

## HISTORY OF SNOW SURVEYING IN THE WEST

by

Harlowe M. Stafford <sup>1/</sup>The Pioneer

In the winter of 1895 a young professor of the classics, newly arrived from the University of Michigan, braved the snows and climbed to the 10,800-foot summit of Mt. Rose overlooking Reno on one side and Lake Tahoe on the other. That climb was made because this individual was an enthusiastic winter mountaineer, but as it turned out later, it was in reality the beginning of a life work.

That climber was Dr. James E. Church of the University of Nevada and the life work which had its inception then was the study of snow in all of its phases.

In order to get an observatory on Mt. Rose, Dr. Church, in 1906, offered to climb the mountain every month for a year to obtain temperature readings. The U. S. Weather Bureau furnished the thermometers and the project began. Subsequently the observatory was made a department of the University of Nevada and the Agricultural Experiment Station, and with financial assistance from the Adams Fund the initial research project became the study of "The Effect of Mountains and Forests on the Conservation of Snow".

The Beginning of Snow Surveying

In the succeeding 10 years, automatic recording instruments were developed and installed at the observatory to obtain records of pressure, temperature, humidity, wind movement, precipitation, and sunshine; the Mt. Rose snow sampler and scale were developed as early as the winter of 1908-09 to determine the water equivalent of the snow deposited on the ground; and by 1914 a very considerable body of data concerning the climate of a mountain peak in the Sierra had been assembled. Then, in 1914, because the Experiment Station was basing all of its new program of research upon primary problems in Nevada agriculture, a single aspect only of the study of mountain weather and climate was selected as having genuinely important agricultural relationships and possibilities. That aspect was really an offshoot from the main project and consisted in a method of measurement of depth and water content of snow which made it possible to make rather accurate predictions of the quantity of snow-melt runoff to be available for irrigation during the ensuing season. The project leader, Dr. Church, was therefore asked to center all efforts upon the perfection of this method and he was given two years in which to do it. Here, then was the beginning in the west of snow surveying for the forecasting of runoff. And because it was only the successful development of a snow sampler that would measure the water content in extreme depths of snow, it is fitting that we should date the beginning of snow surveying as 1909, the year of the design and successful use of the Mt. Rose Snow Sampler. Hence, we are now, in 1959, observing the fiftieth anniversary of the beginning of snow surveying.

First Application to Forecasting

The first application of snow surveying to forecasting was in forecasting the rise of the water level in Lake Tahoe, thereby ending the so-called Tahoe War. The waters of the lake are controlled by a dam first built in the 1870's and located at the lake's outlet into the Truckee River. Water is released at the outlet gates for downstream power development and for municipal and irrigation rights. Because in some years the snow runoff caused a rise in the lake that flooded the lakeshore dwellers, the latter about 1909 issued an ultimatum to the Power Company that the water of Tahoe must be drawn down low enough each fall that the next spring rise could not possibly cause flood. The Engineer of the Company appealed to Dr. Church for permission to compare his snow data with past lake levels. A good correlation was found between water content of the snow on Mt. Rose and the spring rise of the lake; a better correlation subsequently was developed with additional snow measurements at other locations around the lake; the Power Company was enabled to regulate releases to prevent both flooding and waste of water; and the "war" was over.

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<sup>1/</sup> Supervising Hydraulic Engineer, California Department of Water Resources, Sacramento, California.

In passing it is interesting to note that in a paper by Dr. Church on "Snow Surveying" published in 1917, the forecasts of the lake rise were found to be within 10 per cent of the actual rise in the years 1910 through 1915. In 1916, however, the actual rise exceeded the forecast by 29 per cent.

