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Volume III: Operational Applications of Satellite Snow-Cover Observations in California

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and J. F. Hannaford

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Volume III: Operational Applications of Satellite Snow-Cover Observations in California

A. J. Brown
California Department of Water Resources
Sacramento, California

J. F. Hannaford
Sierra Hydrotech
Placerville, California

NASA

National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

ABSTRACT

This investigation involves an Applications Systems Verification and Transfer (ASVT) effort in California using five southern Sierra snowmelt basins and two northern Sierra-Southern Cascade snowmelt basins to evaluate the effect on operational water supply forecasting by including as an additional parameter the Snowcovered Area (SCA) obtained from satellite imagery.

Manual photointerpretation techniques were used to obtain SCA and equivalent snow line for the years 1973 to 1979 for the seven test basins using Landsat imagery supplied by NASA and GOES imagery supplied by NOAA/NESS. Timeliness of image delivery was a problem throughout the investigation. Delivery of NASA standard product was never within the 72-hour objective. Some Quick-Look and NOAA imagery was received within 72 hours.

The use of SCA was tested operationally in 1977-79. Results indicated the addition of SCA improved the water supply forecasts during the snowmelt phase for those basins where there may be an unusual distribution of snowpack throughout the basin, or where there is a limited amount of real-time data available. A high correlation to runoff was obtained when SCA was combined with snow water content data obtained from reporting snow sensors.

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A. J. Brown
J. F. Hannaford

Department of Water Resources
Sacramento, California
Sierra Hydrotech
Placerville, California

INTRODUCTION

Authorization and Areas of Responsibilities

As part of the national effort to apply space-age technology to evaluation and monitoring of earth resources, the National Aeronautics and Space Administration (NASA) has cooperated with operating agencies in investigations into the utility of satellite imagery in water supply and other hydrologic analysis. Prior research conducted by NASA has led to application of snow-covered area from satellite imagery to specific hydrologic problems in the Applications Systems Verification and Transfer (ASVT) program. This program has included snow ASVT projects in four areas: Arizona, Colorado, the Pacific Northwest, and California.

For 50 years, the California Department of Water Resources (CDWR) has evaluated water conditions and forecast the snowmelt runoff for those areas of the State within the snow zone. The Department fulfills this forecast responsibility through the California Cooperative Snow Surveys Program administered by the CDWR Snow Surveys Branch.

NASA contracted with CDWR in April 1975 to investigate the application of snow-covered area from satellite imagery to the Department's hydrologic forecasting procedures and designated the Department as manager of the California ASVT project. CDWR subcontracted with Sierra Hydrotech, engineering consultants, to participate in the investigation by providing assistance in data reduction and technical application.

Objectives and General Description of Investigation

The objective of this investigation was to explore the application of snow-covered area (SCA) data obtained from satellite imagery to California's snowmelt runoff forecasting. Four areas of investigation were pursued.

1. Data Interpretation

    Develop techniques and train interpreters in reduction of satellite imagery

Map SCA and snow lines from historic satellite and aircraft observations.

Map SCA and snow lines on a real-time basis from satellite observations.

2. Editing and Pre-Analysis

Develop and apply techniques to estimate and check data.

Compare satellite derived snowcover with conventional snowcover observations.

3. Basic Data File

Generate a file of SCA data for use in developing forecast procedures by CDWR.

Develop data in a format to be made available to others.

4. Application of the Data

Develop and test procedures for application of data from interpretation of satellite imagery to CDWR water supply forecast responsibilities. This investigation is directed specifically to the April-July period of snowmelt for refinement of techniques as the season progresses. Use satellite SCA operationally in forecasts of snowmelt runoff.

BACKGROUND

Area of Investigation

The Sierra Nevada and the southern portion of the Cascade Range supply California's fertile San Joaquin and Sacramento Valleys with water for agricultural, municipal, and industrial use. (The two valleys together form the Central Valley.) The average water year runoff of Sierra streams tributary to the San Joaquin Valley and Tulare Lake Basin is approximately 11 million cubic dekametres (9 million acre-feet), while the average year runoff of Sierra and Southern Cascade streams tributary to the Sacramento Valley is approximately 19 million dkm^3 (15 million ac-ft). In the southern Sierra, where elevations range up to about 4 300 metres (14,000 feet), as much as 75 percent of the average annual runoff occurs during the April-July snowmelt season. In the northern Sierra, where elevations are much lower, only about 40 to 50 percent of the average annual runoff occurs during the snowmelt season.

Value of Water and Water Supply Forecasts

The high degree of development and use of water in California's Central Valley has required development of forecast techniques for predicting volume and time-distribution of snowmelt runoff for water management purposes. The large contribution of snowpack to the runoff hydrograph has made water supply forecasting important in this region of the State. Water Management problems in certain areas require continual surveillance of streamflow and updating of forecasts during the runoff season to provide for management decisions as the season progresses.

Forecast technology has advanced to the degree that application of new data types may possibly generate only limited improvement in forecast accuracy, particularly early in the season when forecast accuracy is highly dependent upon the precipitation which occurs after the date of forecast. Development of new data types, such as SCA from satellite imagery, will not eliminate the necessity or advisability of collecting data on precipitation, snowpack, water content, and rates of snowpack accumulation and melt, but they may lead to additional forecast services not previously possible.

CDWR Forecast Responsibilities

The 1929 California State Legislature gave the California Department of Water Resources (then the Division of Water Resources, Department of Public Works) a mandate to forecast the "annual water harvest", using snow data and other pertinent information. The California Cooperative Snow Surveys Program was organized and the first volumetric snowmelt runoff forecast was made in April 1930. Soon after that, basic forecasts were being prepared four times each season (February 1, March 1, April 1, and May 1) and published in CDWR Bulletin 120. Beginning in 1972, weekly updates of water supply forecasts have also been prepared for selected basins, usually from February 1 through mid May (and occasionally through early June). CDWR works closely with other agencies, public utilities, agricultural interests, municipalities, and other water users and water managers to provide a focal point for the snow measurement and water supply forecast program in California. At the present time, water supply forecasts are made for 48 forecast points on snowmelt streams in the State.

Basic Data for Conventional Forecasts

The Central Valley's widespread development and use of water and its nearness to the Sierra Nevada snow fields has given rise to relatively sophisticated water supply forecasting procedures and the development of a high quality data base. For half a century, measurements of snowpack water content have been made monthly to estimate volume of runoff. Over 300 snow courses are measured for snowpack depth and water content, some as often as four times per year. Presently about 60 snow sensor sites and 160 aerial snow markers provide further snow data. This additional information is gathered from the relatively inaccessible portions of the Sierra Nevada, and in some cases, provides the only on-site measurement of water conditions in areas of a basin where the water supply is generated.

Precipitation measurements have been made historically, generally in the lower elevation portions of the watershed. These lower elevation measurements are used to index the amount of precipitation occurring in the higher portions of the watershed, but success at indexing depends on the features peculiar to individual watersheds. Precipitation measurements are generally of good quality and provide valuable information on water conditions within the watershed for an individual season. In addition, historical precipitation measurements provide for analysis of the impact and probability of future weather conditions upon water supply from the forecast watersheds.

Perhaps one of the better developed types of information applicable to water supply forecasting is runoff data. Water has high value in California, a fact that has made it mandatory to accurately measure and calculate the unimpaired contribution of the various watersheds to overall state water supply. Unimpaired runoff, which is calculated by CDWR and other agencies, is the parameter forecast in the water supply forecast, and records are generally of very high quality.

Historic Use of SCA and Snow Line in California

The concept of using either SCA or snow line within a watershed as an index to snowpack volume and timing of snowmelt runoff is not new. It has long intrigued California forecasters in search of a relationship between observations of snowpack and streamflow. The first application of snow line observation from the valley floor to estimate snowmelt runoff is unknown. However, during the late 1920s in California, Chief Hydrographer George Lewis of the Los Angeles Department of Water and Power observed the snow line of the eastern high Sierra from his office in the Owens Valley and, taking his observations as indicators of remaining snowcovered area, applied them to projections of water supply. Lewis obtained data on snow line from surface and aircraft photographs as an index to snowcover which could be used as one input parameter to his forecasting procedures.

Observation of snow line as an index to snowcovered area on the western slopes of the Sierra Nevada began during the 1940s under the California Cooperative Snow Surveys Program. Observers systematically noted snow line along Sierra roads and railways and mailed the data by postcard for near-real-time use in water supply forecasting.

During the heavy snow season of 1962, the U. S. Army Corps of Engineers began observing snowcovered area from low-flying aircraft in the southern Sierra Nevada in connection with reservoir operation during the period of snowmelt. This work was done initially in the Kings River Basin to assist in the operation of Pine Flat Reservoir. Observations extended to the Kern River Basin in 1954 and eventually included the Kaweah and Tule River Basins.

Observations were taken more or less routinely through the period of major snowmelt -- the time period critical to the fill and spill of reservoirs. Snowcovered areas were sketched from the air, using a transparent overlay on an aeronautical chart. The volume and timing of runoff for periods from 75 to 30 days before the end of the melt season were estimated with varying success, using snowcovered area as an additional parameter. The program continued for about 20 years, providing a source of basic data which was applicable to operations studies described later in this report.

The CDWR explored the potential of aerial photography for determination of snowcovered area, but photography at the scales commonly used for mapping provided data which were too cumbersome and generally too expensive for real-time forecasting over large areas. High altitude aerial photography of extremely high resolution, originally developed for military application, was investigated and would have probably proved useful in the Sierra, but costs at that time were too high to justify its application.

Development of observation satellites under the space program provided a new technique: the use of satellite imagery to estimate SCA within watersheds or over very large areas. Tarble (1962, 1963), formerly of the Sacramento River Forecast Center, suggested the possibility of delineating the area of snow-cover in particular Sierra river basins from TIROS IV weather satellite imagery, with repeat pictures which might relate the receding snowcovered area to the rate of snowmelt.

The high value of water in California has resulted in a data base and conventional procedures for volumetric and time-distribution forecasting which are presently developed to a relatively high degree of refinement. These factors, along with the historical period of aircraft observation of SCA in the southern Sierra, made the Sierra an attractive area to test the potential impact of satellite observation of SCA on improvement in operational forecasting.

PLAN OF INVESTIGATION

The basic plan for the ASVT investigation was developed during July 1974. It was recognized that time, data, and funding limitations would make it necessary to limit the scope of the investigation to achieve certain specific objectives. As a result, the proposed plan and scope restricted the investigation to:

- Area of investigation
- Forecast objective to be achieved
- Approach to and method of reducing basic SCA data

Area of Investigation

The Sierra Nevada, a range of mountains having widely varying climatic and hydrologic conditions, extends for about 640 kilometres (400 miles), generally northwest-southeast, near the eastern boundary of the State. Its peaks reach elevations of 4 300 metres (14,000 feet). The area was selected for this study on the basis of the following objectives.

Objective: to select areas having differing geographic and hydrologic conditions to test capability of reducing and using SCA.

The initial study area selected by CDWR was composed of a northern and southern project area (Figure 1). The northern project area included 24 watersheds and sub-watersheds in or adjacent to the Sacramento River above Shasta Dam and the Feather River above Oroville Dam. The southern project area included 14 watersheds and sub-watersheds in or adjacent to the San Joaquin, Kings, Kaweah, Tule, and Kern River Basins. The southern project area represented a relatively high elevation "high Sierra" region, and the northern project area was characterized by lower elevations and more transient areas of snowcover.

Objective: to obtain a data base of SCA that would effectively test the value of SCA in hydrologic analysis.

Aircraft observations had shown that the southern Sierra Nevada could provide such a data base. This fact was instrumental in the selection of the southern project area for detailed analysis of application of SCA to water supply forecasting.

Forecast Objective

Most April-July water supply forecast procedures currently in use by CDWR have been developed to the point that procedural error, or error in the snowpack-precipitation-runoff relationships (exclusive of error related to weather subsequent to date of forecast), should give calculated April-July runoff values with standard errors in the order of 10 percent of observed runoff values. This degree of accuracy may be entirely satisfactory on April 1, March 1, or even earlier in the season when precipitation following the forecast date represents the major portion of forecast error and time remains to adjust water management plans.

However, as the snowmelt season progresses from mid May through early July, procedural error in conventional procedures remains the same in terms of acre-feet and may become critical in the operation of a water project. In the southern Sierra, the critical period is generally from mid May through mid-June when snowmelt runoff rates are highest and reservoirs are nearing capacity. In the northern Sierra, this critical period normally occurs earlier in the season. Procedures for increasing the reliability of forecasts

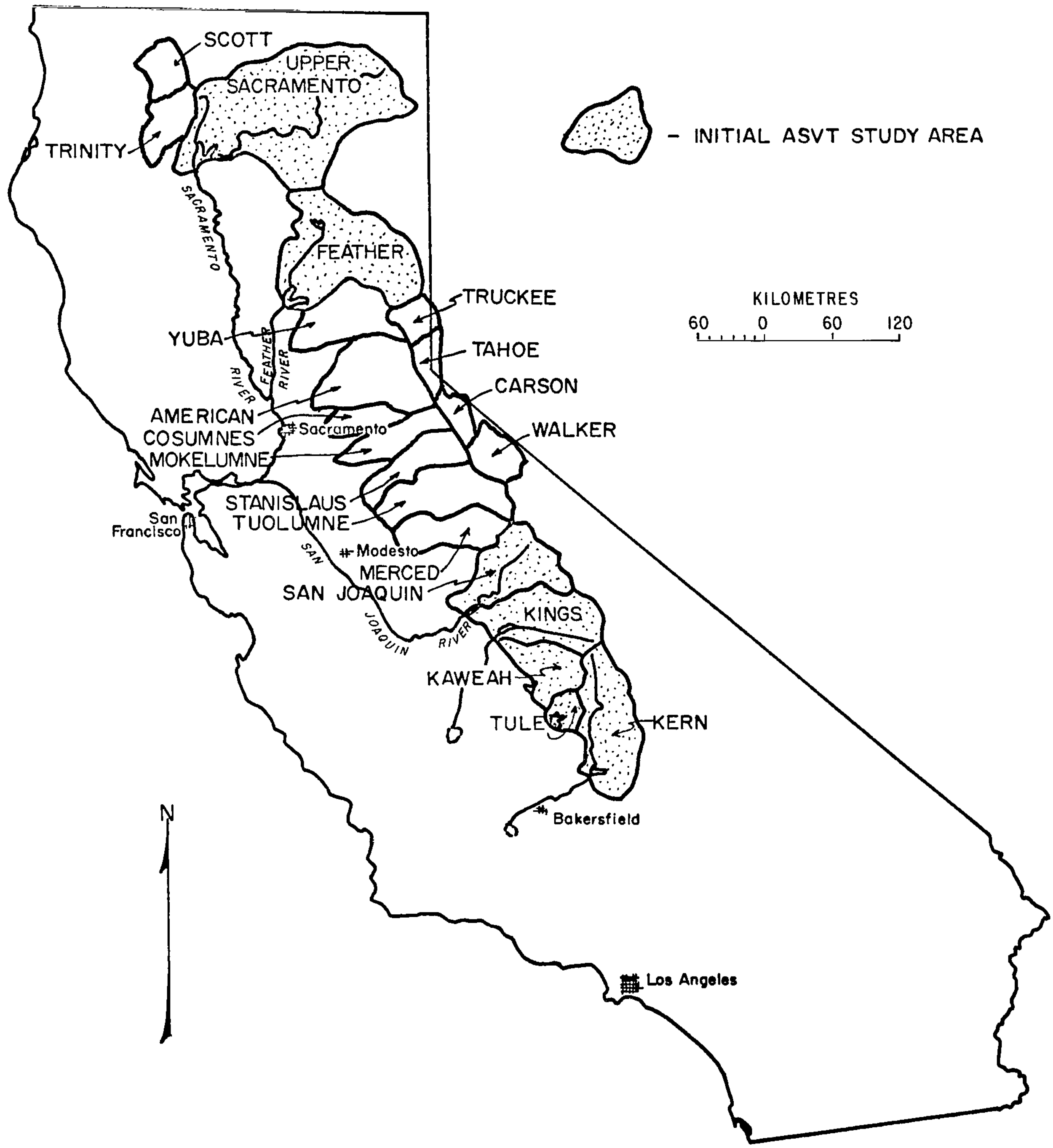


Figure 1. Major snowmelt watersheds in California.

as the snowmelt season progresses are of great value to water managers who must make important decisions regarding reservoir filling, reduction of spills, power production, flood releases, and the requirements of water users.

Preliminary analysis suggested that the greatest potential for use of SCA in water supply forecasting would be in updating operational forecasts during the period of snowmelt runoff rather than in the early season forecasts. Analysis during the investigation has verified that SCA data during the period of snowpack accumulation shows a very transient snow line with little apparent impact on the observed snowmelt runoff and no definable effect on forecast procedures, thus justifying the concentration of effort in the period of snowmelt. Efforts in both data reduction and application, therefore, were concentrated in the period of snowmelt, generally April 1 through July 31.

Reduction of SCA Data

A substantial part of the research budget for this investigation was necessarily committed to interpretation of satellite imagery for SCA. Although several sophisticated techniques are available for automated and semi-automated data reduction, it was felt that these techniques would be too costly to be justified by this investigation. Because the more important objective was to investigate application of SCA, data interpretation was held to minimum cost by conventional manual interpretation techniques. In addition, the manual techniques provided for a certain amount of subjective input and personnel training regarding conditions of snowcover.

