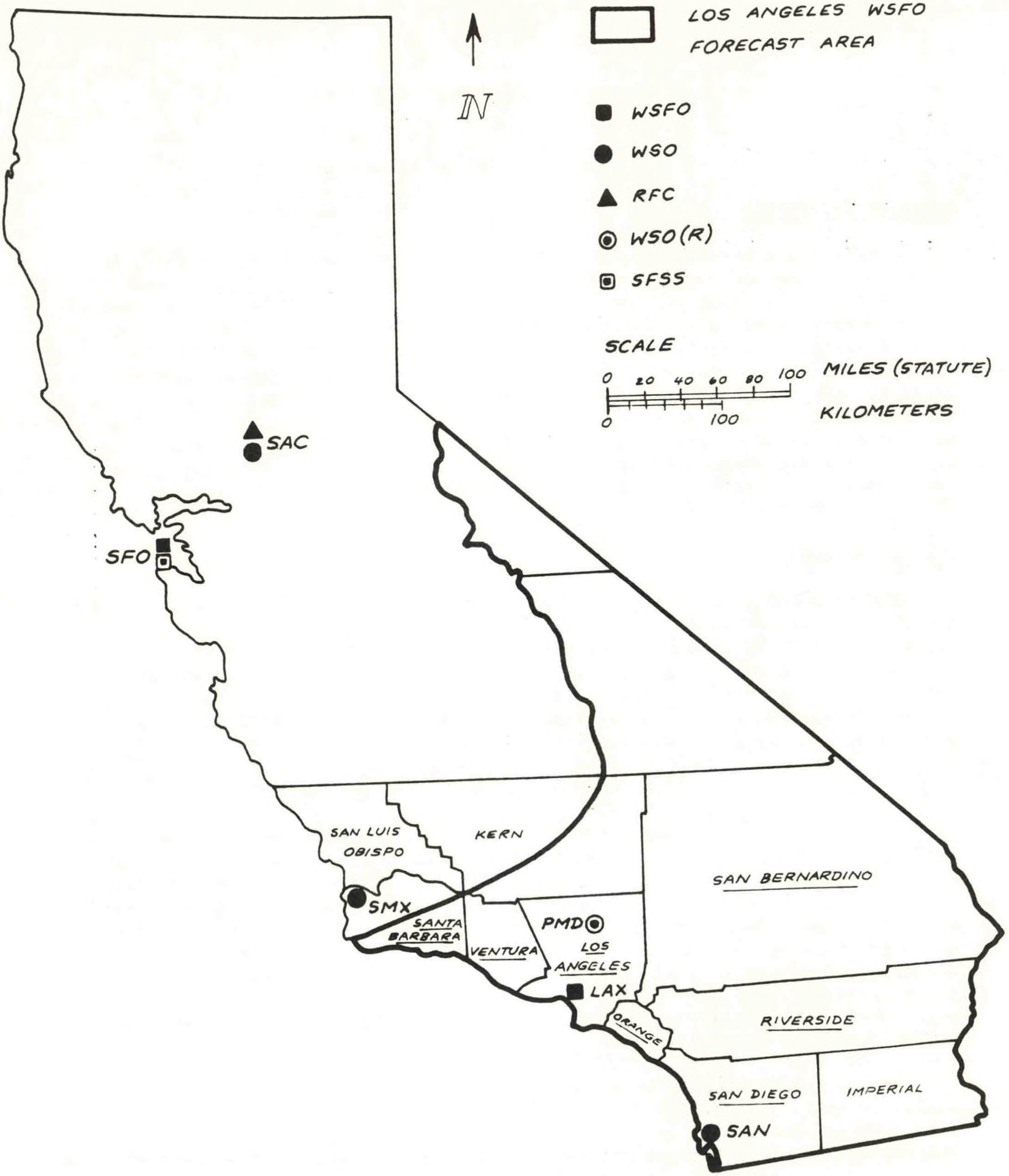


Figure 4.1--Weather Service forecast areas and offices involved in the February 1980 disasters in Southern California counties. Counties with names underscored were declared Federal disaster areas.

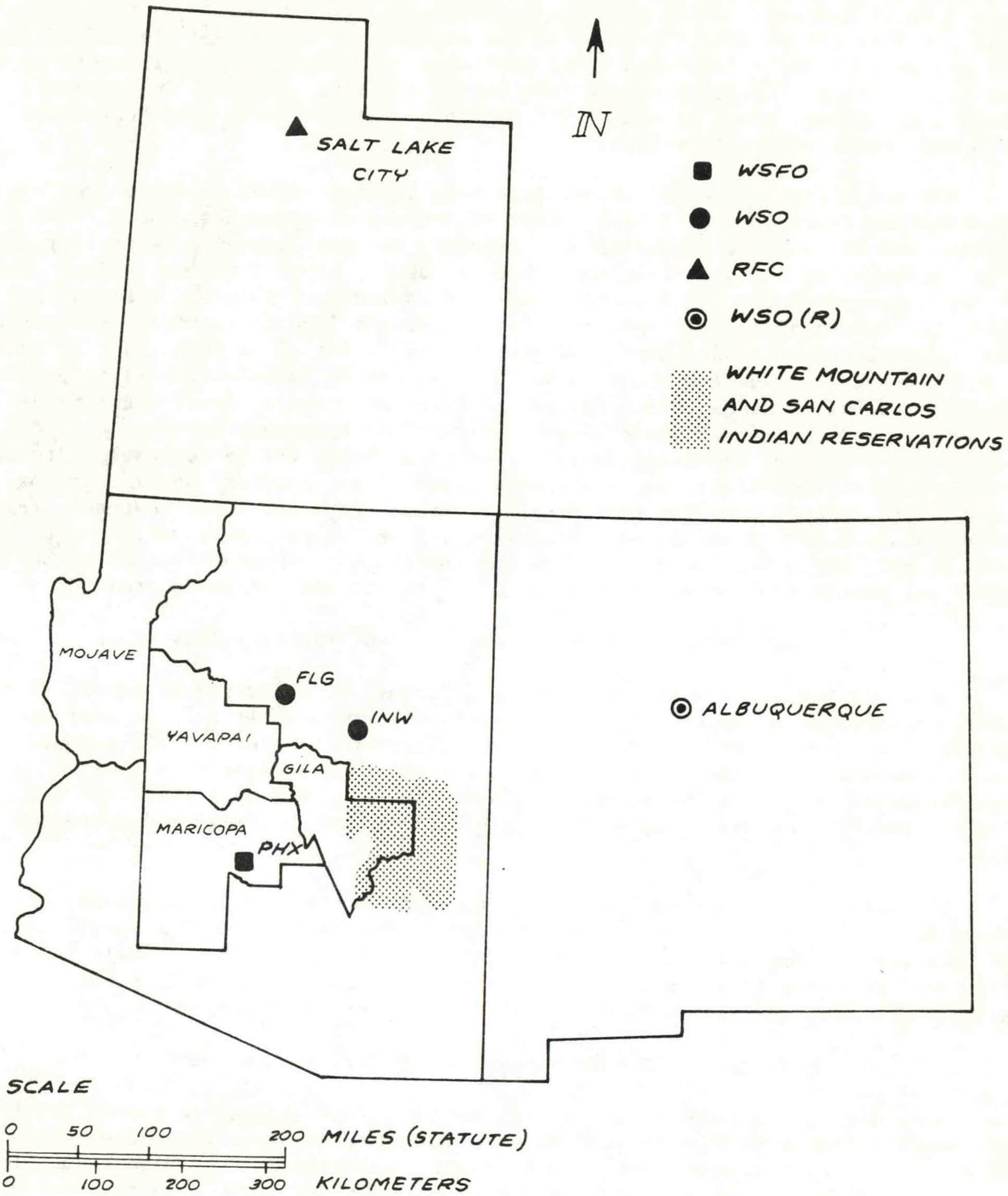


Figure 4.2--Weather Service offices in areas affected by the February 1980 floods in Central Arizona. The counties and Indian reservations which were declared Federal disaster areas are shown.

only 5 to 15 percent. There were two occasions of significant "yo-yo" guidance (e.g., 85% to 45% to 75%). Because of the significant biases and the undulating values, the MOS POP's forecasts would have been very misleading if released to the public without modification by the forecasters locally. However, in spite of these limitations, areas of higher POP probabilities generally were correlated with main areas of precipitation.

The subjective Quantitative Precipitation Forecast (QPF) guidance from the Quantitative Precipitation Branch (QPB)* of NMC was of mixed usefulness. The 24-hour and 48-hour QPF guidances were helpful, but the excessive rainfall potential outlooks, both the 24-hour and 6-hour products, were of minimal value. Part of the explanation for the limited value of the excessive rainfall outlooks may be that they were updated only once per day. Also, the lack of rainfall observations and adequate flash-flood guidance values were contributing factors. The 24-hour and 48-hour QPF's, and the short technical discussions issued three times per day, provided useful guidance to the forecast offices on when to expect significant rainfall events and on the general area of rainfall coverage, but the lead forecasters at the WSFO, sometimes in consultation with the QPB forecasters, altered the forecasts considerably to gain greater spatial and temporal specificity by taking into account detailed knowledge of terrain and other local features. Also, the local forecasters had access to some real-time rainfall observations not available at NMC, which were used to refine and update their forecasts. The number of real-time rainfall observations available at the QPB was extremely limited.

Satellite Information from the San Francisco SFSS

As described in chapter 2, satellite information was extremely useful in the early recognition of approaching storms while they were still far out over the Pacific Ocean. The GOES satellite pictures received over the UNIFAX, normally each 30 minutes, and the SIM's routinely received each 6 hours from the San Francisco SFSS of NESS, proved invaluable to both the Los Angeles and the Phoenix WSFO's. Appendix 1 contains a synopsis of the information received in the SIM's.

The GOES satellite imagery was not only critical to remaining abreast of the synoptic situation, but also was very useful in determining the timing and extent of rain areas. However, forecasters at both locations stated that while the satellite pictures were indispensable, an even better understanding of the synoptic situation could have been achieved with animated satellite imagery.

Forecasts and Guidance from the Los Angeles WSFO

In general, the forecasts, watches, warnings, and statements issued by the Los Angeles WSFO were timely, well worded, and contained specific action statements. In a few instances, however, the action statements might have been interpreted and disseminated more effectively if the most important informational and action sentence(s) had consisted of shorter, simpler phrases and had occurred earlier in the text of the statements, i.e., clear, succinct news-style writing is generally more readily comprehended. Appendix 3 contains a chronology of the issuances.

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*Now called the Heavy Precipitation Branch (HPB).

Forecasters at the Los Angeles WSFO recognized the potential for rain 2 days in advance. Forecasts issued at 2:10 p.m., Monday, February 11, indicated rain spreading over Southern California on Wednesday. Rain began in Los Angeles between 7:00 and 8:00 a.m., Wednesday, February 13.

In general, watches covered every event or storm which produced heavy rain in Southern California. Within 2 hours of the start of rainfall in the coastal areas of Los Angeles on February 13, a special weather statement alerted the populace to the dangers of heavy rains, rock and mudslides, and flooding of small streams and dry washes. It read:

SPECIAL WEATHER STATEMENT
NATIONAL WEATHER SERVICE LOS ANGELES CA
9:15 AM PST WED FEB 13 1980

MODERATE TO HEAVY RAIN FOR SOUTHERN CALIFORNIA TODAY AND TONIGHT...
TRAVELERS ADVISORY FOR MOUNTAIN AREAS..

A LOW PRESSURE SYSTEM CENTERED ABOUT 700 MILES WEST SOUTHWEST OF SAN DIEGO HAS SPREAD LIGHT TO MODERATE RAIN OVER MUCH OF SOUTHERN CALIFORNIA THIS MORNING. THE LOW IS MOVING SLOWLY TOWARDS THE COAST AND THE RAIN IS EXPECTED TO CONTINUE THROUGH THE NIGHT AND GRADUALLY END THURSDAY. SNOW HAS BEEN REPORTED IN THE MOUNTAINS ABOVE 6000 FEET. SATELLITE PICTURES AND RADAR INDICATE THERE ARE SOME THUNDERSTORMS OVER THE COASTAL WATERS. LIGHT TO MODERATE RAIN TODAY WILL BECOME HEAVIER TONIGHT AS THE LOW APPROACHES. RAINFALL AMOUNTS WILL TOTAL 1/2 TO 3/4 INCH IN THE COASTAL SECTIONS AND DESERT AREAS AND 2 TO 3 INCHES IN THE MOUNTAINS WITH LOCALLY HEAVIER AMOUNTS IN THE SOUTHERN MOUNTAINS.

DRIVING CONDITIONS WILL WORSEN TONIGHT. AS THE RAINFALL RATE INCREASES, THIS WILL INCREASE THE LIKELIHOOD OF ROCK AND MUDSLIDES IN MOUNTAIN AND CANYON AREAS WITH LOCALLY HEAVY RAIN FALLING ON SATURATED SOIL. SOME SMALL STREAMS AND DRY WASHES ALSO MAY BECOME FLOODED.

CAUTION IS ADVISED WHEN TRAVELING INTO THE HIGHER MOUNTAIN AREAS BECAUSE OF SNOW AND YOU SHOULD CHECK ON ROAD CONDITIONS BEFORE STARTING YOUR TRIP.

THE NEXT STATEMENT [WILL BE ISSUED] ABOUT 3:30 THIS AFTERNOON OR SOONER IF CONDITIONS WORSEN.

END CLC 9:22 AM WED FEB 13 1980

A flash flood watch followed (1:30 p.m., February 13, 1980) for the mountain areas of Santa Barbara and Ventura Counties, the San Gabriel Mountains, San Bernardino Mountains, and the San Jacinto Mountains southward through the mountains of San Diego County. Statements issued at 5:00 p.m. and 10:00 p.m. on Wednesday, February 13, and at 3:30 a.m., February 14, amplified and extended the original watch. The 1:30 p.m., February 13, flash flood watch read:

FLASH FLOOD WATCH
NATIONAL WEATHER SERVICE LOS ANGELES CA
1:30 PM PST WED FEB 13 1980

A FLASH FLOOD WATCH HAS BEEN ISSUED FOR THE MOUNTAIN AREAS OF SANTA BARBARA AND VENTURA COUNTIES...THE SAN GABRIEL MOUNTAINS... SAN BERNARDINO MOUNTAINS...AND THE SAN JACINTO MOUNTAINS SOUTHWARD THROUGH THE MOUNTAINS OF SAN DIEGO COUNTY. VALID TIME 1:30 PM PST TODAY THROUGH MIDNIGHT.

THE CENTER OF THE CURRENT STORM SYSTEM AFFECTING SOUTHERN CALIFORNIA WAS LOCATED ABOUT 200 MILES WEST SOUTHWEST OF LOS ANGELES AT 1 PM. IT IS MOVING EASTWARD ABOUT 25 MPH. SOME LOCAL HEAVY SHOWERS ARE EXPECTED TO OCCUR THROUGH MIDNIGHT IN THE ABOVE MENTIONED AREAS. AMOUNTS WILL AVERAGE FROM 2 TO 3 INCHES WITH LOCAL FLOODING AND MUDSLIDES.

THE STORM WILL BE MOVING INLAND EARLY THURSDAY MORNING WITH SHOWERS TAPERING OFF AFTER MIDNIGHT. THE AIRMASS WILL REMAIN MOIST AND UNSTABLE ENOUGH THURSDAY FOR PARTLY CLOUDY SKIES WITH STILL A CHANCE OF A FEW SHOWERS.

ANOTHER STORM SEEMS TO BE DEVELOPING 1300 MILES WEST OF THE SOUTHERN CALIFORNIA COAST. THIS STORM MAY FOLLOW THE SAME PATH THAT THE CURRENT ONE FOLLOWED AND REACH OUR AREA LATE THURSDAY NIGHT OR FRIDAY WITH SOME ADDITIONAL RAIN. IT IS STILL TOO SOON TO DETERMINE THE AMOUNT OF RAIN FROM THIS SECOND STORM SINCE IT IS STILL IN THE DEVELOPING STAGE.

THE NEXT STATEMENT WILL BE ISSUED AT 7 PM THIS EVENING.

A special weather statement issued at 6:55 a.m., Thursday, February 14, cancelled the watch, stating "the main portion of the storm system which produced the heavy rainfall...(had moved)...to southern Nevada and western Arizona." It also alerted residents to the second storm which was expected to move inland late Thursday or early Friday.

Another special weather statement issued at 4:00 p.m., Thursday, February 14, warned the populace that storm rainfall totals could "average about 2 inches in the coastal areas...4 inches in the mountains...and 1 to 2 inches in the deserts." This and a similar statement at 10:00 p.m. laid the foundation for the second flash flood watch, which was issued at 12:15 a.m., Friday, February 15. Several statements followed, and at 3:00 p.m., Friday, a third flash flood watch was issued. This watch cancelled a portion of the area covered by the previous watch and redefined the area now expected to be affected. It is gratifying to note that the watch not only warned residents of existing dangers due to the persistent rainfall, and the threat of additional heavy rain the following day, Saturday, but also alerted the population to a new danger, "another storm about 850 miles north-northwest of Hawaii which could move to the California coast by Monday bringing with it additional rain."

Flash flood watches, flood statements, and special weather statements continued in a similar fashion throughout the remainder of the storm period. (See appendix 3.) On Friday, February 22, the last flash flood statement was issued. This stated:

BULLETIN

FLASH FLOOD STATEMENT
NATIONAL WEATHER SERVICE LOS ANGELES CA
12:15 AM PST FRI FEB 22, 1980

THE FLASH FLOOD WATCH FOR THE MOUNTAINS AND AREAS BELOW THE CANYONS OF SANTA BARBARA VENTURA LOS ANGELES ORANGE SAN DIEGO RIVERSIDE AND SAN BERNARDINO COUNTIES HAS BEEN CANCELLED EFFECTIVE IMMEDIATELY. HIGHER PRESSURES ARE BUILDING UP OVER THE SOUTHWESTERN STATES FORCING THE PATH OF PACIFIC STORMS FARTHER NORTH. THE LAST STORM THAT WAS EXPECTED TO BRING SHOWERS TO SOUTHERN CALIFORNIA LATE TONIGHT AND FRIDAY MORNING HAS WEAKENED...AND ONLY THE TAIL END OF THAT SYSTEM IS NOW EXPECTED TO AFFECT SOUTHERN CALIFORNIA BRINGING THE THREAT OF A FEW SHOWERS TO AREAS NORTH OF LOS ANGELES TODAY. AND THESE SHOWERS ARE NOT EXPECTED TO BE HEAVY.

FAIR SKIES ARE EXPECTED TO PREVAIL ACROSS SOUTHERN CALIFORNIA SATURDAY AND SUNDAY...A WELCOME RESPITE FROM THE SERIES OF HEAVY STORMS THAT HAVE BEEN RACING FROM THE PACIFIC THROUGH SOUTHERN CALIFORNIA FOR MORE THAN A WEEK. DURING THE LAST NINE DAYS ENDING YESTERDAY...THE LOS ANGELES CIVIC CENTER RECEIVED TWELVE AND THREE QUARTERS INCHES OF RAIN..AND MOUNT WILSON JUST NORTH OF LOS ANGELES HAD ABOUT 30 INCHES OF PRECIPITATION.

NO FURTHER STATEMENTS WILL BE ISSUED ON THESE STORMS UNLESS CONDITIONS CHANGE.

DBH 220815

In all, three flash flood warnings, 12 flash flood watches, and over 30 statements were issued during the 9-day period to advise and alert the public of weather and flash flooding conditions. (See appendix 3.) Although the Los Angeles WSFO issued many flash flood advisories as conditions dictated, no advisories were issued during the storm series explicitly on river conditions. The reasons for this and the future plans for expanding the river forecast services provided by the Sacramento RFC in Southern California were discussed in chapter 3.

Performance of the WSO's in Southern California

In California, the WSO's at San Diego and Santa Maria and an NWS radar unit at Palmdale were involved with advising the public of the potential for flooding, flash flooding, and mudslides. The offices generally performed at very high levels of effectiveness during the 9 days of the storms. Watches and updates were disseminated upon receipt by the San Diego WSO. In addition, each of the applicable San Diego public forecasts contained information on anticipated rainfall amounts. A member of the WSO staff provided a personal briefing twice daily to the San Diego County Flood Control District, city police, and the International Boundary Water Control. The San Diego WSO also had numerous calls from officials in Baja, California.

Between 5:00 p.m. and 6:00 p.m. on February 20, 0.91 inches of rain fell at San Diego. The San Diego WSO called the Los Angeles WSFO and provided them with this information. It was decided that a flash flood warning should be issued at 7:00 p.m. Since heavy rain was falling over a large area of Southern California, it was agreed that the Los Angeles WSFO would issue the warning which included Los Angeles, Riverside, San Bernardino, Orange, and San Diego Counties, even though the WSO at San Diego has warning responsibility for San Diego County. The heavy downpour caused considerable flooding in Mission Valley (Fig. 1.1). Additionally, flash flooding occurred at 1:00 a.m., February 21, in San Clemente.

The Santa Maria WSO has warning responsibility for Santa Barbara and San Luis Obispo Counties. San Luis Obispo County and much of Santa Barbara County did not appear to be hard-hit by the series of storms, although watches and warnings were issued in these areas. The WSO functioned very well throughout the storm period. In nearly every instance the watches and warnings were promptly disseminated. The WSO operates normally on a 16-hour per day basis, but overtime was used to extend hours every day from February 15 through February 21, and the station was manned on a 24-hour basis on February 18, 19, and 20.

