CHAPTER 7 - AREAL SNOW COVER

7-01. INTRODUCTION

7-01.01 General. - The area of snow cover has long been recognized as a prime variable in many applications of snow hydrology. Systematic observations of snow cover, however, have been generally lacking. Hydrologists have therefore resorted to empirically derived relationships between snow cover and runoff, assumed distributions of snowpack water equivalent by elevation zones and assumed zonal melt rates, or snow-cover indexes from ground observations of parts of a basin. Because of the lack of direct observation of snow covered area, none of these methods could be verified. As a result, the area of snow cover has been used to compensate for errors in other hydrometeorologic elements. Direct observations of snow cover are important as a forecasting tool, both for volume and rate-of-flow forecasting. In recent years there has been increasing recognition of the importance of snow cover to efficient operation of storage reservoirs, and a number of Corps of Engineers offices have begun making aerial snow-cover surveys during the spring melt season as an aid in reservoir regulation. As yet, an insufficient length of record is available to permit generalizations from snow-cover data; rather, the present use of the data has been limited to evaluating conditions at a specific time and developing observational techniques.

7-01.02 Definitions. - For the purpose of this report, the term snow cover refers to the extent of the ground area covered by snow, regardless of the depth of snow or its water equivalent. It may be expressed in units of area, such as square miles, or as a percentage of either the total basin area or an arbitrary maximum snow-covered area. The term snowpack refers to the total volume of snow on a basin. Snow-cover accretion is the increase in snow cover, while snow-cover depletion refers to a decrease in snow-covered area. Accumulation of the snowpack is the net increase in basin snowpack water equivalent, usually expressed in inches, while ablation refers to a net volumetric decrease of the snowpack water equivalent.

7-01.03 Functional use of snow-cover data. - There are two principal uses of snow-cover data in snow hydrology. One is for obtaining a measure of the areal extent of snowmelt at a given time, for the purpose of hydrograph synthesis. This may be involved in establishing procedures for streamflow reconstitutions, short-term forecasts, or design-flood computations. The second use of snow-cover data is in connection with volumetric forecasts of seasonal runoff. Snow cover may be used as a variable in establishing the volume of water stored in the snowpack, thus supplementing snowpack water-equivalent data from snow-course measurements, as was done in Research Note 22. In some mountainous regions, the area of snow cover may be used directly as an index of the water stored in the snowpack, as was done by Potts 5/ and

Croft.2/ A particularly useful application of snow-cover data is in connection with forecasting runoff for reservoir regulation after the melt season is well underway. All early-season volumetric forecasts possess a residual error, and as the melt season progresses, the magnitude of this error becomes a larger percentage of the remaining runoff. After the basin is less than, say, 50 percent covered, snow-cover data is particularly useful for verifying or adjusting earlier forecasts of runoff.

7-01.04 Requirements for hydrologic use. - In evaluating snow cover to meet the uses outlined above, there are three basic requirements to be considered: (1) the need for basic research on snow-cover accretion and depletion, and their relation to meteorologic and terrain factors which cause variation in precipitation and melt; (2) the necessity of direct observation of snow cover on project basins; and (3) the preparation of indexes or derived relationships for estimating the accretion and depletion of snow-covered area, for periods when observations are not available, or for design conditions.

7-01.05 Basic research is needed in order to improve present knowledge of the factors affecting snow cover accretion and depletion. If all basins had systematic snow-cover observations regularly taken through the accumulation and melt periods, this requirement would be much less important. Snow cover would then be simply another measured quantity. At the present time, however, observations are limited, and estimates of snow cover must be made indirectly.

7-01.06 The importance of obtaining direct observations of snow cover cannot be overemphasized. Subjective evaluations made from scanty and unrepresentative data are often misleading, because of the heterogeneity of basin areas and the complexity of the relationships between snow cover and its environment. The need for direct observations is three-fold. First, each basin has a characteristic pattern of snow-cover depletion, more or less consistent from year to year, which can be determined from direct observations of snow cover. A series of such observations over a period of years makes it possible to establish relationships for use when observations are not available. Second, such variations that do occur from year to year are so complex that they can only be determined by actual observation. Third, observations of snow-covered area, as measured quantity, are useful as a forecasting parameter for determining residual runoff volumes.

7-01.07 Primary factors affecting snow-cover accretion and depletion. - The accretion of snow cover usually begins on the higher elevations of the watershed, and continues through the accumulation period until all or a part of the watershed is covered. The depletion of snow cover begins with the exposure of the first bare ground in a completely snow-covered basin or with the date of maximum basin snowpack accumulation in a partially snow-covered basin. There are large differences between years in the length of accretion and depletion periods, depending primarily upon the meteorological regime during the accumulation and melt seasons.

7-01.08 During the accretion period, an elevation contour adequately defines the area of snow cover for small- to moderate-sized basins with relatively large ranges in elevation. This is due to the fact that the form of precipitation varies with elevation during individual storm periods, as explained in section 3-05, and the transition zone between areas of rainfall and snowfall is narrow. In addition, melt varies largely as a function of elevation during the winter period. Since solar radiation is at a minimum at this time, what little melt occurs is largely a function of air temperature, which in turn generally varies with elevation. The net result of these factors, then, is a fairly definite snowline during the accretion period.

7-01.09 Snow deposition, as related to meteorological and terrain factors, is a prime variable affecting snow-cover depletion. The variability of snow accumulation is discussed in chapter 3. During the accumulation period, the variations in the snow depths over basin areas show the combined effects of the terrain and meteorological factors. These factors include atmospheric circulation and airmass character during precipitation, opportunity for modification of airmasses, and large- and small-scale topographic influences. All of these influence the variations of snow depth from one point to another, which in turn will affect the depletion of snow cover during the melt period.

7-01.10 Snowmelt is the second prime factor affecting snow cover depletion. The meteorological and terrain factors causing variability of melt rates over a basin may act in entirely different ways from those affecting the deposition of snow. The principles involved in the variation of melt rates with respect to meteorological conditions, forest cover, and exposure to radiation are discussed in chapter 5. During winter, the melt rates over a basin are generally fairly uniform within a given elevation zone, and the amount of melt is usually small. During the spring and early summer there is wide variability to melt, due primarily to exposure; elevation effects are of lesser consequence. A definite snowline elevation does not exist during the melt period. Snow-cover depletion, therefore, reflects the variable influence of both the deposition and the melt of snow. The terrain influences on each are independent and should be considered separately.

7-01.11 In general, the seasons of heaviest snow accumulation have the longest lasting snow covers and those of lightest snowfall have the shortest. The interactions between meteorologic and topographic features determine the patterns of snow cover for individual cases. These factors are too varied and too complex to permit a practical general formula for assessment of snow cover from independent meteorological and topographic observations. Instead, a relatively simple empirical formula or chart for individual basins is needed to relate snow cover to readily observed data. Basin snow-cover depletion, snowpack ablation, and runoff are all the integrated effects of the same basic factors. Consequently, "depletion-ablation" or "depletion-runoff" curves may be constructed for a given basin if adequate and dependable data are available. The relationship may be improved by the introduction of a parameter such as the ratio of initial depth to areal snow cover, the initial basin snowpack water equivalent, or the ratio of snowpack water equivalents at low and high elevation snow courses. Using these relationships, one can determine the area of snow cover. Conversely, if a snow-cover survey is made, basin snowpack water equivalent or remaining runoff can be determined. These relationships can also provide the means for reconstructing the snow-cover depletion for years of historic floods of large magnitudes and establishing snow-cover criteria for design.

7-01.12 Organization of material and methods of approach. - The first part of this chapter deals with methods of obtaining direct observations of the snow-covered areas and summarizes generalizations on the accretion of snow cover. Then, observations of snow-cover depletion at the snow laboratories are used as a basis for discussing: (1) the relationships between snow-cover depletion, snowpack, ablation, and runoff; (2) the influences of terrain on snow cover. Finally, methods are given for using snow-cover data in forecasting residual runoff and in hydrograph synthesis.

7-02. METHODS OF OBSERVING SNOW COVER

7-02.01 General. - Systematic and complete observations of snow-covered area have been obtained only in recent years. Consequently, observational techniques for the collection of snow-cover data are not as standardized as those for many other basic hydrologic data. Also, the determination of snow-covered areas from the ground is extremely difficult, especially for rugged mountainous headwater areas, where routes of communication are generally lacking. The increasing use of aircraft for snow-cover observations has, however, made headwater areas readily accessible to both visual and photographic observations. In general, the following methods have been employed to obtain snow-cover information:

(1) Ground reconnaissance, utilizing prominent vantage points and transmountain highways to observe and map areas of snow, and also to define the elevation of the snowline when possible.

(2) Ground photography of selected sections of the drainage basin from fixed reference or vantage points.

(3) Aerial photography, either vertical or oblique.

(4) Aerial reconnaissance, from high- or low-level flight, supplemented by photographs, maps, sketches, and snowline elevation observations.

7-02.02 Ground reconnaissance. - Reliable determinations of the snow-covered area based on visual observations from the ground require considerable competence. No check or evidence exists to support the subjective opinions of the observer. The coverage cannot be as complete as coverage from aerial surveys because of obstructions, such as forest and hills, to the field of vision. In addition, the travel to satisfactory vantage points make ground observations expensive and time consuming. These limitations of ground reconnaissance surveys are more serious during the ablation than during the accumulation period. During the accumulation season, the use of ground reconnaissance is practical, since snowline elevations in mountainous areas are satisfactory indexes of snow-covered areas. In many basins, transmountain highways provide access through a range of elevations thus making possible the determination of the average snowline by automobile reconnaissance. Such observations may be made in conjunction with regular early-season snow-survey measurements. After the onset of the melt season, however, ground observations of snow cover are not recommended as a means of determining basin snow cover.

7-02.03 Simultaneous and independent observations of snow-covered areas by ground observation and aerial photographic methods were made at CSSL during the 1947 melt season. Comparison and analysis of these observations are presented in Appendix I to Research Note 16. Assuming the aerial photography analysis to give the correct snow cover, ground estimates of snow cover were found to be too high early in the season and too low later in the season. Estimates of snow cover made from high vantage points were found to be more reliable than those made from lower, inferior view points. On some of the sub-areas, the ground estimates of snow cover were as much as 50 percent less than those determined by aerial photography. For over half of the basin, however, the estimate from ground survey was within 15 percent of the value determined from the aerial photographs. From this experience, it is concluded that estimates from the ground should be made from high points whenever possible. Care should be taken not to bias the results to favor the more readily observable open areas in preference to wooded or more obscure areas. This results in overestimates early in the season and underestimates late in the season.

7-02.04 Ground photography. - Ground photographs are generally used as indexes of areal snow cover rather than measures of the total snow-covered area. Actual snow-covered area can be determined by relating these photographic indexes to actual snow-cover amounts determined by other means. Potts 5/ has utilized ground photographic methods for providing a direct index to snowmelt runoff on the middle fork of the South Platte River in Colorado, by-passing the determination of areal snow cover. Miscellaneous Report 1 describes a procedure for establishing a snowline index from horizontal ground photographs of the Sierra Nevada in the vicinity of CSSL. Panoramic photos were taken at a site at about the 5000 foot level near Emigrant Gap, California. The procedure consisted essentially of obtaining a master photograph, on which were located prominent features of the landscape with their elevations. A considerable portion of the 40 sq. mi. drainage area of the South Fork of the Yuba River is visible from this site. Between 8 March and 21 June 1948, thirteen series of panoramic photographs were taken from the site, and snowline indexes from elevation zones and exposure sectors were determined for each series. The index was used for the purpose of correlating snow cover to measurements of water equivalent of the snowpack and runoff.

7-02.05 In 1950, the U. S. Weather Bureau established a snow-cover investigations unit, for the purpose of estimating the extent of snow cover in the Columbia River basin, to be used in connection with seasonal and short-term streamflow forecasting. A report of the activities of this unit was made at the annual Cooperative Snow Investigations Conference of 1 April 1952, and at the Western Snow Conference in 1953. 1/ The principal method used by this unit to estimate snow cover has been by ground photographs from key stations. A photographic record is currently being accumulated from which indexes of snow cover may be determined. The photographs are taken periodically through the melt period by cooperative observers and using standardized photographic procedures.

7-02.06 The standardized procedure used by the snow-cover unit to photograph selected portions of a basin from fixed vantage points, for the purpose of establishing an index of snow cover, consists of:

(1) Selecting photographic stations.

(2) Preparing a master panoramic view of the watershed from each station.

(3) Dividing the master photograph into convenient exposure sectors.

(4) Identifing and determining elevation of prominent landmarks on the master photograph.

