CHAPTER 2 - SNOW LABORATORY DATA

2-01. INTRODUCTION

2-01.01 At the inception of the Cooperative Snow Investigations in 1944, the selection of snow laboratory areas was given careful consideration by a group of men from both the Weather Bureau and Corps of Engineers, who were at that time working on the problem of snow hydrology research. This committee worked under the general guidance of the instituting conference and was instructed to recommend locations for three laboratories, one in the upper Columbia River Basin, one in the middle Willamette River Basin, and one in the central Sierra Nevada. General specifications were established as to physical, climatological and hydrological features of each of the laboratories. They were intended to be out-of-doors laboratories of about 5 to 20 square miles in extent, located in areas of heavy precipitation and snow accumulation, with freedom from hydrologic uncertainties regarding their physical character. Three types of climatic regions with regard to winter season precipitation were to be sampled: (1) snow, (2) rain and snow with snow predominating, and (3) rain and snow with rain predominating. Accordingly, the locations for the three laboratories were selected, and types of instrumentation were chosen. Each laboratory contained a headquarters area, where studies of physics of snow were made and continuous observations of hydrometeorological events were assured. There were also field stations located at various points throughout the laboratory area at which instruments were checked periodically by field crews and observations were made of precipitation, snow accumulations and related meteorological elements.

2-01.02 In addition to the meteorological variability among laboratories, significant differences in exposure, topography, and forest cover prevail. Inasmuch as the forest influence has particular significance in establishing methods for evaluating snowmelt rates and also in consideration of forest influence on deposition and interception of snow, the amount and type of forest were carefully considered in the selection of laboratory areas. One of the principal aims of the laboratory program was to test methods of basin application in areas which were highly instrumented relative to that generally found in project basins. Differences in environment among laboratories were essential in order to sample effectively the range of conditions that are experienced in project basins.

2-01.03 Observations at the headquarters area of each laboratory were designed to provide continuous record of the hydrometeorological elements, with the equipment serviced at least once a day, according to the requirements of individual instruments. In addition, some special experiments were performed which would provide information on the physics of snow and hydrologic application of the principles as determined by point measurements. These include observations of soil and snow temperatures, soil moisture, radiation exchange, vertical gradients of wind, temperature, and humidity, snow characteristics at surface and within the snowpack, and thermal quality and liquid water content of snow; special tests conducted on impervious snow lysimeters, water holding capacity of snow, temperature and moisture gradients of the air close to the snow, atmospheric moisture transfer experiments, water transmission through the snow, and radiation penetration into the snowpack; and testing of equipment such as precipitation gages, soil moisture blocks, and automatic radio-reporting snow gages. Determination of snow-covered areas during the melt season was considered to be essential and was made at two of the laboratories for various seasons, primarily by aerial photographs.

2-01.04 The laboratory program was designed, therefore, to meet the objectives of the Investigations, both in determining physical relationships at a point and in applying these methods to basin areas, whereby the hydrologist could analyze with assurance, problems of snowmelt runoff for project design and operation, or for river forecasting.

2-02. GENERAL COMPARISON OF LABORATORY CHARACTERISTICS

2-02.01 All laboratories were located in rugged mountainous headwater areas of the western United States on the windward side of principal mountain ranges. All are characterized by rough topography in primarily virgin areas and thereby may be used to sample hydrologic variables in remote regions which ordinarily comprise a large part of the drainages effective in producing runoff for major rivers and tributaries in the West.

2-02.02 The geographical locations of each of the three laboratories (hereinafter designated CSSL, UCSL, and WBSL for Central Sierra Snow Laboratory, Upper Columbia Snow Laboratory and Willamette Basin Snow Laboratory, respectively) are shown on plate 2-1. Topographic maps showing locations of observation stations and general topographic features for each of the laboratories are shown on plates 2-2 through 2-4. Table 2-1 lists comparative data for each of the three laboratories, by which the general features of topography, climate, and hydrology may be evaluated. Detailed descriptions of laboratory characteristics are contained in section 2-04.

2-02.03 Upper Columbia Snow Laboratory. - UCSL was located on Federal lands in the Montana Rockies at the extreme headwaters of the Columbia-Clark Fork-Flathead river system. It lies just west of Marias Pass on the Continental Divide, which forms its eastern boundary, and is partly within the Waterton-Glacier International Peace Park. The basin comprises an area of 20.7 square miles with elevations ranging between 4500 and 8600 feet msl, with an average elevation of 5700 feet. It forms the headwaters of Bear Creek and its tributaries, Skyland Creek and Autumn Creek. It is traversed by the Great Northern Railroad and U. S. Highway No. 2, which cross the Continental Divide at Marias Pass (elevation 5215 msl), and is generally accessible at all times during the year. The laboratory area comprises three sub-basins: those of Skyland Creek, Upper Bear Creek, and Lower Bear and Autumn Creeks. Streamflow is measured so as to separate Skyland Creek basin from the rest of the area. Skyland

Creek basin, comprising 8.1 square miles, has a fairly deep soil mantle and is densely forested with lodgepole pine, while the other sub-basins have less soil cover and timber. The land surface of Skyland basin has an average slope of thirty percent and an average orientation toward the west. The climate in the laboratory region is characterized by a cold snowy winter with mean temperatures during December to March of 15° and short mild summers from July through August with temperatures averaging 55° F. During the year extremes of temperatures range from about 45° below zero to more than 90° above zero. Airmasses affecting the area generally move across the mountains from the Pacific Ocean or from the Arctic plains of Canada during the winter months. Summer airmasses produce appreciable amounts of rainfall. The annual basin precipitation before interception totals approximately 50 inches, or about 40 inches after interception, and it is fairly evenly distributed during the year. Virtually all winter precipitation is snow, which accumulates to an average basin water equivalent (after interception) of about 20 inches toward the end of March, just prior to the melting period. Estimated annual runoff averages 26 inches, of which about 85 percent occurs during the six-month period, April through September.

2-02.04 Central Sierra Snow Laboratory. - CSSL is a 4-square-mile area comprising the basin of Castle Creek, a tributary to the South Fork of the Yuba River, just west of the crest of the Sierra Nevada in California. It was located partly on leased and partly on Federal lands. The area ranges in elevation from 6900 to 9100 feet with a mean elevation of 7500 feet msl. It has a moderately rough surface of granite and lava inclined toward the south-southwest. This surface bears patches of soil and moraine and is sparsely covered with stands of lodgepole pine. The laboratory basin is served by the Southern Pacific Railroad and U. S. Highway No. 40, which cross the Sierra Divide a few miles to the east at Donner Pass. The climate is distinguished by summers that are warm and rainless and winters that are cool and snowy. Winter temperatures average a few degrees below freezing. Most winter precipitation falls as snow, occasionally interspersed with fairly heavy rainfall. The annual precipitation before interception averages 70 inches, 83 percent of which occurs during the six months, October through March. The snow pack begins to accumulate in November and increases by the end of March to an average basin water equivalent (after interception) of approximately 40 inches.

2-02.05 Willamette Basin Snow Laboratory. - WBSL is an 11-square-mile area on Federal land in the dense wet forest of the middle Cascade Range, about 30 miles east of Willamette Valley and 10 miles west of the high lava plateau of central Oregon. It includes the headwaters of the Blue River, a tributary of the McKenzie River, which flows west to join the Willamette River near Eugene, Oregon. Almost all the area is covered with heavy virgin forest of Douglas fir, hemlock, and other conifers. The ground surface has an average slope of 35 to 40 percent and is oriented generally toward the south and southwest. The basin lies between 2000 and 5500 feet msl, with a mean elevation of 3400 feet. Access to the area is by Forest Service roads and trails. The climate is maritime, with a seasonal shift in airflow from southwest in winter to northwest in summer. Precipitation is heavy, totaling over 100 inches per year, about one-half of which falls as snow. Mean air temperatures vary from slightly below freezing during the winter to the high fifties in late summer. Maximum precipitation occurs in early winter and diminishes during late winter and spring to a minimum in late summer, which is nearly dry. The snowpack begins to accumulate during November and continues to increase in depth to an average of about 120 inches (as estimated for headquarters station) near the end of March, with a water equivalent of about 60 inches. Runoff from the basin averages about 75 inches annually, and is concentrated in the winter, the greatest portion occurring in the six months from November through April. Rainfall on the snow is prevalent during the winter and this situation was of importance in original selection of the laboratory site. Ordinarily, flood peak runoff, which may be expected in December and January, is primarily due to rainfall on the snow-covered watershed.

2-02.06 General comparison of topographic and environmental features. - Inspection of data contained in Part I of table 2-1, reveals that the mean elevations of the laboratory basins range from about 3400 feet for WBSL to 7500 feet for CSSL. Considering the effect of latitude differences on climatic elements for western United States, it is estimated that the mean basin elevation of each of the laboratories corresponding to a reference latitude of 45°N would be equivalent to about 6000 feet for CSSL, 3500 feet for WBSL, and 6500 feet for UCSL. The range in elevation within individual laboratories is 2200 feet at CSSL, 3400 feet at WBSL, and 4100 feet at UCSL. Skyland Creek in the UCSL has a range of 2800 feet. All basins are relatively steep, and considering average slopes of each basin area, WBSL, with an average slope of 40 percent, is steepest. Skyland Creek in UCSL is next steepest, with 32 percent average slope, while CSSL has an average slope of 25 percent. The slopes are predominantly south-facing in WBSL and CSSL, while in Skyland Creek, slightly over half of the area faces north. There is a wide range of forest types among laboratories. CSSL is sparsely forested, predominantly with lodgepole pine; only 40 percent of the basin area is forested, and the canopy density on the forested portion is estimated to be 50 percent. WBSL on the other hand, lies in an area of heavy forests of Douglas fir and hemlock-fir types which cover 93 percent of the area. Skyland Creek at UCSL is heavily forested, mainly with immature lodgepole pine, over about 90 percent of the area, and average canopy density is estimated to be 80 percent. In contrast, the remaining area on UCSL is estimated to have only 30 percent of its area forested. Considering the geology of the laboratories, the predominant rock formations range from granite and other non-porous volcanic rocks at CSSL, and relatively non-porous formations of volcanic origin at WBSL, to old sedimentary rocks which have been extensively glaciated in recent times at UCSL. None of the laboratories is known to have significant uncertainties from unknown conditions of ground water outflow from its basin. Soils are thin at CSSL and UCSL, but there are deep mountain soils at WBSL. There are large parts of the Bear Creek drainage in UCSL and at CSSL that are devoid of soils.

2-02.07 General comparison of climatic features. - Part II of table 2-1 lists general comparative climatic data for each laboratory, adjusted to basin means and based on a period representing approximately a 20-year normal ending in 1954. The average annual basin temperature ranges from 34°F at UCSL to 45°F at WBSL. CSSL is intermediate at 38°F. There is little spread in mid-summer temperatures among laboratories and they range between 56°F and 62°F for July averages. Winters, however, are much colder at UCSL than at the other laboratories. The mean January temperature for Skyland Creek is 14°F, while at the WBSL it is 32°F. At CSSL, the January temperature is 23°F.

2-02.08 There is wide variation in amount of total precipitation at each laboratory. Each year, the UCSL normally receives 50 inches, CSSL 70 inches and WBSL 105 inches*. The winter months of October through March are wettest on each of the basins; about 63 percent of the annual amount falls in winter at UCSL, about 80 percent at WBSL, and about 83 percent at CSSL. During April through September, UCSL receives nearly 60 percent more precipitation than CSSL. The average amount of winter precipitation falling as snow is about 90 percent at UCSL and CSSL, and only about 50 percent at WBSL. Interception of snowfall accounts for 10 to 20 percent loss from basin snowfall. Melt during the winter period, including ground melt and melt caused by atmospheric processes, varies in average seasonal amount from 4 to 30 inches, the UCSL being least and WBSL greatest. Solar radiation was measured at UCSL and CSSL, and incident radiation averaged about 30 to 40 percent greater at CSSL than at UCSL during the spring melt months of April, May and June. It is difficult to compare mean windiness on the basis of surface data, but average air flow at the 700 mb level (equivalent to about 10,000 feet) offers some guide to predominant wind directions. Wind data, given in Part II of table 2-1, were obtained from the Normal Weather Charts for the Northern Hemisphere 7/ and actually represent the vectorial sum of wind at a given point. All three laboratories lie in the zone of prevailing westerly wind, but there are seasonal shifts from southwest to northwest. In general, the circulation is somewhat stronger at the more northerly laboratories than at CSSL.

2-02.09 General comparison of hydrologic features. - Part III of table 2-1 lists comparative streamflow data, for a general comparison of hydrologic features of the laboratory areas. The variation in average annual runoff among laboratories corresponds to the variability of annual precipitation. Considering average basin runoff in inches, adjusted to a 30-year normal period ending in 1950, the WBSL, whose average is 77.0 inches per year, is wettest of the three laboratories. The upper portion of WBSL, as shown by the Mann Creek and Wolf Creek gages, has from 10 to 20 percent more runoff than the basin average. CSSL is intermediate among laboratories, in terms of average annual runoff, and normally has about 43 inches. Annual runoff from UCSL averages 26.5 inches, and the Skyland Creek portion has about 8 percent more runoff than the basin as a whole. Seasonal distribution of runoff for UCSL and CSSL is characterized by low winter flows, which average 15 to 22 percent, respectively,

* Beneath the forest crown.

of the annual amount during the six-month period, October through March. At WBSL, on the other hand, from 50 to 60 percent of the runoff occurs during the winter season.

2-02.10 Because of the relatively short periods of record at the laboratory basins, extremes of discharge are not necessarily significant for comparative purposes. The maximum flow at CSSL corresponds to a discharge of 300 cfs per square mile, and occurred in November 1950, as the result of an intense rain on a light snowpack. This flow is considered to represent a near-record maximum for this type of area. At WBSL, the maximum observed discharge of 122 cfs per square mile is one which would be expected once in every few years for its area, on the basis of maximum flow in surrounding streams. At UCSL, the maximum recorded discharge was only 35 cfs per square mile. Minimum discharges range from 0 to 0.26 cfs per square mile. At CSSL, the flow in Castle Creek entirely ceases every summer. In the other two laboratories, there is sufficient flow from ground-water storage to cause a carryover of runoff during periods of no basin moisture input.

2-02.11 In order to define the relative basin time lags resulting from all factors serving to delay runoff other than the snowpack itself, average recession curves were derived for each laboratory basin. These curves define the time rate of change of flow during normal flow recession and thereby provide a measure of the natural time lag characteristics of the basin. From curves derived empirically by methods set forth in chapter 4, it can be stated in general that in Castle Creek at CSSL, the delay of runoff that is due to surface and subsurface storage is about one-half of the corresponding delay for either WBSL or UCSL, throughout the various ranges of unit flows in cfs per square mile. When comparing recession coefficients on the basis of actual magnitude of discharges, CSSL has, at relatively high flows, about one-third to one-fourth the delay that either USCL or WBSL has. This effect is evident from the much greater magnitude of diurnal fluctuation of flows at CSSL, compared with WBSL and UCSL. The recession characteristic integrates a multitude of basin effects, including average slopes over the basin, types of soil, channel lengths and conditions, ground-water geology, forest cover, and many lesser influences, into a single average relationship, and thus becomes a very useful tool in applied hydrology and hydrograph analysis. More detailed comparisons of laboratory recession curves are presented in paragraph 2-04.35.

2-03. LABORATORY ADMINISTRATION

2-03.01 The Cooperative Snow Investigations had, as its first major operation, the establishment of each of the three snow laboratories, including the necessary provisions for laboratory operation and instrumentation. In addition, operational and administrative channels were formulated, in order to provide adequate control of the operation as a whole. Reference is made to plate 1-1, showing channels of command for laboratory operation during the cooperative phase of the work between the Weather Bureau and the Corps of Engineers. The responsibility for selection of instrumentation, type and frequency of observations, and methods of handling the data was held by the program director. Coordination and standardization of observational techniques for the laboratories, as well as supervision of special tests and development of new instrumentation, were effected by the Technical Supervisor. The administration of the physical operation of laboratories, including arrangements for procurement of supplies and equipment, living facilities, transportation and land acquisition, was accomplished by the Corps of Engineers District Offices having supervision of the area in which the laboratory was located. The direct responsibility of laboratory operation, to implement the requirements set forth from both technical and administrative supervision, rested in the laboratory director, who was a Weather Bureau employee at CSSL (up to 1950) and a Corps of Engineers employee at UCSL and WBSL. Both Weather Bureau and Corps of Engineers employees were on permanent duty at CSSL and UCSL, and personnel administration was accomplished by their respective offices. At WBSL, all employees on permanent duty were under the supervision of the Corps of Engineers. Table 2-2 lists the laboratory director and average number of employees, both Corps of Engineers and Weather Bureau, for each year of laboratory operation.

2-03.02 Staffing presented a major problem in laboratory operation. Since the laboratories were located in remote, headwater regions in the mountainous areas, there was considerable difficulty in obtaining properly trained personnel who could adapt themselves to the rigors and isolation required, and at the same time pursue with diligence their normal and sometimes unique duties. Trips to field stations were made weekly or bi-weekly throughout the winter, and instruments were, as a rule, serviced under adverse weather conditions. The WBSL was particularly isolated and a large percentage of the effort of the staff was required for maintenance of minimum living standards.

2-03.03 Agency cooperation. - Besides the Weather Bureau and Corps of Engineers, other Federal Agencies participated in some of the functions of the field observational program, on a cooperative basis. The U. S. Geological Survey installed and operated the stream gaging stations at both WBSL and UCSL, on a reimbursable basis. Aerial photographs of snow cover through the melt season were made in cooperation with the U. S. Air Force at CSSL and U. S. Forest Service at UCSL. Aerial photographs were also obtained by the Forest Service for the purpose of constructing aerial mosaics of each laboratory, from which basin topographic maps could be prepared. The Forest Service also installed soil moisture meters at UCSL and obtained observational data from them. Forest Service cooperation included construction and maintenance of roads and trails, notably at UCSL, and in some cases, use of buildings or shelters.

2-03.04 Cooperation with Snow, Ice, and Permafrost Research Establishment. - Responsibility for snow, ice and permafrost research for the joint benefit of the U. S. Armed Services was assigned to the

Department of the Army and to the Chief of Engineers for operations in 1949. The Snow, Ice and Permafrost Research Establishment (hereinafter referred to as SIPRE) was organized the same year. Its purpose is to perform basic research on properties of snow, ice and permafrost, and the application of basic snow research to military problems.3/ In 1950, the Weather Bureau terminated its participation in the Cooperative Snow Investigations laboratory program, and at approximately the same time, SIPRE was embarking on an observational program in snow research. Since the facilities of CSSL were available, arrangements were made whereby SIPRE could establish its facilities for observations at CSSL, and the observations were then cooperative between SIPRE and the Snow Investigations. While the Snow Investigations Unit was interested primarily in hydrologic application of snow research, and SIPRE was concerned with basic research leading to application for military use, many of the observations could satisfy both requirements. The establishment of a micrometeorological program at the Lower Meadow was one of the major accomplishments done under the direction of SIPRE, and special observations were performed at the request of each of the agencies. The laboratory director was employed by SIPRE, but administrative operation of the laboratory was under the direction of Sacramento District. This phase of the observational work at CSSL closed in June, 1953, when SIPRE moved to its new laboratory in the midwest, and the snow investigations terminated year-round observations.

2-03.05 CSSL was operated during the 1954 melt season under the direction of the Snow Investigations Unit. Observations were confined to special studies in connection with previously constructed snow lysimeters. Runoff for the laboratory basin was measured, and meteorological instrumentation was maintained at the headquarters area and at the Lower Meadow. No basinwide snow surveys or precipitation measurements were made. At the close of the 1954 melt season, CSSL was closed and no further observations were performed by the Snow Investigations Unit. UCSL was closed at the end of the 1951 melt period, and observations at WBSL were terminated in 1952.

2-04. DETAILED DESCRIPTION OF THE LABORATORY AREAS

2-04.01 General. - It was originally the intent of the program to prepare detailed technical reports on the physical and climatological features of each laboratory. Lack of time precluded the completion of those reports, except for Technical Report 4-A, entitled, "Terrain Characteristics, Central Sierra Snow Laboratory." This report presents in detail the features of that basin with regard to topography, geology, vegetation, and drainage, whereby analysis could be made for transferring the hydrologic variables to conditions of known environment on project basins. The work included the delineation of the 4 square mile basin into 20 topographic units of individual characteristics. Such detailed analyses have not been accomplished for the other laboratories, and later studies have indicated that more general classifications of terrain factors affecting snow accumulation and snowmelt are adequate, when considering the relative degree of accuracy of measured amounts in basin application. Therefore, this section presents comparative data generally in less detail than was originally considered necessary in developing hydrologic relationships, but the comparisons are believed to be adequate for the purpose of obtaining qualitative evaluation of methods used in relating measured to basin amounts. Each laboratory is discussed as to its physical landscape and general characteristics of climate and hydrology. Insofar as possible, direct comparisons of laboratory features are presented, with regard to both verbal descriptions and presentation of data by diagrams.

2-04.02 Laboratory access. - The ease of operation of each laboratory and the maximum utilization of personnel on the observational program was dependent to a large extent on the ease of access to the basin area from major communication routes and on the extent and quality of roads and trails within the basin areas. The headquarters area at UCSL was located adjacent to U. S. Highway 2 and the Great Northern Railroad, both of which are all-weather arteries through the Continental Divide at Marias Pass and connect the Pacific Northwest with the midwest of the United States. Although the highway is occasionally blocked by snow during the winter, railroad traffic is interrupted only under very unusual conditions. Travel within the laboratory was accomplished by roads and trails, which could be negotiated by four-wheel drive vehicles during the summer to service outlying gages. In winter, snow tractors were utilized for transportation within the laboratory area whenever conditions would permit, but approximately half of the distance traveled was accomplished on foot, either with skis or snowshoes. Commercial power facilities were not available at the time the laboratory was established, so portable power supplies were used to furnish electrical power at the headquarters area.

2-04.03 CSSL is similar to UCSL with respect to major highway access; U. S. Highway 40 borders the laboratory area on the south, and the Southern Pacific Railroad connecting San Francisco with the East parallels the highway at Donner Pass through the Sierra Nevada. With the exception of short periods following major storms they were kept open throughout the winter season. Within the laboratory area, roads and trails served as access to field stations during the summer, and snow tractors could be utilized over much of the area during winter. About 50 percent of the travel to service outlying stations was accomplished by snow vehicle, and the remainder on foot, either with skis or snowshoes. Commercial power supplied electrical energy to the headquarters area and later to the Lower Meadow micrometeorological observation station.

