USING RATIOS OF RUNOFF TO SNOW WATER CONTENT AND PROJECTED RAINFALL-TO-COME AS A METHOD OF NARROWING THE WATER SUPPLY FORECAST RANGE.

by
Richard E. Stein [1]

INTRODUCTION

After two critically dry years, the East Bay Municipal Utility District's water storage reservoirs, located in the Mokelumne Watershed in the Central Sierra Nevada, were so depleted that an accurate estimate of the amount of water supply likely to be available for a possible third dry year was essential.

The need to provide accurate, weekly water supply forecasts when snow surveys are conducted only monthly, and the need to be continuously prepared if dry conditions persisted during this last drought, led to development of a forecasting technique that uses a combination of snow survey information, and the historical relationships between runoff, snow water content and rainfall. This paper describes how the historical records of rainfall, runoff, and snow water content were used to develop a forecasting tool that turned out to be a valuable means of narrowing the range in the amount of water supply likely to be available for the season and, in particular, to define the worst case, or lowest amount of water supply to be shared between all water users.

GETTING STARTED

It is generally known that the more rainfall we receive in any given season, not only does the gross amount of runoff increase, but the yield of that precipitation, or the amount of runoff we receive per unit of precipitation also goes up.

As a starting point the entire historical record of seasonal rainfall (July through June) was statistically analyzed with the historical estimates of seasonal runoff (October through September). For each year the ratio of runoff to rainfall was computed, and the entire record was arranged in order of magnitude by runoff to rainfall ratio. Plate A shows the results of that analysis. The plate shows that greater yield can be expected per unit of precipitation as seasonal rainfall increases, or since we were more concerned with the continuation of the drought, less yield can be expected as our watersheds continue to dry up.

SETTING UP THE FORECAST MATRIX

The goal I wanted to achieve was to set up a forecast matrix that would provide the most accurate and narrowest range in forecasted runoff, or indirectly the amount of water supply we could count on for the year. For my analysis I assumed that for any forecast, the precipitation-to-come would never be less than the historical minimum. This seemed to be practical minimum to use for water supply management purposes. The upper limit of precipitation-to-come was assumed to be average precipitation. Anything more than average would make this drought-year forecasting technique unnecessary.

The first thing I did was divide seasonal runoff into three components: (1) runoff which had already occurred, (2) runoff from the melting of the existing snowpack, and (3) runoff to occur from assumed precipitations to come. The last runoff component was from precipitation either in the form of rainfall or snowfall.

In order to test the possibility of using this three component theory, and also get a first look at what a worst-case runoff for EBMUD in 1988-89 might look like, we made use of actual runoff, water content, and precipitation records for the previous two years, and used them to "compute" the runoff/rainfall ratios. These would then be compared to the analyses of the entire record.

Presented at the Western Snow Conference, April 17-19, 1990; Sacramento, California

[1] Senior Civil Engineer for Water Supply; East Bay Municipal Utility District, Oakland, California

Plate B shows this first cut at checking the runoff/rainfall ratios on a specific date. Actual runoffs, snow water contents, and precipitations for 1986-87 and 1987-88 were used to determine the runoff to precipitation ratios. The total runoff from snow water content plus precipitation-to-come was computed by subtracting runoff through Feb 28 from total seasonal runoff. The difference, which represents runoff-to-come was divided by the total of snow water content plus precipitation-to-come to obtain the runoff to precipitation ratio. Determination of any differences between the yield of the snowpack and the yield of precipitation-to-come was beyond the scope of this project.

The numbers "fit" with historical rankings. The snow water contents are the average of four stations ranging in elevation from 1,500 meters to 2,600 meters. For our forecasting matrix, we unfortunately have only one of these four stations equipped with a snow sensor for real-time data acquisition. Because the one station we do have and intend to use in our model is one of the higher elevation stations, we decided to use runoff to rainfall ratios conservatively lower than the historical analysis indicated. This is another example when having more data stations would improve our ability to manage limited water resources.

When we began to look at the "worst case" precipitation-to-come for that component of runoff, analysis showed that selecting the driest year of record for precipitation-to-come as you moved through the season, did not always give the worst case scenario. Plate C shows precipitation-to-come in the Mokelumne Basin from April 1st.

The next step was to set up the forecast matrix. Plate D shows the water supply forecast matrix for March 27, 1989. The first component of runoff, or the runoff which has already occurred, is included in the matrix as the difference between columns (6) and (7). The second component of runoff is the yield of the existing snowpack (columns (2) and (3)). The third component is the runoff from various assumed precipitations-to-come (columns (4) and (5)). As seasonal precipitation increases, the ratio of runoff to precipitation also is shown to increase. As mentioned before, determining any actual differences in yield between snowpack on the ground and precipitation-to-come will require further analysis.

THE RESULTS

The narrowing in the range of runoffs likely to be available for the year is shown in Plate E. Obviously the range gets narrower as we move further into the runoff season, but because the decisions made to manage water supply and demand have such significant impact, being able to accurately define the amounts in the forecast range becomes increasingly more critical as water supplies decline, or water demands increase.