(5) Photographing the progress of snow-cover depletion from each point.

(6) Determining the average snowline in each exposure sector and assigning a snow-cover index value to each snow-line elevation.

The procedure is subject to considerable personal judgment and requires experience in taking the photographs and evaluating the snow line. A disadvantage is that some areas are obscure, and also there is great distortion with increasing distance from the camera, so that the use of a uniform grid system is not practical. An additional disadvantage of the method of ground photographs is that for routine observations a considerable time is required before the pictures are ready for analysis. Since these photographs provide only an index of snow-covered areas, if actual basin snow cover is desired, results must be correlated with simultaneous observations of the actual cover. The method does have the advantage of being inexpensive and of providing records to supplement personal judgment.

7-02.07 Aerial photography. - Aerial photography is an exact method of determining the area of snow cover. It furnishes a permanent record which can be analyzed at any time, and information which can be transferred to basin maps for evaluation of the true cover. Aerial photographs are taken both vertically or obliquely. Their use varies from a supplement to visual observations to a complete and precise delineation of the snow-covered area. The principal advantages of aerial photographs are: (1) a record is obtained which may be preserved, and from which detailed analyses may be made of true snow-covered area; (2) remote regions which are not accessible to ground surveys may be covered by air; and (3) through use of stereo-pairs, determinations of snow cover and surrounding terrain elements may be made from which the two may be correlated. Aerial photographs have been used primarily for special studies of snow cover on small basins. Their application to larger basins for operational use, however, is subject to the following limitations: (1) the large number of photographs required to cover such basins; (2) the high cost of operation of aircraft which can operate at high elevations; (3) the time required for photograph processing and evaluation; (4) the difficulty of interpretation of snow cover in forested areas; and (5) the near-ideal weather conditions required during periods when snow-cover observations are needed.

7-02.08 Aerial photographs of snow cover were obtained for UCSL and CSSL, for the years listed in table 2-6 (chapter 2). Those for UCSL were vertical photographs, taken at flight levels ranging from 13,000 to 17,500 feet and using aerial mapping cameras. For CSSL, oblique photographs were obtained primarily by light aircraft not equipped for vertical photography. Data from these flights were used for detailed studies of snow-cover relationships.

7-02.09 In the application of vertical aerial photographs for project-size basins, the most critical difficulty lies in the large number of photographs required to cover the basin. Flying at 10,000 feet above the ground surface and using a 9 x 9 inch camera with an 8.15 inch focal length, the total area covered by each picture is about 4 square miles. If only one quarter mile overlap is provided for each picture, the effective area is 2.2 square miles per picture. For a 10,000 square mile area, about 450 photographs would have to be taken, processed and interpreted. Even when photographing only the marginal zones of snow cover, a large number of pictures is required.

7-02.10 Aerial reconnaissance. - The most feasible method for obtaining timely and accurate estimates of snow cover is aerial reconnaissance. Unlike the data from aerial photographs, the reconnaissance snow-cover information is available to the hydrologist as soon as the flight is completed. The probable small increase in accuracy would not warrant taking aerial photographs, particularly when special skills for processing and interpreting them are not generally available. The cost of aerial reconnaissance using light aircraft is less than ground reconnaissance, considering the difference in time required. Its cost is far less than that for obtaining complete coverage by aerial photogrammetric methods. While suitable weather conditions are required for aerial reconnaissance, these requirements are considerably less than for aerial photos. The principal disadvantages of the method are: (1) evaluation is subjective and results cannot be verified, and (2) it is dependent to some extent upon weather conditions. Observing snow under the forest is difficult, regardless of the basic method used, whether from ground or air. Supplementing aerial reconnaissance with oblique aerial photos provides continuity between observations and aids in verifying subjective observation.

7-02.11 Various Corps of Engineers offices, including Sacramento, Portland, Seattle, Walla Walla, and Omaha districts, have made regular observations of snow cover by aerial reconnaissance for use in flood evaluation and reservoir regulation. The methods used have varied, depending upon the areas involved, aircraft available, weather, and preference of those making the flights. In general, two procedures have been used successfully. Both consist basically of observing snow-covered areas and plotting them on a topographic map. In one case, flight altitude is maintained 4000 to 5000 feet above the highest ridge lines, thus enabling the observer to obtain a fairly broad view of the basin as a whole. The other method is to fly in the canyons approximately at the elevation of the snowline. The high-level flight requires better conditions of ceiling and visibility, which often limits the time that observations may be made; however, more comprehensive definition of the snow-covered area may be made from high-level flight. Also in some cases mountain ranges may be too high to permit the use of light planes in the high-level flight procedures. Early in the season when snow generally covers a large portion of the basin, only the lower portions of the basin are exposed and there is less variability of the snowline. At such time, low-level flight may be preferred. Whenever cloud conditions prevent flying over mountain ridges, low-level flight must suffice. A hand level is sometimes used to maintain the flight level at the approximate snowline elevation so that altimeter readings can be used to measure the height of the snowline. When it is impossible to fly the entire basin, a system of sampling the elevation of snowline on various aspects and areas may be used to evaluate an average basin snowline. This in turn may be applied to an area-elevation curve to determine the snow-covered area. When viewing heavily forested areas from low-level flight, the line of sight being more or less horizontal, it is difficult to determine snow cover under trees. Viewing the area vertically gives a better opportunity to estimate snow cover under those conditions. Snow-free patches, well within the snow-covered area, often occur on steep slops. These areas appear relatively large when viewed horizontally or obliquely; actually, they may represent negligibly small areas on a horizontal projection. A detailed report on aerial recommaissance of snow cover in the Kootenai and Flathead basins by the Seattle District office is contained in Technical Bulletin 15.

7-02.12 The following general recommendations are made for conducting aerial snow-cover reconnaissance surveys:

(1) Trained personnel who know the basin hydrologic characteristics should make the survey.

(2) The observer should be familiar with landmarks throughout the basin, and ground features should be identified continually during the flight.

(3) The snowline should be identified as to elevation or location and plotted on the base topographic map.

(4) Where spotty or patchy fringe areas of snow cover exist, an average snowline should be estimated and plotted.

(5) Aerial snow-cover reconnaissance flights should be scheduled to coincide with ground snow-course surveys, insofar as possible.

(6) Aerial snow-cover surveys should not be made immediately after a new snowfall.

(7) Supplementary photographs should be taken which will show progress of snow-cover depletion in a given area from flight-to-flight. Photograph points should be established which are easily recognizable. Pictures should be taken from the same point each time, at a specific altitude. Areas photographed should show both northerly and southerly slopes.

(8) Low-level flights should be made at the snowline level and this level plotted on the topographic map.

7-02.13 The interpretation of the snow-covered area from aerial reconnaissance surveys is made by planimetering the areas of snow on the basin map. As an independent check, average snowline data may be applied to area-elevation curves, but this latter method is less reliable. Where basin coverage is not complete, area-elevation relationships must of necessity be used. For this purpose, the average snowline should be carefully weighted to reflect the various conditions of exposure throughout the basin.

7-03. SNOW-COVER ACCRETION

7-03.01 Although a simple method for quantitative evaluation of snow-cover accretion has not been developed, a few qualitative statements may be made concerning the processes involved. Broadly speaking, there are two types of areas to be considered, namely, mountainous regions and open plains. For mountainous regions, as was explained earlier, the area covered with snow during periods of accumulation varies primarily with elevation. Reference is made to section 3-04 for a discussion of elevation effects on snow accumulation. While there may be large variation in the depth of snow because of meteorological and terrain effects on snow deposition, the amount of melt during the accumulation period is small and generally is not sufficient between storms to expose the lightly covered areas. The elevation of the snow-line, therefore, is primarily a function of the form of precipitation in individual storms, and accordingly is dependent upon elevation.

7-03.02 On wind-swept open plains, snow-cover accretion may be irregular because of drifting. In such areas, the elevation range is small and the effect of elevation on accretion is usually negligible. The variation in snow cover in this case is a complex function of meteorologic conditions, primarily of wind, temperature, precipitation, and the sequence of these events, superimposed on small-scale terrain irregularities. The relative magnitudes of these effects have not been determined separately.

7-03.03 In some mountainous regions, the combined effects of steep slopes, high wind, and lack of forest may result in local patches of snow-free ground in an area which is generally snow-covered during the accumulation period. Usually, the relative magnitude of these areas is small when considered with respect to the drainage basin as a whole.

7-03.04 The effect of forest on snow accretion is to cause greater uniformity of cover than would occur in bare areas. The effect of forest on snow accumulation may be considered analogous to its effect on snowmelt, in that it tends to "level out" the variability of meteorologic processes. In the case of snowmelt, forest influence permits the use of temperature to index the radiation melt process. For snow accumulation, a uniform forest stand provides a means for distributing snow more equitably with regard to the rest of the terrain features and minimizes the variability of deposition in locations of abnormally high winds or steep slopes.

7-04. SNOW-COVER DEPLETION AND ITS RELATION TO TERRAIN

7-04.01 General. - The factors affecting snow-cover depletion are extremely complex and include the interrelationships between terrain and meteorologic conditions during snow deposition, as well as during melt periods. It is not feasible to attempt evaluation of snow cover depletion by rational procedures. Rather it is necessary to derive empirical relationships with readily observed data for the purpose of determining snow cover for individual basins. Not only do these relationships vary from basin to basin but, with regard to snow-cover depletion on a particular basin, each year has its peculiarities, resulting primarily from the meteorological differences during the accumulation and melt periods. Therefore, a precise quantitative definition of snow-cover depletion applicable to all areas and to all years is not possible from the limited observations which are available. It is, rather, the intent of this section to present a qualitative evaluation of the processes of snow-cover depletion and their relation to terrain. These are based primarily on observations at the snow laboratories. Later sections of this chapter deal with snow-cover depletion as related to ablation of the snowpack and accumulated runoff.

7-04.02 Analyses of snow-cover depletion in relation to terrain have been made on the basis of snow-cover observations at CSSL and UCSL (as reported in Research Note 16). The results of the analyses contained in Research Note 16 are summarized in the following paragraphs.

7-04.03 Analysis of the 1947 season at CSSL. - A detailed analysis of snow-cover depletion during the 1947 season at CSSL was accomplished by subdividing the basin into twenty topographic units of homogeneous character, as shown on figure 2, plate 7-1. The percent snow cover was determined for each unit from analysis of aerial photographs of the entire basin which were made that year. Several flights were made from which the progress of depletion could be determined.

7-04.04 The 1946-47 season at the CSSL was deficient in snowfall; the snowpack water equivalent was less than 70 percent of normal. The melt season was warm and free of storms from 10 April until the end of May when most of the snow was gone. Consequently, the determination of snow cover during the melt period was not complicated by new-fallen snow from spring storms. The initial streamflow rise commenced on 10 April, and the snowmelt contribution of runoff terminated early in June. The peak discharge occurred on 1 May. In general, the continuous nature of the melt season made it ideal for the study of snow-cover depletion.

7-04.05 Depletion of snow cover, 1947, at CSSL. - A generalized description of the progress of depletion of snow cover during 1947 is as follows:

a. On 31 March snow cover was substantially complete over the entire basin, with minor exception of some steep slopes on Castle Peak.

b. At the middle of April, cover was still high, averaging about 92 percent over the basin; bare areas had appeared on high parts of Castle Peak and on the south side of Andesite Ridge.

c. At the end of April, cover averaged about 80 percent. Bare spots that had appeared in the middle of April were larger, and snow cover in Uhlen Valley was also partly broken up. In the other areas little change in extent of snow cover had occurred. Most of the topographic units still had more than 60 percent snow cover, and in the upper basin there was a large block of units with more than 90 percent cover.

d. At the middle of May, snow cover averaged 37 percent over the whole basin, but the dispersion was quite large. In two topographic subdivisions, mostly in the upper part of the basin on both sides of Willow Valley, snow cover exceeded 90 percent. On the other hand, eight subdivisions, chiefly south-facing slopes in both upper and lower basins, were nearly bare. Figure 7, plate 7-1, shows the areal distribution of snow cover on 30 April and 15 May, when the average basin snow cover was 79 percent and 37 percent respectively. The similarity of patterns on the two dates may be noted. The relatively stationary status of the units with above average snow and the rapid depletion of units that were initially below average in cover result in an increase of dispersion.

