The three Kings River precipitation-stations listed in the above snow-survey report are at elevations 6,775, 1,300, and 500 feet, so there might be some question as to the quantitative correction to apply to the snow-water content of April 1, on account of abnormally high or low precipitation during April at these low-altitude stations, to obtain points for the adjusted graph for May 1.

However, I think enough has been said to show that for this basin the snow-surveys afford a very good criterion for estimating the runoff during April to July.

Figures 3 and 4 show a very good correlation between distant valley temperature and the runoff resulting from an evidently nearly parallel temperature at the snow-fields, with a natural lag of a few days between a temperature high or low and the corresponding high or low runoff-rate. This relationship holds as long as there is sufficient snow left to have a pronounced effect on the runoff, even for several weeks after the peak-flow has been passed in the case of the year 1938. The lag as seen on Figure 3 seems to be less at times of high discharge than at low stage probably because of greater velocity of flow, requiring shorter time for the effect to travel down to the gaging-station.

The correctness of the statement in the third paragraph under "Water-conservation considerations" is not clear to me. For instance, referring to Figure 5, assuming total runoff during April to July to be 2,000,000 acre-feet and that, case 1, the flow does not fall below 10,200 second-feet until July 9 (similar to the year 1911) or, case 2, that with the same total during April to July of 2,000,000 acre-feet the flow drops to 10,200 second-feet by June 16. In the second case the peak-flow would probably be passed considerable earlier than in the first case. The danger of flood-rains would probably be passed by the middle of May. In order to be sure and have the reservoir full at the latest practicable date, could not the filling be started at a later date in case 1 than in case 2? Something would depend on the low point in the reservoir from which filling would start. But in case 1 where the flood-flow lasts until July 9 there should certainly be more remaining acre-feet left to flow after June 16 than in case 2. Then why should it be necessary to start filling earlier in case 1?

Such great difference in time of falling below the flood-stage would naturally be due to effect of temperature. Assuming normal spring precipitation in both cases, the shape of the thermograph would determine the shape of the hydrograph as in Figure 3. That being the case, if strongly subnormal temperature occurred in April and May indicating delayed melting and runoff, would that justify early filling of the reservoir if snow-surveys had given assurance of ultimate total runoff?

As a matter of fact, I believe that prolonged sub-normal temperature, -5°F or more, during May will result in some actual loss of surface-runoff.

The graphs of Figures 7 and 8 for hypothetical operation of the Pine Flat Reservoir for the year 1938 look reasonable, both leaving the reservoir full at the end of July, which should be expected in a high year as was 1938.

SOME ACCOMPLISHMENTS IN SNOW-SURVEYING

W. W. McLaughlin

Snow-surveying, as it is now understood, means a determination of the amount of water stored in the mountains in the form of snow and ice. The depth of snow and its compactness are incidental factors not essential in attaining the main objective.

The measurement of snow for the purpose of estimating the amount of water that would result from its melting has been made use of at various times for a long time. During the past 30 to 40 years occasional determinations of water-content of the snow have been made by means of melting samples. The so-called "stake" method of snow-surveying and the melting of snow-samples have been replaced by the present method known as the "course" method. In this latter method samples of snow are taken, by means of a hollow tube, through the full depth of the snowpack at approximately the same place each year and year after year. The core of snow is of such diameter that one ounce in weight of snow is equivalent to one inch in depth of water. In other words, the melting of the snow-samples is replaced by weighing the samples and the conversion of this weight directly into water-content.

