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BASIC DATA CHARACTERISTICS IN RELATION TO RUNOFF FORECAST ACCURACY 1/

By

R. A. Work and R. T. Beaumont 2/

Abstract

The analyses presented in this paper stress the importance of basing forecasts of river flows upon data secured as nearly as possible at the water sources. Data of the most simple and direct character are most efficient. The basic data, as gathered by snow surveys from the heart of the water-producing areas, generally result in the most accurate forecasts because it is a more precise method of sampling the greatest factor in streamflow production in mountainous western areas.

Introduction

Numerous agencies conduct snow surveys in order to forecast the seasonal runoff of western rivers. Prominent among such agencies are the California Department of Water Resources, the British Columbia Water Rights Branch, a considerable number of private or public utilities, numerous irrigation and soil conservation districts. The U. S. Soil Conservation Service has since 1935 coordinated most of the western snow survey activities outside of California and Canada. The Service has been strongly supported in the activity by various State Engineers and Agricultural Experiment Stations of western states, and by federal agencies specifically concerned with water and natural resource problems, including the U. S. Bureau of Reclamation, Forest Service, Corps of Engineers, Geological Survey, Bonneville Power Administration, National Park Service, Indian Service, Fish and Wildlife Service, and others. The results and interpretations of the snow surveys have been made available for the past 23 years through the published "Federal-State Private Cooperative Snow Survey and Water Supply Forecast" reports.

More recently, beginning in 1944, forecasts of the annual runoff of western rivers have also been developed. These forecasts, based largely upon precipitation measurements, are issued by the U. S. Weather Bureau in its publication entitled "Water Supply Forecasts for the Western United States." The methods used have been detailed in numerous references. The merits of the water year forecast have been described by Kohler (1).

1/ Paper presented at Western Snow Conference, Bozeman, Montana, April 17, 1958.
2/ The authors are respectively, Head, Water Supply Forecast Section, and Head, Analysis Unit, Water Supply Forecast Section, both of Soil Conservation Service, Portland, Oregon. Mrs. Helen Woodbury, Statistical Clerk, developed and assisted in interpretation of the tabular material herein. The authors are deeply indebted to Mrs. Woodbury for her interest and assistance.

Forecast Methods

The basic formulae for most forecasts of runoff are based upon the relationship P - L = R, in which P = precipitation, L = losses, and R = runoff. In measuring or estimating both P and L there are significant differences between the weighted precipitation method and the snow survey method for forecasting runoff. The accumulated precipitation method, in which antecedent runoff is included as a factor in estimating the seasonal runoff, relies largely upon measurements of precipitation on the inhabited valley floors, since the network of accumulative mountain gages is not sufficiently dense to provide records at high elevations for many watersheds. The mountain snow survey measures the residual water equivalent of the snowpack at the water-producing source at the beginning of spring melt. Snow surveys also tend to measure the total accumulation of precipitation at the higher levels, particularly when interpreted in conjunction with estimates of watershed soil moisture deficiency. The Soil Conservation Service in recent years has established 109 stations in western mountains for determining soil moisture beneath the snow pack and intends to increase the density of the watershed soil moisture measurement stations as facilities are available. Water supply forecasters of the Soil Conservation Service are convinced that such measurements will improve the future accuracy of seasonal water supply forecasts from snow surveys. Both procedures utilize data of fall and spring precipitation, and both recognize, in differing fashions, the river base flow factor.

In 1956 the forecasts of annual runoff were expanded to include forecasts of the residual or seasonal runoff by deducting at each forecast date the actual or estimated runoff of the preceding months since October 1 (beginning date of the streamflow year). This is an important and constructive forward step, adding significantly to the utility of the annual runoff forecast but restricted of course in its usefulness by the availability of antecedent runoff values. As of early April 1957 for instance, nearly 50 percent of the published forecasts of annual flow were converted into terms of a seasonal forecast of runoff predicted to come through the April-September or shorter term irrigation period.