7-04.06 The sequence of depletion for 1947 is illustrated in figure 6, plate 7-1. This diagram shows for each topographic unit the number of days after active melt had begun before a snow cover of 60 percent was attained. It presents, therefore, a measure of the rates of snow-cover depletion for various conditions of terrain. Seven of the units reached 60 percent snow cover within 25 days, while two of the units required in excess of 50 days to reach 60 percent cover. The shortest time was 13 days for the steep, south-facing slopes of Castle Peak, while the longest time was 60 days for the sheltered north slopes of Andesite Ridge. Figure 5, plate 7-1 illustrates schematically the sequence of snow-cover depletion for an unforested area with relatively steep north- and south-facing slopes. For the CSSL, the windward slopes face south and the leeward slopes face north. As a result of local topographic influences the accumulation of snow is greater on north than on south slopes (see chapter 3). Also, since melt rates are greater on south-facing slopes, the combined depletion effect results in south slopes going bare well in advance of other areas. North slopes, with their greater accumulation and reduced melt rates, exhibit the opposite effect.

7-04.07 <u>Topographic influences</u>. - Watersheds differ from one another in topography and orientation with respect to exposure to the flow of airmasses and to solar radiation and other factors affecting deposition and melt. The differences cause variation in depth of snow and in the duration of the melt season between basins. Even within a watershed, local differences in topography exist which cause variability in the accumulation and melt of the snowpack, and consequently in the snowpack ablation and snow-cover depletion. In relatively flat areas, such as open meadows and valleys or in plains regions, the snow cover tends to remain in tact for a relatively long time until it becomes quite shallow. It then exhibits a rapid change as large areas of thinned snow become bare simultaneously. This tendency is characteristic of all snowpacks of uniform depth subject to uniform melting rates. In mountainous areas, on the other hand, there is wide variability in the snow-cover depletion with area. Yet, for a given area, the depletion pattern is remarkably similar from year to year. A characteristic effect of topography is manifest in the appearance and development of bare patches, which appear at the same sites and grow in nearly identical patterns each year.

7-04.08 Orientation. - The basic considerations of the effect of slope orientation on snow-cover depletion were mentioned in paragraph 7-04.06. The following tabulation, based on CSSL data for the 1947 season, shows the progress of depletion of snow cover as a function of slope orientation:

DEPLETION OF SNOW COVER WITH RESPECT TO ORIENTATION, CSSL, 1947

Orientation	Percent of area snow covered				Percent of basin area
	31 Mar	30 Apr	13 May	16 May	
N	100	83	76	57	4
NE	100	82	72	69	5
E	100	87	76	75	8
SE	98	74	37	22	18
S	99	67	32	25	27
SW	100	74	35	27	15
W	100	79	58	38	13
NW	100	83	69	56	10

The plotting of the above data in figure 3, plate 7-1, illustrates the progressive decrease in snow-covered area for the various orientations relative to one another. In extreme, the rate of change of snow-cover depletion is from two to three times greater for south slopes than for north slopes. (Actually the depletion rate tends to be least in the northeast octant, which reflects the greater deposition of snow on the lee side of local barriers during the southwesterly atmospheric circulation accompanying storms, as well as the reduced melt rates on northerly slopes.) Strictly speaking, slope orientation should not be evaluated without also considering the steepness of slope. Very flat slopes of north and south orientation would tend to be quite similar in depletion characteristics while steep north and south slopes would be markedly different. The effect of steepness will now be examined.

7-04.09 Steepness. - In general, the accumulation of snow varies inversely with the steepness of slope, as was pointed out in chapter 3. For the CSSL, the fact that most steep slopes are for southerly orientation also results in greater melt rates. The combined effect of below average snow depths and high melt rates causes snow cover to deplete at a fast rate on these steep slopes. Separate evaluation of the relationship between depletion and steepness of slope is not practical from CSSL data, because of the interrelationship between steepness and orientation.

7-04.10 Elevation. - The data from CSSL are inadequate to relate depletion with elevation, because the entire basin is within the headwaters area of the Sierra Nevada. The range in elevation is small and other topographic influences at these high elevations obscure the effect of elevation. Data from WBSL presented in chapter 3 showing the variation in slope of the snow-wedge with time reveal the nature of depletion in that type of area. As was pointed out in paragraph 3-04.06, the slope of the snow-wedge increases through the accumulation period, but after active melt is under way, there is little variation in melt with respect to elevation, resulting in a nearly uniform decrease of the snowpack water equivalent with elevation. Under these conditions, the depletion of snow cover with respect to elevation is a function almost entirely of the variation in snow accumulation, and only slightly of the variation in melt. When considered over large ranges in elevation (sea level to, say, 10,000 feet) elevation is of course the most important single topographic variable in its effect on depletion of snow cover.

7-04.11 There are several compensating factors affecting variation of melt with elevation. What melt occurs during the accumulation season is largely a function of elevation. Solar radiation melt is small, hence air temperature mainly determines the amount of melt. During the late spring melt season, however, solar radiation is the prime source of energy for melting snow.

7-04.12 Figure 4, plate 7-1 shows the snow cover-elevation relationship for various dates of observation for CSSL during 1947. This diagram illustrates the depletion of snow cover with elevation and shows that the relative magnitude of depletion in the various elevation zones was greatest in the upper and lower portions of the basin, and least in the mid-elevation zones. The effect of topographic features other than elevation obscured any quantitative evaluation of elevation effect on depletion.

7-04.13 Forest. - It is difficult to evaluate quantitatively the effect of forest on snow-cover depletion. Studies from CSSL show little relation between forest and depletion, but the results were obscured by the effect of more significant terrain parameters. Figure 1, plate 7-1 is an aerial mosaic showing the distribution of the forest at CSSL. It was shown in chapter 4 when considering the interception of snow by the forest crown that the accumulation of snow under dense forest may be less than 80 percent of that in adjacent open areas. Factors affecting melt in various-sized forest openings have been discussed in chapter 5, and in general, melt rates are highest in large clearings and decrease to a minimum in small clearings protected from sunshine by the surrounding trees. In a broad sense, the effects of forest on accumulation and melt tend to balance each other, so that the depletion rates would be similar in magnitude. It has been observed in the heavily forested WBSL that the last remaining snow patches are in the small forest clearings, which again shows the integrated effects of above-normal accumulation and reduced melt in these locations.

7.04.14 Kittredge 4/ performed an exhaustive study on the influence of forest on snow in the central Sierra Nevada using observations made over a period of seven years. Measurements included profiles of snowpack water equivalents, under various densities and species of forest, made at various times through the snow season. Those conclusions from the study directly pertinent to snow-cover depletion are quoted below:

"1. From 13 to 27 percent of the seasonal snowfall was intercepted by the forest canopies.

"2. The maximum water equivalents of the total snow on the ground or the amounts of water in storage in the snow are larger in red fir and in the cutover stand with large openings than in the clearings, and smallest in dense fir and ponderosa pine stands. The dates of maximums in the forested areas are usually later than in the open areas. Maximum water equivalents in the cutover mixed conifer and in a few other areas, for some years, vary inversely with the crown coverage within a 20-foot radius.

"3. The effect of trees on the south side of the large clearing on the water equivalents of the snow was to maintain greater storage not farther to the north than the height of the trees, as compared with the smallest amounts at greater distances where melting was more rapid.

"4. Openings between the crowns showed average maximum accumulations of 1 to 5 inches water equivalent larger than did areas under the crowns.

"5. The first exposure of bare ground varied from March 28 to May 5 between extremes in different forest types, and more than 60 days in different years in the same type.

"6. The average date of disappearance of the snow varied from April 17, in the old ponderosa pine, to June 1 in the red fir, and by about 2 months between extreme seasons.

"7. The date of disappearance of the snow varied inversely to the crown coverage within a 20-foot radius in the cutover mixed conifer area, and in some other types in certain years.

"8. The average duration of the snow cover varied from 117 days, in the ponderosa pine, to 160 days in the red fir area.

"9. The percentage of area covered by snow decreased after the first exposure of bare ground by from 4.4 percent per day, in the red fir area, to 17.2 percent in the lower meadow.

"10. The rates of melting tended to be lower under the crowns than in openings, and lower in openings than in the large clearing, per unit change in the independent variable in each case, but the influence of trees in retarding melting was quite small."

7-04.15 Snow- cover depletion, UCSL. - To illustrate the process of snow-cover depletion in an area of non-uniform deposition of snow, successive aerial photographs of the progression of depletion within the Blacktail Hills, UCSL, are shown on plate 7-3, for 1946 and 1947. The area shown in each photograph is slightly over one square mile. The growth of bare areas is apparent during successive periods of melt. The wind-swept ridge of the Blacktail Hills possesses little forest and conditions are favorable for low deposition and high melt of snow. The ridge becomes bare of snow early in the season, but on the lee side (northeast), snow remains much later in the season. These photographs illustrate the uniformity of depletion patterns between the two years (1946 and 1947) which serves to give confidence to the use of index relationships for estimating snow cover in mountainous regions. Plate 7-2 is an aerial photograph of the entire UCSL, taken on 2 May 1946, showing approximately the mid-season condition of snow-cover depletion on the basin. Also outlined on this photograph is the area of the Blacktail Hills contained in the successive photographs of plate 7-3. Notice the wide diversity of areas bare of snow for the various slopes within the basin.

7-04.16 Effect of diversity of terrain on snow-cover depletion. - The preceding paragraphs have discussed the variability of snow-cover depletion caused by each of the primary terrain factors. The integrated effect of all these factors on a basin area determines the rate of snow-cover depletion. The greater the diversity of terrain, the longer will be the time of depletion of snow cover. Areas having uniform conditions of accumulation and melt will exhibit rapid changes in snow cover from the time the first areas become bare to the condition of complete loss of snow.

7-05. SNOW-COVER DEPLETION VS. ABLATION OF THE SNOWPACK

7-05.01 General. - The preceding section described in general terms the variation of snow cover depletion with major terrain factors, in order to show the fundamental processes involved in snow-cover depletion. For the practical determination of snow-covered areas, however, it is necessary to determine average relationships between basin snow cover and commonly observed data. One such usable relationship is that with ablation of the snowpack, or as a step further, accumulated runoff.

7-05.02 Figure 1, plate 7-4 is a schematic diagram illustrating basic differences in the character of snow-cover depletion-ablation relationships of deep snowpacks. Curve A represents the conditions for heterogeneous basins, where snow accumulation and melt are affected by topographic variability. Beginning with the time the basin first begins to go bare, the area of snow cover decreases quite uniformly with ablation of the snowpack, resulting in a curve which is slightly concave downward. The reverse curvature near the bottom of the curve is caused by the few remaining deep drifts which last long after the major portion of the original snow-covered area has gone bare. Curve A is typical of mountainous areas of western United States. Curve B shows the rate of depletion on a homogeneous basin, where large amounts of snow are uniformly distributed over the area, and where melt rates are relatively uniform. Here, the snow-cover depletion with respect to ablation is slow at first and then suddenly increases. This type would be expected in the plains regions.

7-05.03 Depletion vs. ablation, CSSL. - Depletion-ablation relationships are shown in figure 2, plate 7-4 for several of the homogeneous topographic units of CSSL for the 1947 melt season. Also shown in the figure is a curve representing the basin as a whole. Curves for each of the units lie above the one for the entire basin and show that for areas of homogeneous character, there is a trend for a more pronounced "knee" in the curve as discussed in the preceding paragraph. When an area has a large variety of slope facets, as in the case of the basin as a whole, the curvature becomes less pronounced.

7-05.04 Figure 3, plate 7-4, shows the depletion-ablation relationships for four years at CSSL for the basin as a whole. Data for 1948, 1950, and 1952 are less complete than those for 1947. It is seen that the curve for 1947 lies below that of the other three years. This is accounted for by the fact that the relationship is begun on 1 April at which time the 1947 snowpack was relatively less than in the other years. Because of this fixed starting date, the curvature in the relationship is greater for years of above-normal snowpack accumulation while for years with below-normal snowpack the curvature is less than it is for normal snowpack conditions. Beginning the accumulated ablation-snowcover curves at 98 percent cover regardless of date, these curves are all similar in shape.

7-05.05 The difference between accumulated ablation of the snowpack and accumulated runoff represents the net effect of losses (evapotranspiration and soil-moisture increase) and ground-water and other basin storage. Figure 4, plate 7-4, indicates the 1947 CSSL snow-cover depletion as a function of accumulated runoff as well as accumulated ablation of the snowpack. The displacement of the runoff curve to left of the ablation curve is due to losses and storage. (In the case of CSSL, storage is relatively small in proportion to the total runoff.)

