Soil Moisture Data Collection and Water Supply Forecasting: the sequel.

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Abstract

The strong relationship between snow water equivalent and seasonal water supply has long since been demonstrated. Theses statistical relationships vary in strength depending on a host of factors such as latitude, elevation, and others. Part of the error associated with these relationships is due to unknown future meteorological conditions that impact the timing and volume of the runoff. Another part of the error associated with statistical relationships is due to the variable state of soil moisture. Soil moisture conditions across a watershed are generally presumed to influence seasonal water supplies from snowpack(Wetzel and Woodward, 1987). If extremely dry conditions are prevalent in the fall prior to the seasonal snowpack, then it is presumed that these soils have additional capacity to absorb and retain some greater than normal amount of snowmelt, leaving a reduced amount to generate seasonal streamflow. Conversely, if the soils are saturated prior to the onset of snowmelt, it is presumed that, since the soils have less capacity for infiltration and certainly less storage, that the majority of snowmelt should contribute directly to seasonal streamflow. The total potential snowmelt loss to soil moisture recharge can be significant, assuming a 24 inch soil depth, 8 to 10 inches of snowmelt or more, could be infiltrated depending on soil type and condition. Some portion of this would eventually contribute to runoff and some portion would be lost from the immediate contributing system through either evapotranspiration or to deeper groundwater. The Natural Resources Conservation Service now has soil moisture sensors at five sites in Utah (Julander and Cleary, 2001) with plans to install many more. Preliminary data indicate great potential value from these data in reducing water supply forecast error. Interesting relationships between summer/fall precipitation and soil moisture are analyzed. Snowpack, soil moisture and runoff are compared.

INTRODUCTION

Natural Resources Conservation Service has installed soil moisture sensors at 5 sites along the Wasatch Front and in northern Utah to determine if the use of such data can reduce the error associated with statistical water supply forecasting. These sensors, installed at the 5.1 cm, (2-inch), 20.3 cm, (8-inch), and 50.8 cm (20-inch) depths have been in place for 3 years and thus only preliminary data are available for analysis. All are located on small watersheds near dense populations where flooding or debris flows could have a significant impact on the safety of citizens.

The soil moisture sensor installed is the Vitel Hydra Soil Probe. The operation principle is based on high frequency complex dielectric constant and measures soil moisture by volume. Both the capacitive and conductive components are measured. A thermistor is used to determine temperature. It is designed for a field life of approximately 15 years and is constructed of stainless steel. It has an accuracy of plus/minus 3 percent in the absence of specific soil calibration and about 0.5 percent if soil analysis is done (Vitel, 1994). With the advent of a sensor with this longevity and anticipated stability, many of the complex problems associated with long

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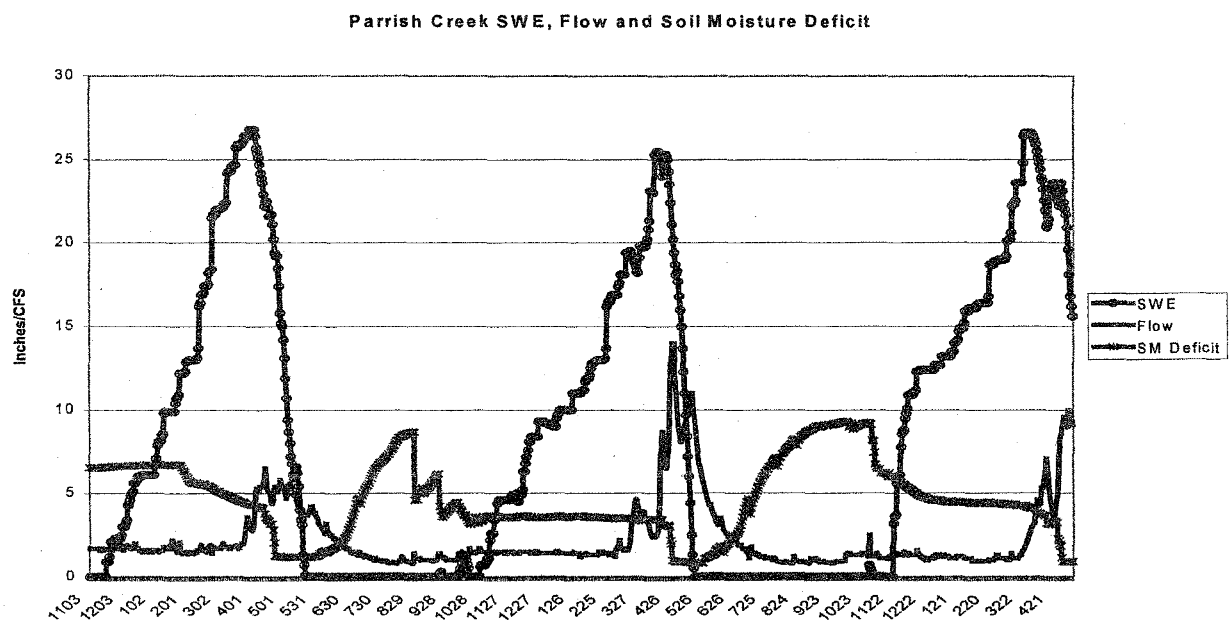
term soil moisture monitoring may be avoided. This, in turn, could lead to a relatively accurate soil moisture index with the potential to reduce water supply forecast error.