Prior to the winter of 1935-36 snow-surveying by the course method was in progress in

California and parts of Nevada and Utah, with local measurements in two or three other western States. As of July 1, 1935, the Federal Congress authorized the Division of Irrigation of the United States Department of Agriculture to coordinate and extend snow-surveying and the forecasting of irrigation-water supplies to all western States. For the past eight years such coordinations and extensions of snow-course measurements into the eleven western States have been progressing, and cooperation has been effected with the western Canadian provinces. Exchange of data as between States and with Canada has been most effective. A picture of the general accomplishments to date shows that in the western States there are now 829 dependable snow-courses. There have been almost 1,000 courses, but the elimination of those which appeared to be unnecessary has reduced the present active number to 829. The number of measurements on each course averages at least 15, or about 12,500 measurements in all. There are 177 active cooperators with a minimum number of five in one State and a maximum of 28 in another. The snow-courses are measured three times each year in some States, four times in others, and five times in still others, complete measurements being made February 1 and April 1. Releases of snow-survey and water-supply information are made from two to five times in each State each year. There were 153 radio broadcasts this past year, giving information on water-supply and snow-conditions. In addition, information is furnished to the local presses and for release in Washington by the Federal Government. This past year there were 966 individuals who took part in snow-surveying as of February 1 and again as of April 1. The snow-surveyors have at their disposal 266 shelter-cabins, and of these 77 are owned by the Government. We stock with food, bedding, stoves, cooking utensils, et cetera, 115 shelter-cabins. Many of the snow-courses are so located that they are readily accessible to roads that are kept open during the winter, or near habitations where food and shelter are obtainable.

Prior to 1935-36 the equipment used in snow-surveying in the different States was of sizes, materials, and workmanship that accorded with the wishes of the State or local leaders. In some States there were from two to four different-sized snow-tubes made of steel, aluminum, or other materials. The water-content of the snow was determined by melting a sample and by weight and then converting the weight of snow into its equivalent in water. Under these conditions the data obtained in different States and in some cases within a single State were not interchangeable. One of the first efforts of the Division of Irrigation was to standardize the snow-tubes as to size and material so that equipment and data obtained from its use were interchangeable. Today all snow-tubes are made of duraluminum of the same dimensions, and the sections are interchangeable not only upon the same snow-tube but on any other snow-tube. There are two styles and sizes of scales--the tubular type first developed in Utah and the dial type developed in Nevada. However, since the units of weight are identical, the data are interchangeable. Each of these types of scales has its advantages and its disadvantages with respect to the other, and for the most part selection of one type in preference to the other has been decided on the basis of respective cost and weight.

High mountain ranges are often the source of streams that flow in opposite or nearly opposite directions and frequently into different States. In many instances, snow-survey data are obtained on both sides of these mountain ranges by a single snow-survey party, that is, within a State, and the results of these snow-surveys are sent to the proper State agency for forecasting the runoff. Frequently it is much easier for a snow-survey party from one State to make the snow-surveys in a part of another State. For instance, crews from Idaho, Montana, and Utah measure the snow in parts of Wyoming, but the main survey job is accomplished by Wyoming snow-survey parties.

In these days when aluminum and other critical materials are difficult if not impossible to obtain for snow-tubes, scales, and other equipment, there has been worked out an exchange of existing equipment which has enabled the work to be carried on up to the present time without too serious difficulties.

The first drought-conference, called as much as two to three months prior to the occurrence of the drought, was assembled in Utah in 1934 as the result of snow-surveys which indicated an extremely serious deficiency in the snowpack. The drought was not confined to Utah but extended to almost every western State, which stimulated inquiries from them relative to the prospective water-shortage. As the result of these deliberations, Federal and State funds were made available for the purpose of alleviating as far as possible the drought in Utah, Idaho, and Nevada. The extremely dry years of 1934 and 1936, coupled with the somewhat prevalent sub-normal snowfall for the seven-year period beginning in 1934, focused public attention upon the importance of knowing as much as it is possible to learn of the prospects for the season's water-supply in sufficient time to outline the season's agricultural program to conform to the water-supply. I think it is safe to say that as a result of snow-surveying on the intensified program beginning with the winter of 1935-36 there is hardly a person in the western United States interested at all in the utilization of water who does not look forward to our forecasts.

