As Dr. Court points out, careful study of each course should be made before eliminating any sample points. We would like to further recommend that along with the statistical review of points, a logical review of the physical characteristics of the course be made considering the aforementioned criteria.

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## PROGRESS IN SNOW MANAGEMENT RESEARCH IN CALIFORNIA

Henry W. Anderson[1/]

### INTRODUCTION

Snow studies are underway in California to develop and test methods of managing the snow zone for improved water yield. The studies are being made by the California Forest and Range Experiment Station of the U. S. Forest Service with the cooperation of the Department of Water Resources of the State of California.

The snow zone in California lies mostly on the west side of the Sierra Nevada and in the Cascade Ranges, roughly above 5,000 feet in elevation in the southern Sierra and above 3,500 feet in the northern Sierra and Cascade (figure 1). It is the area where more than half of the annual streamflow is yielded April 1 to September 30. The snow zone covers about 12 million acres - only 12 percent of the state - yet this area yields about 50 percent of the State's total streamflow (1). About 9 million acres of this zone are classed as commercial forest; they contribute about 40 percent of the State's water yield. Water yielded by melt of the snow pack is important not only because it is a large amount, but also because it is high in quality and is the principal water that feeds streams long after the rains have stopped.

Timber stands in the snow pack zone are still largely uncut, but logging is moving upward; it is only a matter of time until these high elevation commercial forests will be cut. We must learn how to cut forests and manage other lands in this zone in ways that will (1) exert control over water releases (2) guard against deterioration of water supplies originating there, and (3) improve water yield.

### IMPROVE WATER YIELD

Water yield would be improved if we could develop ways of accomplishing one or more of these objectives:

1. Increase total streamflow in all years, and especially in dry years.
2. Improve the timing of streamflow, by delaying snow melt and yielding more water in late spring and summer.
3. Maintain or improve water quality.
4. Minimize local floods and reduce sedimentation damages.

In developing methods that will improve water yield we need to be able to predict the effects of any possible management practice on water yield. Since tomorrow's demands for water may be completely different than today's; our research must span the possible practices, not just aim at the immediately practical.

### KINDS OF STUDIES

This is a report of progress in the studies during 1957 and early 1958. It outlines the studies underway, gives preliminary results from some studies, and tells of our plans. The studies are of 3 kinds: (1) Inventories of present conditions of water yield, land condition, and soil erodibility. (2) Development of methods of improving water yield and controlling sediment, and (3) Pilot tests of selected methods on experimental watersheds for their effects on streamflow and sedimentation.

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Reprint WESTERN SNOW CONFERENCE 1958 Proceedings