7-06. SNOW-COVER DEPLETION VS. RUNOFF

7-06.01 General. - Relating snow cover to observed runoff during the active melt period provides a convenient method for estimating snow-covered area continuously through the melt season. Snow cover may be related directly to observed data, or a mathematical function may be used to express the relationship. Data from Research Note 16, showing the relationships at the laboratories and a few miscellaneous basins, are presented to illustrate the general character of the relationships. Runoff may be accumulated commencing either from (1) the time of initial rise in streamflow, (2) the time of maximum snowpack, or (3) an arbitrary date, such as 1 April. It is also useful to accumulate historical runoff data from the end of the snowmelt runoff season, backward through the melt period, and thus relate snow cover to "future runoff." All values of accumulated runoff should be corrected for spring precipitation (either rain or snow) so that the relationships will express conditions resulting from the initial snowpack and thus will be more consistent from year to year.

7-06.02 Examples of depletion vs. runoff relationships. - Figure 5, plate 7-4 shows curves of snow-cover depletion as a function of accumulated runoff from snowmelt for the period 1 April through 31 July for the CSSL basin, Skyland Creek at UCSL, St. Louis Creek in Fraser Experimental Forest, Colorado, 3/ and for Kings River, California. These curves reflect the effects of snow-cover depletion, ground-water storage, losses, and the magnitude of the snowpack in individual years. Similar curves could be constructed on the basis of generated rather than actual runoff, and thereby eliminating the effect of storage. For the cases shown, runoff from CSSL is the least affected by storage (the curves are displaced farthest to the right). Skyland Creek at UCSL and St. Louis Creek at Fraser Experimental Forest possess longer times of storage delay to runoff, and accordingly their curves are displaced to the left.

7-06.03 Figure 6, plate 7-4 shows the snow-covered area (in percent of initial snow cover) plotted against future runoff (in inches over area initially snow covered). As would be expected, there is wide divergence in amount of future runoff associated with a given snow cover early in the season. When snow-covered area is high, the future runoff depends principally upon the water equivalent of snowpack;

as the melt season progresses, the lines converge to indicate future runoff is largely a function of remaining snow cover. Such empirical relationships suggest the possibility of forecasting from direct observation of snow cover the remaining volume of snowmelt runoff after the melt season is under way.

7-06.04 Mathematical expression for snow-cover depletion. - In the absence of observed data, snow-cover values may be obtained from a theoretical snow cover-runoff curve, (Research Note 19). The general expression used to relate snow cover to generated runoff is as follows:

$$A_s = 1.0 - (\Sigma Q_{gen})^n \qquad (7\text{-}1)$$

where A_s is the fractional portion of the basin area which is snow covered, Q_{gen} is the generated runoff relative to the total seasonal runoff from the initial snow-covered area, and n is an exponent expressing the characteristic basin snow-cover depletion with runoff. For basins which are initially 100 percent snow covered, the runoff summation begins when the basin first begins to go bare. Runoff is expressed in terms of generated flows, and hence, storage effects are not pertinent. The value of n reflects the diversity of terrain effects on snow-cover depletion. In the case of WBSL, where a snow wedge adequately defines the variation in the snowpack water equivalent with elevation, a value of n = 2 gave reasonable values of snow cover. The curve for the value of n = 2 approximates closely the condition of a uniformly ablated snow wedge for a basin with a typical S-shaped area-elevation relationship, and with snowpack water equivalent proportional to elevation above the snowline. A smaller value of n would be expected in areas of greater diversity of terrain. In plains regions with uniform deposition of snow and melt, the value for n may be 3 or more. Figure 7, plate 7-4, illustrates the rate of snow-cover depletion for various values of n in equation 7-1. It is pointed out that these mathematically expressed curves do not account for the reverse curvature which appears near the end of season in some basins, as illustrated by curve A, figure 1.

7-07. METHODS OF ESTIMATING SNOW COVER FROM INDEXES OR DERIVED RELATIONSHIPS

7-07.01 General. - In the derivation of design floods and in seasonal-runoff or rate-of-flow forecasting, it is necessary to evaluate the area of snow cover for the particular melt sequence. In some such procedures, the area of snow cover is implicitly evaluated by another variable which is related to snow cover. For example, many procedures for forecasting seasonal runoff from snow-course data do not account for the area of snow cover directly, but derived relationships between snow-course water equivalent and runoff implicitly include the average relationship between area of snow cover and snowpack water equivalent. However, since there is variability in the relationship between snowpack water equivalent and snow cover, the average relationship can at best only approximate the true volume of water stored in the snowpack.

7-07.02 The most reliable estimate of snow cover is one made from direct observation, as described in section 7-02. In many cases, however, such observations are not feasible, and estimates must be indirectly made from other observed data. Also, once a sufficient period of record of snow-cover observations have been obtained and related to other data, the frequency of making snow-cover observations can be reduced, and snow-cover estimates can be made more quickly and more economically by indirect relationships than by direct observation.

7-07.03 In estimating snow cover from other observed data, derived relationships are used in two ways. One is in obtaining a single estimate of snow cover at a specific time and the second is for estimating day-to-day changes in snow cover. Methods used for determining snow-covered areas are listed below under these two categories:

A. Methods of estimating snow cover at a specific time.

1. Index relations of snow cover to fixed ground or aerial observations, or photographs of snow cover at a point or series of points.

2. Use of snowline observations and area-elevation relationships.

3. Relation of snow cover to point measurements of snow.

a. Water equivalent measurements.
b. Snow depth measurements.

B. Methods of estimating changes in snow cover.

1. Empirical relation of snow-cover depletion to accumulated runoff.

a. Curves derived graphically from observed data.
b. Mathematical equation.

2. Relation of snow-cover depletion to temperature or some index of melt.

3. Use of current precipitation and temperature data to establish areas of new snow, within the accretion or depletion period.

4. Subdivision of basin into elevation zones or homogeneous sub-areas.

7-07.04 Indexes of snow cover. - Methods of observing snow cover, from a point, either on the ground or from the air, have been described in section 7-02. The quantitative evaluation of basin snow cover using point observations as indexes, required simultaneous observations of the index and of basin snow cover until a relationship has been established between the two. Average snowline elevations may be used with area-elevation relationships to determine snow cover in mountainous regions, particularly during the accumulation period, but care should be exercised in their use during the melt period.

7-07.05 Snow course measurements of snowpack water equivalent at one or more snow courses may be related to snow cover as a simple function. Obviously, snow courses selected for use in this relationship should be those on which snow remains for the longest possible time. The principal deficiency of the method is that such a simple correlation does not account for variation in slope of the snow wedge. In Research Note 22, the area of snow cover of the North Santiam River basin above Detroit Dam was expressed as a function of the ratio between the snowpack water equivalents of two snow courses at different elevations. Only one season's snow-cover observations were available, however, so the reliability of the method on this basin cannot be assessed. Snow-depth observations are useful primarily in defining the times that areas become bare of snow for given locations and elevations. Care should be taken in selection of the point(s) to secure representativeness of basin conditions, both with regard to snow deposition and melt. In the West, snow-course measurements are made at monthly or bimonthly intervals, so that their use is limited to the times of observations. Snow-depth measurements at weather observation stations are available daily during the period of snow cover.

7-07.06 Estimates of basin snow-cover depletion. - A knowledge of the change in snow cover between times of observation during the melt period is required for many snow-hydrology problems. The most feasible method is to assume snow cover to vary with some continuous function, such as runoff, time, or a melt index. Section 7-06 described relationships between snow-cover depletion and accumulated runoff, based on snow-laboratory observations. The procedures have been used by the Seattle District on the Kootenai and Flathead River basins, as described in Technical Bulletin 15. The available observations are insufficient, however, to derive general relationships for these areas. Empirical relationships in graphical or mathematical forms may be used to relate snow-cover depletion to runoff according to methods set forth in section 7-06. The use of a time function alone to express depletion is not too reliable because of the variations in melt (and hence depletion), with time. A simple index of melt, such as degree days, may be used to evaluate depletion, but the use of accumulated generated runoff is considered to be more practical because (1) it integrates all factors affecting melt, (2) it is simpler to use than melt indexes, and (3) it is readily available.

7-07.07 During the period of snow depletion, snow-cover estimates may be improved by use of current temperature and precipitation data. The purpose is to delineate areas of shallow new snow which contribute little to runoff. Once the areas covered by new snow are evaluated the time required to melt the new snow in order to re-establish the snow-cover depletion rate of the old snow can be determined.

7-07.08 A different approach to the determination of snow-cover depletion is that of subdividing a basin area into zones of equal elevation. Beginning with an assumed or known distribution of snowpack water equivalent with elevation, values of snowpack water equivalent are determined for each zone. By maintaining an inventory of snowpack accumulation and ablation, the depletion of snow on successive elevation zones is determined. The principal difficulty of the method is in the evaluation of precipitation distribution with elevation, particularly for heterogeneous areas. A refinement of the method is to assume a non-uniform distribution of snowpack water equivalent within a given zone.

7-08. APPLICATION OF SNOW-COVER OBSERVATIONS TO BOISE RIVER BASIN

7-08.01 General. - Of recent years, the Walla Walla District of the Corps of Engineers has determined the area of snow cover on various drainage basins within their district by means of aerial reconnaissance. Some of this information has been used by the Snow Investigations in studies of daily snowmelt and streamflow for the Boise River near Twin Springs, Idaho (D.A = 830 sq. mi.). Results of those studies are presented in chapters 6 and 9. The importance of snow cover in these studies led to a detailed analysis of snow cover on the Boise River basin during the 1954 and 1955 melt seasons. These analyses are described in this section.

7-08.02 Description of 1954 and 1955 seasons. - The snowpack on 1 April was above normal in 1954 and somewhat below normal in 1955. During April, 1954, melting conditions prevailed and light precipitation fell, principally in the form of rain. April, 1955, on the other hand, was characterized by below normal temperatures and above normal precipitation, thereby resulting in a large increase in accumulation of snow. The major portion of the snowpack ablation occurred during May of both years. In 1954 the last few days of May and the first half of June were cold and wet, thereby retarding the melt of the remnants of the snowpack.

7-08.03 Progression of snow-cover depletion. - Plate 7-5 presents the results of the aerial observations of snow cover on the Boise River basin above Twin Springs, Idaho, during the 1954 and 1955 melt seasons. Principal streams and elevation contours are shown on each of the basin maps to convey a general idea of the topography. Figure 3 on plate 7-5 shows the location of hydrometeorological stations within the basin and in the surrounding area. Plate 7-6 shows the hydrometeorological events for each of the two years, including estimated basin precipitation (both rain and snow are shown separately), mean daily temperature at Atlanta (elev. 6000 ft msl), daily discharge hydrographs for Boise River near Twin Springs, Idaho, for the period March through June, and snowpack water equivalents for snow courses within the basin or adjacent areas for those dates for which records are available. Also shown are the observed snow-cover data, plotted on the same time scale. For times between observations, the 1955 values are interpolated by means of the snow cover-generated runoff relationship (corrected for subsequent precipitation), shown in figure 3, plate 7-6. For 1954, estimates of snow cover between observations were made by drawing a smooth curve drawn through the four observed points thus defining the snow-cover depletion only in a general way. Precipitation and temperature data, between dates of observation, suggest significant deviations between the actual cover and that shown by the snow cover-time curve.

7-09. SUMMARY AND CONCLUSIONS

7-09.01 Snow-cover information is, like temperature or heat supply, an important hydrometeorological element. Snow cover is a factor in all hydrologic problems which involve basin snowmelt. At present systematic snow-cover surveys are being made in a number of basins. Despite the complexity of the variables affecting the snow-cover depletion, the hydrologist is able to approximate the snow-covered area between snow-cover surveys using available hydrometeorological data.

7-09.02 The recession of snow cover is very slow early in the melt season compared to ablation of the snowpack or runoff. Since areas of homogeneous heat supply exhibit uniform melt rates, the snow cover depletes gradually to a thin layer. A sudden increase in depletion then takes place. In years with very deep snow, a large amount of snow-depth reduction or runoff takes place before the appearance or substantial enlargement of the snow-free areas in the basin. The principal factors affecting the snow-cover depletion are the variations in snow deposition and variations in snowmelt, both of which are affected by terrain features, including orientation, steepness of slope, elevation, and forest cover. The snow-cover depletion-runoff patterns vary between basins in accordance with the difference in topography and ground-water character. Variation is also expected within each watershed from year to year on account of differences in the snowpack accumulation at the onset of the snowmelt runoff season.

7-09.03 During the winter accumulation period the determination of the snow cover is relatively simple and accurate; the snowline is well defined and coincides with an elevation contour. The area-elevation curve is used in determining the snow-covered area. In the absence of snowline or snow-cover surveys, a current snow-course survey may be used to determine snowline elevations. The water equivalent-elevation curve, even though poorly defined, will indicate the average elevation below which no snow exists on the drainage basin. The snow-covered area, as of the date of snow-course curvey, can be determined from the area-elevation curve or from the snow chart, shown in figure 1, plate 4-2 of chapter 4. The snowline elevation subsequent to the most current snowline survey can be estimated by reducing the snow wedge at the time of the survey, by an amount proportional to heat supply, or by lowering the snowline elevation if subsequent precipitation, in the form of snow, caused the snowline to advance to a lower elevation.