#### California's Initial Project

As the success of snow surveys in the forecasting of runoff became known, the State of California early recognized the great value that such forecasts could be to the irrigation interests in the Sacramento and San Joaquin Valleys. And through the efforts of the late Major Paul M. Norboe, who was Chief Assistant State Engineer, the Department of Engineering in 1917 was authorized by the State Legislature to engage in this activity. One of the first problems encountered was that of obtaining the necessary equipment - the snow samplers and scales - and this difficulty and the start of the snow surveys are well described in the Biennial Report of the Department of Engineering for 1916-18 as follows:

"Upon taking up the subject, it was found that some of the instruments required are not made by any manufacturer and can only be obtained by having them made to order. Under war conditions, it was found impossible to have this done. Fortunately however, through the good offices of Professor Church, the Department has secured enough apparatus (and practically all there is in the United States), to enable investigations to be made upon the headwaters of about seven of the principal streams of the Sierras, four of which run into the Sacramento and San Joaquin Valleys, and three into the irrigated districts of Nevada.

"Tentative agreements have been made for the cooperation of the United States Forest Service, U. S. Weather Bureau and Reclamation officials, as well as of some large users of water in the territory named. Professor Church has generously placed his knowledge and experience at the service of the Department, and it is felt that it is engaging upon a line of research that will result in very great good."

Thus, in cooperation with the State of Nevada, snow surveys were carried on for several years in the watersheds of Yuba, Truckee, Carson, and Walker Rivers. In 1923, however, this work, as a State of California activity, was discontinued because of a lack of funds.

#### Events from 1917 to 1929

From 1917 until 1929, when snow surveying again became an activity of the State of California, the most significant events with respect to snow surveys and runoff forecasting in the west appear to have been: The establishment of the Nevada Cooperative Snow Surveys in 1919; start of the Jackson Lake, Wyoming, snow surveys by the United States Reclamation Service in 1919; initiation of snow surveys in Coeur d'Alene Basin in 1920 and subsequently in Lake Chelan Basin, by Washington Water Power Company; establishment of the Utah Cooperative Snow Surveys in 1923; start of snow surveys in the Owens River Basin of California by the Los Angeles Department of Water and Power in 1925; and beginning of the Oregon Cooperative Snow Surveys in 1928.

#### The Utah Snow Sampler

In connection with the Utah Cooperative Snow Surveys, it should be noted that in the early 1920's Professor George D. Clyde of Utah Agricultural College (the present Governor of the State of Utah), had developed a snow sampler that was somewhat lighter than the Mt. Rose sampler. It had a cutter which cut a core of snow 1.485 inches in diameter. And because a cylinder of water 1.485 inches in diameter and one inch long weighs just one ounce, it was possible to use commercial scales in determining the water content of the snow. The use of this size of cutter subsequently was adopted by the Division of Irrigation of the Soil Conservation Service although the latter developed and used cylindrical scales with two different capacities to cover the range of samples from small snow depths to depths of more than 20 feet.

#### Nevada Cooperative Snow Surveys

With the establishment of the Nevada Cooperative Snow Surveys, the Nevada snow surveys covered courses in the Truckee, Tahoe, Carson and Walker River basins, including the courses in those basins in California. Dr. Church was chairman of the first Nevada Forecast Committee, and the other members

of the committee were George G. Devore, of the Sierra Pacific Power Company, and the late Leigh Sanford of the Reno Evening Gazette. After 1928, at Dr. Church's insistence, chairmanship of the committee was assumed by H. P. Boardman, Professor of Civil Engineering at the University of Nevada, who had long been associated with Dr. Church on the snow survey and forecast activities. Dr. Church then took over direction of snow surveys and forecasting in the Humboldt Basin and other regions in Nevada. Professor Boardman remained as chairman of the Forecast Committee through 1947.

