SOIL MOISTURE DATA AS A FORECASTING VARIABLE

By

Homer J. Stockwell[1/]

Introduction

Not far from this location, on the slopes of Long's Peak in Colorado, the first soil moisture station was installed on August 12, 1952--at least the first station to be installed as a formal part of the snow survey network.

The Southern Rocky Mountain area had a heavy snow accumulation during the winter of 1951-52. Most snow courses had a maximum snow accumulation for some 17 years of record up to that date. In general, the maximum still stands. However, the runoff from this snowmelt was disappointing. Summer streamflow was above average, but generally far short of that which should have been expected from the snowpack. This occurrence could not be reasonably explained by the deficiency in spring and summer precipitation.

The installation of about a dozen soil moisture stations here in Colorado in 1952 and 1953 was motivated by a desire to explain the apparent deficit in snowmelt runoff. We did know that mountain soils were dry in 1951 and there had been some three years of below normal precipitation in the area.

Since that date over 200 soil moisture stations have been installed in western states. Details were reported to the Conference by Farnes and others in 1963. A/

THE SOIL MOISTURE STATION

Description of Units

The development of the electrical resistance soil moisture units during the 1940's provided a practical method of obtaining a measure of soil moisture beneath the snowpack. One type of unit selected for the installation is commonly known as the Colman Unit, which was developed by the Forest and Range Experiment Station, U. S. Forest Service, California Region. B/ This unit consists of two small monel metal screen electrodes, wrapped in fiberglas, and encased in monel metal. Holes in the case allow a free flow of moisture into the fiberglas. The dimensions of the unit are roughly 7/8" x 1-1/8" x 1/8". Insulated leads from the two electrodes allow for the measurement of resistance through the fiberglas between the electrodes.

The units are designed so that the resistance between the electrodes is about 1000 ohms in soils at field capacity and some 150,000 to 200,000 ohms at wilting point. The resistance is measured with a portable A.C. Ohmmeter with a frequency of about 90 CPS.

The Installation

Installation is not the subject of this paper, but Figure 1 is a sketch of a typical installation. A pit is dug to the depth of the root zone, usually 4 to 6 feet deep. The units are pressed into undisturbed soil at approximately one-foot intervals. Near the surface spacing is usually at six-inch intervals. The wires lead into a pipe up to a level above the prospective snowpack.

Interpretation of Meter Readings

The reading obtained by the ohmmeter measures only the resistance of the unit with a certain moisture content. While this resistance could be used as a measure of soil moisture, it has been the practice to convert the meter readings to approximate soil

