SOIL MOISTURE IN FORECASTING

By

P. E. Farnes [1/], M. W. Nelson [2/], and T. G. Freeman [3/]

ABSTRACT

Soil moisture has been recognized for many years as an important factor affecting streamflow runoff, but instrumentation for measuring this factor has been slow in development.

A practical and economical measurement of soil moisture and temperature has been developed utilizing electrical resistance through fiberglass soil moisture units.

Records of data obtained in the past few years are too short to analyze statistically. However, in comparing soil moisture data to fall precipitation, and base flow and winter flow on streams in Montana and Idaho, results indicate that soil moisture explains forecast errors better than other variables.

Soil moisture data, although primarily obtained for streamflow forecasting, has many other uses. Relationships between soil moisture or temperature, and forage production, timber management, forest or grass fire potential, soil classification, flood potential and wildlife management are presently evident.

As records become available and the network expands, data on soil moisture should become a practical and useful factor in water supply forecasting as well as other related uses.

Soil moisture has been recognized for many years as an important factor affecting streamflow from a snow pack or rainfall.(1) Attempts have been made to measure the soil moisture in mountain watersheds in the fall or in conjunction with snow survey measurements by taking actual soil samples. Such measurements were generally abandoned as being impractical or too costly. It wasn't until the fiberglass electrical resistance unit and a suitable read-out meter were developed by the U. S. Forest Service at the California Forest and Range Experiment Station, that an economical and practical network for obtaining soil moisture data appeared feasible.(2) Recently, Montronics, Inc. of Bozeman, Montana has developed and produced a transistorized ohmmeter which is lighter and less costly than the original ohmmeter.

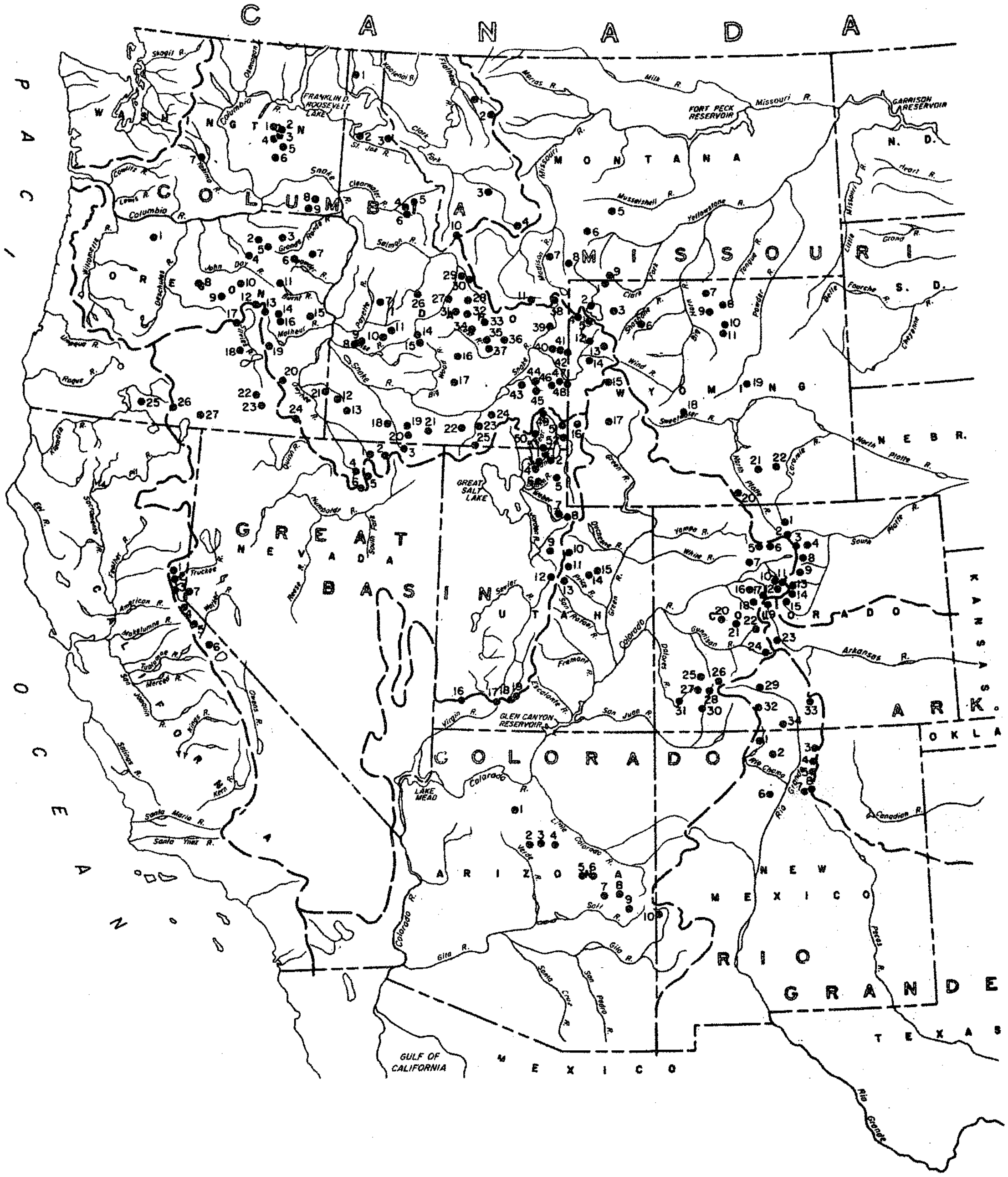
Utilizing these commercially produced components, considerable effort has been directed by the Soil Conservation Service toward establishing a network of soil moisture installations in mountainous areas of the western states.

