DETERMINATION AND USES OF BEST INDIVIDUAL SAMPLING POINTS ON INDIVIDUAL SNOW COURSES 1/

As a result of advancements in the technology of snow measurement and development of single point snow-water equivalent measurement methods, basic data collectors and analysts have become quite concerned with the question, "What is the 'best' sample point on a snow course?" A closely related question, "How many samples are needed for a snow course?", has been asked for many years by snow surveyors required to travel long distances in adverse weather conditions to collect the data and by technicians who compute and analyze a vast amount of information.

Why should we seek answers to such questions? Before undertaking a study in search of answers, the questions should be examined and the need for answers justified. Four papers were presented at the South Continental Divide Snow Survey Conference in June, 1937 at Denver, dealing with the number of samples needed for a snow course. Since then, several papers and talks have been presented on this subject at various Snow Conferences, American Geophysical Union meetings, and other gatherings. One of the more recent presentations was "Selection of 'Best' Snow Course Points" by Arnold Court (1) at the 1958 Western Snow Conference in Bozeman, Montana. Over the years, a number of arguments have been advanced in favor of fewer samples. At the Denver meeting, Elges (2) proposed: "Fewer measurements will be taken by the observer with greater care, especially during adverse weather conditions." Two years later, Paget (3) stated: "The big argument in favor of fewer samples is the conservation of time and labor expended needlessly where snow courses have, through lack of knowledge of local snow conditions, been laid out with several times the number of samples necessary." In 1957, Wyckoff (4) asked: "Is it necessary statistically to collect more than 10 samples on one snow course? Some courses contain a score of samples. When there are ice layers to twist through, every sample can bring forth blood, sweat, tears, and a profusion of profanity. A few statistical calculations in the office might save a lot of effort in the field, and I know the snow surveyors would welcome any possible reduction in the number of samples taken." The next year, Court (1) said: "Today, travel is faster, although more expensive. A trip that took three days on skis may be done in less than a day with an over-snow vehicle and in an hour by helicopter. In such cases, the length of 'down time' for the vehicle or 'copter' is important. Courses must be cut to the absolute minimum for speed and economy of operation."

In short, taking fewer samples per course should result in greater sampling accuracy, better efficiency and economy, and a more satisfied field man.

The justification for determining the best individual sample is also accuracy, efficiency, and economy. The aerial snow-depth marker single point sampling method is inherently efficient and economical, so proper location is of prime importance for data accuracy. The relatively high cost of other types of single point snow-water measurement installation require that they be installed at points which will provide the best possible index to future runoff volume.

In order to properly answer these questions, it is first necessary to define "good" snow course and "best" sample point. At the 1951 Western Snow Conference, Clyde and Houston (5) stated: "The course method of snow surveying is not an attempt to determine quantitatively the actual amount of snow stored water on any particular watershed. Rather it is to establish a relationship between snow cover at designated locations and subsequent stream runoff from the watershed." Stated in different terms: The snow-water equivalent on a given snow course is an index to future runoff past a given point. Thus, a "good" snow course and/or "best" sample point(s) would be those providing the best possible index to streamflow.

Previous studies have been confined almost entirely to the relationship of individual samples and averages of five or more samples with the average of all samples on

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a snow course. Mr. Court (1) in 1958 briefly commented on the correlation of these parameters with streamflow but did not pursue it to any length.

In line with the previous definitions, little can be gained by correlating individual samples or averages of a group of samples with a snow course average unless that average has the best possible correlation with streamflow at a gaging point. In this study, the analysis primarily concerns the relationship between snow water, either individual point or group average, and seasonal streamflow; however, other secondary relationships are obtained in the process.

The measure of an index is most commonly expressed in terms of "coefficient of correlation" (r) and "coefficient of determination" (r^2). Variations in relationships are more readily observed by utilizing the coefficient of determination. These were the criteria used in this study to determine the best relationship between snow-water and runoff. Since the objective was to arrive at the best possible correlation between snow-water parameters and seasonal streamflow for a given base period, significance, standard error, and other statistical tests were not considered necessary.

This individual snow course analysis work has consisted of three phases:

1. Determining simple correlation coefficients between seasonal streamflow at a forecast point and
   (a) The average snow-water content for a snow course
   (b) Systematic combinations of five or ten samples.
2. Determining correlation coefficients between streamflow and individual sample point snow-water equivalents.
3. Determining correlation coefficients between runoff and random combinations of the best individual samples - usually an average of the best five or ten.

