SELECTION OF "BEST" SNOW COURSE POINTS

by

Arnold Court 1/

Introduction

Five measurements should be enough to characterize the water content of a snow course. Furthermore, the median of these five measurements should provide almost as good an index of the water equivalent as would their mean. These two separate but related hypotheses were tested, and verified, by analyzing in detail the individual measurements made on a typical 19-point Sierra Nevada snow course for the last 15 years.

The course studied is that of Onion Creek, 6,100 feet above sea level in the headwaters of the North Fork of the American River, at 39° 15.5 N, 120° 22.5 W. Laid out late in 1936, the course has been measured annually in late March or early April since then. It was also measured in early March in 1937, 1939, and 1940, and around the first of February, March, and May regularly since 1951. Only the late March and early April measurements have been used in this analysis. Their actual dates have ranged from March 26 in 1946 to April 3 in 1939; only 4 of the 21 measurements came in April.

The Onion Creek snow course forms a cross. The 7-point minor leg runs almost North-South (true), crossed at an angle of 77° by the 12-point major leg, running from ENE to WSW. It is in a meadow surrounded by mixed conifers (white and red fir, incense-cedar, and Jeffrey pine) and a few cottonwoods. One side of the meadow is crossed by the road from Soda Springs, 4 miles to the north, to The Cedars, 2 miles to the south.

The Onion Creek watershed above the snow course, about 5 square miles, is being studied intensively in the snow research program of the California Forest and Range Experiment Station in cooperation with the Department of Water Resources of the State of California. Eventually the snow course data will be used to extend the stream flow and precipitation measurements being made in the basin since 1956, so their detailed analysis was desirable.

Onion Creek flows through the meadow just to the southeast of the snow course, and joins the North Fork of the American River about 1.5 miles to the southwest. Flow of the North Fork has not been measured extensively. The uppermost stream gage, only 715 feet above sea level, is about 50 miles downstream at North Fork Dam, northwest of Auburn; its drainage area is 343 square miles. (From 1911 to 1941, flow was measured near Colfax, about 10 miles upstream from the present site.)

However, the flow of the South Yuba River, the adjacent drainage to the north, has been measured at Cisco, about 10 miles NNW of Onion Creek, since 1943. The gage is 5,500 feet above sea level, or only some 600 feet lower than the Onion Creek course. The flow is unregulated except for Lake Van Norden, in which 5,611 acre-feet are stored from late May until September or October. Since this capacity is only about 5 percent of the average April-September flow, and less than 10 percent of the lowest flow (60,820 acre-feet in 1947), this regulation has been ignored.

The upper South Yuba drainage area, above the Cisco gage, of 50 square miles contains meadows quite similar to that of Onion Creek. Hence the spring and summer flow of the South Yuba at Cisco should be predictable, in large part, from the April 1 water content of the Onion Creek snow course, even though the course is outside the actual drainage. This presumption was also investigated in the analysis of the snow course data.

On the whole, the Onion Creek course is just one of the several score snow courses measured regularly in California. Its length of 19 points spaced over about 1,000 feet is near the average for such courses. Its measurements have not been made with any special care over the years, but at about the same standard of accuracy as other courses.

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Not all 19 points were measured each year during the first few seasons. In 1938 three points were unreported, in 1941 two points, and in 1942 and 1946 one each. Presumably these omissions arose from "unrepresentative" cores or other difficulties, but their existence complicates any computations. Consequently, the analysis was restricted to the observations beginning in 1943—which was also the first year for which stream flow data were available. The one missing observation (Point No. 9 in 1946) was interpolated from the standard formula,

$$x_{ab} = (m\Sigma_j x_{aj} + n\Sigma_i x_{ib} - \Sigma\Sigma_{ij} x_{ij}) / (m - 1)(n - 1).$$

Here x_{ij} is the observation on the i^{th} point in the j^{th} year, x_{ab} is the missing observation on the a^{th} point in the b^{th} year, and m and n are the numbers of points and years, respectively.

Historical

Snow courses have been increasing in number, and in frequency of measurement, and also have been growing shorter. But the shortening has been very slow.

In the formative years of the organizations which became the Western Snow Conference, the number of points per course was discussed extensively. Four papers on the subject were presented at the South Continental Divide Snow Survey Conference in Denver in June, 1937.

Assuming that "The points of measurements along the course are presumably all drawn from a single homogeneous population", Connaughton (9) computed how many points were needed to yield a mean whose standard error was less than 10 percent of that mean. Of 55 courses studied, 22 were so homogeneous that they could have been shortened, while the rest required still more points—one of them as many as 2,173 points to meet his criterion.