Through a system of microwave links, Paso Robles, San Pedro, Mt. Laguna, Las Vegas, and Boron Federal Aviation Administration (FAA) Air Route Traffic Control (ARTC) radars were monitored at the Palmdale, California, Air Route Traffic Control Center (ARTCC), (Fig. 4.3). The NWS has a radar unit located at the ARTCC [the Palmdale WSO(R)] which monitors these radars. Through the use of overtime and compensatory time, the Palmdale WSO(R) maintained at least double coverage on all shifts during which watches or warnings were in effect. With this arrangement, one weather radar specialist devoted his time to data collection, analysis, and communications, while the other briefed WSFO's, WSO's, county flood control offices, and local warning action agencies.

The FAA ARTC radar-scope depictions of the affected storm areas were extremely valuable in identifying areas of significant rainfall. The arrangement of five radar systems being monitored in one location was especially well suited to keeping track of the storm events of mid-February. The broad, composite area monitored at Palmdale with the FAA ARTC radars, together with the NWS local warning radars, essentially covered the most seriously affected areas in Southern California and western Arizona.

The Palmdale WSO(R) effectively provided radar information to the three WSFO's (LAX, PHX, SFO) and seven WSO's involved. The Los Angeles WSFO received 58 calls from the Palmdale WSO(R). Each call included a radar briefing, and there were eight which included radar rainfall estimates, four with suggestions for flash flood warnings, eight with recommendations for flash flood watches or confirmation of existing watches, and two with recommendations for statements. Also, any reports from spotters were passed on. Other coordination calls by the WSO(R) included 14 to the San Francisco WSFO, 12 to the San Diego WSO, nine to the Phoenix WSFO, and nine to the Yuma WSO. Excellent teamwork and rapport existed during this storm between the radar staff at Palmdale and the other NWS offices in the affected area. Without a doubt, the effectiveness of the Palmdale WSO(R) contributed very postively to the overall performance of the NWS during this series of storms.

Forecasts and Guidance from the Phoenix WSFO

Appendix 3 contains a listing of issuances made by the Phoenix WSFO during the severe flooding. From February 12 through February 21, over 80 issuances were made, keeping the public and special users well-advised of the expected weather and flood conditions.

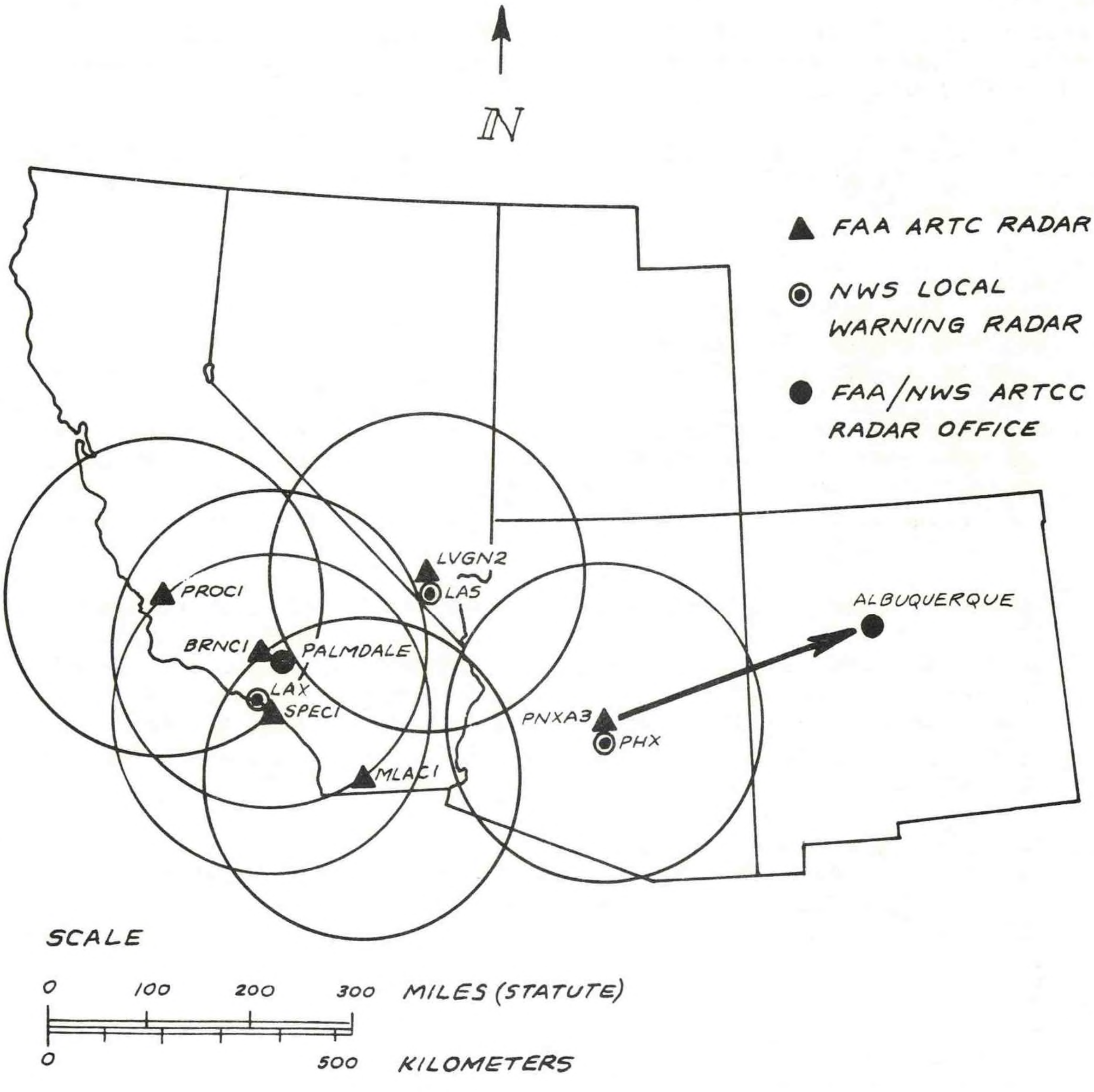

Figure 4.3--The network of NWS and FAA radars used to provide weather radar information for Southern California and Central Arizona during the February 1980 storms. Circles indicate maximum probable range for qualitative coverage. Extent of quantitative coverage would be less.

As with the forecasters at Los Angeles, forecasters at Phoenix recognized the threat of heavy rain in Arizona well in advance. At 1:25 p.m. MST on Tuesday, February 12, the Arizona Department of Public Safety was called and advised to expect heavy precipitation late Wednesday through Thursday with heavy snow accumulation in the mountains above 7,000 feet. The forecast issued at 3:10 p.m. MST, Tuesday, called for numerous and locally heavy rain or snow showers Wednesday night and Thursday.

Rain began in Arizona during the day on Wednesday, with rainfall intensities varying from moderate to heavy at times. At 1:30 p.m. the following flash flood watch was issued:

BULLETIN
FLASH FLOOD WATCH BULLETIN
NATIONAL WEATHER SERVICE PHOENIX AZ
1:30 PM MST WED FEB 13 1980

THE NATIONAL WEATHER SERVICE HAS ISSUED A FLASH FLOOD WATCH FOR ARIZONAS CENTRAL BASIN REGION...AS WELL AS THE ADJOINING DESERT AND FOOTHILL REGION FROM PHOENIX NORTH AND EASTWARD. THE WATCH INCLUDES PHOENIX..PRES COTT...THE VERDE VALLEY AND OAK CREEK CANYON...PAYSON...THE SALT RIVER LAKES AND GLOBE.

MODERATE TO HEAVY RAIN DEVELOPED AT MIDDAY AND IS EXPECTED TO CONTINUE THROUGH TONIGHT...POSSIBLY LONGER. THE SOUTH AND WEST FACING MOUNTAIN SLOPES ARE FORCING THE WET AIR TO RISE AND DUMP ITS MOISTURE. THIS CAN RESULT IN RAINFALL MUCH GREATER THAN OCCURS IN THE VALLEYS. PHOENIX STANDS TO PICK UP ABOUT AN INCH OF RAIN...THE MOUNTAINS MAY HAVE THREE OR FOUR INCHES. THAT IS ENOUGH TO CAUSE FLOODING IN MOST OF THE CANYONS AND MOUNTAIN STREAMS...AND MOST DESERT WASHES.

FLOODING..OR AT LEAST...HIGH WATER...IS LIKELY ON JUST ABOUT ALL STREAMS IN THE WATCH AREA. BUT THE FLOODING MAY DEVELOP VERY RAPIDLY ON SOME OF THE MOUNTAIN STREAMS...A DANGER TO CAMPERS AND FISHERMEN AS WELL AS TRAVELERS. ALL TRAVEL OFF THE MAIN HIGHWAYS WILL BE HAZARDOUS...MANY STREAM CROSSINGS WILL SOON BECOME IMPASSABLE. EVEN ON THE PAVED ROADS...WATCH FOR FLOODED DIPS. THERE IS ALSO A DANGER OF ROCKSLIDES ON MOUNTAIN ROADS.

FISHERMEN CAMPED AT THE SALT...VERDE LAKES SHOULD MOVE THEIR CAMPS WELL AWAY FROM THE WASHES THAT DRAIN INTO THE LAKES.

IF YOU ARE NEAR A STREAM AND THE WATER STARTS TO RISE...ESCAPE BY CLIMBING AWAY FROM THE STREAM. NEVER TRY TO OUTRACE A FLOOD BY GOING DOWNSTREAM... EITHER ON FOOT OR IN YOUR CAR.

UPDATING STATEMENTS WILL BE ISSUED THIS AFTERNOON AND EVENING AS THE STORM DEVELOPS. JT WSFO PHX 1320307

This watch is typical of the watches, warnings, and statements issued by Phoenix WSFO during the 9 days of heavy rains. It exemplifies the excellent action statements issued, alerting the public to specific hazards. As in the case of a few of the issuances of the Los Angeles WSFO, however, the effectiveness of the responses to the statements might have been improved in a few instances by consistent application of the principles of news-style writing; e.g., placing the action statements at the beginning of the message.

From February 14 to 19, a succession of short-wave troughs moved through Arizona. These troughs, which contained subtropical moisture, brought rain, heavy at times, to the State. On February 18, one of the short-wave troughs moved into Arizona with more subtropical moisture than was available previously. The heavy rain combined with snowmelt at higher elevations to cause a rapid rise on Oak Creek in Central Arizona. A flash flood watch was issued for most of Arizona south and west of the Mogollon Rim late on the morning of February 18. The snow level was near 10 thousand feet above msl. Shortly after midday, a flash flood warning was issued for Oak Creek Canyon and the Sedona area based on radar observations and reports of a debris dam on Oak Creek. The flash flood watch and flash flood warning were cancelled on the evening of February 18, as rain subsided and flooding ebbed.

On the following day, February 19, severe thunderstorm activity accompanied the last of the significant short wave troughs crossing the state. This trough had evidence of cold air south of 35°N, and satellite pictures showed tropical clouds streaming up ahead of the short-wave trough off the northern Baja coast. As this trough and associated warm tropical moisture combined over Arizona on the afternoon of February 19, local thunderstorms approaching severe intensities developed over the State. Severe thunderstorm watches covered much of the State during the late afternoon and evening hours. Most of the energy apparently was dissipated in the form of moderate-to-heavy rain in Central Arizona. For this reason, a flash flood warning was issued for a large part of Central Arizona on the evening of February 19 as it became apparent that heavy rain was falling on already wet ground. Flooding was reported along the New River, Agua Fria River, and Big Bug Creek.

In total, including the rain periods that were precursory and posterior to the series of short-wave troughs, Central Arizona received moderate to heavy rain on 9 consecutive days (February 13-21). The numerous well-worded statements issued during the 9 days kept the public and specialized users well advised of the seriousness of the hydrometeorological situation.

Careful meteorological analyses were made continually by the Phoenix WSFO staff in deriving local QPF's. The QPF is probably the most difficult of all meteorological forecasts to make and was the most useful during the series of storms. For QPF's to be most useful, it is necessary not only to determine where and when the rainfall will occur but also to quantify the precipitation for various basins and elevations.

While not directly involved with the issuance of watches and warnings during this event, the Salt Lake City WSFO was the backup for the Phoenix WSFO. At one point during the Arizona flooding, it appeared that the Phoenix WSFO might be inundated with water. The Salt Lake City WSFO acted promptly to set into motion plans to take over forecast responsibility from Phoenix. A plan was laid out and communication channels were readied for that eventuality. These actions provided an excellent demonstration of the alertness of the back-up office and the readiness of the "system" to back up offices in an emergency.

Performance of the WSO's in Central Arizona

In Arizona, the Flagstaff WSO and the Winslow WSO were involved in the flood warning effort.

The Flagstaff WSO issued one revised forecast that included a flash flood warning for Oak Creek Canyon on February 18. All other watches, advisories, and warnings were those issued by the Phoenix WSFO, which routinely were disseminated by the Flagstaff WSO. Coordination between the Phoenix WSFO and the Flagstaff WSO was excellent. This was especially true when the Flagstaff WSO received reports of a debris dam in Oak Creek Canyon. The Flagstaff WSO provided many live briefings to local radio stations during the storm. A total of 26 hours of overtime was worked at the WSO during the storm series.

The Winslow WSO issued one special weather statement for flooding on the Little Colorado River on February 20. This was coordinated with the Salt Lake City RFC. Their coordination with the Phoenix WSFO during the series of storms also was excellent. The Winslow WSO effectively disseminated all pertinent watches, warnings, and advisories issued by the Phoenix WSFO.

Operations of the Salt Lake City RFC

The Salt Lake City RFC was open 24 hours per day for 2 days and remained open nearly 20 hours per day for the rest of the sequence of storms. Advisories were given continually to the Phoenix WSFO as well as periodically to the SRP, the U.S. Army Corps of Engineers (COE), and other water managers. Water users and emergency services personnel were aware of the expected near-record flows and were able to evacuate residents of flood-prone areas and warn others. Appendix 4 contains sample flood warning and river statements released to the Phoenix WSFO over RAWARC by the Salt Lake City RFC. The flood advisories issued by the Salt Lake City RFC were timely and accurate. However, the formats of a few of the issuances were at variance with proper forecast format. For example, incorrect header and identification information appeared in a few instances.

The Phoenix WSFO frequently advised the Salt Lake City RFC of current and expected weather conditions. Consequently, flood forecasts and warnings as early as noon, Friday, February 15, indicated that near-record flows were expected that evening. While the heavy precipitation that occurred was forecasted, the forecasts were not exact with regard to the time distribution and location of the precipitation. In spite of these deficiencies, the QPF's provided by the Phoenix WSFO for the February 14-15 storm allowed river forecasters to indicate near-record flooding, although timing of peak flows could not be determined with great accuracy.

The QPF's that the Salt Lake City RFC received from the Phoenix WSFO for the heavier February 14-15 and 19-20 storms were relatively more accurate than the QPF's for the lighter storm systems during the February 13-21 period. (Fig. 3.3 and Figs. 4.4-4.6.) As the Pacific storms approached and hit the coast of California, meteorological analyses generally indicated that heavy amounts of precipitation could fall throughout Central Arizona. However, by the time the smaller storms in the series began encroaching into Arizona, they weakened rapidly, resulting in lower precipitation amounts. Consultations between the Phoenix WSFO and the Salt Lake City RFC helped identify some of the QPF overestimates in time for revisions to be made before the river forecasts were disseminated.

The QPF's received by the Salt Lake City RFC from the Phoenix WSFO usually were in a generalized form; e.g., "3.0 inches in the mountains, 1.0 inches in the valleys, during the next 24 hours for all basins." Because QPF's were received in this form, RFC personnel were required to spend valuable time reducing the QPF's

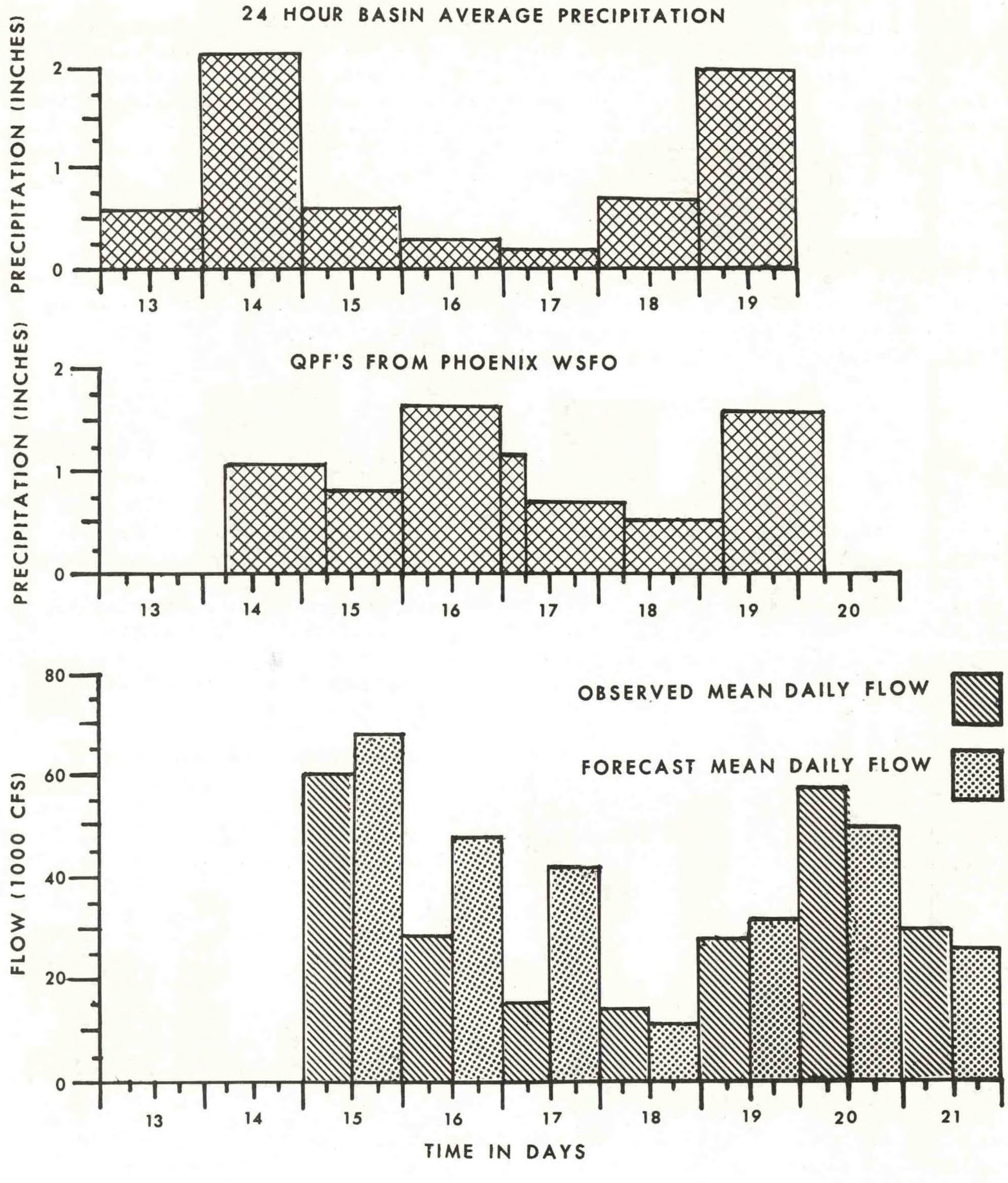

Figure 4.4--Histograms comparing, for the Verde River drainage above Horseshoe Dam, observed precipitation averaged over the basin; the QPF's available to the Salt Lake City RFC; and the observed and forecast mean daily streamflows. The basin-average precipitation estimates were derived from postanalysis using only those rain gages which were available for operational use during the series of storms, i.e., those gages contained in the Central Arizona section of appendix 5.