ANALYSIS

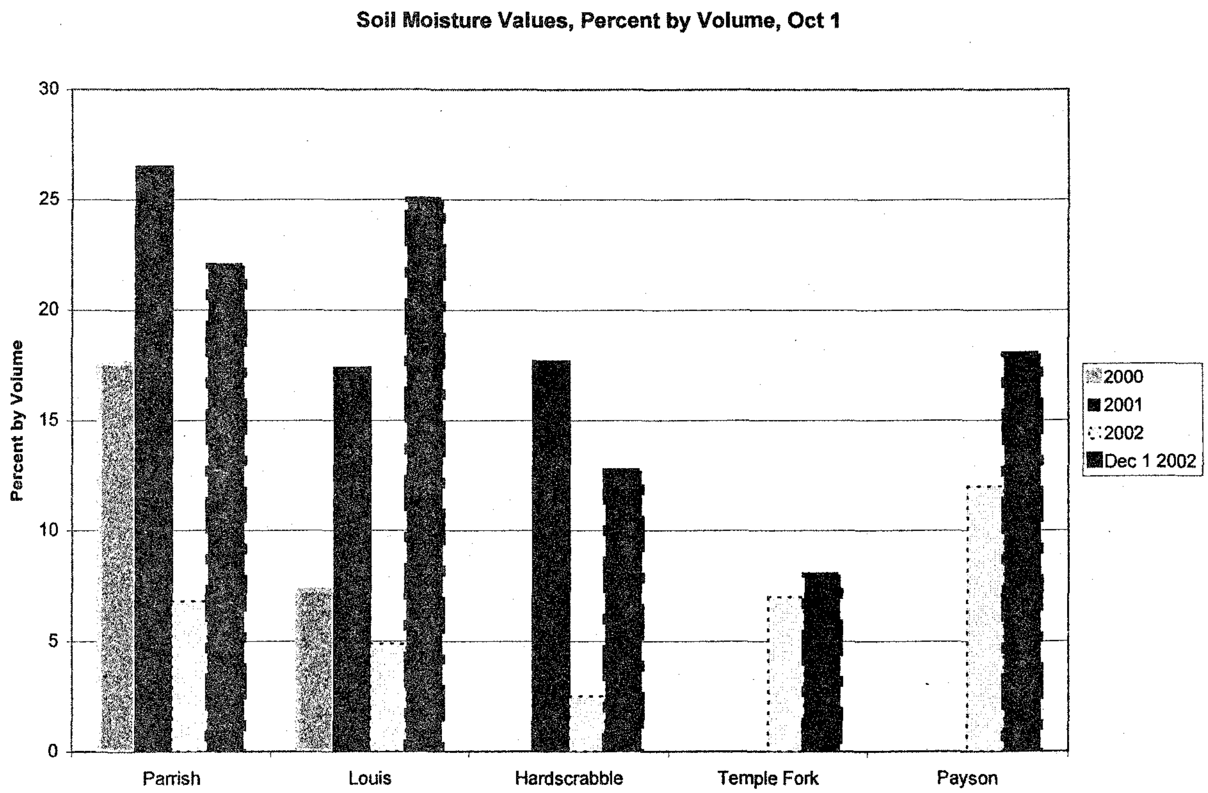
The original paper presented at the Western Snow Conference detailed a significant soil moisture deficit that impacted snowmelt runoff. In the subsequent year, soil moisture values improved dramatically, going from a deficit of almost 17.8 cm (7 inches) to about half that amount. Chart number 1 shows the Parrish Creek Station with a calculated soil moisture deficit, snow water equivalent and streamflow. The soil moisture deficit is an estimated amount based on the equation supplied by the manufacturer of the soil probe and should be used as a relative index and not an absolute value.

Chart 1



At this site, the first year of analysis, the soil moisture deficit was about 17.8 cm (7 inches) going into the snow accumulation season. The total snow water equivalent available for melt was about 68.6 cm (27 inches), about 26% of which would bring the upper 61 (24 inches) of soil to complete saturation. The April-July runoff that year was particularly poor at 970,370 cu meters (787 acre-feet) of volume. The next year, with only 63.4 cm (25 inches) of snow water equivalent, 5 cm (2 inches) less than the previous year, the April-July volume of streamflow was 1,405,620 cu meters (1140 acre-feet). This was 145% of the previous year's flow with less snow. The difference in runoff efficiency is mostly attributable to the difference in soil moisture. In 2000, there was a 17.8 cm (7-inch) soil moisture deficit to overcome and in 2001, there was only an 8.9 cm (3.5-inch) deficit. In the year 2002, the soil moisture deficit is greater than in 2001, but less than 2000. The October 1 soil moisture deficit is much greater, but a permanent snowpack had not been established at that time and several late season precipitation events brought the soil moisture values up significantly, potentially avoiding a huge snowpack to soil moisture loss during this runoff season. Preliminary numbers indicate that with a 10.2 cm deficit (4 inches) and a similar snowpack to 2000, streamflow is going to be much higher, again confirming that higher soil moisture values produce higher streamflow with similar snowpacks. Chart 2 shows the October 1 soil moisture values in percent by volume. It is unclear at this time what soil moisture time frame will be most closely correlated to runoff efficiency. However, given the magnitude of soil moisture deficit, which was even less than the original comparison year of 2000, water supply forecasts were anecdotally adjusted to compensate for anticipated soil moisture losses.