Figure 1 shows the location of existing soil moisture stations as of January 1, 1963. Many of the stations are located at or near existing snow survey courses.

Generally, three to seven fiberglass soil units are used at an installation to obtain moisture and temperature data at various soil depths. Information is usually obtained for the top three to six feet of the soil profile. Using calibration curves, meter readings are converted to soil temperature and moisture.(3)

1/ Acting Snow Survey Supervisor, Soil Conservation Service, Bozeman, Montana.
2/ Snow Survey Supervisor, Soil Conservation Service, Boise, Idaho.
3/ Staff Assistant, Soil Conservation Service, Portland, Oregon.

Paper to be presented at Western Snow Conference, Yosemite National Park, April 17-19, 1963.



SOIL CONSERVATION SERVICE

SOIL MOISTURE STATIONS

WESTERN UNITED STATES

JANUARY 1963

50 0 50 100 150
SCALE IN MILES

TABLE I

South Fork Flathead River near Columbia Falls, Montana

Water Year	Actual Flow 1/ 1000 A.F.	Forecast Flow 1/ 1000 A.F.	Deviation 1000 A.F.	Marias Pass Soil Moisture April 1 Inches	Fall Precip. 2/ Aug+Sept+Oct Inches	Base Flow 3/ Nov. 1 cfs	Winter Flow Oct+Nov+Dec+Jan 1000 A.F.
1950	2952	2841	-111	5.81	23.99	850	276.4
1951	2440	2435	-5	5.47	34.23	2300	525.1
1952	2067	2344	+277 4/	5.51	41.25	2000	357.7
1953-56	Soil moisture data not available						
1957	1976	2173	+197	4.92	26.53	750	262.0
1958	1941	2144	+203	4.88	19.44	780	158.4
1959	3165	2986	-179	5.82	24.77	950	548.6
1960	2147	2044	-103	5.71	40.96	3000	681.1
1961	2248	2134	-114	5.35	20.74	800	179.5
1962	2465 3/	2539	+74 5/	5.48	27.16	980	257.7 3/

1/ April through September.
2/ Sum Gibson Dam, Ovando 1SW, Seeley Lake, Summit and West Glacier.
3/ Inflow to Hungry Horse Reservoir as computed by U. S. Geological Survey.
4/ Hungry Horse Reservoir began filling, September 1951.
5/ Provisional data.