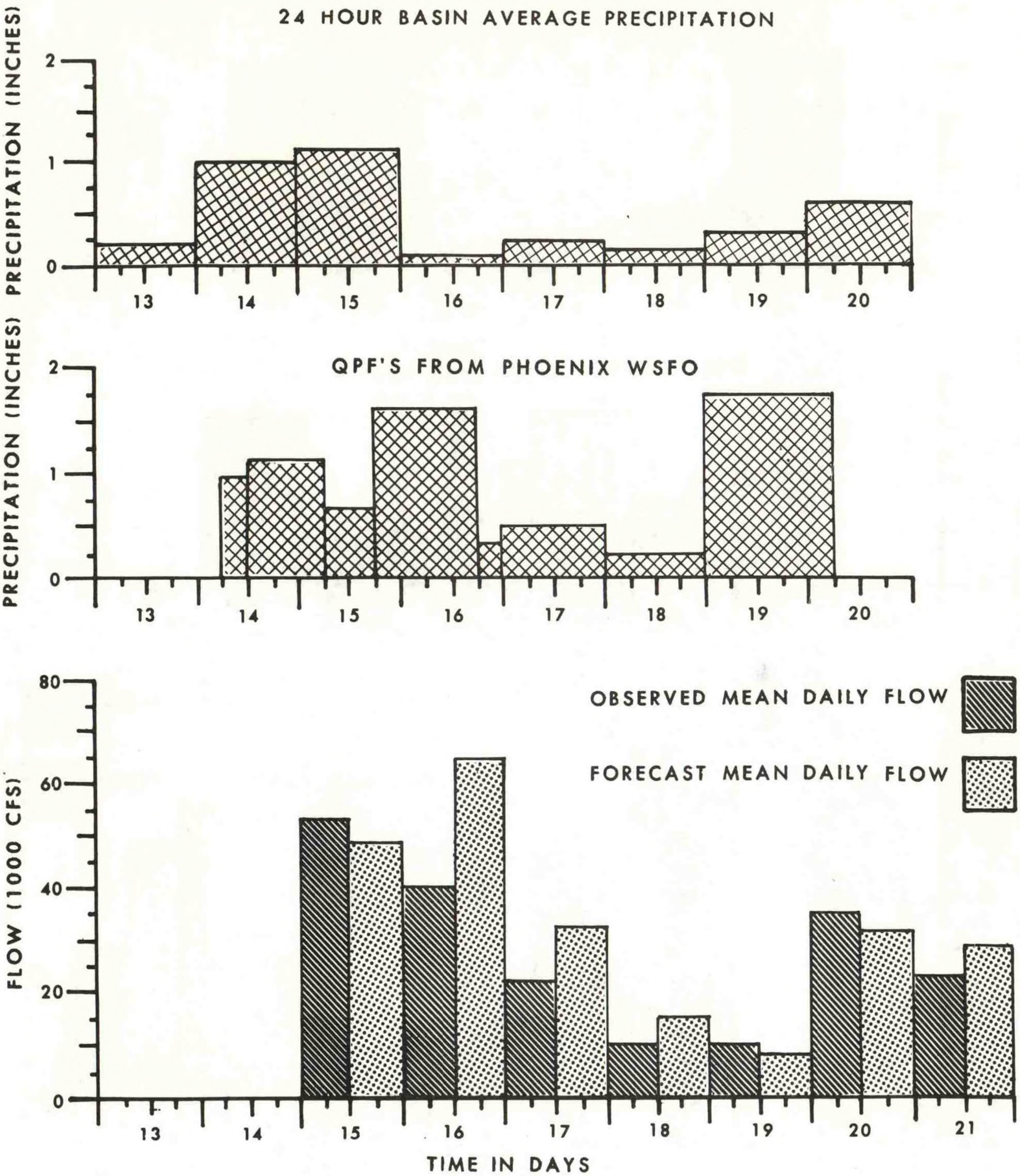

Figure 4.5--Histograms comparing, for the Salt River drainage above Roosevelt Dam, observed precipitation averaged over the basin; the QPF's available to the Salt Lake City RFC; and the observed and forecast mean daily streamflows. The basin-average precipitation estimates were derived from postanalysis using only those rain gages which were available for operational use during the series of storms, i.e., those gages contained in the Central Arizona section of appendix 5.

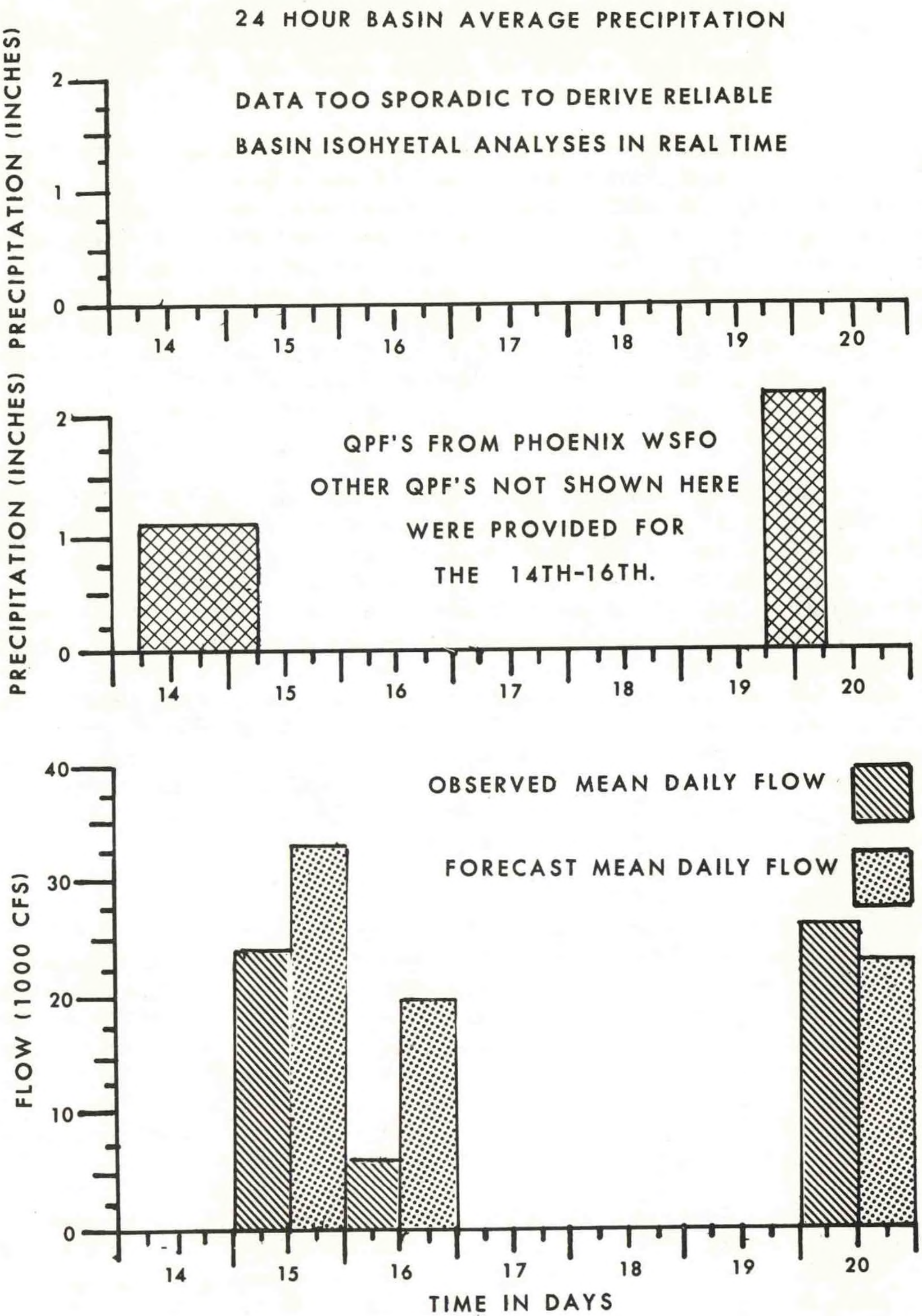

Figure 4.6--Histograms comparing, for the Agua Fria River drainage above Lake Pleasant, observed precipitation averaged over the basin; the QPF's available to the Salt Lake City RFC; and the observed and forecast mean daily streamflows. The basin-average precipitation estimates were derived from postanalysis using only those rain gages which were available for operational use during the series of storms, i.e., those gages contained in the Central Arizona section of appendix 5.

into the 6-hourly time series needed for preparing the forecasts. Disseminating QPF's in a format compatible with time series input into the computer model would be very beneficial to the Salt Lake City RFC.

The Salt Lake City RFC, in consultations with the Phoenix WSFO, adapted the generalized QPF's to specific river basins. Figures 4.4, 4.5, and 4.6 show the interrelationships of the QPF's, the river forecasts, and the observed values. The upper histogram in each figure shows the observed rainfall. The middle histograms illustrate the QPF's for the Verde Basin above Horseshoe Lake, the Salt River Basin above Roosevelt Reservoir, and selected QPF's for the Agua Fria Basin above Lake Pleasant Reservoir. The lower histograms compare the observed and forecast mean daily river flows. Examination of these figures indicates the direct influence of the QPF's on the river forecasts. Forecasts generated by the river forecast model using QPF's were tempered somewhat as later data became available, i.e., observed precipitation and satellite data.

Figures 4.4 through 4.6 show that the accuracy of the QPF's for 24-hour amounts was within the state of the art. However, the amounts shown can be misleading, especially since the actual rainfall values varied considerably from one 6-hour period to another, as did the spatial location of the heavy rainfall. For example, the assumption that the QPF given in figure 4.6 for the Agua Fria on February 19-20 would produce a 2-inch basin average over a 6-hour forecast period resulted in magnitude and timing errors, because indications are that 1.5 to 2 inches fell over only a 3-hour period, causing a higher and earlier peak. From examination of table 3.1, it becomes evident that there also was a bias toward late predictions of crest times for most of the other cases listed. Most of the error in the "timing" of the crest predictions can be attributed to errors in the mean areal precipitation inputs. It is possible, however, that part of the timing bias might have been attributable to the hydrologic model or its calibration.

Fortunately, human interaction with the automated river forecast system allows for integration of hydrometeorological knowledge to further refine QPF and runoff forecasts. For example, preliminary assessments of the QPF for February 18 indicated that 3 to 4 inches of precipitation were expected for higher elevations. A runoff forecast was generated projecting near-record flow. Additional hydrometeorological considerations strongly suggested that this was a large overestimation; therefore, through more consultation between the Phoenix WSFO, the Salt Lake City WSFO, and the Salt Lake City RFC, the QPF was downgraded and the runoff forecast was reduced by a factor of two, which was much closer to observed values. Similar iterative adjustments were required on other days.

In summary, the Salt Lake City RFC, in coordination with the Phoenix WSFO and other offices, provided many useful advisory statements on the expected flows for the major rivers in Central Arizona and on the accompanying flooding conditions resulting from the sequence of storms. The river forecasts were made with strong reliance on QPF's provided by the Phoenix WSFO. The QPF's, which were further refined by the Salt Lake City RFC in consultation with the Phoenix WSFO, proved invaluable, particularly in view of the very inadequate rainfall observations available for real-time forecasting.

Findings and Recommendations

See Executive Summary for Findings and Recommendations pertaining to chapter 4.

CHAPTER 5

DATA COLLECTION AND COMMUNICATIONS

This chapter describes those basic hydrometeorological reporting stations that potentially furnished data operationally for use in near real-time by the various NWS offices which provided forecasting and warning services during the February 1980 series of storms. (See appendix 5.) Deficiencies associated with the rainfall data and networks are discussed specifically. The chapter ends with a description of the communication networks that were available to deliver the data.

Surface Weather Reporting Stations

Appendix 5 contains the surface weather reporting stations from which observations potentially were available for operational usage by the NWS offices in Southern California and Central Arizona. The stations are grouped by type, and the data provided by each station are identified as falling into one or more of three categories or types; i.e., basic weather, precipitation, and streamflow.

Rainfall reports were the most important type of surface data used by the meteorological and hydrological forecasters during this series of rain storms. Forecasters at the WSFO's and WSO's relied heavily on rainfall reports to identify potential or existing flash flood conditions. Rainfall reports also were invaluable for alerting officials in Southern California to probable occurrences of mudslides. Although the number of near real-time rainfall reports was very inadequate, the available reports were indispensable as input to the river forecasts derived by the hydrologic forecasters at the Salt Lake City RFC.

Other surface meteorological parameters also were useful to the hydrologic forecasters, especially temperature to the forecasters at the Salt Lake City RFC who used it to delineate between frozen and liquid precipitation states and to determine potential snowmelt.

Upper Air Observations

Four NWS upper air stations in the Southern California and Central Arizona areas were used routinely during the storm. These are San Diego, Vandenberg, Tucson, and Winslow. All upper air observations, at both 00Z and 12Z, were available February 12-22, 1980. Upper air observations also were available from Isle Guadalupe but were sporadic.

River Gage Readings

River gage observations also were used by the hydrologic forecasters at the Salt Lake City RFC in the preparation, updating, and verification of their river forecasts. Most river stage reports received by the Salt Lake City RFC were gathered through telemetered equipment or relayed by the Salt River Project from their radio gages (Fig. 5.1). Streamflow data were valuable to the Salt Lake City RFC in making river forecasts, but were somewhat less effective than rainfall reports. The six SRP river gages were the primary source of stage data for the affected area during this series of storms. All river data received were generally very reliable and timely.

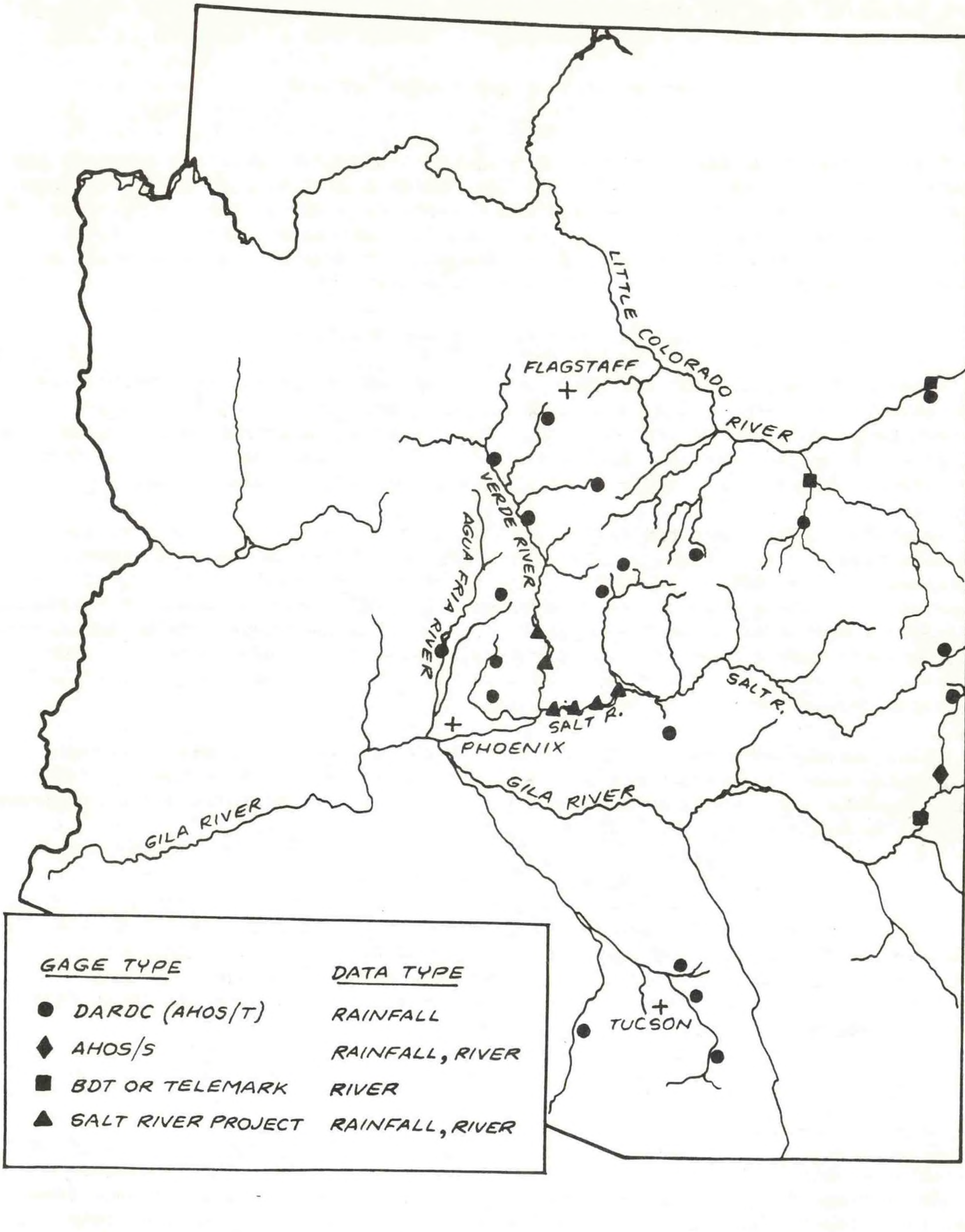

Figure 5.1--Automated rainfall and river gages in Central Arizona which potentially were available for operational use during the February 1980 series of storms.

A potential total of 14 river gage readings was available, but more than half of these gages were outside the primary area of interest and/or they malfunctioned at some point during the series of storms. (See appendix 5.) Four of the 14 gages are located in New Mexico and do not appear on figure 5.1. The major problems encountered with the malfunctioning river gages were: 1) they were plugged with debris or damaged on their mountings when rivers became swollen to near record levels, and 2) they mechanically or electronically malfunctioned.

Special Snow Data

Snow data also were important to the hydrologic forecasters at the Salt Lake City RFC in assessing how much snowmelt runoff might occur in a basin. The primary sources of snow information were GOES satellite observations and the SCS SNOTEL platforms.

The GOES satellite data provided information from which the percent of a basin covered by snow could be estimated. The SNOTEL platforms provided data on precipitation amounts and the equivalent depths of water contents in snow packs. The SNOTEL stations, which were available in Central Arizona for inclusion in the postanalysis from which the isohyetal map of total period rainfall was derived (Fig. 3.7), are given in appendix 2. None of the stations are included in appendix 5, because the precipitation data from them could not be made available, with the existing communication system for receiving SNOTEL data, in time for the Salt Lake City RFC to use the data in their current operational forecast system. The SNOTEL data were not available to the RFC until they were at least 6 to 7 hours old. This time lag could be reduced in the future if the RFC had its own computer to acquire the SNOTEL data in a more direct and automatic fashion.

Deficiencies of Rainfall Data and Networks

The networks of surface reporting stations that were potentially available in near real-time to the NWS offices in Southern California during the February 1980 series of storms are listed in appendix 5. As illustrated in previous chapters of this report, heavy and spatially variable rains in the Southern California area resulted in flash floods and mudslides on scales smaller than this operational rainfall network could resolve with great site specificity. Only a very limited amount of feedback as to actual mudslide and flash flood conditions was available to the Los Angeles WSFO during the series of storms, mainly from the Mass News Disseminators (MND). Lack of site specificity in the NWS warnings (e.g., the identification of specific canyons, streams, etc.) led to failure on the part of some residents, particularly in the Los Angeles area, to recognize the danger of imminent flooding. A greater density of real-time rainfall data, as well as improvements in the state of the art of quantitative precipitation forecasting, would significantly enhance the ability of the forecasters to issue more site-specific forecasts.

There were sources of additional rain gage data that could have been available to the Los Angeles WSFO. The Los Angeles District of the COE routinely collects real-time hydrometeorological data from various locations. Although the interrogation system used has some limitations for applications in quick-response watersheds, availability of the data would have been useful. The necessary equipment to receive these data was in place at the NWS and COE offices, but the computer software required at the COE office to relay the data to the NWS offices was not available.

Another source of real-time rain gage data for the Los Angeles WSFO could have been the event-reporting radio rain gages in Ventura County, California. This network, installed as part of an automated flood recognition system, provided excellent real-time data to county officials in affected areas of that county and allowed effective action to be initiated on the part of local officials to protect life and property. However, these data were not available to the forecasters at the Los Angeles WSFO, because a terminal suitable for accessing the computer data base was not available.

As in Southern California, the availability of real-time precipitation reports in Central Arizona was very inadequate, causing the Salt Lake City RFC to rely heavily on QPF's for inputs to their river forecast model. The Salt Lake City RFC could have received a maximum of 32 real-time precipitation reports for flood-prone areas in Arizona (appendix 5): twenty from DARDC sites (AHOS/T equipment -- see figure 5.1); two from AHOS/S (one is in New Mexico -- not shown on figure 5.1); and five from Service A reports (Phoenix, Flagstaff, Prescott, Tucson, and Douglas). And, precipitation totals were generally available on request from the SRP from the six automatic sites shown in figure 5.1.

Five of the DARDC sites (Chambers, Robles Junction, Sabino Canyon, Saguaro National Monument, and Vail) were outside the area contributing runoff to the river reaches that underwent significant flooding. (See chapter 3.) The DARDC gages at Black Canyon, Blue School, and Happy Jack Ranger Station were inoperative during the entire February 1980 storm series; the gage at Tuzigoot National Monument became inoperative after the first 2 days; and the gage at Lake Pleasant operated very sporadically. All of the remaining ten DARDC stations had at least one report missing during the critical 9-day period. Only four stations (Alpine, Junipine, Payson, and Tonto Creek Fish Hatchery) had three or less reports missing. Two stations, Globe and Snowflake, gave data that were questionable at critical times. Outages were due mainly to telephone lines being down. There were some mechanical failures. The two AHOS/S reports were in the headwaters of the Gila River and, therefore, were not in the area of heavy precipitation. Generally, fewer than 20 real-time precipitation reports were available -- for an area of over 65,000 square kilometers.

The Phoenix FWO, a unit attached to the Phoenix WSFO, collected additional precipitation reports via telephone from observers. There were two significant problems concerning operational use of these data by the Salt Lake City RFC: 1) the data usually were not available for entry into the computer system until 8:00 or 9:00 a.m. MST, 1 to 2 hours after the morning forecast run was made, normally at 7:00 a.m.; and 2) many of these data were in a time sequence unusable on a real-time basis with the current Salt Lake City River Forecast System. The FWO was formed only shortly before this series of flood events. The staff of the FWO consists of two state hydrologists and one NWS service hydrologist, of which the latter was not yet on board in February 1980. Coordination of the data collection requirements between the FWO and the Salt Lake City RFC should improve with time, as the new FWO becomes fully established.

The limited number of real-time precipitation reports provided very inadequate coverage of an area of over 65,000 square kilometers. By analyzing precipitation reports received from the Phoenix WSFO following the flooding, and plotting these data with the automated data and observer reports received during the series of storms, some significant results were revealed. Basin averages based on the post-analyses, which included a significantly larger number of gages, generally showed increases over the basin averages calculated from data available at forecast time. For example, there were virtually no real-time precipitation reports in the

Agua Fria basin during the flood. The actual basin average for the 9-day period was as much as 12" greater than was indicated by rain-gage information available during the series of storms. The Black Canyon and Lake Pleasant DARDC gages are located in the Agua Fria basin; but the Black Canyon gage was inoperative for the complete period, and data from Lake Pleasant were available only on a very limited, intermittent basis. Data from the DARDC gage at Carefree, although outside the basin, were of some value in estimating the rainfall over the basin. It was fortunate that relatively accurate QPF's were available as the primary precipitation inputs used in forecasting for the Agua Fria basin.