2-04.04 Access to WBSL was difficult. The closest highway to the headquarters area was 5 miles by forest road, which required that when snow was in the area (usually from October through May or June), transport of all supplies, equipment and personnel be by snow vehicle or on skis. The South Santiam highway, which the forest road joins at Rabbit Camp, was kept open throughout the winter but was occasionally closed following a major storm. Travel within the laboratory area was tedious. The use of snow vehicles was limited to about 10 percent of the total travel to outlying stations, because of many fallen trees over the roads and trails, and because of the steep slopes in the area. There was no commercial electric power, and portable power equipment was utilized at the headquarters area.

2-04.05 Surface configuration. - For the purpose of this description, comparative data for each laboratory are given below for stream systems and profiles, area-elevation relationships, steepness of slopes, and orientation. It is believed that these general classifications of topography are sufficient for defining the features of each laboratory, in order to arrive at a qualitative appraisal of the characteristics of each area. Reference is made to the topographic maps of each laboratory contained on plates 2-2 to 2-4.

2-04.06 UCSL, with 20.7 square miles total area, may conveniently be divided into two subdivisions: (1) Skyland Creek basin and (2) the Intermediate area of Upper Bear, Lower Bear and Autumn Creeks. Skyland Creek drains 8.09 square miles of steeply rolling forested area bounded by the Continental Divide on the east, Challenge Divide on the south, and Mule Ridge on the southwest. The Intermediate area of 12.61 square miles is bordered by the rugged Algonkian Ridge on the northwest, which is a very steep glaciated escarpment about 4 miles long whose summit averages about 2500 feet higher than the gentle slopes of the valley floor. The Blacktail Hills separate Upper Bear Creek drainage from Autumn Creek drainage and are low-lying hills whose summit averages about 6000 feet. Stream profiles for Bear Creek and Skyland Creek are shown on figure 1, plate 2-5. The average slope of Bear Creek is about 140 feet per mile after it emerges from the rugged slopes of Bear Peak. The slope of Skyland Creek averages about 200 feet per mile in its lower reaches and the channel slopes gradually steepen when approaching the headwaters of Elkcalf Mountain. In general, all major tributaries are typical mountain streams consisting of alternate cascades and pools. There are no lakes on the stream courses, but a portion of Upper Bear Creek passes through an area of marshy ground which is slightly less than a mile long. Almost all of the analytical work on UCSL was performed on the Skyland Creek drainage because of its freedom from excessively irregular topography and its greater homogeneity, in comparison with the Intermediate area.

2-04.07 CSSL contains 3.96 square miles of rugged land located just west of the summit of the Sierra Nevada, the eastern boundary of the laboratory forming a segment of the divide. The northern end of the basin is bounded by Castle Peak (elevation 9105 ft.) which forms a sharp escarpment with steep slopes, in places almost vertical, and rises about 1500 feet above the valley floor. On the west, the divide is formed in part by Andesite Peak, whose maximum elevation is 8215 feet. Andesite Ridge projects southeastward into the basin from Andesite Peak, and effectively divides the western half of the basin into two parts. Castle Creek is the only major drainage channel within the basin. It heads on the slopes of Castle Peak, flows southeastward through Willow Valley and

Upper Meadow and swings in around Andesite Ridge, from where it flows southwestward to the basin outlet. Channel slopes average about 200 feet per mile except for the Lower Meadow, where the slope is about 70 feet per mile. The headwaters of Castle Creek on the face of Castle Peak are much steeper. There are no lakes on the main stem of Castle Creek. Grass Lake, located in Euer's Saddle on the eastern edge of the basin has little effect upon runoff because of the very small area contributing to it. Reference is made to Technical Report 4-A for more detailed description of the terrain features of CSSL.

2-04.08 The 11.5 square mile area of WBSL may be divided into three segments. Mann Creek, which drains nearly the entire northern half of the basin, contains 5.12 square miles. Wolf Creek drains a segment of 2.06 square miles on the east side of the basin. Mann Creek and Wolf Creek join to form Blue River. The area draining into Blue River below the confluence and above the laboratory basin outlet is the third segment and is identified as Intermediate Blue River Drainage (D.A. = 4.33 sq. miles). The northern edge of WBSL is formed by the divide separating McKenzie River and Santiam River drainages. Squaw Mountain (elevation 5235 ft.) is the principal peak on this portion of the divide. The eastern boundary is formed by a divide culminating in Carpenter Mountain (elevation 5364 ft.), located in the southeast corner of the basin. Mann Ridge, which varies from about 3000 to 4000 feet msl, serves as the western boundary of the basin. A small butte known as Wolf Rock is a volcanic neck rising some 1000 feet above the surrounding valley and lies in the east central portion of the basin. Mann Creek heads in the vicinity of Squaw Mountain and flows generally southward to confluence with Wolf Creek near the center of the basin. Wolf Creek originates in Wolf Meadow and flows westward to the south of Wolf Rock. Blue River flows generally southwestward to the laboratory basin outlet, which in turn is some 14 miles above its junction with the McKenzie River. Channel slopes on Blue River, within the laboratory basin, average about 200 feet per mile, but slopes of Mann and Wolf Creeks are about 500 feet per mile. The streams are all swift mountain cascades, and there are no lakes of significance within the basin.

2-04.09 Area-elevation relationships. - Area-elevation data were computed for each laboratory, and graphical plots of these relationships are shown on figure 1, plate 2-6. The data were obtained by planimetering zones of elevation from the topographic maps for each laboratory. The curves represent the percentage of area above a given elevation for each laboratory basin and major subdivision. All are plotted on a common scale of elevation and percentage of area, so that direct comparison of elevation characteristics of each laboratory may be made. The following table summarizes the data from this diagram:

Laboratory Drainage	Drainage Area Sq. Mi.	Elevation Feet MSL			Elevation above which lies given percent of area	
		Mean	Max	Min	25%	75%
UCSL (Total)	20.7	5700	8605	4480	5950	5350
Skyland Creek	8.09	5900	7610	4800	6175	5600
Intermediate Area	12.61	5500	8605	4480	5700	5225
CSSL (Total)	3.96	7500	9105	6880	7725	7275
WBSL (Total)	11.51	3433	5364	1959	3925	2950
Mann Creek	5.12	3760	5235	2491	4175	3350
Wolf Creek	2.06	3600	5364	2491	3850	3275
Intermediate Area	4.33	2980	5364	1959	3325	2550

2-04.10 Area-slope relationships. - Area-slope relationships were derived for each laboratory, on the basis of sampling on a topographic map the slope characteristic at the grid-intersection points uniformly spaced over the basin. There were approximately 250 such intersection points on each laboratory sub-basin. The percentage of area for a given slope was accumulated from the steepest slope, downward, and curves were plotted representing the percentage of area whose slope is equal to or greater than a given slope, as shown on figure 2, plate 2-6. A summary of these data is listed in the following tabulation:

Laboratory	Drainage Area Sq. Miles	Slope in Percent*				
		Basin Mean	Values of slopes equalled or exceeded, for given percentage of area			
			10	20	50	80 % of area
UCSL (Skyland Creek)	8.09	32	52	44	30	21
CSSL (Total)	3.96	21	51	26	16	9
WBSL (Total)	11.5	40	63	53	38	25

It is seen that the mean slope of CSSL is about one half of that for WBSL, and that Skyland Creek in UCSL is about midway between the two. There

*Slope is measured as the vertical rise in feet per 100 feet of horizontal distance, averaged for a distance of 500 feet from each intersection point.

are some very steep slopes in all the laboratory areas, as shown by the values given for the steepest 10 percent of the area, ranging from 51 to 63 percent.

2-04.11 Orientation. - The basin orientation is important for two general considerations: (1) its effect on the accumulation of precipitation, both in the form of rain and snow; and (2) its effect on snowmelt rates. The effects may be independent of one another, when considering the prevailing meteorologic conditions during the snow accumulation period and their relationships with terrain, and also, when considering the meteorologic and terrain factors affecting melt. General evaluation of orientation was determined on the basis of basin averages for each of the laboratories, and graphical plottings of the percentage of the basin area facing in a given octant of the compass are shown in figure 3, plate 2-6, for (1) Skyland Creek, UCSL; (2) Mann Creek, WBSL; (3) the entire WBSL; and (4) CSSL. These graphs are presented in such a manner that the area in a given octant on the graph is directly proportional to the percentage of basin area whose orientation is within the octant.

2-04.12 Comparing orientation among laboratories, it is shown that the CSSL and Mann Creek (WBSL) areas have similar average orientation, with nearly 50% of the two areas facing in the quadrant from SE to SW. Skyland Creek, on the other hand, is nearly uniformly distributed between north and south orientation. The following table lists percentages of basin area for given sectors of orientation:

Laboratory Drainage Area	Percentage of area facing quadrant centered on: N	E	S	W
Skyland Creek, UCSL	31	15	31	23
WBSL (entire area)	17	21	34	28
Mann Creek, WBSL	6	22	48	24
CSSL (entire area)	11	17	49	23

2-04.13 Geology. - The evaluation of the effect of surface and subsurface rock formations on transmitting and storing water requires adequate geologic investigation. To accomplish this, detailed geologic field surveys were performed for UCSL and CSSL. No such survey was made for WBSL, but geologists from the Portland District made cursory field examinations of that area; in addition, published geologic descriptions for the Cascade Mountains were reviewed in detail. It is sufficient for the purpose of this report to describe the geology only in general terms, but emphasis is placed on the conclusions from investigations regarding the water permeability of the basins, considering the likelihood of water passing into the basin from surrounding areas or out of the basins through underground channels and thereby not measured as basin outflow. The storage time of delay to runoff by the combined effect of storage and flow through subsurface channels (both through the soil and underlying rocks) is taken into account by streamflow recession analysis, and direct evaluation of water stored in basin aquifers is not necessary. Therefore, the principal consideration of the geologic character of each basin is the determination of how well the basin boundary determined by surface drainage patterns represents the true area contributing to runoff, considering also the possibility of water loss by deep percolation.

2-04.14 The physical condition of UCSL is characterized by a mature stage of stream erosion, with sharp ridges and steep slopes, as shown on the topographic map (plate 2-2). It has been modified somewhat by glaciation, and glacial debris remains on a large part of the area and varies in thickness from a few feet up to 150 feet in the valley bottoms. Rock is exposed practically everywhere around the border except at Marias Pass, and there are rock outcrops scattered throughout the basin. The rocks are sedimentary and consist predominantly of sandstones, limestones, shales, and conglomerates belonging to the Jurassic and Cretaceous periods of the Mesozoic era. On the north end of the basin, the rocks forming the higher portions of Algonkian Ridge belong to a Pre-Cambrian belt consisting of limestone and argillite, and lie above the Lewis Overthrust Fault, which is exposed on the south slopes of Bear Peak. Nearly everywhere the rock strikes about north 60 degrees west and dips about 40 degrees to the southwest. The entire area is intricately faulted but with minor folding, and it is believed the flow of water through fault zones is negligible. Because the entire drainage area of Skyland Creek is bounded by rock ridges, it is believed that the basin neither gains nor loses water underground around the periphery. A careful study of conditions at the junction of Skyland with Bear Creek, where ground water is observed seeping into the creek from the overburden, revealed that there is no loss of water from Skyland Creek near its mouth. The boundaries of the drainage area of Bear Creek in the vicinity of Marias Pass are poorly defined, but since nearly all studies of runoff are confined to Skyland Creek, it is of little consequence.

2-04.15 CSSL is founded on granite which forms part of the Jurassic batholith of the Sierra Nevada. Subsequent to the erosion of the granitic surface, flows of volcanics including rhyolite, andesite, volcanic mud, and basalt covered the area, part of which was later removed by glaciers, which in turn left small patches of moraine. Along Castle Creek are small areas of recent alluvium. The following tabulation lists the proportional amounts of the basin area presently exposed to the above listed formations:

Formation	Percent of Basin Area
Granite, mostly unweathered and tightly jointed	35
Overlying volcanic rocks, some rather porous	55
Glacial moraines, permeable but discontinuous	5
Alluvial deposits	5

Detailed descriptions of the rocks and delineation of the surface geologic pattern are contained in Technical Report 4-A. In general, the lower (SW) quadrant of the basin is predominantly granitic, while the entire upper portion contains volcanic rocks. Alluvial materials have been deposited along the sections of the stream channel with flatter gradients characteristic of the Lower and Upper Meadows. Little is known of the fault structure within the basin proper. Surface drainage boundaries are well defined except in Euer's Saddle, lying on the eastern edge of the basin. Conditions of subsurface flow near the basin boundaries are not known, but it is assumed they conform closely to the surface pattern. Deep percolation, whereby water could leave the basin unmeasured by the stream gage for Castle Creek, is assumed to be negligible, but no definite geologic information is available to substantiate this. When determining the water balance for CSSL as a whole for 5 years of record, (see chapter 4), the measured outflow appears to be too low. This is not sufficient evidence to conclude that there is unmeasured ground-water outflow from the basin, but it does point to that possibility.

2-04.16 No detailed geologic investigation of the WBSL was made, primarily because of the difficulty in identification of rocks and their structure. The heavy soil and forest cover over nearly all of the area effectively obscures the underlying formations, and rock outcrops appear only on Wolf Rock and on some of the peaks bordering the basin. Generalizations of the geologic structure of the basin were determined from published surveys of areas in the mid-Cascades, and by field reconnaissance of the area. The geology is considered to be typical of the middle Cascades area, which was formed from volcanic material ranging from lavas to agglomerates and tuffs. It has gone through a period of faulting and folding, and in recent times may have been subjected to glaciation, but there is no direct evidence of morainal deposits. The basin has been eroded to an early stage of maturity, and stream patterns are well defined except for small meadow areas. Heavy vegetative cover and high precipitation have resulted in deep weathering, and in most places the rock is covered with a thick mantle of relatively impervious soil. The bedrock underneath the soil mantle consists of weathered andesite (a fine grained volcanic rock) together with tuffs and breccias, which help to serve as a storage reservoir to supply summer flows for the numerous perennial streams in the area. The small butte known as Wolf Rock has been identified as a volcanic neck, but so far as is known, it has no particular significance in relation to the basin's ground-water geology. The basin boundary is formed by sharp divides between adjacent drainages, and considering the relatively impervious character of the soil mantle and underlying rocks, there is little reason to suspect underground water loss or gain from adjacent areas. No information exists on the strike and dip of the rocks within the laboratory area. Inspection of streamflow records for adjacent areas and on the entire Blue River (D.A. = 75 sq. miles) during periods of summer ground water recession flow show that unit rates of runoff per square mile are nearly identical for areas in the vicinity. This points to the probability that there is no sizeable water loss by underground flow past the stream gaging station, in view of the homogeneity of the area as a whole.

2-04.17 <u>Soils</u>. - The soil mantle on laboratory basins is important in the analysis of basin water-balance computations as a storage reservoir for the infiltrating water upon which plant growth normally draws in the transpiration process. It also represents a part of the ground-water zone which induces a time delay of runoff from water excesses. The soils at the laboratories are described qualitatively from field observations; however, no comprehensive soil surveys were performed whereby the soil characteristics for the basin as a whole could be evaluated. There are two differing concepts used in defining soils. In agricultural usage the zone of soil consists of that part of the earth's crust penetrated by plant roots; and in engineering usage soil is the total layer of unconsolidated material, thus differentiating between rock and earth materials. Both definitions are important to the hydrologist when considering separately the processes of transpiration and ground-water flow.

2-04.18 Skyland Creek in UCSL is almost completely covered with a thin soil mantle formed primarily by weathering of the sedimentary rocks underlying the basin, and, also, of the relatively small areas of old glacial debris. The remaining Bear and Autumn Creek areas were scoured heavily by glaciation during recent times, and there has been little opportunity for the formation of soils. The soils are thinner and there is a much larger percentage of area bare of soil than on Skyland Creek.

2-04.19 In general, soils at CSSL are thin, and the area is characterized by wide variation in soil conditions over the basin. Post-glacial weathering has not appreciably affected the granite rocks that were scoured by ice during recent glaciation, but the glacial deposits have been weathered to form immature soils. Soil is lacking on many of the steeper lava slopes, but the flatter areas of agglomerate have weathered fairly deeply. The meadows containing principally alluvial material have an overlying soil mantle. For the basin as a whole, it is estimated that about half of the area is soil-covered. The texture of the soil is generally light, and it is classified as sandy loam. There are, however, a few areas where the soil is underlain with clay.

2-04.20 Soils at WBSL are thick and cover nearly the entire basin, with the exception of portions of Wolf Rock and Squaw Mountain. They have resulted from weathering of the underlying volcanic rocks and consist primarily of clayey material. There was no soil probing or sampling program in the area, but generalizations on probable soil conditions can be made from known conditions in adjacent basins of similar topographic conditions. The total depth of earth materials probably ranges from a foot or two to as much as perhaps 50 feet. In general, it is believed that the thickness over the major portion of the area would be in excess of 10 feet. Observations of the soil conditions at the 5 ground-water wells showed uniformity of conditions, with approximately $1\frac{1}{2}$ feet of loam at the surface, and a shallow transitional zone into the underlying clayey material. The wells were not necessarily dug to bedrock and the depths range from 7 to 12 feet. The active zone penetrated by the plant roots is believed to be no more than four feet throughout the basin, and soils below this depth are aquifers for ground-water flow.

2-04.21 Vegetation. - The vegetation cover at each laboratory is an important factor to be considered in the hydrologic comparison of laboratory areas and in the extension of methods of analysis from the laboratory to project basin areas. The effect of grasses and low-growing shrubs on the accumulation and melting of the snow pack is minor, but they would have some influence on transpiration and infiltration rates. Forests, on the other hand, have a major influence on the accumulation of snow, because of differences in snow accumulation between sites in clearings and those beneath the forest crowns, and interception of precipitation in the form of both rain and snow. Forests also play a major role in the process of heat transfer to the snowpack and to the lower layers of the atmosphere. Water loss by evapotranspiration from a snow-covered area is accomplished largely by forest transpiration. In the following descriptions, therefore, the amount and type of forest is given primary consideration.

2-04.22 UCSL is characterized by wide variation in amount of forest from one side of the basin to the other. Skyland Creek, comprising the southeast third of the basin, is heavily forested with conifers, predominantly lodgepole pine (Pinus contorta), over about 90 percent of that area, and the average canopy density is estimated to be 80 percent. In contrast, large sections of Autumn and Upper Bear Creeks are unforested, and those areas which are forested are patchy. The net crown cover for this area as a whole is estimated to be 30 percent. An aerial mosaic of UCSL is shown on plate 2-7, and illustrates the forest cover over the basin. While lodgepole pine is the dominant type, it is intermixed with Engelmann spruce.(Picea engelmanni), white fir (Abies concolor), and tamarack (Larix laricina). This forest is not the climax type for this area, and there is evidence of old burns. The climax types would be Douglas fir (Pseudotsuga taxifolia) and western yellow pine (Pinus ponderosa) in the lower portions of the basin, and fir-hemlock species in the higher levels. The trees in the forest at present average between 30 and 50 feet in height; the Skyland Creek stands are dense, and the average distance between tree trunks is about 10 feet. In general, there is little underbrush beneath the dense forest canopy, but in the openings, there is a heavy growth of a wide variety of shrubs. Bear grass grows in the openings at the higher elevations. The bare areas, particularly on the north side of the basin, are rock outcrops or talus slides which cannot support plant growth.

2-04.23 The forest at CSSL is primarily second-growth lodgepole pine and the basin is characterized by a relatively light, open forest. There is considerable range in forest density in different portions of the basin, varying principally with elevation, soil, and exposure. The average timberline in this area is at about 8000 feet, but occasional growths of hemlock and fir occur above this elevation. Plate 2-8 is an aerial mosaic of CSSL taken when the area was bare of snow, and shows the forest density over the basin. For the basin as a whole, about 40 percent of the area is forested, and it is estimated that only 20 percent of the basin is directly beneath the tree crowns. The average height of the pines is from 30 to 50 feet. There are interspersed a few stands of red fir (Abies magnifica), white fir (A. concolor) and western yellow pine, whose heights range up to 125 feet. Various brushes cover about 15 percent of the basin. Grass covers about 6 percent of the area with no other cover, and 40 percent of the basin is bare of any vegetation.

2-04.24 WBSL is heavily forested and is typical of the climax type of the western Cascades in Oregon. Non-timbered areas are few and consist of small mountain meadows which are usually less than one-quarter acre in size. A notable exception, however, is Wolf Rock, whose area is about one-eighth of a square mile. Douglas fir is the dominant species and comprises about 60 percent of the timbered area. The remaining 40 percent of the forest belongs to the hemlock-fir types and consists of Pacific silver fir (Abies amabilis), noble fir (A. procera), white fir, western hemlock (Tsuga heterophylla), Engelmann spruce, and mountain hemlock (T. mertensiana). Old-growth and second-growth trees of all sizes are found in both timber types. The average height of trees is estimated to be about 150 feet. The total forested area is 93 percent of the basin as a whole, and the average canopy density is estimated to be about 90 percent. Plate 2-9 is a panoramic photograph taken looking south from Squaw Mountain over the basin area, showing the character of the dense forest. Beneath the forest crown is an understory of various types of shrubs which in turn cover low-lying ferns and other weeds. The understory is denser in the lower part of the basin and includes small deciduous trees.

2-04.25 Climate. - The climatic regimes of the three laboratories are similar, in that all of the areas are predominantly exposed to Pacific maritime airmasses as the result of the western atmospheric circulation of the middle latitudes. Occasional reversals in circulation, however, cause invasion of continental airmasses, and in some periods the circulation is weak, so that there is established a local climate which is mostly independent of the atmospheric circulation. The average climate of the regions, then, is a function of (1) the relative frequencies of the above listed meteorological patterns, (2) the opportunity for modification of the airmasses, which is primarily a function of distance from the sea coast and extent of intervening topographic barriers, and (3) the latitude and elevation of the basins. Reference is made to plate 2-1, which shows the geographical location of the laboratories with respect to the major topographic features of western United States.

2-04.26 In order to determine climatic averages of basic hydrometeorologic variables for each laboratory, the relatively long-term records of temperature, precipitation, snowpack water equivalent, and runoff for key stations in or adjacent to the laboratory areas were analyzed on the basis of mean monthly amounts. Means were computed for the entire period of record of the individual stations and also for the shorter period of laboratory record, in order to establish the relation between the meteorologic characteristics during the period of laboratory record and long-term climatic means. The following tabulation lists the key hydrometeorologic stations and the total years of record used for each element to represent the long-term hydroclimatic mean at each laboratory.