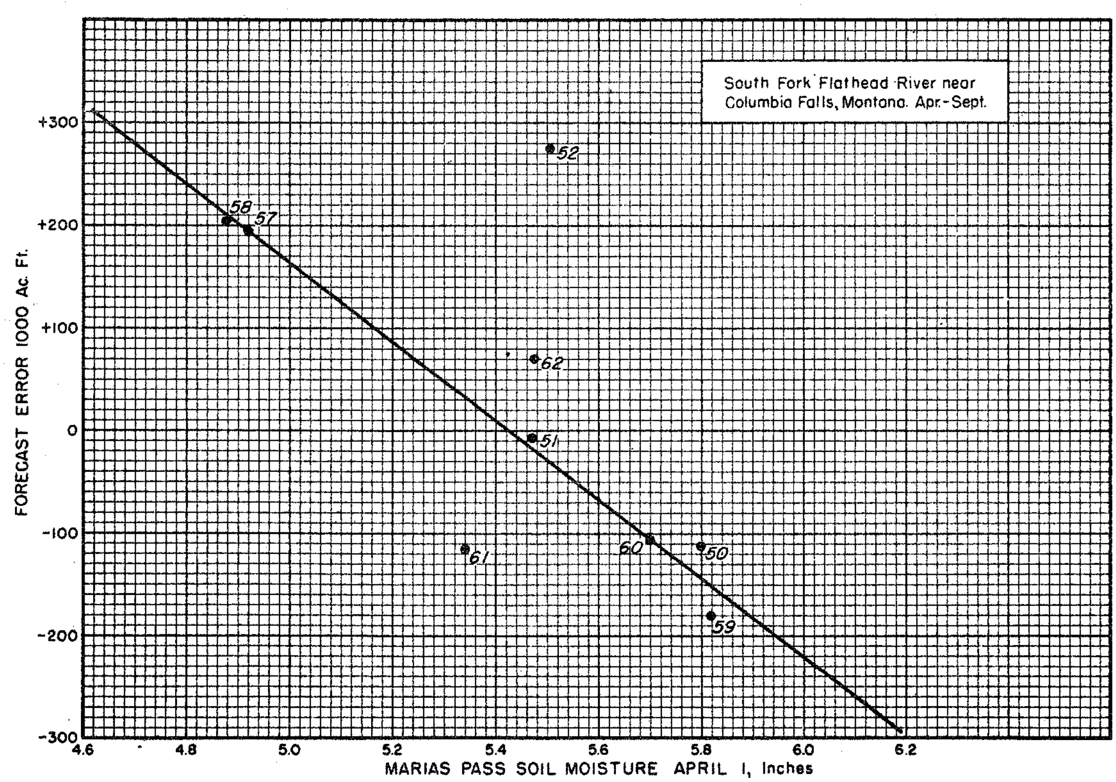


FIGURE 2

TABLE II

South Fork Flathead River near Columbia Falls, Montana

Water Year	Actual Flow 1/ 1000 A.F.	Forecast Flow 1/ 1000 A.F.	Percent Error 2/	Forecast Corrected for Soil Moisture 1000 A.F.	Percent Error	Forecast Corrected for Fall Precip. 1000 A.F.	Percent Error	Forecast Corrected for Base Flow 1000 A.F.	Percent Error	Forecast Corrected for Winter Flow 1000 A.F.	Percent Error
1950	2952	2841	-3.8	2986	+1.2	2779	-5.9	2709	-9.2	2761	-6.5
1951	2440	2435	-1.0	2450	+0.4	2555	+4.7	2640	+8.2	2540	+4.1
1952	2067	2344	+13.4	2374	+14.8	2589	+25.2	2476	+19.8	2327	+12.6
1953-56	Soil moisture data not available										
1957	1976	2173	+10.0	1978	+0.1	2165	+9.6	2017	+2.1	2081	+5.3
1958	1941	2144	+10.5	1932	-4.6	2002	+3.1	1994	+2.7	1974	+1.7
1959	3165	2986	-5.7	3136	-0.9	2938	-7.2	2876	-9.1	2858	-9.7
1960	2147	2044	-4.8	2149	+0.1	2286	+6.5	2409	+12.2	2274	+5.9
1961	2248	2134	-5.1	2104	-6.4	2021	-10.1	1989	-11.5	1982	-11.8
1962	2465 3/	2539	+3.0	2559	+3.8	2534	+2.8	2434	-1.3	2447	-0.7
	Average error		6.4		3.6		8.4		8.4		6.5

1/ April through September.
2/ Forecast flow divided by actual flow minus 100.
3/ Provisional data.

