AN EXPERIMENT IN USE OF SEASONAL LONG-RANGE WEATHER FORECASTS FOR WATER SUPPLY FORECASTS IN NORTHERN CALIFORNIA

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ABSTRACT

From 1978 through 1992 Scripps Institution of Oceanography made quarterly long-range weather forecasts of precipitation in the Sierra Nevada. The 15 year experiment showed some skill in the winter and spring season. In the 1980s an attempt was made to apply the skills that existed to an early season December 1 forecast of water year runoff on selected rivers. The methodology of adjusting the conventional runoff forecast and the conventional expected range of runoff (which are based on climatology for future weather) for the demonstrated weather forecasting skill will be described in the paper. Some test results are shown. Unfortunately, the weather forecasting skills declined during the period of hydrological testing to below the threshold of usefulness and the forecasting experiment was put aside for a later time. But we believe there is merit to documenting the methodology and results of this experiment for other professionals.

INTRODUCTION

Each year the California Department of Water Resources' Snow Survey Program collects snow and related hydrologic data and produces forecasts of the state's potential snowmelt and water year runoff. The official forecast report is Bulletin 120, *Water Conditions in California*; it is published in 4 editions -- February, March, April and May. Similar water supply forecasts are made by other agencies throughout the west; primarily by the Natural Resources Conservation Service and the National Weather Service in other western states of the U.S. and by the western provinces in Canada.

The Bulletin 120 report contains a summary of current water supply conditions and numerical forecasts of unimpaired runoff of the major rivers. The Central Valley river forecasts are placed in two facing pages so that the reader can see forecasts for the entire drainage basin at a glance. One side has the April through July snowmelt runoff forecasts including the 80 percent range of possible runoff, the other side has the water year forecast (which ends on September 30). A partial sample of both pages is attached.

The forecasts are for unimpaired flow (essentially natural runoff). Unimpaired runoff represents the natural runoff of a river basin, unaltered by upstream diversions, storage, or by export or import of water to and from other watersheds.

Forecasts are based on observed snow water content, precipitation, and runoff conditions for the season and other hydrologic parameters as well as historical patterns of weather and runoff. The median forecasts assume normal (median) weather for the remainder of the runoff season.

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Sample of Forecast Bulletin Table

CALIFORNIA COOPERATIVE SNOW SURVEYS
APRIL 1, 1997 FORECASTS from BULLETIN 120-3-97

APRIL-JULY UNIMPAIRED RUNOFF / WATER YEAR UNIMPAIRED RUNOFF

HYDROLOGIC REGION and Watershed	Unimpaired Runoff in 1,000 Acre-Feet					Unimpaired Runoff in 1,000 Acre-Feet (1)												
	HISTORICAL			FORECAST		HISTORICAL			DISTRIBUTION								FORECAST	
	50 Yr Avg (2)	Max of Record	Min of Record	Apr-Jul Forecast (range)	Pct of Avg	50 Yr Avg (2)	Max of Record	Min of Record	Oct Thru Jan*	Feb *	Mar *	Apr	May	Jun	Jul	Aug & Sep	Wat.Yr. Forecast (range)	Pct of Avg
SACRAMENTO RIVER																		
Upper Sacramento River																		
Sacramento River at Shasta Lake (3)	297	702	39	160	54%	856	1,964	165										
McCloud River at Shasta Lake	392	850	185	330	84%	1,184	2,353	577										
Pit River at Shasta Lake	1,056	1,796	480	1,020	97%	3,078	5,150	1,484										
Total Inflow to Shasta Lake	1,801	3,189	726	1,650	92%	5,896	10,796	2,479	4,390	710	500	580	480	340	250	420	7,670	130%
				(1260 - 2350)**													(7200 - 8520)**	
Sacramento River above Bend Bridge	2,451	4,674	943	2,030	83%	8,518	17,180	3,294	6,210	1,030	710	750	620	380	280	510	10,490	123%
				(1590 - 2880)**													(9940 - 11580)**	
Feather River																		
Feather River at Lake Almanor	333	675	120	250	75%	780	1,269	366										
North Fork at Pulga (3)	1,028	2,416	243	740	72%	2,417	4,400	666										
Middle Fork near Clio (4)	86	518	4	60	70%	219	637	24										
South Fork at Ponderosa Dam (3)	110	267	13	80	73%	291	562	32										
Total Inflow to Oroville Reservoir	1,831	4,676	392	1,320	72%	4,526	9,492	994	4,380	555	530	540	440	220	120	165	6,950	154%
				(950 - 2030)**													(6550 - 7790)**	
Yuba River																		
North Yuba below Goodyears Bar (3)	286	647	51	260	91%	564	1,056	102										
Inflow to Jackson Mdws & Bowman R.	112	236	25	100	89%	181	292	30										
South Yuba at Langs Crossing (3)	233	481	57	210	90%	379	565	98										
Yuba River at Smartville	1,029	2,424	200	940	91%	2,337	4,926	369	2,500	300	265	330	390	180	40	35	4,040	173%
				(760 - 1330)**													(3850 - 4450)**	
American River																		
North Fork at North Fork Dam (3)	262	716	43	250	95%	616	1,234	66										
Middle Fork near Auburn (3)	522	1,406	100	500	96%	1,070	2,575	144										
Silver Cr. below Camino Div. Dam (3)	173	386	37	170	98%	318	705	59										
Total Inflow to Folsom Reservoir	1,261	3,074	229	1,220	97%	2,674	6,381	349	3,180	340	295	440	510	230	40	25	5,060	189%
				(1030 - 1740)**													(4860 - 5610)**	