Snow Lab.	Temperature	Precipitation	Snowpack Water Equivalent	Runoff
UCSL	Summit, Montana 1938-1954	Summit, Montana 1937-1954	Marias Pass, Montana 1936-1955	Middle Fork Flathead River at Essex, Mont. 1940-1952
CSSL	Soda Springs, California 1930-1954	Soda Springs, California 1930-1954	Soda Springs, California 1930-1955	South Fork, Yuba R., near Cisco, Calif. 1943-1952
WBSL	Leaburg, Oregon 1934-1954	Leaburg, Oregon 1934-1954	Santiam Jct., Oregon 1941-1955	Blue River near Blue River, Ore. 1936-1952

Tables 2-3 through 2-5 list mean monthly values of temperatures in ^{o}F, precipitation in inches, and runoff in inches over the contributing area for January through December, for the above listed stations. Average snowpack water equivalents are given for the first of each month, from January through May, but for some of those months at certain stations values are omitted because records are incomplete or lacking entirely.

2-04.27 Reference is made to the descriptions of general climatic and hydrologic features of the laboratories contained in paragraphs 2-02.07 through 2-02.11 for summaries of the hydroclimatic characteristics of the basins. The climatic comparisons set forth in tables 2-3 to 2-5 are presented for the purpose of interpreting values of prime hydrometeorologic variables presented on the basis of averages for the laboratory basins and for the period of laboratory record.

2-04.28 During the period of laboratory operations, the mean annual temperature at each laboratory was within one degree F of its long-term mean, but there were some anomalies for individual months. At UCSL, winters averaged somewhat colder than normal, and in extreme, January was nearly 7^{o}F below normal. During the spring months the temperatures averaged slightly above normal. Precipitation at UCSL for the water years 1947 through 1950 was about 10 percent above normal; most of the excess occurred during the period October through March. Spring and summer precipitation was very nearly normal. Water equivalent of the snowpack as measured at Marias Pass averaged a little over 20 percent above normal, reflecting the above normal precipitation and below normal temperatures during the winter. Annual runoff was about 15 percent above the long-period average. WBSL similarly experienced somewhat below normal winter temperatures, and above normal precipitation, water equivalents, and runoff during the period of laboratory operation. Values of temperature, precipitation, and runoff averaged near normal at CSSL during the period of laboratory record. The water equivalent measured on the snow courses at Soda Springs indicated that the snowpack contained only 60 to 80 percent of the normal amount for the early spring months, but it is believed that the apparent departure may be due to above normal percentages of winter precipitation falling as rain during the period of laboratory operation.

2-04.29 Hydrologic comparison. - One of the principal objectives of the laboratory program was to establish with relative assurance the components of the hydrologic cycle in areas of snow accumulation, under varying conditions of climate and environment. This has been accomplished on the basis of basin mean values for each element for each of the laboratories, by monthly increments over the period of laboratory record. The methods used in deriving those values are set forth in chapter 4, and tabulations of amounts by individual months are presented in that chapter. The average amounts for the period of record for each laboratory were summarized for the purpose of presenting in this chapter a hydrologic comparison of the areas. Graphical representation of these summaries is shown on plate 2-10 and include mean monthly values of (1) basin temperature, (2) incident radiation (where available), (3) basin precipitation and basin snowfall, (4) accumulated net basin snowfall (after interception) and basin water equivalent, and (5) generated runoff.

2-04.30 Basin temperatures were computed on the basis of means for the period of record adjusted to the mean elevation, except for CSSL, where elevation effect is small and station 1-B was used to represent basin means directly. Records of insolation were obtained at CSSL and UCSL, but are not available for WBSL. Total basin precipitation represents, as a basin mean value, the gross amount for tree-top level. Basin snowfall similarly represents the average monthly amount above the tree canopy. Separation of rain and snow was made on the basis of detailed studies of the form of precipitation and independent checks by the total water balance computation. The accumulated net basin snowfall represents average basin amounts of the water equivalent of newly fallen snow that arrives at the ground level and, accordingly, interception losses are accounted for in these amounts. The basin water equivalents are given as of the end of the month and represent mean basin amounts of water remaining in storage in the snowpack. Differences between accumulated net basin snowfall and basin water equivalent are the summation of melt to that particular time. The values for generated runoff are the equivalent basin inches of monthly runoff, adjusted for changes in ground-water storage by means of recession curve analysis as described in paragraph 2-02.11.

2-04.31 Plate 2-10 presents a graphical comparison of the characteristics of each laboratory basin with regard to the hydroclimatic features discussed above. These comparisons serve as orientation for detailed analysis of laboratory data presented in subsequent chapters, with regard to snow accumulation, snowmelt, and hydrograph reconstitution. In general, it is seen that UCSL has severe, snowy winters, and warm summers. Precipitation occurs predominantly during the winter season and is almost entirely in the form of snow during that period. There is significant precipitation, largely in the form of rain, during the spring and summer months, and a secondary precipitation maximum occurs in June. On the average, basin snowpack water equivalent accumulates through March of each year, but the heat supply is usually sufficient after April first to produce enough melt to cause a net decrease in water stored in the snowpack. Runoff generated during the winter months is generally very small, but October or November rainfall, or occasional minor periods of snowmelt, may provide water in excess of soil moisture requirements and thereby produce runoff. About 80 percent of the annual runoff is generated in the 3 months of active snowmelt, April through June. Usually, the snow is completely melted by the first of July, but occasionally, a late melt period will cause a small carryover of snowmelt into July.

2-04.32 Winters at CSSL are not as cold as at UCSL, but precipitation is about 50 percent greater. The proportion of precipitation falling as rain during the winter (October through March) is greater at CSSL than at UCSL, and for the period of laboratory record was about 22 percent. It is believed that this value is somewhat above normal for this area, because of unusually heavy rains that fell in November, 1950 and other periods. The average April 1 basin snow accumulation each year at CSSL is equivalent to about 32 inches of water, while it is about 24 inches at UCSL. Seventy-six percent of the annual runoff at CSSL is generated in the three-month period, April through June, resulting from the melting of the snowpack. Summer precipitation is negligible, and Castle Creek usually becomes dry near the first of August. Winter flows are proportional to winter rains and snowmelt, and while they are greater than those experienced at UCSL, the volume of runoff is relatively low. Occasionally at CSSL, a short period of heavy winter rain produces a peak discharge far in excess of that normally experienced during the snowmelt runoff season.

2-04.33 Winters at WBSL are warmer than at either UCSL or CSSL and are characterized by heavy snowfall, occasional rainfall, and heavy runoff. Summers are warm and relatively dry. Mean yearly precipitation (tree-top level) for the period of record was 125 inches, more than twice as much as at UCSL. Precipitation is concentrated in the winter season, more than 80 percent of the yearly total falling in the winter (October through March). Summer precipitation is variable, but usually light, and intense convective showers are infrequent. Rain averaged 40 percent of total precipitation during the winter months, ranging from 26 percent (1948-49) to 47 percent (1947-48 and 1950-51). Though much of the winter runoff resulted from rain on snow, considerable runoff was generated by the relatively mild weather conditions associated with the basin's location and elevation range (2000 - 5500' msl). In general, precipitation catch at WBSL gages showed a marked increase with elevation except for gages at windy sites. Variation in snowpack water equivalent was even more marked. In many storms, the freezing level was located well above the basin's lower boundary (2000' msl). Variation in snowpack water equivalent due to initial differences in amount and form (snow or rain) of precipitation was further aggravated by the higher melt rates characteristic in the lower part of the basin. Average basin water equivalent on 1 April was about 25 inches. In two of the four years of record, snowfall in late spring resulted in seasonal maximum water equivalents during May. In marked contrast to UCSL and CSSL, WBSL is characterized by high winter runoff. Nearly two-thirds of the yearly total generated runoff occurred during October through March; only one-third occurred during the spring snowmelt months of April through June. The percentage of yearly runoff occurring in winter ranged from 54 percent (1948-49) to 78 percent (1950-51). Peak flows resulted from rain on snow.

2-04.34 It is pointed out that the above comparisons of hydrologic characteristics are based on water balances derived for the period of record at each laboratory. Cognizance should be taken of the relation between these laboratory period averages and the longer-term normals, as set forth in paragraph 2-04.26.

2-04.35 In order to compare the basin hydrologic character with respect to the time delay to runoff, empirically derived recession curves are presented on plate 2-11 for Skyland Creek, UCSL; Mann Creek and Blue River, WBSL; and Castle Creek, CSSL. Recession curves are shown both in terms of cfs and cfs per square mile. There are also shown the recession coefficients, $\underline{C_r}$, and their corresponding values of $\underline{t_s}$, for the various ranges in flow for each laboratory. Inspection of the curves shows that Castle Creek, CSSL, has the fastest recession and accordingly the least time of storage delay. Mann Creek and Blue River at WBSL have similar recession characteristics in terms of unit rates of runoff and show a relatively slow recession, particularly for low flows. The recession for Skyland Creek is intermediate between Castle Creek and Blue River, for flows expressed in cfs per square mile. For flows higher than 5 cfs per square mile (equivalent to about 0.2 inch per day), the recession for Mann Creek is nearly identical to that of Skyland Creek.

2-05. REGULAR OBSERVATIONS AND INSTRUMENTATION AT LABORATORIES

2-05.01 General. - The observations of hydrometeorological elements at the snow laboratories were taken with two basic considerations: (1) adequate sampling of the elements with respect to time variations, and (2) adequate sampling of elements with regard to areal variation over the laboratory basins. Determining the sampling requirements of each of the elements with respect to those considerations is a complex problem, and considerable subjective judgment is required in order to arrive at a proper balance between feasibility of measurements with available resources, the variability of the elements with respect to time and space, and the relative importance of the elements in the hydrologic cycle. The amount and type of instrumentation were also chosen to meet the specific problems of snow hydrology as set forth in the initial objective of the program, which are problems of snow accumulation and its relation to the water balance, snowmelt, and the storage and transmission of liquid water in the snowpack. A network of regular observations at predetermined frequency of attendance was established for each laboratory and included both recording and non-recording types of instrumentation. Many of the observations were made in the vicinity of the headquarters living area to insure continuity of record during adverse weather conditions, and in some cases, concentration of observations were made in an area of particular environment, away from the headquarters area. The major portion of the time spent in servicing gages, however, was for the outlying stations which were established for measurement of precipitation, snow depth, water equivalent, wind, air temperature and humidity over the laboratory areas.

2-05.02 Table 2-6 summarizes the number of regular observation stations or points maintained at each laboratory during each of the years of operation. This summary provides a synopsis of the scope of the regular observational program and how it varied with time. The elements are listed in the categories of general weather, radiation, air pressure and wind, temperature and humidity, precipitation, snow, soil, and streamflow. Instrumentation is listed as recording or non-recording. A synopsis of hydrometeorological elements, showing in graphical form the daily progress of each of the elements as measured at key stations, is presented for each laboratory-year of record in its appropriate hydrometeorological log. In addition to the regular observations, there were many special observations taken for a specific purpose of analysis of conditions at a point, but not necessarily continuously with respect to time. These are listed in section 2-07.

2-05.03 Each of the hydrometeorological logs published for each laboratory (see Appendix I) contains an inventory of meteorologic and hydrologic data, which consists of a graphical day-to-day plotting of the actual period of record of all elements observed at the various stations throughout the laboratory. Instrumental characteristics, such as type of instrument, height above ground, number of snow course points, etc., are listed in each log under tabulations entitled, "Status of laboratory observations." A summary of station site characteristics is also published with each log and contains data on the physical conditions of local environment at the site of each gage. Site maps were prepared for the stations and show the topographic features of the sites within a radius of about 200 feet from the gage. Copies of these site maps are included in the hydrometeorological log for 1948 at UCSL, 1950-51 at CSSL, and 1947-48 and 1948-49 at WBSL.

2-05.04 Methods of observation. - In general, the measurements of meteorologic and hydrologic elements were performed in accordance with normal procedures used in data gathering by the U. S. Weather Bureau, U. S. Geological Survey, and other governmental agencies. Some instrumentation, however, was developed for special purposes, as for example the non-selective radiometers for measuring the transfer of radiant energy to and from the snowpack. Modifications of commonly used equipment were made in some cases to adapt them to conditions at the laboratory. There was little precedent for performing routine measurements of the characteristics of the snowpack and the underlying soils; accordingly, many of the methods for measuring them were developed in connection with the laboratory program of the Cooperative Snow Investigations. The quality of data obtained under the regular observational program is discussed in section 2-06.

2-05.05 A discussion of the methods used in obtaining each of the measured elements is contained in the prefacing remark for each of the hydrometeorologic logs, under the title of "Discussion of Tabulated Values." Reference is made to the logs for this information.

2-06. QUALITY OF DATA

2-06.01 General. - A major portion of the effort of the entire Cooperative Snow Investigations program was that of collecting and processing snow laboratory data. Considerable time and expense went into providing adequate instrumentation, but in any measurement involving hydrologic application, variability of the measured element in time and space precludes an exact determination of the quantity on an areal basis. Even at a single point, accurate measurements are often difficult to obtain in the field, and when considering local variability of the element, they may be meaningless. Some of the observations of snow processes at a point were made by precise methods from which quantitative physical relationships could be derived. The majority of the observations, however, were made to evaluate relative variability of the elements and to provide a network of observations much denser than ordinarily available on project basins, thereby leading to a more adequate understanding of hydrologic processes in areas of snow accumulation. These observations cannot be considered to be precise in the sense of laboratory controlled scientific measurements. The emphasis of the observational program was to minimize the controllable errors caused by mechanical deficiencies of the instruments, inadequate frequency of servicing, substandard methods of observation, or untrained personnel.

2-06.02 At the snow laboratories, most of the observational stations were located too far from the headquarters to be serviced at less than weekly intervals. At times, extended storm periods caused delays in the weekly visits. These delays, if prolonged, could cause serious loss in record. Fortunately, they were at a minimum, and in most cases the record could be kept intact through carefully processing the data.

2-06.03 In general, the types of errors introduced into the data were similar at all three laboratories; i.e., observer and instrument errors. Others that were peculiar to individual laboratories, were such things as the effect on recording instruments of the extremely cold temperatures at UCSL or the impounding of water at the interface of the soil and snow which affected the ground water level in one well at CSSL. As much as possible, errors were corrected or compensated for before the data were published. Some of the most common sources of error were those encountered in the recording instruments. They were such items as pen running dry or not being set on the chart; pen clogging; ink blurring or smearing; clock gaining or losing time; clock stopping; time checks missing or illegible; chart being on crooked; trace overlapping due to delay in changing chart; wind vibration or other interference with trace; ice and snow on working mechanism; instrument or ink frozen; chart distorted due to changes in temperature or humidity. Many of these deficiencies were overcome by careful reduction of the data through comparison with nearby instruments.

2-06.04 In the introductory statements in each of the logs, there are references to quality of data, some for that particular water year, and others that obviously apply more broadly. These statements are too numerous to index in this brief section, but, for example, cover such items as the following:

1. Position and accuracy of temperature-sensing elements in the snowpack.

2. Apparent inconsistencies between ground-water stage and nearby streamflow.

3. Limitations in exposure of the reflected pyrheliometer at UCSL for estimating albedo.

4. Apparent inconsistencies in dewpoint data, with respect to air temperature.

5. Below-freezing water temperatures.

This brief section on quality of data supplements the earlier statements which are in the logs rather than including them in a comprehensive manner.

2-06.05 Radiation. - The incident radiation pyrheliometer bulbs were given a good exposure at both CSSL and UCSL, but the reflected radiation bulb at UCSL was poorly exposed, both because the area at which it was aimed was in the shade during early and late portions of the day and because road dust occasionally fell in the area, giving a low bias to the reflected radiation readings. Occasional errors in measurement could be attributed to the collection of frost on the bulb. This resulted in readings being at times too high and at others too low. Generally, this could easily be adjusted for in the tabulations. At times there would be gaps in the record due to power failure; the Micromax recorder being out of balance or running slow; recorder pens being out of ink or clogged; a Micromax chart not changed and running out of paper. It should be pointed out that some instrumental error has been attributed to effects of ambient temperature. 6/ On one or two occasions the pyrheliometers were checked against a standard instrument with "good correspondence."

2-06.06 Air temperature. - Between 10 to 20 percent of the hourly temperature data was lost in the coldest months when the clock mechanism would freeze or fine snow would accumulate on the instruments. The over-all loss for the year was only about 2 or 3 percent. The hygrothermograph record was adjusted to agree with the maximum and minimum readings and the dry bulb temperature checks at the time the charts were changed. Some difficulty was experienced because of non-agreement of the hygrothermograph readings with maximum and minimum thermometer temperature readings, presumably due to separation of the alcohol column in the minimum thermometer. It can be assumed that the temperature values are correct within 2°F. Some possible error might be attributed to reflection from snow up through the louvers or slits in the bottom of the instrument shelter. On rare occasions some fine snow would blow into the shelter and settle on the thermometers and thermograph. The quality of temperature data from thermograph charts is generally not as good as that from direct reading thermometers. Most of the error can be attributed to lack of attendance, a condition that would be impossible to overcome at remote stations but could be controlled at the headquarters site. Temperature measured by Thermohms and liquid thermometers showed a quicker response, indicating a 10 to 20 minute temperature lag in the thermograph reading during rapid changes in temperature. Thermohms and liquid thermometers showed also a greater range (2-4 degrees in maximum and/or minimum readings) than the thermograph.

2-06.07 Humidity. - Humidity was measured by means of the hygrothermograph and the psychrometer. Values of wet and dry bulb temperatures were taken daily at the laboratory headquarters but, at field stations, only at times of changing charts (generally at weekly intervals, except when extreme storm conditions prevented attendance). From the available psychrometric data, the dewpoint was calculated by either conversion tables or psychrometric slide rule.

2-06.08 Errors inherent in the hygrothermograph and the wet bulb thermometer are similar to those already discussed under air temperature (para. 2-06.06). Some error in dewpoint could be attributed to the observer not reading the wet-bulb temperature at its coldest point. Difficulty in checking psychrometric data with hygrograph data was due largely to the different time response between the two instruments as well as to the fact that they were read several feet apart at the field stations. Most comparative data were taken during the morning hours when hygrothermograph temperature and humidity readings lagged as much as one-half to one hour behind readings from the wet and dry bulb thermometers. These factors should be taken into consideration when relating the data to other parameters.

2-06.09 Under certain conditions, the humidity element of the hygrothermograph was not very satisfactory. The hairs would collect moisture and then freeze. Fine snow would drift into the shelter and clog the hairs, later to melt and re-freeze. The slow reaction time made it difficult to calibrate. In reducing the charts it was often necessary, due to the poor quality of the data, to compare the trace from one station with those from other nearby stations with similar elevations and exposures. It was found that, for the most part, the character of the traces was the same and that they agreed for humidities below 70 percent. The greatest disagreement was found in the range from 80 to 100 percent, where corrections up to 20 percent occasionally had to be applied. A tolerance of ± 5 percent was used for humidity. This would amount to 4 to 6 degrees in corresponding dewpoints when the air temperature was about 20°F and 1 to 2°F where the air temperature exceeded 60°F. This would account, in part, for some of the occasions when the dewpoint at the time of minimum temperature was recorded as being higher than the minimum temperature.

2-06.10 Precipitation. - Perhaps the most intensive observation of any of the meteorological elements, aside from snow surveys, was that of precipitation. Several types of gages were installed and tested under field conditions. A wide variety of exposures, both good or bad, were used in an attempt to determine the variability attributable to differences in exposure. As a consequence, some of the records are quite reliable as indexes whereas others are almost worthless. Much has been written on the subject of precipitation gage exposure (see chapter 3). In this section, the types of gages used in the laboratories will be treated as to their individual deficiencies and sources of error. The problem is twofold: (1) to determine the comparative performance of various types of gages under optimum observational conditions (at headquarters sites where they could be in constant attendance), and (2) to devise and compare the best methods of obtaining snowfall records in the field at long unattended sites and under adverse weather conditions.

2-06.11 Performance of recording gages. - At headquarters sites, the caliber of record of the recording gages was generally high. Operational differences between the standard Friez and Stevens gages were slight, the catch amounts agreeing with a correlation coefficient of 0.98. Some observer preference has been expressed for the greater ease of servicing of the Friez gage during weighout and weigh-in operations. Unfortunately, the small capacity of the standard Friez gage precluded its use at the field stations, where single storms could exceed its effective capacity of approximately 6 inches (or 12 inches using the enlarged Friez gage). For experimental use at outlying field stations, a number of large-capacity Stevens gages were built to CSI specifications, capable of holding 96 inches of liquid (of which approximately half would be anti-freeze charge). Several years observation indicates that, in general, the recording difficulties experienced even in small-capacity, frequently-attended gages, were multiplied considerably in these special gages. In every case where these large-capacity gages were exposed to wind for considerable periods of time, the recorder trace tended to become obscured by the pen vibrations. At times when the wind speed was relatively light, it was not too difficult to follow the pen trace during times of precipitation. But high winds are frequently associated with precipitation, and as the wind speed increased, the trace would become at times as much as 1½ inches wide. In such cases, only a rough estimate of the actual precipitation accumulation could be made. Occasionally, the system of weights and balances became fouled. There was some loss due to leaky valves. Trace variations of 1 inch occasionally occurred without precipitation--probably due to expansion and contraction from temperature and humidity changes. There were some instances when as much as one-half inch of precipitation fell without being recorded. Errors such as these are difficult to account for. Perhaps friction or fine blowing snow accumulating on the interior mechanism retarded the movement. The capacity of the gage made it difficult to read the chart in increments of less than 6 hours or 0.10" precipitation. Between 5 and 10 percent of the record was interpolated. The short-duration records from these gages should not be considered as being better than 20 percent accurate, though the seasonal totals have been corrected for weighout, and have been pro-rated.

2-06.12 Sacramento storage gage. - A comparative study made of the weigh-in of the initial charge versus the amount indicated by the initial stick reading revealed that there was often a discrepancy (up to 25 percent) between the two values. In comparing the weighout versus the stick reading at the end of the season, this discrepancy averaged only 4 percent, with the weighout volume generally greater than that indicated by the stick measurement. This obvious error may be attributable either to poor calibration, deformation of the bottom of the gage from the increased pressure of accumulated precipitation, improper stick measurement or incorrect values of weigh-in or weighout. The seasonal increments, as determined by the stick, were adjusted to agree with the value obtained from the final weighout. This final value can be considered to be of good quality even though there might be some error in the incremental readings. Other sources of measurement error were: failure to read an average depth in the gage; taking readings with ice or slush in the gage. The largest error encountered was from leaky valves and faulty weighouts. There was no way to account for these losses except to indicate their occurrence, which fortunately was very rare.

2-06.13 Precipitation gage catch deficiencies due to turbulence, wind, and capping are known to affect the quality of data of any of the gages but are not considered instrumental or observer errors. The magnitude of these deficiencies are dependent upon gage exposure, frequency of servicing, and meteorological conditions, and they are discussed in detail in chapter 3.