#### Return to Snow Surveying in California

The return to snow surveying as an activity of the State of California came about in 1929 through the efforts of the California Economic Research Council of the State Chamber of Commerce. The California Legislature in that year appropriated \$15,000 to organize and carry on this work and this function was assigned to the State Engineer's organization, the Division of Water Resources. During the summer and fall of 1929, 150 snow courses throughout the Sierra from the Upper Sacramento River basin on the north to the Kern River basin on the south were established, the necessary preparations in the way of stocking shelter cabins and providing equipment for the surveys were made, and arrangements were completed for the surveys to be made largely through the cooperation of agencies such as public utilities and irrigation districts who had employees located in the mountains in connection with their regular duties. In the following spring of 1930, a "Monthly Bulletin of Snow Survey and Precipitation Data" issued on February 1, marked the first of this series of bulletins of snow survey data and forecasts of runoff which have been issued, nearly every year since that time, and which now are titled "Water Conditions Reports". In the first forecast of April-July runoff issued on April 1, 1930, forecasts were possibly only for South Yuba River Basin, Tahoe Basin, and Truckee, Carson, and Walker River Basins, because only in those basins had the surveys been carried on long enough to develop "snow-course normals". The estimates for the eastern slope basins were made by the Forecast Committee of the Nevada Cooperative Snow Surveys through the cooperation between California and Nevada. Although in the other stream basins practically all of the snow courses were newly established, it is interesting to note that by some means or other "normals" had been developed for a few courses in several basins and the "water content in per cent of normal" was reported for these courses.

#### Committee on Snow of American Geophysical Union

An event of great significance in the history of snow surveying that took place at about this time was the establishment in 1931 in the Section of Hydrology of the American Geophysical Union of a Permanent Committee on the Hydrology of Snow, with Dr. Church as Chairman. Dr. Church remained as Chairman of this Committee through 1944, and it is through his annual reports of the activities of the Committee, as published in the Proceedings of the American Geophysical Union, that we can trace much that is of importance not only to the history of snow surveying but to all phases of snow research.

#### Western Interstate Snow Survey Conference

Thus, in the second annual report of this Committee, the report for the year 1932-33, we find an account of another event that was a milestone in the history of snow surveying - the first meeting of the Western Interstate Snow Survey Conference, forerunner of the present Western Snow Conference.

In the words of Dr. Church:

"Through the enthusiasm of Professor George D. Clyde, eastern Great Basin representative on the Committee, and quite contrary to the tendency set by the depression, a personal conference on research problems expanded into an Interstate Conference on snow surveying embracing all of the central and northern states from the Great Divide westward to the coast. The response was eager and the interests unexpectedly wide. Personal representatives from Utah, California, and Nevada met at the Nevada Agricultural Experiment Station, the pioneer in western snow surveying, on February 18, 1933, as guests of the University of Nevada. There was a registration of 30 from Nevada, 8 from California, and 2 from Utah. Representatives from southern California were blocked from attending by snow."

"At the conclusion, it was voted that the Conference should be made an annual meeting to be designated as the Western Interstate Snow Survey Conference and that future conference arrangements and publication of proceedings should be in the hands of an Executive Committee of five, elected each year. It was desired that the representation on the Executive Committee should be as wide as possible and the following were elected for the first year: Harlowe M. Stafford, Chairman, Snow Supervisor, Division of Water Resources, California State Department of Public Works; J. E. Church, Meteorologist, Nevada Agricultural Experiment Station; George D. Clyde, Professor of Irrigation and Drainage Engineering, Utah Agricultural College; W. C. Lowdermilk, Senior Silviculturist, U. S. Forest Experiment Station, Berkeley, California; and V. H. Greisser, Chief Engineer, Washington Water Power Company."

Because the subsequent history of the Western Snow Conference is practically synonymous with the history of snow surveying in the west, this paper, from this point, is largely a statement of outstanding events and highlights taken from proceedings of the snow conference as well as from reports of the Committee on Snow of the American Geophysical Union. Perhaps the paper might just as well have been titled, "History of the Western Snow Conference".

#### Status in 1935

In the report of the Committee on Snow for the year 1934-35, interesting items on the status of snow surveying are noted as follows:

"Utah now has a state-wide network of snow courses - 65 in number. These courses, for the most part, are located above 8,000 feet elevation. The courses are surveyed by various cooperating agencies consisting for the most part of United States Forest Rangers, United States Park Rangers, irrigation company officials, and officials of municipalities. The work is conducted under an informal cooperative agreement between the Utah Agricultural Experiment Stations, the United States Forest Service, the United States Weather Bureau, and the Utah State Engineer."

