many other agencies have begun a program in which each basic datum is being carefully analysed to determine its reliability as an index before it is included in the final multiple regression study. The final forecast equations may very well consist of 7 or more independent variables which will be selected on the basis of combinations determined as most reliable by statistical procedures. This type of detailed study, which would be impossible to make without the use of a digital computer, will certainly improve present forecast procedures. Therefore, it is my opinion that the culmination of forecasting improvement is still a goal of the distant future. In fact, Mr. Stafford very aptly states this himself at the end of his paper when, in discussing the future, he says "... 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."

In the course of my search through the old archives, I also noted that seasonal snow-rain gages were devised and, as early as 1912, installed at several remote locations in the upper San Joaquin and Kern River basins. Essentially, these consisted of fifty-gallon drums with an eight-inch standpipe. The standpipes were cut long enough to extend above the maximum snow line when the drum was buried below the frost line. Who knows but that these crude seasonal gages were the progenitors of the Sacramento gage we use today. Even though they were later used to check the water content of the snow surveys at certain locations, they, like snow surveys, were primarily used as an index of the watershed water supply.

There are at least two recent advances in securing basic data for runoff forecasting that were not mentioned by Mr. Stafford. One of these is determining the soil moisture content by use of electrical resistance soil moisture units. The units were developed by E. A. Coleman of the U. S. Forest Service. H. J. Stockwell of the Soil Conservation Service installed some of these units in Colorado as early as 1952 and now has a network over several states with from three to six years of historical record of soil moisture.

The other advance has been the development of a Radio isotope-Radiotelemetering Snow-Gage by the Corps of Engineers, U. S. Army. This work has been conducted in King's River basin since 1947 with such encouraging results that it is now being extended to the Kern River Basin in California and to the Columbia River basin in Washington.

What the future holds in store for us remains to be seen. One thing, however, is certain and that is that there will be an acceleration in the application of electronics to the collection and processing of field data as well as to the study and use of forecasting procedures. It has been a real pleasure to discuss Mr. Stafford's paper and to add these remarks to his most excellent history.

HISTORY OF SNOW SURVEYING IN THE EAST

By

Gordon R. Ayer [1]

The practice of making snow surveys on regular snow courses in the East began in 1914 when snow observations were started at Somerset, Vermont, in connection with a hydroelectric development. Prior to that time at least two concerted efforts had been made to determine depth and water equivalent of snow on the ground.

In 1836, in a report[1] to the Canal Commissioners of the State of New York, John B. Jervis, Chief Engineer of the Chenango Canal, stated that "Snow on the ground which fell in November and December 1834 on the watershed of Madison Brook (9.37 square miles) amounted to 87,120,000 cubic feet of water." Although we have no definite knowledge of the method he used, still his work, so reported, would seem to constitute essentially a snow survey, the first such survey, in all probability, to have been made in the United States and presumably in the world.

A somewhat detailed discussion of what may be considered another early effort to measure water content of snow on the ground is contained in a letter dated March 7, 1903 from Charles A. Mixer,

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resident engineer of the Rumford Falls Power Company at Rumford Falls, Maine, on the Androscoggin River, to Dr. H. C. Frankenfield, in charge of the River and Flood Service of the Weather Bureau.

"My usual gaging of the snow on the ground consists of simply getting a correct and full sample of the snow on the ground and then melting it to get the water equivalent. The sample is secured by forcing a cylinder down to the ground, then shoveling down around it and inserting a sheet metal bottom and lifting it out. On my voluntary observer's report for March 1900, there is given my first report of such measurements. On account of the unusual depth of snow on the ground at a late date and its peculiar condition, I was led to make some measurements that season. These were on March 17, depth of snow 38 inches, water equivalent, 10.49 inches; on the 31st the snow had settled to 20 inches, and the water equivalent was 9.84 inches. This represents ordinarily about 100 inches of winter snowfall, and is practically the whole winter's precipitation, to be added, when it runs off, to the greater spring precipitation. Think of this depth of water covering the surface waiting to be released, and imagine what would happen if all of it should run at once into the little river channels! This must have an important bearing on flood warnings. By gaging the snow, one can know in advance what may be expected, modified of course by considerations as to whether the snow melts and evaporates in the sunshine only or melts with the added help of a warm rain. I have kept up the measurements since my first observation in 1900, especially at the end of winter when the snow begins to go off.