The forecasting of the water-supply of the West is a tremendous job and worthy of the combined efforts of all agencies that can contribute to the undertaking. It is believed also that when a person contributes to a program, whether it be much or little, he takes an intimate interest in it; and this has proved to be so. The Act of Congress setting up the snow-survey work had in mind a cooperative effort, for it provided that the Division of Irrigation should coordinate and extend existing snow-survey work. The policy of cooperation has been followed with very good results. At the last group meeting in Portland for the purpose of forecasting water-supplies in the Northwest, there were present as active participants from 50 to 75 persons, all extremely interested in contributing whatever they could to make the forecast most accurate and usable. As indicated in the forepart of this paper, there are this year 177 active cooperators contributing money, equipment, and time to the common cause.

When the so-called Mount Rose, later called the course-method of snow-surveying, was first advocated, its practicability and its accuracy were questioned, but in the past 30 years or more, it has demonstrated its utility and has produced reasonably accurate results in almost all cases. Today it is accepted as the standard method in each of the western States, although it is recognized that some of the natural factors affecting runoff from snowpack are not yet evaluated. For instance, the nature of the material that composes the earth-mantle on the watershed, together with its depth and topography, affects the capacity of the watershed to store the melting snow. The percentage of moisture in the earth-mantle is another prime factor influencing the runoff. We have made progress in our investigations into evaluating these factors but have still much to learn about them.

It is astonishing that such a variety of commercial and agricultural interests are concerned with water-supply forecasts, especially when a shortage of snowfall exists. We have inquiries from financial institutions, mercantile companies, eastern wholesale houses, power-companies, mines, municipalities, navigational interests, agriculture--including lumbering and stock raising--and many others. Many of the sugar-beet companies defer their acreage-contracts until the water-supply forecasts are made in order to guard against over-planting in relation to the water-supply available in the late irrigation-season.

Since so many persons are called upon to make snow-surveys each year entailing long and hard trips most of which may be accomplished only with snowshoes or skis, the safety of these men while engaged in this work is one of our first considerations. Certain rules have been promulgated. For instance, the men are not to venture out during periods of storm, and they are not to traverse known or expected snow-slide areas during the critical snow-slide period. The best of equipment is provided in the way of snowshoes and skis, proper clothing is prescribed, and as rapidly as possible cabins are being built where other shelters are not available. Where these cabins are not accessible to habitations, they are stocked with sufficient food and other supplies for a party of two persons for at least two weeks, and in some isolated areas a supply of four weeks for two men is stocked. The distance between shelter-cabins is determined by the terrain and the difficulty of travel. Emergency first-aid kits are also provided, and instructions are given as to their use. General methods for treatment of frost-bite, the prevention of snow-blindness, et al, are also outlined.

In recognition of the air-travel incident to military operations and by commercial air-lines, these shelter-cabins have been made available to the armed air-forces and to the commercial air-companies. On the inside and outside of the door of each shelter-cabin is a map indicating the nearest habitation and highway and directions are given on how it may be reached. One such map was the means of guiding to safety a party from a plane that was forced down in the wilds of Idaho. In another instance this past season, cabins were made available to searching parties in quest of planes that had been forced down.