DATA ACQUISITION AND INTERPRETATION - SATELLITE SCA

General Plan

The general plan for acquisition and interpretation of SCA entailed acquisition of both historic and operational satellite imagery from various sources, acquisition of aircraft observations, and reduction of SCA by manual techniques.

Because of its high resolution, Landsat imagery was to be used for the main reference to SCA, with supplemental data from the National Oceanic and Atmospheric Administration (NOAA) or other sources to be used when necessary to provide timely information. The use of manual reduction techniques kept costs during the investigation within acceptable limits, permitted the interpreter to gain experience in the meaning of the observed conditions on the image, and permitted development of operator skills to accurately estimate results under adverse conditions or with missing imagery.

Sources of Satellite Imagery

During the course of the investigation, imagery from Landsat 1, 2, and 3 were used as a primary source of basic data for analysis and the standard of comparison for data from other sources. Landsat, with its 18-day repetition cycle, repeated the data at a given location every 18 days, but usually every 9 days, when two of the satellites were functioning simultaneously. However, if cloud cover obscured an image or if some failure occurred, images could be spaced at 18 days, 27 days, or possibly more.

During the initial phase of the project, Landsat imagery from NASA arrived in California usually more than two weeks after the pass.

Canadian Landsat Quick-Look imagery from Integrated Satellite Information Services, Ltd. (ISIS), a readout station and service, was acquired on a more timely basis to simulate operational forecasting requirements, and came closer to meeting the target time of 72 hours from time of Landsat passage to receipt of data in Sacramento.

Imagery from other satellites, principally the earth-orbiting TIROS[1/], and also the stationary GOES[2/] satellite, both sponsored by NOAA, were used for supplemental information between Landsat passes. Additionally, results from NOAA and Landsat imagery were compared to determine the effect of resolution on interpretation. Daily imagery from NOAA-NESS[3/] in Redwood City, California, proved very useful during periods of operational forecasting. In spite of the poorer resolution, the timeliness of NOAA imagery made this source attractive for operational forecasting.

Interpretation of Historic Data

During the initial phase of data reduction, techniques for data interpretation were mastered, and historical (as opposed to operational) image sets were reduced to obtain SCA.

Techniques described by Barnes and Bowley (Handbook of Techniques for Satellite Snowcover Mapping, December 1974) were adapted to interpretive problems encountered in the Sierra project areas. During the early phases of the project, historic imagery obtained from NASA was interpreted on 24 watersheds and sub-watersheds in the northern project area and 14 watersheds and sub-watersheds in the southern Sierra project area.

1/ TIROS - Television Infared Observational Satellite

2/ GOES - Geostationary Operational Environmental Satellite

3/ NESS - National Environmental Satellite Services

By 1978, pre-analysis and editing of interpreted data indicated that sufficient information had been obtained from most of the sub-watersheds for the purposes of the investigation. As a consequence, the program for acquisition, reduction, and interpretation of satellite imagery was revised to meet the future operational needs of CDWR. As of the date of this report, the historic data from 22 major basins and 31 sub-basins in the Sierra Nevada, the Cascade Range, and the Coast Range are being interpreted to provide a data base for development of forecasting procedures in the major snowmelt runoff areas of California.

Interpretive Problems

Timeliness of receipt of imagery for operational forecasting posed one of the major problems in this project. During the initial work on historic data, many problems in interpretation and interpretive techniques became apparent. The work of Barnes and Bowley was useful in development of interpreter skills, but "hands on" interpretation was important to training personnel in the techniques of interpretation.

Many interpretive problems were also encountered in reducing historic data during the initial phase of the project.

Cloud Cover

Cloud cover is much more predominate in the northern project area than in the southern project area. NOAA imagery was used in an attempt to fill in missing Landsat imagery. In May 1977, cloud cover was present in the southern Sierra almost the entire month, with a very transient snow line between intermittent storm activity. Cross-basin plots were used to estimate snowcover when clouds covered part or all of a basin.

Reflective Rock

Much of the Sierra, the southern Sierra in particular, is composed of granodiorite, a light-colored granitic rock. At higher elevations, the rock has been subjected to glaciation, and soils are poorly developed or non-existent. Little or no vegetation visible to satellites exists in portions of the area. Bare rock ridges are highly reflective and cannot be easily distinguished from snowpack when they are viewed from satellite images in the bands being used for interpretation. Areas of reflective rock were determined from summer imagery and delineated on the base maps. When the snowcover and reflective rock posed a potential problem during snowmelt, particular care was taken in interpretation. Band 7 imagery appeared to be useful during analysis of these areas.

Shadows

Shadows posed an interpretive problem in the deep canyons of the southern Sierra. The problems were also great in the northern Sierra because longer shadows were cast at higher latitudes. Some of the dark lava flows prevalent in the area also hindered interpretation. Interpreter experience usually solved problems related to shadow effects.

Timber Cover

Timber and brush cover posed one of the most difficult interpretive problems encountered. Tree tops covered with freshly fallen snow were readily visible. However, in much of the Sierra, particularly the northern portion, heavy timber cover forms a canopy which effectively precludes observation of snow-cover on the ground. Experience in observing snow in large forest openings was useful in developing consistent results in areas of heavy timber.

Interpretive Techniques

Historic data were initially reduced from Landsat images by both direct overlay and Zoom Transfer Scope (ZTS). Comparison of results indicated that reduction of Landsat images at a scale of 1:500,000 with the ZTS gave more consistent results, but took considerably more time than a 1:1,000,000 direct overlay. NOAA images, used to fill the periods between Landsat images, were also reduced by ZTS. NOAA-NESS furnished enlarged prints at a scale of about 1:3,350,000 which, although not as sharp as the Landsat imagery, provided adequate results in most cases.

In the reduction of Landsat imagery, the following items have been noted:

- Transparencies of the Landsat imagery appear to be more consistent and more easily interpreted on the ZTS than are the prints. Photographic processes used in printing may have been responsible for some loss in clarity for interpretation.

- Direct overlay from 1:1,000,000 prints takes about one-third the time of 1:500,000 ZTS analysis using transparencies, but the consistency of results observed using the transparencies has reduced the time required for editing and pre-analysis.

- Landsat imagery on transparencies received well after the time of observation (standard products) was decidedly better and more easily interpreted than the near-real-time data from Canadian Quick-Look or imagery from other sources, such as NOAA.

For the purposes of this investigation, an image set is an image or group of images representing a nominal time of observation. NOAA images which cover much of the western United States in a single image have only one image per image set. A single NOAA image set includes all of California, but data were interpreted from two enlarged prints, each covering a portion of the Sierra. Landsat image sets may include up to 13 images taken over a period of six days to cover the snowmelt streams of the State. The image set for a given basin or area represented all images required to describe that area on a given nominal date of observation. Interpreted data representing a basin-day included the snowcovered area and effective snow line of a given basin or sub-basin for a given image set. The overlay of images on succeeding passes provided an opportunity to obtain observational data when storm activity and clouds may have obscured a single pass.

Table 1 is a summary of image sets interpreted and reduced for the California ASVT since the beginning of the project. Some data sets have been reinterpreted as techniques were improved. A significant portion of the imagery received but not interpreted was either obscured by cloud cover, had no remaining snow, or was recorded outside the time period of investigation.

Using the techniques described above, we interpreted about 12,000 basin observations from 1973 through 1979. Many of these were duplicates because of the sources from which the imagery was obtained (NASA Landsat Quick-Look or standard product, Canadian Landsat Quick-Look, or NOAA), or method of interpretation (overlay or ZTS). Interpretation during this contract cost an average of approximately $3.00 per basin observation.

Interpretation of Operational Data

Canadian Landsat Quick-Look imagery was obtained directly from ISIS during the snowpack accumulation and melt periods, beginning with 1976, for use in operational forecasting. Quick-Look Landsat imagery was also obtained from NASA, starting at the same time.

Beginning with the 1977-78 water year (October 1-September 30), 22 major basins and 31 sub-basins throughout the State were interpreted for SCA periodically during the period of accumulation and more continuously during the period of melt and depletion. Landsat imagery for major watersheds not covered in the initial study area was supplied by NASA for the historic file. A number of major basins (Figure 1) contain sub-units with differing characteristics. Table 2 lists major basins and sub-basins which are currently being mapped and will continue to be mapped for the data base. Operational data for the Feather, San Joaquin, Kings, Kaweah, Tule, and Kern River Basins for the 1973-1979 snow seasons appear in Tables 3 through 8.

Receiving timely data is imperative in making operational forecasts. One of the major operational problems during the 1978 and 1979 snowmelt seasons was securing timely imagery when runoff forecasts were required. Canadian Quick-Look imagery was mailed promptly after observation but was often slow to

Table 1

Summary of Interpreted and Reduced Satellite Imagery
California ASVT Through July 31, 1979

Image Sets for Analysis

Type of Imagery	1973		1974		1975		1976	
	Rec.1/	I&R2/	Rec.	I&R	Rec.	I&R	Rec.	I&R
NOAA & GOES	15	15	28	28	29	29	69	20
Landsat 10^6								
North	8	7	8	8	15	13	15	6
South	14	9	13	9	27	19	29	14
Landsat $0.5x10^6$								
North	8	7	8	8	15	10	15	15
South	14	11	13	6	27	18	29	18
Quick-Look 10^6								
North							12	5
South							12	9
Quick-Look $0.5x10^6$								
North							12	6
South							12	7

Image Sets for Analysis

Type of Imagery	1977		1978		1979		Total	
	Rec.	I&R	Rec.	I&R	Rec.	I&R	Rec.	I&R
NOAA & GOES	61	11	59	12	134	4	395	119
Landsat 10^6								
North	16	4	17	0	64	0	143	38
South	16	3	14	0	61	0	174	54
Landsat $0.5x10^6$								
North	16	10	17	7	64	14	143	71
South	16	16	14	11	61	17	174	97
Quick-Look 10^6								
North			15	0	26	0	53	5
South			13	0	34	0	59	9
Quick-Look $0.5x10^6$								
North	17	4	15	10	26	20	70	40
South	14	9	13	12	34	9	73	37

1/ Received and logged in Sierra Hydrotech.
2/ Interpretation and reduction.
Note: Many images, especially GOES and NOAA, were too cloudy or had insufficient snow for reduction.

Table 2

California ASVT Investigation, Major Basins and Sub-Basins Included in Data Base

Basin Name	Basin No[1/]	Basin Area Mi^2	Average April 1 Snow Line Ft	Area Above Avg. Apr. 1 Snow Line Mi^2	Average Runoff[2/] April-July 1000 AF	Average Runoff[2/] Water Year 1000 AF
COAST RANGE						
Scott River near Fort Jones	121	653	4500	260	200	
Trinity River inflow to Clair Engle	131	692	4200	405	616	
CASCADE RANGE						
Sacramento River inflow to Shasta Reservoir[3/]	500	6421	4650	3085	1777	5482
Area A	512	1892	3750	860		
Sacramento River near Mt. Shasta	501	135	4200	98		
McCloud River near McCloud	511	463	3350	444		
Area B	513	1008	4175	610		
Area C	514	214	4550	135		
Area D	516	386	5350	10		
Area E	504	1017	5600	435		
North Fork Pit River at Alturas	502	212	5600	96		
South Fork Pit River near Likely	503	247	5600	174		
Area F	509	1904	5050	1035		
Ash Creek at Adin	506	258	5150	181		
Hat Creek near Hat Creek	507	162	4725	151		
Burney Creek at Park Avenue near Burney	508	89	4050	70		
NORTHERN SIERRA						
Feather River inflow to Oroville	520	3607	4700	2315	1862	4287
West Branch near Paradise	527	110	4100	65		
Indian Creen near Crescent Mills	524	739	5000	538		
East Branch of North Fork	526	1025	4800	725		
Inflow to Almanor	523	491	4500	490		
Middle Fork near Clio	521	686	5250	375		
South Fork at Ponderosa Dam	522	108	4350	60		
Yuba below Englebright	530	1108	4600	590	1081	2274
Middle Yuba below Jackson Meadows Dam	531	38	5717	38		
North Yuba below Goodyear Dam	532	250	4600	194		
American at Folsom	536	1861	4750	855	1231	2573

1/ Used for retrieval reference.

2/ 50-year averages, as published in CDWR Bulletin 120.

3/ Explanation of area designations appears in "Notes to Table 2" following the table.

Table 2 (continued)

California ASVT Investigation, Major Basins and Sub-Basins Included in Data Base

Basin Name	Basin No[1/]	Basin Area Mi^2	Average April 1 Snow Line Ft	Area Above Avg. Apr. 1 Snow Line Mi^2	Average Runoff[2/] April-July 1000 AF	Average Runoff[2/] Water Year 1000 AF
CENTRAL SIERRA						
Cosumnes at Michigan Bar	539	536	4850	95	132	351
Mokelumne inflow to Pardee	541	578	4900	325	466	705
Stanislaus at Melones	546	904	5100	540	717	1085
Tuolumne at Don Pedro	550	1533	5200	860	1236	1854
South Fork Tuolumne River near Oakland Rec. Camp	551	87	5425	44		
Merced at Exchequer	555	1037	5450	500	608	920
Merced River at Happy Isles Bridge	536	181	5800	180		
SOUTHERN SIERRA						
San Joaquin at Millerton	564	1638	5500	1200	1193	1659
Willow Creen near Auberry	569	130	5100	70		
At Miller Crossing	566	249	4800	245		
South Fork near Florence Lake	567	171	7200	170		
Huntington Lake near Big Creek	568	81	6900	80		
Kings River inflow to Pine Flat	571	1545	5550	1160	1157	1549
North Fork near Cliff Camp	572	181	6150	180	230	265
Above North Fork near Trimmer	573	952	5800	795		
Kaweah at Terminus	575	561	6100	245	270	403
Middle Fork near Potwisha Camp	576	102	6350	67		
South Fork at Three Rivers	577	87	5900	33		
Tule River inflow to Success	580	391	6100	85	59	133
Kern River at Isabella	591	2074	6200	1335	420	627
Kern near Kernville	592	846	5300	800	353	521
South Fork near Onyx	593	530	7000	380		
SIERRA EAST SIDE						
Truckee near Farad	631	429	5300	420	264	
Lake Tahoe at Tahoe City	635	503	6300	280		
West Fork Carson at Woodfords	642	66	6300	65	51	
East Fork Carson near Gardnerville	641	341	6300	285	181	
West Walker near Coleville	545	245	6550	230	143	
East Walker near Bridgeport	651	359	7100	280	60	

Table 2 (continued)

California ASVT Investigation, Major Basins and Sub-Basins Included in Data Base

Basin Name	Basin No[1/]	Basin Area Mi^2	Average April 1 Snow Line Ft	Area Above Avg. Apr. 1 Snow Line Mi^2	Average Runoff[2/]	
					April-July 1000 AF	Water Year 1000 AF
ADDITIONAL BASINS ANALYZED IN PHASE I						
Shasta River near Yreka	115	763	4975	169		
Cow Creek near Millville	517	425	4100	73		
Battle Creek below Coleman Fish Hatchery near Cottonwood	518	357	4500	156		
Mill Creek near Los Molinas	519	131	4350	56		
Deer Creek near Vina	529	208	4300	108		
Chowchilla River below Buchanan Dam	562	236	5200	5		
Fresno River near Daulton	563	258	5100	12		
Deer Creek near Fountain Springs	586	83	5750	13		
Pine Creek near Susanville	623	226	5120	226		
Susan River at Susanville	621	184	4900	168		
Mono Lake near Mono Lake	660	685	7350	640		
Owens River near Big Pine	671	2195	7500	882		

Table 2

California ASVT Investigation, Major Basins and Sub-Basins Included in Data Base

Basin Name	Basin No[1/]	Basin Area Km^2	Average April 1 Snow Line M	Area Above Avg. Apr. 1 Snow Line Km^2	Average Runoff[2/] April-July 1 000 Dam^3	Average Runoff[2/] Water Year 1 000 Dam^3
COAST RANGE						
Scott River near Fort Jones	121	1 691	1 372	673	247	
Trinity River inflow to Clair Engle	131	1 792	1 280	1 049	760	
CASCADE RANGE						
Sacramento River inflow to Shasta Reservoir[3/]	500	16 630	1 417	7 990	2 192	6 762
Area A	512	4 900	1 143	2 227		
Sacramento River near Mt. Shasta	501	350	1 280	254		
McCloud River near McCloud	511	1 199	1 021	1 150		
Area B	513	2 611	1 273	1 580		
Area C	514	554	1 387	350		
Area D	516	1 000	1 631	26		
Area E	504	2 634	1 707	1 127		
North Fork Pit River at Alturas	502	549	1 707	249		
South Fork Pit River near Likely	503	640	1 707	451		
Area F	509	4 931	1 539	2 681		
Ash Creek at Adin	506	668	1 570	469		
Hat Creek near Hat Creek	507	420	1 440	391		
Burney Creek at Park Avenue near Burney	508	231	1 234	181		
NORTHERN SIERRA						
Feather River inflow to Oroville	520	9 342	1 433	5 996	2 297	5 288
West Branch near Paradise	527	285	1 250	168		
Indian Creek near Crescent Mills	524	1 914	1 524	1 393		
East Branch of North Fork	526	2 655	1 463	1 878		
Inflow to Almanor	523	1 272	1 372	1 269		
Middle Fork near Clio	521	1 777	1 600	971		
South Fork at Ponderosa Dam	522	280	1 326	155		
Yuba below Englebright	530	2 870	1 402	1 528	1 333	2 805
Middle Yuba below Jackson Meadows Dam	531	98	1 743	98		
North Yuba below Goodyear Dam	532	648	1 402	502		
American at Folsom	536	4 820	1 448	2 214	1 629	3 174

1/ Used for retrieval reference.