The technique worked. There is much room for improvement, and an effort to do so will be undertaken. The principles of the water supply forecasting technique are not new, and the individual parts of the procedure are not complicated, but the combination of these elements of forecasting led to a technique that proved valuable for maximizing storage and minimizing water use restrictions during the third year of an unprecedented drought.

PLATE A

MOKELUMNE WATERSHED RELATIONSHIP BETWEEN RUNOFF AND RAINFALL

Runoff/Rainfall Ratio Arranged in Order of Magnitude

	(1) Water Year/ Rainfall Year	(2) Runoff (Cubic-Meters)	(3) Rainfall (Millimeters)	(4) Runoff/Rainfall Ratio (Cubic-Meters/Millimeters)
1	1976 - 77	159,360,000	584	272,900
2	1930 - 31	266,690,000	752	354,600
3	1987 - 88	311,940,000	690	452,100
4	1975 - 76	302,960,000	665	455,600
5	1960 - 61	353,880,000	770	459,600
6	1933 - 34	371,870,000	789	471,300
7	1986 - 87	324,750,000	688	472,000
8	1946 - 47	491,940,000	945	520,600
9	1938 - 39	424,760,000	808	525,700
10	1963 - 64	535,870,000	1,006	532,700
11	1980 - 81	456,040,000	847	538,400
12	1959 - 60	521,220,000	931	559,800
13	1967 - 68	505,240,000	843	599,300
14	1929 - 30	570,270,000	950	600,300
15	1965 - 66	575,070,000	957	600,900
16	1958 - 59	481,820,000	794	606,800
17	1943 - 44	558,990,000	915	610,900
18	1954 - 55	551,030,000	900	612,300
19	1932 - 33	530,390,000	817	649,200
20	1953 - 54	669,170,000	1,023	654,100
21	1984 - 85	598,070,000	912	655,800
22	1948 - 49	642,690,000	964	666,700
23	1961 - 62	799,520,000	1,194	669,600
24	1947 - 48	791,160,000	1,169	676,800
25	1956 - 57	755,000,000	1,110	680,200
26	1978 - 79	850,950,000	1,248	681,900
27	1971 - 72	652,780,000	928	703,400
28	1974 - 75	960,640,000	1,362	705,300
29	1936 - 37	867,240,000	1,227	706,800
30	1934 - 35	872,830,000	1,234	707,300
31	1977 - 78	1,182,400,000	1,629	725,800
32	1945 - 46	929,740,000	1,274	729,800
33	1962 - 63	1,091,000,000	1,489	732,700
34	1949 - 50	936,880,000	1,264	741,200
35	1939 - 40	1,072,600,000	1,434	748,000
36	1944 - 45	961,860,000	1,283	749,700
37	1952 - 53	856,570,000	1,128	759,400
38	1935 - 36	1,112,100,000	1,465	759,100
39	1931 - 32	924,960,000	1,204	768,200
40	1972 - 73	980,800,000	1,271	771,700
41	1940 - 41	1,046,800,000	1,343	779,400
42	1970 - 71	961,850,000	1,233	780,100
43	1969 - 70	1,126,000,000	1,425	790,200
44	1973 - 74	1,235,700,000	1,526	809,800
45	1941 - 42	1,229,200,000	1,496	821,700
46	1942 - 43	1,246,600,000	1,515	822,800
47	1957 - 58	1,322,500,000	1,590	831,800
48	1966 - 67	1,421,400,000	1,702	835,100
49	1985 - 86	1,543,500,000	1,790	862,300
50	1983 - 84	1,332,400,000	1,538	866,300
51	1964 - 65	1,488,300,000	1,700	875,500
52	1968 - 69	1,651,200,000	1,877	879,700
53	1979 - 80	1,400,900,000	1,592	880,000
54	1937 - 38	1,536,100,000	1,745	880,300
55	1950 - 51	1,438,700,000	1,616	890,300
56	1955 - 56	1,550,800,000	1,697	913,800
57	1951 - 52	1,632,800,000	1,695	963,300
58	1981 - 82	1,917,300,000	1,987	964,900
59	1982 - 83	2,244,400,000	2,213	1,014,000

Notes: (2) True Natural Flow Mokelumne River near Mokelumne Hill (WY 1929-30 thru 1987-88).
(3) 4-Station Average Precipitation (RY 1929-30 thru 1987-88):
Calaveras Big Trees, Salt Springs Powerhouse
Caples Lake, Tiger Creek Powerhouse