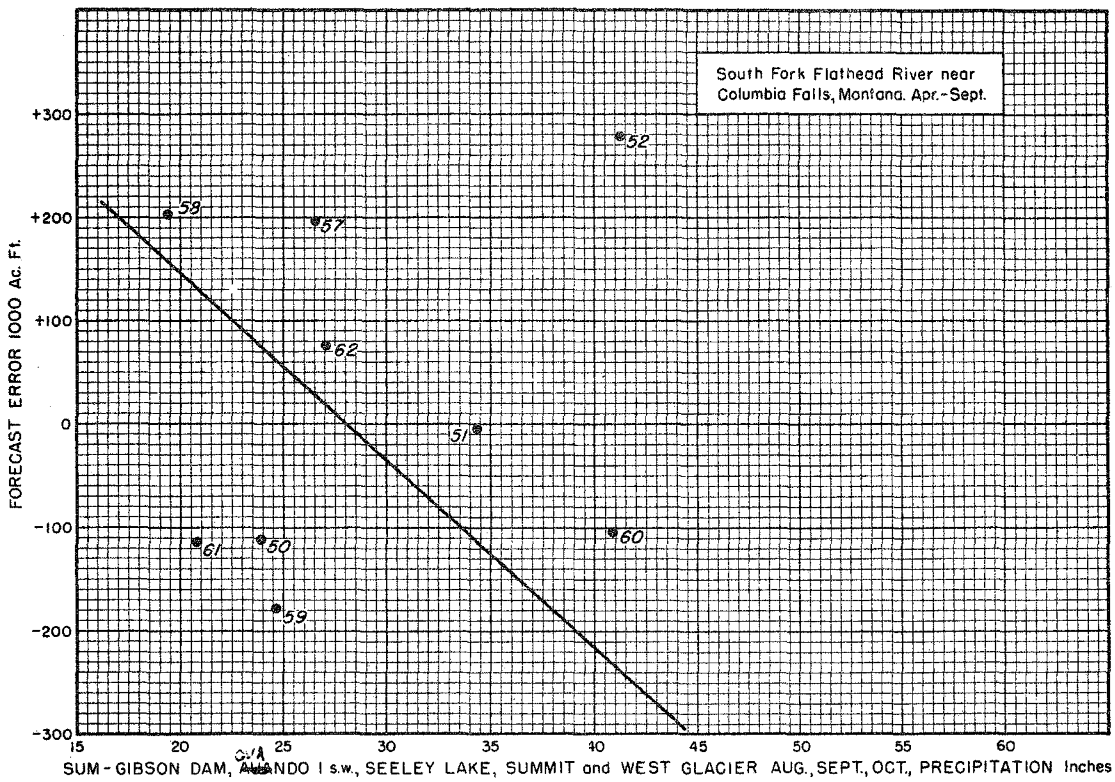


FIGURE 3

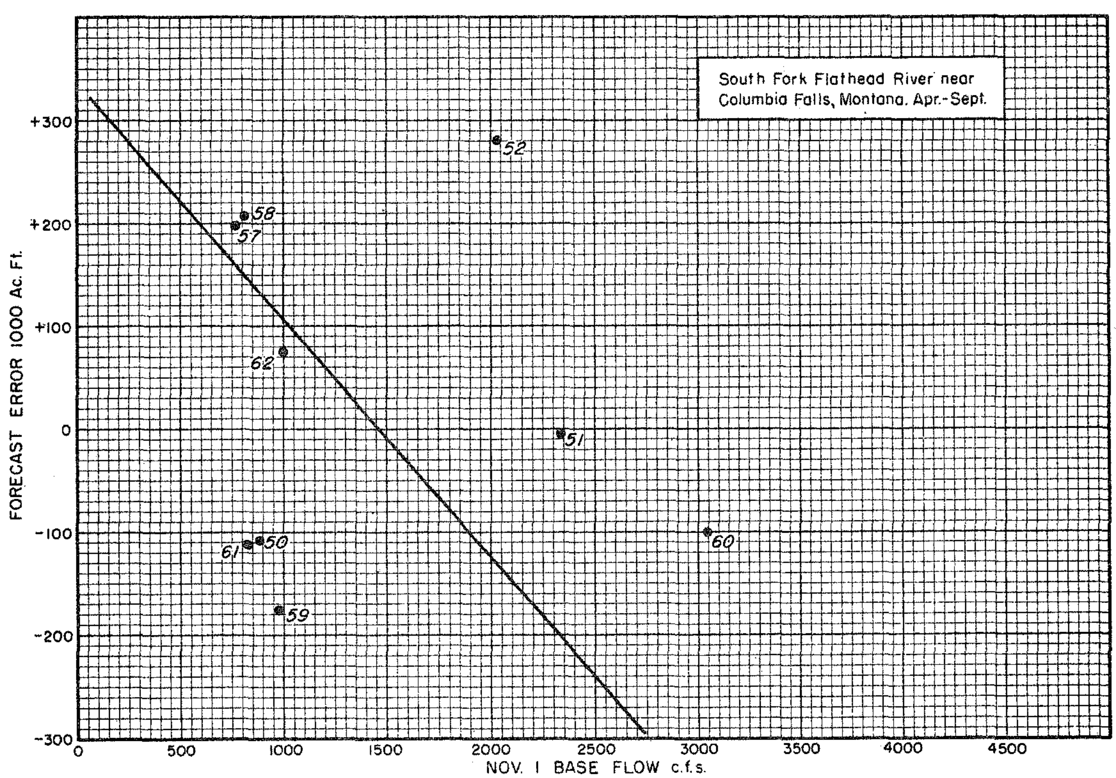


FIGURE 4

Readings are taken at various time intervals. Most stations are observed once or twice in the fall and concurrently with snow course measurements. Other stations are observed monthly and a few stations weekly.

Soil moisture data are reported in the Water Supply Outlook and Federal-State-Private Cooperative Snow Survey bulletins as the total amount of water in a given soil profile. Temperature and moisture data at the various levels are not currently published but may be obtained from the State Snow Survey Supervisors.

Snow water equivalent and winter and spring precipitation indexes are generally used for forecasting streamflow, as the winter accumulation of snow accounts for a large portion of runoff in the western states.

On many streams, fall precipitation, base flow and winter flow are being used with these variables to improve forecasting relationships. Fall precipitation, generally a three or four month accumulation of precipitation at one or more stations, does not always provide a good index to mountain soil moisture conditions.

Precipitation that occurs during the fall months is sometimes but not always snow, which is measured later through regular snow surveys. Soil moisture measurement provides a direct measure of the total influences of precipitation, evaporation and transpiration which determine soil moisture. They also have the advantage of being located high in the watersheds near snow courses that correlate with streamflow. This gives the data additional significance. The fact that the soil moisture sites are high in the mountains gives a better measure than if they were in the valleys, which might not be representative of the higher elevations.

Base flow is generally computed as the flow of a stream on November 1 corrected for precipitation, diversions and reservoir storage. A portion of this flow represents drainage of underground storage which does not always have an effect on spring and summer runoff. It may also be influenced by above or below normal fall temperatures which have considerable effect on melting of the low elevation snow pack. In some drainages base flow may be more representative of the conditions in the lower elevations than in the higher elevations.