2/ 50-year averages, as published in CDWR Bulletin 120.

3/ Explanation of area designations appears in "Notes to Table 2" following the table.

Table 2 (continued)

California ASVT Investigation, Major Basins and Sub-Basins Included in Data Base

Basin Name	Basin No[1/]	Basin Area Km^2	Average April 1 Snow Line M	Area Above Avg. Apr. 1 Snow Line Km^2	Average Runoff[2/] April-July 1 000 Dam^3	Average Runoff[2/] Water Year 1 000 Dam^3
CENTRAL SIERRA						
Cosumnes at Michigan Bar	539	1 388	1 478	246	163	433
Mokelumne inflow to Pardee	541	1 497	1 493	842	575	870
Stanislaus at Melones	546	2 341	1 554	1 399	884	1 338
Tuolumne at Don Pedro	550	3 970	1 585	2 227	1 525	2 287
South Fork Tuolumne River near Oakland Rec. Camp	551	225	1 654	114		
Merced at Exchequer	555	2 686	1 661	1 295	750	1 135
Merced River at Happy Isles Bridge	536	469	1 768	466		
SOUTHERN SIERRA						
San Joaquin at Millerton	564	4 242	1 676	3 108	1 472	2 046
Willow Creek near Auberry	569	337	1 554	181		
At Miller Crossing	566	645	1 463	635		
South Fork near Florence Lake	567	443	2 195	440		
Huntington Lake near Big Creek	568	210	2 103	207		
Kings River inflow to Pine Flat	571	4 002	1 692	3 004	1 427	1 911
North Fork near Cliff Camp	572	469	1 875	466	284	327
Above North Fork near Trimmer	573	2 466	1 768	2 059		
Kaweah at Terminus	575	1 453	1 859	635	333	497
Middle Fork near Potwisha Camp	576	264	1 935	174		
South Fork at Three Rivers	577	225	1 798	85		
Tule River inflow to Success	580	1 013	1 859	220	73	164
Kern River at Isabella	591	5 372	1 890	3 458	518	773
Kern near Kernville	592	2 191	1 615	2 072	435	643
South Fork near Onyx	593	1 373	2 134	984		
SIERRA EAST SIDE						
Truckee near Farad	631	1 111	1 615	1 088	326	
Lake Tahoe at Tahoe City	635	1 303	1 920	725		
West Fork Carson at Woodfords	642	171	1 920	168	63	
East Fork Carson near Gardnerville	641	883	1 920	738	223	
West Walker near Coleville	545	635	1 996	596	176	
East Walker near Bridgeport	651	930	2 164	725	74	

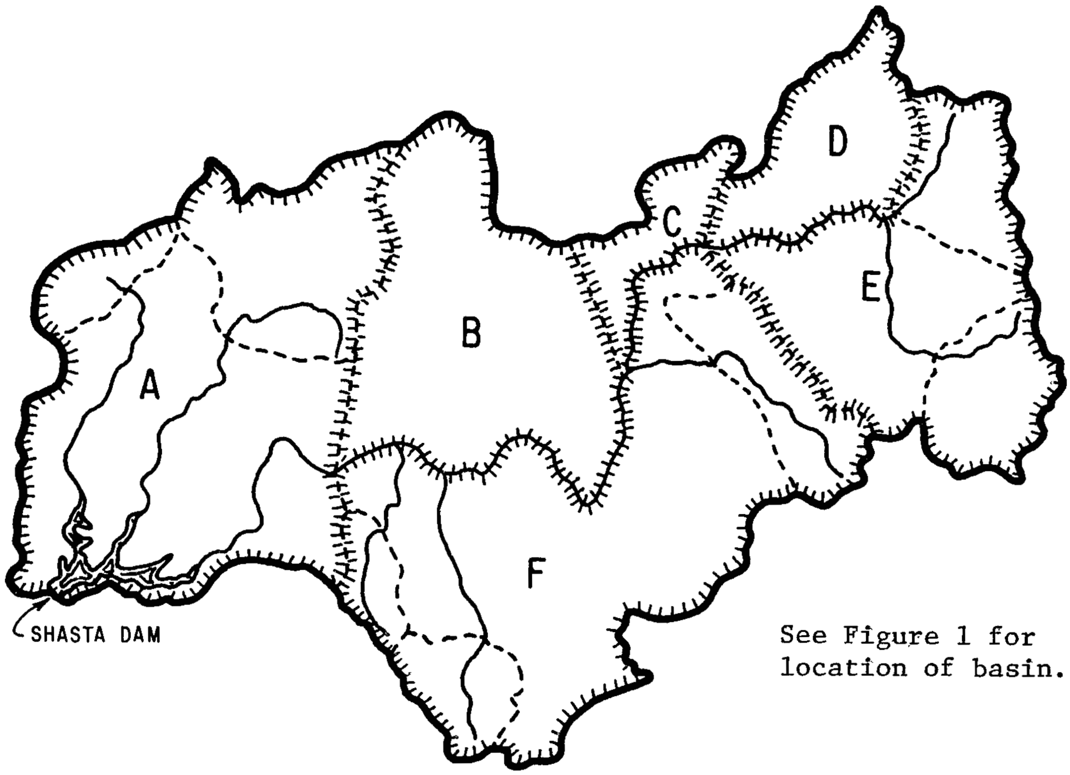
Table 2 (continued)

California ASVT Investigation, Major Basins
and Sub-Basins Included in Data Base

Basin Name	Basin No[1/]	Basin Area Km^2	Average April 1 Snow Line M	Area Above Avg. Apr. 1 Snow Line Km^3	Average Runoff[2/]	
					April-July 1 000 Dam^3	Water Year 1 000 Dam^3
ADDITIONAL BASINS ANALYZED IN PHASE I						
Shasta River near Yreka	115	1 976	1 516	438		
Cow Creek near Millville	517	1 101	1 250	189		
Battle Creek below Coleman Fish Hatchery near Cottonwood	518	925	1 372	404		
Mill Creek near Los Molinas	519	339	1 326.	145		
Deer Creek near Vina	529	539	1 311	280		
Chowchilla River below Buchanan Dam	562	611	1 585	13		
Fresno River near Daulton	563	668	1 554	31		
Deer Creek near Fountain Springs	586	215	1 753	34		
Pine Creek near Susanville	623	585	1 561	585		
Susan River at Susanville	621	477	1 494	435		
Mono Lake near Mono Lake	660	1 774	2 240	1 658		
Owens River near Big Pine	671	5 685	2 286	2 284		

Notes to Table 2

Area Designations Used for SCA Subunits,
Sacramento River, Inflow to Shasta, Upper Sacramento Basin



See Figure 1 for location of basin.

The Sacramento Basin was divided into a number of subunits for SCA analysis because of its large size and diverse topography and snow conditions. The following list and sketch describe the subunits used in analysis.

Area	
A	Western mountains and canyon area with relatively heavy precipitation but low elevation except along ridges. Includes Sacramento River and McCloud River above Shasta Reservoir.
B,C, and D	Northern side of Pit River from McCloud River to Goose Lake. Relatively dry area, with sagebrush and scattered timber. Snow line rises substantially from west to east across these units, and snow is usually gone early in the season.
E	Eastern portion of Pit River Basin including the relatively high elevation, intermediate precipitation Warner Range as well as some lower elevation sagebrush area.
F	Southern side of Pit River heading along the divide east of Mt. Lassen. Most of the area is above 4,000 feet, but relatively dry with the exception of the higher elevation, higher precipitation region along the southern drainage divide.

Table 3

Snowpack Observations, Feather River Basin
9 340 Square Kilometres (3610 Square Miles)

Nominal Date of Observation		SCA		Elevation Effective Snowline		Snowpack Water Content
		Sq. Kilometres	Sq. Miles	Metres	Feet	Percent Average[1/]
1973	Feb. 1	8 300	3210	990	3250	121
	Mar. 1	8 160	3150	1 060	3475	145
	Apr. 1	6 730	2600	1 340	4400	153
	May 1	3 370	1300	1 710	5600	
1974	Feb. 1	5 310	2050	1 520	5000	103
	Mar. 1	8 330	3220	980	3225	104
	Apr. 1	5 570	2150	1 800	4900	149
	May 1	3 240	1250	1 720	5650	
1975	Feb. 1	6 450	2490	1 380	4525	62
	Mar. 1	8 080	3120	1 080	3550	126
	Apr. 1	6 730	2600	1 340	4400	164
	May 1	5 910	2280	1 460	4800	
1976	Feb. 1	3 930	1520	1 660	5425	42
	Mar. 1	8 480	3275	910	3000	47
	Apr. 1	2 380	920	1 810	5925	31
	May 1	997	385	2 000	6525	
1977	Feb. 1	4 220	1630	1 620	5325	48
	Mar. 1	7 620	2940	1 220	4000	31
	Apr. 1	3 000	1160	1 740	5700	27
	May 1	332	128	2 150	7050	
1978	Feb. 1	6 860	2650	1 330	4350	135
	Mar. 1	5 880	2270	1 460	4800	147
	Apr. 1	4 980	1925	1 560	5100	144
	May 1	2 720	1050	1 770	5800	
1979	Feb. 1	6 520	2520	1 370	4500	74
	Mar. 1	7 710	2980	1 190	3900	107
	Apr. 1	5 270	2040	1 520	5000	103
	May 1	1 940	750	1 850	6075	

1/ Expressed as a percent of the April 1 average water content.

Table 4

Snowpack Observations, San Joaquin River Basin
4 240 Square Kilometres (1640 Square Miles)

Nominal Date of Observation		SCA		Elevation Effective Snow Line		Snowpack Water Content Percent Average[1/]
		Sq. Kilo-metres	Sq. Miles	Metres	Feet	
1973	Feb. 1	3 340	1290	1 460	4800	107
	Mar. 1	3 150	1220	1 660	5450	134
	Apr. 1	3 180	1230	1 630	5350	140
	May 1	2 710	1050	1 940	6375	
1974	Feb. 1	2 620	1010	1 980	6500	115
	Mar. 1	3 340	1290	1 460	4800	90
	Apr. 1	2 980	1150	1 780	5850	120
	May 1	2 370	915	2 110	6925	
1975	Feb. 1	3 410	1320	1 350	4425	71
	Mar. 1	3 040	1180	1 740	5700	87
	Apr. 1	2 850	1100	1 870	6125	113
	May 1	2 890	1120	1 840	6050	
1976	Feb. 1	1 110	430	2 840	9325	44
	Mar. 1	3 480	1340	1 240	4075	36
	Apr. 1	2 000	772	2 300	7550	31
	May 1	1 460	565	2 620	8575	
1977	Feb. 1	2 220	859	2 190	7175	47
	Mar. 1	2 450	945	2 070	6800	29
	Apr. 1	2 310	890	2 140	7025	23
	May 1	930	358	2 960	9700	
1978	Feb. 1	3 180	1230	1 620	5325	149
	Mar. 1	3 030	1170	1 750	5750	169
	Apr. 1	3 060	1180	1 730	5675	191
	May 1	2 900	1120	1 840	6025	
1979	Feb. 1	3 370	1300	1 420	4650	94
	Mar. 1	3 220	1240	1 600	5250	101
	Apr. 1	3 320	1280	1 500	4900	111
	May 1	2 430	940	2 070	6800	

1/ Expressed as a percent of the April 1 average water content.

Table 5

Snowpack Observations, Kings River Basin
4 000 Square Kilometres (1545 Square Miles)

Nominal Date of Observation		SCA Sq. Kilo-metres	SCA Sq. Miles	Elevation Effective Snow Line Metres	Elevation Effective Snow Line Feet	Snowpack Water Content Percent Average 1/
1973	Feb. 1	3 330	1285	1 230	4025	131
	Mar. 1	3 070	1185	1 600	5250	159
	Apr. 1	3 110	1200	1 550	5075	177
	May 1	2 770	1070	1930	6325	
1974	Feb. 1	2 760	1065	1 940	6350	115
	Mar. 1	3 170	1225	1 460	4800	90
	Apr. 1	2 850	1100	1 850	6075	120
	May 1	2 530	978	2 130	7000	
1975	Feb. 1	3 340	1290	1 220	4000	74
	Mar. 1	2 980	1150	1 730	5675	93
	Apr. 1	2 950	1140	1 760	5775	127
	May 1	3 060	1080	1 920	6300	
1976	Feb. 1	1 470	568	2 790	9150	44
	Mar. 1	3 340	1290	1 200	3950	36
	Apr. 1	2 230	860	2 360	7750	31
	May 1	1 440	555	2 800	9200	
1977	Feb. 1	2 400	928	2 230	7300	50
	Mar. 1	2 620	1010	2 070	6800	30
	Apr. 1	2 310	892	2 290	7525	24
	May 1	1 160	447	2 960	9725	
1978	Feb. 1	3 040	1175	1 650	5400	149
	Mar. 1	2 890	1115	1 820	5975	169
	Apr. 1	2 930	1130	1 770	5800	191
	May 1	2 750	1060	1 950	6400	
1979	Feb. 1	3 170	1225	1 460	4800	94
	Mar. 1	3 080	1190	1 590	5225	101
	Apr. 1	3 080	1190	1 590	5225	111
	May 1	2 490	960	2 160	7100	

1/ Expressed as a percent of the April 1 average water content.

Table 6

Snowpack Observations, Kaweah River Basin
1 450 Square Kilometres (560 Square Miles)

Nominal Date of Observation		SCA		Elevation Effective Snow Line		Snowpack Water Content
		Sq. Kilo-metres	Sq. Miles	Metres	Feet	Percent Average[1/]
1973	Feb. 1	1 140	440	880	2900	133
	Mar. 1	650	250	1 850	6075	152
	Apr. 1	813	314	1 530	5025	172
	May 1	642	248	1 860	6100	
1974	Feb. 1	515	199	2 100	6875	117
	Mar. 1	816	315	1 520	5000	92
	Apr. 1	816	315	1 520	5000	117
	May 1	448	173	2 230	7300	
1975	Feb. 1	881	340	1 410	4625	68
	Mar. 1	565	218	2 010	6600	81
	Apr. 1	712	275	1 710	5626	110
	May 1	658	254	1 830	6000	
1976	Feb. 1	246	95	2 650	8700	41
	Mar. 1	894	345	1 370	4500	32
	Apr. 1	466	180	2 190	7175	27
	May 1	205	79	2 740	9000	
1977	Feb. 1	414	160	2 230	7325	47
	Mar. 1	632	244	1 870	6150	25
	Apr. 1	658	254	1 830	6000	23
	May 1	596	230	1 950	6400	
1978	Feb. 1	632	244	1 870	6150	137
	Mar. 1	567	219	2 000	6550	161
	Apr. 1	746	288	1 680	5500	191
	May 1	658	254	1 830	6000	
1979	Feb. 1	1 310	504	580	1900	86
	Mar. 1	1 290	497	610	2000	90
	Apr. 1	679	262	1 800	5900	112
	May 1	510	197	2 100	6900	

1/ Expressed as a percent of the April 1 average water content.

Table 7

Snowpack Observations, Tule River Basin
1 010 Square Kilometres (390 Square Miles)

Nominal Date of Observation		SCA Sq. Kilometres	SCA Sq. Miles	Elevation Effective Snow Line Metres	Elevation Effective Snow Line Feet	Snowpack Water Content Percent Average[1/]
1973	Feb. 1	591	228	1 010	3300	175
	Mar. 1	249	96	1 830	6000	176
	Apr. 1	407	157	1 510	4950	237
	May 1	179	69	1 980	6500	
1974	Feb. 1	145	56	2 070	6775	109
	Mar. 1	306	118	1 710	5600	69
	Apr. 1	396	153	1 520	5000	91
	May 1	96	37	2 230	7300	
1975	Feb. 1	490	189	1 310	4300	37
	Mar. 1	207	80	1 920	6300	67
	Apr. 1	246	95	1 820	5975	123
	May 1	256	99	1 810	5950	
1976	Feb. 1	13	5	2 850	9350	15
	Mar. 1	469	181	1 370	4500	16
	Apr. 1	75	29	2 320	7600	21
	May 1	18	7	2 760	9050	
1977	Feb. 1	60	23	2 400	7875	37
	Mar. 1	168	65	2 000	6550	3
	Apr. 1	218	84	1 890	6200	8
	May 1	153	59	2 040	6700	
1978	Feb. 1	212	82	1 910	6250	121
	Mar. 1	396	153	1 520	5000	132
	Apr. 1	127	49	2 120	6950	172
	May 1	174	67	2 000	6550	
1979	Feb. 1	772	298	610	2000	79
	Mar. 1	772	298	610	2000	102
	Apr. 1	269	104	1 800	5900	133
	May 1	130	50	2 100	6900	

1/ Expressed as a percent of the April 1 average water content.