PLATE B

RUNOFF COMPARISONS

Water Years 1987 and 1988 Actual – Water Year 1989 Worst Case Projection

Runoff Component	1986–87			1987–88			1988–89 (Worst Case)		
	Precip (mm)	Runoff to Precip Ratio (cu–m/mm)	Runoff (cu–m)	Precip (mm)	Runoff to Precip Ratio (cu–m/mm)	Runoff (cu–m)	Precip (mm)	Runoff to Precip Ratio (cu–m/mm)	Runoff (cu–m)
Runoff – Oct. 1 to Feb. 28			43,050,000			66,980,000			65,370,000
Snow Water Content (1)	276	528,200	145,550,000	287	502,100	143,820,000	462	500,200	231,280,000
Precip. – Mar. 1 to Jun. 30	243 (2)	528,200	128,410,000	207 (2)	502,100	103,740,000	163 (3)	500,200	81,290,000
Water Year Runoff Total			317,010,000			314,540,000			377,940,000

Notes:

(1) Average of Snow Water Content at Caples Lake, Dorrington, Upper Carson Pass, and Lumber Yard Snow Courses.

(2) Actual 4-Station Average Precipitation. Average of Caples Lake, Calaveras Big Trees, Salt Springs Powerhouse, and Tiger Creek Powerhouse.

(3) Assumed as a repeat of 1976 4-Station Average Precipitation.

PLATE C

Mokelumne Watershed Precipitation - Average of 4 Stations

April thru June [1930 thru 1988]

Record Number	Rainfall Year	Total (Millimeters)		Record Number	Rainfall Year	Total (Millimeters)
1	1984 - 85	35		31	1979 - 80	160
2	1939 - 40	54		32	1950 - 51	163
3	1945 - 46	55		33	1929 - 30	164
4	1967 - 68	57		34	1987 - 88	166
5	1972 - 73	77		35	1931 - 32	168
6	1986 - 87	79		36	1944 - 45	168
7	1948 - 49	83		37	1932 - 33	168
8	1958 - 59	84		38	1969 - 70	173
9	1975 - 76	84	- Third Driest Year of Record	39	1937 - 38	174
10	1961 - 62	86		40	1935 - 36	189
11	1985 - 86	91		41	1954 - 55	194
12	1946 - 47	92		42	1943 - 44	203
13	1965 - 66	94		43	1974 - 75	204
14	1933 - 34	104		44	1940 - 41	204
15	1936 - 37	109		45	1963 - 64	208
16	1980 - 81	111		46	1949 - 50	232
17	1951 - 52	112		47	1964 - 65	239
18	1938 - 39	113		48	1982 - 83	241
19	1959 - 60	116		49	1955 - 56	249
20	1942 - 43	122		50	1956 - 57	255
21	1930 - 31	124	- Second Driest Year of Record	51	1977 - 78	257
22	1976 - 77	134	- DRIEST YEAR OF RECORD	52	1981 - 82	268
23	1978 - 79	138		53	1952 - 53	284
24	1960 - 61	143		54	1957 - 58	332
25	1971 - 72	145		55	1934 - 35	353
26	1953 - 54	146		56	1941 - 42	373
27	1970 - 71	152		57	1947 - 48	402
28	1983 - 84	153		58	1966 - 67	421
29	1968 - 69	155		59	1962 - 63	458
30	1973 - 74	155				
					Average:	174 mm

Note: Mokelumne Watershed Precipitation Stations:
- Calaveras Big Trees
- Caples Lake
- Salt Springs Powerhouse
- Tiger Creek Powerhouse

PLATE D

WATER SUPPLY FORECAST (PRECIPITATION FORECAST)

as of March 27, 1989

(1) Projected Precipitation to June 30	(2) Caples Lake Snow W.C. as of Mar 27 (mm)	(3) Runoff per Inch of Snow W.C. (cu-m/mm)	(4) Rainfall-to-come Mar 28 thru Jun 30 (mm)	(5) Runoff per Inch of Precipitation (cu-m/mm)	(6) Runoff for Mar 27 thru Sep 30 (cu-m)	(7) Water Year Runoff (cu-m)
Repeat of 1975-76 (43% of Average)	757	461,300	84	461,300	387,950,000	597,640,000
Repeat of 1976-77 (68% of Average)	757	534,200	135	534,200	476,510,000	686,200,000
80% of Average	757	582,800	157	582,800	532,680,000	742,370,000
100% of Average	757	655,600	198	655,600	626,100,000	835,790,000
			Actual = 137			Actual = 698,510,000

Column Descriptions:

- (1),(4) Projected precipitation from date of forecast to June 30th.
- (2) Elevation of Caples Lake Station is 2,390 meters.
- (3),(5) Projected runoff for each millimeter of snow water content already on the ground, or projected runoff for each millimeter of precipitation from date of forecast to June 30th.
  Value based upon analysis of historical data, Mokelumne River True Natural Flow at Mokelumne Hill and Mokelumne Basin 4-Station Average Precipitation, Period of Record.
- (6) Equals (2)*(3) + (4)*(5)
- (7) Equals (6) + Actual runoff October 1st of previous year to date of forecast.

PLATE E

WATER SUPPLY FORECASTS

For Various Assumed Projected Precipitation