SNOWPACK RATIOS IN RUNOFF FORECASTING 1/

By

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Introduction

For the greater part, formulae for forecasting seasonal volume of streamflow weight the "X" variables of snowpack, precipitation (fall or winter or spring), watershed soil moisture, base flow, etc. Their summation is then related to the runoff.

In assessing weightings for the independent variable or variables, these are normally treated individually alike for all winters by whatever weightings are used. Each variable is so entered into the forecast formula.

Years ago, there were available only 10 to 15 years of snow survey record. In consequence, there was little choice in recognizing various types of winters. Now there are 20 years of record on many snow courses and up to 30 years on some. It now becomes possible to search for additional means of increasing the accuracy of forecasts through differentiating the types of winters.

In most watersheds, the earliest snow courses were located at higher elevations, where winter melt is a minimum and where maximum accumulation of snow occurs. Fortunately, there are also now many lower elevation courses which help to define snowpack variations. More are needed.

Snowpack can differ considerably from winter to winter in its relative amounts from one elevation to another. Thus there is not necessarily a constant ratio from year to year between snow accumulation at high or lower elevations in a basin. Still, the lower levels often represent, in area, the greater part of the drainage area of the stream being forecast. The absence of low elevation snow or presence of abnormal amounts thereof may dramatically alter outcome of a forecast based mostly on high elevation snow courses. Hannaford, Wolfe, and Miller described this situation. (1)

The elements of climate, especially precipitation, vary markedly with elevation. It may therefore be concluded that one common runoff forecast formula intended to best fit the average of all years, will not fit certain individual years in the record. Criteria for differentiating the various winters are thus needed. If the winters can be successfully differentiated by objective criteria, it seems then of advantage to have more than one forecast formula for a single gaging station. One formula is used for years of a certain class, and another formula for years of another class. Even a third or fourth formula can be used for still other groups of years whose winter characteristics can be recognized and evaluated, providing there are enough years of record in each formula to support statistical dependability.

Specific Problem

As a specific case, for several years forecasts of volume of North Fork of Rogue River, Oregon have consistently fallen to the minus side. That is, volume obtained was greater than forecast. The watershed appeared to be yielding more water each year from a given amount of snow. The inclination was to charge this off to continued logging. There may be another or further explanation which came to view in connection with the study herein which was requested in 1960 by the Medford, Oregon Irrigation District. Reasons were sought by the District for preponderantly minus volume flow forecasts of North Fork of Little Butte Creek from 1949 through 1959.

Data

A forecast formula for North Fork Little Butte Creek was developed in 1942-43 and up-dated about 1952. Using that formula the runoff volume for April-September was forecast from a relation to streamflow of total October-March precipitation at Fist Lake plus the maximum water equivalent of snowpack at Billie Creek snow course. Snow surveys at Billie Creek (elevation 5,300') have been conducted since 1928. (See Figure I for sketch of watershed showing location of snow courses, elevations, reservoirs, etc.)

Fish Lake snow course was established at elevation 4,655' in 1933. Lake-of-the-Woods course,

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about three miles off the drainage, was established at elevation 4,960' in 1939. A fourth course, Fourmile Lake, also off the drainage, was established at 6,000' in 1950. The records of this latter course are relatively brief, so have not been used in this current study, but should be useful at a future time. Snow survey data at the three courses varies as to reliability; the records for Billie Creek and Fish Lake are considered average; Lake-of-the-Woods, good. A precipitation gage has been measured at Fish Lake since 1918. Precipitation at Fish Lake in general was carefully measured in earlier years. Natural flow of Little Butte Creek below Fish Lake is computed as follows:

Measured runoff for April-September plus storage change in Fish Lake reservoir April 1 - September 30, inclusive, minus 90 percent of discharge of Fourmile Reservoir input canal to Fish Lake. (This canal brings water from Fourmile Lake and discharges it into a jumble of lava rock about one-half mile above Fish Lake. Managers of the District estimate that 90 percent of the canal discharge reaches Fish Lake through the springs near the head of the Lake). Runoff records are kept by the Irrigation District and District Watermaster and for the most part are considered fair to good.