Table 8

Snowpack Observations, Kern River Basin
5 390 Square Kilometres (2080 Square Miles)

Nominal Date of Observation		SCA		Elevation Effective Snow Line		Snowpack Water Content
		Sq. Kilo-metres	Sq. Miles	Metres	Feet	Percent Average[1/]
1973	Feb. 1	4 710	1820	1 310	4300	113
	Mar. 1	4 030	1560	1 680	5500	145
	Apr. 1	3 520	1360	1 900	6225	162
	May 1	2 500	965	2 250	7375	
1974	Feb. 1	2 580	996	2 220	7275	99
	Mar. 1	4 340	1680	1 520	5000	84
	Apr. 1	3 370	1300	1 940	6375	114
	May 1	1 930	747	2 450	8050	
1975	Feb. 1	4 750	1830	1 280	4200	45
	Mar. 1	2 740	1060	2 160	7100	59
	Apr. 1	3 480	1340	1 910	6250	87
	May 1	2 510	971	2 240	7350	
1976	Feb. 1	523	202	3 200	10500	22
	Mar. 1	4 340	1680	1 520	5000	23
	Apr. 1	1 680	650	2 530	8300	27
	May 1	544	210	3 120	10250	
1977	Feb. 1	2 390	924	2 290	7500	36
	Mar. 1	2 640	1020	2 190	7200	29
	Apr. 1	2 890	1120	2 100	6900	26
	May 1	1 110	428	2 770	9100	
1978	Feb. 1	3 530	1360	1 890	6200	129
	Mar. 1	4 190	1620	1 600	5250	178
	Apr. 1	3 340	1290	1 950	6400	216
	May 1	2 570	994	2 230	7300	
1979	Feb. 1	5 170	2000	910	3000	61
	Mar. 1	4 770	1840	1 250	4100	80
	Apr. 1	3 390	1310	1 940	6350	97
	May 1	1 450	560	2 620	8600	

1/ Expressed as a percent of the April 1 average water content.

arrive. Quick-Look from NASA usually arrived after the Canadian Quick-Look. The average time was about six to seven days, rather than the 72 hours originally hoped for. During 1979, Landsat transmission problems early in the season made it impossible to obtain near-real-time data. NOAA imagery was used almost exclusively for operational forecasting during 1979.

SCA BASIC DATA FILE

General

Some preliminary work with the data files indicated that the number of individual basin-observations is now about 12,000 and the number is continually growing. As a consequence, computer handling of data appeared much more practical than any type of written summary. As many as 53 major watersheds and sub-watersheds have been observed throughout the Sierra at various times during the project. Observations have been made from Landsat, NOAA, and GOES imagery. In many cases, Landsat data have been reduced at more than one scale by more than one method. In some cases, duplicate interpretation has been made, using NASA Landsat Quick-Look imagery as well as the higher quality standard product Landsat imagery from NASA. The various combinations of sources of imagery, interpretation, etc., have made the presentation of results in tabular form rather awkard at best.

A substantial amount of data editing and pre-analysis of the interpreted data were performed before these data were entered into the basic data file. In addition, a certain amount of editing can be done by computer on the basic data file, and errors in interpretation can be located and checked. For example, the interpreter's estimate of effective snow line was compared with the estimate of snowcovered area to determine if the two were comparable within certain limits.

Basic Data File Description

The basic data file can be used to list historic data in any form required in analysis. Usually, data would be required for the period March 15 through the end of snowmelt for all years of record for a given watershed. To illustrate the data file format a listing for the Kings River, inflow to Pine Flat Reservoir, appears in the appendix. Similar tabulations for other watersheds listed in Table 2 are available to users through the Snow Surveys Branch of the California Department of Water Resources.

There are three card types in the file. The first is a header card naming the watershed. It includes certain fixed descriptive data. The second card type carries the area-elevation curve of the watershed. Card types one and two, placed together, provide the means for calling and checking data from the main file. The main file contains the third card type, which carries the individual SCA observations by watershed, with a single card per basin observation. Formats for these three card types appear in Table 9.

The basic data cards are arranged in a file with the following specifications:

- All header and area-elevation cards are assembled by pairs in one file.
- All type three data cards are filed chronologically in the main file for the entire period of record. A CDWR basin number system has been used to assign numbers to the basins and sub-basins which have been observed. In addition to date of observation and basin number, the card carries the observed and interpreted information of snowcovered area and elevation of effective snow line. Description of data source, method of interpretation, and other items pertinent to analysis of the data appear in Table 9.

EDITING AND ANALYSIS OF SCA DATA

Objectives

The objective of editing and pre-analysis of SCA data was to generate a level of quality control on the interpreted data. Techniques developed to check interpreted data also have application in estimating SCA during periods of partial cloud cover or between observations.

Data Checking

Evaluation of results of this investigation indicated that snowcovered area can be practically determined from Landsat by ZTS for watersheds as small as 100 km^2 (40 sq. mi.) and snowpack depletion may be determined within reasonable limits of accuracy, even as the area of snowpack becomes fragmented. As the investigation proceeded, it became apparent that quality control techniques would be very necessary to assure consistency of data from date-to-date and basin-to-basin.

Cross-basin plots were developed for the various sub-basins and major basins to provide a means of testing for possible discrepancies in individual observations, to estimate SCA on basins partly or completely covered with clouds from data available on adjacent basins or sub-basins, and to provide an effective means of manually checking basin observations and estimating missing data to develop forecast procedures.

During the interpretive process, additional near-real-time data was acquired to assist the interpreter in assessing conditions pertinent to SCA. Data used included temperature readings from the watersheds, precipitation, and snowpack and snowfall data recorded on the California Department of Transportation road condition reports. Data on water content of snowpack from snow courses and

Table 9

SCA Basic Data File
Formats for Data Storage on Cards

1. Basin Card

Col.	Format	Data
1	1X	Blank
2-4	I3	Basin number
5	1X	Blank
6-53	48H	Basin name or other alpha information
54-60	F7.0	Basin area in square miles
61-67	F7.3	Maximum elevation in feet
77-80		Identifier SCA1

2. Area-Elevation Data Card

Col.	Format	Data
1	1X	Blank
2-4	I3	Basin number
5-80	8F3.2	Area-elevation curve data
	13F4.2	Elevation in thousand feet corresponding to each 5 percent change in area from gaging station site (100 percent area data field 1) to the elevation above which 5 percent of area occurs (data field 20). Field 21 is elevation above which 2 percent of area occurs and maximum elevation is on card 1.

3. Basic Data Card --- One card for each observation for each basin, filed by year and date of observation

Col.	Format	Data
1	1X	Blank
2-3	I2	Year (i.e., 73=1973)
4-5	I2	Month (i.e., 02=February)
6-7	I2	Day--nominal date of pass or observation
8-9	I2	Day--date of secondary observation if two passes required to cover basin
10	1X	Blank
11-13	I3	Basin number
14-18	F5.0	SCA in square miles
19-23	F5.0	Elevation of effective snow line in feet
24	1X	Blank

Table 9 (continued)

SCA Basic Data File
Formats for Data Storage on Cards

Basic Data Card (continued)

Col.	Format	Data
25	I1	Source of imagery. Number indicates sources 1 Landsat standard product 2 Landsat Quick-Look, Canadian 3 NOAA 4 GOES 5 Landsat Quick-Look, NASA 6 TIROS 9 Other
26	I1	Type of imagery. Number indicates type 1 Print 2 Transparency 9 Other
27	I1	Band. Number indicates band 4-7
28	I1	Method of reduction. Number indicates method 1 Overlay 2 ZTS 9 Other
29-31	F3.1	Scale of reduction. Number indicates scale $.5 = 1{:}.5\times10^6$ $1.0 = 1{:}1\times10^6$ $1.5 = 1{:}1.5\times10^6$ 9 Other if scale cannot be shown
32	I1	If method of estimating SCA is 9 (other), the method of estimating area is indicated by number. Blank, unless method is 9. 1 Cross basin plot 2 Extrapolated area from previous observation 3 Highway data 4 Topographic map 9 Other

Table 9 (continued)

SCA Basic Data File
Formats for Data Storage on Cards

Basic Data Card (continued)

Col.	Format	Data
33	I1	Reason for non-standard method of estimate. Blank, if Col. 32 is blank. 1 Missing Imagery 2 Poor quality imagery 3 Cloud cover 4 Too small to planimeter
34-39	6X	Blank
40-76	41H	Written remarks
77-80		Card identifier for record SCA3

snow sensors proved useful in determining areas subject to heavy melt and the rate of melt. Scattered aircraft observations were also used when they were available.

A plot of SCA against time during the period of snowpack depletion was a very useful tool in the checking and application of SCA in an individual watershed. Examples of plots of SCA against time for the Kings River Basin appear in Figures 2 through 5 (1973 through 1979). Observation of precipitation, temperature, and other factors were also used on these plots to verify storm activity, unusual melt rate, and other factors that may relate to SCA. Data from a plot of this type was used to estimate daily SCA for hydrologic modeling.

All SCA basin data from satellites were stored on computer cards, and a number of tests were run to check for errors or inconsistencies.

For example, snow line estimated by the interpreter was checked against an effective snow line based on the area-elevation curve of the watershed. If the observations appeared inconsistent, the information was flagged.

We believe that the final data file is of high quality and entirely satisfactory for development of forecast procedures by CDWR, as well as by others.

Comparison of SCA from Various Sources

Interpreted data from various satellite sources show some differences and discrepancies, even for observations made at the same time. Part of this difference is undoubtedly due to interpretive problems. A number of factors associated with the imagery influenced interpretation of SCA to some extent. These included:

- Type and source of imagery
- Scale of reduction
- Print or transparency
- Band

Experience suggests that two interpreters using the same image show less variability in result than a single interpreter using two different bands, scales, or sources. Nevertheless, results from the various types of imagery, when adjusted for observable differences, all fall within acceptable limits for water supply forecasting. For example, if band 5 is normally used, but band 7 is the only source available, an adjustment can be made consistent with past experiences with bands 5 and 7. Agreement of results continues to improve with improvement in interpretive techniques and skills.

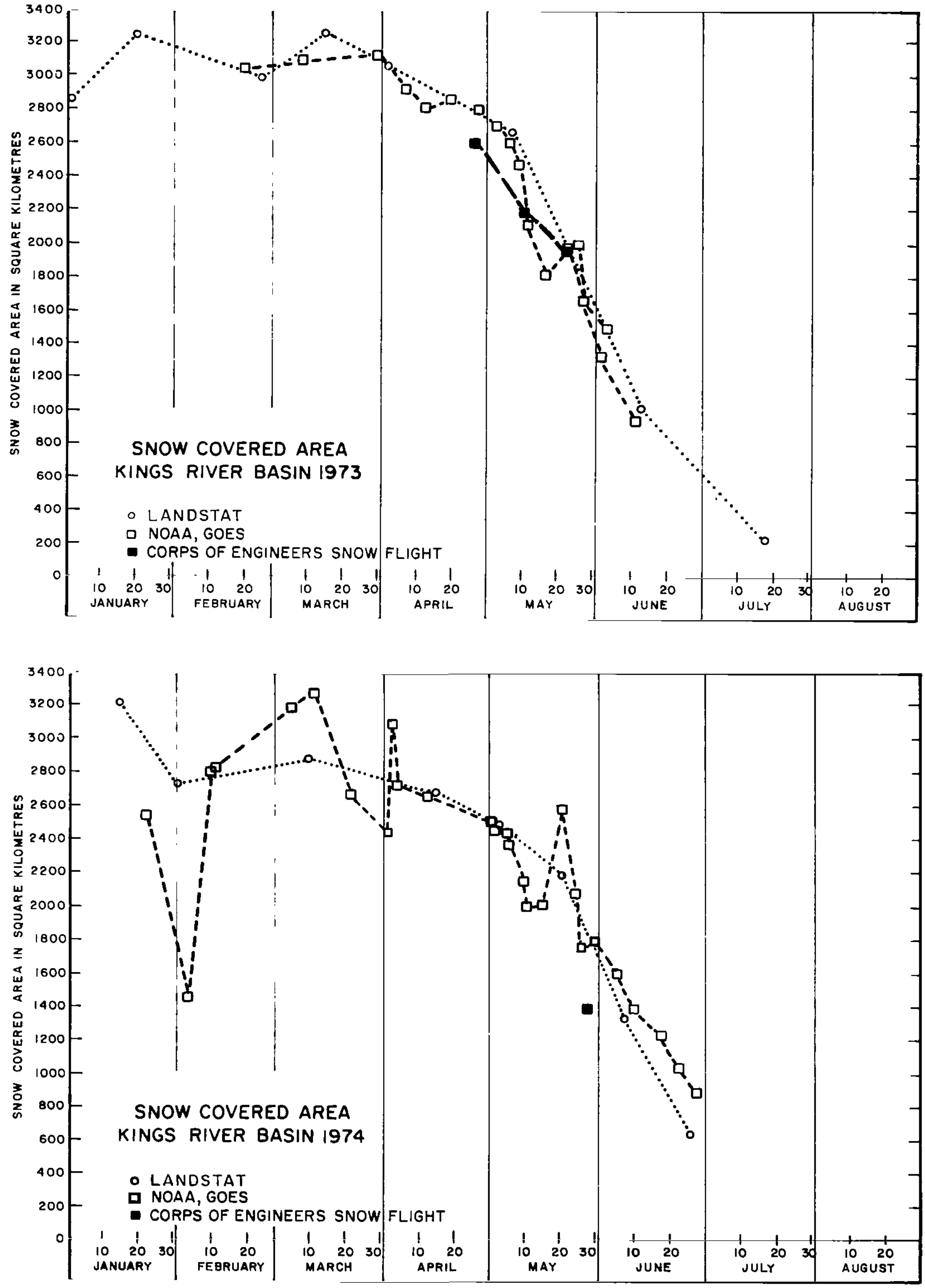


Figure 2. Snowcovered area, Kings River Basin 1973 and 1974.

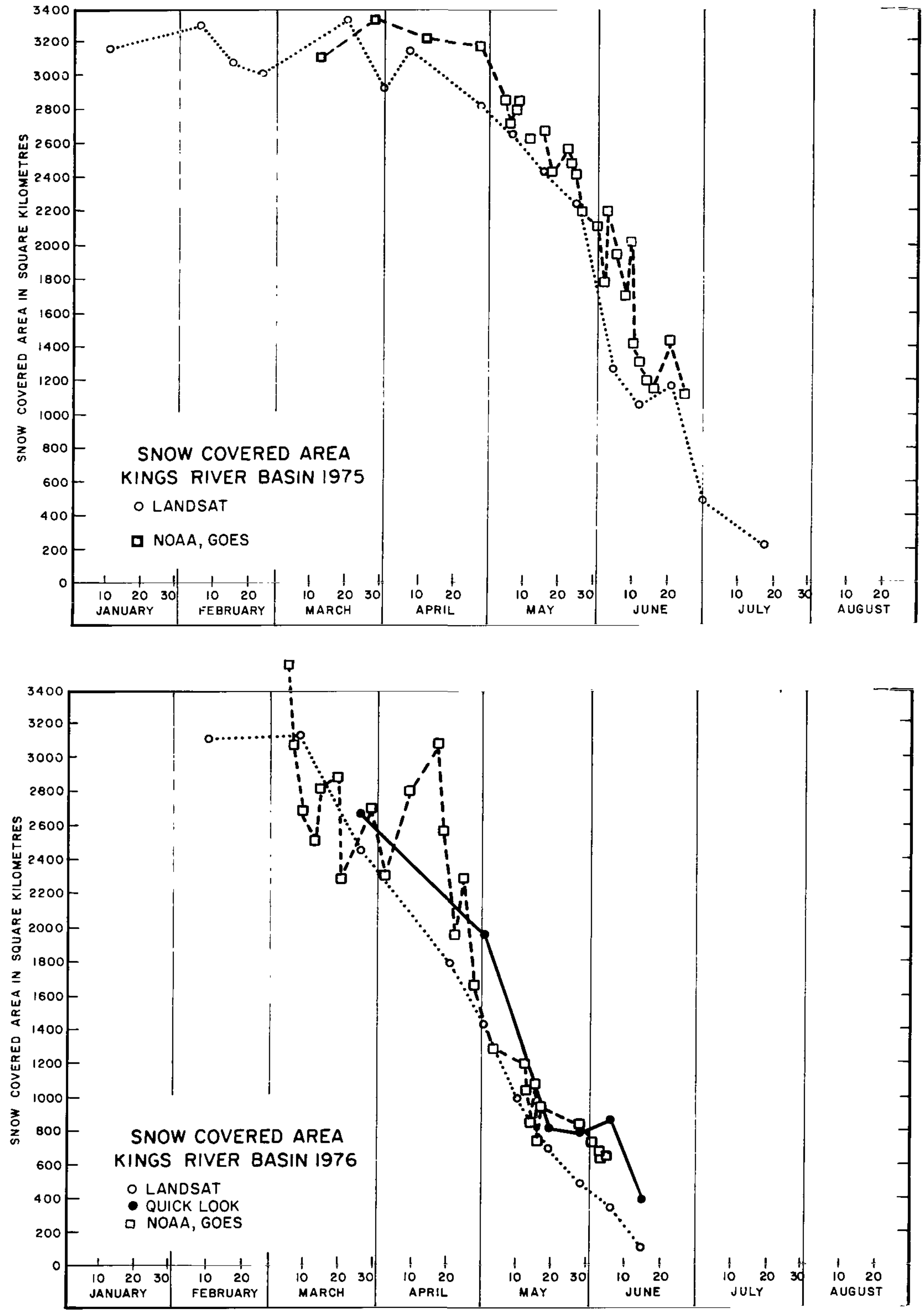


Figure 3. Snowcovered area, Kings River Basin 1975 and 1976.