Other examples of the inadequacies of the real-time data collection network include: 1) record flows occurred near Alamo Dam, but no observed precipitation data were available to indicate the heavy rainfall until 3 days following the event; 2) although 16.63 inches of rain occurred at Crown King during the 9-day period, isohyetal analysis based on real-time data available during the period indicated not even half this much; 3) rainfall on Tonto Creek basin approached 4 inches on February 15, but the highest amount observed in real time was 2.5 inches; and 4) the north slopes of the Salt River drainages do not contain a single real-time rain gage because of the remoteness of the area.

Comparison of the isohyetal map shown in figure 3.7 with the operational reporting network shown in figure 5.1 further indicates the inadequacy of the gage density and distribution. For example, it is clear that some very heavy precipitation occurred during the sequence of storms in areas where no real-time reporting stations existed (e.g., on the north slopes of the Salt River drainages). The sharp gradients in the isohyetal pattern in figure 3.7 (e.g., in the vicinity of Crown King) clearly illustrate that the real-time gage network was scarcely adequate for any part of the affected area, especially when one considers that several of the existing gages malfunctioned or were inoperative during this series of storms. (See appendix 5.)

Because of the inadequate gage networks in Central Arizona and the need to acquire as much lead time in the river forecasts as possible, the Salt Lake City RFC was prompted to rely heavily on QPF's. (See chapter 4 --"Operations of the Salt Lake City RFC".) Thus, the limited precipitation reports, supplemented with QPF's, were used as the primary sources of information for deriving average precipitation amounts over the various basins for input to the hydrologic model. Not only is it likely that, in some instances, there were significant errors in the rainfall amounts derived in this manner, but it also is likely that significant biases in the model predictions could result from the large disparity between the number of gages used for calibrating the model (approximately 85) and the number available for real-time forecasting during this series of storms (less than 20). This problem would become even greater if the forecast time-step is shortened below 6 hours in the future.

A deficiency also existed in the availability of snowmelt information. Snowmelt data normally were not available at the elevations where significant melting could have occurred.

In summary, the deficiencies in the rainfall data and networks fall into two basic areas: 1) the number of existing real-time reporting gages is very inadequate, and 2) the data that do exist are not being used optimally because of insufficient computer hardware and software facilities to provide adequate data handling and data management capabilities. Several examples already have been given where data would have been available if certain (relatively simple) data communication or formatting requirements had been met. Furthermore, it is essential for the Salt Lake City RFC to obtain a data collection ("gateway") computer and accompanying versatile data management software. The gateway system should be capable of automatically retrieving data from various sources, of performing various data management functions, and of relaying these data to the larger computer system, where additional data editing and preprocessing functions are performed. Improved software is needed so that data can be rapidly assimilated and data quality can be checked before input into the forecast procedures. This software should be flexible enough to permit use of data from "stranger" stations that may be available for non-standard times or locations. Such information, while not in the preferred format, at least will be valuable for updating the forecasts and/or the states of the model(s).

Satellite Information

The GOES satellite pictures, normally received each 30 minutes on the UNIFAX facsimile recorder, and the SIM's routinely received each 6 hours from the SFSS of NESS at San Francisco provided invaluable information to the Los Angeles and Phoenix WSFO's. (See appendix 1.) The SRP office also had a facsimile drop for receiving the GOES pictures. Reception of satellite information was not only critical to remaining abreast of the synoptic situation but also was extremely useful in determining the timing and extent of rain areas. However, quantitative satellite rainfall estimates based on objective numerical procedures were not made available to any forecast office. Such rainfall estimates could have helped fill the informational void caused by the great sparsity of conventional rain-gage measurements.

Weather Radar Observations

Weather radar surveillance in Southern California and Arizona is provided by the FAA ARTC radars and the NWS local warning radars (LWR's). Figure 4.3 is a map showing the location of the radars and their approximate areas of coverage. Data from the ARTC radars in California, and from the one at Las Vegas, Nevada, were collected hourly and composited at the Palmdale WSO(R) for transmission over the Radar Facsimile (RAFAX) circuit. (See chapter 4 -- Performance of the WSO's in Southern California.) Similarly, data from the ARTC radar at Phoenix were used by the WSO(R) at the FAA ARTCC in Albuquerque. Both the Phoenix WSFO and the Los Angeles WSFO are on the RAFAX circuit and received the data, except (as noted in a later section) when the Palmdale to Los Angeles RAFAX circuit was out during part of the storm series.

The ARTC radars functioned throughout the storm period. Requests made to the FAA by NWS radar specialists to operate the ARTC radars in an optimum weather surveillance mode were honored, with virtually no exceptions, throughout the sequence of storms. Specifically, requests to change from circular polarization to normal mode, and to switch the Sensitivity Time Control (STC) on and off, received the full cooperation of the FAA. An examination of radar data from both the Palmdale and Albuquerque WSO(R)'s indicated that the ARTC radar systems detected nearly all significant rainfall during the storm period, and the data collected compared well with data from local warning radars, especially at Phoenix. Because of the broad expanse of the storm series, the NWS local warning radars at Los Angeles and Phoenix alone would not have been adequate.

The Los Angeles and Phoenix WSFO's each have a WSR-74C (C-band) radar system assigned to local warning responsibility. The Los Angeles LWR is restricted somewhat by surrounding mountains, especially from northwest through east. Propagation anomalies in the marine layer can also cause variations in detection capability. Blocking terrain also hampered data collection with the Phoenix WSR-74C, but to a lesser degree than in the case of the Los Angeles radar. Both radars appeared to attenuate significantly during periods of heavy rainfall on the radome, as evidenced by a noticeable reduction in the contoured patterns. This occurred for short periods during several hours at Phoenix and for longer periods at Los Angeles.

Blocking terrain, propagation anomalies, and attenuation (especially due to wet radome) during periods of heavy rain tended to limit the usefulness of the Los Angeles LWR. Discussions with the Los Angeles WSFO staff indicated that they had a lack of confidence in the Los Angeles LWR data because of these problems and that the data were often unreliable during periods of heaviest rainfall. The radar, however, was monitored by the lead forecaster, and others as necessary, in order to acquire as much usable information as possible. Only a few overlays were prepared, and therefore the survey team could not review problems in great detail.

The Phoenix LWR was operated throughout the storm period and performed satisfactorily. The LWR was used in conjunction with the ARTC radar reports and composites from the Palmdale and Albuquerque WSO(R)'s. The LWR data correlated well with the ARTC radar data and were used effectively to augment the surface network data, providing local detail and echo movement. The radar was monitored throughout the series of storms by staff dedicated to this function during emergency situations. Continuity of observations was quite good, and overlay documentation was excellent. Eight forecasters and one Weather Service Specialist at the Phoenix WSFO have been trained in radar operation. On-station procedures for training and refresher courses in radar operation are documented and practiced.

A radar repeater scope from the Phoenix LWR located at the SRP Headquarters also proved effective in providing rainfall distribution information to SRP personnel for input to their decisions on reservoir operations, but SRP staff expressed a strong need for provisions for real-time computer processing of digital radar data. High-resolution rainfall estimates derived from computer-processed radar data should provide valuable inputs to the hydrologic forecasting procedures used by the Salt Lake City RFC.

Communications

There are many types of communications media used to deliver data and information to the various NWS offices, ranging from individual telemetered systems (such as the DARDC (AHOS/T)) to telephone, teletype, and facsimile networks. The number of circuits, printers, facsimile recorders, and other items of equipment increases with station activity and responsibilities. The communications networks available to the Los Angeles and Phoenix WSFO's are listed in table 5.1. Fewer communications networks are normally available to the WSO's than to the WSFO's; for example, only those networks with an asterisk in table 5.1 are available at the three Arizona WSO's mentioned in the footnote.

All communications networks functioned effectively throughout the series of storms except the RAFAX circuit from Los Angeles to Palmdale, which went out for part of the period because of line problems. This outage required more coordination via telephone than normal.

Findings and Recommendations

See Executive Summary for Findings and Recommendations pertaining to chapter 5.

Table 5.1--Communications networks available to deliver data and weather information to the Los Angeles and Phoenix WSFO's

Teletype	Facsimile	Telephone	Other
Service A*	NAFAX*	NAWAS*	AFFIRMS
Service C*	RAFAX	FTS*	
Request Reply*	DIFAX	Commercial*	
NWWS	UNIFAX		
RAWARC			
FAA/NWS Local (Los Angeles only)			
Coast Guard (Los Angeles only)			
KCRT (Phoenix only)			

*Communications networks available to the Flagstaff, Winslow and Tucson WSO's in Arizona, except FTS is not available at the Winslow WSO.

CHAPTER 6

DISSEMINATION OF FORECASTS AND WARNINGS AND USER RESPONSE

Southern California

Dissemination

The Los Angeles WSFO used the Automation of Field Operation and Services (AFOS) System for message composition during the mid-February floods. Watches, warnings, and special weather statements, as well as routine forecasts, were preformatted with headings in AFOS. Message composition was performed effectively and efficiently by forecasters with no hardware or software problems. AFOS generated a paper tape which was transmitted on a number of different teletype circuits as follows:

Service C:	FA35 teletype circuit
RAWARC:	Radar and Warning Coordination Circuit
7GT-75:	Primarily flood-control users (Local Circuit)
7GT-138:	Southern California Weather Wire Service (NWWS)
7GT-175:	Primarily aviation interests (Local Circuit)
7GT-331:	U.S. Coast Guard (Local Circuit)
11-WU-1469:	Western Union Telegraph (Local Circuit)

In addition, forecasts, watches, warnings, and statements were immediately broadcast by Los Angeles WSFO personnel on NOAA Weather Radio (NWR) [KWO-37 (Los Angeles), 162.55 MHz; and KIH-34 (Santa Barbara), 162.40 MHz]. A warning alarm signal was activated for all warnings and short-fuse watches, including flash flood watches.

The California Office of Emergency Services (OES) in Sacramento was advised via the National Warning System (NAWAS) hot line. OES, in turn, immediately notified public safety officials in the affected counties. A follow-up hard-copy message was then transmitted to OES by telecopier, and from this a teletype message was prepared and transmitted via the California Law Enforcement Telecommunication System (CLETS) to public safety offices.

Use of NAWAS also was very effective in disseminating watches and warnings to responsible local officials such as fire departments or police departments. However, the Los Angeles WSFO forecasters pointed out that whenever a watch was issued over NAWAS, county officials received the watch, and then called the WSFO on the unlisted number that rings at the lead forecaster's desk, asking for more information regarding the watch. This, of course, interrupted the lead forecaster's work, and usually there was no additional information to add to what was already in the watch.

All communications equipment used by the Los Angeles WSFO worked properly except the Santa Barbara NWR. Also, as described in chapter 5 (section on Communications), all communications networks functioned effectively except the RAFAX circuit from Los Angeles to Palmdale which was out for part of the period.

The Santa Barbara NWR was off the air from 12:10 a.m., February 17, until 4:00 p.m., February 20. Repeated commercial power failures at the transmitter site caused the outage. Repair was delayed because the road to the transmitter site was blocked by mudslides. Moreover, the NWR operated by the San Diego WSO

(KEC-62, 162.40 MHz) was off the air because of a power outage at the transmitter site from the evening of February 17 until 6:00 p.m. on February 18.

Because of the anticipated cutbacks in personnel after implementation of AFOS, the Los Angeles WSFO is staffed with several temporary forecaster aides. These employees, while highly motivated, lacked training and experience in responding to inquiries from the public or special users. Because of this, a higher than normal number of telephone calls had to be transferred to a forecaster. Under normal conditions this would have caused no serious problems, but during this prolonged period of intensively active weather an extra burden was placed on the forecasters when they were already extremely busy.

Response of Local Officals and Users

While watches and warnings were generally disseminated effectively to responsible county and local officials and the general public, response varied considerably, as is demonstrated by the description of several different areas outlined below.

Topanga and Mandeville Canyons:

Topanga and Mandeville Canyons in Los Angeles County are examples of suburban encroachment into areas that are susceptible to flash floods and mudslides. Such canyon areas are numerous in Southern California.

In Topanga Canyon, most structural damage to residential property, bridges and roads was caused by flooding. A resident of the Bonnell Park area of the canyon measured 9 inches of rain in 10 hours on Saturday, February 16, with 3.5 inches falling between 3:00 p.m. and 6:00 p.m. The Los Angeles WSFO had no reports to indicate that rainfall of this intensity was falling in the area. Interviews with some residents in the canyon indicated that they were aware of flash flood watches and warnings on radio and television, but they did not relate them to a specific flood threat in Topanga Canyon. Other comments made by residents specifically pointed to the desirability of site-specific warnings, the lack of local warning prior to the flood event, the lack of reception of NWR in the canyons, and the continuance of flash flood watches for long periods after the rainfall had ended.

The fatality and most of the property damage in Mandeville Canyon were caused by mudslides. Interviews with some canyon residents indicated that there was awareness of the mudslide danger, due primarily to public awareness programs after a brush fire two years ago. (It is interesting to note that, ironically, the worst slides occurred in the area of the canyon that was not burned. Residents in this area thought that they were reasonably safe, since their vegetation was intact.)

Residents of Mandeville Canyon appeared to be aware of flash flood watches and warnings and special weather statements, and they related them to the danger of mudslides. There was local warning via vehicles and also a voluntary evacuation program that was initiated in response to the first occurrences of mudslides. Some residents chose evacuation, while others remained with their homes and attempted to protect their property.

Ventura and Riverside Counties:

Discussions with the Ventura County Flood Control Office and OES and the Riverside County OES vividly pointed out the contrast in warning service between a locality that had an automated flood-warning system and one that did not.

During the past 2 years, the RFC at Sacramento has been developing the technology necessary to provide quantitative flash flood warnings in the rapidly responding drainages in parts of Southern California. Ventura County officials, having had a disastrous flood on Sespe Creek in 1978, decided to implement this newly developed technology. The system consists of event-reporting radio rain gages which transmit data to a minicomputer at the Ventura County Flood Control Office. Analyses of these data are performed each 6 hours during heavy rain periods by the Sacramento RFC, and forecast advisories are input into the Ventura minicomputer. (See chapter 3.) These advisories provide forecasts of flow for Sespe Creek at Fillmore for a range of precipitation amounts.

According to county officials, this system, in conjunction with a three-level preparedness plan, resulted in substantial savings in property damage and potential savings of life on the evening of February 16th. The system provided the lead time required for manpower and equipment to repair a levee break. County flood control officials said that they could not have effectively handled the flood emergency without their automated data acquisition and advisory system.

Discussions with Riverside County OES regarding flooding on the San Jacinto River demonstrated the contrast in service when there was no automated flood-warning system. Rainfall had stopped in the San Jacinto and Riverside areas during the day on February 20. Flows in the San Jacinto had stabilized and levees were holding. People who had been evacuated were advised that they could return to their homes. Later that night, rainfall in the mountains caused substantial flows in one of the tributaries of the San Jacinto. The main river channel levees were eroded by the flow, causing widespread flooding. A sheriff in a patrol vehicle saw the high water at about 7 a.m., February 21, commandeered a school bus, and conducted an evacuation of the senior citizens' trailer park. The last evacuees were taken out in waist-deep water. It was good fortune that a lot of people were not drowned. The comparison between this situation and that in Ventura County illustrates the value of a well-designed, automated flood recognition system.

The City of San Clemente

During the series of storms, the city of San Clemente activated an emergency operation center in the building housing the police and fire officials, and the City Manager served as director of the center. Weather information from the CLETS system and the San Diego NWR was received at the center. Although San Clemente is just over the San Diego County line in Orange County, the emergency center received clarification of watches and warnings, when necessary, from the San Diego WSO.

Prima Deshecha Cañada in San Clemente experienced a flash flood during the night of February 20-21. Approximately 30 houses were evacuated by the San Clemente Fire Department before the flooding. The fire chief involved in the evacuation was highly complimentary of the National Weather Serivce. He stated that, because of the flash flood warning issued at 7:00 p.m., February 20, he had his men in the field and ready at the time of the flash flood. The fire chief stated that he based the decision to evacuate the homes in Prima Deshecha Cañada on several factors: first, it was raining heavily, and the NWS indicated that the heavy rain probably would continue, prompting him to keep his men on alert; second, past experience indicated that this canyon was prone to flash flooding; third, the flash flood warning coupled with the heavy rain prompted him to have his men in that area; and finally, when rising water was reported, he acted to evacuate. The flash flood warning was a critical input into his decision-making process and, when coupled with other inputs and emergency operation plans, resulted in effective action.

San Diego County

Mr. James W. Hunt, San Diego County Office of Disaster Preparedness, was contacted by the survey team by telephone. He said he was kept well informed by the NWS of heavy rains during mid-February and that the San Diego WSO supplied him with invaluable information over the telephone. Mr. Hunt usually had no problem with wording of any forecasts or warnings, and when clarification was needed he was able to obtain assistance promptly from the San Diego WSO. When a watch is received, Mr. Hunt's office is required to notify 14 different people and/or organizations, including the sheriff's watch commander, fire stations, flood control personnel, Department of Forestry, and an animal rescue unit. When a warning is received, they must also notify radio stations and the chief administrative official for the city. Overall, Mr. Hunt's office felt the service and products provided by the San Diego WSO were very good. They did suggest that their actions could have been improved if more site-specific information, with greater lead time, had been available.

Mr. Calvin Chong, City of San Diego Engineering and Development Department, was interviewed on the telephone. He said that his office called the San Diego WSO during rainy periods and whenever large amounts of rain were forecasted. He also obtained weather information by monitoring NWR. Mr. Chong stated that the forecasts were "disturbingly accurate, and all but one were right on the money," and that he would rate the Weather Service's performance during this series of storms as high, on both accuracy and service. During the disaster, Mr. Chong's department also maintained contact with the City of San Diego Disaster Preparedness Office, which transmitted watch/warning information to other city departments, such as the Police Department, the City Manager, road maintenance crews, etc.

Mr. Carey Stevenson, Flood Control Office of the San Diego County Department of Public Works, was contacted on the telephone. His office received weather information during the sequence of storms by teletype and by talking directly to the San Diego WSO. After they received the watch/warning information, it was broadcast over their radio network to their field people. His office staff also monitored the NWR broadcasts. Mr. Stevenson judged all statements to be understandable, and he said that he would "give the Weather Service a gold medal" for its accuracy and service during this storm.

Mr. Alton L. Goff, U.S. Department of State International Boundary and Water Commission, was also queried by telephone. He was very satisfied with the information he had received from the San Diego WSO. Watch/warning information was relayed by Mr. Goff to Mexican officials. He had found all statements to be clear during the heavy rain periods. Of the officials surveyed in San Diego, he was the only one who was not certain of the difference between a watch and a warning. Mr. Goff also had not heard of NWR, but when the system was described to him he displayed a high degree of interest in obtaining a system for his office.

Media Relations

During the course of this extended period of rainy weather, demands made upon the Los Angeles WSFO by the media were unprecedented. This was especially true after it became apparent that the local area could be affected by a lengthy siege of heavy rains. A good working relationship exists between the WSFO and the electronic media. (This is particularly true of the major TV outlets -- ABC, CBS, and NBC, and to only a slightly lesser degree with the other independent TV outlets in the area.) This cooperation definitely contributed to the numerous briefings made during the 9-day period. The number of media outlets in the greater Los Angeles area is probably unmatched in any other area of the country and includes the following: 1) about 85 radio stations, 2) 17 TV stations, 3) more than 40 daily newspapers, some six to eight of which have circulation of more than 100,000 copies. (The *Los Angeles Times* has a circulation of about 1,350,000, and the *Herald-Examiner* has more than 300,000.)

The three major TV outlets have a large viewing audience; thus, much of the weather information released by the Los Angeles WSFO was received by a TV audience numbering in the millions. This is not an exaggeration, for a Nielsen survey conducted during the month of February 1980 estimated the following combined audience for the three major TV networks (ABC, NBC, and CBS) at the times given: 5:00 p.m. News -- 1,725,000; 6:00 p.m. News -- 2,100,000; 11 p.m. News -- 1,775,000. The other major independent TV outlets in the greater Los Angeles area accounted for an additional 1,000,000 to 1,250,000 viewers. Therefore, the importance of providing these television outlets with the latest information cannot be overemphasized.

Of the approximately 85 radio stations that serve the area, two are 24-hour, all-news stations. The Los Angeles WSFO has close relationships with both of these stations, which are in direct competition with each other. Both stations rely heavily on the WSFO to provide live or taped broadcasts. WSFO personnel go to great lengths to provide this service, especially during periods of "bad" weather. At times, the demands are impossible to fully meet, and such was the case during this storm period. The problem was particularly troublesome during times of peak activity when the stations' representatives insisted on speaking to a meteorologist, and would not talk to a Weather Service Specialist.

Besides the demands made by these two radio stations, requests were made by several other radio stations. As mentioned above, the demands made upon the Los Angeles WSFO were unprecedented. During the series of storms, office personnel, including the Meteorologist-in-Charge (MIC) and Deputy Meteorologist-in-Charge (DMIC), granted a total of approximately 115 interviews of all types.

The meteorologists interviewed from the major TV and radio stations gave the Los Angeles WSFO a good performance rating for its forecasting during the recent storms. Adequate statements, watches, and warnings were received in sufficient time. These were considered to be clear and comprehensive for the most part.

The one complaint most often voiced was that the flash flood warnings were not specific enough. One TV broadcast meteorologist said he was reluctant to air a flash flood warning on February 20 because it was not specific enough. The warning called for possible flash floods in the canyons below the Santa Monica Mountains, which cover a broad area.