Analysis Method

Analysis of the basic snow survey data was performed by graphical methods comparing each snow course record to runoff at North Fork Little Butte Creek. Precipitation record of Fish Lake was also analyzed by graphical comparison with the runoff. Approximate weightings for the snow survey data and precipitation were derived. Maximum water equivalent regardless of date appeared better related to runoff than was either April 1 or March 1 water equivalent. Thus, maximum water equivalent for all courses, regardless of time of occurrence, was used in the correlations, although not in the elevation ratios as explained later. Maximum water equivalent at Billie Creek occurred 70 percent of the years on April 1 and in 30 percent of the cases on March 1. In 50 percent of the years, maximum water equivalent occurred on both Fish Lake and Lake-of-the-Woods courses on April 1. In two years maximum water equivalent occurred February 1 on Lake-of-the-Woods and in four years the maximum occurred at Fish Lake on February 1. Weightings developed were as follows:

Fish Lake precipitation (inches)for October-March	0.45
Billie Creek maximum (inches) snow water equivalent	0.22
Lake-of-the-Woods maximum (inches) snow water equivalent	0.18
Fish Lake maximum (inches) snow water equivalent	0.15

Thus, the snow weighted 55 percent and fall and winter precipitation (as measured at the lower level of the watershed) at 45 percent. No effort was made to weight the precipitation by months, as inspection of the data showed little promise. Weighting of precipitation by months sometimes is done in order to simulate a value for snowpack. In this case there were snowpack values. However, due to winter snowmelt in this watershed, or due to warm winter rains, the snowpack does not infallibly represent an index for the total winter precipitation. Thus, both values were used.

The plotting of weighted snow plus weighted precipitation against runoff was carred out for the years 1935-58. 1959 was left outside the formula for use in subsequent proof. Records of Lake-of-the-Woods were estimated for 1935 and 1936 since Fish Lake and Billie Creek records were available for those years, and any possible error introduced into the formula through estimating Lake-of-the-Woods was quite small. That seemed preferable to losing two full years of comparison. However, even though Billie Creek records begain in 1929, the record for 1929-34 was not used since it was judged too risky to estimate both Fish Lake and Lake-of-the-Woods for those several years. Thus, for use in correlation, there were 23 years of fair to good records of runoff, precipitation at one gage, and snowpack at three courses, one of the latter not being directly on the watershed.

These plottings were widely dispersed. Aside from the ever present possibility of error in any one of the various data records, it might be of concern that the evaporation from the surface of Fish Lake varies from season to season. Fish Lake has surface area of about 500 acres. On average, it may lose about 1,400 acre-feet per year to evaporation. It seems doubtful if the lake evaporation would differ more than 500 acre-feet from a maximum loss season to a minimum loss season, since variation in the lake area is small as related to storage changes. No effort was made to estimate lake evaporation due to lack of clearly applicable climatological records. This introduces an error into the procedure but this is not thought to be appreciable.

The plottings showed a noticeable tendency for greater flows in the past ten years for nearly identical x factors. This seemed unlikely as a result of logging, since there has been little of that on this watershed. No serious fires are recalled, and immediate environment of the snow courses seem unchanged. However, canopyometer measurements as suggested by Codd (2) are not available. Billie Creek and Fish Lake courses are in the open, but Lake-of-the-Woods course is along a narrow road in rather heavy fir timber where some overstory encroachment in the past 15 years is possible.

To determine the relative proportions of low level and high level snow, a ratio of water equivalent of snow at low elevations to snow at higher elevations was prepared for each of the 23 years, using Billie Creek (the highest course in elevation) to represent High Level snow and Lake-of-the-Woods to represent low level snow. Fish Lake was not used for the reason that it represents the extreme lowest elevation of the watershed, being only about 50 feet higher than and 1/2 mile upstream from the stream gaging station. Lake-of-the-Woods course is 300 feet higher than Fish Lake and believed representative of the low elevation snow in a greater percentage of the basin. See Table I for computation.

In preparing the ratio, April 1 water equivalent was used for each course, rather than the maximum at each course for each season. This selection was based on the opinion that the high-low snow ratio on April 1, just as runoff for the forecast period begins, would be more significant that the ratio earlier in the winter, say February 1, or March 1.

These ratios were then arranged in descending order. (See Table I.) It was observed that in each of the ten years immediately preceding 1959 the ratio each year was higher than the mean for the 23 years. This means then that on April 1 in each of the ten years, 1949-58, there was more snow water residual at the lower elevations relative to the high elevations, than in most of the earlier years. The 23-year period was then divided into one category of high ratios (13 years with ratios which happen to range from 0,39 to 0.70) and one category of lower ratios (11 years with ratios which happen to range from 0.08 to 0.38).

These two categories were treated as separate regressions. (See Table II and Figures II and III.) The years of highest ratio of low elevation snow produce the most water during April-September per unit of high elevation snow.