Sources of variability were studied by Hunter and Devore (12) on 12 Truckee-Tahoe courses. "Most of the present courses are unnecessarily long and with a little study could be cut down so that better results could be obtained. In most cases, they concluded, "8 to 15 samples should be ample if carefully selected". Boardman, discussing this paper by two of his students, declared that similar research should permit establishment of "new courses of 10 to 15 samples which will give more consistent results than many of our old, longer courses".

At the same Denver meeting, Elges (10) said: "In some cases the courses are exceedingly long. By proper inspection it should be possible to lay out a short snow-course, approximately 20 measurements, which will give good results. ... If wind action can be prevented on a course, there should be no difficulty in getting shorter reliable courses. Furthermore, fewer measurements will be taken by the observer with greater care, especially during adverse weather conditions."

"How long should a snow course be?" asked Clyde (6) at the same meeting. "When snow courses were first laid out in Utah it was thought that the courses should be from one-half to one mile in length with measurements every 100 feet". Analysis of four courses revealed, however, "that long courses are not necessary and that perhaps relatively short courses of 10 to 20 measurements at 50- to 100-foot intervals with short cross courses would be most desirable."

Two years later, Paget (14) reported that investigations "... for separate California courses indicate that in many cases a lot of sampling points can be cut out without altering the resultant measurement of mean water-content at the course. ... In the Kings River watershed ... most of the snow courses have only six or seven sampling points each. ... The big argument in favor of fewer samples is the conservation of time and labor often 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 his manual, Marr (13) said: "Measurements must be made at a sufficient number of fixed points on an established marked course to insure that the average of the measurements will not be unduly affected by drifting or wind-swept snow. ... Each course is planned definitely to permit a group of measurements, the average of which will represent the snow cover at the given elevation and exposure."

A dozen years ago, a research committee (3) of this Conference commented on course shortening. "We can considerably reduce the number of observations on our long snow courses," Clyde reported. "The cutting off of the ends of some courses has actually improved them," Langbein added.

In his monograph, Boardman (2) maintained that "the average of ten or more samples" of a snow course is better than a single precipitation gage reading. "The early tendency was to use long courses involving 50 or more samples in some cases," he said, "but more recently it has been decided that 10 to 20 samples are usually sufficient."

In the East, only three or four samples were taken at each of 50 sites established in 1937 in the Androscoggin Valley of Maine (1). In New York, "ten samplings from 25 to 50 feet apart generally constitute a course, the results of which are averaged" (11).

"Most courses are located in small mountain meadows and usually have 8 to 12 observation points, or enough to give a dependable sampling average", Gregory L. Pearson said in a talk, as yet unpublished, presented to the SCS Snow Survey Conference in Estes Park, Colorado, in September 1954 and also to the American Geophysical Union at Seattle in November, 1956. His approach, while similar to Connaughton's (9), improved on it by recognizing "that many good snow courses have considerable irregularity in snow cover throughout their length while the irregularity is very regular from year to year." To estimate the reliability of course means, Pearson studied the variability of the difference of the individual point values from the course mean. "If the allowable standard error (of a course mean) is taken as 2.5 percent, then only 5 samples would be required" for the Pine Creek—Chalk Creek course in Utah. However, "it was decided to take the 9-sample course with its greater accuracy."

Only three years ago, Codd and Work (8) recommended that "The number of samples should be at least 10, and not more than 15. ... Two courses of 10 samples each, at 1000-foot difference in elevation", they felt, were far more desirable than 20 samples at one elevation. And just last year, Wyckoff (16) 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."

This study was undertaken largely to answer Wyckoff's lament.

Reliability

Snow courses are not uniform throughout their length. Some points usually have more snow than others. For the Onion Creek course, this variation is exhibited in Figure 1, which shows the water content measurements of the individual points, and their mean, on the late March survey of each year from 1937 to 1957. For each year, 19 dots are shown, except for those early years with missing observations, denoted by an M at the bottom of the column; one interpolated value, Point No. 9 in 1946, is indicated by an X.

Also shown in Figure 1 is the flow of the South Yuba River at Cisco since gaging began in 1943; data were available only through 1956. For each year, the flows of the individual months from April through September are indicated in the cumulative bar.

On the whole, the streamflow follows fairly well the late March water content of the snow. Flow in July, August, and September is generally so small, compared to that of the three preceding months, that the full half-year can be predicted about as well as the first quarter. The correlation between the water equivalent and the stream flow is 0.89, but since this is based on only 14 pairs of observations, the 90-percent confidence interval for the true correlation is from 0.75 to 0.97.

The regression equation of Y, the April-September flow of the South Yuba in thousands of acre-feet, on X, the Onion Creek snow water content in late March in inches of water, is

$$Y = 59.8 + 0.513\ X.$$

To allow for the constant term in this equation, the two sets of bars in Figure 1 have been offset by 50 thousand acre feet.