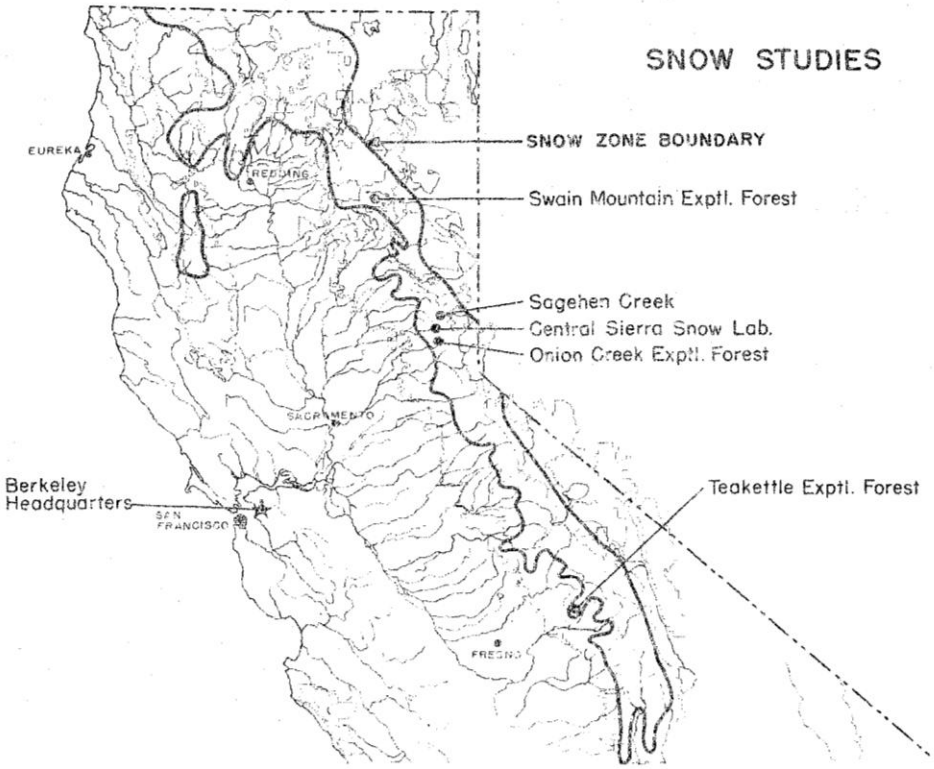


Figure 1.--Location of snow zone and study areas, California 1958.

Figure 2.--Onion Creek No. 2 stream gaging station and dam--typical setup for pilot testing effects of management on streamflow and sedimentation.

## STUDY AREAS

Studies are being conducted in 6 places (figure 1). At the Berkeley headquarters, we conduct inventories and analyses. At the Swain Mountain Experimental Forest, we are making plot studies of the effects of cutting forests in strips and blocks. At Sagehen Creek we are making plot and watershed tests which relate particularly to the effects of land treatment on fish habitat. At the Central Sierra Snow Laboratory, we are studying basic meteorology, snow physics, and forest hydrology. At the Onion Creek Experimental Forest, we are plot-testing the effects of ordinary logging and brush conversion, and preparing for watershed treatments. And at Teakettle Experimental Forest, we are calibrating watersheds to test the effects of forest cutting and grazing practices on streamflow and sedimentation.

## INVENTORIES

Snow zone forest, water, and soil are being inventoried to tell us: What conditions require research; how much land is subject to each land treatment; and where each treatment will have the most effect on snow and on water yield.

### Land Condition Inventory

The land condition inventory tells us the kinds of forests and their densities, the sizes of openings and the ground conditions in the openings—brush, grass-herb, bare ground, or rock outcrop—together with the topographic conditions where each occurs (2). We are interpreting aerial photo and topographic maps to obtain the needed information. Results for 18 transects sampling about 2/3 of the Sierra above 5,000 feet elevation, are shown in Table 1. The results were obtained by studying 40-acre plots located at 5-minute intersection of latitude and longitude.

The first results say that much of the Sierra is open; over 60 percent is in openings greater than 1 chain in radius (132 feet across): over 30 percent of these openings is occupied by brush. This information emphasizes that we should not only study management of timber areas in the snow zone, but also the management of brush areas for improved water yield. Slopes in the snow zone are mostly gentle. Over two-thirds are less than 30 percent, but about one-sixth are steeper than 40 percent. About two-thirds of the slopes face south or west. When the inventory is complete we will know not only the individual characteristics but the combinations of slopes, forests, and elevations which exist in the Sierra.

### Water and Soil Inventories

We are studying the streamflow of 130 Sierra streams and the sediment discharge from 75 northern California watersheds. From the study of streamflow we will make statistical analyses from which we can learn when water is delivered and in what amounts from each facet of each watershed of the snow zone. From the study of sediment discharge of watersheds we will locate the principal sediment sources. In this study, we are determining the erodibility of the soils of the wildlands. Soil samples are being taken of representative soil series. Then soil and watershed characteristics will be related by statistical analyses to the sediment discharge from the watersheds. From this study we will be able to tell where special precautions for erosion control might be most needed.

Starting in the summer of 1959 we hope to inventory the soil-moisture storage capacity and summer evaporation occurring in the major soil and vegetation types in the wildlands of northern and central California.

## DEVELOPING METHODS

How do we develop methods of improving water yield? The trial and error method is out. Too many forest conditions exist, too many thousands of trials could be made and still many questions remain unanswered. A better way is to study the hydrologic processes—what happens to snow—under differences in snowfall, vegetation, soil moisture, and heat and wind at any site.

In studying hydrologic processes we are first analyzing data already available. At the same time we have begun studies of snow behavior in natural openings and forest stands. Plot studies will follow to test the effects of cutting forests, treating brush, and other land treatments on water yield. Some first results are reported here.