Winter flow is generally considered as the mean or total streamflow for a three or four month period, beginning in October or November. This flow can be influenced by low elevation snow melt, precipitation, drainage of underground storage, diversion and reservoir storage. It may also be more indicative of conditions in the lower reaches of the watershed.

Factors such as temperature, evaporation, precipitation, soil type, slimate, plant use and other phenomenon affect the amount of water within a soil profile. By measuring the soil moisture directly an index is obtained, that when combined with snow survey data and winter and spring precipitation, should provide more accurate and reliable streamflow forecasting equations.

Records are too short to make a statistical analyses of the full value of soil moisture as a variable in streamflow forecasts. However, to evaluate the effect of soil moisture, fall precipitation, base flow and winter flow as forecasting indexes these variables can be plotted against forecast errors. An April through September forecast equation has been developed by multiple regression for the South Fork Flathead River near Columbia Falls, Montana using 20 years of record for the 1941-60 period. Base flow, winter flow, fall precipitation and soil moisture data were not used in developing the equation.

Table I shows the forecast flow, actual flow and deviation for the South Fork as well as soil moisture, fall precipitation, base flow and winter flow data. Forecast deviations are plotted against these data in Figures 2 through 5. Lines drawn on these figures were located visually.

Table II shows the forecast and error if the corrections for soil moisture, fall precipitation, base flow and winter flow from Figures 2 through 5 are applied to the original forecast. The indications shown on Table II are very favorable even though the period of record for soil moisture data is short. As the length of record increases, these comparisons are expected to become more significant.

A similar forecast equation has been developed for Salmon Falls Creek near San Jacinto, Nevada, using 17 years of record. Seven years of soil moisture data are available from 1956 through 1962. The forecast flow, actual flow and deviation, with soil moisture data are shown in Table III. Deviations and soil moisture data are plotted in Figure 6. No comparisons are made with fall precipitation, base flow or winter flow on this stream.