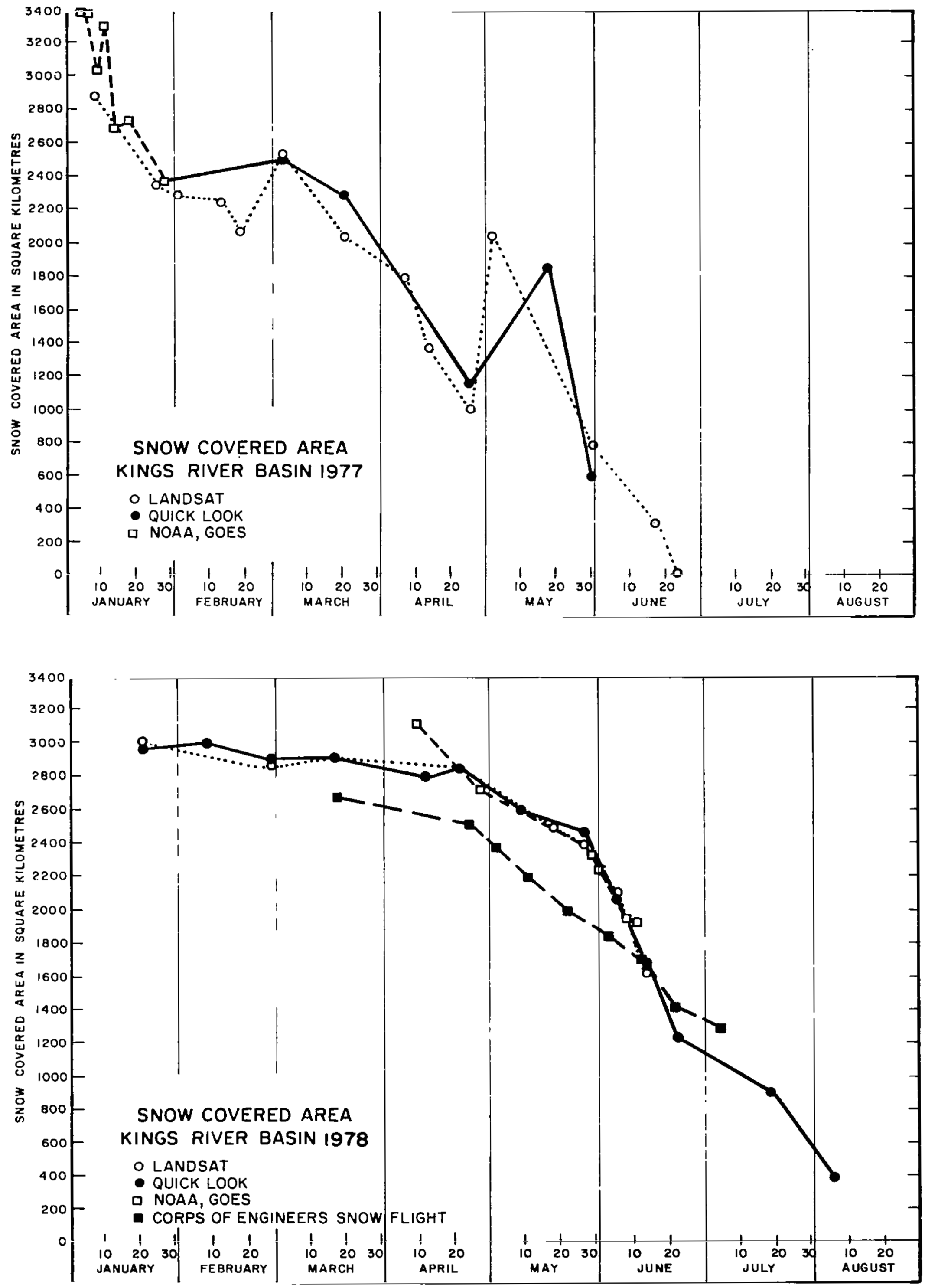


Figure 4. Snowcovered area, Kings River Basin 1977 and 1978.

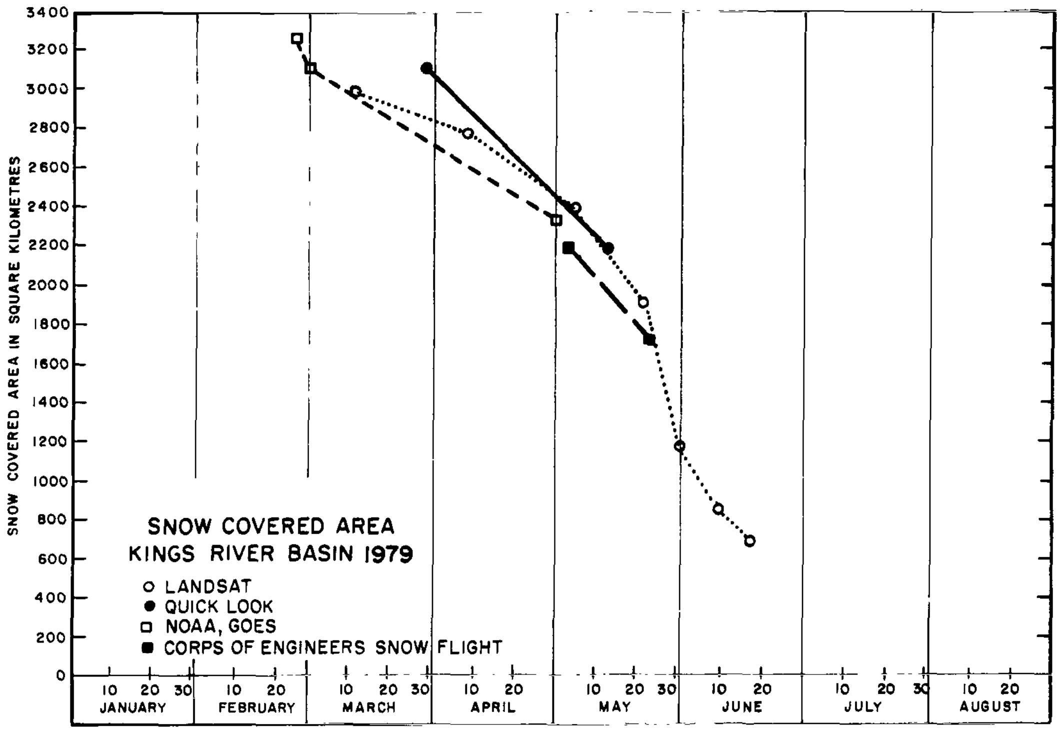


Figure 5. Snowcovered area, Kings River Basin 1979.

Limited observations from light aircraft conducted during the period of satellite observations were available for some comparison. Data from aircraft observation on the Kings River watershed by the U. S. Corps of Engineers appear in Figure 2, Figure 4, and Figure 5. In many cases, aircraft observations varied considerably from satellite observations. Generally, aircraft observations showed less SCA than did satellite observations, as of a given date. About mid June in the 1978 snowmelt season, some precipitation occurred, including light snowfall at higher elevations, and this was probably very apparent to aircraft observers at that time. Differences may be attributable to several causes:

- Aircraft observers deleted patches of snow that were below the major unbroken snowpack. (Historical aircraft observations may not be entirely consistent in this respect.)

- Aircraft observers tried to delete areas with fresh, light snowpack that did not represent the major winter accumulation. (These areas might show up as snowcovered area on the satellite imagery, but an observer close to the ground could possibly identify the freshly fallen snow on bare ground and eliminate it from the observation.)

In 1978 the line joining the Landsat observations appeared to flatten from late June through mid July. Temperatures dropped, averaging some five degrees below normal for the period. This delayed the melt season. In mid July, temperatures rose to well above normal and the rate of snowpack depletion apparently increased.

Plotted SCA data show aircraft observations have somewhat less area than satellite observations until well into the melt season (early to mid June). Since there had been no means of otherwise testing or adjusting the data obtained by aircraft before satellite imagery was available, when we were analyzing forecast procedures, we decided to correct all flight data by increasing the SCA obtained from aircraft observations of the Kings River Basin by eight percent and of the Kern River Basin by 14 percent.

SCA APPLICATION TO WATER SUPPLY FORECASTING

General

Although the use of SCA as an additional parameter in seasonal runoff predictions appeared logical at the beginning of this study, the duration of satellite data was too short for conclusive testing of SCA in conventional forecast procedures. To investigate the potential value of SCA data to runoff prediction, we conducted detailed analyses, using longer term aircraft observations of SCA in conjunction with satellite-derived SCA for two watersheds, the Kings River and Kern River Basins. They were selected because:

- The Kings River Basin is representative of a watershed with relatively uniform area at all elevation bands; and the Kern River Basin is representative of a watershed in which certain elevation bands predominate.

- The two watersheds, although sharing one common boundary in the southern Sierra Nevada, are very different in hydrologic characteristics.

- Many watersheds in the Sierra Nevada have characteristics which fall between the extremes of the characteristics of these two watersheds. Therefore, conclusions derived from studies of the Kings and Kern River Basins are applicable to other watersheds in the Sierra Nevada.

- More than 20 years of aircraft observations of SCA were available. This permitted statistical assessment of the potential of SCA as a supplemental parameter in operational forecasting.

As described earlier, preliminary analysis suggested that the most effective use of SCA as a forecast parameter would be during snowpack melt. At the present time, only limited data are available from the watersheds to describe the snowpack during such a period. SCA provides another parameter to monitor watershed information, one which may be useful in updating water supply forecasts during major snowmelt.

Specific Study Area Description

The Kings and Kern River Basins are adjacent (Figure 6) and discharge into the Central Valley near the cities of Fresno and Bakersfield, respectively. Each basin ranges in elevation from below 300 m (1,000 ft) in the foothill area to over 4 300 m (14,000 ft) along the Sierra Nevada crest, which forms the eastern boundary of both watersheds.

The Kings River Basin has an east-west orientation, with high sub-basin divides and sub-basin drainage in deep canyons. The Kern River Basin has a north-south orientation, with the Great Western Divide along its western boundary. The Kern River Basin is characterized by plateau areas with broad meadows and timbered slopes: the North Fork rises in a steep, rocky area near the Kings-Kern basin divide and flows in a deep canyon through most of its length to Lake Isabella.

Area-elevation curves in Figures 7 and 8 contrast the relatively uniform distribution of area with elevation in the Kings River Basin, with the concentration of area between 1 800 m (5,900 ft) and 2 800 m (9,200 ft) in the Kern River Basin. The average elevation of the April 1 snow line, as determined from CDWR records, is about 2 000 m (6,500 ft) in the Kings River Basin and 2 150 m (7,000 ft) on the Kern River Basin.

The 4 000 km^2 (1,545 mi^2) Kings River Basin has an average runoff of 1 934,000 dkm^3 (1,568,000 ac-ft) which represents about 48 cm (19 inches) basinwide runoff. On the average, 74 percent of the annual runoff occurs during the April-

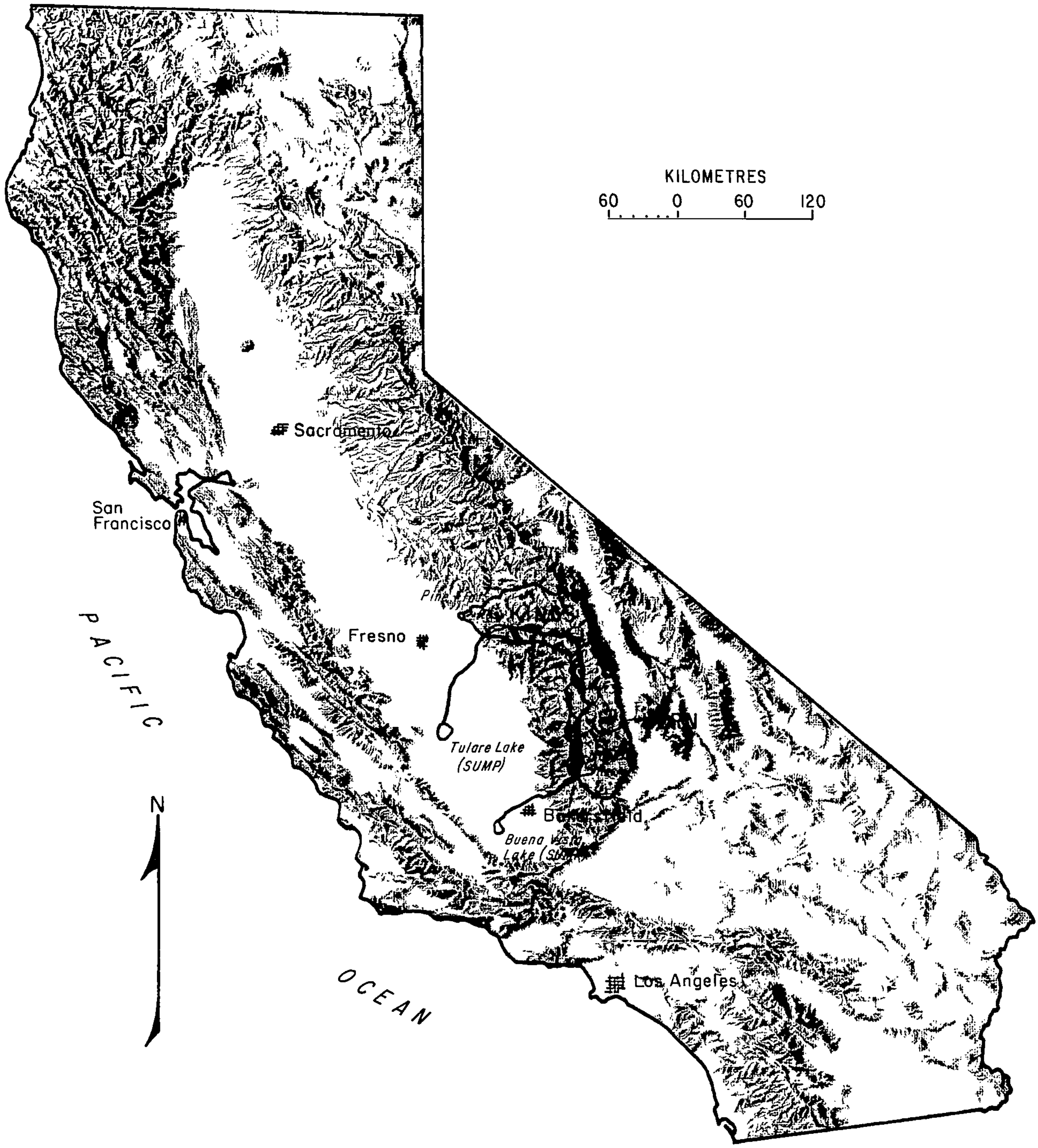


Figure 6. Kings and Kern River Basins.

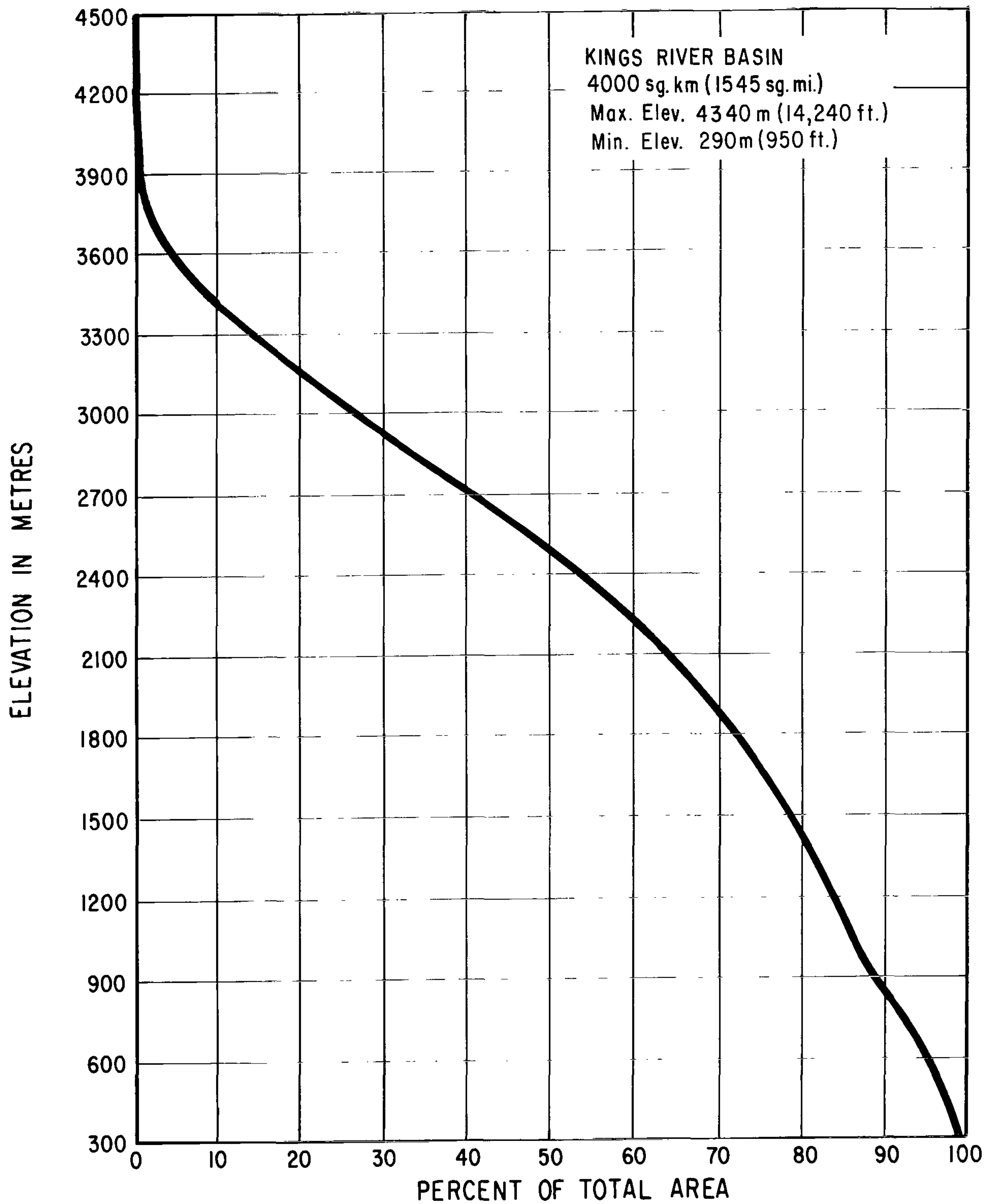


Figure 7. Area-elevation curve, Kings River Basin.