7-09.04 During the active melt season, the determination of an average snowline is not dependable because the snowline is not as well defined as in the accumulation period. The lower portion of the snow wedge is quite ragged or patchy for 1000 feet or more in elevation. In general, this ragged zone is higher on southerly slopes than it is on northerly slopes. It is less patchy and lower in a heavily forested area than on an open slope of same exposure. During the period of active melt season, the use of an average snowline elevation for determining the snow-covered area can be considered only a rough approximation. The most dependable basin snow-cover estimates are made from aerial reconnaissance surveys. Snow cover between surveys is determined in accordance with runoff and with the meteorological events affecting new snow cover. A characteristic of snow-cover depletion is the definite pattern in which snow depletes from year to year on a given basin. As a result of this year-to-year uniformity, only a few sites, representative of the topography of the watershed, need be observed as an index to snow cover.

7-09.05 The determination of snow-covered area by means of established "cover-runoff" or "cover-ablation" curves is accomplished from analysis of historical data. If accumulated runoff is plotted in percentage of the season's total from beginning of the appearance of the effective spring melt at the stream gaging station, the curves will tend to be close together and serve as guide for the extrapolation of the snow-cover recession for the melt season considered. Undoubtedly "cover-mass" relationships can be improved if a parameter such as the initial basin snow cover is used. The relation between snow cover and "future runoff" provides a method for estimating residual runoff. Forecasts based on those relationships are particularly useful in connection with regulation of reservoirs near the end of the filling period.

7-10. REFERENCES

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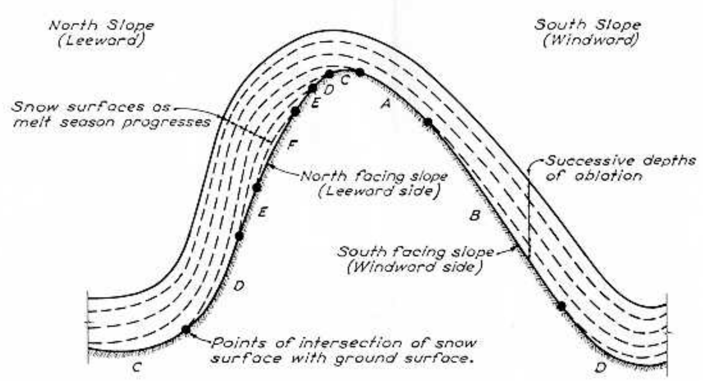
AERIAL PHOTOGRAPH, CSSL, SHOWING FOREST COVER

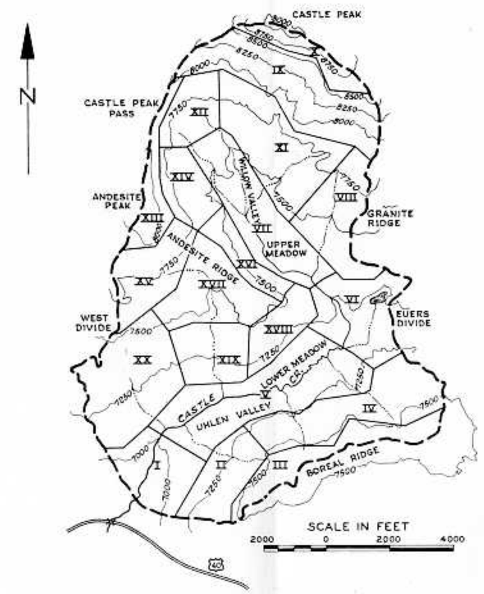
FIGURE 1



Note:
This diagram illustrates the progress of depletion of the snow cover during period of active melt. The sequence of appearance of bare ground are lettered successively beginning with the letter A. Relative melt rates are shown by the vertical distance between snow surface lines corresponding to various dates. Rate of snow cover depletion for a particular area depends chiefly on the orientation of the slope, which affects both accumulation of snow and the supply of heat for melting the snow. Note the drift effect on the accumulation of snow on windward and leeward slopes near edge of crest.

SCHEMATIC DIAGRAM OF SNOW COVER DEPLETION, UNFORESTED SLOPES, CSSL

FIGURE 5



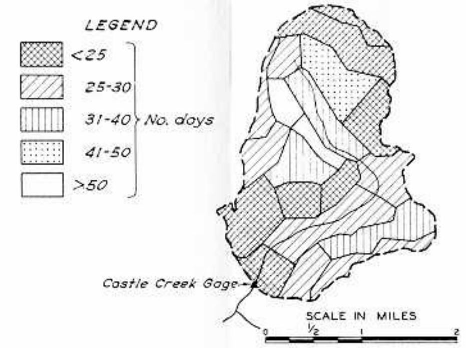
TOPOGRAPHIC UNITS, CSSL

DRAINAGE AREA 3.96 SQUARE MILES

FIGURE 2

DATE WHEN SNOW COVER IS REDUCED TO 60% OF AREA OF TOPOGRAPHIC UNIT

Topo unit	Date	Days after 10 Apr	Topo unit	Date	Days after 10 Apr
I	4 May	24	XIII	13 May	29
V	7 "	27	XIV	5 June	55
VI	7 "	27	XVI	10 "	60
II	9 "	29	VII	20 May	40
III	9 "	29	XII	7 "	27
IV	20 "	40			
			VIII	2 "	22
XV	7 "	27	IX	28 Apr	18
XVII	15 "	35	X	23 "	13
XVIII	1 "	21	XI	1 June	50
XIX	3 "	23			
XX	30 Apr	18			



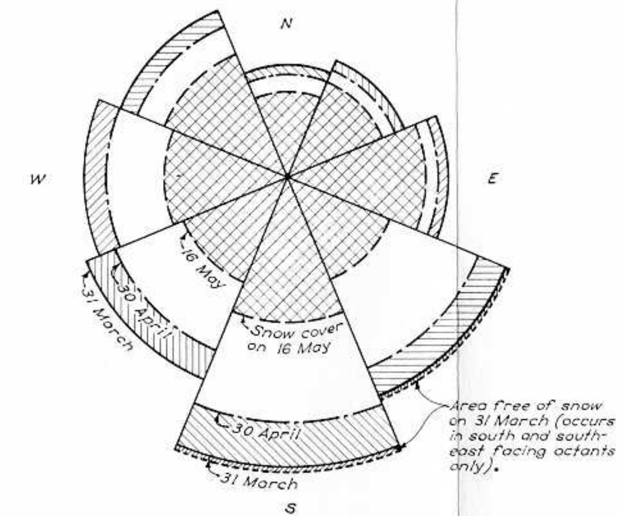
DAYS AFTER 10 APRIL 1947 WHEN 60 PERCENT OF THE AREA IN EACH UNIT WAS COVERED WITH SNOW

FIGURE 6

COVER vs ORIENTATION

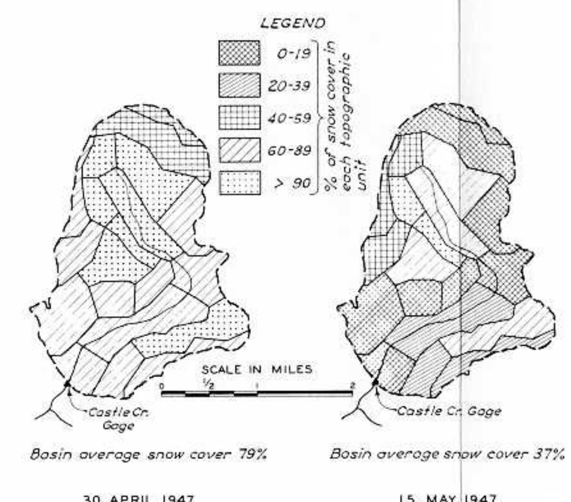
Orientation	Area in % basin	Snow cover in % basin 31 Mar	30 Apr	16 May	Median el.
N	4.0	4.0	3.3	2.3	7420
NE	5.0	5.0	4.1	3.5	7550
E	8.0	8.0	7.0	6.0	7620
SE	18.0	17.6	13.3	4.0	7410
S	27.0	26.1	18.2	6.7	7510
SW	15.0	15.0	11.1	4.1	7610
W	13.0	13.0	10.3	4.9	7530
NW	10.0	10.0	8.3	5.6	7360
Total	100.0	98.7	75.6	37.1	

Note:
Areas shown in each octant are directly proportional to snow covered areas for that octant in basin.



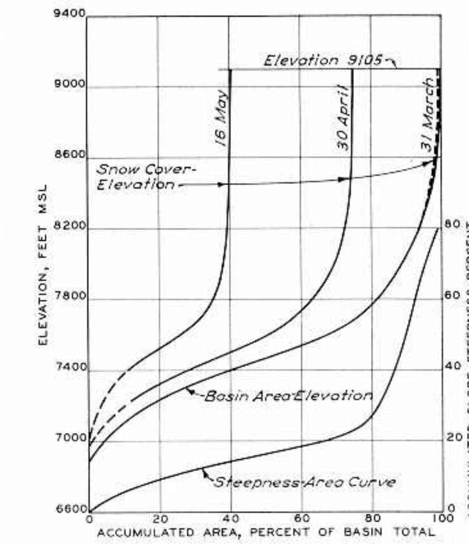
PROGRESS OF SNOW COVER DEPLETION WITH RESPECT TO ORIENTATION CSSL, 1947

FIGURE 3



AREAL DISTRIBUTION OF SNOW COVER

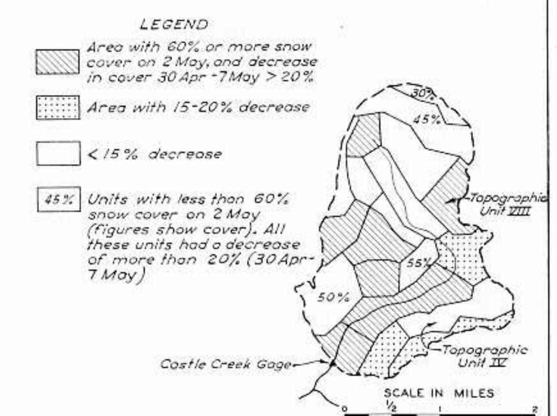
FIGURE 7



SNOW COVERED AREA-ELEVATION CURVES, CSSL, 1947

AREA-STEEPNESS CURVE, CSSL

FIGURE 4



SNOW COVER AT TIME OF PEAK FLOW ON 1 MAY 1947

FIGURE 8

Notes:
1. On 31 March snow cover was 100 percent over all topographic units, except on a few very steep slopes at high elevations.
2. The basin snow water equivalent depth reached its maximum value on about 10 April when snow melt runoff began to appear at the gaging station in Castle Creek.
3. On 15 April approximately 92 percent of the basin was covered with snow.