Several of the broadcast meteorologists said that they preferred warnings which alerted the public to areas of heavy rain instead of flash floods. And one media representative said that radio stations could have used an hourly statement on what the radar showed during the storms.

Another problem mentioned by the media representatives was that they could not always get through to the Los Angeles WSFO by telephone during the storms, and that sometimes when they did get through, the meteorologist did not have time for interviews.

Interviews with the media in the San Diego area indicated that the San Diego WSO enjoys good rapport with the electronic and printed media in that city.

Weathermen and assignment editors for the TV and radio stations in San Diego were pleased with the service they received. One TV weatherman with a network-affiliated station remarked that the San Diego WSO does an outstanding job and that the products put out during the recent storms were excellent.

During and following the storms, the San Diego WSO put its AFOS system to good use by issuing special reports which were of high interest to the media as feature material. (For example, see figure 6.1.)

Some local governmental groups, particularly in the San Diego area, have NWR and used it effectively for updates during the series of storms. However, some non-Federal governmental agencies with flood or emergency-related responsibilities lack access to NWR for want of suitable receivers.

Most private citizens in Southern California do not have access to an NWR receiver. All of the people interviewed at the Laguna Beach Red Cross Assistance Center received their weather information via commercial radio or television -- generally TV at night and radio during the day. None knew about NWR, and even the name of the system seemed to perplex them. Upon further questioning, one woman replied that her son had an AM/FM tuner with a crystal that could pick up weather information but that the family rarely listened to it.

Foreign Language Broadcasts

Some evidence exists that a significant proportion of the Hispanic population in Los Angeles and surrounding areas do not speak or understand English or are not sufficiently fluent in English to ensure comprehension of urgent warnings. In the Southwestern U.S., watches and warnings are transmitted over NWR and most commercial radio stations only in English, leaving some portion of the population without warnings broadcast directly in their native language. At least one Spanish speaking station, however, did translate into Spanish and broadcast the watches, warnings, and statements.

Institutional Variations

The Flood Control Districts in Southern California have institutional variations. In some counties, such as Los Angeles and Ventura, Flood Control Districts provide river forecast service to the OES and regard forecasting as their responsibility. In other counties, such as Riverside, the Flood Control District provides no forecasts for the OES. Some Flood Control Districts that provide a forecast service of their own are not highly supportive of the NWS initiating flood warning services in their area. It is therefore important that NWS personnel, before contacting county officials, understand the mission of the particular agency they are contacting.

Several local governments in the Los Angeles area employ private weather forecasters and rely heavily on their products. Private weather forecasters probably have little, if any, basic data or technology not available to NWS forecasters. The reasons why the private weather forecasters' services are popular and given higher credibility, by certain users, than those provided by the NWS are not fully known but probably rest primarily on their ability to tailor services to specific users. A fuller understanding of the role of the private forecaster may enable the NWS to improve public acceptance and use of its products and services as well as strengthen the ties between private and NWS meteorologists.

WOUSOO KWRH 221713
THE CURRENT WEATHER PATTERN DEVELOPED OVER SOUTHERN CALIFORNIA ON FEB 13 WHEN THE FIRST IN A SERIES OF STORMS MOVED INTO THE SOUTHWEST. AFTER 9 CONSECUTIVE DAYS OF MEASURABLE RAIN THAT SERIES IS FINALLY OVER AND TOTAL ACCUMULATIONS RECEIVED BY THIS OFFICE ARE AS FOLLOWS.

ALPINE	10.63	LEMON GROVE	05.55
BORREGO	04.59	MIRAMAR	07.16
BROWN FIELD	03.02	MONTGOMERY FIELD ...	06.23
CAMPO	08.27	MOUNT LAGUNA	18.27
CHULA VISTA	03.17	NATIONAL CITY	04.38
CORONADO	03.61	OCEANSIDE	07.21
DEL MAR	(03.34)(FIRST 8 DAYS)	PALOMAR MOUNTAIN ...	25.56
EL CAJON	07.82	POINT LOMA	04.33
EL CENTRO	01.36	POWAY	08.16
ESCONDIDO	10.09	RAMONA	12.88
FALLBROOK	13.71	SAN DIEGO STATE	05.94
IMPERIAL BEACH..	02.74	THERMAL	03.34
JULIAN	20.65	VISTA	09.12
LAKESIDE	07.52	WILD ANIMAL PARK ...	07.83
LA MESA	06.80	LAKESIDE 2 E	09.08
CUYAMACA	24.34	END	NNNN<<<<<<<<<<<

WRHDAHSAN
WOUSOO KWRH 262137

EVEN THOUGH THIS RAINFALL YEAR* IS NOT OVER, WE HAVE ALREADY HAD ABOVE NORMAL RAINFALL WITH 11.17 INCHES. WITH THE 15.55 INCHES REPORTED LAST YEAR AND THE 18.71 INCHES RECORDED IN 1977-78, WE NOW HAVE 3 CONSECUTIVE YEARS OF ABOVE NORMAL RAINFALL. THIS HAS NOT HAPPENED IN THE PAST 35 YEARS AS RAINFALL PATTERNS HAVE BEEN ERRATIC AND QUITE VARIABLE. THE LAST TIME CONSECUTIVE RAINFALL YEARS EQUALLED OR EXCEEDED THIS RECORD WAS A 6-YEAR PERIOD WHEN AMOUNTS WERE IN DOUBLE DIGITS: 1939-40 11.30 1940-41 24.74
1941-42 13.05 1942-43 11.10 1943-44 14.47 1944-45 11.04

IN 1980 THE JANUARY 5.58 INCHES AND FEBRUARY 4.47 INCHES ADDS UP TO 10.05 INCHES FOR THE 2 MONTHS. THERE HAVE ONLY BEEN 6 TIMES SINCE PRECIPITATION RECORDS BEGAN BACK IN 1850 THAT BACK-TO-BACK MONTHS TOTALING MORE THAN 10 INCHES HAVE BEEN RECORDED

FEB 1884	9.05	MAR 1884	6.23	=	15.28
DEC 1889	7.71	JAN 1890	2.79	=	10.50
DEC 1915	2.60	JAN 1916	7.56	=	10.16
DEC 1921	9.26	JAN 1922	3.45	=	12.71
FEB 1941	5.31	MAR 1941	5.89	=	11.20
NOV 1965	5.82	DEC 1965	6.68	=	12.42

*July 1, 1979 through June 30, 1980.

Figure 6.1--Sample special reports prepared and disseminated with the AFOS system. The upper message, released at 1713 GMT on February 22, gives the rainfall accumulations for the 9-day series of storms for selected stations in Southern California; and the lower message, released at 2137 GMT on February 26, contrasts some historical rainfall statistics with the rainfall amounts for the 1979-1980 rainfall year.

Site Specificity of Warnings

The climate, topography, soils, and other geomorphic factors, combined with rapid residential development in canyon areas and lack of effective land-use controls, have resulted in creation of numerous areas with potential for catastrophic loss of life and property due to mudslides and other hazards associated with heavy rainfall. Flooding and mudslides in canyons in the Los Angeles area are apt to occur rapidly and with such force as to constitute severe risk to life. The appropriate response to this threat is evacuation.

Many incidents of flooding in the Los Angeles area occurred during daylight hours, when dissemination of warnings and evacuation could be accomplished most effectively. The flash flood watches and warnings issued by NWS offices were not site-specific with regard to particular canyons and other areas expected to be affected. Because of the lack of site specificity, some residents of the endangered areas did not perceive that the danger was to them, or their particular area, and therefore failed to take any action.

Eight people were interviewed at Laguna Beach Red Cross Assistance Center. All had experienced damage to their homes because of mudslides or flooding. They all recognized, because of the publicity given to the series of storms, the heavy rain that was falling, and past experiences, that there was potential for damage from mudslides in their area. None perceived the situation as life threatening, but most recognized the threat to their property. Many took some action to protect their property (such as channeling runoff, putting down plastic sheets, etc.). Even after sustaining damage to their property, none considered leaving the area.

Most of those interviewed at the Assistance Center knew the difference between a watch and a warning. One woman who knew the definitions almost word-for-word said that she had learned them when she lived in Dallas, Texas, from television "spots" on tornadoes. She was able to transfer this knowledge to a new location and a new threat.

Community Preparedness Planning

Local emergency plans, developed pursuant to Federal and California State guidance, tend to be stereotyped, to focus on broad aspects of communications and coordination, and to lack specific analysis of potential flash flood or mudslide emergencies and needs for mitigative action. Some existing flood-preparedness plans for local governments in the Los Angeles area lack formal implementation and depend for their success on extemporaneous decisionmaking and coordination. Explicitly detailed plans for dealing with flash flood or flood emergencies are, for the most part, lacking in this area.

Efforts by non-Federal governments in the Los Angeles area to ensure dissemination of warnings to the public were limited, and those warning efforts which were made often took place after flooding and/or mudslides had begun.

The Los Angeles WSFO lacks the necessary funds and personnel to render much encouragement and assistance to the flood preparedness planning of local governments, except for presentations at meetings to explain NWS products. Because of this and the size and complexity of the area, the Los Angeles WSFO was not very familiar with the status of preparedness planning on the part of local governments. The Los Angeles WSFO does not have enough personnel who are adequately trained, nor is the office staffed or equipped to provide adequate technical assistance to local governments. Furthermore, the role of local governments in flood preparedness planning has not been clearly defined in most instances. Better definition of responsibilities must consider the newly established Federal Emergency Management Administration (FEMA) whose role was not clearly defined at the time of the February 1980 disasters.

Central Arizona

Dissemination:

Product Distribution over Communications Networks

Watches, warnings, statements and forecasts issued by the Phoenix WSFO during the course of the mid-February storms were disseminated on the following teletype circuits:

RAWARC:	Radar and Warning Coordination Circuit
NWWS:	NOAA Weather Wire Service
Service C:	FA35 teletype circuit

Issuances at the Phoenix WSFO were composed on a Sanders Keyboard Cathode Ray Tube (KCRT). Forecasts were sent through the KCRT system to Washington, D.C., where a computer distributed them to the appropriate Service C circuit. Watches and warnings were sent on RAWARC and NWWS by means of a paper tape generated by the KCRT. RAWARC provided rapid interstate distribution of the watches and warnings. NWWS provided distribution to Arizona WSO's, the Arizona Department of Public Safety (DPS) and the Mass News Media (MNM).

In addition, all watches, warnings, statements, and forecasts were broadcast on NWR (KEC-94, 162.55 MHz), and issuances affecting the Flagstaff area were broadcast on the NWR operated by Flagstaff WSO (WXK-76, 162.40 MHz). No problems occurred with dissemination equipment throughout the period of the storm.

NAWAS was used extensively during the flooding to disseminate watches, warnings, and statements to the DPS, the Arizona OES, WSO's in Arizona, and all sheriffs' offices in the State. This proved to be very effective in keeping responsible officials up to date with the latest information.

The principal communication interface between NWS and the Arizona DPS is the NWWS. The DPS perforates the pertinent weather information coming over NWWS and retransmits it over the Arizona Law Enforcement Teletype System. This DPS system also serves as the State control center for Civil Defense ties to, for example, county sheriff departments.

Previously existing close ties between the Phoenix WSFO and the Arizona DPS were drawn even closer about two months prior to this disaster when DPS initiated a concerted effort to better educate their officers on interpretation of Weather Service products. Selected DPS personnel have been routinely attending the 12:30 p.m. weather briefing at the WSFO.

Another communication resource provided by the DPS is their separate telephone system, which bypasses the CENTREX system of Mountain Bell Telephone Company. Also, DPS is attempting to establish a Media Alert System, under which the media would pay for the lines, and DPS would furnish the base station. The primary use by the media would be to receive reports of traffic and highway conditions, but the system could also be used for relaying weather information, especially if the primary weather-communications system failed.

DPS officials were pleased with the Weather Service forecasts and statements. They believed dissemination to the media and others was good, as evidenced by statements from the media and by road conditions, traffic density, and traffic flow. Ample warnings were received to divert traffic and seal off affected bridges and roads.

Weather Briefings:

Normally, the Phoenix WSFO holds weather briefings at 12:30 p.m. daily. These briefings are open to specialized users, and, as noted above, DPS frequently attends. During the mid-February storms, three briefings were held daily. SRP personnel attended all briefings. In addition, the briefings were frequently attended by the news media, DPS officials, emergency services officials, and county flood control personnel. The briefings were very useful in keeping the concerned officials alerted to the latest weather information.

Twice during the course of the storm, the MIC of the Phoenix WSFO was called upon to brief Governor Bruce Babbitt. At 11:00 p.m., February 15, and again at 8:00 a.m., February 16, a briefing was presented to the Governor, State Emergency Services personnel, the National Guard, SRP personnel, and the news media, on current and expected weather and flood conditions.

Response of Local Officials and Users

Maricopa County Flood Control District

The spokesman for the Maricopa County Flood Control District, Mr. Bill Mathews, Chief Flood Control Engineer, stated that he and the staff of the Maricopa County Flood Control District were very pleased with the NWS forecasts and warnings and that these had significantly contributed to the decisionmaking process in determining how much water would be released and spilled from the various reservoirs, as well as in determining the resulting implications of when and where to evacuate people and property. He emphasized, however, that even longer lead times on the quantitative precipitation and streamflow forecasts would be extremely useful, if it were within the state of the art to forecast these quantities, with any degree of accuracy, for longer periods.

Arizona Department of Public Safety

Representatives from the Arizona DPS need advance information to aid in scheduling shifts in manpower (sometimes from other parts of the State), to assist in directing traffic, barricading bridges, etc. DPS officers often make contact with local officials and the general public and, therefore, provide a good source for dissemination of information. These officers also can provide information voluntarily, or upon request, directly to NWS offices. Such information may be extremely useful in determining physical conditions at some remote location; e.g., whether a debris dam may exist on a stream, whether precipitation is liquid or frozen, the level of the snow line, or verification of questionable precipitation reports.

Arizona Department of Emergency and Military Services

The Arizona Department of Emergency and Military Services (DEMS) was pleased with NWS services. Mr. Charles A. Ott, the Director, asked how they, as a State agency, could best interface with FEMA, and FEMA, in turn, with the NWS. There seemed to be confusion on this point, perhaps because FEMA was still a young agency that was not yet completely organized.

Maricopa County Department of Civil Defense and Emergency Services

The Maricopa County Department of Civil Defense and Emergency Services (CDES) expressed appreciation for NWS services during this disaster. CDES is the nerve center for county emergency services; within the control center, decisions are made and actions are initiated during disasters. Much information, including weather and river conditions, is disseminated to other affected parties. During an emergency, personnel in the control center typically include representatives from the County Flood Control District, the Sheriff's Office, the DPS, the SRP, the media, and the Red Cross, as well as CDES personnel. CDES is tied to the NWS via NAWAS and NWWS. They also sent people to the daily weather briefing at the Phoenix WSFO during the emergency.

Salt River Project Headquarters

Mr. Jack Pfister, SRP General Manager, stated that ties with the NWS had been especially good in several areas, including receipt of river forecasts from the Salt Lake City RFC, quantitative precipitation forecasts from the Phoenix WSFO, remote radar displays from the local warning radar at the Phoenix WSFO, and GOES satellite imagery from the SFSS Office in San Francisco via the UNIFAX system. Also, sharing of data from surface sensors was invaluable. All of this information was extremely useful for management of the SRP reservoirs. Suggestions offered by SRP for improvements in the future were:

1) Better precipitation inputs, especially on the Salt River Basin. More automatic systems are needed (e.g., DARDC-type systems). (Plans for increasing the automated surface network are in progress.)

2) Digitization of radar information. Although the present radar information has proven very useful, it could be even more useful quantitatively if it were compatible with computer processing. Alternatives and associated problems were discussed, ranging from the SRP's purchasing their own radar to adding radar-data processing equipment to the Phoenix NWS radar.

3) Acceleration of development of hydrologic forecast procedures. SRP would like to see the Salt Lake City RFC accelerate even faster their development of hydrologic forecast procedures for the Verde and Salt River systems. SRP emphasized that the RFC and WSFO services provided during this emergency were invaluable. However, SRP stated that the river forecasts could have been even more useful if the lag time between data acquisition and the receipt of the forecasts by SRP had been shorter. Achieving this is very much dependent on acquiring sufficient data in near real-time to produce an accurate forecast for shorter computational time steps. (Refer to items 1 and 2.)

4) Improvement of peak predictions. While the Salt Lake City RFC forecasts for the Verde and Salt Rivers did warn of record or near-record flows, the SRP stated that the peak predictions sometimes contained significant errors and

that the worst cases appeared to be biased low. However, it is not clear whether perfect peak forecasts would have resulted in significantly different reservoir operations by SRP, since the forecast flows already meant that maximum or near maximum releases would have to be made during the crest period. It would be useful, as suggested by SRP, to do a postanalysis to determine the source of any biases, for example, from unrepresentative precipitation inputs.

There is no question, based on general agreement of all SRP representatives, that the forecasts made by the Salt Lake City RFC were invaluable to them in arriving at decisions on reservoir operations, and that these decisions translated into dollars and, possibly, lives saved. There remains some question as to how much better their operations might have been if the forecasts had been improved with enhanced data inputs and forecast procedures.

Media Relations

Unanimously, media representatives in Phoenix rated the performance of the Phoenix WSFO high for the quality, timeliness, and content of its public issuances during the storm. These comments came from TV broadcast meteorologists, news editors, general assignment reporters, and one TV news anchorman.

One radio station news editor lauded the NWS people for their special understanding and efforts regarding the needs of his station, which temporarily was without NWWS during the storm. Another TV weatherman avowed that he has never seen a "more cooperative, interested, and involved NWS group." He attributed the high quality of media relations at Phoenix to the attitude of the meteorologists-in-charge (past and present).

The only problem mentioned was that forecasts for the State as a whole tend to suffer somewhat during periods when severe storms exist in one area of the State. He was quick to add that he understood why this was the case.

One TV broadcast meteorologist would like to see the NWS office expand its telephone answering service, a capability which had been reduced recently for reasons of economy and because of the implementation of NWR.

Findings and Recommendations

See Executive Summary for Findings and Recommendations pertaining to chapter 6.

APPENDIX 1

SYNOPSIS OF INFORMATION FROM THE SATELLITE INTERPRETATION MESSAGES

The following is a chronological summary of satellite information for the period February 13-21, 1980, taken from the Satellite Interpretation Messages (SIM's) issued by the San Francisco Satellite Field Services Station (SFSS).

11-12 Feb: The westerlies were described as "breaking under" the blocking ridge over the Gulf of Alaska. An active front proceeded toward California. Satellite data showed that the vorticity maximum to the rear of the front was farther south and was associated with colder air than suggested by the Limited Fine Mesh (LFM) prognoses.

13 Feb: Enhancement of the front occurred as the front swung northeastward into Southern California with heavy precipitation. Developing convection associated with vorticity maxima to the rear of the front followed as it spread into Southern California. The seven-layer Primitive Equation (PE) model failed to show the vorticity center approaching along 30°N.

14 Feb: Heavy thunderstorms associated with the above vorticity maxima passed through Southern California and Arizona while the front became quasi-stationary oriented east-west along 30°N. The next upstream vorticity maximum moving eastward along 32°N between 145° and 135°W was as much as 6 degrees too far north and appeared to weaken in both the LFM and seven-layer PE model "runs."

15 Feb: Positive vorticity advection (PVA) ahead of the approaching vorticity center enhanced the front southwest of Southern California and the sharpening of the approaching upper trough caused the front to shift northward into the southwestern U.S. However, developing thunderstorms along the front and ahead of the vorticity center caused sporadic precipitation across Southern California, with more general heavy rains as the front continued to enhance in an "instant occlusion" process as it crossed Arizona. The LFM 1200 GMT "run" had the upper trough initialized too far west, and did not represent well the west-east elongation of the PVA west of California between 25° and 35°N.

16 Feb: The vorticity center crossing Arizona was forecast too weak by the various numerical weather prediction prognoses. An extensive area of heavy precipitation and thunderstorms was tracked into Southern California. Enhancement of the front over Arizona later on 16 February (local time) was described in terms of cold cloud-top temperatures (around -50°C) from the enhanced infrared imagery. On this day, the vorticity maxima in the trough crossing California were initialized too far south.

17 Feb: Thunderstorms were described developing along an "old front" 450 nm west of Southern California as it approached early on February 17. This convection weakened 200 nm to the west and passed into northern Baja California later on the 17th. The position of the vorticity maximum upstream from the front was farther south than the LFM or seven-layer PE prognoses showed. In addition, the associated east-west elongation of the PVA pattern was not

represented well by the prognoses, and the convection suggested that the PVA in the trough was stronger than the prognoses indicated.

18 Feb: The satellite movie loops at first suggested that convection along the "old front" would continue into Baja California. However, the front expanded northeastward temporarily and brought some rain to the south portions of Southern California early on February 18. The next approaching upper trough west of California (as described in the afternoon SIM) was confirmed later on February 18 as explosive development of the wave took place. The PVA comma-cloud convection combined with this wave to send an "instant occlusion" front toward Southern California.