Table IV shows the comparison between forecast flows and the same forecasts corrected for March 1 soil moisture at Bear Creek Meadows. This shows an improvement in forecasts, particularly in the 1961 water year.

Similar relationships are known to exist in other western states where soil moisture data are available.

Soil temperature and moisture data can be applied to other phases of streamflow forecasting. Flood potential, as created by rainfall or snow melt on frozen or saturated soils, can be evaluated and anticipated. Severe floods in southeastern Idaho in February, 1962, and again in February, 1963, resulted from low elevation snow melt and rain. Soil temperature data showed that soils under the snow pack were frozen. When temperatures warmed rapidly nearly 100 percent runoff resulted in low elevation areas.

Data on soil moisture and temperature provide an index to forage production on range lands. Stocking rates and management can be adjusted to moisture conditions. Reseeding of non-irrigated range or timber land can be shceduled to coincide with favorable moisture and temperature conditions.

Classification and behavior of watershed soils can be more fully explained through knowledge of soil temperature and moisture variations.

Measurement of soil moisture and temperature by electrical resistance units is economical and practical. Even though present records are short, it appears that these data will significantly improve forecasting relationships, particularly where the soil profile is capable of holding a large amount of water in relation to overlying snow. Although the data are collected primarily for streamflow forecasting, they will provide valuable information to other fields.

References

(1) Clyde, George D. and R. A. Work: Precipitation-Runoff Relationship as a Basis for Water Supply Forecasting. AGU Transactions, 1943.

(2) Colman, E. A.: Manual of Instructions for Use of Fiberglas Soil Moisture Instruments, 1947. California Forest and Range Experiment Station.

(3) Codd, A. R. and P. E. Farnes: Soil Moisture Measurement Progress Report. Soil Conservation Service, Bozeman, Montana, July 1961.

