SNOW PACK EVAPORATION FACTORS [1]

By

George W. Peak [2]

At the 1962 Western Snow Conference, held at Cheyenne, Wyoming, a paper entitled "Snow Pack Evaporation" was presented.

The basis of the paper was that the rate of evaporation from exposed areas of the watershed was greater than that from forest protected snow courses.

The paper stated in part that "Wind movement does not cause evaporation, but it is an important factor in determining the rate at which evaporation may occur," and again, "This vast movement of free snow particles, and the formations, or waves, left in the snow surface increase the exposed areas of the snow and indicate that the opportunity for evaporation from the snow pack increases with the velocity of the winter wind."

There is evidence that this "opportunity" is created, to a considerable degree, by temperatures and by solar radiation.

Since this paper is essentially a continuation of the 1962 paper, some of those relationships will be repeated. Plate 1 is again, the total inches of soil moisture, water content, and spring precipitation versus the April 1 to September 30 runoff in thousands of acre feet, of the Smith's Fork near Border, Wyoming.

The errors of estimate, in inches, were determined and plotted against the winter wind in Plate II.

However, in order to provide a smoother forecast procedure, the average winter wind data shown in the 1962 Proceedings are replaced by the total miles of winter wind in Plate II. The results are, of course, almost identical.

The data for all the years of record are held to the same November, December, March, and April period, with one exception.

Early in the fall of 1961, the high country throughout the state was hit by a series of snow storms. Wyoming stockmen worked desperately for days getting their herds down from the heavily drifted summer range. The date of initial snow pack accumulation was October 21. Furthermore, the rate of accumulation was such that there was no possibility of computed early winter evaporation exceeding, at any time, the amount of waterin the exposed areas of the early winter snow pack. The 1962 open point on Plate II is the same rigid November, December, March, and April weighted wind data. The 1962 solid point has, in addition, the proportionate number of miles of wind that occurred during the October 21-31 period.

The mean curve for this relationship was plotted and the new errors of estimate determined.

In Plate III, these errors, in inches of water, were plotted against the total number of degree days from November 1 to April 30. The degree days are taken from the 750 millibar data at Boise, Idaho, and Lander, Wyoming. The base is 0 degrees Centigrade. The 1962 solid point now includes the wind and temperature correction for the October 21-31, 1961 period.

The years 1950 and 1960 will no longer correlate. At Cheyenne, it was noted that

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[1] Presented at the Western Snow Conference, Yosemite National Park, California, April 17, 1963.

[2] Snow Survey Supervisor, Soil Conservation Service, Casper, Wyoming.

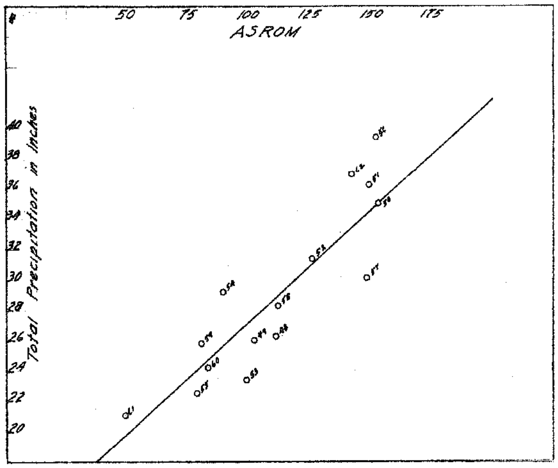


Plate I

Soil Moisture + Water Content + Spring Precip.

VS

ASROM, Smith's Fork nr. Border, Wyo.

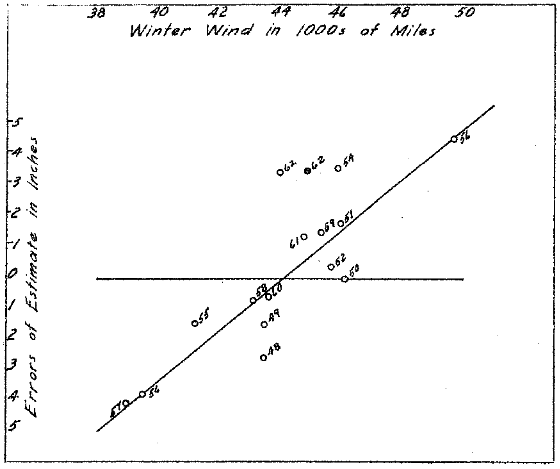


Plate II

Errors of Estimate from Plate I

VS

750 Millibar Wind at Boise, Idaho

100% (Nov. & Apr.) + 47% (Dec. & Mar.)