TABLE I

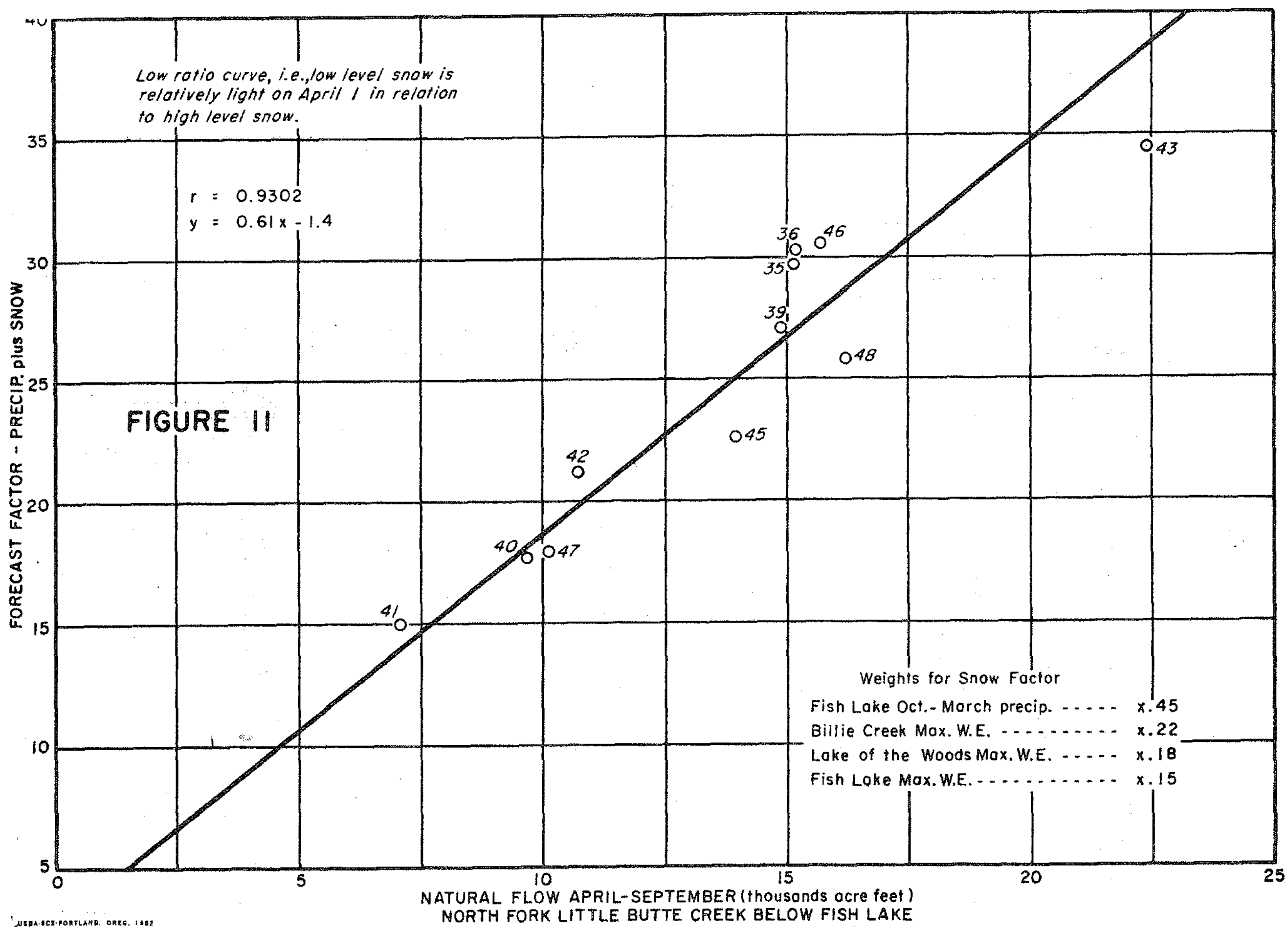
Computation of High Elevation-Low Elevation SnowRatios by Years

Year	April 1 Billie Creek	W.E. L-of-W	April 1 Ratio L-of-W / B.C.	Arranged in descending ratio: Year	Ratio	
1935	32.1	11.5[a]	.36	1938	.70	
36	38.2	11.5[a]	.30	54	.66	
37	26.6	12.8	.48	53	.63	
38	26.4	18.6	.70	56	.61	
39	33.1	10.4	.31	52	.54	
40	9.4	0.8	.08	37	.48	
41	6.7	2.2	.33	49	.48	
42	19.3	7.0	.36	44	.45	
43	31.3	12.0	.38	50	.43	All used on high ratio curve.
44	17.0	7.7	.45	57	.43	
45	22.3	6.2	.28	51	.42	
46	36.6	13.8	.38	58	.41	
47	11.1	1.7	.15	55	.39	
48	29.0	9.8[b]	.34	43	.38	
49	34.6	16.7	.48	46	.38	
50	30.2	13.0	.43	35	.36	
51	21.0	8.9	.42	42	.36	
52	40.0	21.5	.54	48	.34	
53	24.6	15.6	.63	41	.33	All used on low ratio curve.
54	20.3	13.3	.66	39	.31	
55	23.9	9.4	.39	36	.30	
56	39.1	23.8	.61	45	.28	
57	12.9	5.5	.43	47	.15	
58	32.1	13.2	.41	40	.08	
*59	9.8	6.4	.65	—	---Use high ratio curve.	
*60	15.3	6.0	.39	—	---Use high ratio curve.	
*61	24.4	16.1	.66	—	---Use High ratio curve.	
*62 (est) Feb.						