"Another thought that led me first to such observations was my need of a sufficient explanation for certain monthly records of run off amounting to from 200 percent to 500 percent of the monthly precipitation. Of course this applies only to northern rivers, but the higher the altitude and latitude the more it means. At my present station, this season, the snow on the ground in an open place where my gage stands, measured on the 28th of February, 1903, only 10 inches of water, but above us in the woods, the snow is reported to be 5 to 6 feet deep. In connection with some of the northern rivers, this water that is held back, being stored in congealed form and waiting to go down, should be taken into consideration in order to get some advanced information."

The above quotation is from the Monthly Weather Review, Volume XXXI, No. 4, April 1903.

In another place in the same bulletin appears the following:

"I have made more such gagings since then but not regularly. I have not usually made them systematically, but only at what seemed to be the end of the winter season. I have described the method to a number of others, but have never found one who had heard of it or tried it. Of course, in some parts of the country, men have no opportunity to see a large accumulation of snow or the remainder of three or four months of snowfall. Hereafter, I will make the observations frequently and regularly, and will also make them in the woods where the snow is usually twice as deep in the springtime as it is in the open space where snow gages are. I am persuaded that such observations of the snow depths and equivalent water will be valuable everywhere, as additional information relative to the run off that may be expected, but the height of the freshet that it may produce will depend on the rate at which the snow melts." (Mixer goes on to describe the winter hydrology of the Androscoggin River Basin for the period 1899-1903, using graphs of daily stream flow, daily mean temperature, precipitation, and depth of snow on ground).

As far as can be determined, these are the first references to systematic observations of water content of the snow on the ground in the East, and may represent the first scientific approach to snow surveying in the United States.

Since the early start, as noted above, continuous records of snow depths and equivalent water content have been accumulated at more and more sites in the East. Generally, at first, the snow surveys were made by power companies and river regulating agencies, primarily for their own private use. Efforts were made to plan reservoir operation based on a combination of snow and indicated water content in a basin and past experience.

An example of the efforts of one power system in this direction goes about as follows:

The New England Electric System hydro generation had its birth on the Connecticut River at Vernon, Vt. in 1909. When this plant was built the company had little or no interest in runoff due to snow melt, except for flood probability, since the Vernon plant was a run-of-river station with no storage facilities.

Expansion of the System's facilities started in 1912 when a storage reservoir was constructed on the Deerfield River at Somerset, Vt., below which were erected several small hydro plants. With the completion of this reservoir it became evident that anticipated snow runoff from 30 square miles of drainage above the reservoir would be desirable for its efficient operation. Snow measurements, therefore, were started in 1914. These early measurements were simply the conversion of snow caught in a standard 8-inch can to water equivalent in inches. With a density index thus obtained, company caretakers traversed their local areas and measured the total depth of snow on the ground with a rule at various times during the snow season. From these measurements an attempt was made to determine expected runoff. Obviously, the results thus obtained failed to prove accurate enough for efficient operation of the reservoir.

In an attempt to get better data, a snow board was introduced at each precipitation gage site to better evaluate the snow fall reaching the ground during each storm. The snow board consisted of a 28-inch square of 1/4-inch thick beaver board covered with cheese cloth. A hole was cut in one corner to which was attached a light chain 5 to 6 feet long which in turn was attached to a stake driven in the ground. (This snow mat is similar to the mat described in U. S. Weather Bureau Publication WB 771). Briefly, this method of measuring snow depth consisted of placing the board on the ground before the first fall of snow and at the completion of the first snowstorm the observer would measure the depth of the accumulated snow on the board. A sample of the snow was taken by use of the so-called "cookie cutter", a thin galvanized metal cylinder 8 inches in diameter, closed at one end, and provided with a handle. The sample thus obtained was melted and measured in the standard precipitation gage. This measurement was compared with the amount of precipitation gathered by the rain gage during the storm being measured. The observer would then shake the board free of snow, pick up the chain and stake and carry the entire apparatus to some new location nearby and set the clean board on the newly fallen snow in preparation for the next storm at which time the above process would be repeated. The use of the snow board was discontinued after 1925.

What was done if the two methods failed to give comparable results is not known. At any rate, total snowfall was corrected by making assumptions as to loss by winter thaws and evaporation to give an estimate of total water content of snow on the ground from time to time. The subsequent run-off indicated quite clearly that this method left much to be desired as far as accuracy was concerned.