P.21 38°

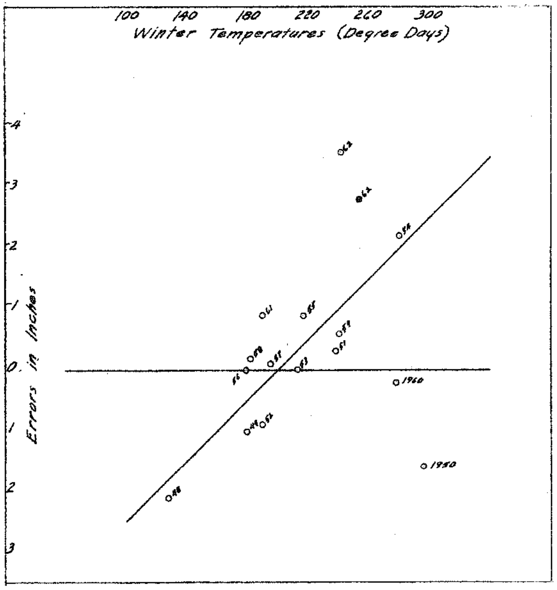


Plate III

Errors of Estimate from Plate II

VS

Nov. 1, to Apr. 30, Total Degree Days, Base 0° Centigrade

Ave. Boise-Lander 750 Millibar Data

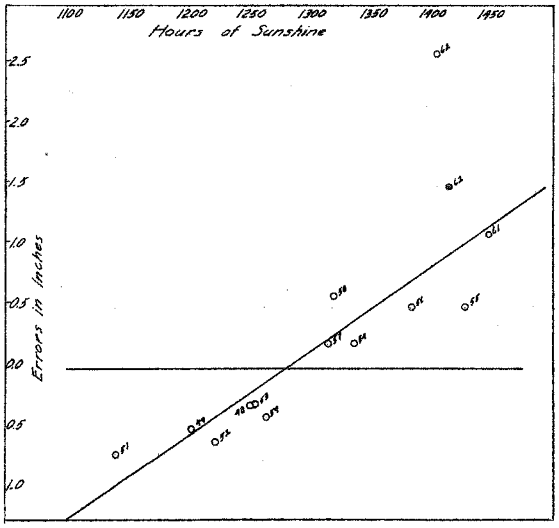


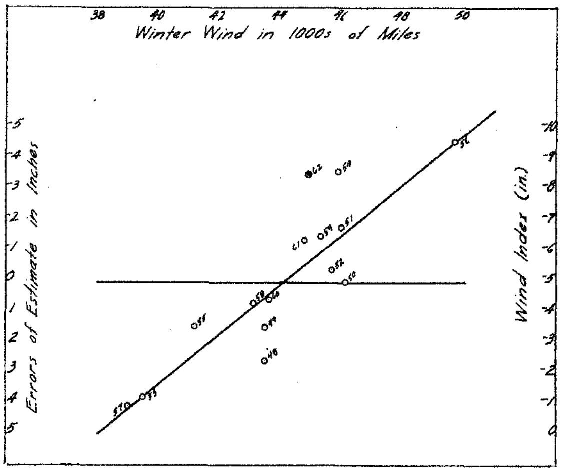
Plate IV

Errors of Estimate from Plate III

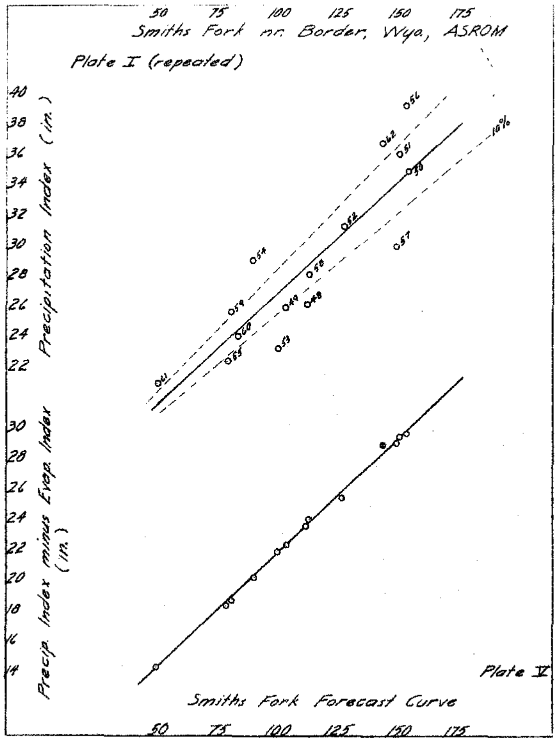
VS

Nov. 1, to Apr. 30, Total Hours of Sunshine

Lander, Wyo.



Repeat Plate II
Errors of Estimate from Plate I
vs
750 Millibar Wind at Boise, Idaho
100% (Nov. & Apr.) + 47% (Dec. & Mar.)



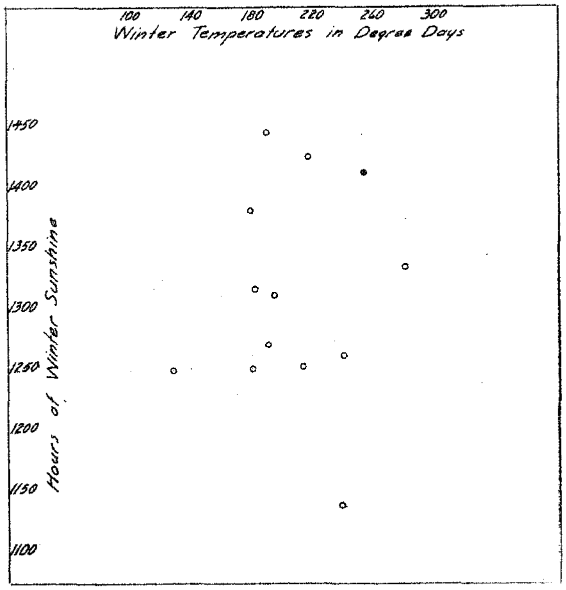
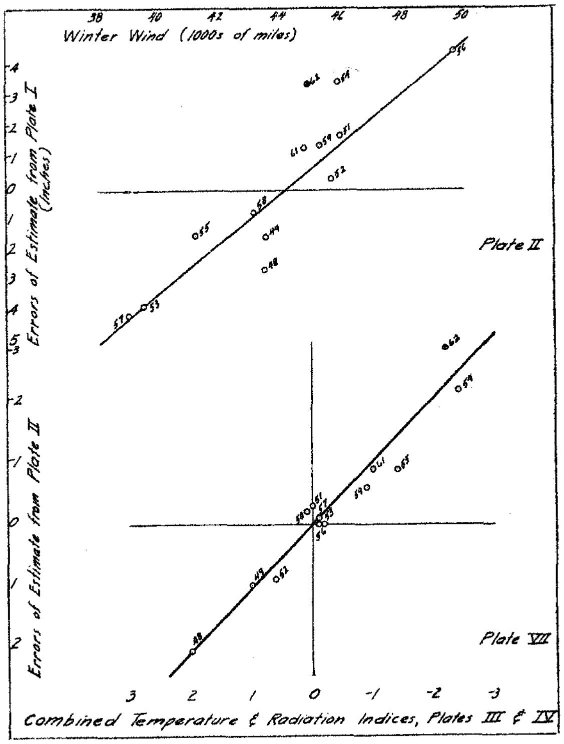


Plate VI
Radiation vs Temperature
(November 1, to April 30)



on the North Platte there was little or no snow in the early winter of 1959-1960. It was also true of this watershed; and November of 1949 proved to be the warmest in the climatological record of Wyoming. This explains, perhaps, why these years do not correlate.

However, no adjustments were made because there is no definite proof of the date of initial accumulation, and no reliable information that the rate of early accumulation was equal to, or greater than the computed rate of evaporation. By the time we reach Plate IV, these two years will plot outside the scale used for analysis.