2-06.14 Snow depth and water equivalent. - This element was measured by standard procedures set forth in Snow Surveyors Manual. 5/ Considerable improvement was made from year to year as experience in the techniques of snow surveying was gained. Also, the snow courses were cleared of rocks and brush over the period of years, which, in itself, aided immeasurably in improving the quality of the measurements. As was the case with the precipitation gages, the snow survey courses were placed in a variety of exposures, mainly to test the variability over the area as well as to determine the influences of the various terrain parameters on the course. For this reason, some of the courses are of much better quality than others. This is discussed in a paper by Wilson on snow measurements at the laboratories. 8/ Some errors occur when the measurement is taken. Certain temperatures of the snow and sampling tube cause the snow to freeze to the tube, creating a plug which does not allow a clean cut through the snow. Ice planes in the snow cause similar errors. Ice at the ground surface may not be completely penetrated, giving an incomplete core. Striking a rock or brush buried beneath the snow also results in an erroneous reading. Strong wind puts enough pressure on the tube to cause the weighing scale to indicate too high a value of water equivalent. Many of these errors were detectable by trained observers, but in the earlier years of the program or with new observers they were allowed to enter into the record. It would be difficult to determine exactly the magnitude of error in water equivalent. The error in the mean value obtained for a given snow course most likely does not exceed 5 percent.

2-06.15 Wind speed. - For the most part, the anemometers performed adequately. The most serious source of error was icing due to freezing rain or from wind-driven snow. It was impossible to determine if this condition existed at field stations unless it occurred at the time of observations. It was difficult also to ascertain how long such icing had prevailed. For that reason it was customary to clear the mechanism of ice and accept the reading, at the same time making a note of the possible error. At the headquarters stations where a closer watch could be kept of the instruments, icing conditions could be cleared up very quickly with little loss of record.

2-06.16 Wind direction. - The values reduced from the Esterline-Angus strip-charts are fairly reliable. Hourly wind directions were obtained by summing the total directions for each minute and determining the prevailing direction by standard Weather Bureau procedure.

2-06.17 Air pressure. - The barometric pressure is considered to be one of the most reliable observations taken at the laboratories.

2-06.18 Snow cover. - Visual observations of snow cover were made at intermittent intervals and were subject to considerable error. It was impossible to observe an entire laboratory basin from a single point on the ground. At times, observers in two different parts of the basin would combine observations to get an over-all estimate. These observations are probably good only to the nearest 20 percent of the value given. More extensive observations of snow cover were made by aerial photography. These estimates were generally better at UCSL where the photos were taken at a higher elevation and perpendicular to the ground rather than at an angle as were many at CSSL. Most of the aerial estimates of snow cover are probably within 5 percent of the correct amount.

2-06.19 Snow thermal quality. - The liquid water content of the snow, computed from calorimetric measurements of thermal quality, was sampled unsystematically with respect to time and space, and the data do not indicate basin averages or depth profiles. Sources of error include drifting of the calorimeter constant; errors in the temperatures of the snow, water, and mixture; and heat loss through the calorimeter stoppers. Average error is estimated at 5 percent of the values given for thermal quality, which, of course, corresponds to an error in the neighborhood of 100 percent in values for liquid water content.

2-06.20 Soil moisture. - The calibration of the Bouyoucos blocks, and their care after installation, was not adequate. The blocks frequently disintegrated after a few months in the ground. The rating curves are poorly defined, particularly under wet conditions. Soil temperature data were not taken at the immediate soil-moisture points. The logs contain inconsistencies, and, in general, the soil-moisture data have little or no quantitative value. A more complete discussion of various types of soil moisture measurements at the laboratories is contained in paragraph 2-07.13.

2-06.21 Ground water. - During the winter, between 50 and 80 percent of the data was either questionable or missing. This was generally due to the water freezing in the well, or to ice or snow dams in the nearby stream. During the spring melt period the record was good, for the most part, with loss of record rarely exceeding 5 percent. No areal sampling or ground water profiles were made.

2-06.22 Soil temperature. - The soil temperatures, indicated by telethermoscope readings, are reliable to the nearest whole degree with a tolerance of $\pm$ 1°F. This applies also to those values reduced from the Micromax recorder charts. Occasionally, the surface Thermohm was exposed to the direct rays of the sun at the time of observation. This gave a reading above what would normally be expected. No attempt was made to correct these values and they were included as reported.

2-06.23 Water temperature. - On the whole, these data are reliable to the nearest whole degree.

2-06.24 Snow temperature. - The quality of these data was dependent upon the calibration of the Thermohms and the security of the support on which they were mounted. The weight of the snow accumulation caused the support wires to sag as the season progressed, making it difficult to determine where the Thermohms were at a given time in relation to the ground surface. Therefore, the temperatures reported in the logs give a good representation of the temperature profile through the snow but the accuracy of the height of the Thermohms is not reliable. Some error can be ascribed to the absorption of radiation through the snow by the Thermohms. There were many instances when temperatures of 33° or 34° were reported below the snow surface due to the heating effect of radiation penetrating to the Thermohm. Readings of snow temperature by the telethermoscope were made only to the nearest whole degree. Readings to any finer degree would not be realistic. In general, the values are regarded as reliable.

2-06.25 Streamflow. - The record obtained from CSSL was excellent throughout the year, mainly due to the daily attention paid to the gage in keeping it cleared of ice and snow. The use of the Parshall flume and V-notch weir along with careful gagings by competent personnel makes this record acceptable for the entire period of record. During the winter periods at UCSL, ice formed in the stream beds, making it difficult to maintain an accurate record. However, this occurred during periods of low flow and only a small portion of the record was erroneous. The over-all error probably did not exceed 5 percent, which is considered "excellent" by USGS standards. Skyland Creek record in the winter of 1946-47 was obviously too low, in comparison with runoff in adjacent streams and in other years. At WBSL, inadequate control and river gaging practices put this record in the "fair" to "poor" category. In addition to the deficient rating curves, there was a poor tie-in between the elevation of the outside gage and the chart. Rating curves for Mann Creek and Blue River were better than those for Wolf Creek. The float froze to the walls and to ice planes in the stilling wells, causing loss in record. Logs and debris in stream beds influenced the control to a great extent, making it difficult to apply rating curves with much degree of confidence. The stilling well intakes were rather sluggish, failing to respond to quick changes in streamflow. As in the case of UCSL, the data at the Willamette laboratory were poor during periods of low flow and ice effect, but were acceptable during the spring melt season.

2-06.26 Lysimeter. - Lysimeter data were obtained at CSSL for the Headquarters and Lower Meadow sites. In the early years from 1949 through 1952, definition of the lysimeter boundaries was indefinite during some periods because of ice planes which formed within the snowpack and thereby caused water loss or gain from adjacent areas. By trenching the perimeter during 1953 and 1954, good definition of daily volumes has been obtained. Pertinent information on the two lysimeters constructed at CSSL is given in paragraph 2-07.02.

2-06.27 Site maps. - In general, the topography and the location of structures, well defined obstructions, and observation points, are precise. There are unidentified instances of changes in snow-sampling points, from year to year. The portrayal of vegetative cover was based partly on aerial photographs and partly on ground observations, and possible errors arise from interpretation and generalizing. The actual height and density of surrounding vegetation is for the most part only a rough estimate rather than a true measurement. The effective height of vegetation varied greatly because of the great range of snow depths. There is a wide range of quality and precision of site maps among laboratories.

2-07. SPECIAL OBSERVATIONS

2-07.01 General. - Several categories of measurements in connection with the laboratory program are classified as special observations, in that either (a) records were not continuous, (b) the measurements were designed for a specific analytical project rather than for studies of the basin as a whole, or, (c) special observational techniques were being developed or tested. The following paragraphs summarize the purpose and extent of these observations. Since many of the special observations were not published in the hydrometeorological logs, reference is made specifically as to availability of data.

2-07.02 Lysimeters. - Two impervious snow lysimeters were constructed at CSSL, one having 1300 square feet of area and located near the headquarters, and the other having 600 square feet and located at the Lower Meadow (Station 3). The methods of construction and physical characteristics were described in the appropriate logs for CSSL, and also in Research Notes 17, 18, and 25. The purpose of the lysimeters was to provide data for (1) the travel and storage of liquid water in the snowpack, and (2) accurate determinations of daily snowmelt, unaffected by soil and ground storage, which could be related to meteorological parameters causing melt. The headquarters lysimeter had provision for artificial sprinkling to simulate the effects of rain on snow. Records for the headquarters lysimeter began in the 1949 water year, and for the Lower Meadow lysimeter in the 1952 water year. Much of the data for the years through 1952 is contained in the CSSL logs. Both lysimeters were operated on a part-time basis through 1954, and tabulations and plotting of the data for the Lower Meadow lysimeter during the 1954 melt season are contained in Research Note 25. Data from the lysimeters have been used extensively in determining the effect of the snowpack on rainfall runoff, and in providing means of estimating snowmelt at a point in the open. With the improvements made in observational techniques during the later years of operation, the lysimeters have proved to be invaluable for determining factors affecting snowmelt runoff at a point and form much of the basis for application of methods to basin areas.

2-07.03 A small (2 square-foot) portable lysimeter was constructed at WBSL in 1950 for the purpose of determining condensation or evaporation from the snowpack, as well as melt. Difficulties in separation of natural and artificial effects preclude its use for quantitative evaluation of amounts.

2-07.04 Deep and shallow pit data. - Observations of the character of the snowpack were obtained at CSSL by SIPRE during the water years 1951 through 1953. The observations were obtained by digging pits in the snow at the Lower Meadow site, at time intervals varying from one to two weeks. "Deep pits" were dug to the snow-ground interface, and the snow structure classified throughout the pack depth. Density and temperature profiles were also obtained, showing the vertical variation of these amounts. "Shallow pits" (usually about one to two feet deep) were dug in connection with vehicle traction tests. Data for 1951 and 1952 are published in the CSSL logs for those years, and data for 1953 are presented in graphical form in chapter 8. Miscellaneous observations of the vertical structure of the snowpack were made at other times and at the other laboratories, but they are not sufficiently complete to present the time variation of the snowpack character through the winter season.

2-07.05 Settling meter data. - In connection with the deep pit data at CSSL, SIPRE installed for the 1953 water year, a slide-wire settling meter, for obtaining undisturbed profiles with respect to time of each snow horizon for individual layers of the snowpack. This device was patterned after one constructed by Bader as reported in "Der Schnee und Seine Metamorphose" 1/ and consists of a vertically mounted electrical resistance wire, to which are attached sliding markers which define the position of each layer of snow. Observations of the positions of snow layers were made once a week through the entire period of snow accumulation and melt, but tabulations of these data have not been published. A graphical plotting of the data is shown on plate 8-1.

2-07.06 Micrometeorological data, CSSL. - Late in 1950, SIPRE instrumented four micrometeorological masts at the Lower Meadow, CSSL, for the purpose of obtaining vertical and horizontal gradients of wind, temperature and humidity over the snow, in an open meadow and adjacent forest areas. Each mast extended approximately 50 feet above ground, and there were various fixed and adjustable levels of measurement. The site is described in the CSSL log for 1951-52, and levels of instrumentation are shown in Miscellaneous Report 5 (see Appendix I). Air temperatures were measured by Thermohms equipped with polished metal radiation shields, dewpoints were measured by Foxboro Dewcels, wind speed was measured by three-cup anemometers, and wind direction by a wind vane. All were recorded by continuous strip-type recorders housed in a shelter with thermostatically controlled heat. Only portions of the basic data from this installation have been published. CSSL logs for 1951 and 1952 and Miscellaneous Reports 4, 5, and 6 contain some of the data for selected periods. Comparisons of air temperature measured on the hygrothermograph at station 3 with the temperature data from the Thermohms indicated that the shielding of the Thermohms was probably inadequate for periods of clear weather.

2-07.07 Special observations of air temperature and humidity near the snow surface (up to 4 feet above the snow) were obtained for short periods during active melt periods at WBSL and CSSL, in connection with special observations of point melt and moisture transfer. This was accomplished late in 1952 at WBSL and reported in Research Note 11. The observations at CSSL were taken in 1952, 1953, and 1954; the data for 1954 are summarized in Research Note 25.

2-07.08 Snow-cover determinations. - Special observations of snow cover were performed by aerial photography or ground surveys at each laboratory. Aerial photographs were taken at UCSL for the years 1946 through 1950, and for CSSL for the years 1947, 1948, 1950, and 1952. From 2 to 6 flights were made each year, during the course of the spring melt season. Data from these flights are presented in the appropriate logs. Ground surveys of snow cover were performed at CSSL in 1946, 1947, and 1948, and at WBSL in 1950.

2-07.09 Radioisotope snow gage. - The radioisotope radiotelemetering snow gage was developed under Civil Works Project 170, assigned to the South Pacific Division Office of the Corps of Engineers, for the purpose of providing an unattended measurement of water equivalent from an undistrubed sample of the snowpack, and telemetering the information by radio to a receiving station. A comprehensive report prepared by the South Pacific Division office describes the development of the gage, its technical aspects, and its application to the Kings River Basin, California. 2/ Data collected with this type of gage during its development at CSSL, for the years 1950 through 1952, are published in the appropriate CSSL logs.

2-07.10 Snow crust thickness and temperatures. - Daily observations of snow crust characteristics at an open site near station 3, CSSL, were obtained during the 1954 melt season in connection with the operation of the lysimeters. They were made near sunrise each morning, before melt had begun, as a means of evaluating total nighttime loss of heat from the snowpack. Measurements were made of the total thickness of the refrozen layer and the temperature profile within that layer. Also, the time variation of temperature of the crust during each night was obtained from Thermohms buried in the snow, as a means of providing continuous estimates of the snow surface temperatures through the night. These estimates are contained in Research Note 25.

2-07.11 Atmospheric moisture transfer. - Direct measurements of the transfer of moisture between the snowpack and the atmosphere by periodic weighings of blocks of snow in pans set on the snow surface were made in order to define the amount of evaporation from or condensation on the snowpack in relation to meteorologic variables. Observations of a few hours to several days duration were made at both CSSL and WBSL. Data have been published in Research Notes 11 and 25, for use in connection with evaluation of heat transfer to the snowpack.

2-07.12 Radiation and snowmelt observations in the forest. - Special measurements of radiation in the forest were made at all three laboratories for relatively short periods. Those at UCSL consisted of incident shortwave radiation through varying densities of forest canopy, and cover the period August to November, 1947. These are reported in Research Note 5. Observations of radiation in the forest at CSSL were made by Gier-Dunkle non-selective radiometers of net allwave radiation exchange, as well as total incoming and outgoing radiation, for the period 27 April 1950 through 9 June 1950, at both forested and open sites. Results of these observations are presented in Technical Bulletin 12. At WBSL in July 1952, observations were made of shortwave and allwave radiation exchange over the snow beneath the forest canopy late in the season. Data from these observations are presented in Research Note 12. In connection with the WBSL observations, snowmelt in the forest was measured by snowpack ablation for the purpose of relating melt in the forest to parameters of heat exchange. Results are presented in Research Note 11.

2-07.13 Special soil moisture observations. - Special observations of soil moisture at the snow laboratories were of two types: (1) testing electrical soil-moisture meters, using experimental units installed adjacent to the regular soil-moisture measurement installation at CSSL and at UCSL; and (2) measuring areal variation in soil moisture, using standard Colman soil-moisture meters installed at field stations at UCSL. The principal purpose of the instrument testing was to find a porous material which combined satisfactory dielectric qualities with sufficient durability under field conditions. In addition to several different types of soil-moisture meters, more than a half a dozen different porous materials were tested. (See "Status of Laboratory Observations" in the hydrometeorological logs.) The results of the tests were summarized by Gerdel in Miscellaneous Report 2 and are abstracted in section 4-06. The second group of special observations consisted of readings from Colman soil-moisture units at nine field stations at UCSL in 1949-50 and 1950-51, in cooperation with the U. S. Forest Service. Sites of the field stations were chosen to sample vegetation cover and, so far as operational schedules permitted, areal variation. Each station consisted of Colman moisture units and temperature units at each of five to seven depths below the soil surface: 1, 3, 6, and 12 inches, plus two or three additional depths usually at 12-inch intervals. The observations were made by laboratory personnel; calibration of the units and reduction of the data were performed by Forest Service personnel. Reduced data were not received by Cooperative Snow Investigations in time to be included in the logs. Analysis of the data is expected to form part of the watershed research program of the Intermountain Forest and Range Experiment Station, Ogden, Utah.

2-07.14 Liquid water in snow. - Observations of the thermal quality of snow, which may be used as a measure of the liquid water held in the snowpack, were obtained by calorimetric methods and are listed under regular observations. A special device for determining changes of liquid water in the snowpack in situ was developed at the CSSL, based on the principle of the differences in dielectric constants of ice and water. The instrument is known as a snow-probe capacitor, and a report on its use is contained in the Transactions of the American Geophysical Union. 4/ In general, the instrument has greatest use in detecting time changes with free-water content of snow, but difficulties in calibration preclude its use for quantitative measures.

2-07.15 In addition to measurements of liquid water in the snow, experiments involving the use of fuchsine dye were performed for the purpose of tracing the movement of liquid water through the pack. Miscellaneous experiments of this type were performed at all three laboratories, and a report of early measurements at CSSL is contained in Technical Report 15, Interim Report No. 1. Reports on other experiments of this type have not been published.

2-07.16 Precipitation gage battery. - A battery of precipitation gages of various types was installed at station 1, CSSL, and operated for 2 to 3 years, for the purpose of comparing the efficiencies of the gages and wind shields in areas where precipitation is predominantly in the form of snow. All were placed in an open clearing approximately 100 feet in diameter, and centered about 100 feet northeast of the laboratory headquarters building. The following tabulation describes the gages in this battery:

STATION	TYPE OF GAGE*	WIND SHIELD	MOUNT AND HEIGHT OF ORIFICES	ANTI-FREEZE CHARGE	PERIOD OF OPERATION (WATER YEARS)
1-A	Std. W.B., manual, 24" capacity	no	on snow surface orifice: 2'	no	1946-1952
1-B	Friez recorder 12" capacity	yes	on tower, orifice: 23'	yes	1947-1952
1-C	Stevens recorder 24" capacity	yes	on tower, orifice: 19'	yes	1946-1951
1-D	Enlarged Friez recorder, 24" capacity	yes	on tower, orifice: 24'	yes	1947-1949
1-E	Std. W.B., manual, 24" capacity	no	on tree stump, orifice: 24'	yes	1947-1949
1-F	Std. W.B., manual 24" capacity	yes	on tree stump, orifice: 24'	yes	1947-1949
1-G	Sacramento, Manual, 200" capacity	yes	on tower, orifice: 24'	yes	1947-1949 1952-1954

*All gage orifices are of standard 8" diameter.
Capacities listed are without anti-freeze charge.
Effective operational capacities, with charge, are approx $\frac{1}{2}$ those above.

The location of these gages is shown on the site map for station 1, contained in the 1950-51 log for CSSL. Data have been published in the appropriate logs for only stations 1-B and 1-C. Comparative data for seven gages for selected periods in the 1946-47 water year were published by Wilson in the Monthly Weather Review. 8/

2-07.17 Supplementary snow-course data, CSSL. - In the spring of 1951, 15 supplemental snow courses at CSSL were measured for more adequate sampling of the snowpack with respect to topographic features. Results of these measurements are contained in the 1950-51 log for CSSL and in Research Note 13.

2-07.18 Penetration of solar radiation into the snowpack. - An experiment on the penetration of solar radiation into the snowpack was devised in 1947, utilizing specially constructed pyrheliometers. A report of the instrument and measurements obtained by it is found in Technical Report No. 8, Interim Report No. 1.

2-08. DATA PUBLICATION

2-08.01 General. - Systematic publication of snow laboratory data was accomplished for the bulk of the observations. Reference is made to the individual hydrometeorological logs for listing of elements and periods for which values have been published (see Appendix I). Each log contains an inventory of meteorologic and hydrologic data, which indicates in chart form the status of the processing and publishing of each of the elements observed at the field stations and at headquarters. No further summary is presented herein.

2-08.02 Method of publication. - All published data are presented in the logs in tabular form from previously reduced and verified recorder charts or field notes. The time interval for tabulated values is not the same for all elements nor is it consistent throughout the year; the selection of the time intervals was dependent upon the time variability of the element, the relative importance of the element, the prospective use of the observations in hydrologic analysis, and the availability and quality of record. In some cases, short periods of hydrologic significance (unusual winter rain storms or periods of melt, etc.) were treated more fully than normal periods when there was little change in conditions.

2-08.03 Unpublished data. - All original field notes, recorder charts and data tabulations are preserved in the files of the North Pacific Division Office, U. S. Corps of Engineers. Any inquiries or requests for transcripts of unpublished data should be directed to that office. These data include records for periods which have not been encompassed by the logs. In addition, there were observations for the 1951-52 water year at WBSL and the 1952-53 water year at CSSL, for which records have not been published. Reduction of data for those years is about 50 percent complete, and information on availability of records may be obtained upon request. Original records for the entire laboratory program of the Cooperative Snow Investigations have been microfilmed, so that copies of the original field notes and recorder charts are available on microfilm. Data for approximately 30 percent of the observations have been placed on IBM punch cards for machine mass data analysis. Reference is made to the inventory of meteorologic and hydrologic data contained in each log, for listing of periods for which IBM punch cards are available.

2-09. REFERENCES

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7/ U. S. WEATHER BUREAU, "Normal weather charts for the Northern Hemisphere," Technical Paper No. 21, October 1952.

8/ WILSON, W. T., "Analysis of winter precipitation observations in the Cooperative Snow Investigations," Mon. Wea. Rev., Vol. 82 No. 7, July 1954, pp. 183-195.