"In Nevada, State cooperation has been restored by the passing of a legislative appropriation of \$1,000 for snow surveying and \$1,500 for stream gaging. Snow Surveys in the Sierra Nevada this present season were supported by a Federal Emergency Relief Administration allotment from unexpended drought-relief funds. Snow surveys in the Humboldt Basin were supported as usual by the State Engineer from funds for the distribution of Humboldt waters and an appropriation by the Nevada Agricultural Experiment Station for research in improving stream flow forecasting."

"The Status of snow surveying in California during the past year has been practically the same as reported for the previous year, 1933-34. Since July 1, 1933, the State has had no appropriation for continuing its cooperative work and the surveys that have been made have been carried on by agencies which were formerly cooperating with the State. Although some of these have faithfully continued the program originally set up, many others have only partially continued the program or have completely abandoned it. There is great need, therefore, for a resumption of the state's supervision, correlation, and financial assistance if the successful beginning and program of the initial four-years effort up to 1933 are not to be gradually lost."

"The Western Interstate Snow Survey Conference met in affiliation with the Western Meeting of the Section of Hydrology, American Geophysical Union, at the Pacific Coast session of the American Association for the Advancement of Science held at Berkeley, California, June 12-17, 1934. James E. Jones, City of Los Angeles Department of Water and Power, was chosen as Chairman of the Executive Committee for 1934-35."

#### Events Reported in 1936

Significant events in the report of the Committee on snow for 1935-36 were establishment of the Federal-State Cooperative Snow Surveys and full resumption of California Cooperative Snow Surveys as a state-supported activity.

### Federal-State Cooperative Snow Surveys

Built upon the foundation of the State Cooperative Snow Survey systems of Nevada, Utah, California and Oregon, the Federal-State Cooperative Snow Surveys was established in 1935 by an Act of Congress with an initial appropriation of \$15,000. Authority was given to the United States Bureau of Agricultural Engineering acting through its Division of Irrigation to cooperate with all agencies engaged in snow surveying, to coordinate so far as possible the work of all such agencies, to fill in gaps and set up such new snow courses as might be necessary, and, in so far as funds permitted, to make the runoff forecasts cover the arid region. It should be noted, in passing, that the successful establishment of the Federal-State Cooperative Surveys was due in large measure to the work of W. W. McLaughlin, then Chief of the Division of Irrigation. By the spring of 1936 the snow survey system was extended from the four original states to Idaho, Montana, Wyoming, and Colorado, and the first snow surveys were made. Broad cooperation was established not only with the states and their cooperating units but also with the National Forest Service, National Park Service, Bureau of Reclamation, Corps of Engineers, Geological Survey, and Weather Bureau.

### New Life to Snow Surveys in California

As the result of a 1935 appropriation by the California Legislature, the California Cooperative Snow Surveys as a State activity were resumed in September, 1935. During the period from June, 1933, to September, 1935, there was no state money to carry this project but due to the fact that many of the cooperating agencies continued to make the surveys using the state equipment permitted to remain in the field, the loss of records was not as great as might have been anticipated. Although the appropriation was only about one-half of the former amount, the project was re-established in good shape with greater contributions in some instances on the part of the cooperating agencies. Additional cooperation that helped substantially in re-establishing the work, was that of the Division of Irrigation under its Federal authorization to establish the Federal-State Cooperative Snow Surveys.

### Snow Courses in Upper Columbia River Basin

Another significant event in the Committee's report for 1935-36 was the establishment and survey by the Water Rights Branch of British Columbia of a number of snow courses in British Columbia. Seven of these courses were established in the Upper Columbia River Basin.

### Joint Meetings of Snow Conference and Hydrology Section

The 1935-36 meeting of the Western Interstate Snow Survey Conference was held at the California Institute of Technology at Pasadena, California, January 31, 1936, in affiliation with the West Coast Regional Meeting of the Hydrology Section of the American Geophysical Union.