1/ Water Supply Forecasting Branch, Soil Conservation Service, Portland, Oregon.
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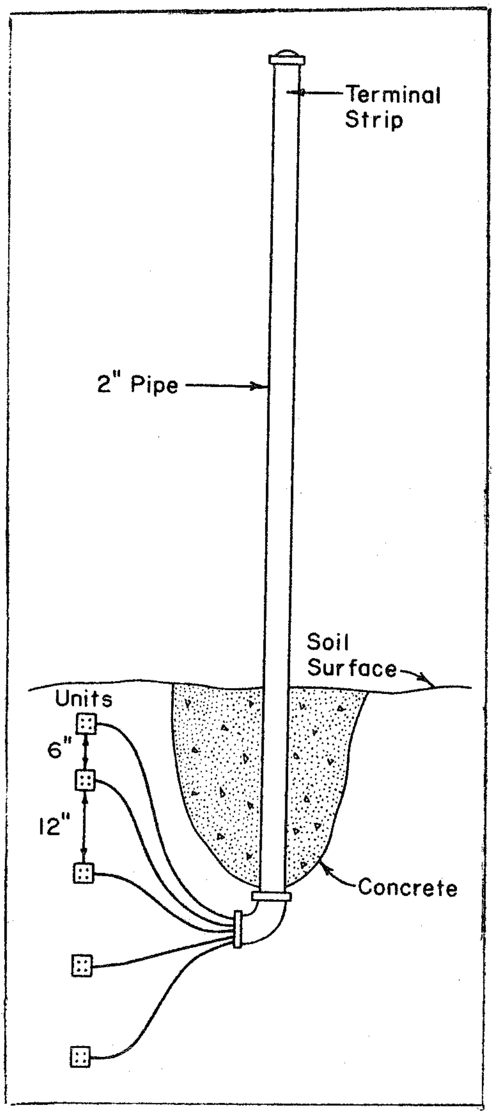
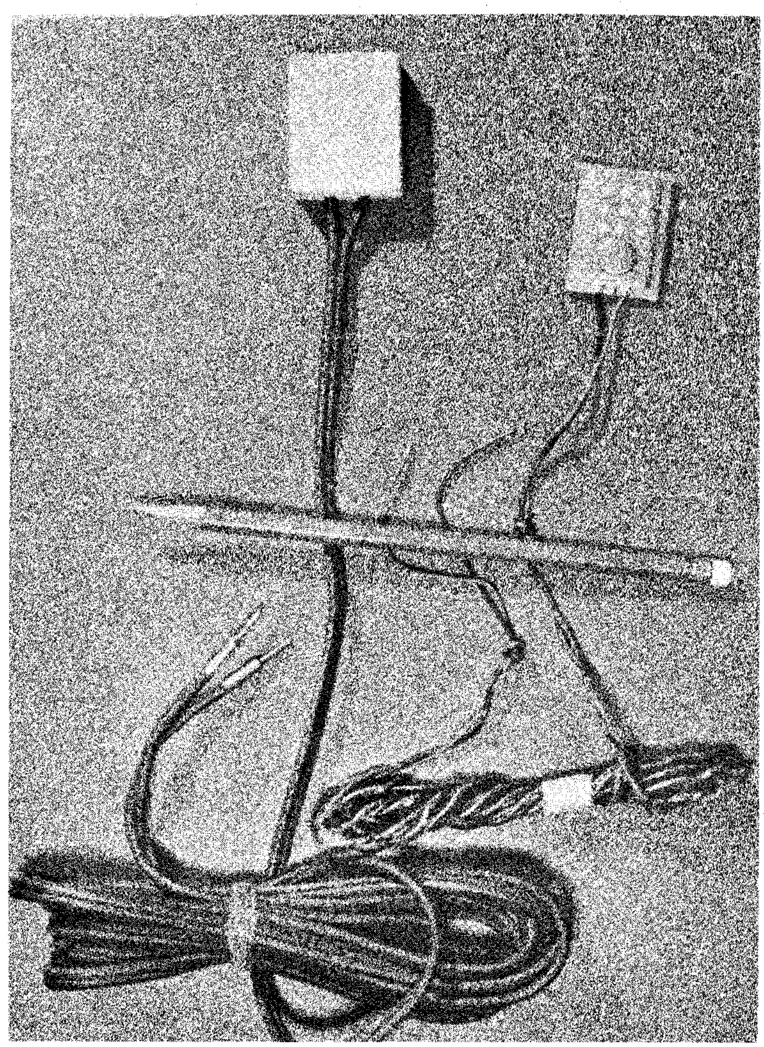


Figure 1. Sketch of a Typical
Soil Moisture Station.



Colman and Bouyoucos Soil
Moisture Units.

moisture in percent of dry weight or in inches of water per foot of depth, or for the soil profile at the site. These are more familiar terms of measurement and reporting of data.

From a practical standpoint, this conversion procedure must be semi-empirical. While details are not to be described here, interpretation must consider essentially two factors.

1. Variation in the Design of the Unit

While these units are reasonably standard, slight variations in spacing of electrodes, the mesh and fiber diameter of the fiberglas, and the compression of the fiberglas does cause variations between units. Generally a resistance of 900 to 1200 ohms will be obtained in a soil at field capacity, but readings from 400 to 3000 ohms have been obtained in extreme cases. In practice, field capacity ohmmeter readings for individual units are determined at the measuring site during the snowmelt season.

2. The Variation in Soil

Variations in soil cover a wide range. Probably no two soil locations will have exactly the same texture or chemical composition. Further, the ability of the fiberglas to take on moisture from the soil varies with soil characteristics and its contact with the soil. The practical solution here is to classify soils into a few general types, such as coarse, medium and fine, and assign a resistance measurement to the various points through the soil moisture range for each soil texture. The texture of the soil also defines general limits of moisture holding capacity.