SNOW INVESTIGATIONS
SUMMARY REPORT

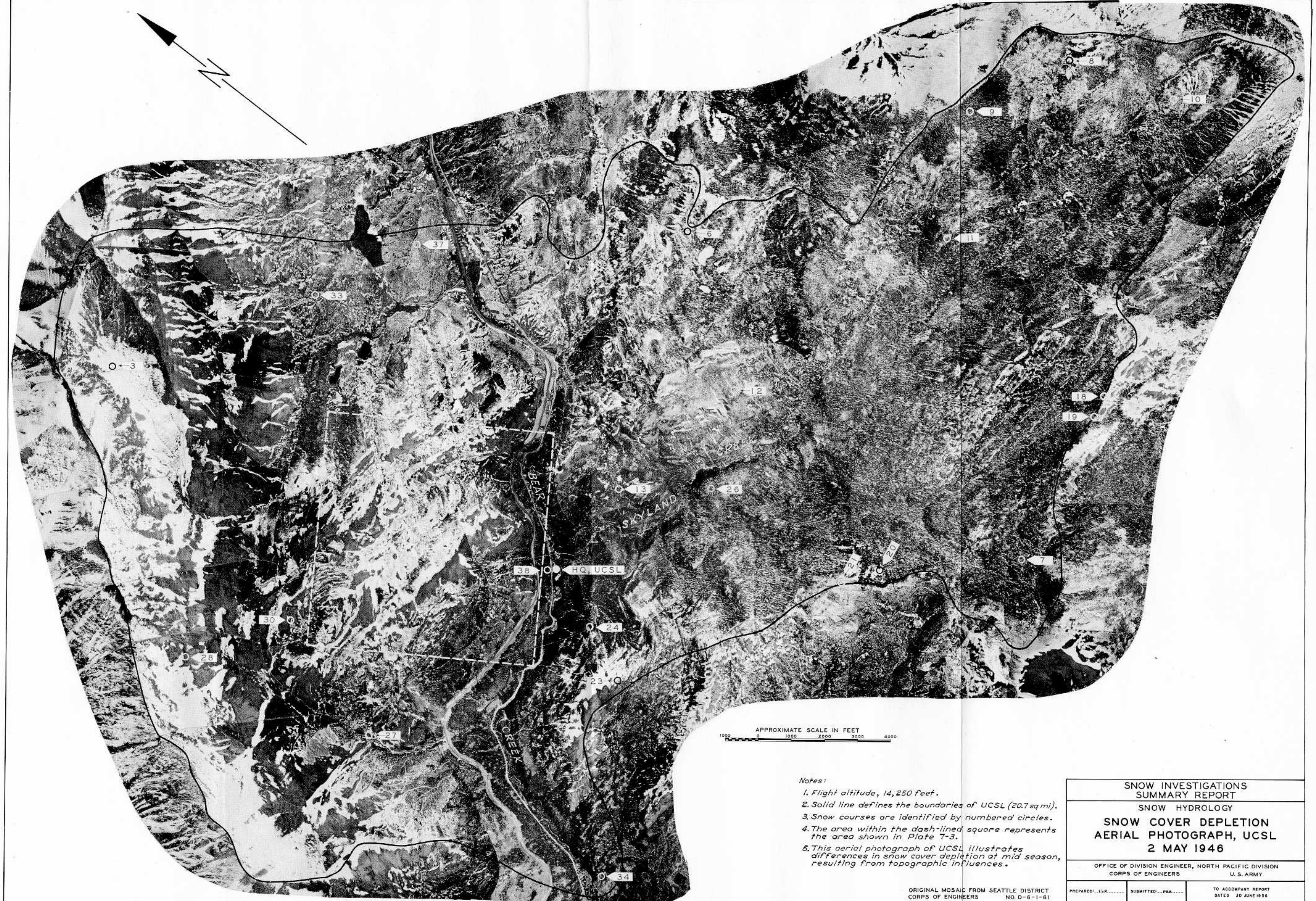
SNOW HYDROLOGY

SNOW COVER DEPLETION CSSL, 1947

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

PREPARED: P.B.B.	SUBMITTED: P.B.B.	TO ACCOMPANY REPORT DATED 30 JUNE 1956
DRAWN: R.V.	APPROVED: D.M.R.	PD-20-25/40

PLATE 7-1



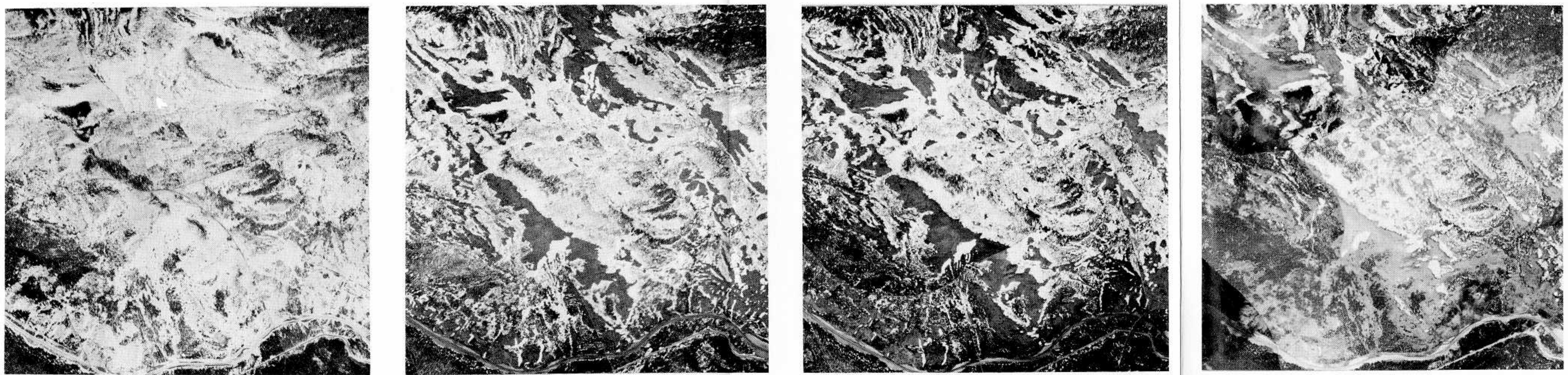
Notes:

1. Flight altitude, 14,250 feet.
2. Solid line defines the boundaries of UCSL (20.7 sq mi).
3. Snow courses are identified by numbered circles.
4. The area within the dash-lined square represents the area shown in Plate 7-3.
5. This aerial photograph of UCSL illustrates differences in snow cover depletion at mid season, resulting from topographic influences.

ORIGINAL MOSAIC FROM SEATTLE DISTRICT
CORPS OF ENGINEERS NO. D-6-1-61

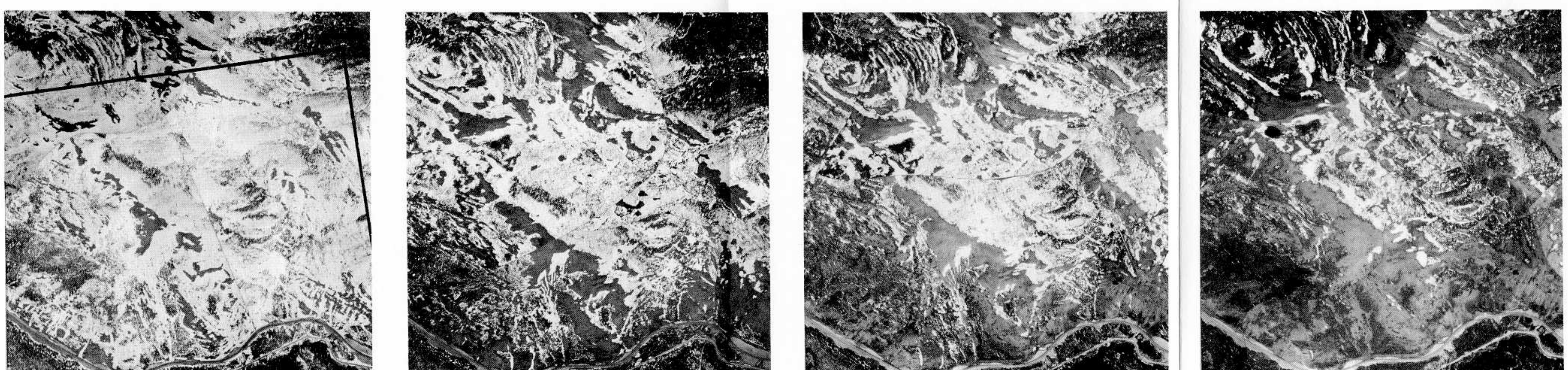
SNOW INVESTIGATIONS SUMMARY REPORT		
SNOW HYDROLOGY **SNOW COVER DEPLETION AERIAL PHOTOGRAPH, UCSL 2 MAY 1946**		
OFFICE OF DIVISION ENGINEER, NORTH PACIFIC DIVISION CORPS OF ENGINEERS U. S. ARMY		
PREPARED: LLP DRAWN: RV	SUBMITTED: PBB APPROVED: DMB	TO ACCOMPANY REPORT DATED 30 JUNE 1956 PD-20-25/41

PLATE 7-2



7 APRIL 24 APRIL 2 MAY 17 MAY

FIGURE 1 — 1946 AERIAL PHOTOGRAPHS



16 APRIL 3 MAY 8 MAY 20 MAY

FIGURE 2 — 1947 AERIAL PHOTOGRAPHS

Note:
The photographs illustrate that each year the sequence of areas going bare is the same. The pattern of growth of bare patches is similar each year if the forest cover is unchanged. The area encompassed in each photograph of this series is approximately one square mile. See Plate 7-2 for general location and orientation of area.

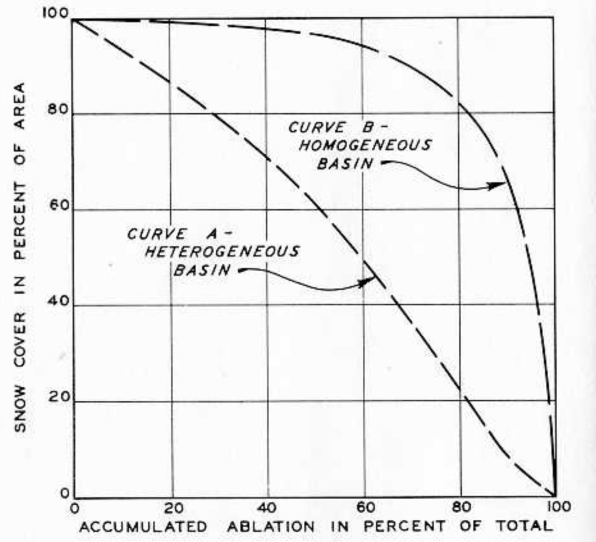
SNOW INVESTIGATIONS
SUMMARY REPORT

SNOW HYDROLOGY

PROGRESS OF SNOW-COVER DEPLETION
UCSL, 1946 AND 1947

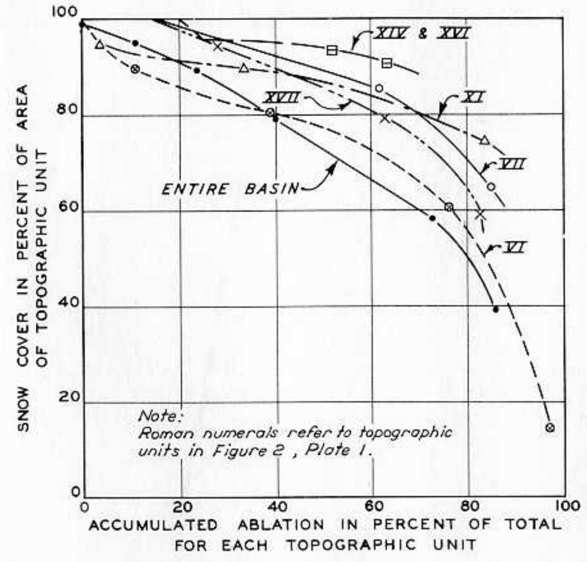
OFFICE OF DIVISION ENGINEER, NORTH PACIFIC DIVISION
CORPS OF ENGINEERS U.S. ARMY

PREP:	SUBM:	TO ACCOMPANY REPORT DATED 30 JUNE 1956
DRAWN:	APPR:	PD-20-25/42



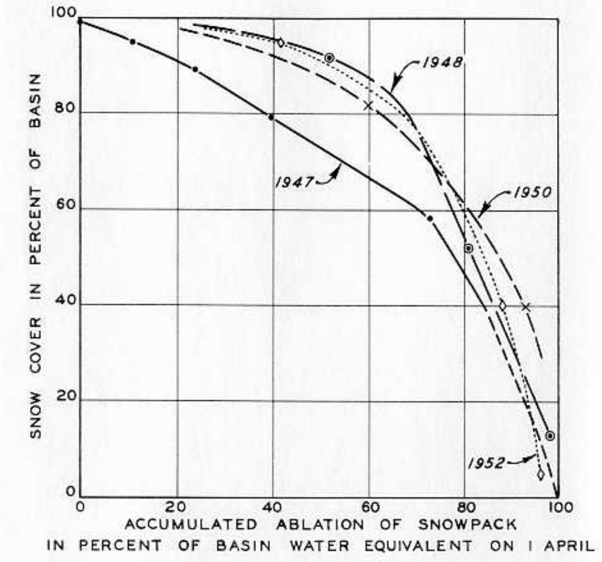
SCHEMATIC DIAGRAM OF SNOW COVER DEPLETION - ABLATION RELATIONSHIP

FIGURE 1



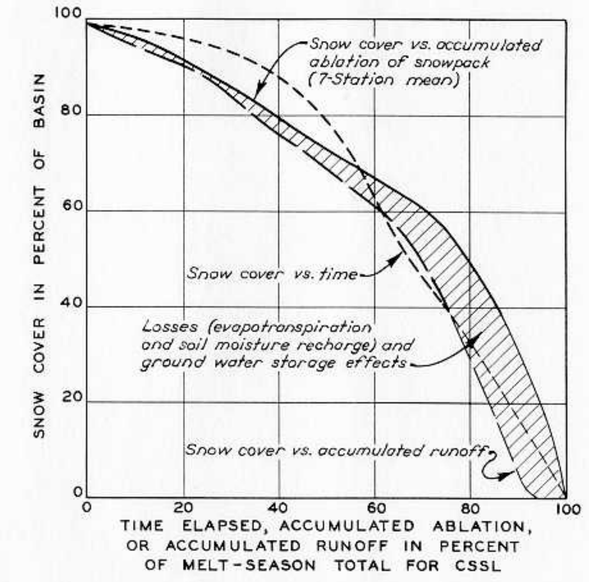
SNOW COVER DEPLETION - ABLATION RELATIONSHIP, CSSL, 1947