19 Feb: This front, with an extensive cloud shield and heavy precipitation, swung rapidly northeast across Southern California and Arizona early on February 19. The upstream vorticity center approaching Southern California was actually about 8 degrees north of the LFM initial analysis position. The Synoptic Analysis Branch of the National Environmental Satellite Service (NESS, located in Camp Springs, Maryland) discussed this displacement with the Quantitative Precipitation and Basic Weather Branches of the NWS National Meteorological Center (NMC, also located in Camp Springs, Maryland) about midday. Following these discussions, the 36-hour and 48-hour facsimile panel prognoses and associated weather statements were modified to bring them into line with conditions observed in the satellite pictures. East-west stretching of the upstream vorticity and thunderstorm fields was greater than indicated by the prognoses, and PVA caused scattered heavy convection across Southern California and Arizona later on February 19 as a vorticity maximum moved onshore near Point Conception. Orographic enhancement of clouds was noted, especially over Arizona.

20 Feb: The above vorticity center continued across upper Arizona with local heavy convection, which spread also into Utah. The next upstream system approaching Southern California was handled well by the 1200 GMT LFM "run." Embedded strong convection was tracked towards Southern California and reference to cold cloud-top temperatures (-50°C) seen in the infrared satellite enhancements was included in the morning and afternoon SIM's. Widespread convection diminished; however, dense PVA clouds and locally heavy precipitation continued eastward across Southern California into Arizona late on February 20.

21 Feb: The front became quasi-stationary east-west across Southern California and lower Arizona as layered clouds and occasional precipitation continued eastward across the region. The front proceeded eastward into New Mexico with orographically-enhanced showers along the Arizona Mogollon Rim decreasing later on February 21. The next upstream vorticity maximum passed east-northeastward north of 40°N toward Oregon, with a front and heavy convection swinging into Northern California later on February 21.

APPENDIX 2

RAIN-GAGE OBSERVATIONS USED IN POSTANALYSES TO DERIVE ISOHYETAL MAPS OF TOTAL PERIOD RAINFALL

Southern California

NOAA/NWS and FAA Stations

Station Name	*Latitude*[a]	*Longitude*[a]	*Rainfall Total*[b]
Beaumont (BUO)	33.93	116.97	13.20
Daggett FAA Airport (DAG)	34.87	116.78	1.72+
Imperial (IPL)	32.85	115.57	0.99+
Lancaster (WJF)	34.73	118.22	5.85
Long Beach WSO Airport (LGB)	33.82	118.15	11.26
Los Angeles WSO Airport (LAX)	33.93	118.40	9.13
Mt. Wilson 2 (MWS)	34.23	118.07	30.71
Ontario (ONT)	34.05	117.62	13.27
Palm Springs (PSP)	33.83	116.50	5.41
San Diego (Brown Field-SDM)	32.57	116.98	3.02
San Diego (Montgomery Fld-MYF)	32.82	117.13	6.23
San Diego WSO Airport (SAN)	32.73	117.17	4.47
Sandberg (SDB)	34.75	118.73	6.31
Santa Ana (SNA)	33.68	117.87	7.89
Santa Barbara FAA AP (SBA)	34.43	119.83	8.14
Santa Maria WSO AP (SMX)	34.90	120.45	5.42
Santa Monica (SMO)	34.02	118.45	9.36+
Thermal FAA Airport (TRM)	33.63	116.17	3.40
Torrance Airport (TOA)	33.80	118.33	9.57

NOAA/NWS Climatological Substations

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Apple Valley	34.52	117.22	5.15+[c]
Big Bear Lake	34.25	116.92	17.28
Culver City	34.02	118.40	4.71+
Lake Arrowhead	34.25	117.18	24.26
Los Angeles Civic Center	34.05	118.23	13.05
Monrovia	34.15	118.00	19.02
Montebello	34.03	118.10	10.86+
Pasadena	34.15	118.15	19.70
Riverside Ag Experimental Station	34.0	117.4	6.16
San Gabriel Fire Dept	34.10	118.10	17.50

[a] Latitude and longitude in degrees
[b] Rainfall totals for February 13-21 in inches
[c] + indicates total not complete (one or more missing observations)

California Division of Forestry, Riverside County Stations

Station Name	Latitude	Longitude	Rainfall Total
Beaumont	33.9	117.0	10.38+
Cherry Valley	34.0	117.0	14.61
Corona	33.9	117.6	10.18
Lakeland Village	33.6	117.4	11.53+
Sage	33.6	116.9	14.27
San Jacinto	33.8	117.0	7.50+
Temecula	33.5	117.2	16.44
West Riverside	34.0	117.5	11.36

California Division of Forestry, San Bernardino County Stations

Station Name	Latitude	Longitude	Rainfall Total
Devore	34.2	117.4	23.42
Etiwanda	34.1	117.5	16.36
Hesperia	34.4	117.3	6.42
Lucerne	34.4	117.0	3.53+
Mentone	34.1	117.1	9.50
Phelan	34.4	117.6	8.53+
San Antonio	34.2	117.7	18.08
San Bernardino	34.1	117.3	13.92
Yucaipa	34.0	117.1	9.24
Yucca Valley	34.1	116.5	5.49+

California Division of Forestry, San Diego County Stations

Station Name	Latitude	Longitude	Rainfall Total
Julian	33.1	116.7	22.97
Monte Vista	32.8	116.9	5.52+
Rainbow	33.4	117.1	16.36

California Division of Forestry, Orange County Stations

Station Name	Latitude	Longitude	Rainfall Total
Irvine	33.7	117.7	4.03+
Orange	33.8	117.9	9.95

U.S. Forest Service, Angeles National Forest Stations

Station Name	Latitude	Longitude	Rainfall Total
Bear Divide	34.3	118.4	8.69+
Big Pines	34.4	117.7	14.10+
Big Tujunga	34.3	118.2	19.70+
Chantry Flat	34.2	118.0	9.99+
Chilao	34.3	118.0	16.74+
Clear Creek	34.3	118.1	17.94+

U.S. Forest Service, Angeles National Forest Stations (continued)

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Crystal Lake	34.3	117.8	26.48+
East Fork	34.2	117.8	9.85+
Glendora	34.1	117.9	8.86+
Green Valley	34.6	118.4	11.28+
Mill Creek	34.3	118.1	15.56+
Monte Cristo	34.3	118.1	9.36+
North Fork	34.4	118.3	2.34+
Oak Flat	34.6	118.7	1.07+
Red Mountain	34.7	118.4	2.80+
San Francisquito	34.5	118.5	6.09+
Texas Canyon	34.5	118.4	6.46+
Valyermo	34.5	117.9	6.24+

U.S. Forest Service, San Bernardino County Stations

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Big Bear	34.3	116.9	12.26
Keenwild	33.7	116.7	15.65
Lytle Creek	34.2	117.5	30.86
Mill Creek	34.1	117.1	10.31

U.S. Forest Service, San Diego County Stations

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Descanso	32.9	116.6	16.23
Oak Grove	33.4	116.8	12.35+
Ramona	33.0	116.9	14.28
Temescal	33.8	117.5	15.80

San Diego County Cooperative Weather Stations

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Alpine	32.8	116.8	10.63
Borrego	33.2	116.4	4.59
Campo	32.6	116.5	8.27
Chula Vista	32.7	117.1	3.17
Del Mar	32.9	117.2	3.34
Escondido	33.1	117.1	10.09
Fallbrook	33.4	117.2	13.71
Julian	33.1	116.6	20.65
Mount Laguna	32.9	116.4	18.27
National City	32.7	117.1	4.38
Palomar Mt Observatory	33.4	116.9	25.56
Point Loma	32.7	117.2	4.33
Poway Valley	32.9	117.1	8.16
Thermal	33.6	116.1	3.34

Ventura County Fire Departments

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Fillmore	34.4	118.9	13.14
Oakview	34.4	119.3	13.20+
Ojai	34.5	119.2	14.24
Santa Paula	34.4	119.1	12.39
Simi	34.3	118.7	10.24+
Thousand Oaks	34.2	118.8	9.57
Upper Ojai	34.4	119.1	15.92

Military Stations

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Imperial Beach (USN)	32.6	117.1	2.74
Miramar (USN)	32.9	117.1	7.16
Oceanside (USN)	33.2	117.4	7.21
San Bernardino (Norton AFB)	34.0	117.3	7.99

Miscellaneous Stations

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Beverly Hills (LA County)	34.1	118.4	8.23+
Catalina-Avalon(Harbormaster)	33.4	118.3	9.55
Dalton (LA County)	34.2	117.9	9.16+
Newport Beach (MARS)	33.6	117.9	6.25
Northridge (LA County)	34.2	118.5	11.58
San Juan Capistrano	33.5	117.7	10.28+
Simi (Rocketdyne Corp)	34.3	118.8	7.14+
Vincent (LA County)	34.6	118.6	3.00+
Wrightwood	34.4	117.6	6.68+

Central Arizona[d]

NOAA/NWS and FAA Stations

Station Name	*Latitude*[a]	*Longitude*[a]	*Rainfall Total*[b]
Deer Valley-Phoenix (DVT)	33.58	112.08	2.67
Flagstaff WSO Airport (FLG)	35.13	111.67	7.81
Kingman (IGM)	35.20	114.02	2.20
Lake Havasu (LHU)	34.45	114.37	1.31
Payson (OE4)	34.23	111.33	9.07
Phoenix WSFO Airport (PHX)	33.43	112.02	2.09
Prescott FAA Airport (PRC)	34.57	112.47	6.59
Safford Experiment Farm (E74)	32.82	109.68	1.93
Scottsdale (SDL)	33.47	111.88	2.80
Show Low City (E03)	34.25	110.03	4.81
Tucson WSO Airport (TUS)	32.13	110.95	2.04
Winslow WSO Airport (INW)	35.02	110.73	1.36

NOAA/NWS Climatological Substations

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Aguila	33.95	113.18	3.99
Alamo Dam 6 ESE	34.23	113.58	2.90
Alpine	33.85	109.13	3.90
Ash Fork 5 N	35.28	112.47	3.83
Ashurst Hayden Dam	33.08	111.25	2.37
Bagdad 2	34.60	113.13	8.62
Bartlett Dam	33.82	111.63	8.57
Beaver Creek Ranger Station	34.67	111.72	4.92
Black River Pumps	33.48	109.77	5.11
Blue	33.62	109.10	5.21
Blue Ridge Ranger Station	34.62	111.12	6.35
Bouse	33.95	114.03	2.96
Bowie	32.33	109.48	1.97
Casa Grande	32.87	111.73	1.20
Casa Grande Ruins Nat'l Monument	33.00	111.53	1.83
Cascabel	32.32	110.40	2.71
Castle Hot Springs Hotel	33.98	112.37	8.35
Chandler	33.30	111.83	2.34
Chandler Heights	33.22	111.68	1.89
Chevelon Ranger Station	34.53	110.92	4.69
Childs	34.35	111.70	9.14
Chino Valley	34.75	112.45	2.60+[c]
Chiricahua	32.00	109.35	1.54
Clay Springs	34.38	110.32	2.74
Clifton	33.05	109.28	2.30
Congress	34.17	112.87	5.38

[a] Latitude and longitude in degrees
[b] Rainfall totals for February 13-21 in inches
[c] + indicates total not complete (one or more missing observations)
[d] Several stations from west central New Mexico are included.

NOAA/NWS Climatological Substations (continued)

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Cordes	34.30	112.17	7.09
Crown King	34.20	112.33	16.63
Deer Valley	33.58	112.08	2.67
Duncan	32.75	109.12	1.96
Eagle Creek 2	33.35	109.48	4.10
Florence	33.03	111.38	2.43
Fort Thomas 2 SW	33.02	110.00	1.40
Fort Valley	35.27	111.73	6.42
Gisela	34.12	111.28	7.97
Globe 2	33.40	110.77	5.69
Greer	34.02	109.47	3.44
Greys Peak Maintenance Yard	33.25	109.38	3.64
Griggs 3 W	33.50	112.48	2.32
Happy Jack Ranger Station	34.75	111.42	5.85+
Harquahala Plains	33.50	113.05	3.99
Hawley Lake	33.98	109.75	10.31
Heber Ranger Station	34.40	110.55	3.52
Hillside 4 NNE	34.48	112.88	6.45
Horseshoe Dam	33.98	111.72	7.93
Iron Springs Ranger Station	34.6	112.6	3.77
Irving	34.40	111.62	8.78
Jerome	34.75	112.12	8.35
Junipine	34.97	111.75	13.94
Kelvin	33.10	110.97	5.50
Leupp	35.28	110.97	2.04
Litchfield Park	33.50	112.37	2.73
Maricopa 4N	33.12	112.03	1.63
McNary	34.07	109.85	7.65
Mesa Experiment Farm	33.42	111.87	2.63
Miami	33.40	110.88	7.79
Montezuma Castle Nat'l Mon	34.62	111.83	3.53
Mormon Flat Dam	33.55	111.45	5.07
N Lazy H Ranch	32.12	110.68	2.72
Oracle 2 SE	32.60	110.73	4.72
Palisade Ranger Station	32.42	110.72	9.32
Parker	34.17	114.28	2.36
Peach Springs	35.55	113.40	2.82
Phoenix City	33.45	112.07	1.81
Phoenix South Mountain	33.33	112.05	1.52
Pinetop	34.12	109.93	4.42
Pinetop Fish Hatchery	34.12	109.92	5.61
Pleasant Valley Ranger Station	34.10	110.93	7.20
Portal 4 SW	31.88	109.20	2.35
Punkin Center	33.87	111.32	9.09
Redington	32.43	110.48	2.90
Roosevelt 1 WNW	33.67	111.15	6.99
Sabino Canyon	32.30	110.82	2.31
San Carlos Airport	33.38	110.47	4.72
San Carlos Reservoir	33.17	110.52	4.49
San Manuel	32.62	110.65	2.28
San Simon 9 ESE	32.17	109.08	0.77

NOAA/NWS Climatological Substations (continued)

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Sedona Ranger Station	34.87	111.77	7.16
Seligman	35.32	112.88	2.70
Seligman 13 SSW	35.13	112.92	3.49
Skull Valley	34.50	112.68	7.70
Snowflake	34.50	110.08	2.20
Snowflake 15 W	34.50	110.33	1.97
South Phoenix	33.38	112.07	2.36
Springerville	34.13	109.28	1.25
Stewart Mountain	33.57	111.53	4.97
Sunflower 3 NNW	33.90	111.48	11.21
Sunrise Mountain	33.97	109.58	7.37
Sunset Crater Nat'l Monument	35.37	111.53	3.69
Superior	33.30	111.10	6.01
Superior 2 ENE	33.30	111.07	8.57
Tempe	33.43	111.93	2.56
Tolleson 1 E	33.45	112.23	2.18
Tonto Creek Fish Hatchery 2	34.35	111.13	13.48
Truxton Canyon	35.38	113.67	2.43
Tucson Camp Ave Exp Farm	32.28	110.95	2.21
Tucson Magnetic Observatory	32.25	110.83	2.30
Tucson Univ of Arizona	32.25	110.95	1.93
Tuzigoot Nat'l Monument	34.77	112.03	3.83
Walnut Canyon Nat'l Monument	35.17	111.52	5.30
Walnut Creek	34.93	112.82	4.56
Whiteriver	33.83	109.97	5.21
Wickenburg	33.98	112.73	5.00
Wikieup	34.72	113.62	5.45
Williams	35.25	112.18	7.21
Winkelman 6 S	32.92	110.72	3.63
Wupatki Nat'l Monument	35.52	111.53	1.50
Youngtown	33.60	112.30	2.91
Yucca 1 NNE	34.88	114.13	2.56

NOAA/NWS Climatological Substations--New Mexico

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Beaverhead Ranger Station	33.42	108.12	1.50
Buckhorn	33.03	108.72	2.06
Cliff 10 SE	32.87	108.52	2.68
Cureton Ranch	32.53	108.57	2.23
Fort Bayard	32.80	108.15	1.42
Gila Hot Springs	33.20	108.22	2.22
Glenwood	33.33	108.88	2.96
Lordsburg	32.30	108.67	1.40
Luna Ranger Station 6H	33.83	108.93	3.02
Mimbres Ranger Station	32.93	108.02	0.80
Quemado Ranger Station	34.35	108.50	1.01
Redrock 1 NNE	32.70	108.73	2.34
Reserve Ranger Station	33.72	108.78	2.79

NOAA/NWS Climatological Substations--New Mexico (continued)

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
White Signal	32.55	108.37	2.10
York Ranch	33.80	108.32	0.83

U.S. Geological Survey--Phoenix

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Black Canyon	34.12	112.10	7.95
New River	33.90	112.15	5.86
Rock Springs	34.05	112.15	8.05

U.S. Forest Service--Flagstaff

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Beaver Creek #20	34.78	111.48	11.21
Beaver Creek #38	34.85	111.60	12.58

U.S. Forest Service--Tempe

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Castle Creek	33.72	109.18	4.98
Mingus MB-3	34.65	112.18	5.35
Sierra Ancha Climate Station	33.80	110.97	8.28
Thomas Creek	33.68	109.27	6.72
Three Bar C-2	33.72	111.32	13.34
Three Bar D-2	33.72	111.32	12.94
Whitespar WSA-3	34.47	112.52	8.76
Willow Creek	33.67	109.32	7.78
Workman Creek Climate Station	33.82	110.92	14.33

Salt River Project Stations

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Bartlett Dam	33.82	111.63	8.57
Horse Mesa Dam	33.55	111.33	6.15
Horseshoe Dam	33.98	111.72	7.63
Mormon Flat Dam	33.55	111.45	5.07
Roosevelt Dam	33.67	111.18	7.17
Stewart Mountain Dam	33.57	111.53	4.97

AHOS/T (DARDC) and AHOS/S Gages

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Alpine	33.85	109.13	3.68
Camp Verde	34.57	111.85	4.43

AHOS/T (DARDC) and AHOS/S Gages (continued)

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Carefree	33.85	111.87	5.47
Clifton (AHOS/S)	33.05	109.28	2.81
Gila, New Mexico (AHOS/S)	33.20	108.22	2.60
Heber Ranger Station	34.40	110.55	3.64
Junipine	34.97	111.75	12.41
Lake Pleasant	33.9	112.2	2.86+
Payson Ranger Station	34.23	111.33	9.00
Robles Junction	32.07	111.30	1.72
Sabino Canyon	32.30	110.82	2.13
Saguaro Nat'l Monument	32.15	110.72	2.84
Taliesin West	33.62	111.85	4.00
Tonto Creek Fish Hatchery 2	34.35	111.13	10.25
Vail	34.57	111.85	2.60

USDA SNOTEL Stations

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Baker Butte	34.65	111.33	12.1
Baldy	33.88	109.53	5.5
Bonita Rock	33.85	109.58	11.0
Coronado Trail	33.78	109.13	5.1
Frisco Divide, New Mexico	33.73	108.97	3.2
Fry	35.13	111.83	10.1
Hannagan Meadows	33.65	109.32	8.4
Hawley Lake	33.98	109.75	9.6
Heber	34.30	110.73	12.0
Lookout Mountain, New Mexico	33.53	107.87	1.8
Maverick Fork	33.73	109.45	7.7
McNary	34.07	109.85	7.5
Mormon Mountain	34.92	111.53	10.4
Signal Peak, New Mexico	32.97	108.13	4.1
Silver Creek Divide, New Mexico	33.42	108.68	5.9
Sugar Loaf	34.67	111.33	8.4
White Horse Lake Junction	35.15	112.13	9.7

Miscellaneous Stations

Station Name	*Latitude*	*Longitude*	*Rainfall Total*
Alhambra 2 NE	33.5	112.1	1.81
Lakeside Ranger Station	34.1	110.0	4.42
Oak Creek Rim	35.0	111.7	10.10
Picacho Reservoir	32.8	111.4	1.79
Summit	33.7	110.9	6.99
Tempe University	33.4	111.9	2.80

APPENDIX 3

CHRONOLOGY OF ISSUANCES OF STATEMENTS/FORECASTS/WARNINGS BY WSFO'S

Southern California

The following is a chronological listing (local time) of the statements, watches, and warnings issued for the series of storms by the Los Angeles Weather Service Forecast Office:

February 11 (Monday)

2:10 p.m. FP1 (Southern CA) -- "Chance of rain northwest area, Tuesday night, spreading over all areas Wednesday." (This was the first forecast of rain.)

February 12 (Tuesday)

2:10 a.m. FP1 -- Continued rain for Wednesday.

2:10 p.m. FP1 mentioned "Locally heavy rain southern mountains, Wednesday and Wednesday night."

February 13 (Wednesday)

2:10 a.m. FP1 mentioned "Locally heavy rain southern mountains, Wednesday and Wednesday night."

7-8 a.m. Light rain began LAX WSFO.

9:15 a.m. Special Weather Statement. "Moderate to heavy rain for Southern California today and tonight..." Travelers advisories for mountains -- forecast 2-3" mountains -- 4" observed; forecast 1/2-3/4" coastal areas -- 1" observed. (Mudslides were mentioned.)

1:30 p.m. Flash Flood Watch issued (valid through midnight). Mountain areas Santa Barbara and Ventura Counties...San Gabriel Mountains, San Bernardino Mountains, San Jacinto Mountains southward through mountains of San Diego County. (Mudslides were mentioned.)

2:10 p.m. FP1 -- Flash Flood Watch until midnight...

5:00 p.m. Flash Flood Statement.

10:00 p.m. Flash Flood Statement.

February 14 (Thursday)

2:10 a.m.	FP1 continued Flash Flood Watch through early Thursday morning.
3:30 a.m.	Flash Flood Statement -- Flash Flood Watch until 8:30 a.m.
	LA Times reported freeways closed, power out early Thursday but power restored/freeways opened by midday Thursday.
6:55 a.m.	Special Weather Statement -- Flash Flood Watch cancelled.
10-11 a.m.	Rains stopped in LAX area.
2:10 p.m.	FP1 continued to forecast rains in the area.
4:00 p.m.	Special Weather Statement. Discussed new storm system approaching coast, preliminary rainfall forecasts for Friday: 1-2" deserts, 2" coastal, 4" mountains; observed 5" Mt. Wilson, extensive 2" amounts.
9:00 p.m.	Rain started in LAX area.
10:00 p.m.	Special Weather Statement -- update of precipitation moving onshore.