The scatter of the individual point measurements about the course mean, year by year, is quite revealing. It seems to be independent of the actual water content: in 1952, when the average was 67 inches, the range of values for the 19 points was 19 inches (57 to 76); in 1947, when the average was only 8 inches, the range was 17 (0 to 17). These relations are shown also by the standard errors of the course means, which range from 0.55 to 1.92 inches, and are essentially independent of the means themselves.

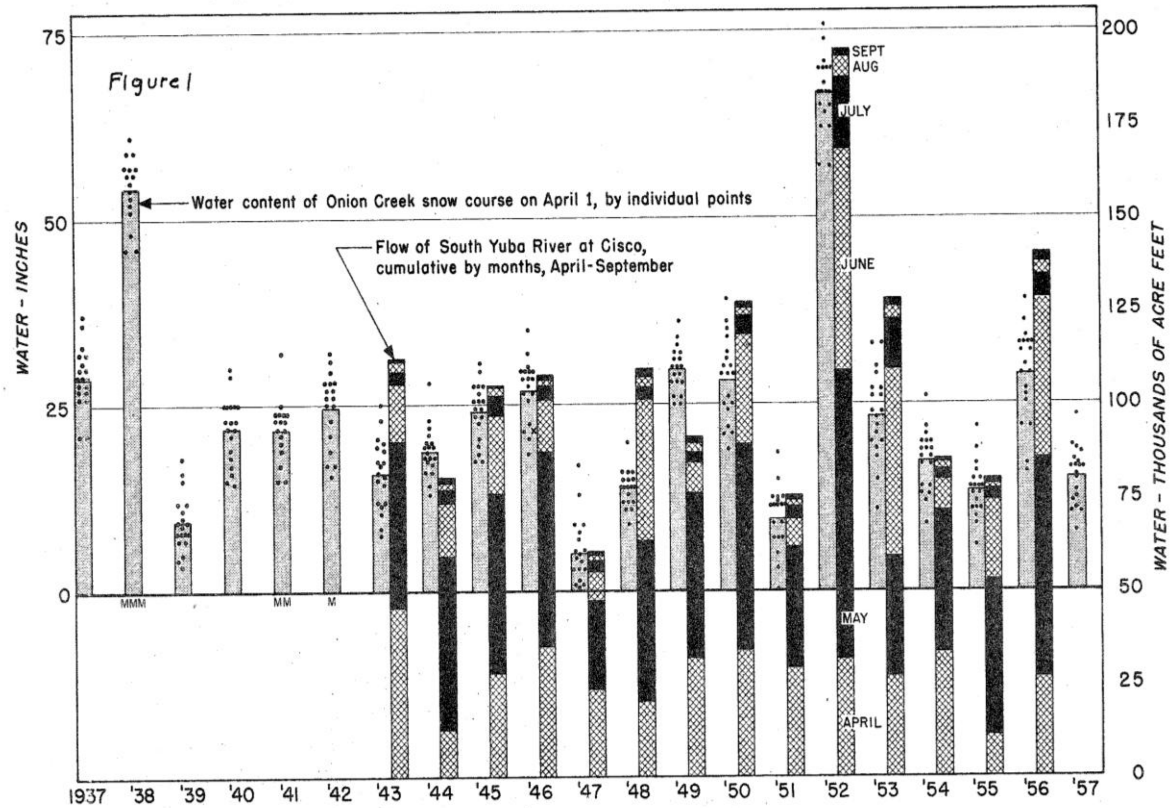
Figure 1
Water content of Onion Creek snow course on April 1, by individual points
Flow of South Yuba River at Cisco, cumulative by months, April-September
SEPT
AUG
JULY
JUNE
MAY
APRIL
WATER - INCHES
WATER - THOUSANDS OF ACRE FEET
MMM
MM
M
75
50
25
0
200
175
150
125
100
75
50
25
0
1937
'38
'39
'40
'41
'42
'43
'44
'45
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'56
'57

Care, however, must be taken in the interpretation of these standard errors. Under Connaughton's (9) assumption that the individual points all sample the same population independently, the mean of the readings at several points is a better estimate of the unknown population value than any individual reading. From this standpoint, the standard error of such a mean indicates a confidence interval for the true mean.

For example, the 19-point mean water content of 15.2 inches on 27 March 1957 had a standard error of 0.9 inches, which could be interpreted as indicating a 68-percent confidence interval of 14.3 to 16.1 inches for the mean. That is, if 19 points on the Onion Creek snow course had been sampled 100 times, each set giving perhaps a slightly different mean and standard error from which confidence intervals could be computed, about 68 of these intervals would actually include the true (but unknown) mean, while about 32 of them would be either above or below it.