Accuracy of Forecasts

Improvement in forecast accuracy by any system would be welcomed by water users in most areas. Alter (2) held that the forecasts of residual flow by the accumulated precipitation method should prove more reliable than forecasts by use of snow survey methods. But, Clyde and Work (3) pointed out that precipitation as measured on populated valley floors and that in adjacent mountainous water-producing areas is often poorly related. The writers have postulated that Alter's theory might find support in localities of relatively low elevation watersheds or in southerly latitudes where winter snow pack accumulations are often subject to sporadic winter melt. If such should be the case, it would appear that the snow survey results there should be qualified by use of suitable precipitation data, particularly through locating precipitation gages of most modern and proven design, at high elevations and read with sufficient frequency. The Soil Conservation Service has recently installed and is reading more than 30 such gages at high watershed elevations for specific use in its seasonal water supply forecasting in Utah. Polos (4) has already described increased forecast accuracy which resulted by adding snow survey data to water year forecast formulae.

In order to see if there are watersheds, where the accumulated precipitation procedure was more reliable, the writers, with the assistance of Soil Conservation Service Snow Survey Supervisors and Assistants1/ have carried out an extensive study of the comparative historical accuracy of April forecasts for identical gaging stations by the two general procedures described. There are several ways to verify forecasts. In recent years Simons (5) has presented to the Columbia Basin Water Forecast Committee a verification by U. S. Geological Survey of forecasts by various agencies. In this paper most of Simon's basic verification method is used. In order to place each year's principal forecasts of annual runoff and seasonal runoff onto a comparable basis the residual runoff for October-March has been deducted from the April first published forecast of the annual water year runoff. Relatively similar comparisons would have resulted by adding the antecedent six-months runoff to the snow survey forecast for the irrigation season. A simple form of expressing the forecast error is used, in which the error equals forecast flow divided by actual flow expressed as difference from 100. Accounting was kept of plus and minus errors to detect any significant trends within either of the two procedures of forecasting.

1/ A. R. Codd, Montana and Missouri River Basin; Robert T. Davis, Washington, W. T. Frost and Manes Barton, Oregon; Norman S. Hall and Roy Malsor, Nevada; Morlan W. Nelson and Jack Wilson, Idaho and Columbia Basin; George W. Peak, Wyoming; Gregory L. Pearson, Utah; Homer J. Stockwell and Jack Washichek, Colorado & New Mexico, and Colorado and Rio Grande Basins; George Watt, Arizona.

The writers are fully aware that this method of expressing error might seem over-simplified for a few cases. For example, in the case of a small, fully utilized stream, producing say, 100,000 acre feet as an average for the April-September period, assume the stream's seasonal discharge is forecast as only 40,000 acre feet, or 40 percent average. Further assume the subsequent measured discharge as 20,000 acre feet. By the authors' method of estimating errors, the forecaster would be charged with a 100 percent error. Actually, however, as a matter of practicality, when the irrigators were forewarned through the snow survey of a water supply to be only 40 percent normal, and had made cropping plans and water conservation adjustments to meet that situation, the actual realization of 20 percent normal flow would not appear to them as 100 percent error. By this method of expressing error, forecasts tending to the minus side produce smaller errors, percentage-wise, than do forecasts tending to the plus side by an equal amount of acre feet.

However, for the purpose of evaluating the relative results of the two forecasting methods for the watersheds, it is felt that the method adopted adequately serves the need.

The average accuracy value for any individual river basin or state does not necessarily reflect the relative stability of the range of values making the average. To illustrate, assume the forecast error of a stream for ten years as follows:

Year 1	-	11 percent error
Year 2	-	14 " "
Year 3	-	9 " "
Year 4	-	8 " "
Year 5	-	14 " "
Year 6	-	13 " "
Year 7	-	5 " "
Year 8	-	15 " "
Year 9	-	12 " "
Year 10	-	100 " "
Average	-	20.1 percent error

In 9 out of 10 years in this example, the forecast error never exceeded 15 percent and was never less than "fair", but in the tenth year (see earlier hypothetical case) the 100 percent arithmetic error would result in classing the <u>average</u> error for this stream as 20.1 percent, which by Western Snow Conference standards (6) rates as "poor".

Therefore, the spread in values for each forecast procedure is also indicated in Tables I, II, and III by a classification of errors by magnitude, and by a showing of closest verification of final results for all paired forecasts by the two forecast procedures.

Since general publication of the annual runoff forecasts began (1944), there have accumulated 1,225 cases on western U. S. rivers, although not including California, where forecasts of runoff by the two procedures can be compared with results for identical gaging stations.

The average accuracy of April 1 forecasts by the two methods is shown in Table I by states.