a - estimated

b - partly estimated

* - year not used in setting up the ratio curves


Low ratio curve, i.e., low level snow is relatively light on April 1 in relation to high level snow.
r = 0.9302
y = 0.61 x - 1.4
FIGURE II
Weights for Snow Factor
Fish Lake Oct.- March precip. ----- x.45
Billie Creek Max. W.E. ---------- x.22
Lake of the Woods Max. W.E. ----- x.18
Fish Lake Max. W.E. ------------ x.15
FORECAST FACTOR - PRECIP. plus SNOW
NATURAL FLOW APRIL-SEPTEMBER (thousands acre feet)
NORTH FORK LITTLE BUTTE CREEK BELOW FISH LAKE

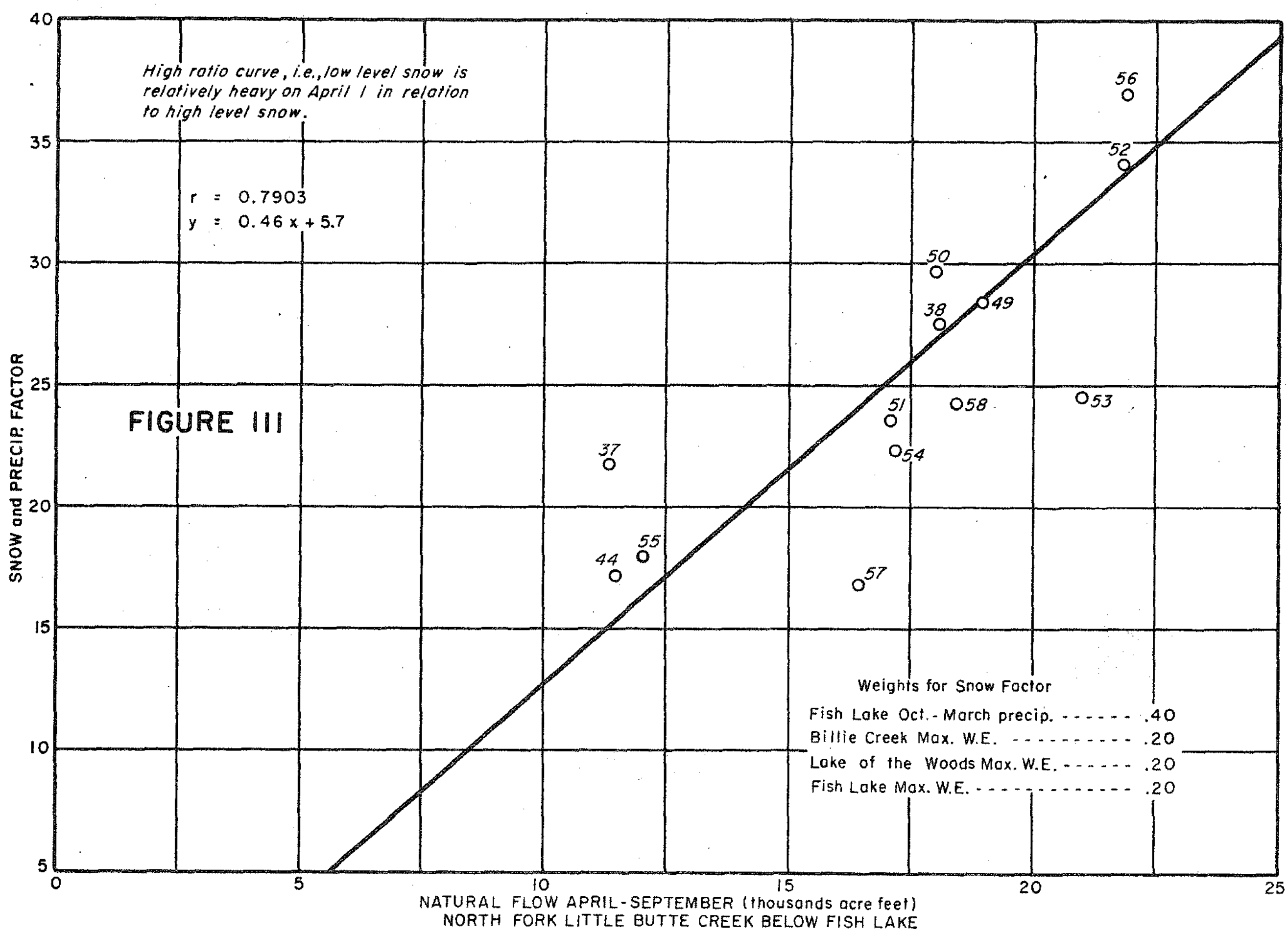

High ratio curve, i.e., low level snow is relatively heavy on April 1 in relation to high level snow.
r = 0.7903
y = 0.46 x + 5.7
FIGURE III
Weights for Snow Factor
Fish Lake Oct.- March precip. ------ .40
Billie Creek Max. W.E. ---------- .20
Lake of the Woods Max. W.E. ------ .20
Fish Lake Max. W.E. ------------- .20
SNOW and PRECIP. FACTOR
NATURAL FLOW APRIL-SEPTEMBER (thousands acre feet)
NORTH FORK LITTLE BUTTE CREEK BELOW FISH LAKE

TABLE II

Computation of Snow-Precipitation "x" Factor 1935-58, incl.

Year	Fish Lake Precip. Oct-March		Billie Cr. Maximum W.E.		L-of-Woods Maximum W.E.		Fish Lake Maximum W.E.		Cols. 1+2+ 3 + 4	Ratio Curve	Natural Runoff N. Fk. Little Butte blw. Fish Lake
	Amt.	x.45 (1)	Amt.	x.22 (2)	Amt.	x.18 (3)	Amt.	x.15 (4)	= 1.00		1000 A.F. April-Sept.
1935	39.8	17.91	32.1	7.06	11.5[a]	2.07	18.0	2.70	29.7	Low	15.1
36	37.9	17.05	38.2	8.40	11.5[a]	2.07	19.2	2.88	30.4	"	15.2
39	33.5	15.07	33.1	7.28	10.4	1.87	19.2	2.88	27.1	"	14.8
40	32.6	14.67	10.8	2.37	2.8	0.50	2.7	0.40	17.9	"	9.6
41	23.2	10.44	13.5	2.97	5.6	1.00	4.2	0.63	15.0	"	7.1