Also tested, in conjunction with the above analyses, was the relationship between these snow-water variables for a given snow course and: Gaging stations on more than one river; more than one gaging station on the same river; more than one seasonal flow period; and more than one historic period.

Systematic combination of samples is averaging five or ten evenly spaced samples on a snow course. Random combination of samples is averaging any combination of best samples regardless of spacing.

The first analyses, beginning in 1954, were made primarily for shortening courses consisting of 15 to 40 sample points. This was accomplished by the systematic combination system, choosing a group of 5 or 10 which produced as good as or better correlation with streamflow than the average of all samples.

The introduction of aerial snow depth markers into the operational snow course network immediately raised the question of best location of such an installation on a given snow course. To better determine this, the correlation coefficient between individual samples, snow course average and streamflow was utilized. Aerial markers were located at or adjacent to the best individual sample, in relation to streamflow, consistent with visibility, safety and other factors pertinent to aerial marker location.

The great variation of correlation coefficients between samples on a snow course aroused curiosity as to the possibility of improving a snow course by using only the best samples. A study was initiated to determine if all snow courses could be shortened and improved by utilizing combinations of best samples.

Individual sample correlation analyses have been performed on 29 snow courses; systemic combination analyses on 42 snow courses; and random combination of best sample correlations on 6 snow courses.

Prior to the correlation analysis computations, the field notes for the courses were checked and corrections made on obvious human errors. It was assumed that any unexplained variations which still existed, though possibly errors, would balance out over the historic period.

Inclusion of such a great volume of computational data is prohibitive. A summary of findings will have to suffice.

In a total of 40 correlation analyses of seasonal streamflow with individual sample water content as compared to snow course average vs. runoff, only one (1) snow course average showed a better relationship than any individual sample, and three (3) provided the same coefficient as the best individual sample.

Comparing 23 cases of individual samples and systematic averages with streamflow, best individual samples had a higher correlation in 16 and the same in three. In four cases, a systematic average yielded a better coefficient than any individual sample.

In eleven cases, comparing random averages and individual samples with streamflow, four averages produced better coefficients and two yielded the same correlation as the best individuals.

The comparisons of snow course average with systematic and random averages showed: In 28 cases, 17 systematic averages improved the relationship and 9 yielded the same coefficient of correlation; in 11 cases, 10 random averages produced higher coefficients and 1 remained the same. These random averages were based on the five best correlating samples and it should be noted that an average of the best two or three samples produced a higher correlation coefficient in every case tried, and in some cases equaled or bettered the highest correlating individual sample.

Comparison of these various snow-water parameters for a given snow course with the runoff of two different rivers showed that the snow course can be an excellent index on one river and have very poor correlation with another. It appears, however, that the best sample points are the same on each river. The same was true of systematic and random average relationships.

The correlation of snow-water parameters of a given snow course and flow at different gaging stations on the same drainage produced considerable variation in coefficient values. There seems to be a difinite relationship between value as an index and the distance between the snow course and the gaging station.

Comparison of snow-water variables for a given snow course with different seasonal flow periods indicates that, although the relationship might be good for all periods, there is enough variation to conclude that the course is a better index for one period than for another.

The correlation coefficient between a given snow course and gaging station varies considerably with the historic period used. The relationship of the individual samples, snow course average and random and systematic averages with streamflow, however, tends to remain the same, changed only in magnitude.

The following observations can be made from these findings:

1. Each snow course must be analyzed and treated individually.
2. Snow courses have one or more samples which correlate better with streamflow than the others. The best sample points appear to be the same regardless of gaging station, flow period, or historic period.
3. Correlation of snow water with streamflow can be improved by altering existing snow courses to include only the best samples. Samples are being included which are detrimental to the best possible relationship.
4. Regardless of grouping, there is at least one sample which will have a coefficient of correlation nearly equal to that obtained for the best average.
5. Coefficient values for individual samples, snow course average, systematic combination average, and random combination average may vary considerably depending upon forecast period, historic period, gaging station, and the river with which the snow-water equivalent for a given snow course is compared.

These observations are interesting and even important when utilized to improve the snow pack-streamflow relationship. Statistically a satisfactory relationship exists with a correlation coefficient of .85 or higher. On a number of snow courses neither averages nor individual sample snow-water equivalents provided correlation coefficients of this magnitude. Thus, the forecaster must incorporate other supporting or contributing parameters to improve the relationship and maintain a high level of forecast accuracy.