But the individual points do not sample the same population. Point No. 19, almost on the banks of Onion Creek, always has a higher water content than the others. As shown by the uppermost dot for each year in Figure 1, it has had from 6 to 12 inches more water than the course mean. If it were eliminated, the scatter would be decreased considerably, the mean would be reduced by half an inch, and the apparent standard error of the new mean would be appreciably smaller.

Similarly, the water content measurement at each of the other points tends to differ from the course mean by about the same amount, year after year. Each point measurement, therefore, is an estimate of the course mean plus a constant difference term, which may be positive or negative. The sum of these differences, over all 19 points, is zero. These average differences, for the 15 years studied, are shown in the upper part of Figure 2.

The actual differences, of course, vary from year to year, because of random fluctuations in the snow, and possible errors of measurement. Their own standard errors are about 1.5 inches, which is, under these assumptions, the standard error of an individual point measurement. The standard error of their mean is $1/\sqrt{n}$ of the root mean square of these standard errors, plus a correction term involving the correlations between the measurements at the various points. If these measurement "errors" are normal and independent, i.e., not correlated, and are all equal, then the standard error of a course mean at Onion Creek in any one year is about $1.5/4.2 = 0.4$ inch.

Whether other snow courses have the same characteristics as the Onion Creek course has not been investigated. Possibly other courses do not show the same constancy in the differences of various points from the course mean, or substantial equality of the standard errors of individual point measurements. Certainly the 68 percent confidence interval for the mean water equivalent may differ substantially from the value of about 1/2 inch that apparently is valid for Onion Creek.

Correlations

If the water content of each snow course point tends to differ from the course mean by a constant amount, and the standard errors of the measurements at each point are all equal, any one point is just as good a predictor of the course mean as any other. The validity of this assumption can be examined by studying the correlations between the water contents of the various points and the mean of all. Such correlations are displayed in the central part of Figure 2.

For each of the 19 points of the Onion Creek snow course, the correlation coefficient of the late March water content with the average water content was computed. The correlations are absurdly high, ranging from 0.960 to 0.998, because each point is correlated in part with itself. This effect could be eliminated by correlating each point with the mean of the 18 others, but the purpose of the computation was to show how well any one point could be used to predict the course mean.

Each of the correlation coefficients is represented, not by a single dot, but by a symbol that indicates a 68-percent confidence interval for the true correlation. The actual computed value is represented by the widest part of the symbol, and the upper and lower limits of the confidence interval by the narrower extremities of the symbol. The vertical scale of Figure 2 has been distorted so that the symbols are all the same size. The transformation used is that known as Fisher's z, defined as