This mutually advantageous arrangement of meeting jointly with the West Coast Meeting, or as it became later, other regional meetings of the American Geophysical Union, was continued from 1936 through 1947. Meetings held jointly with the South Pacific Regional meeting of the Section of Hydrology were held at Davis, California, January 8, 1938; at Los Angeles, December 16-17, 1938; at Stanford, January 12-13, 1940; at Sacramento, January 16, 1941; at Pasadena, January 16, 1942; at Berkeley, February 17-18, 1944; and at Sacramento, February 27, 1946. Meetings jointly with other regional meetings of the Section of Hydrology were those with the South Continental Divide Region at Denver, June 25-26, 1937; with the North Continental Divide Region at Spokane, December 28, 1938; with the North Pacific Coast and the North Continental Divide Regions at Seattle, June 19-20, 1940; and with the North Pacific Coast Region at Corvallis, Oregon, June 16, 1943 and Portland, Oregon, April 21-22, 1947.

With one exception, all of the meetings through the Pasadena Meeting in 1942 were reported as meetings of the Western Interstate Snow Survey Conference; at Denver, in 1937, the meeting was designated as the South Continental Divide Snow Survey Conference. At the Corvallis Meeting in 1943, pursuant to a suggestion by Fred Paget, then Chairman of the Executive Committee, the Conference voted to shorten the name to the Western Snow Conference, and that has remained as the name of the Conference to the present time. The papers and full proceedings of all of the meetings held jointly with the Section of Hydrology through the Berkeley meeting in 1944 were published in the Transactions of the American Geophysical Union. Only selected papers from the 1945, 1946, and 1947 meetings were published in these Transactions.

### Regional Organization of Conference

The various regional meetings with the Section of Hydrology, and the regional designations used by the Section lead to a proposal of by-laws for the Conference providing for an expanded Executive Committee consisting of not more than 20 members with not more than 5 members to be elected from each of four regions corresponding to the divisions of the Western States and adjoining Provinces of Canada used by the Section of Hydrology. These By-Laws, which were adopted by the Conference at the meeting at Stanford in January 1940, established the four regions for election and assembly purposes as: (1) North Continental Divide Area, (2) South Continental Divide Area, (3) North Pacific Area, and (4) South Pacific Area.

### Joint Meetings with Colorado and Columbia River Forecast Committees

Beginning with the meeting at Reno April 15-17, 1948 and continuing to the present time, the meetings of the Conference have always been held in April in conjunction with the meeting of either the Colorado River Forecast Committee or the Columbia River Basin Forecast Committee as the place of meeting dictated. Also beginning with the Reno meeting in 1948, the proceedings have been published separately each year by the Executive Committee of the Conference. For the proceedings of the Reno meeting, the Conference received generous financial support from the Nevada Agricultural Experiment Station. A highlight of the Reno meeting was the presentation by the Conference of a medal to Dr. Church, "In Appreciation of Attainment in Snow Surveying". Following Reno in 1944, the meeting places in chronological order were, Denver, Boulder City, Victoria B. C., Sacramento, Boise, Salt Lake City, Portland, Penticton B. C., Santa Barbara, Bozeman, and now, Reno again.

### Sources of Historical Data

In the records of the Committee on Snow and the Conference Proceedings, many more important items in the history of snow surveying in the west are found than could possibly be included within the limitations of this paper. For example, the Proceedings and "The Snow Surveyors' Forum", an annual publication of the Conference dedicated to the field man and first issued in 1946, are replete with the development and great improvement over the years in snow sampling equipment, snow sampling procedures, maintenance of snow courses and facilities for snow surveys, transportation - from the old tough ski trips to helicopter and plane travel - and techniques of forecasting the runoff. Faced with the necessity of selection, I have chosen to touch on the highlights of (1) progress in techniques and methods of forecasting, and (2) the general expansion of snow surveying throughout the west.