Table 1.--Forest and slope characteristics for elevations above 5,000 feet on the west side of the Sierra Nevada Mountains, Latitudes 36°57-1/2' to 39°57-1/2'

| Item | Acreage | Percent of area |
|---|---|---|
| FOREST OPENINGS | | |
| Less than 132 ft. across 1/ | 1,953.5 | 22.1 |
| Less than 132 ft. across 2/ | 7.3 | .1 |
| 132-264 ft. across | 107.8 | 1.2 |
| 264-528 ft. across | 306.8 | 3.5 |
| 1056-2112 ft. across | 481.6 | 5.4 |
| > 2112 ft. across | 4,423.5 | 50.0 |
| Total | 7,280.5 | 3/ 82.3 |
| FOREST DENSITY | | |
| 0-14 percent | 5,327.0 | 60.3 |
| 15-39 percent | 1,603.5 | 18.1 |
| 40-69 percent | 1,521.5 | 17.2 |
| 70-100 percent | 388.0 | 4.4 |
| Total | 8,840.0 | 100.0 |
| CONDITIONS IN OPENINGS 4/ | | |
| Brush | 1,649.6 | 31.0 |
| Grass-Herb | 675.7 | 12.7 |
| Rock-Ground | 2,498.9 | 46.9 |
| Trees | 218.4 | 4.1 |
| Other | 284.4 | 5.3 |
| Total | 5,327.0 | 100.0 |
| SLOPE | | |
| 0-10 percent | - | 14.9 |
| 11-20 percent | - | 37.1 |
| 21-30 percent | - | 17.2 |
| 31-40 percent | - | 14.9 |
| 41-50 percent | - | 8.2 |
| 51-60 percent | - | 2.7 |
| 61-70 percent | - | 2.3 |
| over 71 percent | - | 2.7 |
| Total | - | 100.0 |

| Item | Acreage | Percent of area |
|---|---|---|
| SLOPE DIRECTION | | |
| North | - | 18.1 |
| East | - | 17.2 |
| South | - | 29.4 |
| West | - | 34.8 |
| Level | - | .5 |
| Total | - | 100.0 |

1/ Collectively determined.
2/ Individually measured openings consisted of roads and streams.
3/ Percent of total area.
4/ Openings greater than 132 feet across.

## Analysis of Past Data

We shall continue to analyze past data until such time as data from our own studies are available. Studies reported last year by Anderson and Pagenhart (3) and by Court (4) are examples of such studies. The results of two additional analyses are reported in these Proceedings. The paper by Court reports analysis of snow course data from the Onion Creek snow course collected as part of the regular California Snow Surveys. The analyses ask the question "What are the best snow course points" for determining the mean of snow course snow accumulation and for predicting the flow of a nearby stream. The paper by Anderson, Rice, and West reports analysis of snow data collected by the Corps of Engineers at the Central Sierra Snow Laboratory in 1947-1951. We have taken detailed measurements of the forest at their courses. These were correlated with snow accumulation and melt in a study of forest effects on snow.

## Natural Site Studies

We are making studies of snow accumulation, evapotranspiration, and wind at natural sites at and near the Central Sierra Snow Laboratory.

### Snow Accumulation

Snow accumulation is being studied in forest openings of various sizes and forest stands of various densities on various slopes. These measurements should tell us which conditions will accumulate the most snow and which delay snow melt longest. Sixty snow courses, with about 24 points in each, were selected last summer near the Central Sierra Snow Laboratory. Snow accumulation at each of the points was measured monthly during the winter of 1957-58 and twice monthly during the 1958 spring melt season. The courses were selected to have all combinations of possible forest conditions. To do this we tried to find courses to fill each blank of the "Selection Table" (Table 2). To fill every one would have required more courses than we could have measured, and probably more than actually exist, but we did select courses so as to get a good distribution of characteristics.

At each snow course a grid of points was randomly located, with the grid arbitrarily oriented North-South and East-West. At forest openings we spaced the points so as to have about one-third of the 24 points within the opening and two-thirds in the adjacent forest. We intend to analyze the snow accumulation at each of the snow measurement points, characterizing the forest in so far as possible by some measure of the energy received at the point and by measurements of the forest density in the solar paths. Ash Codd's pinhole canopymeter[2/] is being adapted to photograph the canopy in about 90 percent of the hemisphere. This instrument gives a permanent record of the canopy thus facilitating determination of several forest variables.