Regardless of the laboratory or field tests made with units or soils, there is some degree of approximation in interpretation procedure. However, with care, it is believed that the units will reflect soil moisture at the point of measurement, and general watershed soil moisture conditions, as well as the gravimetric sample or possibly the more sophisticated neutron counter.

These procedures are covered in standard soils texts. A report showing details of field and laboratory procedure has been prepared by Codd and Farnes. C/

Reliability

During the 12 years that soil moisture stations have been in use there have been very few mechanical failures. Most failures have been due to external damage or rodents. Total failure has been less than 5 percent over this period. No trends toward higher or lower resistances have been noted.

USE AS A FORECASTING VARIABLE

Theory

The theory of effect of soil moisture on snowmelt runoff from a given snowpack is simple. Soil moisture deficiencies are expected to be satisfied by infiltration of moisture from the snowpack. Amounts and rates are dependent on a number of factors.

Variation in Soil Moisture

Water holding capacity of soils is important when using soil moisture as a forecasting variable. This is especially true in the Rocky Mountain area. Soils of this area tend to have a high sand and gravel content and to be limited in depth.

In locating soil moisture stations, extremely rocky or gravelly locations are obviously avoided. However, even with these selected locations, variations in soil moisture as compared to variation in snow accumulation are small.

In this study, the records on 49 soil moisture stations with 7 to 11 years of records were reviewed. On 29 of these stations the difference between the maximum and minimum soil moisture content measured near April or May 1 was less than 4.0 inches for the soil profile. At 15 stations the maximum variation was from 4.1 to 6.0; four stations had a variation of from 6.1 to 8.0 inches and only one exceeded 8.1 inches.

Typically, these stations are located in areas where seasonal snow accumulation is 20 to 30 inches of snow water equivalent and a deviation of plus or minus ten inches is commonplace.

From this record above, it is obvious that the opportunity to increase forecast accuracy depends on moisture holding capacity and variation of moisture on the forecast date. Where the range is small, variations in climatic conditions during the snowmelt season can obscure any improvement in accuracy.

Past Use of Soil Moisture Data

Snow survey supervisors in the Soil Conservation Service have been using measurements of soil moisture as a "judgment" factor in forecasts where available for the past five years or so. Usually these judgments have been backed up by plots of soil moisture data vs. errors in forecasts after adjustments for measured subsequent events, usually spring precipitation. Examples of this procedure were reported by Farnes and Nelson to Western Snow Conference in 1963. A/ Streams involved were the Middle Fork Flathead in Montana, and Salmon Falls Creek in Nevada and Idaho. This report indicated a slight improvement in forecast accuracy for four to seven years of record.

However, "judgment" factors are difficult to record and evaluate. With up to eleven years of record, we need to take a look at soil moisture -- Is it worth the effort?

Study Procedure

Records were assembled for soil moisture stations with seven to eleven years of record. Nearly half of these were in Colorado, but others were selected from Wyoming, Montana, Idaho, Nevada, and Oregon. Some 26 stations had records of this length that were used in the study. There were about 20 others that could have been used but were eliminated for various reasons. A similar number of related snow courses were involved.

The basic procedure was to relate a March 1, April 1 or May 1 snow course measurement to subsequent snowmelt season runoff. Then the data from the most suitable soil moisture station in the vicinity was added to the snow course data and compared to runoff by multiple correlation. The results obtained were comparable correlation coefficients and forecast errors in acre feet.

This procedure was essentially comparing individual items of data to runoff. Individual comparisons would have little meaning with the short record. However, 56 comparisons on 19 streams were made with various combinations of snow courses, soil moisture stations and related streamflow, which allows a trend to be illustrated.

Admittedly, a better procedure would have been to develop forecasts based on snow water equivalent and spring precipitation and possibly other minor factors and then add the soil moisture data. We intend to do this as time and resources are available. Limited studies of this type indicate the results would have been comparable, except that the correlations would be higher and the range of errors slightly less.

Results

In 33 comparisons (31 in April, 2 on March 1) the addition of soil moisture data increased the average correlation coefficient from .714 to .770 and reduced the percentage error of the estimated flow from an average of 17.4 to 15.1. Major improvement in forecast accuracy was noted on the Yampa and Animas in Colorado, the Boise in Idaho, and the Burns and Ochoco in Oregon. Since some of the improvements were rather large, it is more realistic to state that the typical improvement in correlation coefficient was near .03 and the reduction in error 1.0 to 1.5 percent.