### Progress in Forecasting Techniques

At the meeting of the Conference at Davis in January 1938, progress in the technique of forecasting was presented in a paper by Fred Paget describing the so-called "Direct Method". In the early days of forecasting the April-July runoff in Nevada, California, and Utah, the "Percentage Method" was employed. That is, as soon as April 1 normals for the water content at the snow courses in a basin could be developed, the water content in percent of normal for the forecast year was determined for the basin, generally as a weighted average by elevation zones, of the percentages of normal found by the surveys at the individual snow courses. This same basin water content percentage was then applied to the normal April-July runoff at the stream gaging station below to derive the forecast of the snow-melt runoff.

As Paget explained, because it afforded a better basis for accurately modifying the original forecasts for abnormal precipitation during the early runoff period, California had modified the basic method of working from a percentage of normal and had developed the so-called "Direct-method curves". These curves were simply an expression of the direct relation between weighted mean snow-pack water content and April-July full natural flow which most forecasting agencies subsequently adopted.

### Soil Moisture Studies

As the next highlight in forecasting methods, I would mention the paper presented at the Seattle meeting in 1940 by then Dean George D. Clyde on "Soil Moisture Studies as an aid in Forecasting Runoff from Snow Cover".

### Snow Survey Forecasts in Multi-purpose Reservoir Operation

Closely following Clyde's paper, was the paper presented at the Sacramento meeting in 1941 on "The Use of Snow Survey Predictions in the Operation of Combined Flood Control and Conservation Reservoirs for Regulation of Snow-Melt Runoff", by Arthur C. Showman. This excellent paper was the first of a series which developed to a very high degree the involved procedures to accomplish optimum multi-purpose reservoir operation in the regulation of snow-melt runoff. The second and third papers in this series were, "The Use of Snow Surveys as an Aid in Flood Control Operation of Reservoirs" by Fred Paget, presented at the Corvallis meeting in 1943 and a paper with the same title, which was a discussion of Fred Paget's paper, presented at the Berkeley meeting in 1944 by Francis G. Christian.

In his paper, Paget presented the correlation between snow survey measurements and runoff on the Kings River, and using this stream as an example, showed how advance information as to snow-melt runoff might be applied to the dual problem of flood control and water conservation in operation of the Pine Flat Dam on the Kings River. A critical element in the procedure was accurate determination of the time at which the runoff changed from an upward trend to a downward trend. For this purpose, Paget used thermo-hydrographs plotted from both daily data and 10-day running means. In his paper, Christian pointed out that from the thermo-hydrographs the decline in runoff could not be recognized until 15 to 20 days subsequent to the peak flow, and that in the case of storage for irrigation supply such a delay might mean that the reservoir would fail to fill when it otherwise could have. Christian then presented several valuable techniques for recognizing the start of the decline in runoff, the use of which it was indicated would shorten the time from beginning of the decline to time of recognition by some 33 to 75 per cent.

Subsequent papers which further developed the use of forecasts in flood control operations were "Use of Inflow Forecasts in Operation of Hoover Dam and Lake Mead for Flood Control", by Frantz R. Lupton, presented at the Boulder City meeting in 1950, and "Use of Snow Surveys in Planning Regulation of Columbia River Floods", by R. A. Work, H. G. Wilm, and M. W. Nelson, presented at the Victoria meeting in 1951.

#### Additional Factors Considered in Forecasts

Continuing the improvements in forecasting techniques, were the papers, "Adjusting Forecast Curves for Abnormal Spring and Summer Temperatures", by R. A. Work, presented at the Berkeley meeting in 1944, and "A New Forecasting Curve for the Kaweah", by Fred Paget, presented at the Portland meeting in 1945. In the latter paper, Paget developed the curve expressing the April-July runoff of the Kaweah River as a function of April 1 water content of the snow, spring precipitation, and soil-moisture deficiency in the fall. A novel feature of the soil-moisture deficiency factor was its determination by the fall precipitation prior to the accumulation of continuous snow cover.

Other curves by which additional factors affecting the forecasts were taken into account were presented at the Boulder City meeting in 1950 in Fred A. Strauss' paper, "A Revision of Forecasting Methods as Practiced by the California Cooperative Snow Surveys". Utilized in developing these curves were April 1 snowpack indices with corrections for precipitation during runoff, for basin stream flow where necessary, for a temperature-runoff efficiency factor, and for soil priming.