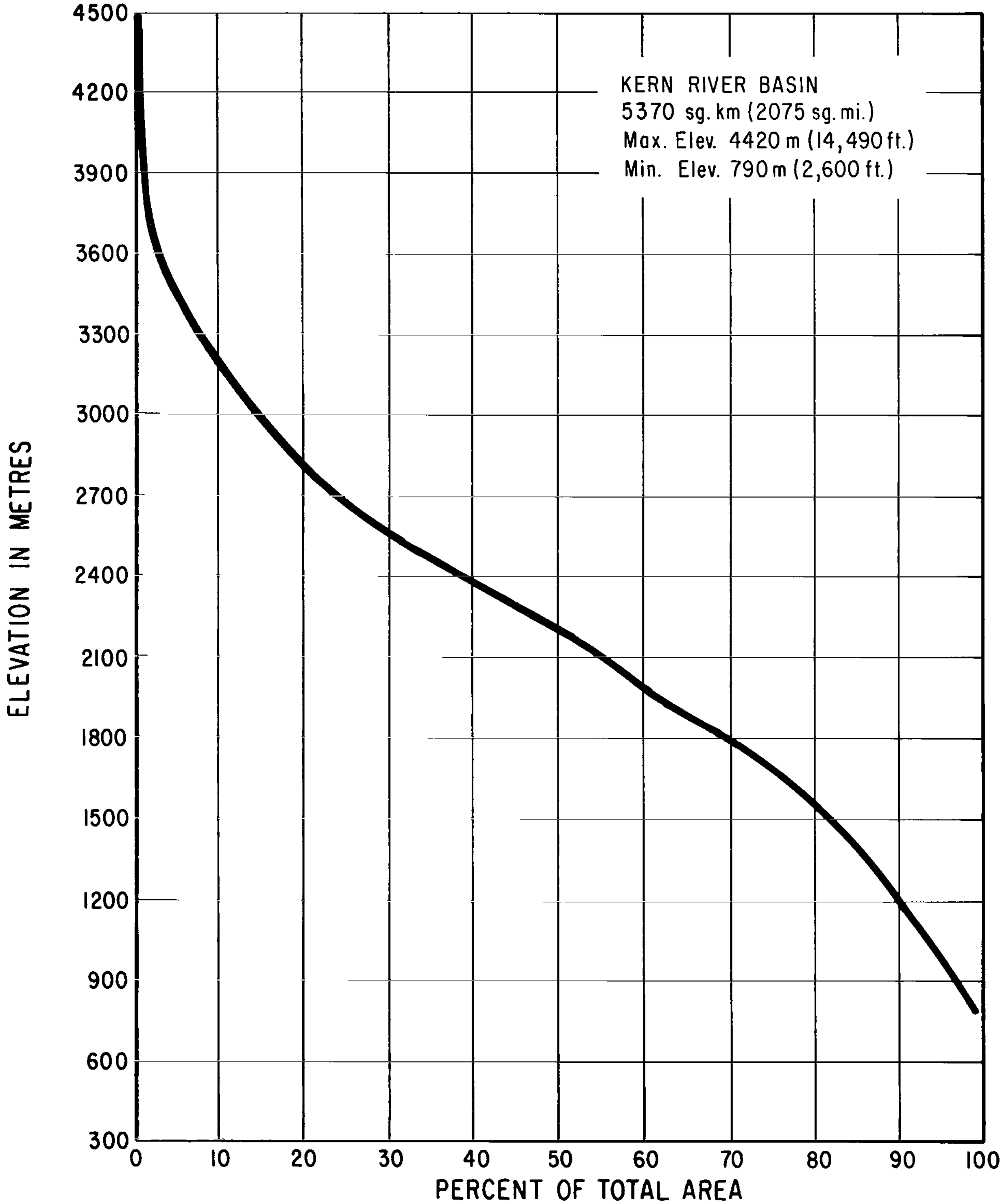


Figure 8. Area-elevation curve, Kern River Basin.

July snowmelt period. Snowpack accumulation increases with elevation to about 2 900 m (9,500 ft) and is fairly consistent at about 75 to 85 cm (30 to 33 inches) of water above that elevation, although local topography may effect accumulation to some extent. Average annual precipitation at the 2 750 m (9,000 ft) elevation is about 90 cm (35 inches). Precipitation measurements made along the frontal slope near the western side of the basin appear to be representative of, or at least proportional to, precipitation amounts at the higher elevations, although some minor variations may occur.

The 5 400 km^2 (2,074 mi^2) Kern River watershed (above Lake Isabella) has an average annual runoff of 773 000 dkm^3 (627,000 ac-ft), which represents 14.5 cm (5.7 inches) of runoff. About 67 percent of this normally occurs during the April-July snowmelt. Precipitation varies both with elevation and location in the basin. At 2 750 m (9,000 ft), average annual precipitation along the Great Western Divide exceeds 90 cm (35 inches), while at the same elevation along the Sierra crest, precipitation may be as low as 40 cm (16 inches). Precipitation, snowpack accumulation, and snowcover appear much more variable over the Kern River Basin than over the Kings River Basin.

Precipitation and resulting runoff are extremely variable from season to season in the southern Sierra. Table 10 illustrates the wide range of unimpaired April-July runoff within these watersheds over the past 11 years.

Test Procedure Description

In a preliminary analysis, we used a multiple regression technique to relate runoff occurring after the date of forecast to causative parameters. The analysis was intended to develop and demonstrate a procedure for updating water supply forecasts during the period of snowmelt to reflect observed conditions of precipitation, runoff, and change in snowcovered area. The objective was to reduce the residual error in the remaining flow following the date of forecast.

Analysis was predicated on the operational requirement for accurate updating of water supply forecasts throughout the period of snowmelt runoff. Forecasts prepared every year by CDWR are based on the April-July snowmelt period, and updating has been based primarily on precipitation observed after the April 1 forecast. However, only a limited amount of data is continuously available from the higher elevations of the mountain watersheds during snowmelt. Observed precipitation, runoff, and depletion of SCA as the melt season advances provide near-real-time parameters to reflect the progress of melt in the watershed. This investigation developed and demonstrated techniques for updating the conventional CDWR forecast procedures during snowmelt.

Forecast parameters used in conventional CDWR procedures were used in the analysis. Snowmelt runoff to date and SCA were used as additional parameters for updating as the snowmelt season progressed. Forecast parameters included:

Table 10

Range of Unimpaired April-July Runoff, 1969-70
Kings and Kern Rivers
In Units of 1000

Season	Kings River			Kern River		
	dkm^3	ac-ft	Percent Average	dkm^3	ac-ft	Percent Average
1969	3 841	3114	245	2 044	1657	326
1970	1 089	883	70	387	314	62
1971	967	784	62	294	238	47
1972	672	545	43	154	125	25
1973	2 048	1661	131	868	704	139
1974	1 887	1522	120	632	512	101
1975	1 562	1266	100	454	368	72
1976	374	303	24	128	104	20
1977	338	274	22	113	92	18
1978	2 900	2351	185	1 311	1063	209
1979	1 556	1262	99	512	415	82
Average	1 566	1270		627	508	

- High Snow Index. An index to the snowpack water content in the higher elevations of the watershed above 2 750 m (9,000 ft) developed from snow survey measurements of water content, adjusted to April 1. The index represented the average of several equally weighted snow courses, expressed as a percent of the long-term average.

- Low Snow Index. Similar to high snow index, but for the lower elevations of the watershed.

- October-March Precipitation Index. An index calculated from observations of precipitation at several equally weighted stations in the lower elevations of the watershed, expressed as a percentage of average water year precipitation.

- October-March Runoff. An index to the amount of surface runoff occurring in the watershed before snowmelt begins, expressed in acre-feet.

- Previous Year's April-July Runoff. An index to the carryover effect from the previous season, expressed in acre-feet.

- Forecast Season Precipitation Index. An index calculated from observed precipitation during the April-July forecast period of snowmelt runoff, expressed as a weighted percent of average.

- Runoff April 1 through Date of Forecast. An index to the amount of melt that had occurred between the April 1 forecast and the time of forecast update, expressed in acre-feet.

- Snowcovered Area. An index to the area (as opposed to water content) of snowpack remaining to contribute to runoff, expressed in square miles.

In procedure development, Forecast Season Precipitation was assumed to be a known value as of the forecast date throughout the April-July period. Statistics related to variability of precipitation during the forecast period are already well understood, and, because the objective was to analyze the effect of using SCA as a parameter, uncertainties related to weather were removed from the analysis. (In operational forecasting, precipitation observed through date of forecast is added to median precipitation occurring after the date of forecast to estimate precipitation for the entire snowmelt period. Probabilities are analyzed around the median forecast.)

Forecast updating procedures were developed for April 1, May 1, May 15, June 1, and June 15 for the Kings and Kern River Basins. The use of Landsat SCA data for 1973-1976 and the previous aircraft observations provided 25 years of record on the Kings and 23 years of record on the Kern. Procedure stability was an important factor to assure a logical sequence of operational forecasts during the progress of the season.

Basic data used in the conventional CDWR procedures were used to prepare the April 1 forecast procedures. Two procedures were developed for May 1 and each subsequent date, one with and one without SCA, to determine and observe the effect of SCA upon forecast reliability. In both procedures, runoff between April 1 and the date of forecast was used as a parameter. The change in forecast error could then be related solely to the addition of SCA as a parameter. The general form of the forecast procedure equation is

$$Y = C_1X_1 + C_2X_2 + C_3X_3 + C_4X_4 + C_5X_5 + C_6X_6 + C_7X_7 + C_8X_8X_1 + K$$

Where:

Y = Basin Runoff in acre-feet from date of forecast through July 31

X_1 = High Snow Index

X_2 = Low Snow Index

X_3 = October-March Precipitation Index

X_4 = October-March Runoff

X_5 = Forecast Season Precipitation Index

X_6 = Previous Year's April-July Runoff

X_7 = Runoff April 1 through date of forecast

X_8 = Snowcovered Area

Regression coefficients are represented by C_1 - C_8 and K represents the regression constant. The conventional April 1 procedures use X_1, X_2, X_3, X_4, X_5, and X_6. Procedures for other times use X_7 or X_7 and X_8, depending upon whether SCA is to be included or not. SCA (X_8) times April 1 snowpack index (X_1 adjusted for precipitation between April 1 and date of forecast) was used as an index of the volume of water available for snowmelt runoff during the melt period. Constraints on time and period of record did not permit investigation of more complex nonlinear analysis techniques.

Employing techniques presently utilized by CDWR, we made simulated forecasts for each year of record and compared them to observed runoff. Because of the limited data set, independent test data were not available, and forecasts were made with data employed in derivation of the regressions. Although not strictly acceptable from a statistical viewpoint, the intention here was only to determine whether SCA would be considered as a potential additional parameter in predicting future runoff. Standard errors and other pertinent statistical measures were calculated for each date of forecast so that results could then be compared, with and without SCA as a parameter, recognizing the limitations of these simple regression techniques.

Statistical Results

Figure 9 illustrates the variation in standard error, expressed as a percentage of April-July runoff, for forecast updates. It depicts the effective reduction in forecast error as snowpack is depleted. Updating procedures without SCA are shown as a dashed line, while updating procedures with SCA are shown as a solid line. The dotted horizontal line represents standard error, assuming the CDWR conventional forecasts were updated according to standard practice at the time those procedures were developed.

In the Kings River Basin, standard error increased slightly between April 1 and May 1, probably as a result of additional forecast parameters used on May 1, which increases the degrees-of-freedom lost. After May 1, standard error declined appreciably, until on June 15 it was approximately 70 percent of the error on April 1. The improvement over the conventional CDWR procedure was significant, with or without SCA. The addition of SCA as a parameter, however, seemed to show little or no significant improvement.

In the Kern River Basin, standard error for the procedure without SCA followed approximately the same pattern as in the Kings. When SCA was included, however, substantial reduction in standard error was apparent as the season progressed. By including SCA as a parameter, May 1 error was reduced approximately 45 percent and May 15 error about 40 percent below that of the updating procedure using only conventional parameters. This represented a corresponding decrease in the volumetric error of remaining runoff. The values of standard error (expressed as a percent of snowmelt season runoff) on the Kern and the Kings were now relatively close.

This result suggested that the use of SCA as a forecast parameter during snowpack depletion permitted a similar level of forecast accuracy on the two watersheds which could not be achieved with conventional parameters alone. Inspection of updating equations suggested that the Kern River SCA coefficients were relatively stable from date to date -- more so than those on the Kings River. Even though the precise numerical value of decrease in procedural error to be obtained by using these methods cannot be generalized for all watersheds, it is apparent that SCA provided information pertinent to updating forecasts which was not readily available from the other sources investigated here.

Examination of Results

Use of SCA as a parameter in forecasting snowmelt runoff may result in significant improvement of forecasting procedures under certain circumstances. There was considerable improvement for each update on the Kern River using SCA, but no significant changes on the adjacent Kings River. We believe it may be hypothesized that watershed characteristics, as well as availability of data representative of a watershed, may be related to the response of forecast procedures to SCA.

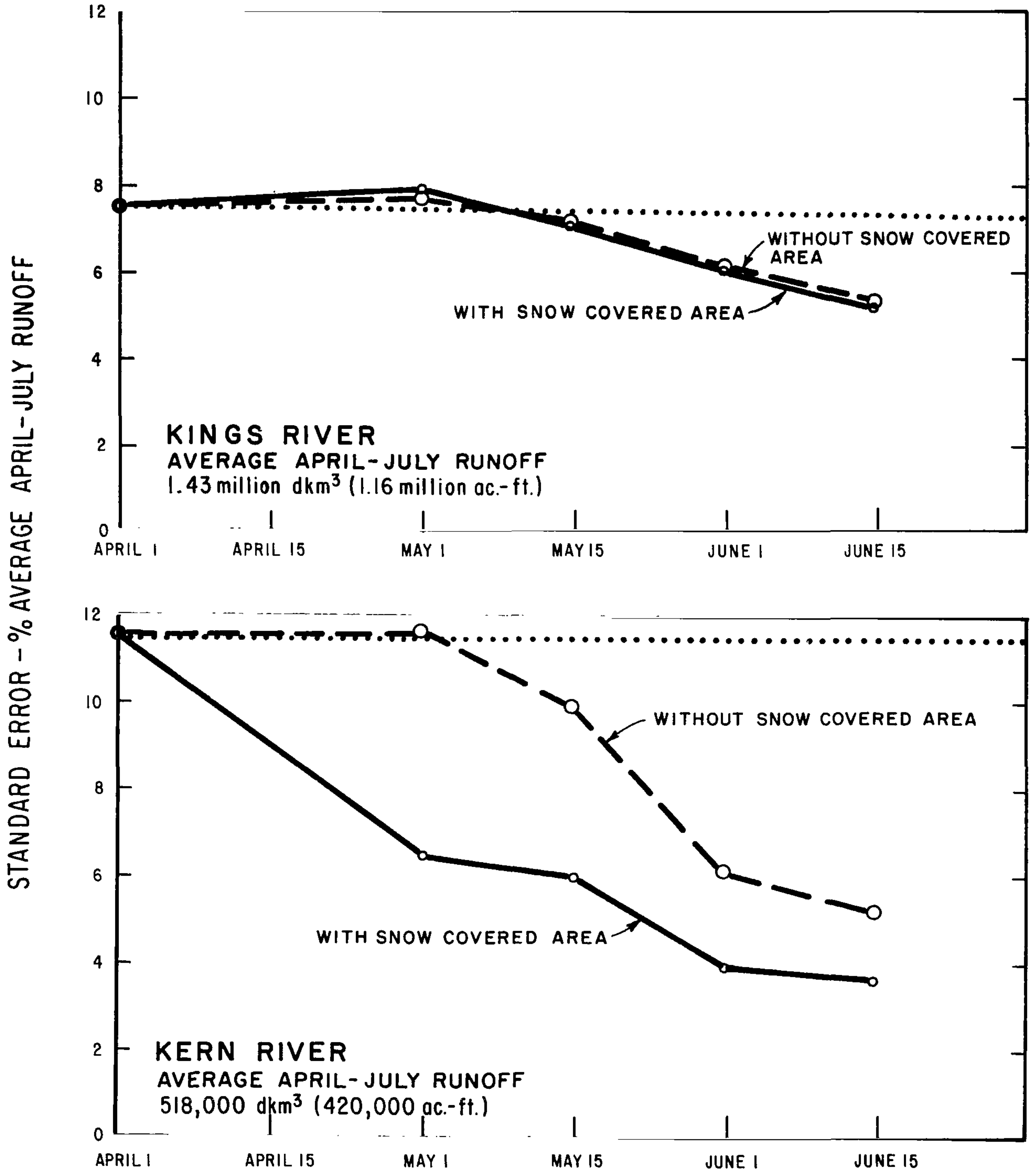


Figure 9. Standard error of forecast procedures versus date during snowmelt, Kings and Kern River Basins.