TABLE 2-1

SUMMARY OF SNOW LABORATORY CHARACTERISTICS

PART I - TOPOGRAPHIC AND ENVIRONMENTAL FEATURES

LABORATORY AREA	DRAINAGE AREA	MEAN LATITUDE	MEAN LONGITUDE	ELEVATION			SLOPE			BASIN ORIENTATION				FOREST COVER			
				Mean	Max.	Min.	Mean	Steepest Quartile	Flattest Quartile	NE	SE	SW	NW	Predominant Type	Forested Area	Mean Canopy Density	Basin Area under Canopy
	(sq.mi.)	°N.	°W.	(ft. msl)			(%)	(%)	(%)	(%)	(%)	(%)	(%)		(%)	(%)	(%)
UCSL (Entire Area)	20.7	48°18'	113°20'	5700	8605	4480	-	-	-	-	-	-	-		-	-	-
Skyland Creek	8.1	48°17'	113°20'	5920	7610	4800	32	40	22	27	11	37	25	Lodgepole Pine, Red Fir	90	80	72
WBSL (Entire Area)	11.7	44°18'	122°10'	3430	5364	1960	40	50	27	15	27	32	26	Douglas Fir, Hemlock, Noble Fir	93	90	84
Mann Creek	5.12	44°19'	122°10'	3750	5235	2490	36	45	26	13	32	43	12	Douglas Fir, Hemlock, Noble Fir	93	90	84
Wolf Creek	2.07	44°18'	122°08'	3590	5364	2490	45	59	26	19	16	27	39	Douglas Fir, Hemlock, Noble Fir	88	90	79
CSSL (Entire Area)	3.96	39°22'	120°22'	7500	9106	6892	21	23	10	11	36	33	20	Lodgepole Pine	40	50	20

PART II - CLIMATIC CHARACTERISTICS

LABORATORY AREA	MEAN BASIN TEMPERATURE*					MEAN BASIN PRECIPITATION *			MEAN W.E. OF TOTAL NEW-FALLEN SNOW, OCTOBER THROUGH MARCH		MEAN BASIN WATER EQUIVALENT	MEAN SOLAR INSOLATION			MEAN WIND AT 700 mb LEVEL							
	Annual	Jan.	Apr.	Jul.	Oct.	Annual	Oct. through March	Apr. through Sept.	Before Interception	After Interception	1 Apr.	Apr.	May	June	JAN. Speed	JAN. Dir.	APRIL Speed	APRIL Dir.	JULY Speed	JULY Dir.	OCT Speed	OCT Dir.
	(°F)	(°F)	(°F)	(°F)	(°F)	(in.)	(in.)	(in.)	(in.)	(in.)	(in.)	(ly/day)			(knots)		(knots)		(knots)		(knots)	
UCSL (Skyland Creek)	34	14	32	56	37	50.5	32.0	18.5	29	23	19	428	489	499	28	290°	15	270°	14	250°	15	270°
WBSL	45	32	41	62	46	122.0	97.0	25.0	46	41	18	-	-	-	24	260°	15	260°	12	240°	14	260°
CSSL	38	23	34	56	41	70.0	58.2	11.8	52	48	40	563	646	706	20	280°	12	270°	7	240°	7	260°

* Temperature and precipitation data adjusted to estimated long term average.

PART III - STREAMFLOW CHARACTERISTICS

LABORATORY AREA	PERIOD OF RECORD	MEAN RUNOFF				EXTREME DISCHARGES				RECESSION DISCHARGES AT VARIOUS FLOWS							
		Annual		Seasonal		Maximum		Minimum		2 cfs/sq.mi.		5 cfs/sq.mi.		10 cfs/sq.mi.		20 cfs/sq.mi.	
		Observed Period of Record	Adjusted to 1921-50 Normal	Oct. through Mar. Period of Record	Apr. through Sep. Period of Record					t_s	C_r	t_s	C_r	t_s	C_r	t_s	C_r
		(in.)	(in.)	(in.)	(in.)	(cfs)	(cfs/sq.mi.)	(cfs)	(cfs/sq.mi.)	(days)	(per day)	(days)	(per day)	(days)	(per day)	(days)	(per day)
UCSL (Entire Area)	10/46-9/51	31.2	26.5	4.68	26.50	696	33.6	5.5	0.26	-	-	-	-	-	-	-	-
Skyland Creek	10/46-9/51	33.3	28.5	4.31	29.02	284	35.0	0.1	0.01	12.0	0.92	4.6	0.80	3.0	0.72	2.3	0.65
WBSL (Entire Area)	11/47-9/51	92.1	77.0	54.95	37.18	1410	122.6	2.1	0.18	40.0	0.975	7.2	0.87	4.5	0.80	2.7	0.69
Mann Creek	12/48-9/52	105.0	93.3	55.43	49.61	585	114.3	1.0	0.20	7.8	0.88	4.2	0.79	2.7	0.69	2.0	0.61
Wolf Creek	12/48-9/52	95.7	84.9	56.00	40.10	124	59.9	0.5	0.24	-	-	-	-	-	-	-	-
CSSL (Entire Area)	2/46-8/51	46.0	42.9	10.11	35.85	1200**	300.0**	0.0	0.00	6.5	0.86	3.2	0.73	1.5	0.52	0.9	0.35

** Gage inoperative 18-21 Nov. 1950; maximum discharge estimated.

TABLE 2-2

SNOW LABORATORY PERSONNEL

WATER YEAR	CSSL Laboratory Director	CSSL Number of Employees CE	CSSL Number of Employees WB	UCSL Laboratory Director	UCSL Number of Employees CE	UCSL Number of Employees WB	WBSL Laboratory Director	WBSL Number of Employees CE	WBSL Number of Employees WB
1945-46	A. R. Codd	1	3*	F. L. Rhodes	3*FS	1	-	-	-
1946-47	A. R. Codd R. W. Gerdel B. L. Hansen	3	3*	F. L. Rhodes W. R. Demme	5*	2	-	-	-
1947-48	B. L. Hansen	3	2*	W. R. Demme	5*	2	W.G.Somerville	5*	0
1948-49	B. L. Hansen	3	2*	W. R. Demme	5*	2	W.G.Somerville	5*	0
1949-50	C. W. Mansfield	2	2*	W. R. Demme	5*	2	W.G.Somerville J. Summersett**	6*	0
1950-51	P. Merrill	3*	0	R. K. Brown	2*	0	W.G.Somerville	6*	0
1951-52	W. H. Parrott	5*#	0	-	-	-	W.G.Somerville	5*	0
1952-53	W. H. Parrott	6*#	0	-	-	-	-	-	-
1953-54	P. B. Boyer	3*+	0	-	-	-	-	-	-

* Includes Laboratory Director
** Technical Director
# Includes approximately 8 man-years SIPRE participation, combined 1951-52 and 1952-53.
+ For approximately 6 weeks during melt season.
FS Forest Service personnel participated at UCSL during 1945-46.

NOTES: Personnel from Analyses Unit also participated in observational program for orientation and special studies, particularly at CSSL, after the year 1950. The number of employees listed are for the major portion of the water year.

TABLE 2-3

COMPARATIVE HYDROCLIMATIC DATA - UCSL

ITEM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN
TEMPERATURE, °F 1/														
Long-term														
Means, 1938-54	14.9	18.5	23.2	34.3	43.3	49.0	56.5	54.6	47.7	39.5	25.0	19.3		35.5
Means, 1947-50*	8.0	17.4	21.7	35.0	43.6	50.0	55.8	55.0	47.2	36.8	26.9	17.9		34.6
Deviation from Long-term Means	-6.9	-1.1	-1.5	0.7	0.3	1.0	-0.7	0.4	-0.5	-2.7	1.9	-1.4		-0.9
PRECIPITATION, IN. 1/														
Long-term														
Means, 1937-54	4.85	3.48	3.31	2.60	2.98	3.93	1.16	1.54	2.52	2.97	3.52	3.97	36.83	
Means, 1947-50*	5.03	4.47	3.69	2.43	2.74	4.30	1.45	1.54	1.97	3.99	5.08	4.67	41.36	
Deviation from Long-term Means	0.18	0.99	0.38	-0.17	-0.24	0.37	0.29	0.00	-0.55	1.02	1.56	0.70	4.53	
SNOWPACK W.E., IN. 2/	1 JAN	1 FEB	1 MAR	1 APR	1 MAY									
Long-term														
Means, 1936-55	7.3	11.7	15.7	18.2	11.6									
Means, 1947-50	10.0	15.4	20.4	23.1	16.3									
Deviation from Long-term Means	2.7	3.7	4.7	4.9	4.7									
RUNOFF, IN. 3/														
Long-term														
Means, 1940-52	0.47	0.43	0.52	3.16	9.53	6.87	2.30	0.71	0.50	0.75	0.74	0.76	26.74	
Means, 1947-50*	0.50	0.43	0.57	2.83	11.67	9.42	2.72	0.80	0.47	0.79	0.77	0.69	31.66	
Deviation from Long-term Means	0.03	0.00	0.05	-0.33	2.14	2.55	0.42	0.09	-0.03	0.04	0.03	-0.07	4.92	

* For period beginning Sep 1946 and ending Aug 1950.
1/ Summit, Montana - Elev. 5213 ft.
2/ Marias Pass " - Elev. 5250 ft.
3/ Middle Fork, Flathead River at Essex, Montana - Drainage Area: 510 sq. mi.

TABLE 2-4

COMPARATIVE HYDROCLIMATIC DATA - CSSL

ITEM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN
TEMPERATURE, °F 1/														
Long-term														
Means, 1930-54	24.8	25.8	29.5	36.8	42.9	50.4	58.6	57.0	53.5	44.6	34.8	28.0		40.6
Means, 1947-51*	23.9	26.1	29.3	37.3	43.0	51.5	57.6	56.0	53.2	43.5	35.1	28.0		40.4
Deviation from Long-term Means	-0.9	0.3	-0.2	0.5	0.1	1.1	-1.0	-1.0	-0.3	-1.1	0.3	0.0		-0.2
PRECIPITATION, IN. 1/														
Long-term														
Means, 1930-54	9.24	7.31	7.46	4.07	2.61	1.26	0.30	0.22	0.54	3.49	6.68	8.66	51.84	
Means, 1947-51*	8.84	5.78	8.43	4.83	3.20	0.98	0.04	0.28	0.49	3.99	8.83	7.01	52.70	
Deviation from Long-term Means	-0.40	-1.53	0.97	0.76	0.59	-0.28	-0.26	0.06	-0.05	0.50	2.15	-1.65	0.86	
SNOWPACK, W.E., IN. 1/	1 JAN	1 FEB	1 MAR	1 APR	1 MAY									
Long-term														
Means, 1930-55	-	22.2	31.3	37.1	-									
Means, 1947-51	-	14.8	21.3	30.1	13.5									
Deviation from Long-term Means	-	-7.4	-9.8	-7.0	-									
RUNOFF, IN. 2/														
Long-term														
Means, 1943-52	2.14	20.08	3.21	10.90	17.55	8.00	1.97	0.91	0.48	0.50	2.64	2.95	53.33	
Means, 1947-51*	2.31	1.95	2.73	10.31	15.01	6.75	1.32	0.74	0.60	0.63	4.24	3.53	50.12	
Deviation from Long-term Means	0.17	-0.13	-0.48	-0.59	-2.54	-1.25	-0.65	-0.17	0.12	0.13	1.60	0.58	-3.21	

* For period beginning Sep 1946 and ending Aug 1951.
1/ Soda Springs, California - Elev. 6750 ft.
2/ South Yuba River near Cisco, California - Drainage Area: 50.2 sq. mi.

TABLE 2-5

COMPARATIVE HYDROCLIMATIC DATA - WBSL

ITEM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	MEAN
TEMPERATURE, °F 1/														
Long-term														
Means, 1934-54	39.6	43.1	46.3	52.0	57.1	61.3	66.9	66.3	62.7	54.1	45.7	41.5		53.0
Means, 1948-51*	35.4	40.8	43.7	50.8	56.2	63.0	66.4	66.0	62.1	52.3	46.4	41.2		52.0
Deviation from Long-term Means	-4.2	-2.3	-2.6	-1.2	-0.9	1.7	-0.5	-0.3	-0.6	-1.8	0.7	-0.3		-1.0
PRECIPITATION, IN. 1/														
Long-term														
Means, 1934-54	9.40	7.73	6.90	4.43	3.61	2.70	0.64	0.89	2.09	7.00	9.11	9.81	64.31	
Means, 1948-51*	10.45	8.89	7.46	3.58	4.01	1.56	0.50	1.16	2.41	9.13	9.50	9.08	67.73	
Deviation from Long-term Means	1.05	1.16	0.56	-0.85	0.40	-1.14	-0.14	0.27	0.32	2.13	0.39	-0.73	3.42	
SNOWPACK W.E., IN. 2/	1 JAN	1 FEB	1 MAR	1 APR	1 MAY									
Long-term														
Means, 1941-55	9.7	18.8	23.3	26.4	-									
Means, 1948-51	12.0	24.0	31.5	35.7	-									
Deviation from Long-term Means	2.3	5.2	8.2	9.3	-									
RUNOFF, IN. 3/														
Long-term														
Means, 1936-52	9.37	9.14	8.75	9.16	6.85	3.23	1.05	0.50	0.49	2.58	7.51	10.20	68.83	
Means, 1948-51*	10.47	12.46	10.03	10.51	10.27	4.05	1.13	0.54	0.55	5.40	8.92	9.76	84.09	
Deviation from Long-term Means	1.10	3.32	1.28	1.35	3.42	0.82	0.08	0.04	0.06	2.82	1.41	-0.44	15.26	

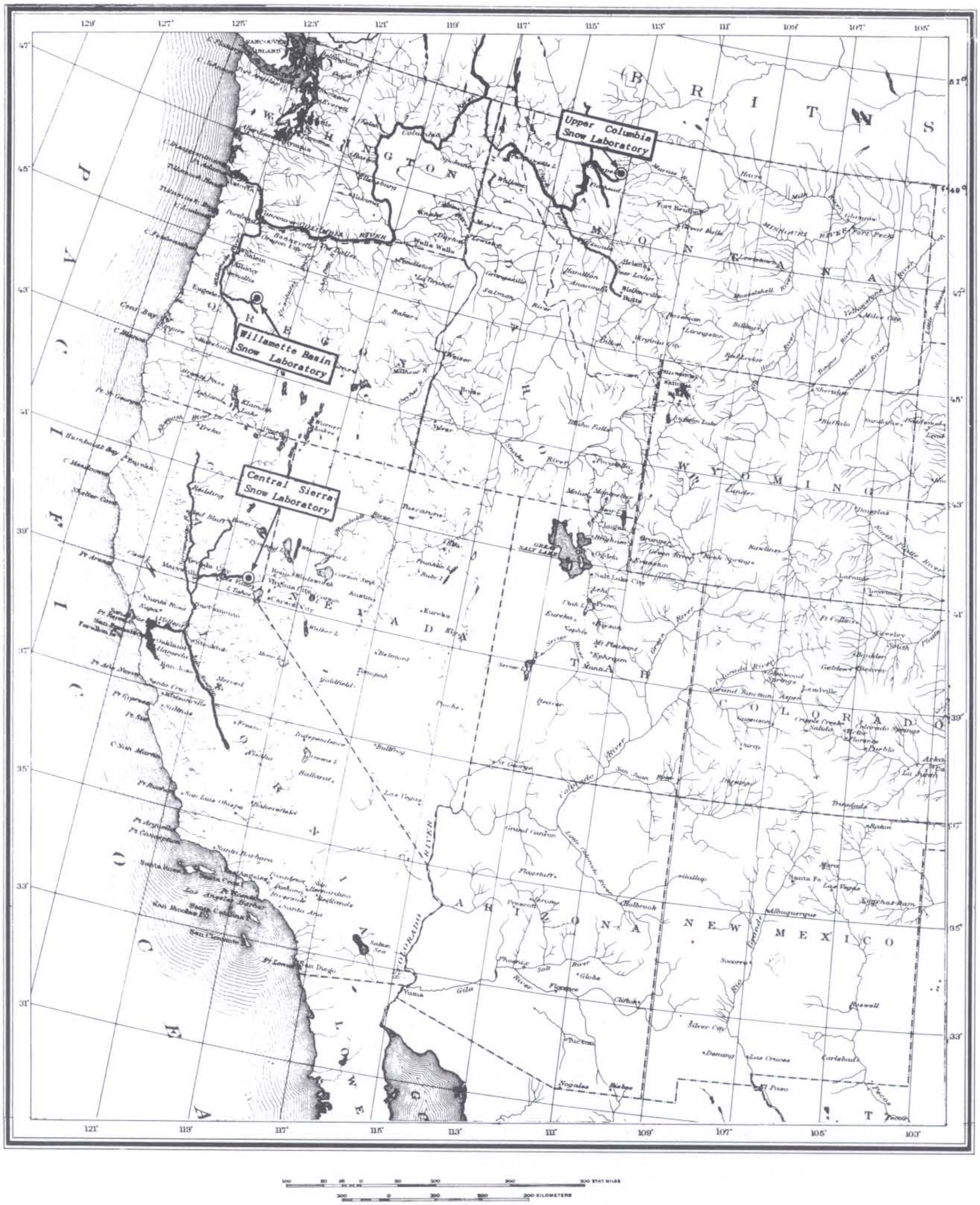
* For period beginning Sep 1947 and ending Aug 1951.
1/ Leaburg, Oregon - Elev. 675 ft.
2/ Santiam Junction, Oregon - Elev. 3780 ft.
3/ Blue River near Blue River, Oregon - Drainage Area: 75 sq. mi.

TABLE 2-6

SUMMARY OF REGULAR OBSERVATIONS AT SNOW LABORATORIES

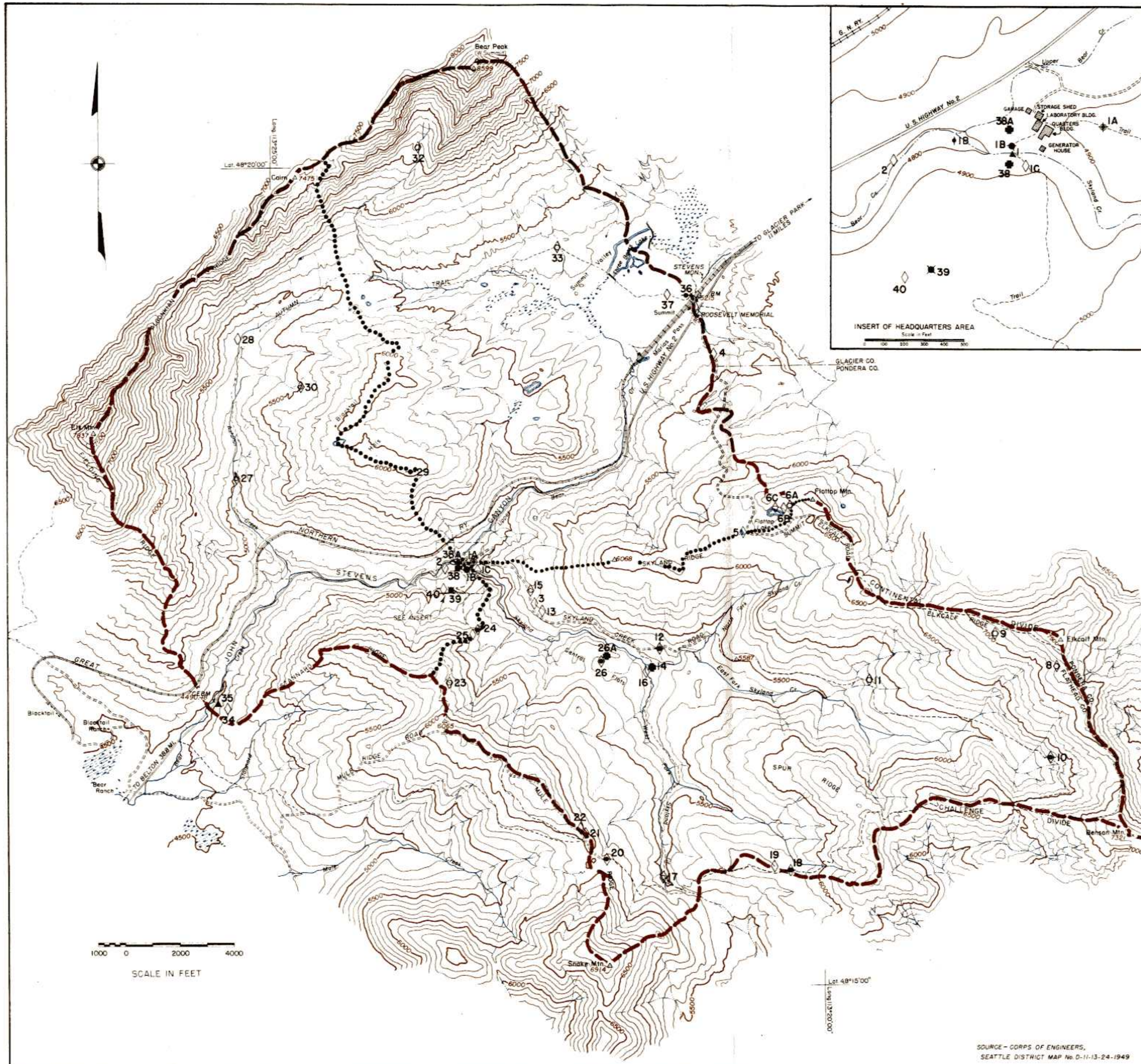
HYDROMETEOROLOGICAL ELEMENT	UNITS	NUMBER OF UNITS OPERATED EACH YEAR																			
		CENTRAL SIERRA SNOW LABORATORY									UPPER COLUMBIA SNOW LABORATORY						WILLAMETTE BASIN SNOW LABORATORY				
		1945-46	46-47	47-48	48-49	49-50	50-51	51-52	52-53	53-54	1945-46	46-47	47-48	48-49	49-50	50-51	1947-48	48-49	49-50	50-51	51-52
GENERAL WEATHER																					
Cloudiness, state of weather, wind direction (visual)	Station	1	1	1	1	1	1	1	1	2P	1	1	1	1	1	1	1P	1	1	1&1P	2
RADIATION																					
Sunshine duration (mercury switch w/recorder)	Station	1	1	1P	-	-	-	-	-	-	1	1	1	-	-	-	-	-	-	-	-
Shortwave incident in open (pyrheliometer w/recorder)	Station	1	1	1	1	1	1	1	1	1P	1	1	1	1	1	1	-	-	-	-	-
Shortwave reflected from snow (pyrheliometer w/recorder)	Station	1	1	1	1	1	1	1	1	1P	1	1	1	1	1	-	-	-	-	-	8d
Longwave net (radiometer w/recorder)	Station days	-	-	-	-	36d*	-	92d	300d	40d	-	-	-	-	-	-	-	-	-	-	8d
Longwave total hemispheric (radiometer w/recorder)	Station days	-	-	-	-	36d*	-	92d	300d	40d	-	-	-	-	-	-	-	-	-	-	8d
AIR PRESSURE AND WIND																					
Pressure (barograph without barometer)	Station	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1P	1	1	1	-
Pressure (barograph checked by barometer)	Station	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1P	-	-	-	-	-
Wind direction (vane w/recorder)	Station	1	1	1&1P	1P	-	1	1	1	1P	1	1	1	1	1	1	-	-	-	-	-
Wind movement (anemometer totalizer)	Station	-	6	7	6	7	5	2	2	1P	5	5	5	5	5	3	-	-	-	2	2&2P
Wind speed (anenometer w/recorder)	Station	3	3	3	2	-	14P	6&6P	11	5P	1	2	2	2	2	2	-	-	-	-	-
TEMPERATURE AND HUMIDITY																					
Air temperature (thermograph w/checks)	Station	6P	6&3P	9	8&2P	7	5	2	2	2P	7P	7&2P	9	9&1P	9	4	-	1&4P	5	5	5
Air temperature profile (Thermohms w/recorder unless marked-N)	Station	1P	1	1	-	-	4	2&2P	2&1P	1P&1PN	-	1P	1	1	1	1N	-	-	-	-	-
Humidity (hydrograph w/checks)	Station	6P	6&3P	9	8&2P	7	5	1&5P	2	2P	6P	6&2P	8	7&2P	8	2&1P	-	4P	4&1P	5	5
PRECIPITATION																					
Precipitation (standard 8" U.S.W.B. gage)	Station	1P	1	1	1	1	1	1	1	2P	2	2	2	2	2	1	-	1	1	1	1
Precipitation (storage gage-N)	Station	-	14	14	16	12	12	1	4	1	12	12	12	12	12	5	7	7	11	10&1P	13
Precipitation (recording weighing-type gage)	Station	1	4	4	4&4P	7	6	2	2	1&1P	8	8	8	8	8	4	1	1&1P	5	5	4
SNOW																					
Snowfall (snowboard or snowboard battery)	Station	1	1	1	1	1	1	1	1	1P	1	1	1	1	1	1	-	-	1P	1&1P	2
Water equivalent of new snow	Station	-	-	-	-	1	3	3P	1	1P	-	-	-	-	-	-	-	-	-	-	-
Snow depth(snow stake read daily)	Station	1	1	1	1	1	1	1	2	2P	2	2	2	2	2	2	1P	1	1	1	1
Snow cover(aerial photograph set)	Flights	-	11	4	8	7	2	6	-	-	3	5	5	5	5	-	-	-	-	-	-
Snow depth, water equivalent, density (snow course)	Courses	18	22	22	21	23	41	3&15P	6	2&2P	21	28	28	28	29	6	10	11	19	18	13
Temperature profile (Thermohm bridge-N)	Sets of determinations	-	88	22	26	28	-	5	-	-	-	-	-	-	-	1	-	-	14	64	106
Temperature profile (Thermohm w/recorder)	Station	1P	-	1	1	-	-	-	S	1CP	-	-	1	1	1	-	-	-	-	-	-
SOIL																					
Temperature profile (Thermohm bridge-N)	Sets of determinations	19	191&47	54	52	111&48	-	-	-	-	-	-	-	-	-	191	-	-	14	64	106
Temperature profile (Thermohm w/recorder)	Station	-	-	1	1	-	1	1	1	-	-	1P	1	1	-	-	-	-	-	-	-
Moisture profile (porous blocks w/resistance bridge-N)	Sets of determinations	19	216&48	183&53	128&51	120&49	-	-	-	-	-	5	69	83	70	8	-	-	-	-	-
Ground water (well w/float and tape-N)	Wells	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	4
Ground water (float activating a recorder)	Wells	-	1	2	1&3P	2&1P	1&1P	-	-	-	-	-	1	3	4	2	-	-	2	2	1
STREAMFLOW																					
Water stage (staff only)	Station	-	-	-	-	-	-	1P	1P	-	1	-	-	-	-	-	-	-	-	-	2P
Water stage (recorder w/staff for checks)	Station	1	1&2P	1&1P	1	1	1	1	1	2P	1	2	2	2	2	2	1	3	3	3	3
Water temperature (Thermohm w/recorder)	Station	-	1	1	1	1	-	-	-	-	-	1	1	1	1	1N	-	-	-	-	-