Shelter-cabins are just what the name implies, that is, places where the snow-surveyors will find shelter and food. Summer homes are utilized when they are advantageously located, of course with the consent of the owner. Frequently mine buildings, lumber camps and sawmills, Forest Service and Park Service buildings, and such other structures as may be available are used. When no suitable building can be secured a cabin is built by the Division of Irrigation, either alone or in cooperation with the Forest Service. The material for construction is, for the most part, logs and other materials found locally, and only such material as can not be found in the hills is imported. One of the first experiences which has a marked influence on the design of cabins where the snowfall is deep was the difficulty of two of our snow-surveyors to find a cabin which they had helped construct. Some 18 or 20 feet of snow had completely covered the building, and only after what seemed to be hours of probing with the snow-tubes did they finally locate it. You can imagine the difficulty the men had in digging down and obtaining entrance through the door to the cabin. We now provide what is known as the Santa Claus chimney, which is in fact a shaft extending high enough above the cabin so as to be above the snow at all times, with doors that permit the men to enter the chimney and ladders that let them descend into the cabin. Another experience that almost resulted in the snow-surveyors having no food in the cabin was caused by porcupines eating their way through the wooden Santa Claus chimney and helping themselves to as much of the food as they could tear into. Suitable safeguards are now made to prevent recurrences of this kind. The cabins are stocked with food and other supplies in the summer and fall and are inspected each season. Food is left in shelter-cabins not longer than two years, and it is either replaced or used. Canned goods are protected by coating them with shellac. There has been little molesting of shelter-cabins as people realize the importance of these havens of refuge in the protection of human life.

One of the real difficulties that is much accentuated at the present time by the shortage of man-power is means of travel to out-of-the-way places. Snowshoeing is difficult and time-consuming. Therefore, some means of power-locomotion over mountains and canyons is most desirable. Two general types of power-driven transportation facilities are available; one type is the tractor, and the other the toboggan. Varying conditions of snow-cover make it difficult and in many cases all but impossible for locomotion by either of these means of travel. Fresh-fallen snow in very cold weather is fluffy and has little supporting power, and ski and propeller types of transportation bog down. In very cold weather the runners of the propeller-driven toboggan freeze to the snow and are very difficult to start. On crusted snow and steep side slopes, runners do not cut into the snow and the direction of travel may be sidewise down the slope rather than across it. Likewise when the snow is melting in the middle of the day a toboggan may settle so far into the snow that it is unable to push ahead through the snow.

To overcome most of these difficulties the Utah Agricultural Experiment Station and the Division of Irrigation adopted the tractor-type of snow-mobile. One of the first difficulties encountered was packing of snow on the inside of the track, sometimes breaking it. Likewise there is difficulty in guiding, for when one track stops and the other moves forward the latter tends to dig down into the snow. In the shops of the Utah Agricultural College a snow-mobile was constructed from scraps obtained in used-car lots. The results so far have been quite satisfactory. In a recent letter, Dean Clyde of the Utah Agricultural College writes: "I am convinced that this type of snow-transportation will successfully meet most of the conditions encountered in our snow-surveys, especially where the route follows a road or where the country is open so that close timber does not prevent passage. I believe that with the return of peace, when strategic materials again become available for research, this machine can be developed into an inexpensive, light but successful means of transportation on snow-cover."

We have had considerable experience with the motor-propelled toboggan. In writing of the experience the report reads: "The first time the machine was used was February 1. A heavy snowstorm had occurred a few days before the trip and was still in progress during the trip. After we had covered about two-thirds of the distance the loose, powdery snow reached a depth of about two feet. We had to lower the track about this distance below the toboggan and the effect was that we were unable to guide the machine. Whenever the road sloped sideways to any degree we could not keep the toboggan in the road. The work of getting off into the snow and pulling the machine into the proper position became so arduous that we finally abandoned it and made the rest of the trip on skis. The next trip was made on March 1, and at that time the snow was firm and we had absolutely no trouble making the entire trip on the toboggan."

Two years ago a propeller-type toboggan was used in the Jackson Hole country very successfully with the result that within two days a survey-party had accomplished work that had previously required eleven days.

Consideration has been given to the use of the airplane in making trips to out-of-the-way snow-courses. So far, however, we have been unable to locate suitable landing-fields close enough to the snow-courses. We are hopeful that some day we may be able to use the helicopter.