On March 1 and April 1 two of the soil moisture variables out of the 33 comparable relationships had negative coefficients, thus increasing the error. These were the March 1 readings on Bear Creek Meadows on Salmon Falls Creek in Nevada and the Onion Gulch station on Tensleep Creek in Wyoming on April 1.

For May 1 the results were more erratic. The reason lies in the fact that May 1 data alone is seldom, if ever, used in a forecast procedure. However, coefficients for snow water equivalent were always positive, while some one-quarter of the soil moisture coefficients were negative. In cases where soil moisture was positive, the increase in correlation coefficient with snow water equivalent plus soil moisture over snow alone was substantial. So, if properly used, it appears the May 1 data will also be valuable where the major snowmelt starts near or after May 1.

Now for a few interesting sidelights. In accounting for flow in a forecast, snow water equivalent was, as a mean, about 1.2 times as effective as soil moisture per inch of water. Since snow water equivalent is far the largest variable, this factor is five or more times as effective as soil moisture in accounting for variation in runoff.

On one stream investigated, the soil moisture data had a slightly higher correlation with runoff than the snow water equivalent over an eight-year period.

There was no instance when the correlation between soil moisture and runoff was negative. The coefficient varied from .01 to .89. The general range was about .30 to .40.

Of course it must be recognized that these extremes are due to short records and a characteristic of the multiple correlation procedure.

CONCLUSIONS

Data on soil moisture does tend to increase forecast accuracy. There is some question as to the practical value of the improvement, depending on the forecast station and use of the forecast. In a forecast for agricultural purposes, a two percent error is not of much consequence in relation to overall losses and variation in irrigation water demands. On the other hand, on a river such as the Colorado, two percent is roughly 200,000 acre-feet at Lake Powell and represents an important amount of water.

More pertinent, I believe, is that this study indicates under what conditions the soil moisture stations are of most value and where they are of little or no value.

1. Forecasts which are relatively good based on measurements of snow water equivalent tend to be more improved by adding soil moisture than in areas where forecast errors are high. Geographically, the data was of more value on Colorado River tributaries, the Rio Chama in New Mexico, the Boise River in Idaho and two small streams in Oregon. This is in contrast to streams such as the South Platte and Arkansas here in Colorado where spring and summer precipitation has a substantial affect on snowmelt season streamflow.

2. Soil moisture capacity must be sufficient to allow a reasonable variation in soil moisture. Soils with less than 6 or 8 inches of total soil moisture capacity in the root zone are questionable locations for soil moisture stations. These include the typically mountain soils which have lots of sand and gravel and only a foot or so of good soil mantle. These variations of four inches or less are generally not sufficient to over ride other forecast variables that contribute to forecast errors.

The improvement in accuracy using soil moisture data is definitely related to the moisture holding capacity of the soil.

3. Bouyoucos soil moisture units have sometimes been used instead of Colman Units. These are installed on the Rio Chama and on small tributaries to the Rio Grande in New Mexico, the Animas River in Colorado, and a few other locations in Colorado. Data from these stations generally tended to improve forecasts more than the data obtained from Colman units. While it is suspected that this situation is a result of a combination of soils and hydrologic conditions in the particular watersheds rather than soil moisture units, this deserves further investigation.

4. While not directly involved with soil moisture, the Colman units have a soil temperature thermistor. This has been valuable on occasions in estimating the early season runoff potential where a substantial low elevation snowpack existed. If the soils are not frozen, some snowmelt will usually be taken up by the soils. If the soils are frozen, higher runoff is likely to result.

No record has been obtained where soils were frozen under three or more feet of mountain snowpack.

RECOMMENDATIONS

We should continue the soil moisture station program, taking advanatage of the ten years of experience in making changes or expansion in the network. We should continue installations in areas of 10 to 30 inches of snow water accumulation. We should continue to avoid unusual soil conditions such as extremem rocky conditions and flat areas with poor drainage. We should limit soil moisture stations to watersheds which have a sufficient soil mantle to allow for a variation of four or more inches in soil moisture on the forecast date.

We will follow up on these investigations as more record becomes available to more definitely define the value and limitations of soil moisture data.

REFERENCES

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LIST OF FIGURES