The Kings River Basin

This basin consists of a number of small basins having similar characteristics and, overall, has a markedly uniform area-elevation distribution. (See Figure 7.) The conventional April 1 forecast procedure for the Kings River Basin is relatively more accurate (when expressed in terms of percentage of April-July runoff) than is that for the Kern River Basin. April 1 procedural standard error represented about 7.5 percent of average April-July runoff on the Kings River and about 11.5 percent on the Kern (assuming that precipitation after April 1 is known). The higher initial degree of accuracy on the Kings River may make it considerably more difficult to obtain a marked improvement through SCA or other update parameters as the snowmelt season progresses.

The Kern River Basin

The basin consists of a number of small basins of diverse character and nonuniform area-elevation distribution. (See Figure 8.) The relatively large area between 1 850 m to 1 750 m (6,000 - 9,000 ft) on the Kern River is subject to extreme variability in precipitation and in snowpack accumulation and depletion creating a relatively inconsistent relationship between precipitation and snowpack, and elevation and location within the Kern River watershed. It may be desirable to break the Kern area into a number of sub-basins and forecast each sub-basin independently. The inclusion of SCA, however, may provide an attractive solution to water supply forecasts in areas with nonhomogeneous characteristics and limited hydrologic data.

This test study on the Kern and Kings Basins suggested that SCA can be an effective parameter for water supply forecasting in California. Watersheds which will show the greatest response to the use of SCA will probably be those with a substantial portion of their area within a limited elevation range, with areal distribution of precipitation and snowpack accumulation not strongly related to elevation, and with climatological data which do not adequately reflect conditions in the water-producing areas of the basin.

As an example, the Feather River Basin in the northern Sierra has many of the characteristics that may make SCA a valuable parameter in water supply and other hydrologic forecasting. SCA is being investigated as an input parameter to forecasting the unimpaired flow of the Feather River at Lake Oroville, a major feature of the California (State) Water Project, operated by the Department of Water Resources.

OPERATIONAL FORECASTING

General

Water supply forecasts using SCA as a forecast parameter were prepared for the Kings River and Kern River watersheds during the snowmelt period for the 1977, 1978, and 1979 water years. During the 1978 season, heavy snowpack occurred at the higher elevations of the southern Sierra, generating a substantial degree of concern regarding forecasted water supply. At the request of local water users, additional forecast procedures using SCA as a parameter were developed to update the Kaweah River forecasts for the 1978 and 1979 snowmelt season.

Operations in 1977

California experienced the driest water year of record on most streams during 1977. This followed the near-record dry 1976 water year. Snowcovered area observed was by far the smallest for any season for which observations were available. Any forecast procedure used during this critical drought period would have shown extremely dry conditions.

About May 1, 1977, the pattern of below-average precipitation was broken, and relatively cold storm activity continued unseasonably throughout the month. Although cloud cover persisted for most of the month, satellite observations indicated that the snow line had dropped from an unprecedented high of 3 000 m (10,000 ft) on May 1 to below 2 100 m (7,000 ft) during the month. However, the water content in the fresh snowpack was very small, and, although it did influence observed runoff and forecast slightly, it did little to relieve the drought situation. The occurrence of snow at low elevations during May provided some interesting data on the accumulation and rapid melt of freshly fallen snow in the area below the receding seasonal snow line. Only minimal incremental runoff resulted.

Operations in 1978

Following the two extremely dry years, water year 1978 brought well above-normal streamflow to the southern Sierra Nevada. Abundant precipitation during the winter months left a heavy snowpack by April 1 at the higher elevations above 1 980 m (6,500 ft). Water content was more than 175 percent of the April 1 average (compared with about 20 percent as of the same date in 1977). However, many of the winter storms were warm, with relatively high freezing levels. As a result, snow lines were much higher and snowcovered areas were much smaller than might have been anticipated.

April 1978 was very cold, with above-average April precipitation, further increasing the snowpack and adding to the April-July snowmelt potential. May was dry, with only slightly below-average temperatures. The short periods of high temperature that normally cause heavy snowmelt runoff toward the end of May were absent, and snowmelt continued at relatively low rates through the month. Less snowcovered area was depleted than would be normally. By mid-May, the greatest snowcovered area of record for that date was observed on both the Kings River and Kern River watersheds (compared with data from satellite imagery, as well as aircraft observations dating back to 1952). Although by mid-June snowcovered area in the Kings River Basin was exceeded by that in 1967, the Kern River Basin continued with the maximum snowcovered area of record for the remainder of the season. Plots of time against snow-covered area for the 1978 season appear in Figure 4.

June 1978 remained cool, with no extended periods of high temperatures. June runoff, though large, continued to be delayed to some extent by low tempera-tures. Had a more normal temperature pattern persisted in early June, peak runoff rates could have been as much as 25 to 30 percent greater than those observed. The delayed runoff with reduced runoff rates was advantageous to reservoir operators, because the filling and possible spilling of reservoirs in early June did not occur.

Southern Sierra streams maintained flows at relatively high rates throughout July. Not until mid-July did temperatures rise to well above normal. By the end of July, flows were still relatively high. Satellite imagery indicated there was still substantial snowpack left in certain protected high-elevation portions of the watersheds well into August, and some isolated snowfields persisted throughout the summer.

Because snowcovered area on April 1, 1978, was well below that which might normally have been anticipated, considering the relatively high snowpack water content at higher elevations, water supply forecasts for the Kings and Kern River Basins, using the SCA as a parameter, were substantially lower than those from other sources. By May 1, forecasts were raised because of heavy precipitation during April, but forecasts using SCA were still substan-tially below the forecasts using conventional procedures. Subsequent updates gave similar results.

Forecasts using SCA verified well, while conventional procedures tended to overforecast. The record high area of snowcover after May 1 gave some assur-ance that the flow predicted by SCA procedures that had not materialized before that date was still in the form of snowpack within the watersheds. The forecasts using SCA were conveyed to certain operating agencies in the southern Sierra as part of the NASA program.

Operations in 1979

The 1979 season was much closer to average conditions than either of the two previous seasons. The April 1 SCA procedures gave about the same forecast as conventional procedures on the Kern and Kaweah Rivers, while the Kings River was somewhat lower. April was dry, with only about 25 percent of average April precipitation. Consequently, all forecasts in the area were lower. On May 1, the Kern and Kaweah River Basins forecasts prepared on the basis of SCA procedures were almost idential to those from conventional procedures, while the Kings River Basin SCA forecast was still about 5 percent lower than the conventional forecast.

Extremely high temperatures occurred from mid-May through mid-June, with rapid depletion of snowpack water content and snowcovered area. Late season updates confirmed the earlier projections, and both conventional and SCA forecasts for the April-July period verified well on all streams (see Table 11).

Summary

Table 11 summarizes the May 1 projection of April-July runoff for the Kings, Kaweah, and Kern River Basins for the three seasons, 1977, 1978, and 1979. Even on the Kings River, where statistics suggested little potential for improvement, the updating procedures employing SCA gave substantially better results than the conventional procedures currently used by CDWR.

Table 11

April-July Water Supply Projections as of May 1
In Units of 1000

Basin		1977 2/		1978		1979	
		dkm^3	ac-ft	dkm^3	ac-ft	dkm^3	ac-ft
Kings River	Observed	338	274	2 900	2350	1 560	1260
	SCA	216	175	2 960	2400	1 570	1275
	CDWR 1/	240	195	3 210	2600	1 665	1350
Kaweah River	Observed			669	542	355	288
	SCA			691	560	339	275
	CDWR 1/			740	600	308	250
Kern River	Observed	112	91	1 311	1060	511	414
	SCA	80	65	1 326	1075	518	420
	CDWR 1/	80	65	1 530	1240	512	415

1/ CDWR Bulletin 120.

2/ Precipitation during May (subsequent to forecast) generated some slight additional runoff.

CONCLUSION

The aerial extent of snowcover derived from satellite imagery appears to have some potential for improving accuracy and timeliness of hydrologic forecasts in California's ASVT test area. The greatest potential for water supply forecasting is in updating forecasts during the period of snowmelt, nominally April through July. Because of transient snow lines and uncertainties in future weather, SCA offers little in the way of improvement of water supply forecast accuracy during snowpack accumulation.

During snowmelt, both rate and volume of runoff can be related to receding SCA, as well as to other parameters. As applied to the Kings and Kern River watersheds and based on the period of analysis of approximately 25 years (including both aircraft and satellite observations), SCA offers considerable improvement in accuracy of forecast updates from watersheds that have a limited amount of representative real-time data available during the period of melt. Moreover, SCA makes forecast procedures more responsive to conditions caused by unusual distribution of snowpack throughout the watershed.

Use of SCA, from an operational standpoint, can become restricted when there is considerable cloud cover over the mountainous region for extended periods of time. At those times, neither the Landsat nor the daily NOAA imagery may be available. The expertise of the interpreter is extremely valuable in estimating SCA during partial cloud cover from observed snowcovered area on surrounding basins or portions of the observed basins and surrounding basins. This skill may be critical to the operational use of SCA. Delivery of imagery from the source to the interpreter also may pose a critical problem. Operational experience during the past three seasons suggests that much more rapid dissemination of observed satellite imagery will be required before completely effective use can be made of SCA in CDWR forecast procedures.

SCA as a supplemental forecast parameter does not obviate the need for other accurate data from conventional sources to define water supply and anticipated runoff. SCA does, however, provide one more piece of information needed to increase the reliability of forecast updates during snowmelt runoff. Although this investigation has been confined to only a few watersheds, principally to the Kings and Kern River Basins, we conclude that SCA will significantly improve forecast results in most watersheds. The results also suggest that the greatest potential for SCA may be in expanding the scope and improving the levels of forecast service, rather than simply providing for some nominal increase in forecast accuracy.

CDWR plans to continue the interpretation of satellite imagery and incorporate the operational use of SCA in water supply forecasting of California's snowmelt streams.

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APPENDIX

SATELLITE SCA DATA
KINGS RIVER, INFLOW TO PINE FLAT
BASIN 571 AREA 4002 SQ KM
WATER YEAR 1973

DATE	SCA SQ KM	SCA PCT	ELEV M	IMAGE SOURCE	IMAGE TYPE	BAND NBR	IMAGE SCALE	INTERP METHOD	ESTIM METHOD	COMMENTS
1 2	2903	73	1800	LDST	PR	5	.5	ZTS		
1 2	2852	71	1830	LDST	PR	5	1.0	OVLY		
1 20	3364	84	1175	LDST	PR	5	1.0	OVLY		
1 20	3289	82	1305	LDST	PR	5	.5	ZTS		
2 20	3090	77	1570	NOAA	PR		1.0	ZTS		
2 25	3041	76	1640	LDST	PR	5	1.0	OVLY		
2 25	3025	76	1670	LDST	PR	5	.5	ZTS		
3 15	3206	80	1420	LDST	PR	5	1.0	OVLY		
3 15	3219	80	1405	LDST	PR	5	.5	ZTS		
3 15	3136	78	1500	NOAA	PR		1.0	ZTS		
3 30	3170	79	1465	NOAA	PR		1.0	ZTS		
4 2	3103	78	1555	LDST	PR	5	1.0	OVLY		
4 2	3108	78	1540	LDST	PR	5	.5	ZTS		
4 7	2968	74	1740	NOAA	PR		1.0	ZTS		
4 13	2836	71	1845	NOAA	PR		1.0	ZTS		
4 20	2966	74	1740	LDST	PR	5	1.0	OVLY		
4 20	2893	72	1815	LDST	PR	5	.5	ZTS		
4 28	2839	71	1860	NOAA	PR		1.5	ZTS		
5 3	2730	68	1950	NOAA	PR		1.0	ZTS		
5 7	2631	66	2045	NOAA	PR		1.5	ZTS		
5 8	2725	68	1950	LDST	PR	5	1.0	OVLY		
5 8	2665	67	2020	LDST	PR	5	.5	ZTS		
5 9	2489	62	2165	NOAA	PR		1.5	ZTS		
5 12	2124	53	2410	NOAA	PR		1.0	ZTS		
5 16	1831	46	2595	NOAA	PR		1.0	ZTS		
5 22	1984	50	2500	NOAA	PR		1.5	ZTS		
5 26	2093	52	2425	LDST	PR	5	1.0	OVLY		
5 26	2012	50	2470	LDST	PR	5	.5	ZTS		
5 27	1494	37	2790	NOAA	PR		1.0	ZTS		
6 3	1458	36	2805	NOAA	PR		1.0	ZTS		
6 13	1396	35	2850	LDST	PR	5	1.0	OVLY		
6 13	1020	26	3050	LDST	PR	5	.5	ZTS		
7 19	262	7	3555	LDST	PR	5	.5	ZTS		

SATELLITE SCA DATA
KINGS RIVER, INFLOW TO PINE FLAT
BASIN 571 AREA 4002 SQ KM
WATER YEAR 1974

DATE	SCA SQ KM	SCA PCT	ELEV M	IMAGE SOURCE	IMAGE TYPE	BAND NBR	IMAGE SCALE	INTERP METHOD	ESTIM METHOD	COMMENTS
1 15	3328	83	1220	LDST	PR	5	1.0	OVLY		
1 23	2580	64	2090	NOAA	PR		1.5	ZTS		
2 2	2761	69	1930	LDST	PR	7	.5	ZTS		
2 2	2903	73	1800	LDST	PR	7	1.0	OVLY		
2 3	2624	66	2045	NOAA	PR		1.5	ZTS		
2 10	2846	71	1860	NOAA	PR		1.5	ZTS		
2 11	2859	71	1830	NOAA	PR		1.5	ZTS		
2 20	3175	79	1465	LDST	PR	5	1.0	OVLY		
3 5	3225	81	1395	NOAA	PR		1.5	ZTS		
3 10	2919	73	1785	LDST	PR	5	.5	ZTS		A FEW CLOUDS
3 10	2994	75	1710	LDST	PR	5	1.0	OVLY		A FEW CLOUDS
3 11	3297	82	1280	NOAA	PR		1.5	ZTS		
3 21	2691	67	1985	NOAA	PR		1.5	ZTS		
4 1	2481	62	2180	NOAA	PR		1.0	ZTS		
4 4	2751	69	1930	NOAA	PR		1.0	ZTS		
4 13	2678	67	2005	NOAA	PR		1.0	ZTS		
4 15	2707	68	1985	LDST	PR	5	.5	ZTS		
4 15	2722	68	1950	LDST	PR	5	1.0	OVLY		
4 30	2528	63	2135	NOAA	PR		1.0	ZTS		
5 2	2468	62	2190	NOAA	PR		1.0	ZTS		
5 3	2497	62	2165	LDST	PR	5	.5	ZTS		
5 3	2574	64	2090	LDST	PR	5	1.0	OVLY		
5 5	2453	61	2195	NOAA	PR		1.0	ZTS		
5 6	2388	60	2240	NOAA	PR		1.0	ZTS		
5 10	2160	54	2380	NOAA	PR		1.0	ZTS		
5 11	2012	50	2470	NOAA	PR		1.0	ZTS		
5 16	2028	51	2470	NOAA	PR		1.0	ZTS		
5 20	2613	65	2065	NOAA	PR		1.0	ZTS		FRESH SNOWFALL
5 21	2199	55	2365	LDST	PR	7	.5	ZTS		
5 21	2212	55	2365	LDST	PR	7	1.0	OVLY		
5 25	2093	52	2425	NOAA	PR		1.0	ZTS		
5 26	1779	44	2625	NOAA	PR		1.0	ZTS		
5 30	1813	45	2595	NOAA	PR		1.0	ZTS		
6 5	1603	40	2730	NOAA	PR		1.0	ZTS		
6 7	1323	33	2890	LDST	PR	5	.5	ZTS		EST MUCH OFF IMAGE
6 10	1386	35	2850	NOAA	PR		1.0	ZTS		
6 18	1233	31	2945	NOAA	PR		1.0	ZTS		
6 23	1036	26	3035	NOAA	PR		1.0	ZTS		
6 26	627	16	3300	LDST	PR	5	.5	ZTS		
6 28	878	22	3140	NOAA	PR		1.0	ZTS		