As a part of our research in snow-surveying we have given attention to various methods suggested for forecasting the ensuing season's water-supply. Some of these methods work successfully where the snowfall is about the same each year, but are not reliable at all where there may be a sub-normal precipitation one year and an above-normal high snowfall the next year. One of the methods to which we have given considerable attention and are still studying involves use of the stream-runoff for certain of the preceding months of the fall, with incorporation of certain snow-survey data. About 75 per cent of the time we have been able, with reasonable accuracy, to forecast the coming season's water-supply, but when the mark is missed there is no question about its being muffed. In some instances there may be a variation of nearly 100 per cent, but most frequently it will be 30 to 60 per cent, which, of course, is not much better than a guess. Attention has also been given to a comparison to ground-water elevations and the flow of natural springs as indices of what may be expected the ensuing year. Probably the greatest value of comparison of the flow of springs is to indicate the probable moisture-condition of the soil-mantle on the watershed. Other methods have been tried, and we are still testing suggestions as they are presented.

The forecasting of water-supply based on snow-measurements has received much attention, and in the Northwest and in Idaho, as well as to some extent in Colorado, Wyoming, and New Mexico, we have committees of people familiar with local conditions who assist in making the final forecasts.

Interest in this forecasting is extremely keen by those taking part. When a sizable error occurs, as it sometimes does in a forecast, it is the effort of everyone of the committee to find the explanation. This has resulted in ironing out many troublesome factors. Finally, each year we attempt to hold a conference of our survey-leaders from each State to discuss problems that arise through experience and for the general exchange of ideas among those actually guiding the snow-survey work.

It is not my purpose here to give many of the results of our forecasting, and we must keep in mind the fact that these forecasts predict only the amount of water which will be derived from the snowpack, assuming there is a normal precipitation during the spring months, that is, from April 1 to July 1. I can, however, give you an example or two. A year ago we were asked by the State officials of New Mexico to forecast the total runoff of the Upper Rio Grande into the Elephant Butte Reservoir. There was considerable river-rectification work in progress between the reservoir and El Paso; and if there was to be much of a spill from the reservoir, protective measures would of necessity have to be undertaken. Also, it was desired to have the reservoir full at the end of the spring runoff and meanwhile to release as little water as possible. To accomplish this end it was necessary to prevent an excessive amount of water from going over the spillway. Our forecast of the filling was 1,941,000 acre-feet. This forecast was made June 16, and late in August the Bureau of Reclamation office at Denver informed us that the actual peak-fill occurred July 4, at 1,938,000 acre-feet, a difference of only 3,000 acre-feet. Between June 16 and July 4 there was practically no rainfall, which accounts in part for our ability to forecast so accurately.

We made forecasts on the Columbia River at the time the Army Engineers were engaged in construction work in the vicinity of The Dalles, and we were able to predict the flow closely enough so that unnecessary protective work was avoided, as was also danger of excess water. In 1942 from April 1 to September 30, we predicted 70,000,000 acre-feet and the actual flow was 84,800,000 acre-feet. You will recall that the spring of 1942 was the occasion of much rain along the lower Columbia. Our forecasts of the flow of the river at Birchbank, British Columbia, for the period April 1 to September 30, and the actual flow in acre-feet, in round numbers, have been as follows:

Year	Forecast, acre-feet	Actual, acre-feet
1940	39,000,000	37,160,000
1941	35,000,000	32,264,000
1942	35,000,000	Actual figure not yet available
1943	41,000,000	?

Finally, and in order to make the forecasting of the season's water-supply as complete as possible, there has been injected into the information given in our forecasts for April 1 the amount of water carried over in storage in the more important and in many of the smaller reservoirs in each State. Also inaugurated this year has been an effort to indicate the available water in underground reservoirs. This will give a complete picture of the total water-supply.