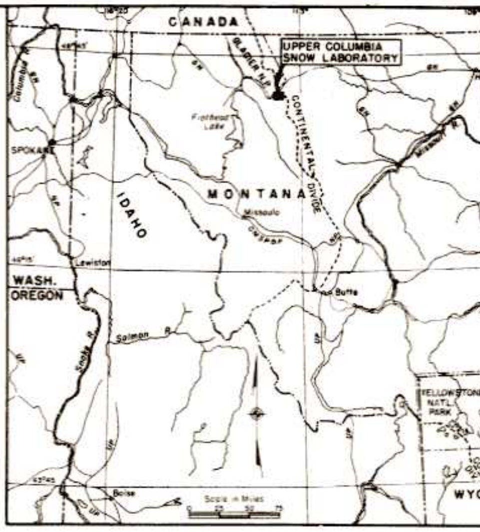
N - Non-recorder
P - Partial year's record
m - 1954 melt season only (12 April - 22 May)
d - Days of record
S - From snow pits only
* - Instantaneous readings - not continuous record
C - In crust zone



MAP OF WESTERN UNITED STATES
SHOWING LOCATION OF SNOW LABORATORIES
OF THE
WEATHER BUREAU — CORPS OF ENGINEERS COOPERATIVE SNOW INVESTIGATIONS

PLATE 2 - I





REGIONAL MAP

LEGEND

ROAD, IMPROVED
ROAD, UNIMPROVED
TRAILS
100-FOOT CONTOURS
BOUNDARY OF SNOW LABORATORY
BOUNDARY OF SUBDRAINAGE AREA WITHIN LABORATORY AREA
MAIN STREAMS
TRIBUTARY STREAMS
LAKE OR POND
ELEVATION OF TRIANGULATION STATION — △ 6914
ELEVATION OF PEAKS OR BENCH MARKS — x 4490.48

HYDROMETEOROLOGICAL STATIONS

NON RECORDING — *RECORDING*

PRECIPITATION
PRECIPITATION, TEMPERATURE
SNOW COURSE
STREAM FLOW
GROUND WATER
SNOW TEMPERATURE, SOIL TEMPERATURE & SOIL MOISTURE
RADIATION

NOTE— VERTICAL CONTROL— 1929 Mean Sea Level.
HORIZONTAL CONTROL— U.S. Geological Survey and U.S. Forest Service.
PROJECTION— Polyconic 1927 N.A. Datum.
PHOTOGRAPHY— U.S. Forest Service, 1948.
TOPOGRAPHY— U.S. Forest Service Stereo-Photogrammetric Methods (K.E.K. Plotter) 1948-1949.

COOPERATIVE SNOW INVESTIGATIONS

U.S. WEATHER BUREAU — CORPS OF ENGINEERS

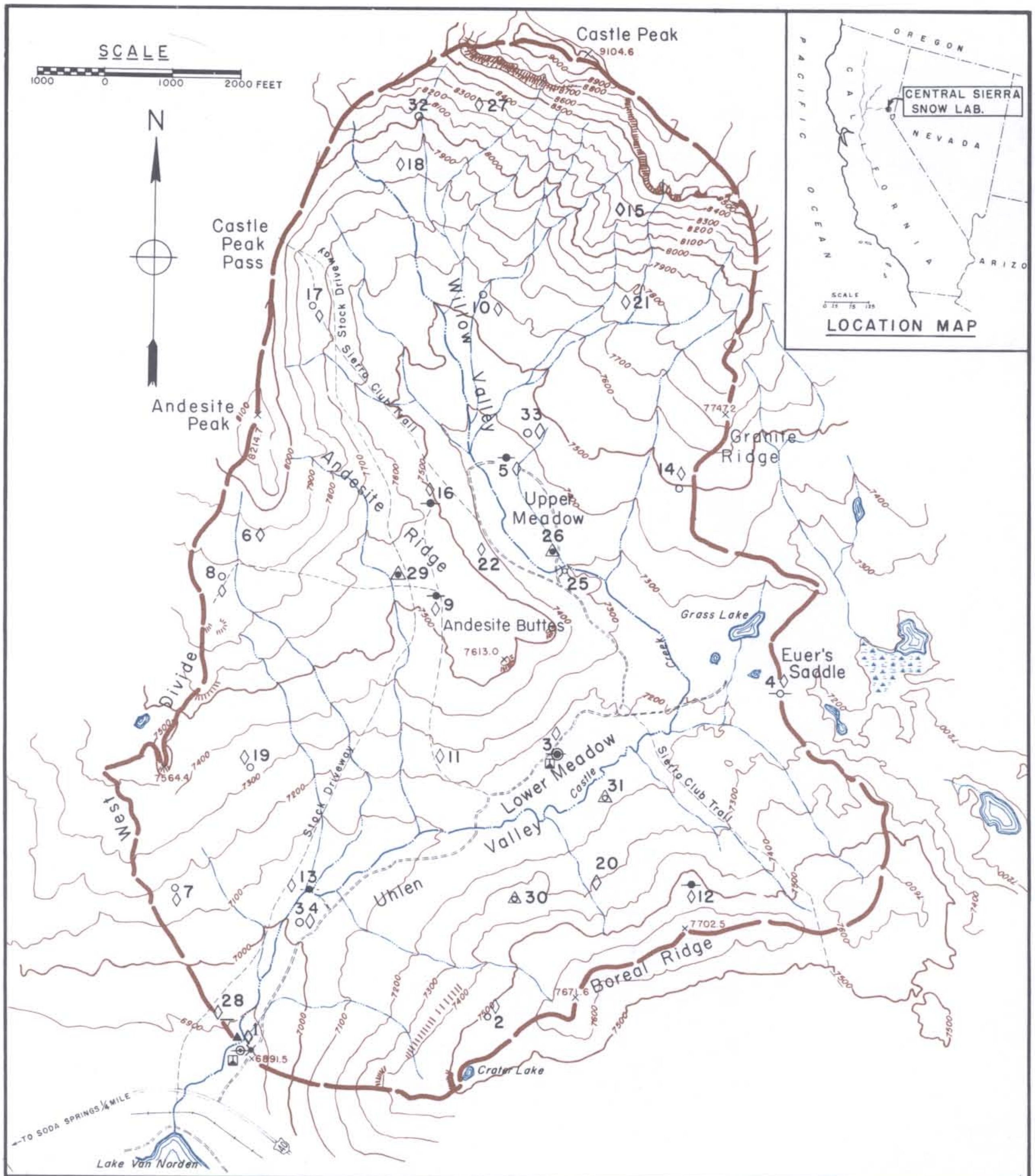
UPPER COLUMBIA SNOW LABORATORY

LOCATION OF HEADQUARTERS AND FIELD STATIONS

OFFICE OF DIVISION ENGINEER, SOUTH PACIFIC DIVISION
CORPS OF ENGINEERS — U.S. ARMY

PREP. G.E.D.	SUBM. D.H.M.	DATE PREP. JULY, 1951
DRAWN W.H.K.	APPR. W.L.D.B.	TO ACCY. T.R. NO.

PLATE 2-2



LEGEND

MEASUREMENTS TAKEN	NON RECORDING	RECORDING
PRECIPITATION	○	●
TEMPERATURE		—
PRECIPITATION AND TEMPERATURE	-○-	-●-
PRECIPITATION, TEMPERATURE & RADIATION		-◉-
SNOW COURSE	◊	
STREAMFLOW	△	▲
GROUND WATER WELLS	△	▲
SNOW TEMPERATURES, SOIL TEMPERATURES, AND SOIL MOISTURE	⌘	⌘
LYSIMETER, TEMPERATURE AND WIND PROFILES		⊞

RIMROCK AND KNOBS
U.S. HIGHWAY NO. 40
ROAD, UNPAVED
TRAILS
100 FOOT CONTOURS
BOUNDARY OF BASIN
STREAMS
LAKES
MARSH
SOUTHERN PACIFIC RAILROAD
ELEVATION OF TRIANGULATION STATION × 6891.5

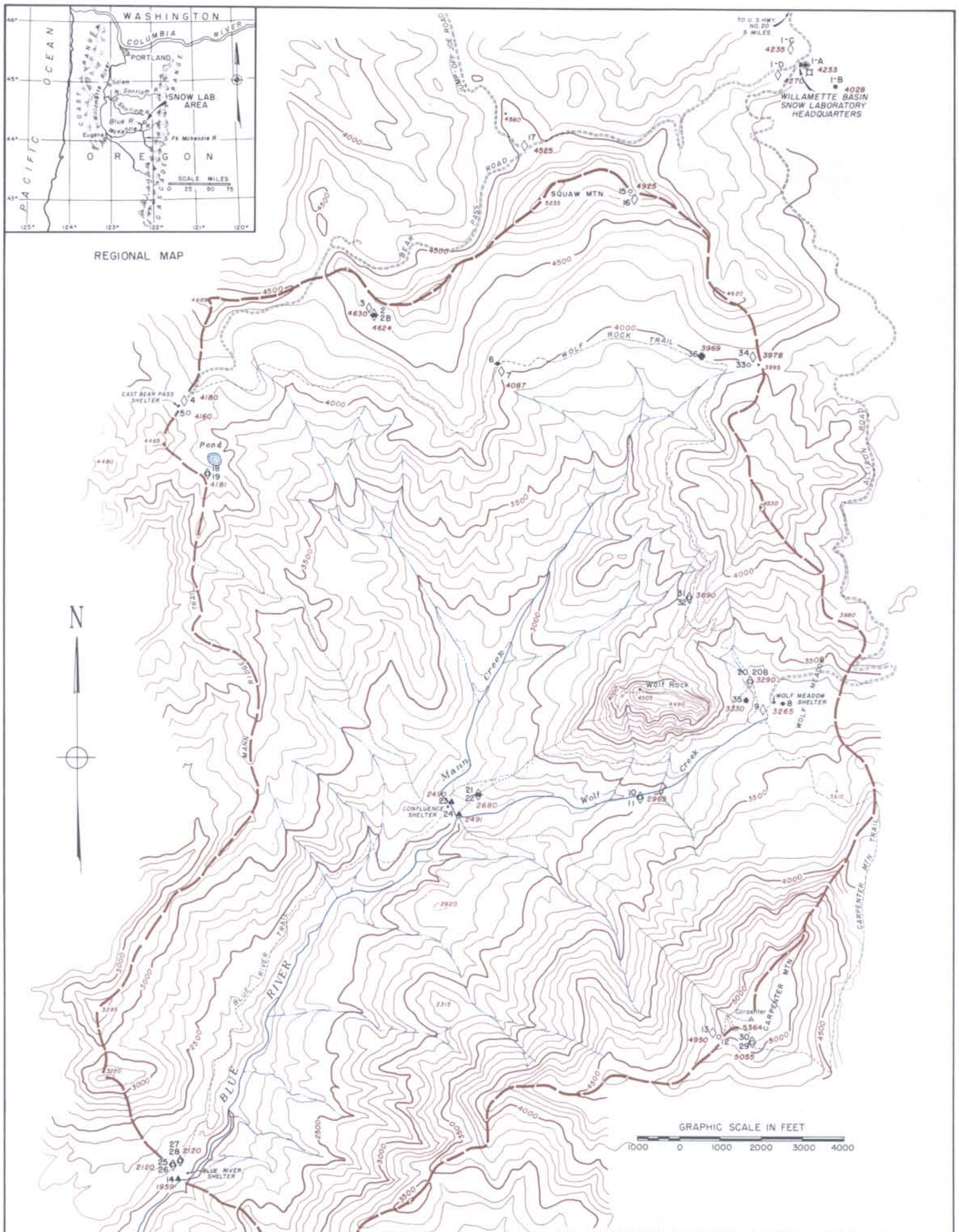
LOCATION OF STATIONS FROM JAN. 1946 TO JAN. 1952

CENTRAL SIERRA SNOW LABORATORY
SHOWING LOCATION OF HEADQUARTERS AND FIELD STATIONS

JANUARY 2, 1952

COOPERATIVE SNOW INVESTIGATIONS

PLATE 2 - 3



WILLAMETTE BASIN SNOW LABORATORY
SHOWING LOCATION OF HEADQUARTERS AND FIELD STATIONS

1 AUGUST 1950 — COOPERATIVE SNOW INVESTIGATIONS

LEGEND

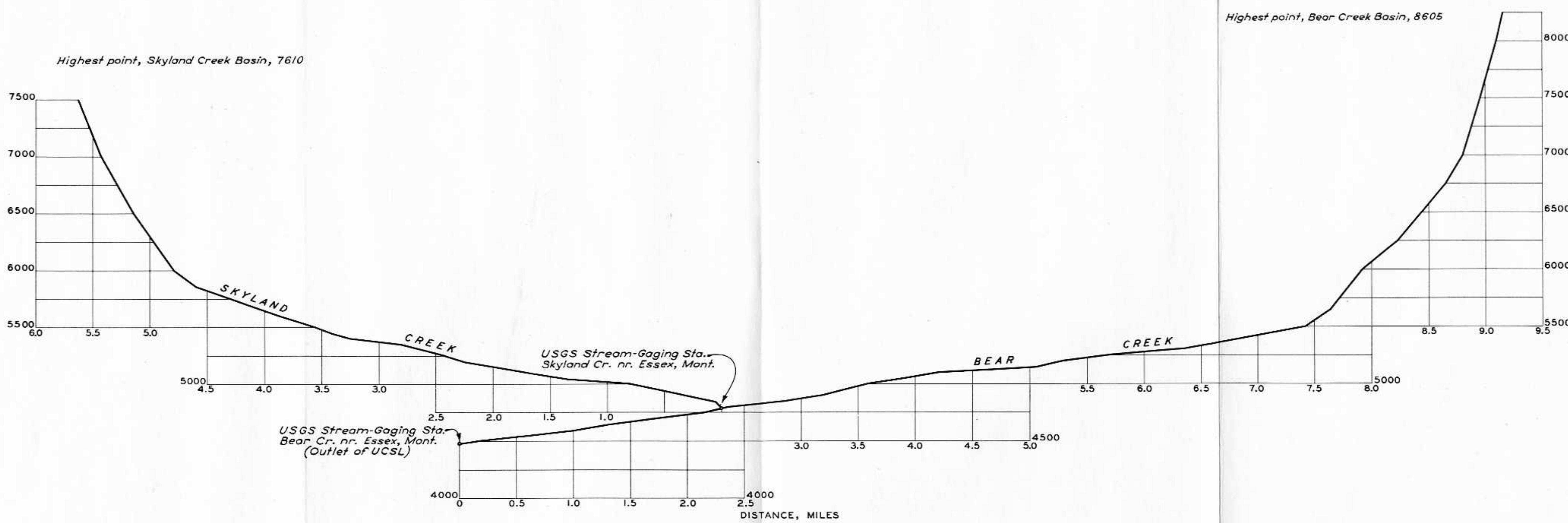
MEASUREMENT TAKEN	NON RECORDING	RECORDING
PRECIPITATION	○	●
PRECIPITATION, TEMPERATURE	-○-	-●-
SNOW COURSE	◇	
STREAM FLOW		▲
GROUND WATER WELLS		✚
SNOW TEMPERATURE, SOIL TEMPERATURE	⌑	

- ROAD, UNPAVED
- TRAILS
- 100 FOOT CONTOURS
- BOUNDARY OF SNOW LABORATORY
- BOUNDARY OF SUB-DRAINAGE AREA WITHIN LABORATORY AREA
- MAIN STREAMS
- TRIBUTARY STREAMS
- POND
- ELEVATION OF TRIANGULATION STATION — Δ 5364
- ELEVATION OF PEAKS — X 3610

NOTE
VERTICAL CONTROL - Altimeter Elevations by U. S. F. S.
HORIZONTOL CONTROL - Multiplex Extension between 4th order Triangulation established by U. S. F. S., 1927 General Adjustment
PROJECTION - Polyconic
PHOTOGRAPHY - U. S. F. S., 15 August 1946
TOPOGRAPHY - By Multiplex Aero-projector
ACCURACY - Good Reconnaissance

SOURCE: CORPS OF ENGINEERS MAP, PORTLAND DISTRICT, Dwg No. WB-1-2/25, Dec 1949

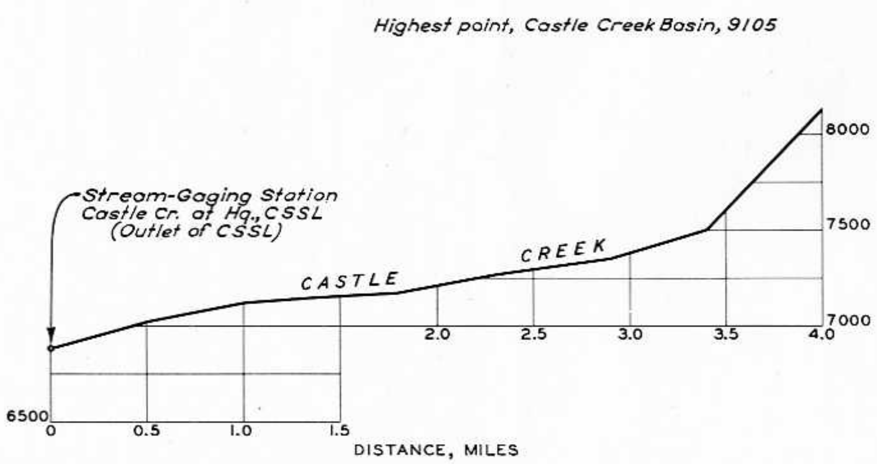
ELEVATION, FEET ABOVE MSL



ELEVATION, FEET ABOVE MSL

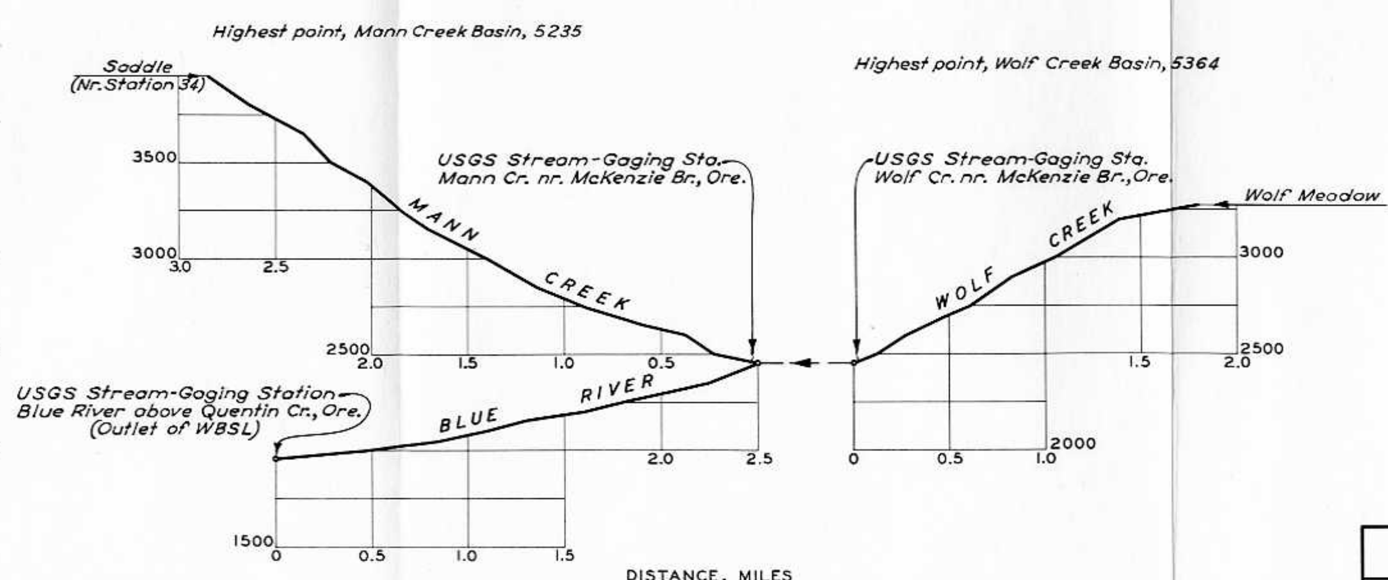
UPPER COLUMBIA SNOW LABORATORY

FIGURE 1



CENTRAL SIERRA SNOW LABORATORY

FIGURE 2



WILLAMETTE BASIN SNOW LABORATORY

FIGURE 3

SNOW INVESTIGATIONS
SUMMARY REPORT

SNOW HYDROLOGY

SNOW LABORATORY
STREAM PROFILES

OFFICE OF DIVISION ENGINEER, NORTH PACIFIC DIVISION
CORPS OF ENGINEERS U. S. ARMY

PREPARED: M.W. SUBMITTED: P.B.S. TO ACCOMPANY REPORT DATED 30 JUNE 1956
DRAWN: S.J. APPROVED: D.M.R.