42	31.3	14.08	19.3	4.25	8.4	1.51	9.6	1.44	21.3	"	10.7
43	50.0	22.50	31.9	7.02	13.8	2.48	16.0	2.40	34.4	"	22.3
45	33.4	15.03	22.3	4.91	6.2	1.12	10.0	1.50	22.6	"	13.8
46	38.2	17.19	36.6	8.05	13.8	2.48	19.1	2.86	30.6	"	15.7
47	30.5	13.72	12.1	2.66	3.9	0.70	6.0	0.90	18.0	"	10.1
48	34.7	15.62	29.0	6.38	9.8	1.76	13.8	2.07	25.8	"	16.2
Mean									24.8		13.7
		x.40		x.20		x.20		x.20	=1.00		
1937	25.2	10.1	27.4	5.5	12.8	2.6	17.2	3.4	21.6	High	11.3
38	36.8	14.7	26.4	5.3	18.6	3.7	19.0	3.8	27.5	"	18.1
44	26.0	10.4	17.0	3.4	7.8	1.6	9.2	1.8	17.2	"	11.5
49	33.6	13.4	34.6	6.9	16.7	3.3	23.3	4.7	28.3	"	18.9
50	41.8	16.7	30.2	6.0	13.7	2.7	21.4	4.3	29.7	"	17.9
51	36.9	14.8	21.0	4.2	10.2	2.0	13.2	2.6	23.6	"	17.2
52	41.8	16.7	43.0	8.6	21.5	4.3	23.0	4.6	34.2	"	21.8
53	33.6	13.4	24.6	4.9	16.9	3.4	14.2	2.8	24.5	"	21.0
54	29.9	12.0	22.8	4.6	14.4	2.9	14.6	2.9	22.4	"	17.2
55	20.2	8.1	23.9	4.8	11.8	2.4	12.6	2.5	17.8	"	12.0
56	49.6	19.8	39.1	7.8	23.8	4.8	23.2	4.6	37.0	"	21.8
57	32.8	13.1	12.9	2.6	5.5	1.1	T	0	16.8	"	16.4
58	31.4	12.6	32.1	6.4	14.2	2.8	13.1	2.6	24.4	"	18.4
Mean									25.0		17.2
1959	21.4	8.6	9.8	2.0	6.4	1.3	3.6	0.7	12.6	High	11.0
60	19.1	7.6	16.6	3.3	8.1	1.6	9.3	1.9	14.4	High	12.0
61	24.2	9.9	21.0	4.2	9.1	1.8	9.8	2.0	17.9	High Ratio Forecast 14.0	
As of Feb.1 62	31.6	12.6	24.7[a]	4.9	16.9[a]	3.4	16.7[a]	3.3	24.3	High Ratio Forecast of 16.9 as of Feb. 1	

a - estimated

Conversely, the years of lowest ratio of low elevation snow to high elevation snow tended to produce less water during April-September per unit of high elevation snow. A slightly different weighting of courses was used for the high ratio curve in order to weight the low level courses slightly more heavily as follows:

October-March precip. (inches), Fish Lake	0.40
Billie Creek maximum (inches) water equivalent	0.20
Lake-of-the-Woods maximum (inches) water equivalent	0.20
Fish Lake maximum (inches) water equivalent	0.20

Results of Method

The new scheme was then "proved" by forecasting the year 1959 (in 1960). Comparison of 1959 forecasts as published, and by the new formula, follow:

	As Published	High-Low Ratio Formula
Forecast runoff (1000 a.f. for April-September)	6.5	10.0
Obtained runoff	11.0	11.0
Percent error	-40.9	-9.1

By going back to 1943, the forecasts as published can be compared for each year by the High-Low ratio formulas as shown in Table II.

This proof sheet is shown as Table III. Including now for the first time the year 1959, we find the following comparison of theoretical accuracy of the two formulae for forecasting runoff North Fork Little Butte Creek:

	Published	High-Low Ratio Formula
No. Forecasts (April 1 only)	17	17
Average Error (%)	15.6	9.3
Maximum Error	-40.9	-25.0
No. of "bests"	4	9
No. Minus Forecasts	14	11

As a check to evaluate efficiency of the high-low ratio procedure, a multiple regression using the same variables was computed. Each variable was used as a independent variable in order to obtain the "best" possible relationship. This regression is given in Table IV -- also included are the "t" values for test of significance of the regression coefficient, multiple correlation coefficient. As indicated in Table IV, not all of the variables show significance when combined into a multiple regression. This is, of course, to be expected since strong inter-correlation always exists between variables of this nature.

The historical verification using this regression gives some indication of the efficiency of the high-low procedure.

It is interesting to note the maximum errors of the high-low procedure are considerably less than those found in the multiple regression procedure. Such a comparison merely serves as a guide to the ability of the high-low procedure to predict accurately since graphical developed procedures are difficult to evaluate by use of standard statistical procedures.

The elevation ratio method was first officially used beginning February 1, 1962. Thus, the results of the elevation ratio method of forecasting can be tested also for 1960 and 1961 against the published forecasts for those years from the original forecast method, as follows:

Year	April 1 Water Equivalent Billie Cr.	April 1 Water Equivalent Lake-O-Woods	April 1 Ratio Lake-O-Woods / Billie Creek	
1960	15.3	6.0	.39	Use High Ratio Curve
1961	21.0	8.3	.40	Use High Ratio Curve

Year	Fish Lake Precip. Oct.-Mar. Amt.	X.40 (1)	Maximum Water Equivalent Billie Cr. Amt.	X.2 (2)	L-O-W Amt.	X.2 (3)	Fish Lake Amt.	X.2 (4)	Cols. 1 + 2 +3 +4	Ratio Curve Used	Fore-cast	Ob-tained
1960	19.1	7.6	16.6	3.3	8.1	1.6	9.3	1.9	14.4	High	11.0	12.0
1961	24.2	9.7	21.0	4.2	9.1	1.8	9.8	2.0	17.7	High	12.8	?

TABLE III

Comparison April 1 Forecasts (for April-September Volume)

Thousands Acre-Feet

Year	Published Forecast	Published Obtained	Published Error %	From Elev. Ratio Curves Forecast	From Elev. Ratio Curves Obtained	From Elev. Ratio Curves Error %
1943	24.0	22.3	+ 7.6	19.9	22.3	-10.8
44	9.4	11.5	-18.3	12.6	11.5	9.6
45	12.0	13.8	-13.0	12.5	13.8	- 9.4
46	17.7	15.7	12.7	17.5	15.7	11.5
47	8.5	10.1	-15.8	9.6	10.1	- 5.0
48	14.0	16.2	-13.6	14.5	16.2	-10.5
49	16.0	18.9	-15.3	18.8	18.9	- 0.5
50	16.0	17.9	-10.6	19.1	17.9	6.7
51	13.2	17.2	-23.3	16.7	17.2	- 2.9
52	19.5	21.8	-10.6	22.1	21.8	1.4
53	14.3	21.0	-31.9	16.7	21.0	-20.5
54	15.3	17.2	-11.1	15.5	17.2	- 9.9
55	11.3	12.0	- 5.8	12.9	12.0	7.5
56	22.0	21.8	0.9	23.7	21.8	8.7
57	14.0	16.4	-14.6	12.3	16.4	-25.0
58	15.0	18.4	-18.5	16.6	18.4	- 9.8
Total		(16)	223.6		(16)	149.7
Average			14.0			6.4
Maximum			31.9			25.0
		4 best 13 minus			8 best 10 minus out of 16	
1959	6.5	11.0	-40.9	10.0	11.0	- 9.1
		(17)	264.5		(17)	158.8
Including 1959 Average			15.6			9.3
Maximum			40.9			
		4 best 14 minus			9 best 11 minus	
1960	10.5	12.0		11.0	12.0	
1961	12.1			14.0		
*1962						

* Did not use the Hi-Lo ratio '60 or '61 but began using it February 1, 1962.