U. S. Department of Agriculture,
Division of Irrigation,
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DISCUSSION

GEORGE H. CANFIELD (District Engineer, United States Geological Survey, Portland, Oregon)--The present procedure of making snow-observations and forecasts in this area is based on observations of snow-water storage made at courses at the beginning of each month from January to April. The Water Resources Review issued by the Geological Survey at Washington, D. C., for the six-months' period October 1, 1942, to March 31, 1943, contained a summary of water-contents of snow and forecasts of runoff. This report indicated that in the northeastern part of the country some forecasts were based on water-content of snow at time of maximum accumulation. It has occurred to me that it may be desirable in this western area to attempt to determine the time of maximum water-content of snow at a few selected courses. This maximum accumulation might occur within a winter or spring month and not be disclosed by the monthly observations. For lower altitudes in Oregon and in the Columbia River Basin, this time of maximum accumulation might occur in February or March and, at higher altitudes, sometimes as late as the middle of April.

I believe observations near the middle of March would be particularly desirable at a few representative stations, particularly at those below an altitude of 4,000 feet. I appreciate that, because of present shortages of labor, this additional work cannot be now undertaken. But in the future it might well be an objective to obtain two or three observations each month from February to April at a few key stations at various altitudes in order to more certainly determine the time and amount of maximum water-content in the snow-cover. Has anything been done along this line in this area by the Soil Conservation Service?

That's all I intended, an attempt to suggest at this time that at some future date, at a few selected courses, more frequent observations be made during those critical months of March and April.

In answer to Mr. McLaughlin's question why 4,000-foot elevation was chosen, I am thinking that at the lower altitudes in the Cascade and Coast ranges there might be an addition to the snow-cover during the first half of the month of February or March, with no snow on the ground at end of month. Also courses below 4,000 feet would be more readily accessible for additional visits and snow-measurements. It would be desirable to extend these more frequent snow-observations at a few key stations at all altitudes.

In the Blue Mountains, as was suggested by Mr. Work and Mr. Marr, some of the runoff from snow-melt may occur during the middle of February from the Silvies River and other streams in that area. The maximum discharges on most streams draining the Blue Mountains this year reached their peaks about the middle of April; that on the Crooked River near Cove occurred at the beginning of April. Because of the cool spring the runoff has been later than usual this year.

R. A. WORK (Irrigation Engineer, United States Division of Irrigation and Oregon Experiment Station, Medford, Oregon)--I think Mr. Canfield's suggestion is well based for this reason: We tentatively have found that on many streams in Oregon the best estimate of snow-melt runoff is often developed by use of the maximum snow-accumulation figure for the winter regardless of whether that accumulation occurred during the middle of February or at the first of May. To that extent Mr. Canfield has substantial argument to back his proposal, but on the other hand we are distinctly limited in the making of such frequent observations by some of the factors that Mr. McLaughlin has spoken of, such as shortage of funds and personnel, difficulties of transportation, inaccessibility of these places, and so forth. I will go on record as concurring most heartily with Mr. Canfield's suggestion concerning need of more frequent observations.

BERTRAM S. BARNES (Regional Engineer, United States Weather Bureau, San Francisco, California)--Mr. Codd has assumed that all of us know that a snowflake is composed of little hollow tubes. You can have two snow-crystals that look very much alike when seen side by side, yet actually they may be widely different. One may be practically filled with water and the other might be filled with air. In other words, you would have one dry and one wet flake and find that externally they would appear to be the same. The difference is in the "quality" of the snow. There is, therefore, a variation in the number of British thermal units required to melt a given weight of snow.

PRECIPITATION-RUNOFF RELATIONSHIPS AS A BASIS FOR WATER-SUPPLY FORECASTING

George D. Clyde and R. A. Work

Early history of snow-surveys--Measurements of snow-water content have been made by scientists and others for more than 40 years. The earliest reported measurements were made by CHARLES A. MIXER at Rumford Falls, Maine, in 1901. Mixer used a tube to cut out a sample of snow which he weighed to determine its water-content. Later, in 1903-1904, ROBERT E. HORTON at Utica, New York, developed a tube for cutting snow-samples and these samples were weighed to determine the water-content. Horton's tube was 5.94 inches in diameter and five feet