The average accuracy of April 1 forecasts by the two methods is shown in Table II by river basins.

In order to note any trend in comparative accuracy of the two procedures over the 14-year period of comparison, the accuracy is shown in Table III and Figure I by years.

Analysis of Accuracy

The mean errors of the two forecasting systems, either by state or by basin, as set out in Tables I - III and Figure I, failed to provide a clue as to the sort of basin or watershed in which precipitation data alone or in combination with snow survey data might improve the forecast accuracy of snow survey formulae. The mean forecast error for all basins and for all states, for the over-all comparison period was, without exception, the least by the snow survey method.

TABLE I

Summary of Forecast Accuracy a/ by States as of April 1 Each Year
Snow Survey and Accumulated Precipitation
1944 through 1957

State	Number of Forecasts	Number Individual Forecasts More Accurate Than Corresponding Forecast by Other System		Number Forecasts With 10% or Less Error b/ GOOD		Number Forecasts With 20% or Less Error b/ FAIR or BETTER		Number Forecasts With More Than 20% Error b/ POOR		Maximum Error b/		Minimum Error b/		Mean Error b/	
		c/	d/	c/	d/	c/	d/	c/	d/	c/	d/	c/	d/	c/	d/
Arizona	24	9.5 g/	14.5 g/	5	4	12	12	12	12	189	117	0	0	31	33
Colorado	214	116.5 g/	97.5 g/	61	61	108	107	106	107	142	200	0	0	26	28
Idaho	140	83	57	68	51	101	92	39	48	68	74	0	0	15	17
Montana	183	97.5 g/	85.5 g/	82	76	126	119	57	64	288	345	0	0	22	24
Nevada	61	35.5 g/	25.5 g/	16	15	26	22	35	39	240	267	0	0	34	36
New Mexico	50	24.5 g/	25.5 g/	11	10	18	22	32	28	733	1033	1	1	73	85
Oregon	217	123	94	80	70	145	124	72	93	226	196	0	0	18	22
Utah	172	100.5 g/	71.5 g/	54	41	95	87	77	85	180	292	0	0	26	28
Washington	101	50.5 g/	50.5 g/	45	50	83	80	18	21	36	54	0	0	12	13
Wyoming	63	38	25	33	24	45	35	18	28	124	144	0	0	19	26
Total e/f/	1,225	678.5 g/h/	546.5g/	455	402	759	700	466	525	733	1033	0	0	24 i/	27 i/

TABLE II

Summary of Forecast Accuracy a/ by River Basin as of April 1 Each Year
Snow Survey and Accumulated Precipitation
1944 through 1957

River Basin	Number of Forecasts	Number Individual Forecasts More Accurate Than Corresponding Forecast by Other System		Number Forecasts With 10% or Less Error b/ GOOD		Number Forecasts With 20% or Less Error b/ FAIR or BETTER		Number Forecasts With More Than 20% Error b/ Poor		Maximum Error b/		Minimum Error b/		Mean Error b/	
		c/	d/	c/	d/	c/	d/	c/	d/	c/	d/	c/	d/	c	d/
Arkansas	13	5	8	2	1	4	3	9	10	100	142	3	8	44	45
Colorado	221	121.5 g/	99.5 g/	64	59	121	111	100	110	189	142	0	0	24	25
Columbia	485	258	227	220	208	364	343	121	142	226	196	0	0	15	16
Great Basin	196	115.5 g/	80.5 g/	58	46	98	86	98	110	240	292	0	0	29	33
No.Pacific Coastal	33	26	7	13	4	25	13	8	20	27	59	1	2	14	26
No. & So. Platte	59	34.5 g/	24.5 g/	17	12	29	24	30	35	124	144	0	3	33	36
Rio Grande	88	45.5 g/	42.5 g/	24	26	39	45	49	43	733	1033	0	0	52	64
Upper Missouri	130	72.5 g/	57.5 g/	57	46	79	75	51	55	288	345	0	0	26	29
All Basins e/ f/	1,225	678.5 g/h/	546.5 g/	455	402	759	700	466	525	733	1033	0	0	24 i/	27 i/

TABLE III

Summary of Forecast Accuracy a/ West-Wide as of April 1 Each Year
Snow Survey and Accumulated Precipitation
1944 through 1957