TABLE IV

Multiple Regression North Fork Little Butte Creek

Year	North Fork Little Butte Creek Below Fish Lake Actual	Forecast	Percent of Error	
1935	15.1	15.9	5.3	
1936	15.2	15.6	2.6	
1939	14.8	13.7	- 7.4	
1940	9.6	11.7	21.9	
1941	7.1	11.2	56.3	
1942	10.7	13.6	27.1	
1943	22.3	20.0	-10.3	
1945	13.8	12.8	- 7.2	
1946	15.7	16.9	7.6	
1947	10.1	11.2	10.9	
1948	16.2	14.7	- 9.2	
		% Average Error of Low Years		15.1
1937	11.3	13.5	19.4	
1938	18.1	18.9	4.4	
1944	11.5	12.1	5.2	
1949	18.9	16.6	-12.2	
1950	17.9	16.5	- 7.8	
1951	17.2	15.1	-12.2	
1952	21.8	21.7	- 0.1	
1953	21.0	18.3	-12.8	
1954	17.2	15.8	- 8.1	
1955	12.0	12.7	5.8	
1956	21.8	24.4	11.9	
1957	16.4	14.1	-14.0	
1958	18.4	16.9	- 8.1	
		% Average Error of High Years		9.4
		Total Average Error		12.0

$Y = 0.2142 X_1 + .0552 X_2 + 0.5886 X_3 - .2372 X_4 + .3161$

$t_{x1} = 2.68$ X_1 = Fish Lake Precip. Oct. - March

$t_{x2} = 0.42NS$ X_2 = Maximum W.E. Billie Creek Snow Course

$t_{x3} = 3.68$ X_3 = Maximum W.E. Lake-of-the-Woods Snow Course

$t_{x4} = -1.25NS$ X_4 = Maximum W.E. Fish Lake Snow Course

Y = April - September flow Little Butte Creek below Fish Lake

	Published			From elev. ratio curves		
Year	Forecast (a.f.)	Obtained (a.f.)	Error (%)	Forecast (a.f.)	Obtained (a.f.)	Error (%)
1960	10.5	12.0	12.5	11.0	12.0	8.3
1961	12.1			12.8		

Use of Method on Chelan River

The high-low ratio snow forecast formula method was tried on Chelan Lake watershed, Washington. This watershed was selected because of the extensive network of snow courses and the favorable length of record. The eighteen snow courses were tabulated in order of descending elevation for all the years of record. It was decided that the high-low split would be halfway, leaving nine courses to be averaged for higher level and nine courses for lower elevation value.

The summation and mean for each set of nine snow courses for each year was computed. A ratio of the mean of the nine lower elevation snow courses divided by the mean of the nine higher elevation snow courses established the high-low elevation ratio. These ratios were arranged in descending order, starting with a high of .73 for 1956 and down to .40 for 1939.

Since there seemed to be enough years of record these ratios were broken into three groups: high, 0.73 to 0.55; medium, 0.54 to 0.49; and low, 0.48 to 0.40. These groupings were selected not for their internal evenness but in order that there would be approximately the same number of years of record in each group. Out of the 27 years of record, there were ten in the high group, nine in the medium and eight in the low.

A forecast formula was derived from each of these groups, as well as for the total courses for all 27 years, using the average of the mean snow water equivalents for the nine high elevation and nine low elevation snow courses as the parameters.

A comparison of the forecast accuracies was made using the single regression equation for all 27 years of record and a combination of all three ratio groups. This comparison is given in the table below:

Forecast error groupings %	Single forecast formulae No.	Combination of three ratio formulae No.
0 - 5%	11	14
5 - 10%	8	6
10 --20%	8	7
Over 20%	0	0
Total cases	27	27
Maximum error	17.6	13.8
Average error	7.3	5.9

A further comparison of the two methods of forecasting show that in the low ratio group, four of the eight years were improved over the single regression using all 27 years. In the medium ratio group, four out of nine years were improved, and in the high ratio group, eight out of ten were improved.

All of these forecast checks were made using the same data for checking as was used in the compilation of the forecasts themselves, but since both the high-low elevation ratio and the single regression for 27 years were checked the same way, a direct comparison may be made.