### Evapotranspiration

How much water is lost from various slope, soil, and vegetation types? Two main studies are underway — summer losses and winter losses.

Summer losses are being determined on about 45 different forest sites at the Central Sierra Snow Laboratory. These sites represent different slope, vegetation, and soil types. Four major soil types, the principal ones found in the Laboratory basin (5), are being studied.

Summer losses are being determined as the difference between moisture stored in the soil at field capacity, soon after the snow disappears in spring, and moisture left at the end of summer (corrected for any summer rain). We have obtained a radio-active soil moisture probe and scaler to speed this and other soil moisture studies.

First results from data obtained in 1957 have been summarized. Within forest stands on a Lytton soil, summer soil moisture losses ranged from 6.3 to 9.7 inches, where the soil ranged from 2 to 5 feet in depth.

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2/ Personal correspondence with Ashton Codd, Soil Conservation Service, Montana State University, Bozeman, Montana.

Table 2. Selected Snow Courses in forest and openings and their site characteristics, Central Sierra Snow Laboratory.

| Opening Size or Density Class 1/ | N Az. 315-45° % Slope 15 | | E Az. 45-135° % Slope 15 | | | S Az. 135-225° % Slope 15 | | | W Az. 225-315° % Slope 15 | | | Level % Slope 0-5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Forest Openings Courses | | | | | | | | | | | | |
| 1/2H to 1H 2/ | 73M | 73M | 76L | 67M | | 73M | 77L | | 74L | 74L | 62L | 61L |
| 1H to 2H | 73M | 74M | 78L | 72S | | 75S | 67S | | 73M | 63M | | 76L |
| 2H to 4H | 76L | | 75M | | | | 72M | | 75S | | | 72S |
| >4H | | 77S | | 75L | | 70L | | | 63L | | | 71M |
| Forest Density Courses | | | | | | | | | | | | |
| 20% to 50% | 73M | 75M | 75S | 77L | | 66L | | | 73S | 69M | 74M | 74M |
| 50% to 80% | 74M | 72M | 76L | 70M | 76L | 75M | 76L | | 74M | 73M | 76L | 76L |
| 80% to 100% | | 67M | 67M | 67M | | 78L | 78M | 76L | 67L | | 67L | 67L |

1/ Openings are in ratios of diameter of opening to height of surrounding trees e.g. 1/2H opening is one-half tree height across.

2/ The number is elevation of course in hundreds of feet, the letter is size of trees: L = Large, over 100 ft. high, M = Medium, 60-100 ft. high, and S = Small, less than 60 ft. high.

Winter losses are also being determined. This year, only evaporation from snow and interception by trees were measured. In the measurement of evaporation from snow, plastic pans were filled with snow (natural surface upward) and put flush with the snow surface in openings and under forest canopies. Studies are underway at the Laboratory and near Wishon Dam in the Kings River Basin. The results from the Kings River Study, taken for us by the Pacific Gas and Electric Company, are summarized in Table 3. Direct evaporation from the snow was rather small in the winter of 1957-58. In a large exposed opening the losses totaled 2.1 inches; in small forest openings, gains by condensation essentially balanced losses — 0.2 inches lost; and under forest canopies a net gain of 2.3 inches was measured. Seasonally, only during a dry spell in late February to April did significant evaporation from snow surfaces occur. Similar results were obtained at the Central Sierra Snow Laboratory. February to June loss in a small forest opening was 0.8 inch; loss under forest canopy was 0.3 inch. How evaporation and condensation from snow vary with position in openings, elevations, and season is also being studied.