FIGURE 2



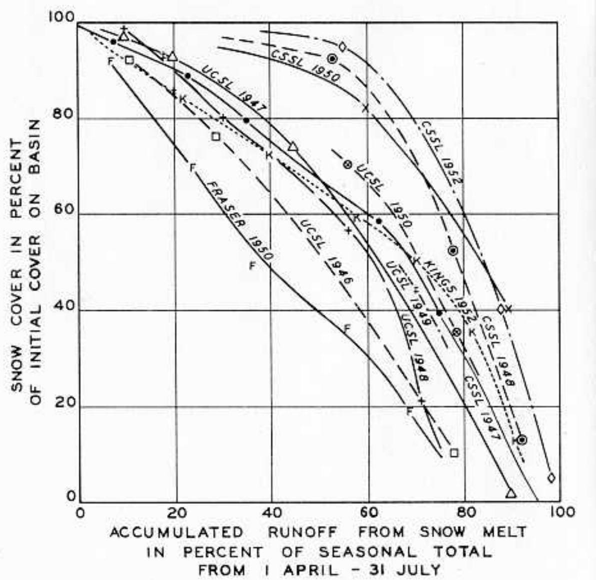
SNOW COVER DEPLETION - ABLATION RELATIONSHIP, CSSL

FIGURE 3



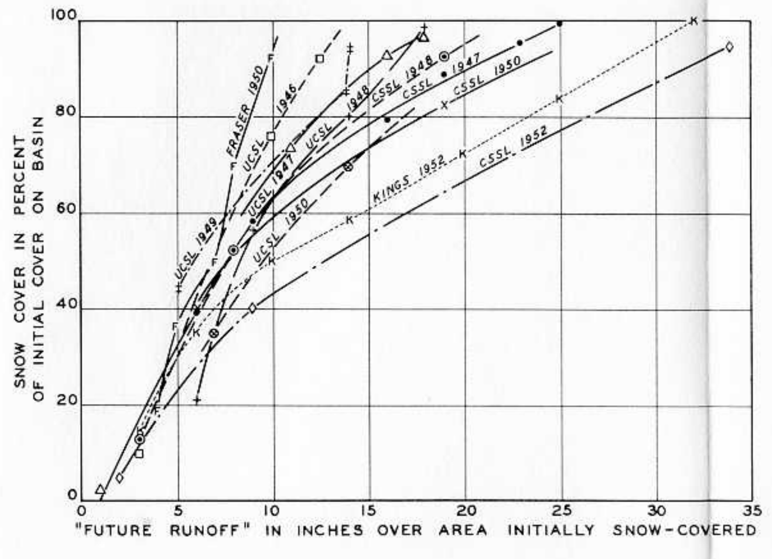
SNOW COVER DEPLETION, ABLATION AND ACCUMULATED RUNOFF, CSSL, 1947

FIGURE 4



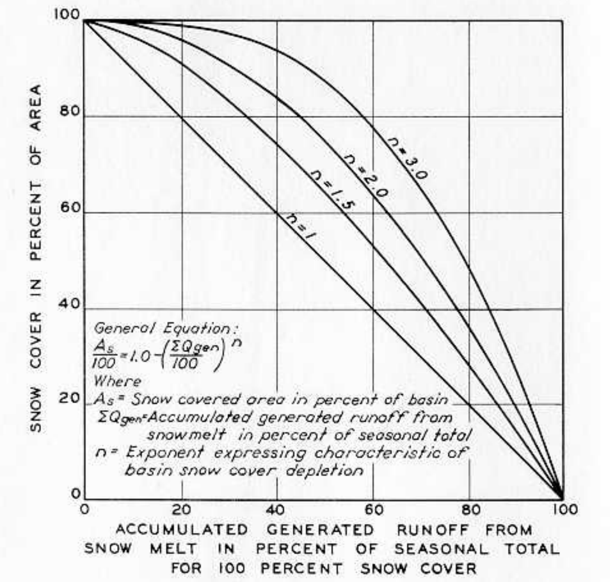
SNOW COVER DEPLETION - RUNOFF RELATIONSHIPS

FIGURE 5



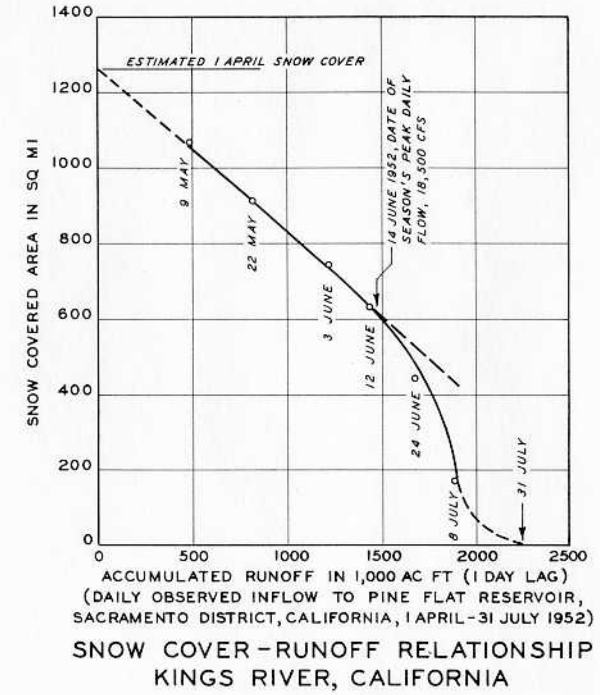
SNOW COVER - "FUTURE RUNOFF" RELATIONSHIPS

FIGURE 6



MATHEMATICAL EXPRESSIONS FOR SNOW COVER DEPLETION

FIGURE 7



SNOW COVER - RUNOFF RELATIONSHIP KINGS RIVER, CALIFORNIA

FIGURE 8

Notes for Figures 2, 3, 4, 5 and 6:

1. *Accumulated runoff from 1 April - 31 July is corrected for rainfall between snow cover surveys but not adjusted for ground water recession flow.*
2. *Initial snow cover is the snow covered area as of 1 April.*
3. *In Figure 3, if the accumulation for 1948, 1950 and 1952 began at 98 percent snow cover the curves would fall close to 1947 curve.*

SNOW INVESTIGATIONS SUMMARY REPORT

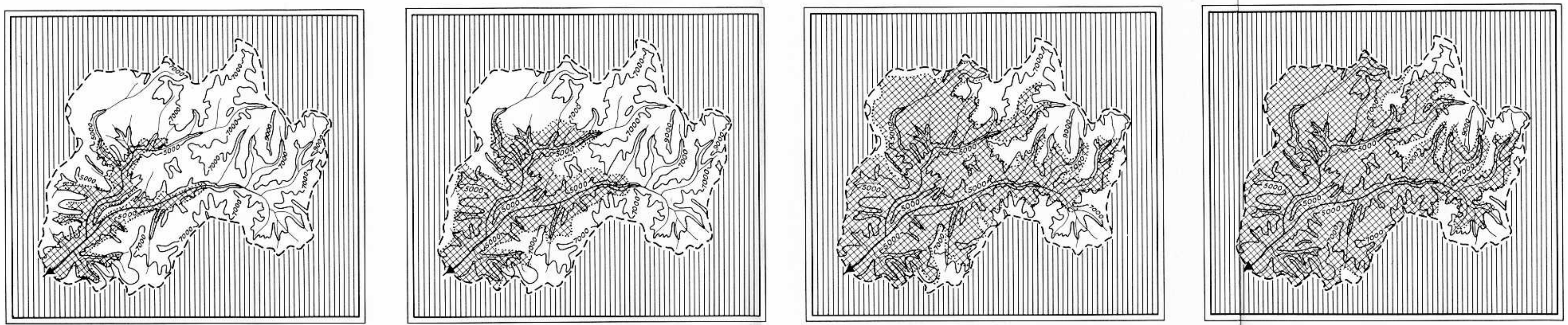
SNOW HYDROLOGY

SNOW COVER DEPLETION, ABLATION OF THE SNOWPACK, AND RUNOFF

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

PREPARED: P.B.B.	SUBMITTED: P.B.B.	TO ACCOMPANY REPORT DATED 30 JUNE 1956
DRAWN: H.E.B.	APPROVED: D.M.R.	PD-20-25/43

PLATE 7-4



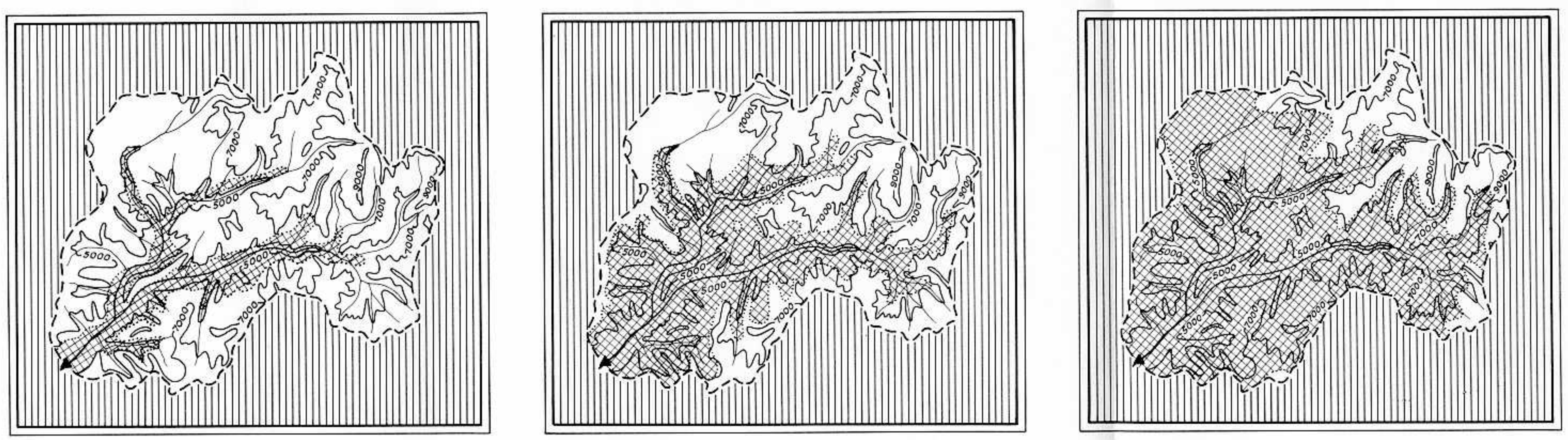
31 MARCH 1954 - 86 % SNOW COVER

22 APRIL 1954 - 69 % SNOW COVER

6 MAY 1954 - 38 % SNOW COVER

20 MAY 1954 - 18 % SNOW COVER

FIGURE 1 - 1954 AERIAL RECONNAISSANCE



5 MAY 1955 - 86 % SNOW COVER

22 MAY 1955 - 59 % SNOW COVER

8-9 JUNE 1955 - 22 % SNOW COVER

FIGURE 2 - 1955 AERIAL RECONNAISSANCE

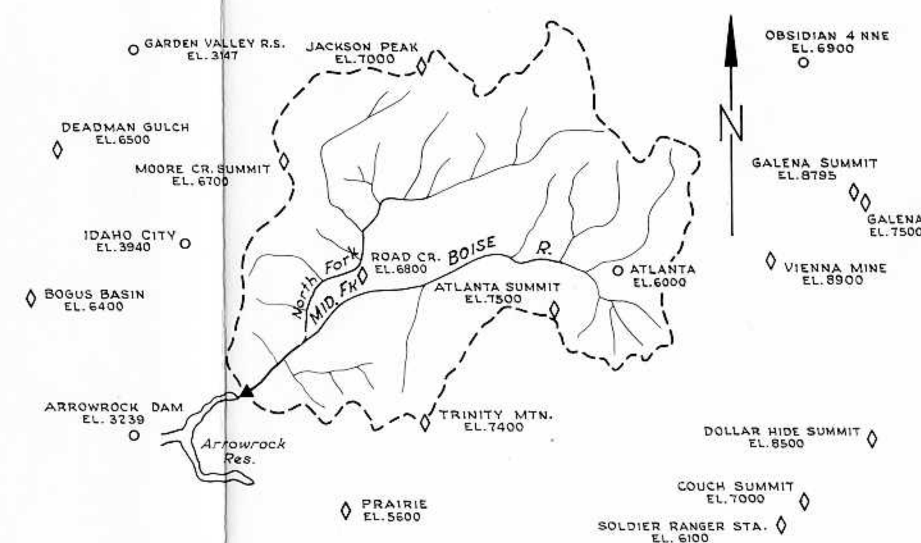


FIGURE 3 - HYDROMETEOROLOGICAL STATIONS

LEGEND

- Snow-free Area } From aerial snow line reconnaissance on dates shown.
- Snow Covered Area }
- Meteorological Station
- Snow Course
- Stream Gage

SUMMARY OF WEATHER				
YEAR	MARCH	APRIL	MAY	JUNE
1954	Temperature slightly below normal. Precipitation 80% of normal. Periods of major storms: 8-12, 7-21, 24-28. Snowfall at lowest elevation on 20th.	Temperature and precipitation slightly above normal. Maximum snow accumulation during first week. Storms: 3-7, 9-10, 13-15, 18-19, 20-21, 27-28,30. Effective snow-melt runoff began on 10th.	Above normal temperatures. Peak stream flow on May 21st. Storms: 1, 16, 21-23, 25-31	Subnormal temperature. Storms: 1-2, 5-8, 8-13, 15-17, 26-29.
1955	Temperature considerably below normal. Precipitation near normal with snow at low levels. Storms: 1-5, 9-16, 22-24, 28-31.	Temperature below normal. Precipitation above normal. Storms: 1-4, 10-30. Effective snow-melt runoff began on 28th.	Temperature below normal. Precipitation above normal. Maximum snow accumulation during first week. Storms: 1-4, 14-17, 21-22, 25-28.	Temperature below normal. Precipitation near normal. Peak stream flow on 10th. Storms: 2-3, 12-15, 24, 26, 28-29.