Chart 2



Clearly in the 2002-water year, October 1 would be inappropriate due to the late season storms that brought precipitation at even the 3048-meter (10,000 foot) level along the Wasatch Front area only. The sites at Temple Fork and Payson Ranger station did not receive the magnitude or the duration of storm events that Parrish, Louis and Hardscrabble did. Thus the soil moisture values and these and basically the rest of the state, remained close to what they were on October 1. The establishment of seasonal snowpack may be the best correlation potential, if there is not significant moisture movement through the soil profile subsequent to that time. Further analysis of the patterns of soil moisture values throughout the seasons reveals that the timing, frequency, magnitude and intensity of storm events play a major role in how soil moisture is replenished at the higher elevations. During the summer of 2001, the Parrish Creek site accumulated 9.4 cm (3.7 inches) of precipitation and soil moisture values dropped from near saturation of 40.5 percent by volume to a bone dry 6.5 percent. A series of small summer storms that ranged from 0.5 cm (0.2 inches) to 2 cm (0.8 inches) moved increased soil moisture in the range of 1 to 2 percent by volume. The duration of impact that these storms had on soil moisture was typically only 1 to 3 days, after which, soil moisture began to drop again. The affect of these few storms was mainly in at the upper 2 sensors at the 5 cm and 20.3 cm (2 and 8-inch) depths. Given the dry state of the soil, these storms were enough to barely wet the upper soil mantle and were subsequently evapotranspired. In late October, there was a more significant storm that dropped 5.8 cm (2.3 inches) of precipitation from October 30 to November 8. This storm raised the soil moisture average from 6.5 percent to 18% by volume. The magnitude was sufficient, the duration short enough, the timing when there is little evapotranspiration and the frequency short enough that this storm significantly altered the soil moisture status throughout the entire soil profile. This reveals a potential error in a common water supply forecasting technique, which is to lump seasonal precipitation as a variable in streamflow correlation. Not all precipitation is equally effective in replenishing soil moisture, 10.1 cm (4 inches) over a month or a season, may not be equal to 10.1 cm (4 inches) over a week. A subsequent, larger storm from November 22 to November 27 dumped 13.5 cm (5.3 inches) of precipitation at this site and brought the average soil moisture value up to 21 percent by volume. Total precipitation of 19.3 cm (7.6 inches) brought soil moisture values from an exceptionally dry 6.5% up to 21% by volume. Soil moisture levels stayed relatively constant over the following winter months and then quickly became saturated as snowmelt began. It took about 9.1 cm (3.6 inches) of snowmelt to bring all sensors to full range or the equivalent of saturation. This give a range of about 28.4 cm (11.2 inches) of soil moisture capacity at the Parrish Creek site, a little more than the 25.4 cm equationally given. This is a potential area of individual site calibration that may provide more accurate soil moisture information.

Using preliminary streamflow data, it is evident that soil moisture has had a huge impact on snowmelt runoff across the state this season. Southeast Utah melted off the entire snowpack by early April and generated 30% streamflow (USGS). The Virgin Basin melted out by late April and streamflows were in the 10 to 20 percent range. The Sevier River had a 50% snowpack and streamflow is running at 19%. In northern Utah, the Bear, Weber and Provo watersheds had 75% to 85% snowpacks and are generating 12% to 75% streamflow with only 3 weeks of snowmelt left as of mid- May. Snowmelt runoff could be essentially over by June with some of the lowest flows ever recorded.

CONCLUSIONS

The Natural Resources Conservation Service, Snow Surveys in Utah has installed soil moisture monitoring sensors at a total of 5 sites. There are plans to install soil moisture sensors at 10 more sites in Utah this year, as well as 3 sites in Nevada and 2 sites in the Sierra Nevada of California. The anecdotal use of the soil moisture information was the basis for lowering streamflow forecasts in much of Utah outside of the Wasatch Front this water year (NRCS, 2002). Preliminary results indicate that forecasts were not lowered enough and that soil moisture may be largely responsible for the snowpack losses. There are many nuances about these sensors that remain unexplored and their full potential will most likely not be utilized until a larger temporal data set is collected. The anecdotal use of the information has been largely successful.

REFERENCES

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