In an effort to meet the steadily increasing demands for forecast accuracy, Wyoming has established an early winter reconnaissance system. Recently, about 15 Pearson totalizing Gages and 15 Soil Moisture Stacks were placed on strategic snow courses throughout the state. Early last fall, Soil Conservation Service personnel began visiting these watershed instruments every 15 days. This was continued until the snow became so deep it was no longer possible to reach them by car. In addition, there are 4 or 5 of these combinations on maintained mountain highways that are being read throughout the winter. This year, 1962-63, the date of the initial snow pack accumulation is known and the rate of accumulation determined every two weeks. We hope that, within a year or two, we will have the experience and ability to apply the evaporation factors at the proper time, and even more important, to avoid application of a computed rate that is greater than actual accumulation.

The mean curve was located in this relationship, and for the third time, new erros of estimate evaluated.

In <u>Plate IV</u>, these errors were plotted against the total number of hours of sunshine from November 1 to April 30.

This estimate of the intensity of solar radiation was determined by totaling the number of hours between sunrise and sunset for each of the winter months and multiplying each of these constants by the percentage of possible sunshine at Lander, Wyoming.

The difference between the open and solid points for 1962 now includes the wind, temperatures, and radiation that occurred during October 21-31, 1961.

Plate II is repeated in order to show that the difference in the amount of evaporation in 1957 and 1956, the two extremes, is close to nine inches. The correlation indicates that this nine inch difference is between forest protected snow course data, and a watershed snow pack that is largely unprotected. If we assume that a third of the watershed is as well protected as the snow course, then the variation between the protected and the unprotected areas can be as high as 14 inches of evaporation. Since there is probably <u>some</u> evaporation in the minimum year, and since there is probably <u>some</u> evaporation on the snow course and in the forest protected areas, it is the writer's opinion that the total of 14 inches of winter evaporation in the exposed areas, is a conservative figure.

In Plate II, the errors of estimate were changed from plus and minus to a Wind Index ranging from zero to a negative ten inches of water.

To the curve values of the Wind Index, the plus and minus curve values of the Temperature and Radiation Indices were added to obtain a total evaporation correction for wind, temperatures and solar radiation.

This correction was applied to the Total Precipitation Index of Plate I, in order to obtain the Basin Index of the Forecast Equation in <u>Plate V</u>.

The graphical analysis indicates that there is no usable interrelationship between the air temperature and radiation factors, but for a clearer picture, Degree Days versus Hours of Sunshine have been plotted. <u>Plate VI</u> shows their independence of each other.

The upper graph is again <u>Plate II</u>, the wind perimeter. In <u>Plate VII</u>, the Temperature and Radiation indices have been combined. The purpose of the two graphs is to illustrate the wide variation in evaporation that the extremes in wind velocities can achieve with years having identically normal evaporation factors. (Note 1957, 1953, and 1956 in both plates.)

Some schools of thought maintain that condensation is equal to evaporation, thereby creating a balance that eliminates consideration of a snow pack evaporation factor.

In this analysis, the 750 millibar data at Boise, Idaho consist of two observations per day, for six months of each year, and for 15 years of record. The air temperatures above zero degrees Centigrade and relative humidity was checked against a Condensation-evaporation chart developed by the U. S. Army Corps of Engineers. Since surface snow temperatures rapidly follow air temperatures, zero degrees was assumed for the snow surface. Of considerable interest is the fact that 97 percent of the data indicated that evaporation was taking place. At Lander, Wyoming, for the same period, 99 percent of the data met the conditions for evaporation.

Condensation occasionally appears early in November and in the latter part of April, when humidity and temperatures are getting higher. To this extent, this factor will be considered in our forecast procedure.

The analysis of the Salt River above Etna, Wyoming is quite similar to the Smith's Fork, and it should be, since some of the snow courses are common to the Smith's Fork and Salt River watersheds, and used in both correlations. However, I would like to briefly show the Salt River analysis, because of an interesting relationship between it and the Grey's River drainage.

Plate VIII is the total precipitation index versus ASROM as shown at the 1962 Western Snow Conference.

The total evaporation index indicated by wind, temperatures, and radiation was applied to the total Precipitation Index of Plate VIII to obtain the Basin Index of Plate IX, the Forecast Equation for the Salt River.

Included in this paper is a map of the Grey's River and the Salt River drainages. These streams are bounded by three mountain ranges, running almost due north from the headwaters of each river, and lying at right angles to the prevaling "Winds Aloft" of Boise and Lander.