Three years in recent times with major forecast errors were 1939, 1948, and 1952. Had a single regression for all 27 years of record been used on Chelan River, the errors in those years would have been +14.8, -17.6, and +15.8, respectively. Had those years been forecasted by use of the high=low elevation ratio method, the synthesized errors would have been reduced to +4.5, -2.6, and +7.9, respectively. The authors recognize the limitations upon this type of comparison, but believe it strongly suggests the possibility of major improvements in forecast accuracy in unusual years.

The method suggested herein has been tried by SCS forecasters on a very limited number of streams in Nevada, Utah, Arizona, and Colorado with indifferent success. It is being used elsewhere in Oregon and on one stream in Wyoming with encouraging results. Further trials on rivers with adequate data would be interesting and should help greatly to define possible applications or limitations of the method.

Conclusion

This paper is intended to stress the possibility of a family of forecast relations for a given stream. The choice of forecast regression to be used for any given season is related to watershed snow conditions at beginning of runoff. Search should be made in each case for objective criteria upon which to base the selection of the forecast regression for that season and stream. The authors believe that greater use of graphics in forecasting, as suggested by Hannaford (3), would be useful in such forecast procedure development.

REFERENCES

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(2) Codd, A. R., "The Photocanopyometer" -- PROCEEDINGS, WESTERN SNOW CONFERENCE, 27th Annual Meeting, 1957.

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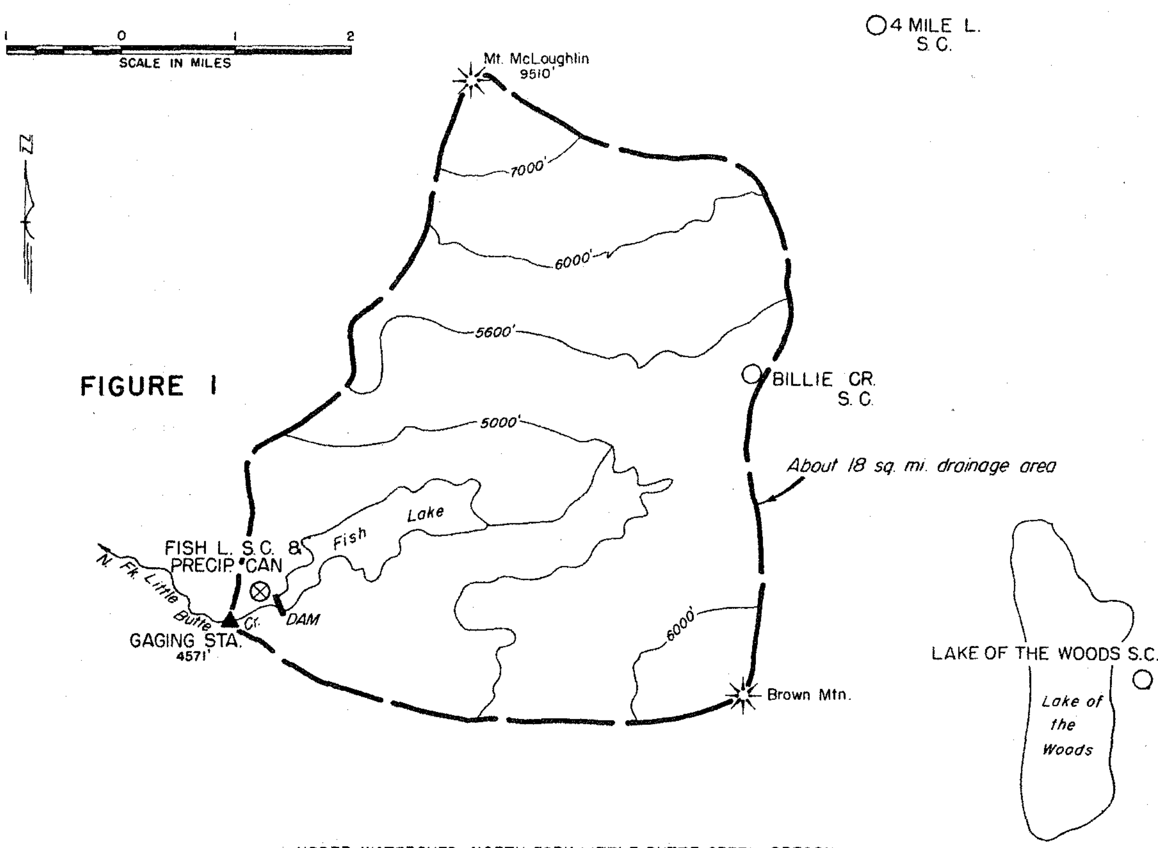
FIGURE I



UPPER WATERSHED, NORTH FORK LITTLE BUTTE CREEK, OREGON