There are general criteria to be followed in locating snow courses, but there is no advance assurance that the correlation will be good for a particular stream gaging station. Assuming the correlation record itself determines how good a snow course is or how good individual sampling points are, the conclusion can be drawn that a more detailed study of snow courses may provide more specific factors important for the best possible location of index points.

An understanding of the peculiarities of the existing snow course network must be approached by a complete analysis of the data. This should include coefficient of correlation for individual samples, snow course average, etc. as covered in this paper as well as other relationships which might appear in the future. With this information, field investigations should be made to determine why certain sample points are better than others. What is the effect of vegetation, soil, geology, aspect, exposure, elevation, etc. on a given sample point that makes it a better index to streamflow? The study, "Snow Accumulation and Melt in Relation to Terrain in Wet and Dry Years", by Anderson and West (6), presented to the Western Snow Conference last year, provides an excellent base for establishing criteria for index station location.

From the studies thus far, several questions can be asked:

1. Should we shorten a snow course to include only the five best samples? There is the possibility of environmental changes which might cause another group to be best at a later date. A different combination may already be best for another station or on another stream.
2. Should we be using different combinations of samples on a given course for different forecast periods, different gaging stations, or different watersheds?
3. Should we establish snow courses of only five samples? Might it not be best to start with ten or twenty and choose the best after sufficient record has been accumulated?
4. Should we drop a snow course because of poor correlation? There is the possibility the course might have a good relationship with another gaging station or with one yet to be installed.

Many other questions will be encountered as such a program progresses.

Returning now to problems relating to the use of the best individual sample point: What has been discovered which might be pertinent?

The choice of the best sample point on an established snow course seemingly presents no problem; however, use of that point by installation of scientific equipment for collecting data is contingent upon other factors.

Installation of a pillow requires a level spot of sizeable proportions. The best sample point on a course may not be satisfactory for such an installation, not only because of slope, but for other environmental reasons. If it is necessary to level too large an area or remove too much vegetation, the sample point may be altered to such an extent it will no longer be a good index point.

The individual sample point analyses reveal there is often wide variance in correlation between adjacent samples, even when closely spaced. Using the poorer samples in an average is detrimental to a relationship. The individual samples taken by snow tube are only one and a half inches in diameter. Will expanding this small a sample to a diameter of 12 feet allow it to remain good, or will the inclusion of a greater area have the same effect as adding two adjacent bad samples to a good one?

Single point measurement by the use of aerial markers has been satisfactory because the installation did not destroy or change the individual sample point. Duplicate records could be gathered from which formulae could be computed for converting from a single reading to an average for the snow course.

At the present state of development, installation of a pillow at or on a sample point will eliminate it from any other type of measurement. Duplicate records cannot be collected and conversion to a snow course average will not be possible without statistical analyses. It would seem much more desirable to scientifically locate the pillow off the snow course so as not to disturb a point where data has been collected for many years.

The main problem in single point or pillow measurement is the same as for locating a snow course - not enough scientific criteria for choosing the best possible site.

Though this study has dealt only with single point sampling of snow-water data, the findings apply to other data collection as well. Single point measuring devices for whatever information, be it precipitation, temperature, soil moisture, evaporation, etc., must be located on the basis of scientifically established criteria in order to provide the best possible usable data.

REFERENCES

(1) Court, Arnold: Selection of "Best" Snow Course Points. Western Snow Conference, Proc. 1958: 1-11.

(2) Elges, Carl: Possible research-projects in snow surveying and streamflow forecasting in the western states. Amer. Geophys. Union, Trans. 1937: 652-655.

(3) Paget, Fred H.: Paraffin versus enamel; optimum number of sampling points; improvement of tubular balance. Amer. Geophys. Union. Trans. 1939, Part I: 74-75.

(4) Wyckoff, Pete: Snow surveys from the snow surveyor's side. Western Snow Conf., Proc. 1957: 57-59.

(5) Clyde, George D. and Houston, Clyde E.: Benefits of snow surveying. Western Snow Conf., Proc. 1951: 84-100.

(6) Anderson, Henry W. and West, Allan J.: Snow Accumulation and melt in relation to terrain in wet and dry years. Western Snow Conf., Proc. 1965.