February 15 (Friday)

12:15 a.m.	Flash Flood Watch issued "mountains and adjacent foothills in S. CA for this morning." Included following counties -- Santa Barbara, Ventura, Los Angeles, San Bernardino, Riverside, Orange, San Diego.
1:00 a.m.	Rain became heavy in LAX area.
2:10 a.m.	FP1 -- Flash Flood Watch mountains and adjacent foothills.
2:20 a.m.	Police report flash flood -- "wall of water 3-4 feet high in Laurel Canyon." Damage -- 22 autos, no deaths/injuries.
2:30 a.m.	Pasadena Glen Flash Flood -- 2-3 cars washed down street, 1 boy injured.
4:00 a.m.	Flash Flood Statement. Update on rainfall amounts in Southern California and expected amounts through Friday evening (very close to observed values).
10:00 a.m.	Flash Flood Watch extended until 2:00 p.m. for same areas.
2:00 p.m.	Rain ended.
2:10 p.m.	FP1 -- Flash Flood Watch extended until 6:00 p.m. for same area.

3:00 p.m. Flash Flood Watch extended until 8:00 p.m. San Gabriel Mountains southward through mountains of San Diego County. Cancelled watch for mountains of Santa Barbara and Ventura Counties. Also mentioned next storm system due Southern California on Saturday, to be followed by still another storm on Monday.

8:00 p.m. Flash Flood Watch extended for large area (reinstated Ventura County) for tonight and Saturday (lead time at least 12 hours). Forecast 1-2" in coastal area; 3-4" in mountains Friday night/Saturday -- observed amounts very close to forecast amounts.

9:10 p.m. FP1 updated to include new Flash Flood Watch "rain heavy at times Saturday and Saturday night."

February 16 (Saturday)

12:05 a.m. Flash Flood Watch added Santa Barbara County valid until Saturday noon.

2:10 a.m. FP1 continued Flash Flood Watch.

LA Times article -- quoted NWS forecasts for no relief in sight until Thursday, February 21st (actually ended 6:00 a.m. Thursday).

This was worst day of storm period in terms of deaths and destruction.

4:00 a.m. Flash Flood Statement -- Watch continued in effect, forecast amounts 1" in coastal areas; 2-3" in mountains "this morning through tonight."

5-6 a.m. Rain began.

9:00 a.m. Flash Flood Watch extended until 3:00 p.m.

2:10 p.m. FP1 -- Watch through 8:00 p.m. "Rain heavy at times through this evening tapering off to showers later tonight."

3:00 p.m. Flash Flood Watch extended until 10:00 p.m. for same areas. Included following on winds -- 25 to 40 mph winds will also be occurring through 10:00 p.m.

7:00 p.m. Flash Flood Statement update and information on rainfall amounts...indicated rains would taper off after 10:00 p.m.

8:00 p.m. Rains began to taper off over the area.

11:30 p.m. Flash Flood Watch and new Watch issued to Los Angeles, San Bernardino, Riverside, San Diego, and Imperial Counties valid until 6:00 a.m. Sunday.

February 17 (Sunday)

1:00 a.m. Rain ended.

2:10 a.m. No watches, but rain forecast Monday.

5:00 a.m. Flash Flood Watch cancelled for Southern California, mentioned major runoff continuing and next storm system expected "tonight and Monday." Forecast 1-2" rains.

12:30 p.m. Special Weather Statement. Discussed next rain system expected "this afternoon and evening."

2:10 p.m. FP1 -- "Showers beginning along coast this afternoon, spreading inland to mountains by early evening and deserts by early Monday morning."

5:00 p.m. Rain began at Civic Center.

6:35 p.m. Flash Flood Watch issued for essentially same areas as before, valid 6:00 p.m. on 18th. Forecast 36-hour amounts of 2-3" in coastal areas, 4-6" in mountains, possibly 8" in mountains.

8:10 p.m. FP1 updated to include new Watch.

10:00 p.m. Flash Flood Statement. Update on rainfall expected mainly Monday and Monday night.

February 18 (Monday)

2:10 a.m. FP1 update for Flash Flood Watch.

3:00 a.m. Flash Flood Statement. Civic Center received 2" since 5:00 p.m., possibly another 2" expected. Mountains possibly 5 to 8" by late in day. "This is a dangerous storm."

4:00 a.m. Heaviest rain over by 4 a.m. mainly coastal plain but continued off and on all day elsewhere.

6:00 a.m. Flash Flood Statement. Update of rain amounts.

9:00 a.m. Flash Flood Watch extended old Watch until 6:00 a.m. on February 20. New storm expected to bring heavy rains this evening.

10:00 a.m. Special Weather Statement -- Heavy Surf Advisory: large swells up to 10 feet heading for Southern California. Greatest danger 10:00 a.m.-1:00 p.m. and around midnight.

2:00 p.m. Flash Flood Statement. Update on weather events, rain amounts expected midnight until noon Tuesday. Coast 1-2", mountains 3-4".

2:10 p.m. FP1 contained Flash Flood Watch.

6:00 p.m. Flash Flood Statement. Update including some of the same information in 2:00 p.m. Statement.

10:00 p.m. Flash Flood Statement. Update "rainfall to increase after midnight."

February 19 (Tuesday)

2:10 a.m. FP1 continued Flash Flood Watch.

2:30 a.m. Gale Warning -- Point Conception to Mexican Border "25 to 45 kn, 5-10 foot seas by noon today." (Roughest weather to hit coast around noon at high tide.)

3:00 a.m. Flash Flood Statement. Update: "The new system on coast this morning appears to be another strong one." Rain forecasts (3:00 a.m. Tuesday to 6:00 a.m. Wednesday) 1-3" coastal areas, 3-6" mountains.

6:10 a.m. Flash Flood Statement. Update -- heavy showers, thunderstorms, hail, strong winds.

8:53 a.m. Flash Flood Warning until 1:00 p.m. in San Diego County along and below the eastern slopes of mountains from Mexican border to Borrego Springs based on radar.

10:00 a.m. Special Weather Statement -- issued new heavy surf advisory -- well worded similar to previous day's advisory.

10:00 a.m. Flash Flood Statement. Update on precipitation distribution.

2:10 p.m. FP1 continued Watch.

4:00 p.m. Flash Flood Statement. Update -- heavy precipitation over Southern California, heavy surf/tides, strong gusty winds.

9:00 p.m. Flash Flood Statement. Very similar to last statement.

9:10 p.m. Gale warning downgrade to small craft advisory -- winds 30 kn, seas 8 feet.

February 20 (Wednesday)

2:10 a.m. FP1 -- clouds and showers decreasing coastal areas this morning -- variable clouds, slight chance showers through Thursday....

2:30 a.m. Flash Flood Statement -- Watch cancelled.

10:00 a.m. Special Weather Statement -- Heavy surf advisory, swells 4-6 feet.

11:00 a.m. Flash Flood Watch issued for mountains/coastal areas in and below canyons for Santa Barbara, Ventura, Los Angeles, Orange, San Diego, Riverside, and San Bernardino Counties valid until 6:00 a.m. Thursday. Described new system spreading rain over area during afternoon, 1-2" amounts predicted.

2:10 p.m. FP1 -- Watch in zone/state.

4:00 p.m. Flash Flood Statement. Rain over coastal and mountain areas again.

7:00 p.m. Flash Flood Warning valid until 9:00 p.m. for areas in and below the coastal mountain slopes of Los Angeles, Riverside, San Bernardino, Orange, and San Diego Counties. Indications of heavy rain over and west of mountains based on radar.

9:00 p.m. Flash Flood Warning -- Same areas, but added Ventura County and extended warning until midnight. Moderate-heavy rain continuing over area.

<u>February 21 (Thursday)</u>

12:30 a.m. Flash Flood Watch -- extended to include Imperial County for indefinite period of time.

2:10 a.m. FP1 -- Watch included.

5:00 a.m. Flash Flood Statement. Update storm "six" over California with storm "seven" approaching from west. Rain forecast 2-4" west of mountains, 3-6" in mountains before ending Friday.

10:00 a.m. Special Weather Statement. Heavy surf advisory -- breakers 6-9 feet with occasional sets 15-20 feet. "Greatest danger during high tide noon-2:00 p.m. and again tonight 1:00-3:00 a.m."

2:10 p.m. FP1 -- Flash Flood Watch in effect.

4:00 p.m. Flash Flood Statement. Next system to bring rains back into area this evening. Forecast 1" coast, 1-3" mountains. Statement indicated break in rain pattern after present system moved through.

6:00 p.m. Special Weather Statement -- heavy surf advisory. Breakers 6-9 feet, possibly 12 feet.

9:00 p.m. Flash Flood Statement. Similar to previous Flash Flood Statement. Timing for precipitation midnight to sunrise, forecast 1/2-1" coastal areas, 1-2" mountains.

<u>February 22 (Friday)</u>

12:15 a.m. Flash Flood Statement. Watch cancelled.

9:00 a.m. Special Weather Statement -- heavy surf advisory. Seas 4-7 feet -- greatest threat to beach structures at high tide (3:30 p.m.).

2:10 p.m. FP1 -- Some cloudiness...otherwise <u>fair</u>.

Central Arizona

The first weather summary mentioning precipitation was issued at 5:15 p.m., Tuesday, February 12. It indicated that numerous, locally heavy showers would spread across Arizona Wednesday night and Thursday and that the weather pattern was changing. This mention of precipitation was continued in the 9:15 p.m., February 12 discussion.

A winter storm watch was issued at 4:45 a.m., MST, Wednesday, February 13. The following is a chronological listing (local time) of the statements, watches, and warnings issued for the series of storms by the Phoenix Weather Service Forecast Office.

<u>February 13 (Wednesday)</u>

4:45 a.m. Special Weather Statement.

10:55 a.m. Special Weather Statement.

1:30 p.m. Flash Flood Watch bulletin. Arizona Central Basin, adjoining desert, and foothill region.

3:30 p.m. Flash Flood and Winter Weather Statement.

5:30 p.m. Flash Flood Watch for all of southwest Arizona deserts and Tucson/Mt. Lemmon area.

6:00 p.m. Flash Flood and Winter Weather Statement.

9:00 p.m. Flash Flood and Winter Weather Statement.

<u>February 14 (Thursday)</u>

4:30 a.m. Flash Flood and Winter Weather Statement. Flash Flood Watch for northwest Arizona and all of Arizona south of rim.

10:10 a.m. Flash Flood and Winter Weather Statement.

2:15 p.m. Special Weather Statement.

2:30 p.m. Flash Flood Watch bulletin for central mountains and foothills down to the edge of the desert north and east of Phoenix.

5:20 p.m. Flash Flood and Special Weather Statement.

7:00 p.m. Flash Flood Warning until midnight for extreme northwest Maricopa, southeast Yavapai, extreme southern Mohave, and northern Yuma Counties.

8:30 p.m. Flood Warning Statement.

9:00 p.m. Flash Flood and Special Weather Statement.

11:00 p.m. Flash Flood and Special Weather Statement.

February 15 (Friday)

2:45 a.m. Flash Flood and Special Weather Statement. Cancel Flash Flood Warning for northwest Maricopa and southwest Yavapai Counties; Flash Flood Watch today and tonight for western Arizona and southern Arizona south of the rim. Flash Flood Watch and Special Weather Statement.

9:10 a.m. Flash Flood Watch for western and southern Arizona, south of rim.

10:15 a.m. Flood Warning: Salt, Verde, Little Colorado Basins.

1:00 p.m. Flood Warning: Salt, Verde, Bill Williams, Agua Fria, Hassayampa.

3:00 p.m. Flash Flood and Special Weather Statement.

5:00 p.m. Flash Flood Warning southeast Mohave, northeast Yuma, southern Yavapai, and Maricopa Counties, including greater Phoenix area.

6:00 p.m. Flash Flood Statement.

7:00 p.m. Flash Flood Statement; Flash Flood Warning cancelled for eastern Maricopa County.

8:20 p.m. Flood Warning.

8:30 p.m. Flood Warning Statement.

9:15 p.m. Flash Flood Statement; Flash Flood Watch for eastern Arizona south of White Mountains cancelled.

February 16 (Saturday)

12:25 a.m. Flood Statement. Flood Warning continued for Salt River system.

5:15 a.m. Flash Flood and Special Weather Statement.

10:15 a.m. Flash Flood and Special Weather Statement.

11:00 a.m. Flood Statement, Phoenix metropolitan area.

4:30 p.m. Flash Flood Statement. Flash Flood Watch southern and western Arizona. Flood watch time unknown.

5:10 p.m. Flood Watch: Salt and Verde drainages.

9:00 p.m. Flash Flood Statement. Flash Flood Watch southern and western Arizona.

9:45 p.m. Special Weather Statement.

10:00 p.m. Flash Flood Warning, Yuma and Mohave Counties.

11:00 p.m. Flash Flood Statement.

February 17 (Sunday)

12:15 a.m. Flash Flood Statement. Flash Flood Warning extended to include Gila and Pinal Counties.

3:00 a.m. Flash Flood and Special Weather Statement.

8:00 a.m. River Statement -- Central Arizona.

8:30 a.m. Flash Flood Watch cancellation bulletin.

8:45 a.m. Special Weather Statement.

9:00 a.m. River Statement, Central Arizona.

11:30 a.m. Special Weather Statement.

4:00 p.m. River Statement, Central Arizona.

5:00 p.m. Special Weather Statement.

February 18 (Monday)

11:20 a.m. Special Weather Statement.

9:00 a.m. River Statement, Central Arizona.

12:20 p.m. Flash Flood Watch bulletin.

1:30 p.m. Flash Flood Warning, Oak Creek Canyon and through Sedona.

2:30 p.m. Flash Flood and Special Weather Statement.

4:00 p.m. Flood Statement, Central Arizona and western Arizona.

4:45 p.m. Flash Flood Statement.

5:20 p.m. Special Weather Statement.

6:15 p.m. Flash Flood Statement. Cancelled Flash Flood Warning for Oak Creek Canyon.

7:00 p.m. River Statement, Central Arizona and western Arizona.

7:20 p.m. Flash Flood Statement. Cancelled Flash Flood Watch for southern and western Arizona.

February 19 (Tuesday)

8:30 a.m.	River Statement, Central Arizona.
3:00 p.m.	River Statement, Central Arizona and eastern Arizona.
3:20 p.m.	Severe Thunderstorm Warning, Yuma County, Arizona.
3:40 p.m.	SELS -- Severe Thunderstorm Watch.
4:00 p.m.	Arizona, areal outline for Severe Thunderstorm Watch.
5:00 p.m.	Severe Weather Statement.
5:45 p.m.	Severe Weather Statement.
6:00 p.m.	Severe Thunderstorm Watch #3.
6:15 p.m.	Areal outline for Severe Thunderstorm Watch #3.
7:00 p.m.	Severe Weather Statement.
8:00 p.m.	Flash Flood Warning, large portion of Central Arizona and western Arizona.
9:00 p.m.	Severe Weather Statement.
9:15 p.m.	Special Weather Watch.
9:30 p.m.	Flash Flood Statement.
10:00 p.m.	Severe Thunderstorm Watch Cancellation.
10:20 p.m.	Severe Weather Statement.

February 20 (Wednesday)

2:30 a.m.	Flash Flood Statement.
8:45 a.m.	River Statement.
9:00 a.m.	Special Weather Statement.
12:00 p.m.	River Statement.
4:30 p.m.	River Statement.
8:00 p.m.	Flash Flood Warning, Central Arizona and western Arizona.

APPENDIX 4

SAMPLE FLOOD WARNING AND RIVER STATEMENTS RELEASED BY THE SALT LAKE CITY RFC

Arizona falls within the area served by the NWS River Forecast Center located at Salt Lake City. Approximately 20 Flood Warning and River Statements were officially released from the RFC and sent (via RAWARC) to the WSFO at Phoenix for dissemination to the public. Copies of five of these statements appear chronologically beginning on the next page. The last four digits of the six-digit day/time group appearing in the headers of the messages give the Greenwich mean time.

ZCZC
RWUS RWRE 151715
SLC
PHX A SLC

FLOOD WARNING.....

SALT... VERDE... LITTLE COLORADO BASINS

FLOODING HAS BEEN REPORTED IN THE OAK CREEK AND BEAVER CREEK BASINS. SOME PERSONS ALONG OAK CREEK ARE BEING EVACUATED..ADDITIONAL SEVERE FLOODING IS LIKELY AND SHOULD CONTINUE THROUGH THIS EVENING..FLOODING IS NOT LIKELY ON THE UPPER GILA OR SANTA CRUZ BASINS..

STORM RAINFALL AMOUNTS OF 2 TO 4 INCHES HAVE BEEN OBSERVED IN THE HEADWATERS OF THE VERDE AND TONTO CREEK BASINS.. 1 TO 2 INCHES OCCURRED LAST NIGHT....THIS HEAVY RAINFALL COUPLED WITH SNOWMELT BELOW 7500 FT IS EXPECTED TO PRODUCE FLOWS SIMILAR TO THOSE EXPERIENCED DECEMBER 1978...

THE FLOWS ARE EXPECTED TO PEAK NEAR MIDNIGHT ON THE LOWER VERDE AND LATE THIS AFTERNOON ON THE TONTO BASIN...

ADDITIONAL RAINFALL TONIGHT WILL CAUSE FLOWS TO REMAIN AT FLOOD STAGE THROUGH TOMORROW...

THE LARGE VOLUMES OF FLOW CANNOT BE STORED IN THE SALT RIVER RESERVOIR SYSTEM...THE PEAK FLOWS SHOULD BE SUBSTANTIALLY REDUCED FROM RESERVOIR REGULATION...AND FLOWS BELOW THE RESERVOIR SYSTEM SHOULD PEAK IN THE SALT AT PHOENIX NEAR 100 THOUSAND CFS..

IMMEDIATE PRECAUTIONS SHOULD BE TAKEN.....

GERALD WILLIAMS
HYDROLOGIST IN CHARGE
SALT LAKE RIVER FORECAST CENTER

NNNN

ZCZC
RWUS RWRE 152030
SLC
PHX A SLC

FLOOD WARNING STATEMENT...
SALT LAKE CITY RIVER FORECAST CENTER
1300 MST FEBRUARY 15 1980

SALT... VERDE... BILL WILLIAMS... AGUA FRIA... HASSAYAMPA

MAJOR RIVER FLOODING IS OCCURRING THROUGHOUT CENTRAL ARIZONA. FLOODING IS EXPECTED TO CONTINUE THROUGH SATURDAY... WITH MINOR FLOODING LASTING SEVERAL DAYS.

FLOWS WILL CONTINUE TO RISE ALONG THE SALT... VERDE... AND AGUA FRIA RIVERS... PEAKING LATE THIS EVENING AND EARLY TOMORROW MORNING NEAR THE HIGHEST OF RECORD.

CONTINUED RAINFALL AND SNOWMELT WILL MAINTAIN HIGH FLOWS AT OR NEAR FLOOD STAGE IN THE PHOENIX AREA FOR SEVERAL DAYS.

PEAK FLOW FORECASTS	PEAK FLOW	TIME	DATE
SALT RIVER NR ROOSEVELT RES	60000 CFS	NOON	FEB 16
VERDE RIVER INFLOW TO HORSESHOE RES	90000 CFS	6 AM	FEB 16
TONTO CREEK NR ROOSEVELT RES	40000 CFS	6 PM	FEB 15
AGUA FRIA RIVER INFLOW TO LAKE PLEASANT RES	45000 CFS	2 PM	FEB 15

GERALD WILLIAMS
HYDROLOGIST IN CHARGE
SALT LAKE CITY RIVER FORECAST CENTER

NNNN

WOUSOO KSLC 160255
ZCZC
RWUS RWRE 150320[a]
SLCRVSSLC[b]
KHSD PHX A SLC

FLOOD WARNING

PHOENIX METROPOLITAN AREAS AND MAJOR TRIBUTARIES OF GILA RIVER ....

TOTAL INFLOW TO THE SALT AND VERDE RIVER SYSTEM IS NEAR 250000 CFS. FLOWS THROUGH PHOENIX ARE NEAR 170000 CFS AND ARE EXPECTED TO REMAIN AT THIS LEVEL UNTIL TOMORROW.

HEAVY RAINFALL HAS FALLEN OFF BUT MORE IS LIKELY TOMORROW.

PHOENIX AND ADJACENT COMMUNITIES WILL EXPERIENCE MAJOR FLOODING FOR SEVERAL DAYS.

INFLOW TO THE VERDE SYSTEM IS NEAR 110000 CFS AND SHOULD BEGIN FALLING TONIGHT BUT REMAIN ABOVE 70000 CFS UNTIL TOMORROW. INFLOW TO ROOSEVELT LAKE IS NEAR 130000 CFS AND IS EXPECTED TO INCREASE[c] TO NEAR 60000 CFS BY MORNING.

TOTAL INFLOWS TO THE SALT AND VERDE SYSTEM SHOULD DROP BELOW 250000 CFS

NO MAJOR FLOODING IS EXPECTED ON THE UPPER GILA RIVER. HOWEVER, SOME MINOR FLOODING HAS BEEN REPORTED ON THE UPPER BLUE RIVER DRAINAGE.

ALL INTERESTS AND COMMUNITY OFFICIALS SHOULD BE ALERT FOR STATEMENTS REGARDING EMERGENCY FLOOD MEASURES...