$$z = \frac{1}{2} \log_e \frac{1 + r}{1 - r} .$$

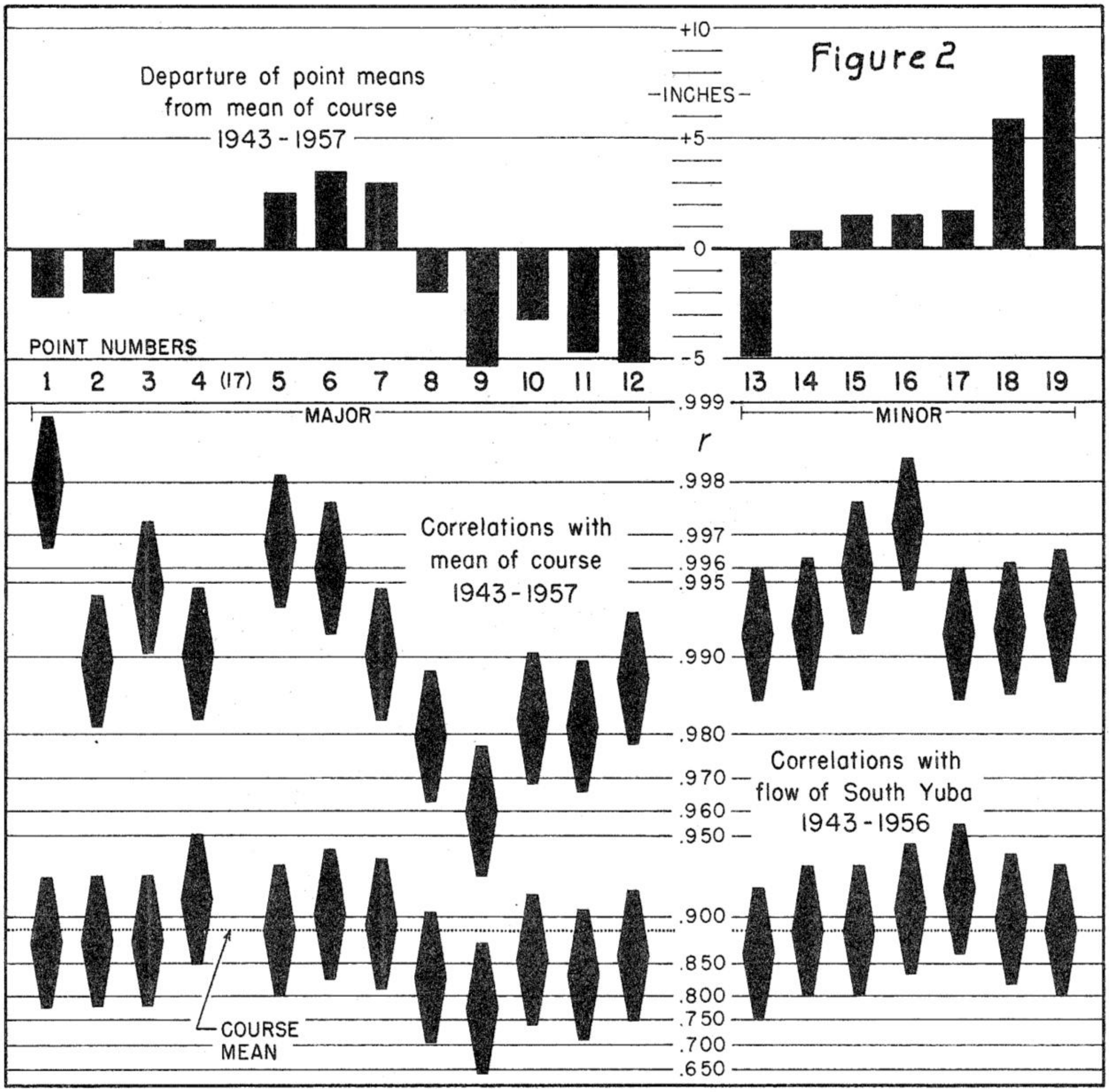
Figure 2
Departure of point means
from mean of course
1943 - 1957
+10
-INCHES-
+5
0
-5
POINT NUMBERS
1 2 3 4 (17) 5 6 7 8 9 10 11 12
13 14 15 16 17 18 19
MAJOR
MINOR
r
.999
.998
.997
.996
.995
.990
.980
.970
.960
.950
.900
.850
.800
.750
.700
.650
Correlations with
mean of course
1943-1957
Correlations with
flow of South Yuba
1943-1956
COURSE
MEAN

The distribution of the quantity z is almost normal, so that confidence intervals do not depend on the actual value of z. Obviously, the intervals in terms of r must depend on the actual value of r. Transformation to z is necessary for averaging, or similar manipulation, of correlation coefficients.

Correlations between stream flow and the water contents at each of the 19 snow course points are shown similarly in the lower part of Figure 2. The flow is that of the South Yuba River at Cisco during the half-year following snow course measurement. These correlations are all substantially lower than those with the course mean because no self-correlation is involved. Consequently they can be plotted on the same scale.

The correlations with the course mean show much more variability than do those with stream flow. Even so, the entire set of 19 correlations of individual water contents with the mean water content could very well all be equal. That is, none of the 19 correlations differs significantly from their mean of about 0.99. Whether the two extreme correlations, 0.998 and 0.960, differ significantly is not certain; the recently-developed multiple-comparison tests are not strictly applicable because of the self-correlation that is inherent in each of the computed values.

Obviously, the correlations with streamflow do not differ significantly, even though the computed values range from 0.77 to 0.92: the 68-percent confidence intervals for these values overlap. Hence, ordinary statistical theory would indicate that any one point could be used about as well as any other to predict the streamflow. Nevertheless, if a few points must be selected for such a prediction, the obvious choice, statistically, would be those points with highest correlations. By this criterion, the five "best" points for this purpose are, in order, nos. 17, 4, 16, 6, and 18.

However, these five points are not, by the same criterion, "best" for predicting the mean water content of the course. Here the highest correlations are, in order, for points no. 1, 16, 5, 15, and 6. Only two points, 6 and 16, appear in both sets. Interestingly enough, point no. 9 has the lowest correlations, both with mean water content and with streamflow. It is the same point whose value was missing in 1946, but the interpolated value that was used should have improved the correlation with water content.

Results

"The course method of snow surveying is not an attempt to determine quantitatively the actual amount of snow stored water on any particular watershed," Clyde and Houston (5) pointed out. "Rather it is to establish a relation between snow cover at designated locations and subsequent stream run-off from the watershed."