Year	Number of Forecasts	Number Individual Forecasts More Accurate Than Corresponding Forecast by Other System		Number Forecasts With 10% or Less Error b/ GOOD		Number Forecasts With 20% or Less Error b/ FAIR or BETTER		Number Forecasts With More Than 20% Error b/ POOR		Maximum Error b/		Minimum Error b/		Mean Error b/	
		c/	d/	c/	d/	c/	d/	c/	d/	c/	d/	c/	d/	c/	d/
1944	5	1	4	2	3	3	4	2	1	25	25	4	0	15	11
1945	15	8	7	6	5	11	8	4	7	26	39	3	1	14	21
1946	30	16.5 g/	13.5 g/	16	16	24	25	6	5	41	50	0	0	12	13
1947	49	33	16	15	11	33	24	16	25	186	47	0	2	21	21
1948	66	37.5 g/	28.5 g/	15	14	30	30	36	36	204	83	1	0	31	27
1949	83	48.5 g/	34.5 g/	35	30	50	47	33	36	134	76	0	0	19	20
1950	108	57	51	47	40	73	65	35	43	733	1033	0	0	27	37
1951	117	70	47	39	31	67	55	50	62	233	465	0	0	24	38
1952	132	73	59	57	49	94	88	38	44	142	56	0	0	17	18
1953	154	95	59	53	47	103	88	51	66	72	75	0	0	18	21
1954	162	70	92	50	50	77	84	85	78	411	402	0	1	42	39
1955	160	89.5 g/	70.5 g/	47	48	100	88	60	72	222	292	0	0	24	25
1956	138	76.5 g/	61.5 g/	73	57	92	92	46	46	116	164	0	0	17	20
1957	6	3	3	0	1	2	2	4	4	43	107	12	0	23	42
All Years e/f/	1225	678.5 g/h/	546.5 g/	455	402	759	700	466	525	733	1033	0	0	24 i/	27 i/

a/ Not all forecasts by two systems are included, but includes all forecasts by both systems where forecasts were issued for the same gauging station. b/ Percent error equals forecast flow divided by actual flow expressed as difference from 100. c/ Forecasts by snow survey formulae. d/ Forecasts by accumulated precipitation method. e/ Some provisional runoff data. f/ All comparable data not yet available. g/ Credit divided for ties. h/ Odds are less than 1 out of 1,000 for obtaining by chance alone 678.5 best forecasts out of 1,225. i/ From individual forecast errors, not from yearly mean errors.

Note: Forecasts of annual runoff have been converted to seasonal forecasts (directly comparable to Snow Survey forecasts) by subtracting October-March flow from annual.

Current as of September 1957

Perhaps compensating errors, existing within the rather large areas being compared, might be masking the information sought by the authors. The writers felt that if the accumulated precipitation formulae were more dependable, year in and year out, as it has been suggested (2) (7), then moving the forecasts by the two methods towards each other, or averaging them, should improve the snow survey forecast (reduce its error) in a preponderance of cases. Similarly, such procedure should reflect adversely upon the accuracy of the forecasts based on the accumulated precipitation. Accordingly, such procedure was followed out, station by station, basin by basin, for the 14-year comparison period for each forecast point where published forecasts by the two methods existed, and regardless as to whether or not the antecedent runoff record might be available as of forecast date. Results are revealed in Tables IV and V.

This study both by states and by basins, suggests some recognizable areas in which snow survey forecast formulae might be improved through adding a winter precipitation parameter. These were the Rio Grande and Arkansas river basins. Elsewhere are noted cases of widely scattered gaging stations where qualification of snow survey data by use of data of accumulated precipitation would probably have improved the snow survey forecast better than 50 percent of the time.

TABLE IV

Effect of Averaging Forecasts

State	Number a/ Forecast Points	Accum. Made Better	Precip. Made Worse	Snow Survey Made Better	Snow Survey Made Worse	As Many Forecasts Made Worse as Better: Accum. Precip.	As Many Forecasts Made Worse as Better: Snow Survey
Arizona	4	2	2	3	1	0	0
Colorado	27	17	7	15	11	3	1
Idaho	17	12	4	6	8	1	3
Montana	37	21	10	14	15	6	8
Nevada	7	6	0	3	2	1	2
New Mexico	7	4	2	4	1	1	2
Oregon	30	21	6	10	17	3	3
Utah	24	17	5	10	11	2	3
Washington	18	11	5	8	8	2	2
Wyoming	6	6	0	2	3	0	1
Total	177	117	41	75	77	19	25
		66%	23%	42%	44%	11%	14%

a/ Each forecast point is a case regardless of number of years in the comparison.