Note:
Snow cover observations by aerial reconnaissance obtained from Walla Walla District, U. S. Corps of Engineers.

SCALE IN MILES
10 0 10 20

SNOW INVESTIGATIONS
SUMMARY REPORT
SNOW HYDROLOGY

SNOW COVER OBSERVATIONS 1954-55

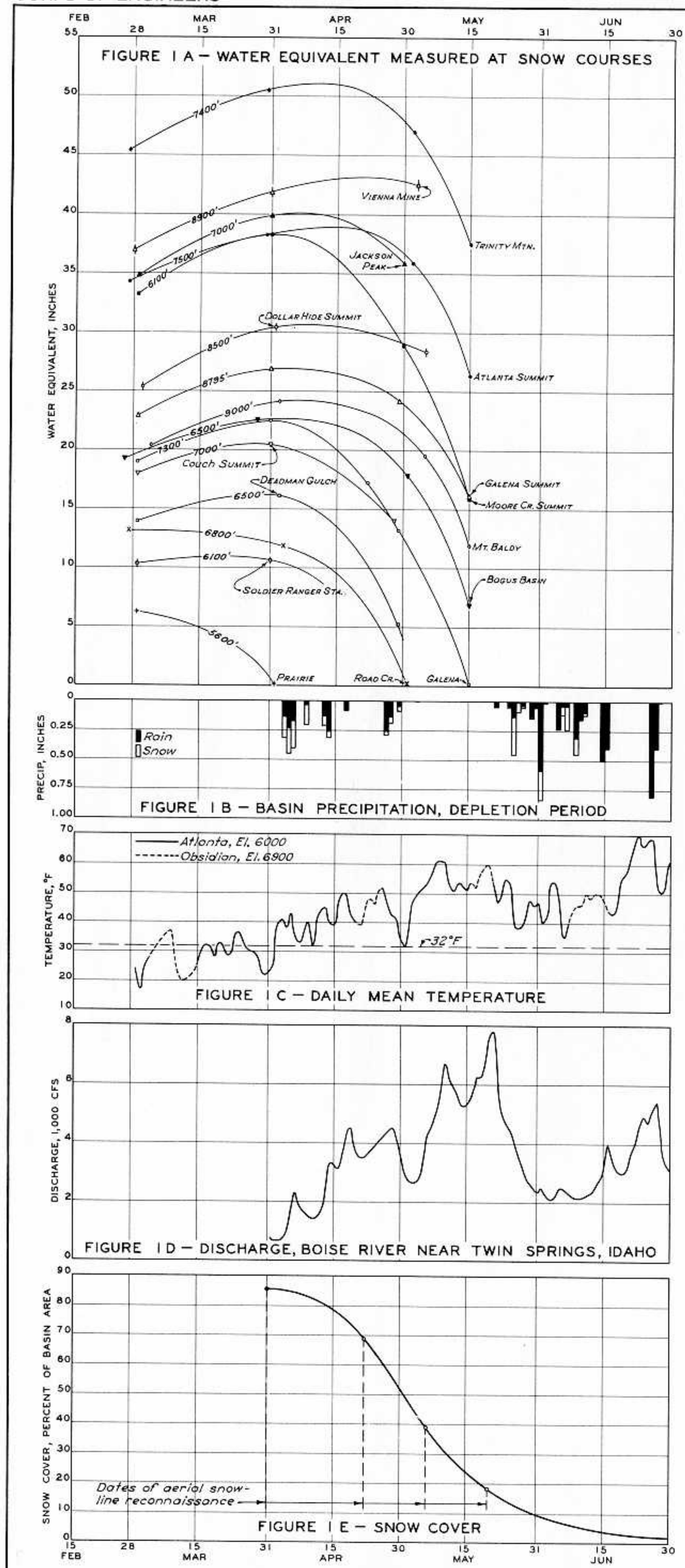
BOISE RIVER ABOVE TWIN SPRINGS, IDAHO
DRAINAGE AREA 830 SQ. MI.

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

PREPARED: PM SUBMITTED: PBB
DRAWN: WJM APPROVED: DMR
TO ACCOMPANY REPORT DATED 30 JUNE 1956

PD-20-25/44

PLATE 7-5



1954

NOTES for FIGURES 1A and 2A:

1. Lines between points are primarily for identification of snow courses and show only the general trend of the water equivalent variation between measurements. Actually the accumulation and depletion of the snowpack is very irregular.
2. Location of snow courses is shown in Figure 3, Plate 7-5.

NOTE for FIGURES 1B and 2B:

Basin precipitation computed from 4-Station average, adjusted to represent basin amounts on basis of normal annual precipitation.

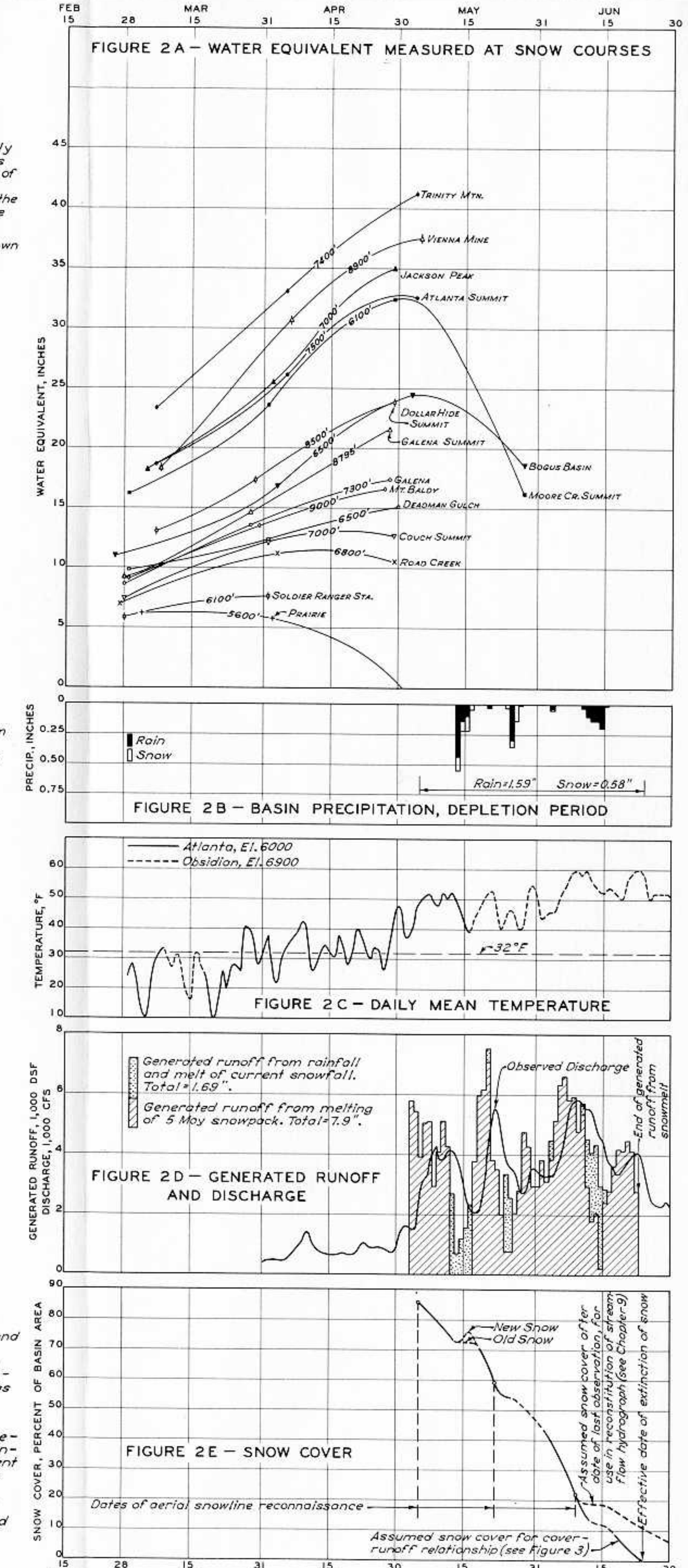
NOTES:

FIGURE 1E

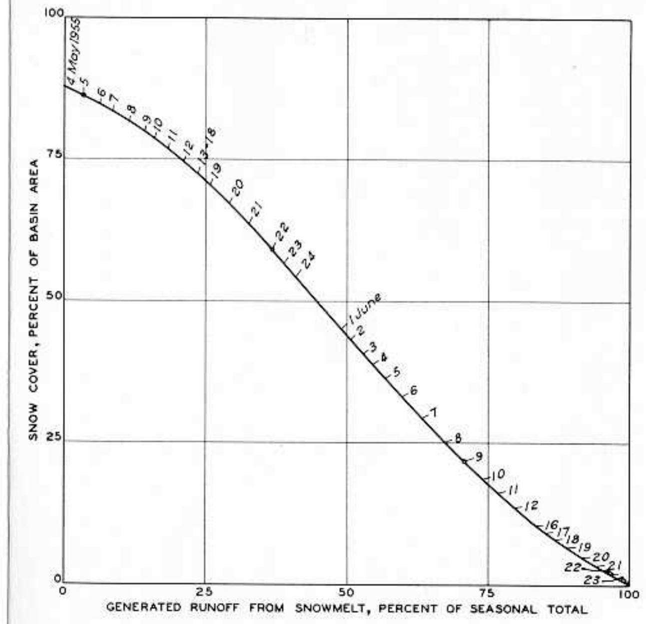
Curve shows only the general trend between observations of snow cover. No attempt was made to estimate the probable values between observation dates as was done for 1955, Figure 2E.

FIGURE 2E

1. Snow cover during periods of precipitation (---), estimated by considering temperature and percent of basin above estimated snow isotherm.
2. Snow cover between storms and observations interpolated with aid of Figure 3, upper right.



1955



NOTE:

This curve is derived from data found in Figures 2D and 2E. The effect of new snow and rain (coverage and runoff) was estimated and the curve adjusted accordingly to represent the cover-runoff relationship for the basin snow as observed on 5 May 1955. This is the date when appreciable snowmelt rise in the discharge hydrograph began. Season's total runoff from the melt of the 5 May snowpack (with 86% cover) was 7.9 inches.

FIGURE 3 – SNOW COVER, GENERATED RUNOFF RELATIONSHIP – 1955

SNOW INVESTIGATIONS
SUMMARY REPORT

SNOW HYDROLOGY

SNOW COVER DEPLETION 1954 AND 1955

BOISE RIVER ABOVE TWIN SPRINGS, IDAHO
DRAINAGE AREA 830 SQUARE MILES

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

PREPARED: C.J.-R.M.	SUBMITTED: R.S.B.	TO ACCOMPANY REPORT DATED 30 JUNE 1956
DRAWN: B.V.	APPROVED: DMR	PD-20-25/45