Such relations usually take the form of multiple regression equations, which use, in addition to snow course water equivalents, other variables, like autumn and spring rainfall and sometimes temperature. Frequently several snow course values are averaged together, with or without weighting, to provide one of the variables in the regression.

Shortening or otherwise altering a snow course will, in almost every case, result in measurement points whose mean will differ from that which would have been obtained on the original course. The mean of the revised course can be adjusted so as to estimate what the mean of the old course would have been. For the Onion Creek course (and presumably most others), such an adjustment would be merely the addition, or subtraction, of some constant.

The five points having the highest correlations with the mean water content had an average water content 1.3 inches greater than the 19-point mean. Corrected for this difference, the mean water content of these five points on the late March surveys from 1943 to 1957 ranged from 1.3 inches less than the 19-point mean of 15.2 inches to 1 inch above it. The standard deviation of the differences between the 5-point and 19-point means was only 0.7 inch.

Eight of the 15 means were within 0.5 inch of the 19-point mean. A standard error of about 1/2 inch was deduced previously for the course mean. Thus the 5-point means fell inside this confidence interval almost as often as the interval is expected to include the true mean. In 14 of the 15 seasons, the five-point mean was within the standard error of estimate computed on the assumption that each of the points is an independent and unbiased estimate of the true mean.

Hence a snow course water content computed as the mean of these five points would have been virtually as reliable as the 19-point mean. Since the water contents at each of the five points individually had substantially the same correlation with the half-yearly flow of the South Yuba, their mean likewise has the same correlation.

However, the straight mean of only five points may, in some years, be unreliable because one of the points may not be representative. The snow tube may encounter a log, a dead deer, or an air pocket; or the point may be bare of snow. When such erroneous readings are likely, the <u>median</u> of five readings may be a more suitable value than the mean, and easier to compute in the field. The median is the middle value, numerically, of a set of numbers. Alternatively, it is a number that is greater than half the observations and less than the other half.

A resolution to "recommend that, in future hydrologic studies, normals of precipitation be defined by the median instead of the arithmetical average" was considered by the Section of Hydrology of the American Geophysical Union, meeting jointly with the Western Interstate Snow-Survey Conference in Seattle June 20-21, 1940 (15). A committee appointed to consider the question reported (4) a year later that "the expression of normals of precipitation be defined by the median". Whether the resolution was actually adopted by the Section is not clear.

Despite this interest in the median for precipitation normals, snow surveyors do not seem to have considered its use for snow course summarization. Yet it has much to commend it. An occasional aberrant value, whether too low or too high, does not affect it. The median of a few observations can be determined without computation, although for large samples some sorting or retabulation may be needed. A basic property of the median, which some statisticians consider the definition, is that the sum of the absolute departures of the observations is less when they are taken about the median than about any other value. For the mean, a similar statement holds for the sum of the squares of the departures.

The medians of the same five points of the Onion Creek course that correlated best with the course mean were determined. The average departures of these five points from the course mean were -2.3, +1.5, + 1.5, +2.5, and +3.5 inches. Hence the median point, No. 15, might be expected to be the median of the sample in the individual years, and the 5-point median should be decreased by 1.5 inches to provide an estimate of the course mean.

When the 5-point medians of the individual years are thus adjusted, only three of the estimates were within 1/2 inch of the course mean, but six others were within 1 inch, and the biggest departure, in 1947, was only 1.3 inches. The standard deviation of the differences between these 5-point medians and 19-point means was 1.2 inches. Thus the median of these five "best" points was not quite as good an estimator of the course mean as was their mean, but perhaps it would have been good enough.

Discussion

How many points should a snow course have? The answer to this perennial question depends on the answers to a couple of other questions: To what precision must the snow course water equivalent be known? What is the cost of sampling each additional point?

In the early days of snow surveying, the cost per point was a minor item. After a survey team had spent two or three days on skis or snowshoes to reach a course, an extra hour or two in sampling was minor. In fact, some people felt that a trip wouldn't be worthwhile unless at least half a day's work was to be done at the end. But 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 oversnow 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.

Snow course water equivalents are only one of the factors used in a streamflow prediction. Often the snow course report is adjusted to allow for precipitation or melting between the actual and nominal dates of survey. Many course means are used in a single equation. At best, the mean water equivalent of a course has a probable error (68 percent confidence interval) of about 1/2 inch; probably the figure is closer to 1 inch.

Consequently, a snow course needs only enough points to provide a value with a standard error of the order of 1 inch. However, enough points must be sampled to permit detection of manifest errors, such as short cores.

Hence, five points seem to be enough for the Onion Creek course, and presumably for many others. And the median of these five, adjusted if necessary, would seem to be almost as good as their mean, if not better. When the mean is used, erroneous samples must be replaced by better ones, but when the median is computed, one or two bad samples do not affect the result.