The range on the west of the Salt River Basin is a comparatively low ridge, offering very little obstruction to the 8,000-10,000 foot west winds.

Lying between and common to both watersheds, are the lofty peaks and ridges of the Salt Range. The western flank forms the major part of the Salt River watershed, and receives the full brunt of the high elevation wind. It also forms a protective barrier that, apparently, forces these high velocity winds to bounce completely over the entire Greys' River Basin.

Plate X is the ASROM of the Grey's River above Palisades Reservoir versus the ASROM of the Salt River above Etna, Wyoming.

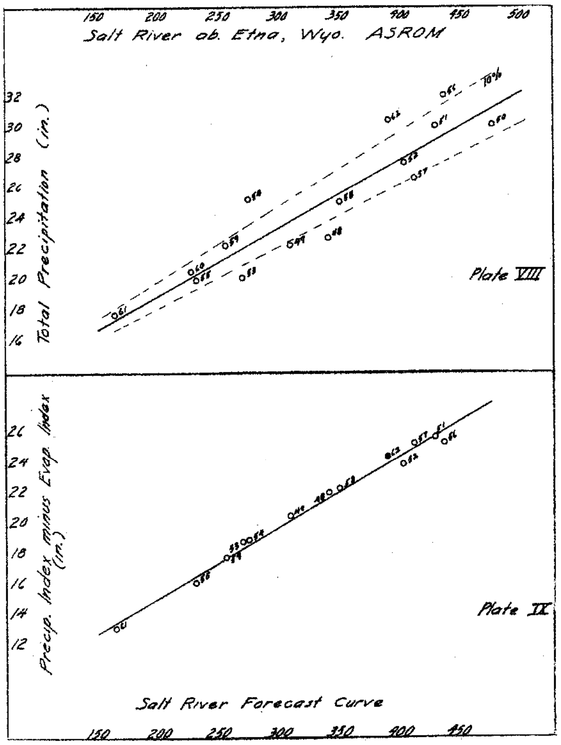
The errors between the mean curve and the Salt River ASROM of Plate X were determined and plotted against the average of the Lander 700 and Boise 750 millibar winter wind shown in Plate XI. The plus and minus errors were then changed to an "Evaporation Loss" ranging from zero to a positive 100,000 acre-feet of water, and the estimated correction for each year determined by its curve value.

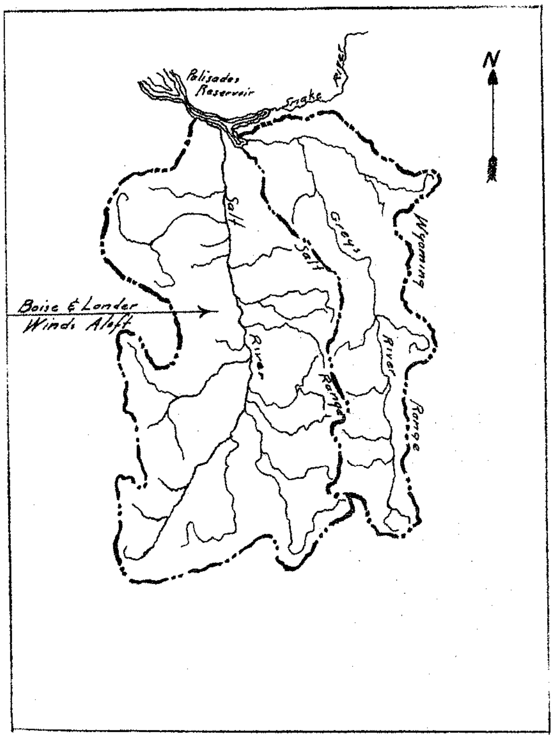
These positive corrections were then added to the measured Salt River ASROM of Plate X as repeated, in order to obtain an estimated runoff that had not been subjected to heavy evaporation losses.