PD-20-25/6

PLATE 2-5

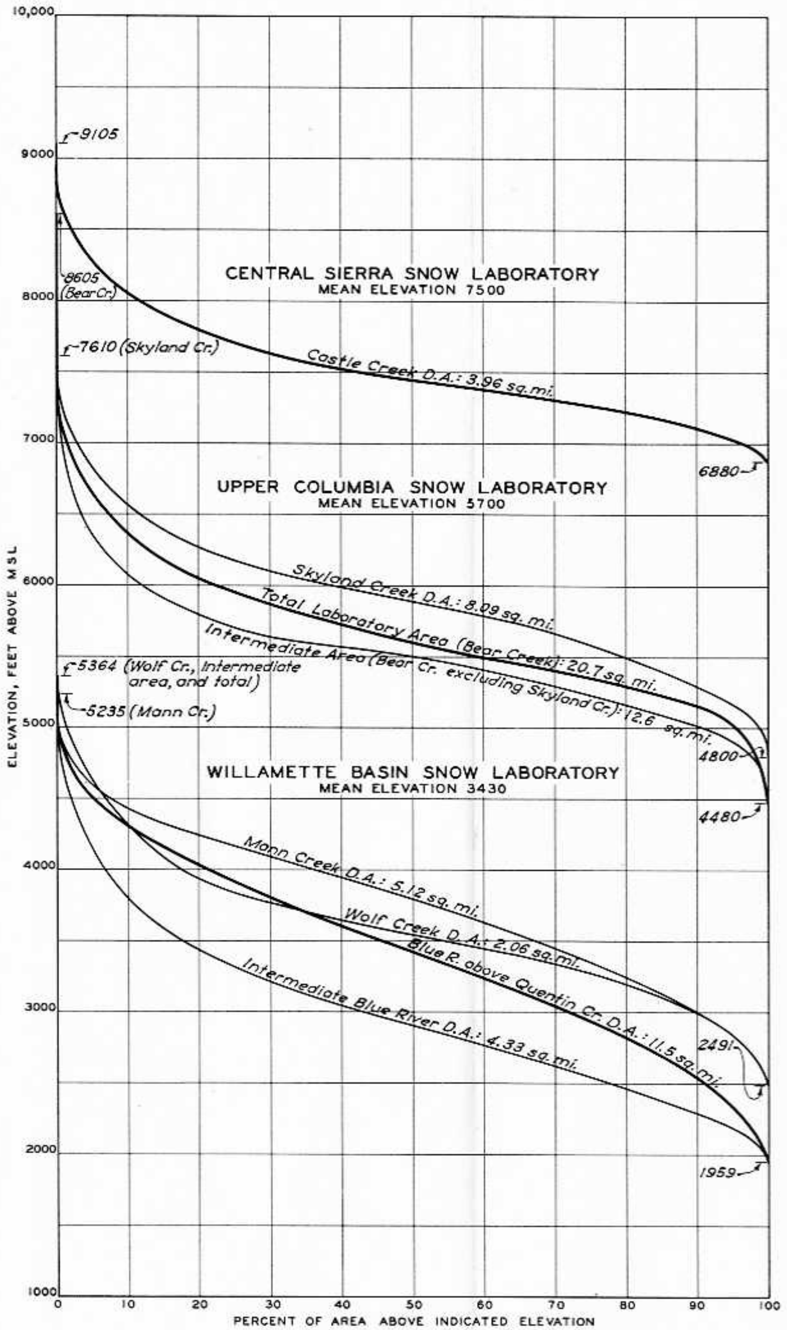


FIGURE 1 — AREA-ELEVATION CURVES

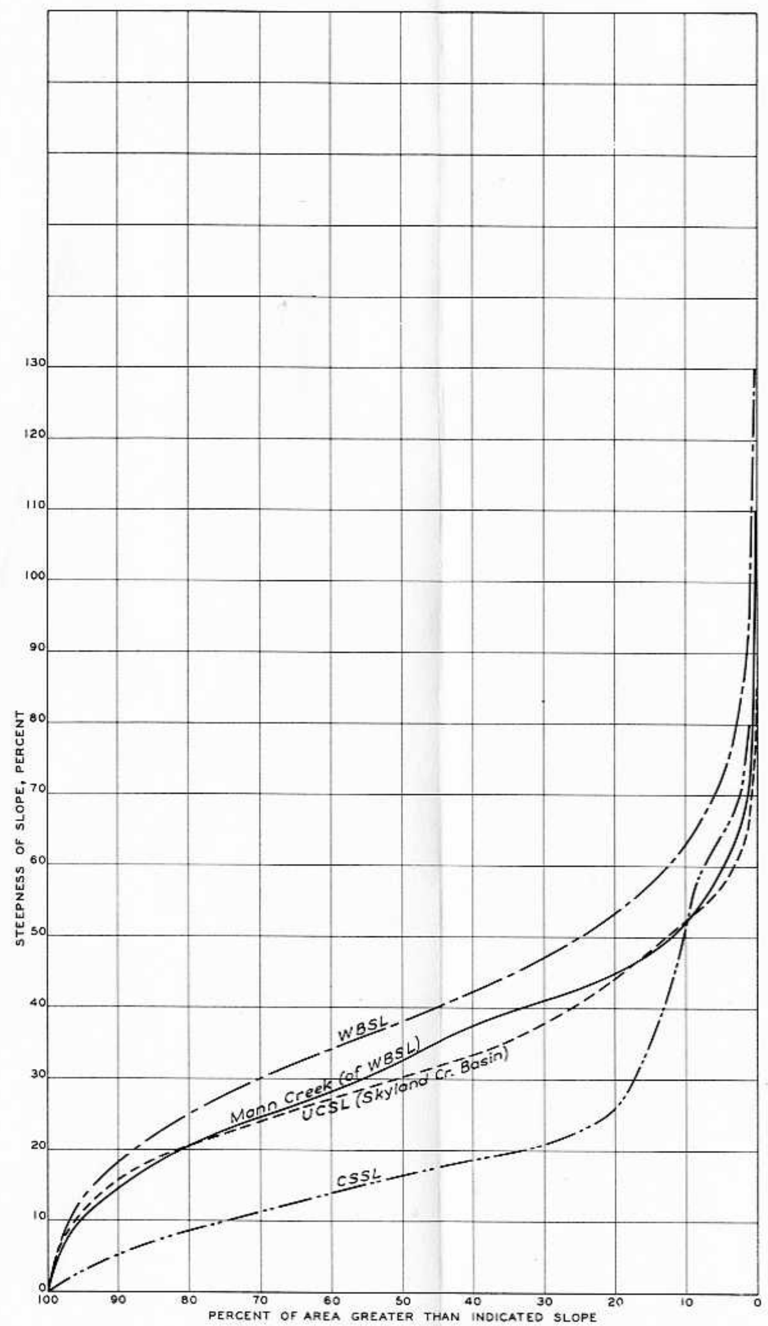
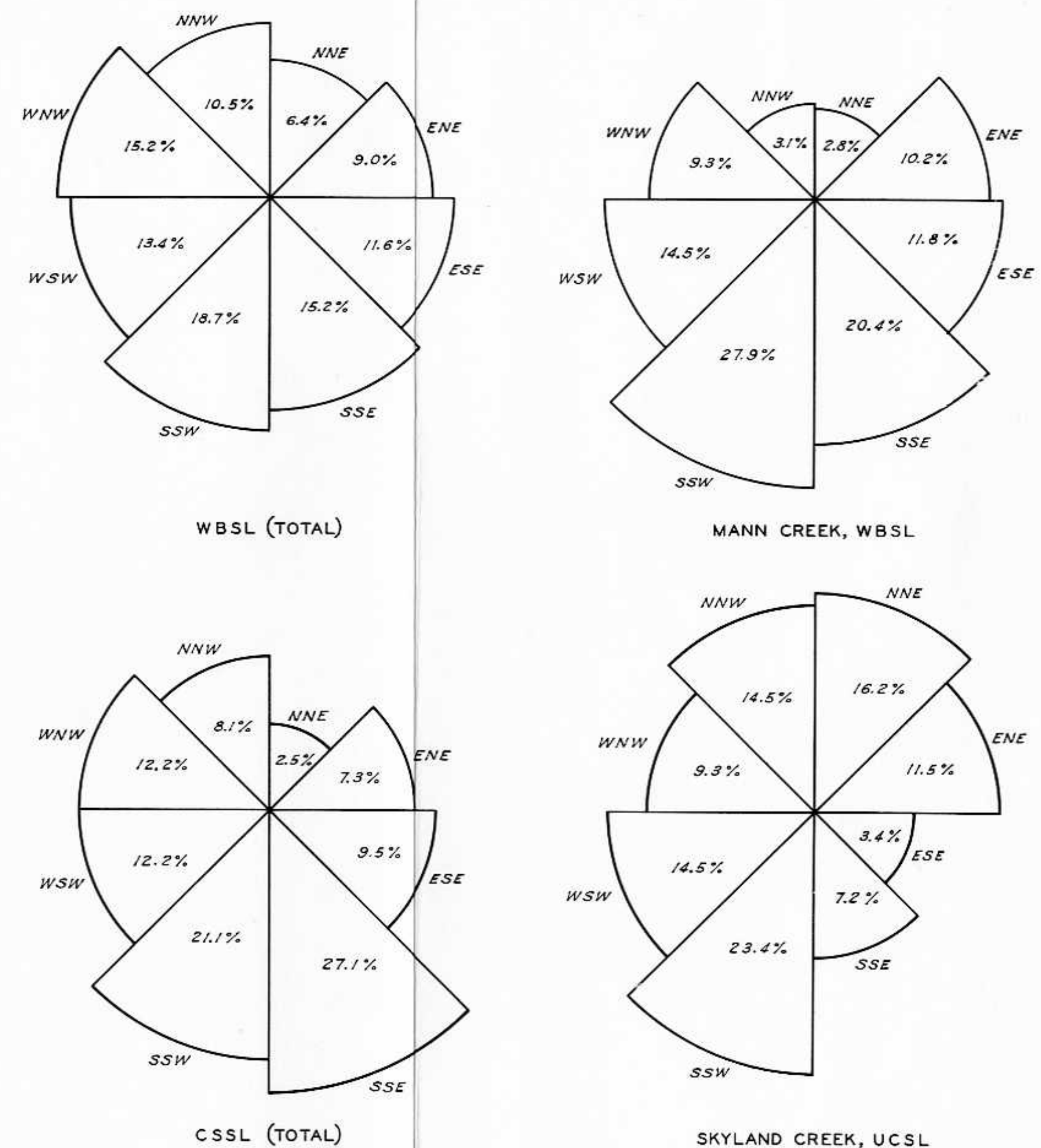


FIGURE 2 — AREA-SLOPE CURVES



Notes:
1. Values shown for each octant represent percent of basin area facing in that direction.
2. Area of each octant is directly proportional to percent of basin area facing in that direction.

FIGURE 3 — BASIN ORIENTATION

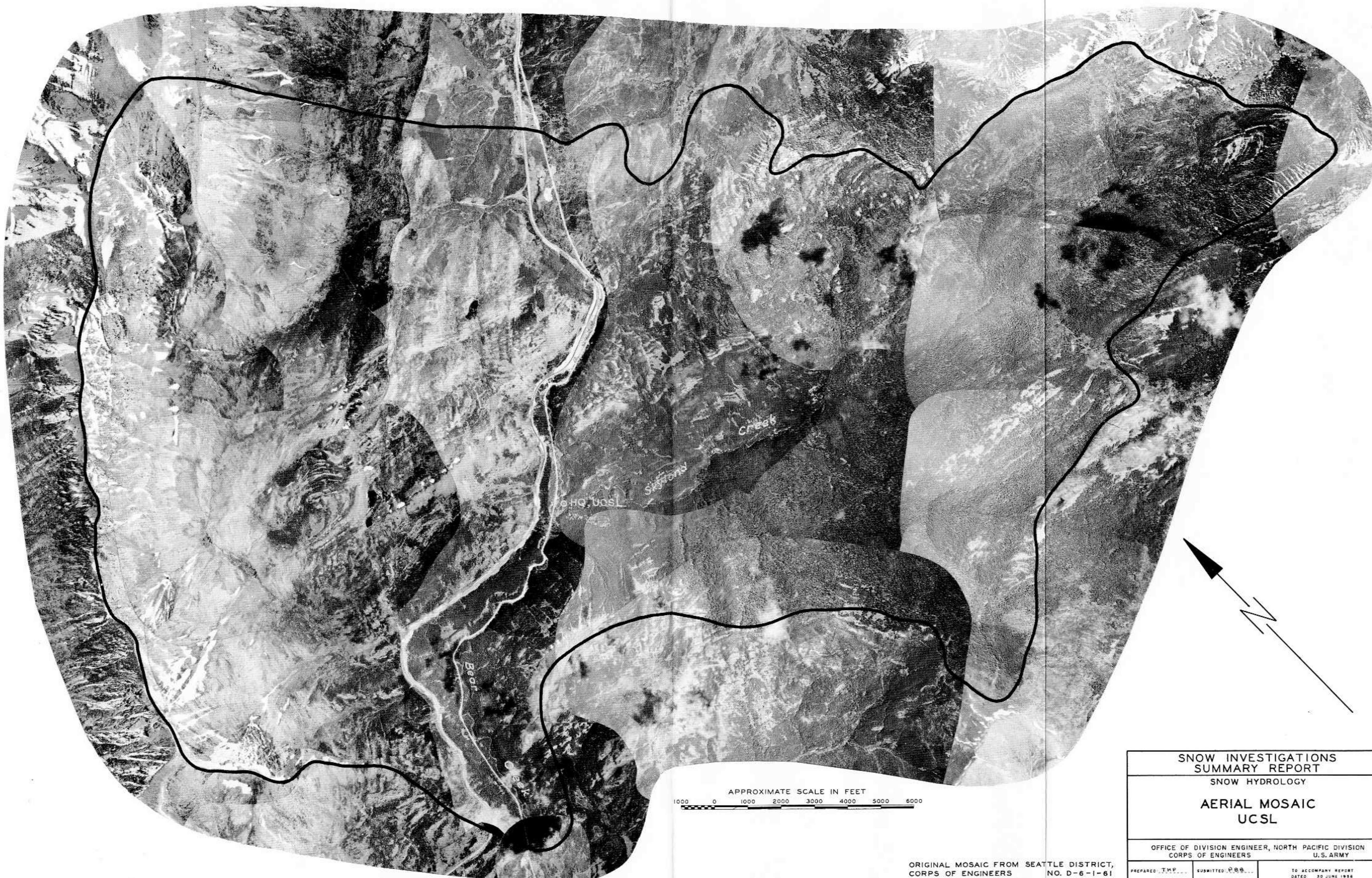
SNOW INVESTIGATIONS
SUMMARY REPORT
SNOW HYDROLOGY

SNOW LABORATORY BASIN CHARACTERISTICS

OFFICE OF DIVISION ENGINEER, NORTH PACIFIC DIVISION
CORPS OF ENGINEERS U. S. ARMY

PREPARED: M.W.-C.S.J.	SUBMITTED: R.B.S.	TO ACCOMPANY REPORT DATED 30 JUNE 1956
DRAWN: B.U.	APPROVED: D.M.R.	PD-20-25/7

PLATE 2-6



ORIGINAL MOSAIC FROM SEATTLE DISTRICT,
CORPS OF ENGINEERS NO. D-6-1-61
DATE OF PHOTOGRAPH—12 JUNE 1946

SNOW INVESTIGATIONS
SUMMARY REPORT
SNOW HYDROLOGY

AERIAL MOSAIC
UCSL

OFFICE OF DIVISION ENGINEER, NORTH PACIFIC DIVISION
CORPS OF ENGINEERS U.S. ARMY

PREPARED: T.H.P. SUBMITTED: P.B.B.
DRAWN: W.J.M. APPROVED: D.M.R.

TO ACCOMPANY REPORT
DATED 30 JUNE 1956

PD-20-25/8

APPROXIMATE SCALE IN FEET
1000 0 1000 2000 3000

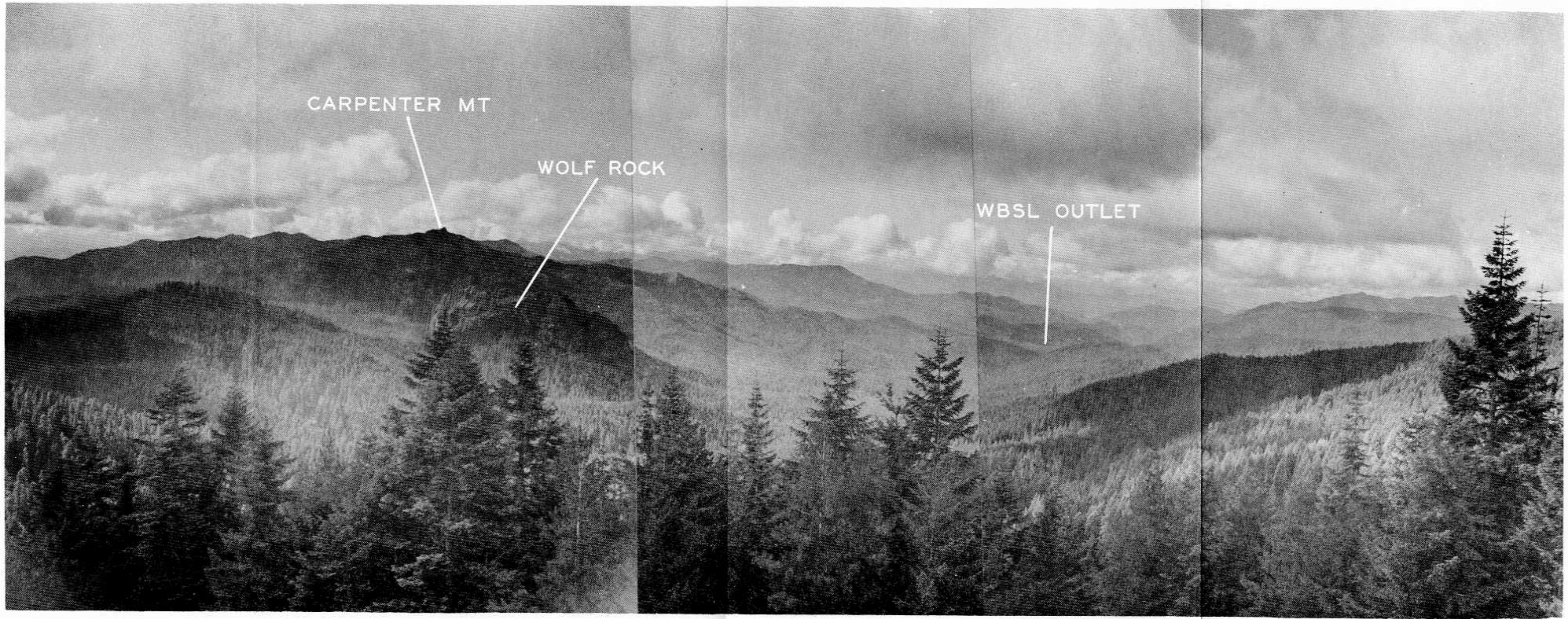
SNOW INVESTIGATIONS SUMMARY REPORT

SNOW HYDROLOGY

AERIAL MOSAIC CSSL

OFFICE OF DIVISION ENGINEER, NORTH PACIFIC DIVISION
CORPS OF ENGINEERS U. S. ARMY

PREPARED: CEJ	SUBMITTED: PBB	TO ACCOMPANY REPORT DATED 30 JUNE 1956
DRAWN: RV	APPROVED: DMR	PD-20-25/9



Note:

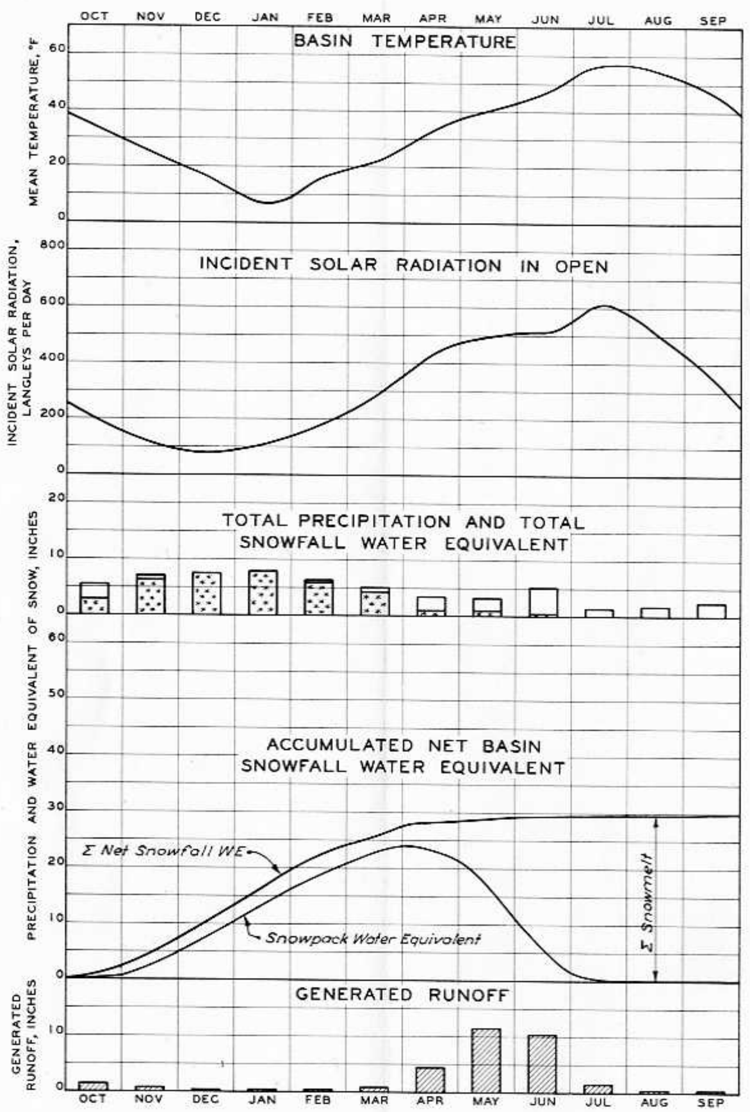
View taken from Squaw Mountain, looking south over Mann Creek and intermediate Blue River drainage areas. Wolf Creek drainage area lies between Wolf Rock and Carpenter Mountain. Photographs by R.W. Gerdel.