TABLE V

Effect of Averaging Forecasts

Basin	Number a/ Forecast Points	Accum. Made Better	Precip. Made Worse	Snow Survey Made Better	Snow Survey Made Worse	As Many Forecasts Made Worse as Better: Accum. Precip.	As Many Forecasts Made Worse as Better: Snow Survey
Arkansas	3	1	1	2	1	1	0
N. & S. Platte	7	6	1	3	4	0	0
Great	26	19	5	14	10	2	2
Rio Grande	10	6	2	6	2	2	2
Up. Missouri	30	17	9	11	14	4	5
Colorado	29	19	8	13	13	2	3
Columbia	67	44	15	27	28	8	12
No. Pac. Coast	5	5	0	0	5	0	0
Total	177	117	41	75	77	19	25
		66%	23%	42%	44%	11%	14%

a/ Each forecast point is a case regardless of number of years in the comparison.

TABLE VI

Distribution of Errors by Algebraic Sign

Year	No. of Comparable Forecasts Yearly	No. of Comparable Forecasts Accum.	Accum. Precip. Forecasts Plus/a Yearly	Accum. Precip. Forecasts Minus/b Yearly	Accum. Precip. Forecasts Plus/a Accum.	Accum. Precip. Forecasts Minus/b Accum.	Zero/c	Snow Survey Forecasts Plus/a Yearly	Snow Survey Forecasts Minus/b Yearly	Snow Survey Forecasts Plus/a Accum.	Snow Survey Forecasts Minus/b Accum.
1944	5	5	2	3	2	3		4	1	4	1
1945	15	20	5	10	7	13		5	10	9	11
1946	30	50	9	20	16	33	1	5	24	14	35
1947	49	99	11	38	27	71		10	38	24	73
1948	66	165	24	42	51	113		34	32	58	105
1949	83	248	26	57	77***	170***		62	19	120	124
1950	108	356	30	78	107***	248***		65	43	185	167
1951	117	473	33	83	140***	331***	1	58	59	243	226
1952	132	605	33	99	173***	430***		83	48	326	274
1953	154	759	37	116	210***	546***	1	34	118	360	392
1954	162	921	108	54	318***	600***		115	45	475	437
1955	160	1,081	86	74	404***	674***		89	71	564	508
1956	138	1,219	89	49	493***	723***		85	52	649**	560**
1957	6	1,225	1	4	494***	727***	1		6	649*	566*
Total			494	727			4	649	566		

a/ Measured runoff less than forecast; that is, overforecast. b/ Measured runoff more than forecast; that i underforecast. c/ Measured runoff same as forecast.

Tests not made for first five years in order to accumulate enough cases.

* Difference between plus and minus errors (accumulated cases) statistically significant at 5% level.