SATELLITE SCA DATA
KINGS RIVER, INFLOW TO PINE FLAT
BASIN 571 AREA 4002 SQ KM
WATER YEAR 1975

DATE	SCA SQ KM	SCA PCT	ELEV M	IMAGE SOURCE	IMAGE TYPE	BAND NBR	IMAGE SCALE	INTERP METHOD	ESTIM METHOD	COMMENTS
12 23	3230	81	1380	LDST	PR	5	.5	ZTS		
12 23	3385	85	1130	LDST	PR	5	1.0	OVLY		
1 10	3196	80	1435	LDST	PR	5	.5	ZTS		
1 10	3105	78	1555	LDST	PR	5	1.0	OVLY		
2 6	3331	83	1220	LDST	PR	5	.5	ZTS		CLOUDY
2 6	3318	83	1250	LDST	PR	5	1.0	OVLY		CLOUDY
2 15	3092	77	1565	LDST	PR	5	.5	ZTS		
2 15	3256	81	1350	LDST	PR	5	1.0	OVLY		
2 24	3030	76	1655	LDST	PR	5	.5	ZTS		
2 24	3085	77	1565	LDST	PR	5	1.0	OVLY		
3 12	3149	79	1495	GOES	PR		1.5	ZTS		CLOUDS
3 23	3351	84	1190	LDST	PR	5	1.0	OVLY		
3 28	3362	84	1160	NOAA	PR		1.5	ZTS		
3 28	3455	86	1070	NOAA	PR		1.0	ZTS		
4 1	2940	73	1770	LDST	PR	5	.5	ZTS		
4 1	3012	75	1685	LDST	PR	5	1.0	OVLY		
4 10	3162	79	1485	LDST	PR	5	1.0	OVLY		CLOUDS PART EST
4 13	3243	81	1375	NOAA	PR		1.0	ZTS		
4 28	3206	80	1420	NOAA	PR		1.0	ZTS		
4 28	2826	71	1875	LDST	PR	4	.5	ZTS		CLOUDS
4 28	2932	73	1745	LDST	PR	4	1.0	OVLY		CLOUDS
5 5	2880	72	1820	NOAA	PR		1.0	ZTS		
5 6	2738	68	1950	NOAA	PR		1.0	ZTS		
5 7	2678	67	2015	LDST	PR	4	.5	ZTS		
5 7	2776	69	1920	LDST	PR	4	1.0	OVLY		
5 8	2836	71	1855	NOAA	PR		1.0	ZTS		
5 9	2880	72	1805	NOAA	PR		1.0	ZTS		
5 12	2660	66	2015	NOAA	PR		1.0	ZTS		
5 16	2694	67	1985	NOAA	PR		1.0	ZTS		
5 16	2453	61	2195	LDST	PR	4	.5	ZTS		
5 16	2549	64	2125	LDST	PR	4	1.0	OVLY		
5 18	2453	61	2195	NOAA	PR		1.0	ZTS		
5 23	2580	64	2090	NOAA	PR		1.0	ZTS		
5 24	2502	63	2165	NOAA	PR		1.0	ZTS		
5 25	2258	56	2335	LDST	PR	4	.5	ZTS		
5 25	2409	60	2220	LDST	PR	4	1.0	OVLY		
5 25	2440	61	2210	NOAA	PR		1.0	ZTS		
5 25	2678	67	2015	GOES	PR		1.5	ZTS		
5 27	2220	55	2350	GOES	PR		1.5	ZTS		
5 31	2126	53	2430	NOAA	PR		1.0	ZTS		
6 2	1792	45	2610	NOAA	PR		1.0	ZTS		
6 3	2222	56	2350	GOES	PR		1.5	ZTS		
6 3	1528	38	2775	LDST	PR	4	.5	ZTS		
6 3	1621	41	2715	LDST	PR	4	1.0	OVLY		

SATELLITE SCA DATA
KINGS RIVER, INFLOW TO PINE FLAT
BASIN 571 AREA 4002 SQ KM
WATER YEAR 1975

DATE	SCA SQ KM	SCA PCT	ELEV M	IMAGE SOURCE	IMAGE TYPE	BAND NBR	IMAGE SCALE	INTERP METHOD	ESTIM METHOD	COMMENTS
6 6	1968	49	2500	NOAA	PR		1.0	ZTS		
6 8	1733	43	2640	NOAA	PR		1.0	ZTS		
6 9	2046	51	2455	GOES	PR		1.5	ZTS		CLOUDS
6 10	1435	36	2805	NOAA	PR		1.0	ZTS		
6 12	1067	27	3020	LDST	PR	4	.5	ZTS		CLOUDS
6 12	1331	33	2875	LDST	PR	4	1.0	OVLY		CLOUDS
6 12	1321	33	2875	NOAA	PR		1.0	ZTS		CLOUDY
6 14	1207	30	2945	NOAA	PR		1.0	ZTS		
6 16	1168	29	2960	NOAA	PR		1.0	ZTS		
6 21	1181	30	2960	LDST	PR	4	.5	ZTS		
6 21	1311	33	2880	LDST	PR	4	1.0	OVLY		
6 21	1450	36	2805	NOAA	PR		1.0	ZTS		CLOUDS
6 25	1129	28	2980	NOAA	PR		1.0	ZTS		
6 30	495	12	3385	LDST	PR	4	.5	ZTS		
6 30	1054	26	3035	LDST	PR	4	1.0	OVLY		
7 18	215	5	3590	LDST	PR	5	.5	ZTS		

SATELLITE SCA DATA
KINGS RIVER, INFLOW TO PINE FLAT
BASIN 571 AREA 4002 SQ KM
WATER YEAR 1976

DATE	SCA SQ KM	SCA PCT	ELEV M	IMAGE SOURCE	IMAGE TYPE	BAND NBR	IMAGE SCALE	INTERP METHOD	ESTIM METHOD	COMMENTS
12 3	1497	37	2775	NOAA	PR		1.0	ZTS		
1 23	1461	37	2805	LDST	PR	5	.5	ZTS		
1 23	1357	34	2860	LDST	PR	5	1.0	OVLY		
1 25	1153	29	2965	NOAA	PR		1.0	ZTS		
1 26	1072	27	3020	NOAA	PR		1.0	ZTS		
2 10	3162	79	1480	LDST	PR	5	.5	ZTS		
2 10	3046	76	1630	LDST	PR	5	1.0	OVLY		
3 5	3600	90	815	GOES	PR		1.0	ZTS		
3 6	3105	78	1550	GOES	PR		1.0	ZTS		
3 8	3181	79	1455	LDST	PR	5	.5	ZTS		
3 8	3155	79	1495	LDST	PR	5	1.0	OVLY		
3 9	2730	68	1965	GOES	PR		1.0	ZTS		
3 13	2549	64	2125	GOES	PR		1.0	ZTS		
3 14	2854	71	1855	NOAA	PR		1.0	ZTS		
3 19	2929	73	1770	GOES	PR		1.0	ZTS		
3 20	2303	58	2295	NOAA	PR		1.0	ZTS		
3 26	2463	62	2190	LDST	PR	5	.5	ZTS		
3 26	2694	67	1985	CNQL	PR		.5	ZTS		
3 26	2466	62	2180	CNQL	PR		1.0	OVLY		
3 29	2743	69	1950	NOAA	PR		1.0	ZTS		
4 2	2315	58	2290	GOES	PR		1.0	ZTS		
4 3	2178	54	2395				.0		XB CL	
4 9	2828	71	1875	GOES	PR		1.0	ZTS		
4 12	1999	50	2500				.0		XB CL	
4 17	3126	78	1525	GOES	PR		1.0	ZTS		
4 18	2717	68	1985	GOES	PR		1.0	ZTS		
4 19	2598	65	2090	GOES	PR		1.0	ZTS		
4 19	2678	67	1990	NOAA	PR		1.0	ZTS		
4 21	1888	47	2560				.0		XB MS	
4 22	1971	49	2515	GOES	PR		1.0	ZTS		
4 25	2315	58	2290	NOAA	PR		1.0	ZTS		
4 28	1665	42	2675	GOES	PR		1.0	ZTS		
5 1	1432	36	2815	LDST	PR	5	.5	ZTS		
5 1	1267	32	2905	LDST	PR	5	1.0	ZTS		
5 1	1976	49	2500	CNQL	PR		.5	ZTS		
5 1	1927	48	2530	CNQL	PR		1.0	OVLY		
5 3	1292	32	2890	GOES	PR		1.0	ZTS		
5 10	995	25	3060	LDST	PR	5	.5	ZTS		CLOUDY
5 13	1054	26	3025	GOES	PR		1.0	ZTS		
5 14	1147	29	2975	GOES	PR		1.0	ZTS		
5 14	852	21	3150	NOAA	PR		1.0	ZTS		
5 15	1077	27	3020	GOES	PR		1.0	ZTS		
5 16	894	22	3125	GOES	PR		1.0	ZTS		
5 16	736	18	3210	NOAA	PR		1.0	ZTS		
5 17	935	23	3105	GOES	PR		1.0	ZTS		

SATELLITE SCA DATA
KINGS RIVER, INFLOW TO PINE FLAT
BASIN 571 AREA 4002 SQ KM
WATER YEAR 1976

DATE	SCA SQ KM	SCA PCT	ELEV M	IMAGE SOURCE	IMAGE TYPE	BAND NBR	IMAGE SCALE	INTERP METHOD	ESTIM METHOD	COMMENTS
5 19	697	17	3240	LDST	PR	4	.5	ZTS		
5 19	1220	30	2935	CNQL	PR		.5	ZTS		
5 19	932	23	3105	CNQL	PR		1.0	OVLY		
5 19	811	20	3170	NSQL	PR		1.0	OVLY		
5 28	479	12	3385	LDST	PR	4	.5	ZTS		
5 28	787	20	3185	CNQL	PR	5	1.0	OVLY		
5 28	831	21	3165	GOES	PR		1.0	ZTS		
5 30	772	19	3205				.0		XB CL	
6 1	710	18	3235	GOES	PR		1.0	ZTS		
6 3	671	17	3265	GOES	PR		1.0	ZTS		
6 4	635	16	3285	GOES	PR		1.0	ZTS		
6 5	648	16	3280	GOES	PR		1.0	ZTS		
6 6	329	8	3490	LDST	PR	4	.5	ZTS		
6 6	857	21	3140	CNQL	PR	5	1.0	OVLY		
6 15	91	2	3750	LDST	PR	5	.5	ZTS		
6 15	386	10	3455	CNQL	PR	5	1.0	OVLY		

SATELLITE SCA DATA
KINGS RIVER, INFLOW TO PINE FLAT
BASIN 571 AREA 4002 SQ KM
WATER YEAR 1977

DATE	SCA SQ KM	SCA PCT	ELEV M	IMAGE SOURCE	IMAGE TYPE	BAND NBR	IMAGE SCALE	INTERP METHOD	ESTIM METHOD	COMMENTS
1 4	3427	86	1075	GOES	PR		1.0	ZTS		
1 6	3388	85	1130	GOES	PR		1.0	ZTS		
1 8	2922	73	1775	LDST	PR	5	1.0	OVLY		
1 9	3067	77	1600	GOES	PR		1.0	ZTS		
1 11	3310	83	1260	GOES	PR		1.0	ZTS		
1 14	2722	68	1985	GOES	PR		1.0	ZTS		
1 17	2771	69	1920	GOES	PR		1.0	ZTS		
1 26	2409	60	2225	GOES	PR		1.0	ZTS		
1 26	2388	60	2235	LDST	PR	5	.5	ZTS		
1 26	2409	60	2225	LDST	PR	5	1.0	OVLY		
1 28	2393	60	2225	GOES	PR		1.0	ZTS		
2 1	2323	58	2290	LDST	PR	5	.5	ZTS		
2 13	2321	58	2290	LDST	PR	5	1.0	OVLY		
2 13	2297	57	2295	LDST	PR	5	.5	ZTS		
2 19	2077	52	2455	LDST	PR	5	.5	ZTS		
3 3	2564	64	2110	LDST	PR	5	.5	ZTS		
3 3	2699	67	1990	CNQL	PR	5	.5	ZTS		
3 3	2538	63	2135	NSQL	PR	5	.5	ZTS		
3 21	2315	58	2290	NSQL	PR	5	.5	ZTS		
3 21	2054	51	2470	LDST	PR	5	.5	ZTS		
4 8	1797	45	2610	LDST	PR	5	.5	ZTS		
4 14	1391	35	2835	LDST	PR	5	.5	ZTS		
4 25	984	25	3075	LDST	PR	5	.5	ZTS		
4 25	1158	29	2965	CNQL	PR	5	.5	ZTS		
5 2	2082	52	2455	LDST	PR	5	.5	ZTS		CLOUDY
5 14	2212	55	2355				.0		XB CL	
5 20	1753	44	2630	LDST	PR	5	.5	ZTS		
5 20	1860	46	2570	CNQL	PR	5	.5	ZTS		
6 1	596	15	3310	CNQL	PR	5	.5	ZTS		
6 1	769	19	3205	LDST	PR	5	.5	ZTS		
6 19	311	8	3510	LDST	PR	5	.5	ZTS		
6 24	23	1	3965	LDST	PR	5	.5	ZTS		

SATELLITE SCA DATA
KINGS RIVER, INFLOW TO PINE FLAT
BASIN 571 AREA 4002 SQ KM
WATER YEAR 1978

DATE	SCA SQ KM	SCA PCT	ELEV M	IMAGE SOURCE	IMAGE TYPE	BAND NBR	IMAGE SCALE	INTERP METHOD	ESTIM METHOD	COMMENTS
1 21	3010	75	1685	LDST	PR	5	.5	ZTS		
1 21	3046	76	1630	CNQL	PR	5	.5	ZTS		
2 26	2955	74	1740	LDST	PR	5	.5	ZTS		MANY CLOUDS
2 26	2890	72	1805	CNQL	PR	5	.5	ZTS		MANY CLOUDS
2 8	3046	76	1625	LDST	PR	5	.5	ZTS		CLOUDY
3 16	2955	74	1740	LDST	PR	5	.5	ZTS		
3 16	2945	74	1760	CNQL	PR	5	.5	ZTS		
3 25	2833	71	1870	LDST	TR	5	.5	ZTS		
4 9	3170	79	1465	NOAA	PR		1.0	ZTS		
4 12	2839	71	1870	LDST	PR	5	.5	ZTS		
4 21	2914	73	1785	CNQL	PR	5	.5	ZTS		
4 21	2890	72	1805	LDST	PR	5	.5	ZTS		
4 27	2756	69	1945	NOAA	PR		1.0	ZTS		
5 9	2657	66	2035	CNQL	PR	5	.5	ZTS		
5 9	2616	65	2045	LDST	TR	5	.5	ZTS		
5 18	2541	63	2135	CNQL	PR	5	.5	ZTS		
5 18	2530	63	2135	LDST	PR	5	.5	ZTS		ENLARGED PRINT
5 27	2435	61	2195	CNQL	PR	5	.5	ZTS		
5 27	2427	61	2205	NOAA	PR		1.0	ZTS		
5 27	2352	59	2255	LDST	TR	5	.5	ZTS		MICROTRANSPARENCY
5 29	2362	59	2255	NOAA	PR		1.0	ZTS		
6 1	2264	57	2335	NOAA	PR		1.0	ZTS		
6 5	2121	53	2440	CNQL	PR	5	.5	ZTS		
6 5	2108	53	2440	LDST	TR	5	.5	ZTS		
6 8	1968	49	2515	NOAA	PR		1.0	ZTS		
6 11	1955	49	2525	NOAA	PR		1.0	ZTS		
6 14	1652	41	2685	CNQL	PR	5	.5	ZTS		
6 14	1704	43	2655	LDST	TR	5	.5	ZTS		
6 23	1254	31	2915	LDST	TR	5	.5	ZTS		CLOUDS
7 2	1039	26	3040	LDST	TR	5	.5	ZTS		
7 11	925	23	3110	LDST	TR	5	.5	ZTS		
7 20	816	20	3205	LDST	TR	5	.5	ZTS		MICRO TRANSPARENCY
7 29	456	11	3410	LDST	TR	5	.5	ZTS		1:500000 TRANSPARENCY
8 7	425	11	3430	LDST	TR	5	.5	ZTS		SOME CLOUDS
8 16	146	4	3675	LDST	TR	5	.5	ZTS		
8 25	51	1	3815	LDST	TR	5	.5	ZTS		

SATELLITE SCA DATA
KINGS RIVER, INFLOW TO PINE FLAT
BASIN 571 AREA 4002 SQ KM
WATER YEAR 1979

DATE	SCA SQ KM	SCA PCT	ELEV M	IMAGE SOURCE	IMAGE TYPE	BAND NBR	IMAGE SCALE	INTERP METHOD	ESTIM METHOD	COMMENTS
2 24	3243	81	1380	NOAA	PR		1.0	ZTS		
2 28	3087	77	1570	GOES	PR		1.0	ZTS		
3 11	2973	74	1730	LDST	TR	5	.5	ZTS		
3 29	3098	77	1555	CNQL	PR	5	.5	ZTS		SOME CLOUDS
4 6	2766	69	1930	LDST	TR	5	.5	ZTS		PART MSS 7
4 30	2315	58	2290	PROV	PR		1.0	ZTS		
5 4	2378	59	2235	LDST	TR	5	.5	ZTS		
5 13	2160	54	2400	CNQL	PR	5	.5	ZTS		
5 22	1870	47	2570	LDST	TR	5	.5	ZTS		
5 31	1142	29	2975	LDST	TR	5	.5	ZTS		
6 9	847	21	3150	LDST	TR	5	.5	ZTS		
6 18	676	17	3265	LDST	TR	5	.5	ZTS		CLOUDY
6 28	471	12	3400				.C		XB MS	

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
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4. Title and Subtitle
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7. Author(s)
A. J. Brown and J. F. Hannaford

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9. Performing Organization Name and Address
California Department of Water Resources
P.O. Box 388
Sacramento, CA 95802

Sierra Hydrotech
P.O. Box 169
Placerville, CA 95667

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Goddard Space Flight Center
Greenbelt, MD 20771

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15. Supplementary Notes

A. J. Brown: California Department of Water Resources.
J. F. Hannaford: Sierra Hydrotech.

16. Abstract

This investigation involves an Applications Systems Verification and Transfer (ASVT) effort in California using five southern Sierra snowmelt basins and two northern Sierra-Southern Cascade snowmelt basins to evaluate the effect on operational water supply forecasting by including as an additional parameter the Snowcovered Area (SCA) obtained from satellite imagery.

Manual photointerpretation techniques were used to obtain SCA and equivalent snow line for the years 1973 to 1979 for the seven test basins using Landsat imagery supplied by NASA and GOES imagery supplied by NOAA/NESS. Timeliness of image delivery was a problem throughout the investigation. Delivery of NASA standard product was never within the 72-hour objective. Some Quick-Look and NOAA imagery was received within 72 hours.

The use of SCA was tested operationally in 1977-79. Results indicated the addition of SCA improved the water supply forecasts during the snowmelt phase for those basins where there may be an unusual distribution of snowpack throughout the basin, or where there is a limited amount of real-time data available. A high correlation to runoff was obtained when SCA was combined with snow water content data obtained from reporting snow sensors.

17. Key Words (Selected by Author(s))
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