SNOW INVESTIGATIONS
SUMMARY REPORT
SNOW HYDROLOGY

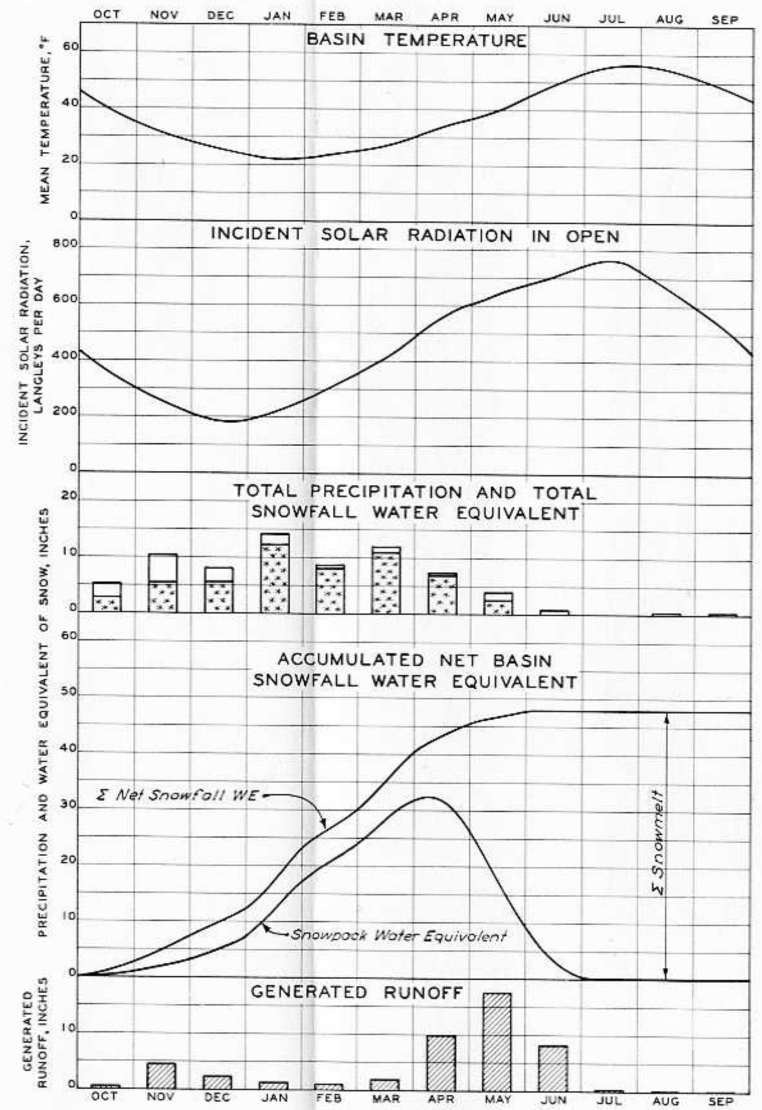
PANORAMA, WBSL

OFFICE OF DIVISION ENGINEER, NORTH PACIFIC DIVISION
CORPS OF ENGINEERS U.S. ARMY

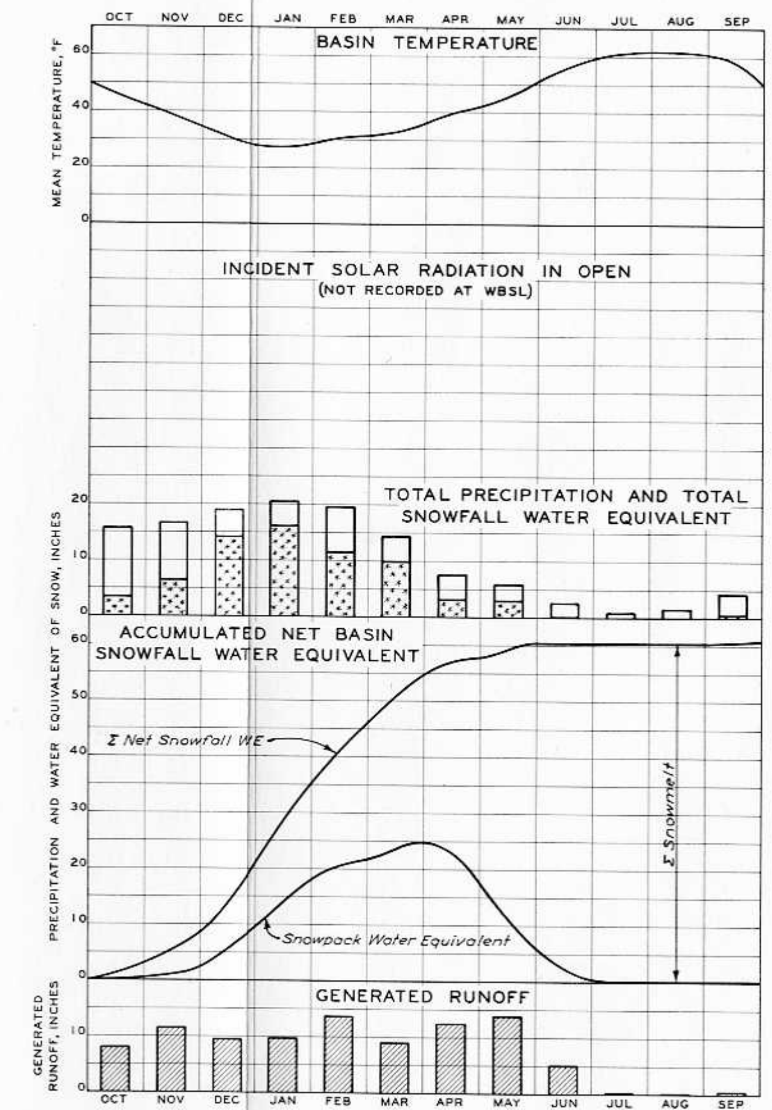
PREP: T.H.P.	SUBM: P.B.B.	TO ACCOMPANY REPORT DATED 30 JUNE 1956
DRAWN: B.Y.	APPR: D.M.R.	PD-20-25/10



SKYLAND CREEK, UCSL
DRAINAGE AREA 8.09 SQ MI
OCT 1946 — SEP 1950



CASTLE CREEK, CSSL
DRAINAGE AREA 3.96 SQ MI
OCT 1946 — SEP 1951



BLUE RIVER, WBSL
DRAINAGE AREA 11.5 SQ MI
OCT 1947 — SEP 1951

Notes:

1. *Data shown in these graphs represent basin mean values for the period of record shown.*
2. *Temperature data represent basin mean values used in computing losses by evapotranspiration in water-balance computations.*
3. *Incident solar radiation was measured by pyrheliometers at UCSL and CSSL. No measurements of solar radiation were made at WBSL.*
4. *Total precipitation and total snowfall were derived from water-balance computations described in chapter 4. Values shown represent total mean basin precipitation and snowfall before interception loss.*
5. *Accumulated net basin snowfall water equivalent represents mean water equivalent of snow accumulation after interception by forest. Difference between ordinates of net snowfall water equivalent and snowpack water equivalent at a particular date represents the accumulated melt to that date from the beginning of the water year. All values were derived from water-balance computations.*
6. *Generated runoff represents the volume of water made available for runoff each month, expressed in inches of runoff over the basin area. Corrections for ground-water storage were made by streamflow recession analysis.*

LEGEND

TOTAL PRECIPITATION: RAINFALL IN INCHES OVER BASIN; SNOWFALL IN INCHES OVER BASIN

GENERATED RUNOFF IN INCHES OVER BASIN

SNOW INVESTIGATIONS
SUMMARY REPORT

SNOW HYDROLOGY

HYDROLOGIC SUMMARY SNOW LABORATORIES

OFFICE OF DIVISION ENGINEER, NORTH PACIFIC DIVISION
CORPS OF ENGINEERS U. S. ARMY

PREPARED: M.W.	SUBMITTED: S.M.-M.H.M.	TO ACCOMPANY REPORT DATED 30 JUNE 1956
DRAWN: B.K.	APPROVED: D.M.R.	PD-20-25/11

PLATE 2-10

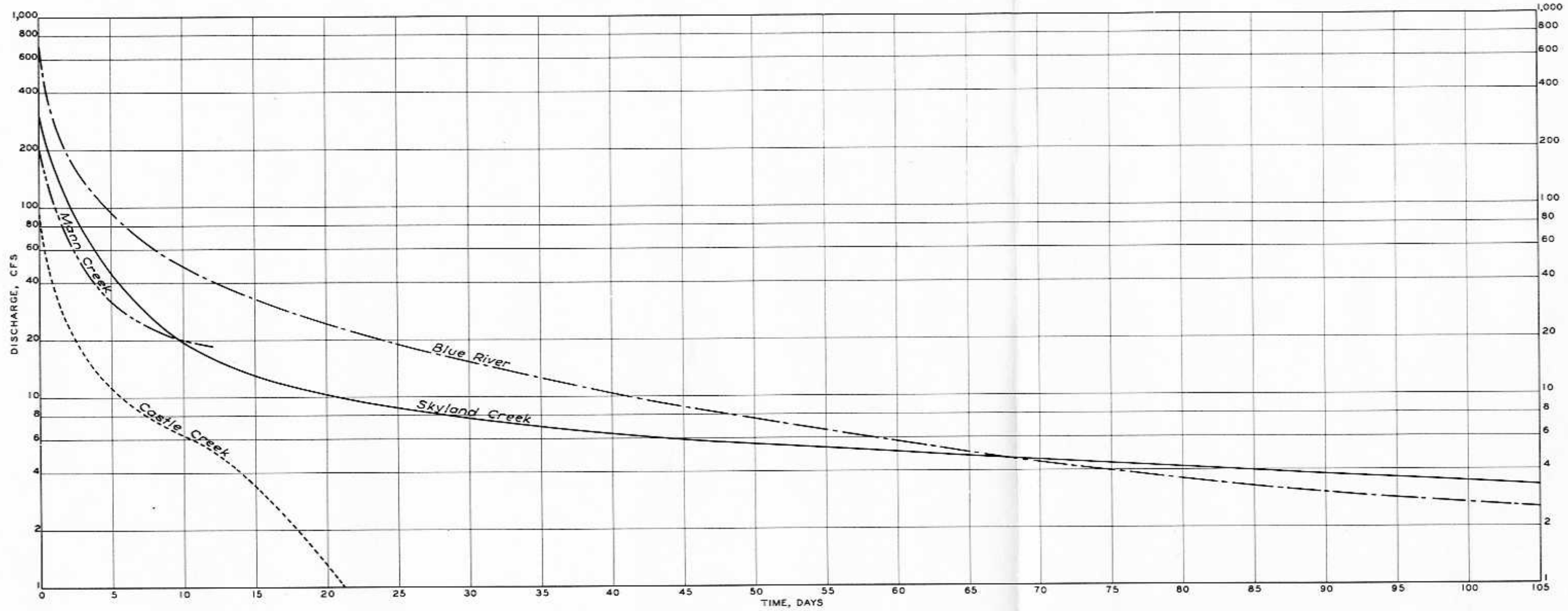


FIGURE 1 — ADOPTED RECESSIONS OF LABORATORY STREAMS

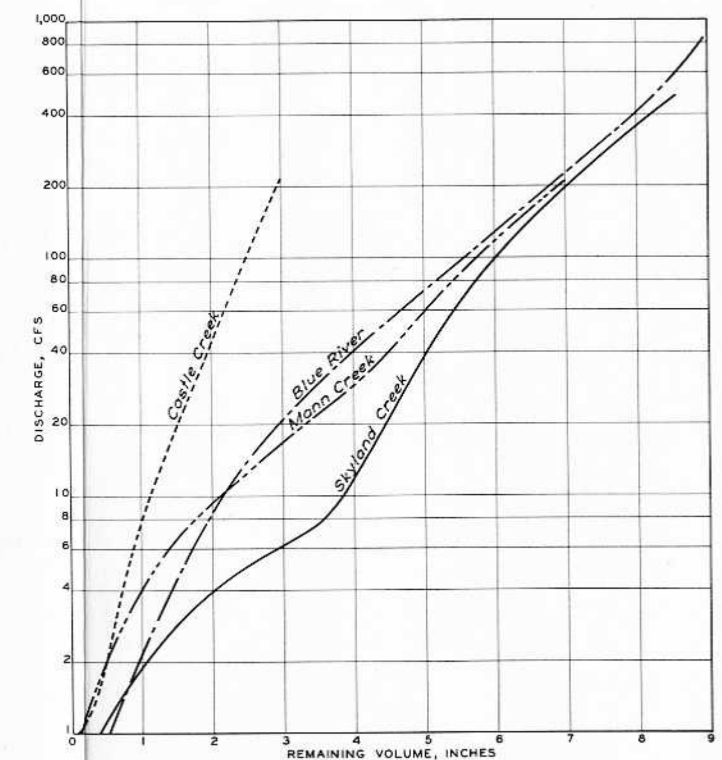


FIGURE 2 — COMPARATIVE RECESSION VOLUMES

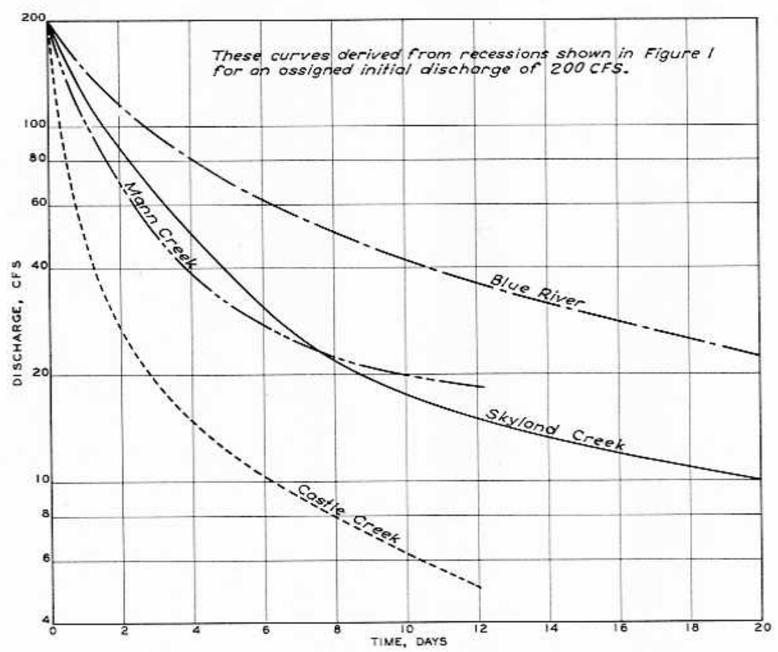


FIGURE 3 — COMPARATIVE RECESSIONS

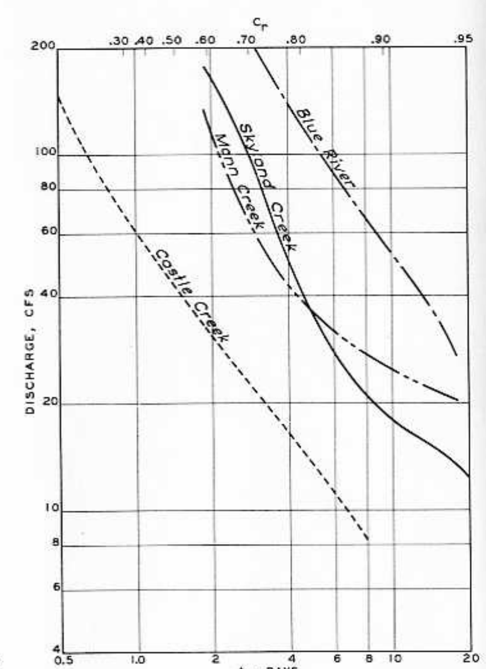


FIGURE 4 — RECESSION COEFFICIENTS AT INDICATED DISCHARGES

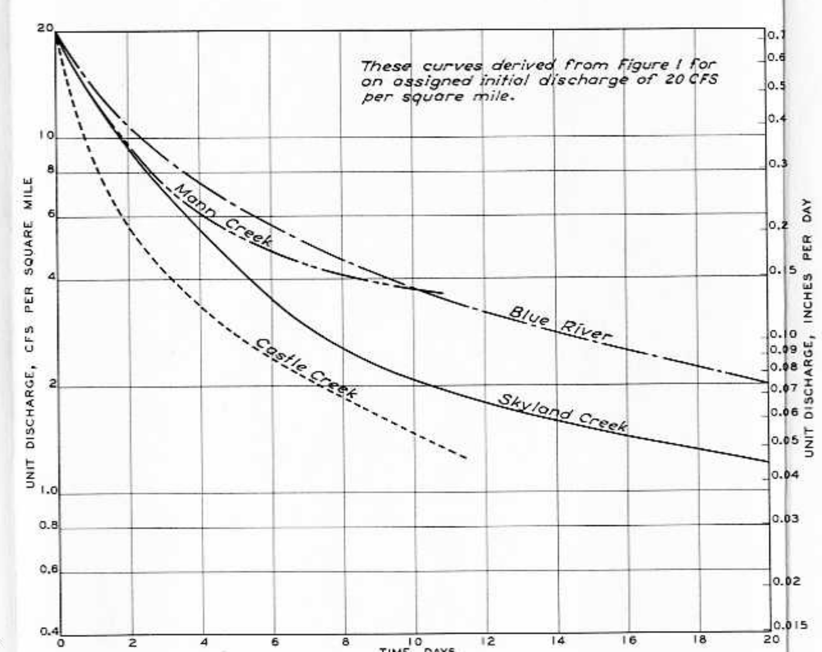


FIGURE 5 — COMPARATIVE UNIT DISCHARGE RECESSIONS

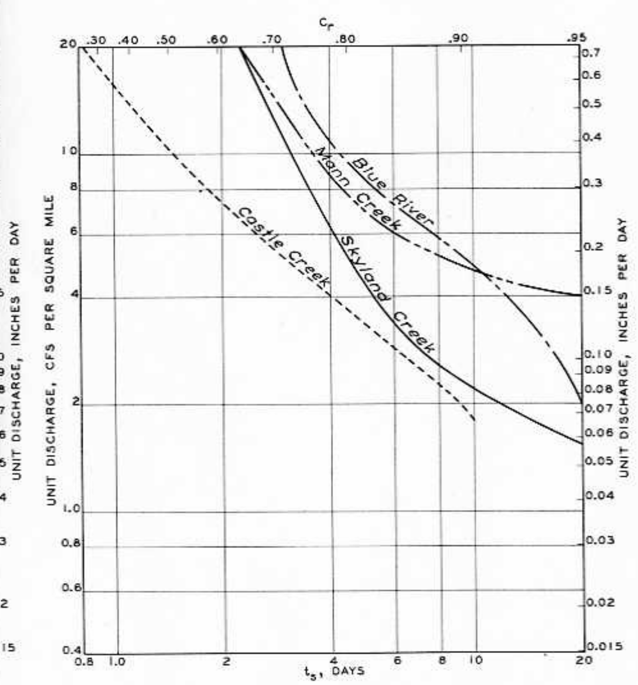


FIGURE 6 — UNIT DISCHARGE RECESSION COEFFICIENTS AT INDICATED DISCHARGES

Notes:

1. *Recession curves were developed by hydrograph analyses during periods of negligible inflow.*
2. *Lower portions of curves for Castle Creek, CSSL, and Blue River, WBSL, probably reflect the effect of evapotranspiration losses.*
3. *Recession volumes are computed by integrating volumes under recession curves shown in Figure 1. Extensions of the recessions to zero discharge are computed on the basis of constant recession as determined by slope at lowest discharge shown.*
4. *Empirical portions of recessions cause irregularities in Figures 2, 4, and 6.*
5. *Basic recession curve equations are as follows:*
   (a) $q_t = q_0 C_r^{\,t}$, or $q_t = q_0 e^{-\frac{t}{t_s}}$
   (b) $S = \frac{-q_0}{\log_e C_r}$, or $S = q_0 t_s$
   (c) $C_r = e^{-\frac{1}{t_s}}$
6. *When, as in Figure 1, recessions plotted on semilogarithmic coordinates are nonlinear, C_r and t_s vary with discharge, q. These variations for the laboratory streams are plotted in Figures 4 and 6. The values of t_s for each discharge are proportional to the slopes of the recession curves, plotted on semilogarithmic coordinates. See paragraph 4-07.05.*

LEGEND

- ———— *Skyland Creek, UCSL, Drainage Area 8.1 sq. mi.*
- —·— *Blue River, WBSL, Drainage Area 11.5 sq. mi.*
- —··— *Mann Creek, WBSL, Drainage Area 5.1 sq. mi.*
- - - - - *Castle Creek, CSSL, Drainage Area 4.0 sq. mi.*

SNOW INVESTIGATIONS
SUMMARY REPORT

SNOW HYDROLOGY

SNOW LABORATORY STREAMFLOW RECESSION CHARACTERISTICS

OFFICE OF DIVISION ENGINEER, NORTH PACIFIC DIVISION
CORPS OF ENGINEERS U. S. ARMY

PREPARED: C.E.J.-M.W. SUBMITTED: P.S.B.
DRAWN: B.V. APPROVED: D.M.R.

TO ACCOMPANY REPORT DATED 30 JUNE 1956

PD-20-25/12

PLATE 2-11