** Difference between plus and minus errors (accumulated cases) statistically significant at 2% level.

*** Difference between plus and minus errors (accumulated cases) statistically significant at .001% level.

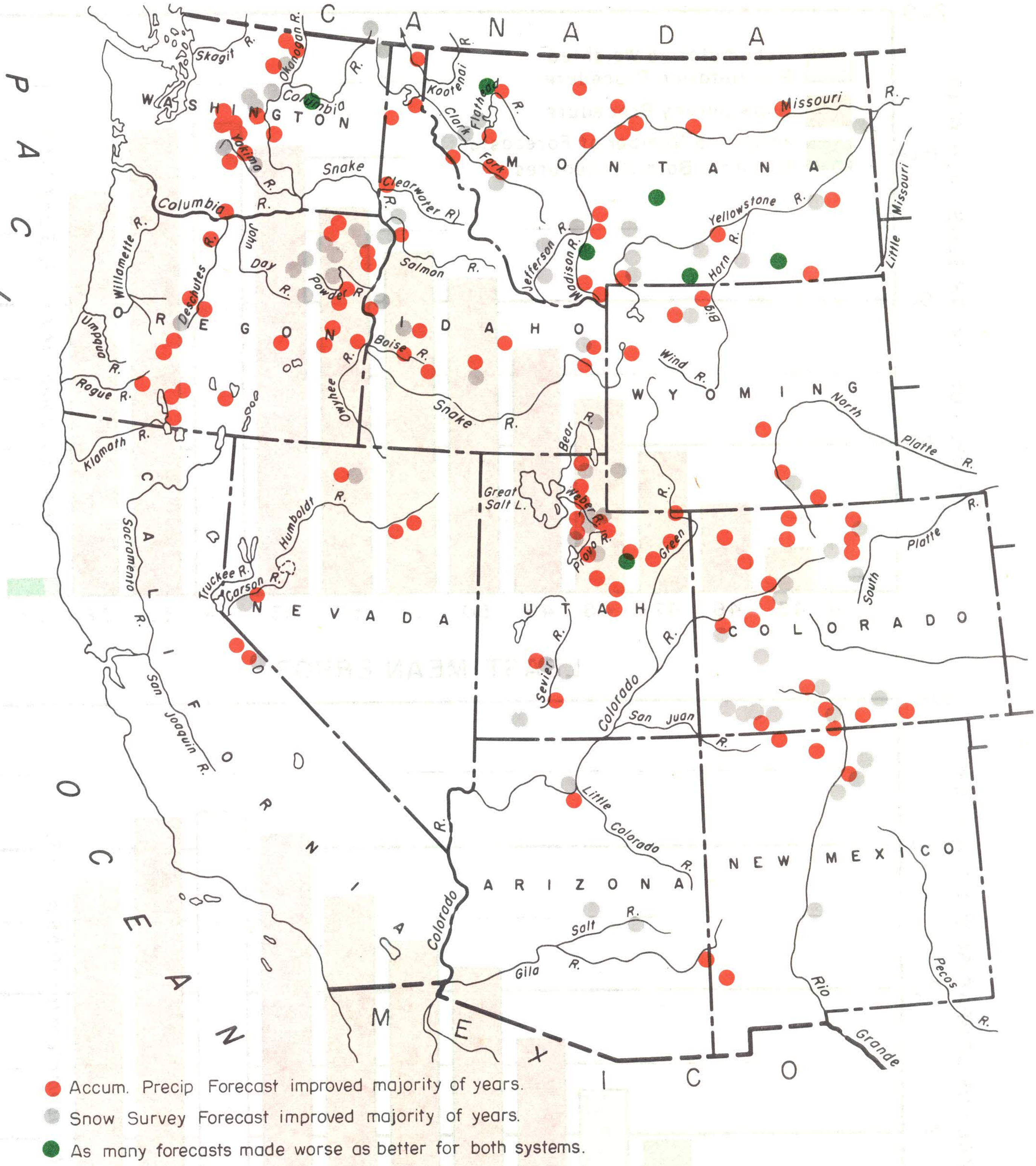

FIG. 2
RESULTS OF MOVING FORECASTS TOWARD EACH OTHER

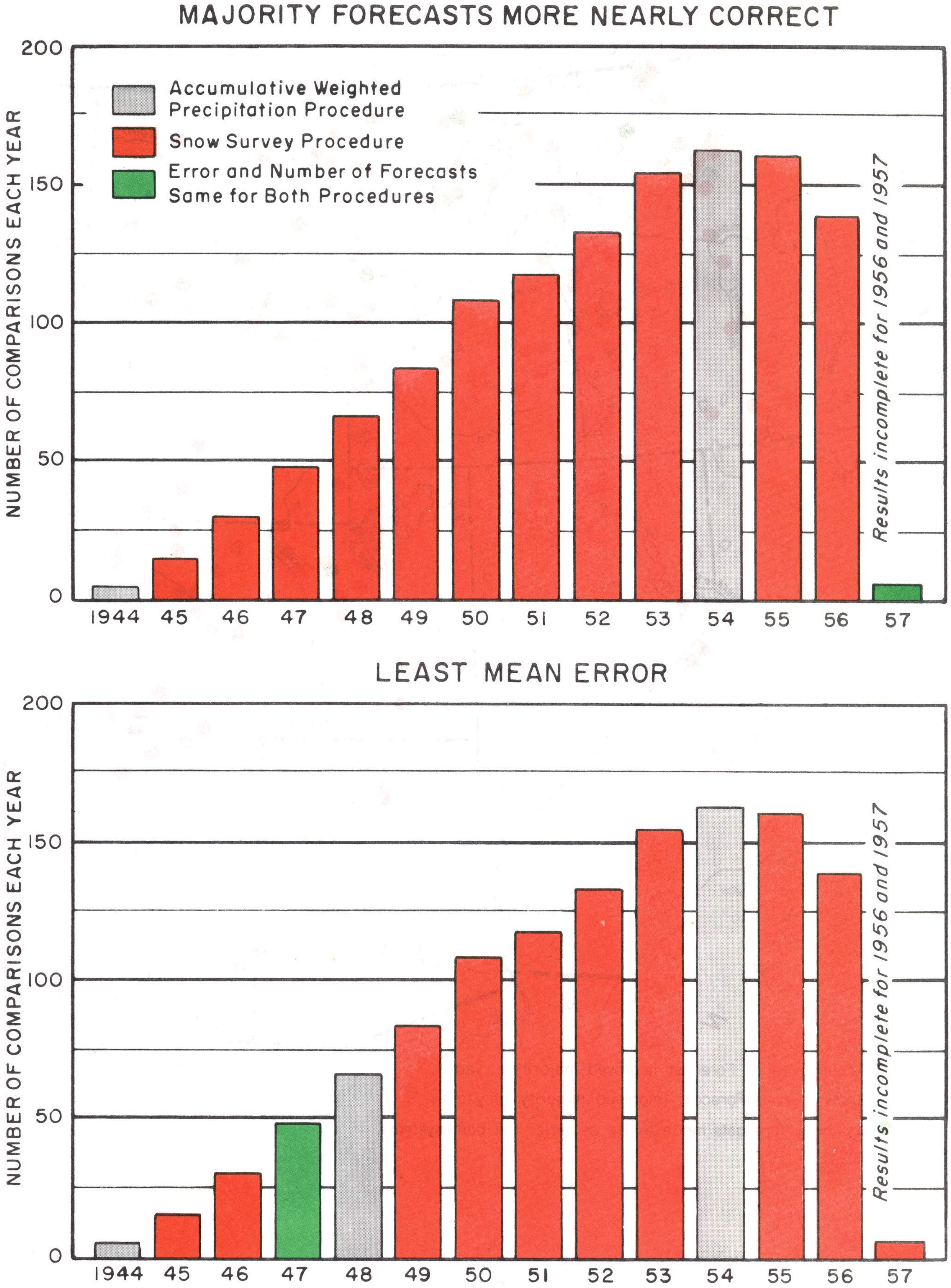

FIG. 1 : ANNUAL FORECAST VERIFICATION

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THE OPTIMUM USE OF WATER FOR POWER CALCULATED BY DATATRON ELECTRONIC COMPUTER

By

J. D. Ellis[1/]

Pacific Power & Light Company completed installation of a Datatron Electronic Computer System at its Portland office in the Public Service Building in June, 1957. The arrangement of computer, computer console, input and output control units and paper tape, magnetic tape and punched card units in the computer room, is shown in chart 1. These principal components of the computer cost about $300,000 and do not include the auxiliary IBM equipment that we lease. The cost of the computer is justified by savings in billing and other accounting work. In addition, it makes feasible the solving of many engineering problems and the processing of much engineering and operating data otherwise not possible.

When Swift No. 1 (440,000 acre-feet of storage) and Swift No. 2 are completed in December, 1958, with existing Yale and Merwin plants there will be approximately 900,000 acre-feet of storage on the Lewis River. This will substantially control the natural flow and whenever Muddy Project (277,000 acre-feet of storage) is built twelve miles up river from Swift No. 1, the five hydro plants and four storage reservoirs with approximately 1,170,000 acre-feet of usable storage will bring the Lewis River completely under control except under extreme conditions. (See chart 2)

The calculation and summation of power generation at all five of these plants, involving drafting and refilling of four reservoirs, is a long and tedious job for an engineer using tables, curves, and a hand calculator and would take him approximately two days to figure energy output and peaking capacity for one year by months.

Recorded natural flows in the Lewis River at Merwin Dam vary considerably (minimum day 700 Cfs and maximum day 129,000 Cfs). This necessitates careful planning of reservoir operation.

Storage is used to augment low natural flow in the fall and winter months in adverse years and to catch excessive high flow in winter and spring months, regulating flow to within capacity of turbines and providing seasonal storage for winter heavy load periods.

1/ J. D. Ellis, Pacific Power & Light Company.