In the early and middle twenties, with the addition of several more plants to the system, it became necessary to devise means whereby the observer could convert actual snow on the ground at any time to equivalent water content. A set of snow surveying equipment was assembled, consisting of a length of 4-inch iron pipe, pail, hammer, ramrod, and platform scales. The sampling technique was to plunge the pipe through the snow to the ground and then remove the pipe and contents from the snow pack. The hammer was used when necessary to break through "ice accumulations in the snow pack or next to the ground." The ramrod was employed to push the snow from the pipe into the pail where it could be weighed on the platform scales. A conversion factor was then used to determine inches of water content.

In 1926, bimonthly determinations of water content were made regularly at five stations starting early in the winter. It was recognized that these five sites served only as indices, so a regular areal snow survey was added as time for spring runoff approached. This survey consisted of a sampling of typical areas throughout the entire watershed by a party of two men who made observations of snow depth, the water content and density. These readings over the entire watershed, in addition to supplementing the bi-monthly observations, also served as a check as to whether the established measurement stations were typical of the watershed as much of the watershed was at higher levels than the regular stations. After several years of observation it was concluded that there was more water content in the snow in the late winter at the higher elevations than at the lower elevations. This in turn led to the conclusion that more precipitation is received at the higher elevations.

The snow sampling apparatus previously described was used until 1928 when complaints from survey groups regarding this weighty and cumbersome equipment resulted in search for an improvement. The change at this time consisted merely of going from a 4-inch diameter iron pipe to the lighter weight 3-inch Shelby steel tube. All other parts of the equipment remained unchanged. The 12-pound steel tube was a welcome substitute for the 40-pound iron pipe.

To allow closer correlation of year to year data, several of the snow stations were permanently marked in 1933 by a 3/4-inch steel rod driven into the ground at each sampling location. These rods were painted with alternate red and white stripes to aid in location and to prevent their being disturbed or moved by unauthorized persons. Each station consists of a course of five stakes, spaced a minimum of 100 feet apart, and laid out in wooded or sheltered areas to avoid inequalities of distribution due to wind action. The leaves and debris are cleared in the fall of the year from around the stakes for a radius of at least 4 feet. Each sample is taken as close to the last sampling as possible and still have available undisturbed virgin snow for future samplings. Measurements are all taken within the 5-foot radius of the stake. The average of the five individual readings obtained at each stake constitutes the reading for the station.

At this time, I shall quote a few paragraphs[2] written by W. E. Sullivan, one of the veteran snow surveyors of the New England Power Co., a part of the New England Electric System.

"In 1933 and 1934 comparative readings were taken at four stations on the Deerfield using our own equipment and also Kadel equipment that had been borrowed from the Black River Regulating District. This latter equipment consisted of a duraluminum tube about four feet long with a changeable steel cutter in the bottom that had an opening 2.655 inches in diameter and a six-pound scale marked off to read the weight of the snow direct in inches of water. The readings for two years using the two sets of equipment were compared and the results did not lead to changing over to the Kadel type of equipment at that time because of the very slight differences noted.

"Study of our 1944 snow sampling results caused us to investigate our whole practice. One of the largest contributing factors to the variations noted was discovered by a study of the snow sampling areas made in the fall of 1945. It was noted that one of the snow stations originally a hard-wood area had taken on a new growth of soft wood which it was thought might radically affect the readings from that station. This theory was checked and proven the following season by the establishment of two new stations in the area and the original station was subsequently abandoned. At this same time it was also decided that all stations and observers should use similar equipment, which decision resulted in the adoption of our present equipment.

"The snow measuring equipment now used is a variation of the Kadel equipment which has been used a good many years in other locations and was adopted by us in 1946. Our equipment consists of a standard rolled 3-inch aluminum tube with a replaceable steel cutter which we designed, having a bore of 2.655 inches and a standard Chatillon spring scale which has a special dial calibrated directly in inches of water. Again, one big advantage proved to be in the weight of the apparatus. The aluminum tube weighs four pounds as against the twelve-pound weight of the steel tube. This equipment has been tried for 12 years and it appears that it is the best we have employed to date."

The Hudson River Regulating District, an agency of the State of New York, has been making systematic snow surveys in the Sacandaga River Basin above Sacandaga Reservoir since 1931. The drainage area of the basin is 1,044 square miles. This basin is on the southern slopes of the Adirondack Mountains at elevations ranging from 735 feet to 3,480 feet above sea level. The area is almost entirely wooded with both hardwood and evergreen trees. The entire area is usually accessible by road throughout the valleys but the more mountainous sections are quite remote.