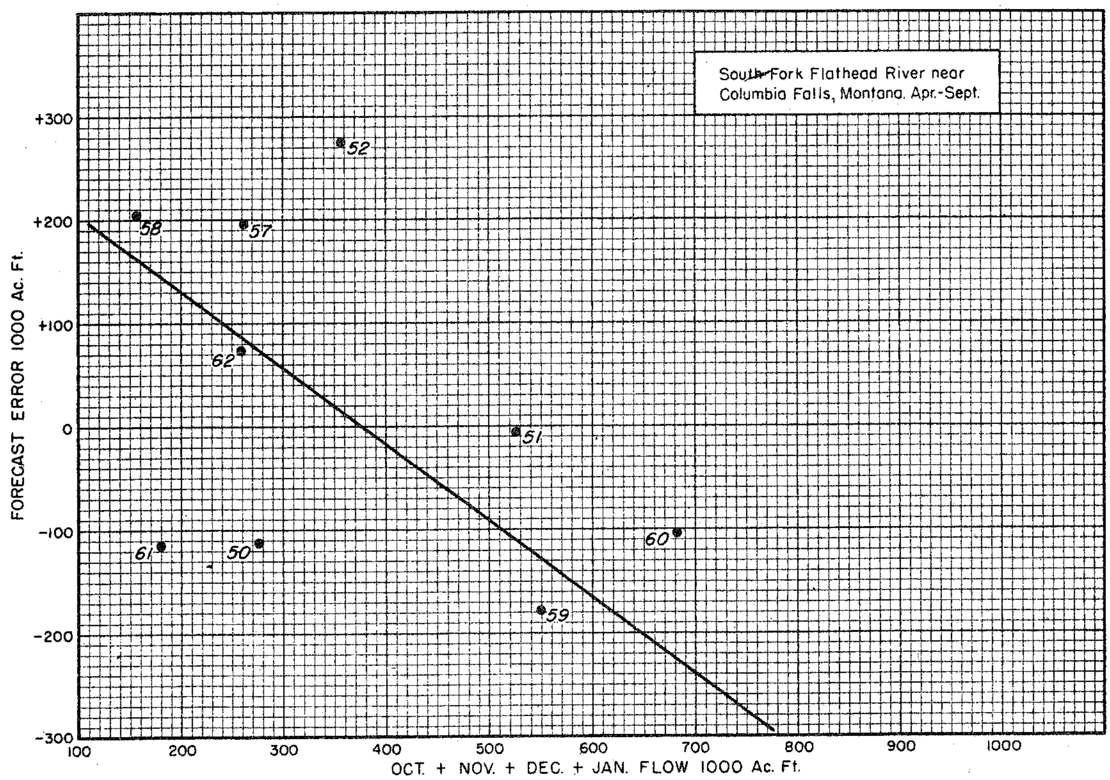


FIGURE 5

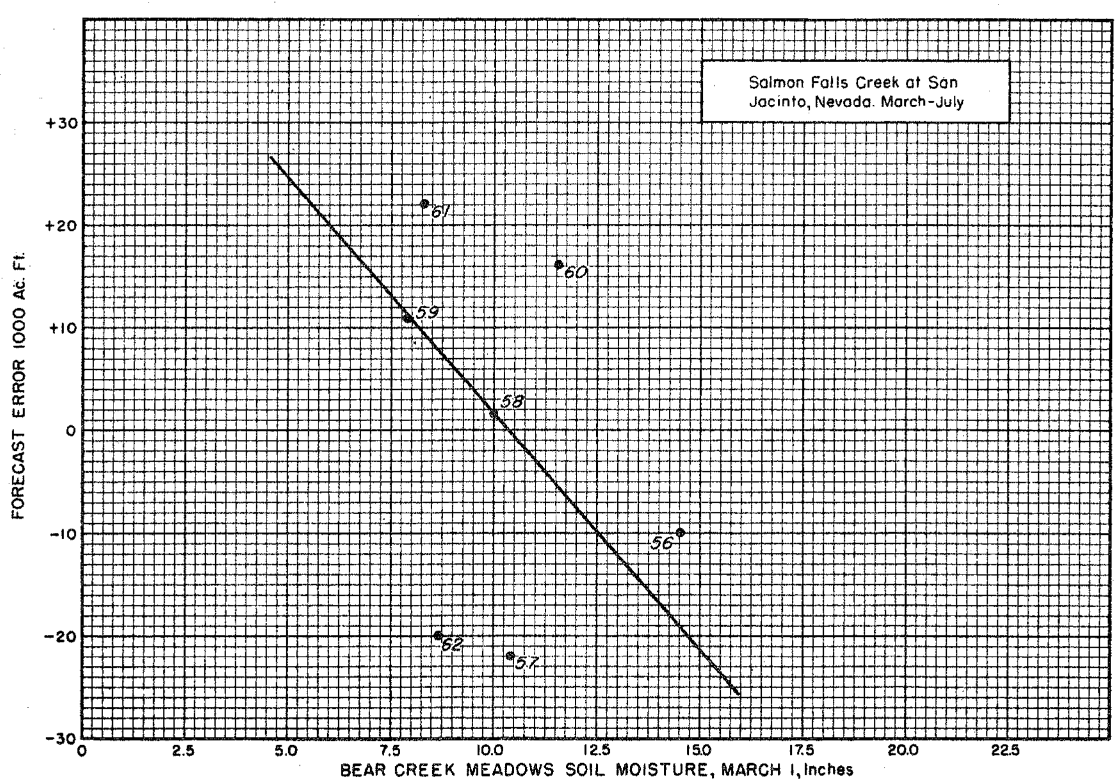


FIGURE 6

TABLE III

Salmon Falls Creek near San Jacinto, Nevada

Water Year	Actual Flow 1/ 1000 A.F.	Forecast Flow 1/ 1000 A.F.	Deviation 1000 A.F.	Bear Creek Meadows Soil Moisture, Mar. 1 Inches
1956	87	78	-9	14.4
1957	102	80	-22	10.4
1958	84	85	+1	10.0
1959	33	44	-11	7.8
1960	61	77	+16	11.6
1961	24	46	+22	8.6
1962	118	98	-20	8.7

1/ March through July

TABLE IV

Salmon Falls Creek near San Jacinto, Nevada

Water Year	Actual Flow 1/ 1000 A.F.	Forecast Flow 1/ 1000 A.F.	Percent Error 2/	Forecast Flow Corrected for Soil Moisture 1000 A.F.	Percent Error
1956	87	78	-10.3	95	+9.2
1957	102	80	-21.6	80	-21.6
1958	84	85	+1.2	84	0.0
1959	33	44	+33.3	33	0.0
1960	61	77	+26.2	81	+32.8
1961	24	46	+91.7	38	+58.3
1962	118	98	-16.9	90	-23.7
		Average	28.7		20.8

1/ March through July.
2/ Forecast flow divided by actual flow minus 100.