So far, only one set of five points for the Onion Creek course has been considered — the five points having the highest correlations, individually, with the course mean. Four of these points are near the cross of the course, and the fifth is at the northeast end. Would five consecutive points give results substantially different?

The five points most convenient to survey are Nos. 8 through 12, at the southwest end of the major course, adjacent to the road. All of them averaged less than the course mean, the departures being 1.9, 3.2, 4.7, 5.1 and 5.3 inches. Corrected for the average difference of 4 inches, the means of these five points ranged from 4.4 inches below to 2.8 inches above it. The standard deviation of the differences was 1.3 inches.

The medians, increased by 4.7 inches to represent the average departure of the median point (no. 11) from the course mean, ranged from 0.7 inches below the course mean to 4.2 inches above it; the standard deviation of the differences was 1.6 inches. Hence, these five "closest" points weren't quite as good predictors of the course mean as were the five best correlated.

But must five particular points be chosen for sampling each time? "A snow course usually includes one or more tangents along which equally spaced samples are taken in the same exact location season after season," Clyde and Houston declared (5). Methods of locating precisely the established points have been discussed repeatedly. How important is this aspect of snow surveying?

Besides picking out the five "best" and the five "most convenient" points of the 19 forming the Onion Creek course, five points were taken at random in each of the 15 years of available data. A table of random numbers was used to sample the course without replacement for each year; if a point was chosen more than once by this procedure, an additional point was picked randomly to complete the set of five.

Since each point had an equal chance of entering into any set of five, the average water content of the five random points might just as well be above as below the course mean, and no adjustment could be made.

This particular set of groups of five random points tended to underestimate the course water content by 0.7 inch. The means of the five points ranged from 2.6 inches below the 19-point means to 1.5 inches above it; the standard deviation of the differences was 1.5 inches. The medians of the five random points ranged from 4.8 inches below the course mean to 3.4 inches above it, but the average of these medians for 15 years was only 0.2 inches less than the course mean; the standard error of the differences was 2.4 inches.

Conclusions

The following estimates of precision, in inches, can be assumed for different estimates of the water content of the Onion Creek snow course:

Points:	All 19	5 "best"	5 "closest"	5 random
Mean:	0.5	0.7	1.3	1.5
Median:	-	1.2	1.6	2.4

These are not guesses at the standard errors of the values obtained by these various procedures. Rather, they are guesses at the precision with which each of these procedures can estimate the true mean of the 19 points. But this true mean may not be worth estimating at all. Since the correlations with stream flow of each of the 19 points do not differ significantly, presumably any estimate of snow course water content is good enough for practical use.

Only two systematic sets of five points, the "best" and the "closest", have been analyzed in this study, along with the "random" set whose composition changed each year. Actually, $19!/5!14! = 11,628$ different sets of five points can be formed from a collection of 19. Perhaps one of the other 11,626 sets, not considered here, would provide a much better estimate of the "mean" water content of the course, or estimate of the flow of the South Yuba.

In particular, a set selected on a physical basis, after detailed examination of the course layout, could be superior to sets chosen on a statistical or convenience basis. But with 11,628 possible choices, the superiority of any such selection over all others would be hard to establish. This is equally true for superiority with respect to streamflow prediction as for estimating the mean water content of the course. Nevertheless, selection of snow course points on physical reasoning is generally desirable.

All this is based on the detailed study of a single snow course, that of Onion Creek. Any other snow course should be studied individually to determine how applicable these conclusions are to it. Such a study could be as exhaustive as the present analysis, but this probably is not warranted.

On a course with at least a dozen years of record, the five most convenient points should be selected. The medians should be computed for each year, and the standard deviation of the differences between these medians and the course mean computed. If it is not substantially greater than 2 inches, the median of these five points probably will be just as good, for stream flow forecasting, as the course mean. Where the mean of the established course is already being used for forecasting, and the 5-point median is considered an estimate of that mean, the median should be corrected for the average difference of the median point of the set from the course mean.

From the statistician's standpoint, the combination of 15 or 20 snow water content measurements into a single mean is a gross waste of information. The median of a small number of points should provide a satisfactory value, since its use eliminates the need for resampling a point whose reading is questionable. The present study indicates that a water equivalent figure sufficiently accurate for the practical use to be made of it can be obtained from the median of only five snow course points.

Acknowledgments

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DISCUSSION

C. G. Wolfe and J. F. Hannaford (Department of Water Resources, Sacramento, California). Undoubtedly, the number of sample points can be reduced without materially altering the usefulness of a snow course. A study of the sampling procedure and conditions is necessary at each course to make a logical selection of a reduced number of sample points. We believe that the following criteria should be used in the selection of sample points in order to make the data most useful and easiest to obtain:

1. Water content for selected points need not have the same mean as that for all points on the original course as long as the change in conditions is taken into account in revising the course normals and making forecasts. We do not believe that the old course sampling points necessarily give a better index of the basin water content than the revised points.