About 20 courses have been measured during the last 28 years and their location has been maintained the same throughout the period of record. These courses range in elevation from 850 feet to 1,900 feet above sea level and no effort has ever been made to change them or to locate additional stations at higher elevations even though it is felt that greater accumulations of snow probably occur on the higher peaks. For comparative purposes it is probably advisable to use the same series of snow courses from year to year even though they may not produce a result which is truly representative of the actual conditions. The surveys have been made on dates coinciding with those of the other cooperatives in the Eastern Snow Conference and also at any other time when it appeared that conditions had changed considerably since the previous survey.

In 1942 a sufficient length of record was available to attempt a determination of any relationship that might exist between snow cover and total runoff.[3] The maximum water content of the snow for each year and date was plotted and connected with a point representing the total March, April and May runoff for the corresponding year. When plotted in this manner a very definite pattern at once becomes apparent as indicated by the sloping lines which are so near parallel in many instances. The computation for 11 years showed that an average of 6.06 inches maximum water content resulted in an average of 13.13 inches of runoff on the watershed, or 2.17 times as much. Moreover, an investigation of the corresponding relationship for 17 years of records now shows that an average of 6.65 inches of water content produced 14.33 inches of runoff or 2.15 times as much. This ratio of total runoff to water content of snow seems sufficiently constant to warrant considerable weight when forecasting total spring runoff. However, that it is far from infallible is demonstrated by the years of 1936 with a factor of 3.11 and 1941 with a factor of 1.11.

Obviously, other very important factors are entering into the problem in addition to the maximum amount of snow cover. Considerable weight must be given to the character of the snow cover.

Heavy layers of crust and ice seem to retard the rate of thawing. The date of the spring breakup may come in February or as late as April. Temperatures during the spring period are important but the dominant feature of weather is the amount and occurrence of precipitation. No formula has been found to express the relationship of these various influences to the volume of spring runoff. They are all kept in mind and frequent surveys are made to follow the progress of the snow melt.

Somewhat unlike conditions in the West, our Eastern snow cover is an extremely erratic actor in that the yield from it is related closely to meteorological conditions existing at any time after the first snow fall in early winter. Thaws, warm rains and partial or complete breakup of ice in the streams may occur several times during a single winter season in some of the river basins, as a matter of fact, occasionally over the entire New York-New England area. As a result, we generally are not able to stock-pile our winter precipitation for runoff in March or April. Part of the runoff may come from melting snow on almost any day from early December on to early April. Thus there is difficulty in predicting or forecasting runoff from snow accumulation alone, and need for experience and "seat-of-the pants" judgment.

In spite of all these uncertainties the number of snow courses measured regularly increased rapidly until in 1937 when the New York Cooperative Snow Survey was formed by about 16 Federal, State, and municipal agencies and several power companies. The assembling, reproducing and distributing of the data from the periodic snow surveys was and still is done by the U. S. Geological Survey, in Albany, New York, which also contributes some of the field data.

The data collected by the New York Cooperative Snow Survey and similar data from the New England area are now assembled and released by the U. S. Weather Bureau as Snow Cover Surveys by the Eastern Snow Conference. This bulletin lists 616 sites, 382 of which are in New York State.

The collection of snow data in the East is not limited to efforts within the Continental United States. The Meteorological Branch of the Department of Transport in Toronto, Ontario, Canada releases, each year, a compilation of snow cover data, Eastern Canada.

The equipment used in the eastern snow surveys is much the same as that used in the West with some modifications to suit eastern conditions. One of the more serious problems is that of sampling shallow snow cover, a condition that frequently prevails and for which the Mt. Rose or Utah samplers are not particularly well suited. Recognizing this quite early in the program, efforts were made to produce a sampling tube of somewhat larger diameter and a scale readable to tenths-of-an-inch equivalent water content. This outfit was termed the Adirondack-type snow sampler. This equipment has proved very satisfactory but unfortunately the tube was designed for and constructed out of some aluminum tubing on hand by one of the power companies and which was found to be nonstandard after the existing supply had been exhausted. At the present time we have a need for additional snow sampling kits and are keeping our eyes on the plastic outfits you of the Western Conference are developing. We think they can be adapted to our needs back east.

The coverage of snow-sampling sites in the East is far from complete. An intensive study of the present program would undoubtedly indicate too few courses at higher elevations and a need for general overhaul of the entire network. In some areas we have a rather dense network of sites as a result of definite interest by a power operation or river regulating establishment. The data in other areas are widely scattered.

In general we plan surveys for early in January, February, and March and frequently about mid-March. Only infrequently is there enough snow left for an early April round of samples. Most courses can be reached by motor car so no over-snow vehicles are needed. Conditions in Canada are more severe and some special transportation equipment is used occasionally.

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