## Wind

How goes the snow as the winds blow? To find out, 8 forest openings have been selected: 4 each on north and south slopes, of exposed and topographically sheltered sites. Snow accumulation patterns in the openings are being examined in relation to the wind. Wind measurements are from exposed sites, at the Laboratory headquarters, twenty miles to the west at Blue Canyon, elevation 5,000 feet (through the cooperation of the Weather Bureau), and on top of nearby Mt. Lincoln, elevation 8,383 feet (mostly with the instruments not cooperating—they ice up). So far, we know several ineffective ways of treating the anemometers on Mt. Lincoln to prevent icing. A special silicon anti-icing compound (General Electric) delayed icing somewhat but the anemometer still

Table 3.--Evaporation from and condensation on snow, and associated meteorological conditions, Kings River area near Wishon Dam, California, 1957 and 1958

| Date | Temperature Max. °F | Temperature Min. °F | Rel. Hum.[1] Max. Percent | Rel. Hum.[1] Min. Percent | Wind Mi./day | Evaporation or Condensation[2] In Forest[3] In. /day | Evaporation or Condensation[2] In Opening[4] In. /day | Evaporation or Condensation[2] In Open[5] In. /day |
|---|---|---|---|---|---|---|---|---|
| Jan 25, 1957 | - | - | - | - | - | +.012 | -.006 | -.010 |
| Nov 6, 1957 | 38 | 18 | 86 | 49 | 64.8 | +.021 | +.001 | +.001 |
| Feb 7, 1958 | 46 | 26 | 96 | 26 | 40.1 | +.006 | +.000 | -.020 |
| Feb 11, 1958 | 46 | 24 | 96 | 29 | 61.7 | +.002 | +.002 | -.013 |
| Feb 28, 1958 | 35 | 16 | 97 | 40 | 71.4 | [6]-.004 | -.005 | -.016 |
| Mar 4, 1958 | 37 | 11 | 92 | 37 | 77.5 | [6]-.007 | -.011 | -.056 |
| Apr 23, 1958 | 49 | 21 | 94 | 22 | 108.6 | -.012 | -.014 | -.011 |
| May 2, 1958 | 56 | 34 | 97 | 42 | 77.5 | +.013 | +.009 | -.007 |
| May 8, 1958 | 59 | 36 | 95 | 16 | 86.5 | +.018 | +.024 | [8] |
| May 16, 1958 | 65 | 40 | 94 | 15 | 93.2 | +.017 | [7]+.014 | [8] |
| | | | | | Median | +.0098 | +.0018 | -0.0104 |
| Estimated seasonal loss or gain Nov 1, 1957 - June 1, 1958 | | | | | | +2.2 | -0.2 | -2.3 |

1/ From Hygrothermograph, absolute accuracy low.
2/ Minus indicates evaporation; plus indicates condensation.
3/ Average Sta. No. 8 and 11.
4/ Median Sta. Nos. 5, 6, 7, 9, 10 & 12.
5/ Sta. No. 4.
6/ Median value used for one missing datum on Sta. 8.
7/ No snow at Sta. Nos. 6 & 7.
8/ Only patches of snow left, insufficient to sample.

Table 4.--Experimental watersheds, measurement devices and results 1956-57

| Name | | Major River Basin | Drainage Area | Elevation | Weir Type & Capacity | Reservoir Capacity | Sedimentation |
|---|---|---|---|---|---|---|---|
| | | | Sq. mi. | Ft. | | A.F. | A.F./Sq. mi. |
| Teakettle | No. 1 | N. Fk. Kings | 0.77 | 6410-8000 | 5'90°V 2x6' Cip. } 200 cfs | 0.351 | 0.058 |
| | No. 2 | N. Fk. Kings | 0.85 | 6920-8160 | 5'90°V 2x6' Cip. ) 200 cfs | 0.106 | 0.041 |
| | No. 2a | N. Fk. Kings | 0.27 | 6890-7940 | 5'90°V 135 cfs | 0.066 | 0.030 |
| | No. 3 | N. Fk. Kings | 0.86 | 6708-8100 | 5'90°V 2'x6'Cip. } 200 cfs | 0.117 | 0.013 |
| | No. 7 | N. Fk. Kings | 1/ 0.11 | 6800-7100 | 2'90°V 22 cfs | 0.204 | 0.211 |
| Onion Creek | No. 1 | N. Fk. American | 0.19 | 6160-7300 | 3'120°V 70 cfs | 0.113 | 2/ |
| | No. 2 | N. Fk. American | 0.48 | 6150-7600 | 4½'120°V 160 cfs | 0.261 | 2/ |
| | No. 3 | N. Fk. American | 1/ 0.51 | 6300-7896 | Section - | - | 3/ |
| | No. 5 | N. Fk. American | 0.39 | 6560-8383 | 4'120°V 140 cfs | 0.177 | 2/ |
| Castle Creek | No. 1 | So. Fk. Yuba | 3.96 | 6865-9103 | 12' Parshal, 300 cfs 149°V, 100 cfs | None | 3/ |
| Sagehen Cr. | No. 1 | Truckee | 11.1 | 6300-8000 | Variable V Section, 500 cfs | None | 3/ |