2. The original course configuration should be maintained (i.e., major and minor courses) insofar as possible to minimize the effect of variations in drift and melt conditions. The snow sampling points used on a revised course should be selected from those used on the original course in order to provide continuity of record.

3. The course should be designed to make the field man's work easier, safer, and less subject to error. Spacing between sample points should be consistent to prevent errors in measuring between samples. In general, courses in California are about 1,000 feet long, so the length is not too critical for a field man, but points that may require wading streams, walking across ice, climbing fences, etc., should be dropped if possible. Sample points falling on rocks or in temporary snowmelt streams which appear every year should be eliminated.

4. An adequate number of points should be maintained to prevent an error or discrepancy at a single point from unduly biasing the resultant snow course water content. Drifting, sun pockets, furrows, etc., vary from year to year, and only by maintaining a large number of sample points may these effects be reduced. Rather arbitrarily we have taken ten points as a compromise between a short, easy-to-sample course and one long enough to eliminate the localized effects of snow distribution.

In the revision of courses to better tie in with the State's helicopter survey program, the criteria for reducing sample points, expressed briefly, have been ten sample points consistently spaced (generally 200' intervals), covering all segments of the course, and eliminating points which may be hazardous or difficult to survey.

Dr. Court's proposal to use median rather than mean water content for a course certainly deserves careful consideration. The idea is good and has a lot to recommend it. The simplicity of computation doesn't seem to be as big an advantage as the elimination of undesirable, obviously erroneous, or questionable samples from the computation. The State Department of Water Resources has made a practice of eliminating such samples in computing mean snow course water contents. This practice, although questionable statistically, does give what we believe to be a more representative sampling of the snowpack. The use of a median would tend to statistically justify elimination of the questionable samples. Often the major and minor legs of a snow course may have quite different depths and water contents, due to exposure, etc. This must be taken into account before applying the proposed median method. (Of course, this same care must be taken in applying the mean.)

As Dr. Court points out, careful study of each course should be made before eliminating any sample points. We would like to further recommend that along with the statistical review of points, a logical review of the physical characteristics of the course be made considering the aforementioned criteria.

PROGRESS IN SNOW MANAGEMENT RESEARCH IN CALIFORNIA

Henry W. Anderson[1]

INTRODUCTION

Snow studies are underway in California to develop and test methods of managing the snow zone for improved water yield. The studies are being made by the California Forest and Range Experiment Station of the U. S. Forest Service with the cooperation of the Department of Water Resources of the State of California.

The snow zone in California lies mostly on the west side of the Sierra Nevada and in the Cascade Ranges, roughly above 5,000 feet in elevation in the southern Sierra and above 3,500 feet in the northern Sierra and Cascade (figure 1). It is the area where more than half of the annual streamflow is yielded April 1 to September 30. The snow zone covers about 12 million acres - only 12 percent of the state - yet this area yields about 50 percent of the State's total streamflow (1). About 9 million acres of this zone are classed as commercial forest; they contribute about 40 percent of the State's water yield. Water yielded by melt of the snow pack is important not only because it is a large amount, but also because it is high in quality and is the principal water that feeds streams long after the rains have stopped.

Timber stands in the snow pack zone are still largely uncut, but logging is moving upward; it is only a matter of time until these high elevation commercial forests will be cut. We must learn how to cut forests and manage other lands in this zone in ways that will (1) exert control over water releases (2) guard against deterioration of water supplies originating there, and (3) improve water yield.

IMPROVE WATER YIELD

Water yield would be improved if we could develop ways of accomplishing one or more of these objectives:

1. Increase total streamflow in all years, and especially in dry years.
2. Improve the timing of streamflow, by delaying snow melt and yielding more water in late spring and summer.
3. Maintain or improve water quality.
4. Minimize local floods and reduce sedimentation damages.

In developing methods that will improve water yield we need to be able to predict the effects of any possible management practice on water yield. Since tomorrow's demands for water may be completely different than today's; our research must span the possible practices, not just aim at the immediately practical.

KINDS OF STUDIES

This is a report of progress in the studies during 1957 and early 1958. It outlines the studies underway, gives preliminary results from some studies, and tells of our plans. The studies are of 3 kinds: (1) Inventories of present conditions of water yield, land condition, and soil erodibility. (2) Development of methods of improving water yield and controlling sediment, and (3) Pilot tests of selected methods on experimental watersheds for their effects on streamflow and sedimentation.

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