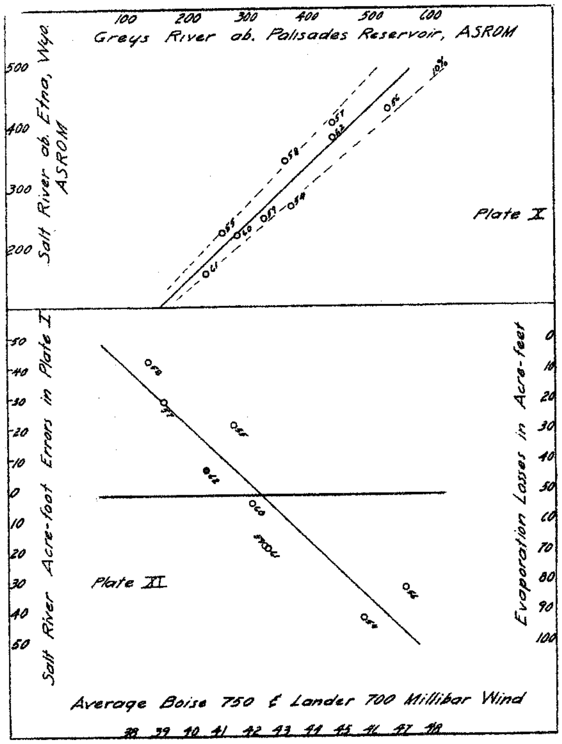
In Plate XII, the estimated Salt River ASROM is plotted against the measured Grey's River ASROM to provide the Grey's River Forecast curve.

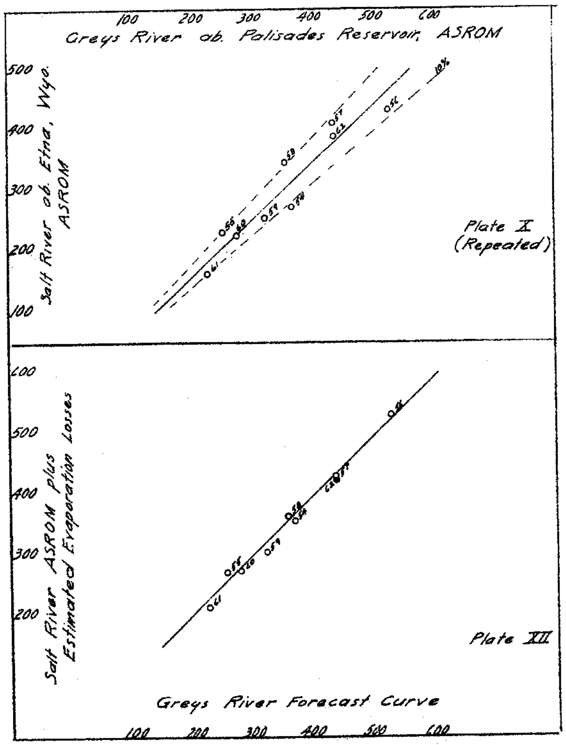
The results indicate that the Grey's River watershed is a protected watershed, subject to comparatively light evaporation losses.

It is believed that there are other Wyoming Watersheds whose mountains form a barrier


150 200 250 300 350 400 450 500
Salt River ab. Etna, Wyo. ASROM
32 30 28 26 24 22 20 18 16
Total Precipitation (in.)
10%
Plate VIII
26 24 22 20 18 16 14 12
Precip. Index minus Evap. Index (in.)
Plate IX
Salt River Forecast Curve
150 200 250 300 350 400 450


N
Palisades Reservoir
Snake River
Salt
Greys
Wyoming
Salt
Boise & Lander Winds Aloft
River
Range
River
Range


100 200 300 400 500 600
Greys River ab. Palisades Reservoir, ASROM
500 400 300 200
Salt River ab. Etna, Wyo. ASROM
10%
Plate X
-50 -40 -30 -20 -10 0 10 20 30 40 50
Salt River Acre-foot Errors in Plate I
0 10 20 30 40 50 60 70 80 90 100
Evaporation Losses in Acre-feet
Plate XI
Average Boise 750 & Lander 700 Millibar Wind
38 39 40 41 42 43 44 45 46 47 48


100 200 300 400 500 600
Greys River ab. Palisades Reservoir, ASROM
500 400 300 200 100
Salt River ab. Etna, Wyo. ASROM
10%
Plate X (Repeated)
600 500 400 300 200
Salt River ASROM plus Estimated Evaporation Losses
Plate XII
Greys River Forecast Curve
100 200 300 400 500 600

against the high velocities of the "Winds Aloft" and the temperatures carried in by these winds. There is also some indication that in these areas, radiation may be the predominant evaporation factor.