Finally, the culmination of forecasting improvements appears to have been reached with the presentation of two papers, one by J. F. Hannaford at the Penticton meeting in 1956, "Multiple-Graphical Correlation for Water Supply Forecasting", and the other by J. F. Hannaford, C. G. Wolfe, and R. W. Miller at the Bozeman meeting in 1958, "Graphical Method for Determination of Area-Elevation Weighting of Snow-Course Data". Salient features of the multiple-graphical correlation techniques were shown to be (1) the family of curves for each of the parameters: April 1 basin snowpack index, October 1 - April 1 runoff, Basin antecedent conditions index, and Basin April - June precipitation index, and (2) the expression of the April 1 basin snowpack as a dimensionless quantity, a "percentage of normal" index, generally derived as the arithmetic average of water contents for several selected snow courses in the basin. Although this would appear to be a return to the "percentage" method of the earlier days, its use in the new forecasting scheme was for a quite different purpose.

By the development of a weighted snowpack index as described in the paper presented at Bozeman, the authors were able greatly to improve the Multiple-Graphical Correlation forecasts for the reason that the weighted snowpack index can be computed with a minimum of data, if necessary, (for example, when the measurements for several courses in the basin are not available) but still it can accurately portray the snowpack distribution over the basin.

### General Expansion of Snow Surveying

And now for a few concluding items on the general expansion and advancement of snow surveying in the west, we turn again to reports of the Committee on Snow and to Conference Proceedings. I cannot refrain from quoting the following choice bit by Fred Paget in his report to the Conference, as Chairman of the Executive Committee at Pasadena in 1942:

"Another advance during the year was the origination and acceptance (in some quarters) of a new word for snow surveying and snow surveyors. The word is compounded from two Greek words nipho meaning snow and metrology, the science of weights and measures. Snow surveying thus becomes Niphometrology and a snow surveyor becomes a Niphometrologist".

### Increased Acceptance of Snow-Survey Data and Forecasts

In his report to the Conference at Berkeley in 1944 Paget said, "By and large the fact that dependence can be placed on snow survey information is gaining more and more ground. Most of the water-using organizations are beginning as a matter of course to accept and rely on snow survey information as an index of the prospective water supply. The Snow Conference is growing in favor. It is becoming easier to secure both moral and financial support for our efforts. The path of the Western Snow Conference has developed from a winding rocky trail to a broad, paved highway going places".

### Dr. Church's Adventures in Foreign Lands

The first chairman of the Committee on Snow to follow Dr. Church was R. C. Farrow, Chief Hydraulic Engineer of the Water Rights Branch, Victoria, British Columbia, who took over when Dr. Church was on his famous adventures in foreign lands. Concerning the latter, Farrow wrote in his committee report for 1947-48:

"An epic - James Church, tireless and apparently ageless, returned in the late spring of 1948 after establishing snow-survey systems in the Himalaya and the Andes throughout 1947. During March, April, and May, 1947 he traveled over 300 miles on horseback mostly on Himalaya Yak trails, starting snow surveys at 17,000 feet elevation. By June he was in New Delhi producing a book-size report. August 1947 found him in Argentina planning snow surveys for the Government. By September he had flown the Andes from end to end, his pilot claiming it to be the first such flight on record."

### West-wide Availability of Snow-Survey Data and Forecasts

In a paper on "Benefits of Snow Surveying" presented at the Victoria meeting in 1951, George D. Clyde and Clyde E. Houston at that time Chief and Irrigation Engineer, respectively, of the Division of Irrigation, Soil Conservation Service, pointed out that snow survey and water supply reports were available monthly beginning January 1, through the winter season for the following states, drainage basins, or provinces: Arizona, British Columbia, California, Montana, Northern Wyoming and upper Missouri River Basin, Oregon, Nevada, Utah, Colorado River Basin, Columbia River Basin, Platte and Arkansas River Basins, and Rio Grande Basin.