1/ Subject to revision after final field check of areas.
2/ Sediment accumulation started 1957-58.
3/ Watershed has no sediment basin. Suspended sediment samples are periodically taken.

iced up. Black paint on the anemometer cups was even less effective. Luckily the anemometer at the Blue Canyon station furnished good records. Analyses of these records showed that wind during snowfall was largely from the south-southwest, confirming analyses reported last year by Court (4).

Wind measurements within forest openings will start when our new field-going data logger-punch out system gets operating. This recorder will record in sequence 96 individual instruments. The records are converted to voltages, printed out on a multilogger, and simultaneously punched on a tape. The tape can be analyzed directly or the data can be punched on cards for summarization and analysis. Detailed measurement of other heat-flow elements in forest openings also await development of this data logger.

## Plot Studies

From basic studies, studies of natural sites, and analysis of past data will come suggested methods of improving water yield. These methods will be tested first on plots.

### Swain Mountain Forest Cutting

Snow accumulation and melt, soil-moisture storage and losses, and erosion are being measured in forest areas soon to be cut in various patterns of strips and blocks. We are taking measurements at 6 snow courses in and near the areas so we may evaluate the effects of the cutting on snow, water yield and erosion.

### Onion Creek Forest Cutting and Brush Treatment

Snow accumulation and melt, soil moisture losses and erosion are being compared in a forest area logged in the summer of 1957 and in a similar uncut area nearby.

Plot testing of brushland conversion to forest and grass is starting. Pretreatment measurements on brush areas will start this summer. Various combinations of slope, exposure, size of brush area, and soil depth will be sampled. We plan to measure snow and water losses for about two years to determine losses under the present brush cover, then convert the areas to grass or trees, or otherwise treat the areas in ways expected to improve water yield. The effects on snow and water will be measured.

## PILOT TESTING

The "best" methods developed for improving water yield must be pilot tested on experimental watersheds. How much is streamflow increased? When is water actually delivered? How much sediment is produced? What water quality results? Answers to these questions are to be obtained from tests on whole watersheds.

To make such tests we are readying eleven experimental watersheds. These occur singly and in groups in the headwaters of 4 major drainages: The Truckee, the South Fork of the Yuba, the North Fork of the American, and the North Fork of the Kings Rivers. The characteristics of the watersheds, the gaging devices, and sediment measurements for 1956-57 are summarized in Table 4. Figure 2 shows one of the dams and gaging stations constructed last summer.

The plan is to gage these watersheds and measure sediment production for 5 years or more as needed to calibrate them. When the flow and sedimentation for any watershed can be predicted with sufficient accuracy to detect a significant change in flow, then the watershed will be used to test methods expected to improve water yield. For example, in one watershed we will apply everything we know that will increase total water yield; in another watershed we will apply everything that will delay snowmelt and water yield; in a third we will treat each vegetation type in sequence, brush first, meadows next, forest and alpine last, to test their individual effects. Concomitant measurement of snow and water losses will be taken. Such are our plans for the experimental watersheds.

## REPORTS

Besides the four papers published in the 1957 Proceedings of the Western Snow Conference (3, 4, 6, 7) and the one paper cited in reference (5) these papers have been published:

(1) "Antifreezing Hood for V-notch Weir" by Carl O. Johannessen. Jour Fourest. 55(8): 590, 1957.

A foil lined plywood hood, resting on V-notch weirs prevents or reduces icing so as to permit accurate measurements of flows during winter. The hood is designed so as to be self-removing when the stage reaches 0.8 feet.

(2) "Relating Sediment Yield to Watershed Variables" by H. W. Anderson. Trans. Amer. Geophys. Union 38(6): 921-924, 1957.

(3) "Operation Wet-Blanket Gets Underway" by H. W. Anderson. Abstracted in Trans. Amer. Geophys. Union 38(3): 414, 1957.