SLC RFC GW

NNNN

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[a]Should have read "160320"
[b]Should have read "SLCFLWSLC"
[c]Should have read "DECREASE"

WOUSOO KSLR 182309
ZCZC
RWUS RWRE 182300
SLCRVSSLC[a]
KHSD PHX A SLC

FLOOD STATEMENT.... CENTRAL AND WESTERN ARIZONA

SALT LAKE CITY RIVER FORECAST CENTER
4 PM FEBRUARY 18 1980

A SOUTH PACIFIC STORM IS EXPECTED TO REACH CENTRAL ARIZONA BY THIS EVENING...HEAVY PRECIPITATION IS POSSIBLE...AMOUNTS EXCEEDING 1 INCH ARE EXPECTED WITH POSSIBLY SOME AS HIGH AS 3 INCHES OCCURRING IN THE HEADWATERS OF THE MAJOR ARIZONA RIVER BASINS..

IF THE RAINFALL MATERIALIZES AS EXPECTED...SIGNIFICANT RISES WILL OCCUR TOMORROW ON THE VERDE...SALT.. AND..TONTO BASINS...SIGNIFICANT RISES ARE ALSO LIKELY ON THE GILA ABOVE SAN CARLOS RESERVOIR WEDNESDAY AND THURSDAY...

THE EXPECTED INFLOW TO THE ENTIRE SALT RIVER SYSTEM ARE AS FOLLOWS

STATION	FORECAST FLOW	WITH 24 HR RAIN AMOUNTS OCCURRING	TIME OF PK
SALT NR ROOSEVELT	90 THOUSAND CFS	3 INCHES BY TOMORROW	MIDNIGHT FEB 19
	25-35 THOUSAND CFS	2 INCHES BY TOMORROW	FEB 19
TONTO CK	40 THOUSAND CFS	3 INCHES BY TOMORROW	6 AM FEB 19
	10-20 THOUSAND CFS	2 INCHES BY TOMORROW	6 AM FEB 19
VERDE INTO HORSESHOE	95 THOUSAND CFS	3 INCHES BY TOMORROW	6 AM FEB 19
	20-40 THOUSAND CFS	2 INCHES BY TOMORROW	NOON FEB 19

THESE FORECASTS ARE MADE USING THE PRECIPTATION VALUES LISTED AND THE HEAVIEST RAINFALL IS EXPECTED IN THE HEADWATERS WITH LESSER AMOUNTS FALLING IN THE VALLEYS...
FURTHER STATEMENTS WILL BE ISSUED AS MORE INFORMATION REGARDING THE APPROACHING WEATHER SYSTEM IS AVAILABLE...

SLC RFC GW

NNNN

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[a] Should have read "SLCFLSSLC"

WOUSOO KSLC 192154

1500 MST FEBRUARY 19 1980

ZCZC
RWUS RWRE 190002[a]
SLCRVSSLC
KHSD PHX A SLC

RIVER STATEMENT.... CENTRAL AND EASTERN ARIZONA

SALT LAKE CITY RIVER FORECAST CENTER
3 PM FEBRUARY 19 1980

PRECIPITATION TONIGHT IS FORECAST TO BE NEAR 2.00 INCHES AT HIGHER ELEVATIONS ON THE SALT AND VERDE DRAINAGES AND NEAR 1.50 INCHES ON THE UPPER GILA BASIN...

FLOWS ON THE SALT AND VERDE RIVERS ARE EXPECTED TO INCREASE LATE TONIGHT AND EARLY TOMORROW ....

PEAK INFLOW INTO THE SALT AND VERDE SYSTEM IS EXPECTED TO NEAR 90 THOUSAND CFS BY MORNING... RIVER FORECASTS ARE 35 THOUSAND CFS FOR THE VERDE INTO HORSESHOE RESERVOIR...30 THOUSAND CFS FOR THE SALT RIVER INTO ROOSEVELT RESERVOIR ... AND 20 THOUSAND CFS FOR TONTO CREEK NEAR ROOSEVELT...

PEAK FLOW INTO SAN CARLOS RESERVOIR IS EXPECTED NEAR 20 THOUSAND CFS ON THURSDAY.....

SLC/RFC GW

NNNN

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[a]Should have read 192200

APPENDIX 5

POTENTIAL NEAR REAL-TIME SURFACE HYDROMETEOROLOGICAL STATIONS IN AFFECTED AREAS OF SOUTHERN CALIFORNIA AND CENTRAL ARIZONA

Southern California

The following list of surface reporting stations were those potentially available in near real-time for operational usage by the NWS offices in the areas affected by the February 1980 series of storms in Southern California.

The principal types of data collected are shown in the "Data Type" column. "Basic" refers to general synoptic or aviation meteorological data such as temperature, wind measurements, etc.

NOAA/NWS and FAA Stations

Station Name	*Station and/or Gage Type*	*Data Type*
Beaumont (BUO)	NWS BASIC	Basic, Precip
Burbank (BUR)	FAA/LAWRS	Basic
Campo (CZZ)	NWS BASIC	Basic, Precip
Carlsbad (CRQ)	FAA/LAWRS	Basic
Chino (CNO)	FAA/LAWRS	Basic
Daggett FAA Airport (DAG)	FAA/FSS	Basic, Precip
El Monte (EMT)	FAA/LAWRS	Basic
Fullerton (FUL)	FAA/LAWRS	Basic
Hawthorne (HHR)	FAA/LAWRS	Basic
Imperial (IPL)	FAA/FSS	Basic, Precip
Lancaster (WJF)	FAA/FSS	Basic, Precip
Laverne (POC)	FAA/LAWRS	Basic
Long Beach WSO Airport (LGB)	NWS WSO	Basic, Precip
Los Angeles WSO Airport (LAX)	NWS WSO	Basic, Precip
Mt. Wilson (MWS)	NWS BASIC	Basic, Precip
Ontario (ONT)	FAA/FSS	Basic, Precip
Oxnard (OXR)	FAA/LAWRS	Basic
Palm Springs (PSP)	FAA/LAWRS	Basic, Precip, River*
Palmdale (PMD)	FAA/LAWRS	Basic
Riverside (RAL)	FAA/LAWRS	Basic
San Diego (Brown Field--SDM)	NWS BASIC	Basic
San Diego (Gillespie--SEE)	NWS BASIC	Basic
San Diego (Montgomery Field--MYF)	NWS BASIC	Basic
San Diego WSO Airport (SAN)	NWS WSO	Basic, Precip
Sandberg (SDB)	NWS AUTOB	Basic, Precip
Santa Ana (SNA)	FAA/LAWRS	Basic, Precip, River*
Santa Barbara FAA Airport (SBA)	FAA/FSS	Basic, Precip
Santa Catalina SR (AVX)	SAWRS	Basic
Santa Maria WSO Airport (SMX)	NWS WSO	Basic

*These river data were not used by NWS offices for forecasting during this storm series.

NOAA/NWS and FAA Stations (continued)

Station Name	*Station and/or Gage Type*	*Data Type*
Santa Monica (SMO)	FAA/LAWRS	Basic
Thermal FAA Airport (TRM)	FAA/FSS	Basic, Precip
Torrance Airport (TOA)	FAA/LAWRS	Basic, Precip, River*
Van Nuys (VNY)	FAA/LAWRS	Basic

Military Stations

Station Name	*Station and/or Gage Type*	*Data Type*
Edwards AFB	USAF	Basic
El Toro (NZJ)	USMC	Basic
Miramar (NKX)	USN	Basic, Precip
Pt. Mugu (NID)	USN	Basic
Riverside (March AFB--RIV)	USAF	Basic
San Bernardino (Norton AFB--SBD)	USAF	Basic
San Clemente Island (NUC)	USN	Basic
San Diego Navy Base (NZY)	USN	Basic
San Diego (Ream Field--NRS)	USN	Basic
San Nicholas Island (NSI)	USN	Basic
Vandenberg AFB (VBG)	USAF	Basic
Victorville (George AFB--VCV)	USAF	Basic

Miscellaneous Stations

Station Name	*Station and/or Gage Type*	*Data Type*
Carpinteria Reservoir	Telemetering (on call)	River*
Figueroa	Telemetering (on call)	River*
San Marcos Pass	Telemetering (on call)	Precip
Santee	Telemetering (on call)	River*

NWS/Coast Guard Stations

Station Name	*Station and/or Gage Type*	*Data Type*
Anacapa Island	MARS	Sea State, Basic
Cabrillo Beach	MARS	Sea State, Basic
Huntington Beach	MARS	Sea State, Basic
Long Beach	MARS	Sea State, Basic
Marina Del Rey	MARS	Sea State, Basic
Mission Beach	MARS	Sea State, Basic
Newport Beach	MARS	Sea State, Basic, Precip
Oceanside Harbor	MARS	Sea State, Basic
Oxnard (Channel Island)	MARS	Sea State, Basic
Point Loma	MARS	Sea State, Basic
Point Arguello LN	MARS	Sea State, Basic
San Mateo LN	MARS	Sea State, Basic
Santa Barbara Harbor	MARS	Sea State, Basic

*These river data were not used by NWS offices for forecasting during this storm series.

NWS/Coast Guard Stations (continued)

Station Name	*Station and/or Gage Type*	*Data Type*
Santa Catalina Island	MARS	Sea State, Basic
Santa Monica Pier	MARS	Sea State, Basic
Scripps Pier	MARS	Sea State, Basic
Terminal Island	MARS	Sea State, Basic
Ventura Harbor	MARS	Sea State, Basic
Zuma Beach	MARS	Sea State, Basic

Central Arizona

The following list of surface observation stations were those potentially available in near real-time to the NWS offices in the areas affected by the February 1980 series of storms in Central Arizona. The entire DARDC and river gage networks are listed here, although some of the stations were considered "out of area" for this storm series (i.e., not in the Gila-Salt-Verde basin, and/or located too far from the areas affected by the storms).

River gage data from the SRP stations were usually available in near real-time to the Salt Lake City RFC (via telephone from the RFC to the SRP office in Phoenix). Precipitation data from these stations were not available in near real-time but were used in postanalyses. SRP data were not available to the Phoenix WSFO. Data from the other stations listed were potentially available to both the Phoenix WSFO and the Salt Lake City RFC.

The principal types of data collected are shown in the "Data Type" column. "Basic" refers to general synoptic or aviation meteorological data such as temperature, wind measurements, etc.

NOAA/NWS and FAA Stations

Station Name	*Station and/or Gage Type*	*Data Type*
Deer Valley-Phoenix (DVT)[a]	FAA/LAWRS	Basic, Precip
Douglas FAA Airport (DUG)[a]	FAA/FSS	Basic
Flagstaff WSO Airport (FLG)	NWS WSO	Basic, Precip
Kingman (IGM)[a]	NWS AMOS	Basic, Precip
Lake Havasu (LHU)[a]	SAWRS	Basic, Precip
Payson (OE4)	NWS BASIC	Basic, Precip
Phoenix WSFO Airport (PHX)	NWS WSFO	Basic, Precip
Prescott FAA Airport (PRC)	FAA/FSS	Basic, Precip
Safford Experiment Farm (E74)[a]	NWS BASIC (RAMOS (MED))	Basic, Precip
Scottsdale (SDL)[a]	FAA/LAWRS	Basic, Precip
Show Low (E03)[a]	NWS BASIC	Basic, Precip
Tucson WSO Airport (TUS)[a]	NWS WSO	Basic, Precip
Winslow WSO Airport (INW)[a]	NWS WSO (AUTOB)	Basic, Precip

NWS DARDC and River Gage Stations (Automated)

Station Name	*Station and/or Gage Type*	*Data Type*
Alpine	DARDC (AHOS/T)	Precip
Black Canyon[b]	DARDC (AHOS/T)	Precip
Blue School[b]	DARDC (AHOS/T)	Precip

[a]Data from these gages were not used as input to the river forecast program at the Salt Lake City RFC, because the stations were outside the basin for which the program was calibrated or data were not received in time to be used operationally.

[b]These gages either did not function or functioned unreliably during part or all of the storm period. (See chapter 5.)

NWS DARDC and River Gage Stations (Automated) (continued)

Station Name	*Station and/or Gage Type*	*Data Type*
Camp Verde	DARDC (AHOS/T)	Precip
Carefree	DARDC (AHOS/T)	Precip
Chambers[a]	NWS BDT	River
Chambers[a]	DARDC (AHOS/T)	Precip
Clifton[b]	NWS Telemark	River
Clifton 17 NE	NWS AHOS/S	Precip, River
Gallup 5E, New Mexico[a]	NWS Telemark	River
Gila, New Mexico[a]	NWS AHOS/S	Precip, River
Glenwood, New Mexico[a]	NWS Telemark	River
Globe[b]	DARDC (AHOS/T)	Precip
Happy Jack Ranger Station[b]	DARDC (AHOS/T)	Precip
Heber	DARDC (AHOS/T)	Precip
Junipine	DARDC (AHOS/T)	Precip
Lake Pleasant[b]	DARDC (AHOS/T)	Precip
Payson	DARDC (AHOS/T)	Precip
Redrock, New Mexico[a]	NWS Telemark	River
Robles Junction[a]	DARDC (AHOS/T)	Precip
Sabino Canyon[a]	DARDC (AHOS/T)	Precip
Saguaro Nat'l Monument[a]	DARDC (AHOS/T)	Precip
Snowflake[b]	DARDC (AHOS/T)	Precip
Taliesin West	DARDC (AHOS/T)	Precip
Tonto Creek Fish Hatchery	DARDC (AHOS/T)	Precip
Tuzigoot Nat'l Monument[b]	DARDC (AHOS/T)	Precip
Vail[a]	DARDC (AHOS/T)	Precip
Woodruff[b]	NWS BDT	River

Salt River Project Stations

Station Name	*Station and/or Gage Type*	*Data Type*
Bartlett Dam	Precip gages are	Precip, River
Horse Mesa Dam	6-inch diameter	Precip, River
Horseshoe Dam	Taylor gages.	Precip, River
Mormon Flat Dam	River gages are	Precip, River
Roosevelt Dam	standard USGS	Precip, River
Stewart Mountain Dam	stilling well type.	Precip, River

[a]Data from these gages were not used as input to the river forecast program at the Salt Lake City RFC, because the stations were outside the basin for which the program was calibrated or data were not received in time to be used operationally.

[b]These gages either did not function or functioned unreliably during part or all of the storm period. (See chapter 5.)

APPENDIX 6

DISASTER SURVEY TEAM CONTACTS AND VISITS

Southern California

This appendix identifies organizations and individuals interviewed in Southern California and Central Arizona by Survey Team members. Results of the interviews appear in chapter 6.

Ventura County

Ventura County Offices of Flood Control and Emergency Services

Los Angeles County

Key local officials
Selected residents of Topanga and Mandeville Canyons

Orange County

Individuals at Laguna Beach Red Cross Assistance Center
Fire Chief in San Clemente

Riverside County

Riverside County Office of Emergency Services

San Diego County (contacted by telephone)

Mr. Calvin Chong, City of San Diego Engineering and Development Department
Mr. James W. Hunt, San Diego County Office of Disaster Preparedness
Mr. Carey Stevenson, Flood Control Office of the San Diego County Department of Public Works
Mr. Alton L. Goff, U.S. State Department International Boundary and Water Commission

Media Representatives in Southern California

Los Angeles

KNXP TV-2 (CBS) -- Mr. Maclovio Perez, Meteorologist
KNBC TV-4 (NBC) -- Mr. Pat Sajak, Weather Anchor
KABC TV-7 (ABC) -- Dr. George Fischbeck, Meteorologist

KFWB Radio (Westinghouse) -- Mr. Eric Williams, Writer/Editor, who covered the storm as breaking news story
KNX Radio (CBS) -- Mr. Bob Sims, Assistant News Director
-- Mr. Beach Rogers, General Assignment Reporter, who covered the storm as breaking news story

The Los Angeles Times -- Mr. George Alexander, Science Editor

San Diego

KFMB TV-8 (CBS) -- Mr. Vic Heman, Assignment Editor
KCST TV-39 (NBC) -- Mr. Bob Dale, Weather
-- Mr. Jim Vella, Chief Assignment Editor
KGTV TV-10 (ABC) -- Mr. Mike Ambrose, Weather
-- Mr. Jack Moorhead, Assignment Editor

KFMB Radio (CBS) -- Mr. Clark Anthony, Weather
-- Ms. Diane Enright, Assignment Editor/Reporter

The Tribune -- Mr. Frank Stone, General Assignment Reporter, who covered weather during the storm period

Central Arizona

Greater Phoenix Area

February 25 -- Maricopa County Flood Control District
Mr. Bill Mathews, Chief Flood Control Engineer
Mr. Dan Sagramoso, Assistant Flood Control Engineer

February 25 -- Arizona Department of Public Safety
Sgt. Allen Schmidt, Public Information Officer
Mr. Ray Freed, Regional Communications Manager

February 26 -- Army National Guard
Col. R. A. Colson, Plans Operations & Military Support Officer
Team flew via Huey helicopter over damaged areas.

February 26 -- Arizona Department of Emergency Services
Mr. Charles A. Ott, Director
Mr. James Lind, Training Officer

February 26 -- Federal Emergency Management Administration
Mr. Joe Winkle, Federal Coordinator for Arizona area

February 26 -- Maricopa County Department of Civil Defense & Emergency Services
Mr. Roy Bluhm, Acting Director
Mr. Frank Russo, Support Services Manager
Mr. Tom Gleason, Chief, Nuclear Division

February 26 -- Salt River Project Headquarters
Mr. Jack Pfister, General Manager
Mr. Bob Amos, Deputy General Manager
Mr. Richard Juetten, Manager, Water Resources and Services
Mr. Reid Teeples, Assistant General Manager for Water
Mr. Sid Wilson, Chief, Surface Water

Oak Creek Canyon Area

February 27 -- Sedona
Private citizen
Businessman/pilot and member Chamber of Commerce

February 27 -- Ten miles north of Sedona
Private citizen, trailer park manager

February 27 -- Flagstaff Weather Service Office
Mr. Byron Peterson, Official in Charge
Mr. Ed Baker, Weather Service Specialist

Media Representatives in Greater Phoenix Area

KOOL TV-10 (CBS)	-- Mr. Joe Dougherty, Meteorologist
	-- Mr. Bill Close, News Anchor
KPNX TV-12 (NBC)	-- Mr. Dewey Hopper, Weather
KTVK TV-3 (ABC)	-- Mr. Jim Howl, Meteorologist
KOY Radio (Independent)	-- Mr. Ed Phillips, Meteorologist
KTAR Radio (ABC/Mutual)	-- Mr. Dave Zorn, News Director

APPENDIX 7

SAMPLE PUBLIC REACTION TO AIRED FORECASTS IN SOUTHERN CALIFORNIA

Flood Victims in Topanga Canyon, Los Angeles

Seven Topanga Canyon residents were interviewed, all of whom suffered some property loss due to the flood. The losses included bridges, driveways, and retaining walls. In one case, a home was inundated, and the resident was interviewed as he spread all of his belongings out in the sun to dry. His home next to the river was flooded within half an hour after a debris dam broke loose less than a quarter of a mile upstream. He had no reaction to weather forecasts, because he had not heard any -- his electricity had been cut off due to the storm.

Most of the people interviewed in the Topanga Canyon, however, were aware of the flood watch and the subsequent warning. They were somewhat critical that the warning did not pinpoint their canyon as the one to be flooded. One woman, a realtor recently settled in Topanga Canyon, was particularly critical of the presentation formats used by TV broadcast meteorologists. She stated that she was interested only in the facts. However, apparently none of the Topanga Canyon victims intended to move as a result of the flood.

There were no known fatalities in Topanga Canyon due to the flood. One of the residents interviewed, however, owes his life to luck and the strength of the rope holding his access bridge across the swollen creek. He displayed a photograph of himself standing in his high boots on the bridge before the rapid water swept the bridge away. Most of the flood fatalities in Southern California were due to such risky acts. Few resulted from people being caught unaware of floods in progress or imminent.

Mudslide Victims in Los Angeles and San Diego

One Los Angeles resident was interviewed in front of the remains of his home which had been destroyed for the second time in two years by a mudslide from a steep hill rising behind his home. During this recent series of rainstorms, he had left the house to photograph his neighbor's home which had just been destroyed by a major mudslide. At the last moment, he turned to reenter his home to get a piece of plastic to protect the camera from the rain. While at his front door, he heard the familiar noise of a mudslide and quickly stepped away from the door. Within a few seconds, many tons of mud had roared down the steep hillside and destroyed his home. (See figure 1.2.) After narrowly avoiding being hit by the front door as it broke loose, he turned and sprinted to safety. Fortunately, his three children and his wife were not at home. They had been sent to stay with friends the night before.

This resident had heard the flood watch and warnings on the TV. He realized that the NWS is not in the business of forecasting mudslides. But the rain and the rain forecasts, along with his previous mudslide experience, made him cautious enough to protect his family by having them stay elsewhere until the danger passed.

When asked if he would rebuild, he said "No. The house now belongs to the bank." It is not difficult to understand his decision. Two years earlier, mud from the same hill, but on a different side, had slid down into his home totally destroying it. His maid had the misfortune to be in the house at the time. As she ran for her life, the mud slammed a house wall into her, knocking her unconscious. She was found dead the next day, buried beneath 4 feet of mud.

Another mudslide victim was interviewed in San Diego. His home was situated atop a steep hill in University City north of San Diego. About 30 cubic yards of mud had slid from beneath the edge of the home. The resident planned to repair the damage with the aid of a Federal loan. He had been aware of the forecasts and had no complaints. He, too, understood that NWS does not forecast mudslides.

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