### Coordinated Federal-State Water Supply Forecasts

In 1953, at the Boise meeting, Arch Work, then Supervisor of Snow Surveys for the Western States for the Soil Conservation Service, told of the new program of coordinated Federal-State water supply forecasts. Under this revised forecasting arrangement, which became effective January 1, 1953, the Weather Bureau, Soil Conservation Service, and the California Division of Water Resources, predecessor of the present Department of Water Resources, continue to issue their respective water-supply forecast and snow-survey water forecast publications after prior collaboration among the respective agencies. And the Bureau's "Water Supply Forecasts for the Western United States", published monthly from January through May, contains all of the forecasts made by all three agencies.

### Use of Aerial Photographs of Snow-Depth Markers

Also at the Boise meeting, T. J. Henderson of the California Electric Power Company, told of the initiation by his Company of the use of aerial photographs of snow-depth markers in water-supply forecasting. By 1953 the Company had established a total of 17 markers at an average



elevation of 11,000 feet in its watersheds on the eastern slope of the Sierra. The Southern California Edison Company and the California Division of Water Resources also had become interested in this method of evaluating snowpack conditions, and in 1951 and 1952 the Edison Company installed 12 aerial markers in the upper San Joaquin River Basin and the Division installed 23 markers in the western slope watersheds of the southern Sierra. A cooperative program had been effected whereby the aerial markers of all three groups were photographed as a unit and the data made available to all organizations affected by the runoff from the watersheds concerned.

#### Boise Meeting Highlight

Incidentally, it should be recorded that the Boise meeting was notable for another reason - the first presentation of the "El Farsante" award which has since become an annual affair.

#### Snow-Survey Activities of the Soil Conservation Service

In the 1950-51 report of the Committee on Snow, Arch Work summarized the progress of the snow survey activities of the Soil Conservation Service in these words:

"The program of snow surveys was expanded, notably in Montana in collaboration with Montana Experiment Station, U. S. Bureau of Reclamation, and the U. S. Forest Service, and also in Colorado. During 1950-51, in all of the western states, nearly 900 men measured more than 1,000 snow courses. In collaboration with Utah Experiment Station, research is being continued to delineate factors other than snow which affect the snow cover-runoff relationship. Arrangements have been made for the establishment, for the Bureau of Reclamation, of snow courses in Eklutna and Swan Lake drainage basins in Alaska".

#### Extended Snow Surveys in British Columbia

Appropriately coupled with Arch Work's last item pertaining to snow courses in Alaska, is the following report for 1955-56 by J. H. Doughty-Davies (Water Rights Branch, Department of Lands and Forests, Victoria, British Columbia) to R. A. Work as Chairman of the Committee on Snow:

"The snow surveys have expanded from the Columbia, Kootenay, and Okanagan River basins to include the Fraser River basin. The runoff for the Fraser River at Hope is now forecast. This brings the total number of river runoff forecasts to sixteen".

#### What of the Future?

We have traced the history of snow surveying and water-supply forecasting from small beginnings to the important place they occupy in our present-day life in the west. With each major advancement in knowledge, technique, and methods we have perhaps thought, "this is really the ultimate, the last word", but each time a new horizon appears and there is a new goal to be attained. And so now, although we may think that surely the top has been reached, let us not forget that the electronic age has just been entered, and who can say what wonders of snow surveying and miracles of forecasting may not lie ahead.

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#### DISCUSSION

W. A. Lang, Chief Hydrographer, Southern California Edison Company, Los Angeles, California.

I was very happy to hear that Mr. Harlowe Stafford had written a paper on the history of snow surveying and equally pleased that I had been asked to discuss it. I believe that Harlowe has done an excellent job of presenting the background and history of snow surveying and is to be highly commended for the manner in which he has so ably assembled and presented his material.

Of course, everyone realizes that no one person could prepare such a history without later hearing that he had omitted mentioning some detail of interest to the critic. For this reason I should like to contribute some material to supplement Mr. Stafford's remarks. My material will primarily cover the period between 1914 and 1930, when progress was being made but the history is either sketchy or lacking, and also the period subsequent to 1945, otherwise known as the electronic age.