(4) "Watershed Management. An Annotated Bibliography of Erosion, Streamflow, and Water Yield Publications by the California Forest and Range Experiment Station" by C. H. Gleason; CF & RES Tech. Paper 23, 79 pp illus. Jan. 1958.

(5) Progress Report, 1957, California Snow Management Research, by H. W. Anderson, California Forest and Range Experiment Station. 12 pp, May 27, 1957, processed.

## PERSONNEL

Eleven Technicians worked directly on the project during 1957-58: 3 meteorologists, 2 soils men, a geographer, a botanist, and 4 foresters. They were assisted by a like number of non-technical people.

## COOPERATION

The chief cooperator in the research is the State of California, Department of Water Resources. Besides furnishing advice and encouragement, they are matching Federal funds to conduct the research.

The Pacific Gas and Electric Company is cooperating by servicing 5 of our streamgaging stations at Teakettle Experimental Forest and by making snow evaporation and meteorological measurements near there.

The Weather Bureau is cooperating by taking wind speed and direction records for us at their Blue Canyon Station, 15 miles west of the Central Sierra Snow Laboratory.

The University of California, Department of Zoology is taking sediment records for us from Sagehen Creek, and making fish habitat studies so that the effects of watershed management on fish life can be evaluated.

A cooperative study of wind and snow temperature as factors in floods in the State grew out of a conference held in Berkeley in 1957. At five widespread mountain stations the Pacific Gas and Electric Company is taking daily readings of wind travel and direction and temperature of the snow. We and the Weather Bureau furnished the instruments; the Corps of Engineers and the State Department of Water Resources were the principal instigators. The records are kept by the PG&E in San Francisco with a copy to us. Bill Parsons of the PG&E reported at Bozeman that during the winter of 1957-58 snow temperatures at depths of 6 inches and greater seldom varied more than a degree from 32 degrees F.

Lastly, we would like to acknowledge receiving many valuable suggestions from colleagues throughout the country.

## CONCLUSIONS

The California Cooperative Snow Management Research Program is fully underway, with federal and state agencies and private companies cooperating. We expect to be able to answer for California: by how much, where, and how the snow zone can be managed to improve water yield.

This research program was stimulated by research results in other areas; we hope that our results will stimulate research in still other areas. Surely the product will exceed the sum of the parts.

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# FOREST SHADE RELATED TO SNOW ACCUMULATION[1/]

H. W. Anderson, R. M. Rice, and A. J. West[2/]

## INTRODUCTION

One of the better ways to start an argument is to make any categorical statement on how forests affect snow and the yield of water from snow. Forests intercept snow; therefore they must reduce the snow pack. Forests shade the snow; therefore they prevent melting and reduce evaporation, causing the snowpack to increase. Forest trees radiate heat and use water; therefore they decrease the snowpack. And so it goes, each effect of the forest has its conflicting effect; each refinement of measurement of the forest demonstrates its own inadequacy and points to the need for further refinements.

This paper is a report of our progress along this path—from measurement of forest effects on snow to refinement of measurements to recognition of still other effects. The study is one of the first steps in our program aimed at developing and testing ways of cutting forests and treating other lands to improve water yield from the snow zone.

We are currently trying to develop a system of physical measurements of forests that will more adequately index the various effects that forests have on snow. To do this, we have tested various measurements of the forest against the snow accumulation and melt at individual points within snow courses. The measures tested range from a single-valued index of forest cover to a 7-variable expression of the same forest cover.

We have made the studies in 3 parts: (1) A study of the effects on snow of the conventional forest variables of hemispherical cover and cover density, (2) a study of the effects on snow of forest variables when the hemispherical cover was differentiated into shade cast by the trees to the south and shielding or radiation produced by the trees to the north, and (3) a study of the effects on snow of several physical indexes of the forest. These studies are frankly exploratory; yet the results are interpreted as the best knowledge we have to date.

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1/ The study is part of the Cooperative Snow Management Research program being conducted by the California Forest and Range Experiment Station, with the cooperation of the California State Department of Water Resources.
2/ Snow Research Leader and Research Foresters, respectively, California Forest and Range Experiment Station, U. S. Forest Service, Berkeley, California.