This summer, The Soil Conservation Service intends to place a Sunshine Duration Recorder at Moran, Wyoming, with the hope that it will improve the forecasts of the Snake River, Shoshone, and Upper Wind River watersheds.

At the Cheyenne and Yosemite Western Snow Conferences, it was suggested that whenever a Wyoming watershed appears to have an evaporation factor, it may actually be the result of a snow course "loading up". Since a varying loss has been found to exist in ten watersheds scattered throughout the state and in Colorado, "loading up" would then be applicable to the majority of the key snow courses in the State.

In order for a protected course to receive foreign snow, it must be placed to the leeward, below, and within the short "reach" of a cornice plume. The slab created is unmistakable.

It was argued, too, that the Wyoming courses might be subjected to direct wind action. To a minor extent, this is true of a few courses in this state--and every state in the west. It is too much, however, to theorize that Wyoming snow courses are consistently piling up in direct proportion to the winter wind velocities. In theory, half of them would scour out.

Toward the latter part of February, belatedly, an effort was made to obtain some measured evaporation data in the timberline region shown above.

This installation consists of two 12-foot Pearson Precipitation towers with the cans replaced by small metal plates. They are located on a bare, wind-swept ridge, a few yards behind the upper Hogadon Basin ski hut. The elevation of the ridge is 8,000 feet. The <u>average</u> winter wind velocity at this elevation is 25 miles an hour.

The towers were deliberately placed in a lower alpine area that is subject to maximum wind velocities, an area comparable to the state's two thousand square miles of gale-swept plateaus and parks, naked ridges, and wind-battered peaks.

To emphasize the tremendous variation in the characteristics of a given snow pack within the periphery of a small watershed, compare this bleak terrain with the Casper Mountain snow course located one mile to the east. The elevation is the same, but the course lies in a quiet, forest protected opening. The March 1, 1963 Water Supply Outlook Bulletin for Wyoming indicates a snow depth of 60 inches, with 9.2 inches of water. The density was 15.3 percent, considerably less than the density of wind packed snow, or the slab formed from wind deposited snow.

On February 20, 1963, a block of ice, weighing about forty pounds, was placed in a shallow, white plastic-lined tray, and installed on Tower No. 1. The Pearson Gage indicated the ice contained the equivalent of 22.15 inches of water in the 8 inch precipitation can. No. 1 was exposed to wind, temperatures, and radiation. Bob Hardesty, manager of the Hogadon Basin, kept it free of fresh snow during the week, and on weekends, my sons kept it brushed off. On March 20, four weeks later, it was reduced to one-third of its original size. There had been no melt. 15.65 inches of water had evaporated and blown away.

Records were kept of the area of the ice exposed. Proportionately, this amounted to 1.48 inches of evaporation from the end area of an 8 inch cylinder, or, perhaps, from the remnants of the scoured snow surface shown here.

Tower No. 2 was for the purpose of eliminating solar radiation. A short record of one week was favorable, but inconclusive. The results indicated an evaporation rate of 90 percent of the fully exposed ice on Tower No. 1.

A third tower will be installed for the winter of 1963-64, in an effort to eliminate the wind, and No. 4 will be a short tower exposed to the three factors, but placed on a northern exposure, in a forest protected opening that would be considered ideal for one sample point on a snow course.

Summary

1. Correct interpretation of evaporation factors seems to be dependent on a pattern of protected snow courses located at both intermediate and high elevations.

2. Temperatures seem to be capable of about twice the effective evaporation range of radiation, and, in turn, high wind velocities seem capable of expanding the combined effect of these evaporation factors to four times their normal values.

3. There is urgent need for a snow pack evaporation formula that will reduce daily meteorological values to inches of evaporation. There is some indication that alpine evaporation rates from ice may be closely proportional to that of snow. If this is true, and we hope to find out in the winter of 1963-64, the installation of evaporation stations on open ridges may provide a practical evaporation factor for the Rocky Mountain snow survey network.

4. Because of the highly untenantable conditions for men and equipment, there has been very little research in alpine hydrometeorology. The recession in area-elevation runoff relationships has been interpreted as a progressive decrease in winter precipitation from timberline up through the middle and upper alpine areas. It is the author's belief that these comparatively lighter snow packs are the result of heavy evaporation rates in the alpine zone.