(1) See inside back cover for definition
(2) All 50 year averages are based on years 1946-1995 unless otherwise noted
(3) 50 year average based on years 1941-90
(4) 44 year average based on years 1936-79
* Indicates observed runoff
** Forecast range is 90% to 10% probability of exceedence

FORECAST RANGE

Many readers are satisfied with the median forecasts. However, an 80 percent probability range is also presented to give users a better idea of the range of uncertainty in the forecasts.

These 80 percent probability ranges represent uncertainties in future weather and forecast procedure error. The range is quite large in the February report but gradually narrows as the season progresses. Figures 1 and 2, taken from work by Jack Hannaford (1977), shows two samples of the range diagram. The Feather River is in the northern Sierra Nevada and normally has a large direct rain runoff component in addition to spring snowmelt. The Kings River basin in the southern Sierra Nevada is higher in average elevation and is predominately a snowmelt runoff stream. Average April through July runoff on the Feather River is 2260 million m^3 (1,831, 000 acre-feet) per year; that on the Kings River is 1460 million m^3 (1,183,000 acre feet) per year.

FORECAST ERROR

Total forecast error may by looked at as the vector sum of hydrologic procedure error and the error due to future weather being different from median. Procedure error is the inability to exactly forecast runoff when all forecasting parameters are known. This includes data errors in addition to model or procedure methodology errors. Potentially, procedural error can be reduced by use of more refined data (but remember this has to be something that can be measured and reported in real time during the forecast season), by including new parameters or by better techniques and models.

The second error component is the inability to predict future weather conditions, especially the amount of rain and snow after the date of forecast. The standard water supply forecast assumes median future weather conditions, based on historical climatology. Thus, the amounts are equally likely to be higher or lower than the forecast, but the most likely outcome will be near the forecasted value.

Figures 1 and 2 show that the future weather component is by far dominant in the early forecasts, even in California where the rainy season is essentially over in April. Therefore, procedure improvement by itself would have little effect on the forecast accuracy in February. Even by April 1, to use the Kings River diagram as an example, the weather component of the upper 10 percent exceedence side of the diagram is about 250 million m^3 (205,000 AF) compared to a procedural component of 100 million m^3 (80,000 AF). These combine vectorially to give a total range of 270 million m^3 (220,000 AF) over median.

Note that the range error diagram is not balanced; the downside range is less than the upper side. That is a reflection of the skewed distribution of precipitation. It is possible for precipitation to be several times the median, whereas it can not be less than zero on the bottom side. In practice, use of these diagrams has to be further tempered by the type of water year. The downside range, especially, would give unreasonable results if used literally in a very dry year.

Irrigators and other water users need to know as early as possible what their water supply for the year will be. But it has been shown that early and even mid-season runoff forecasts cannot be improved much by refining procedures. The only hope for substantial improvement lies in reducing the future weather error component. That requires long range weather forecasts ideally at least three months or more into the future.

USE OF LONG RANGE WEATHER FORECASTS

It is not uncommon for water project operators to modify operations for short term forecasts of one to five days. The reliability of these forecasts decreases rapidly as the forecast period is extended into the future.

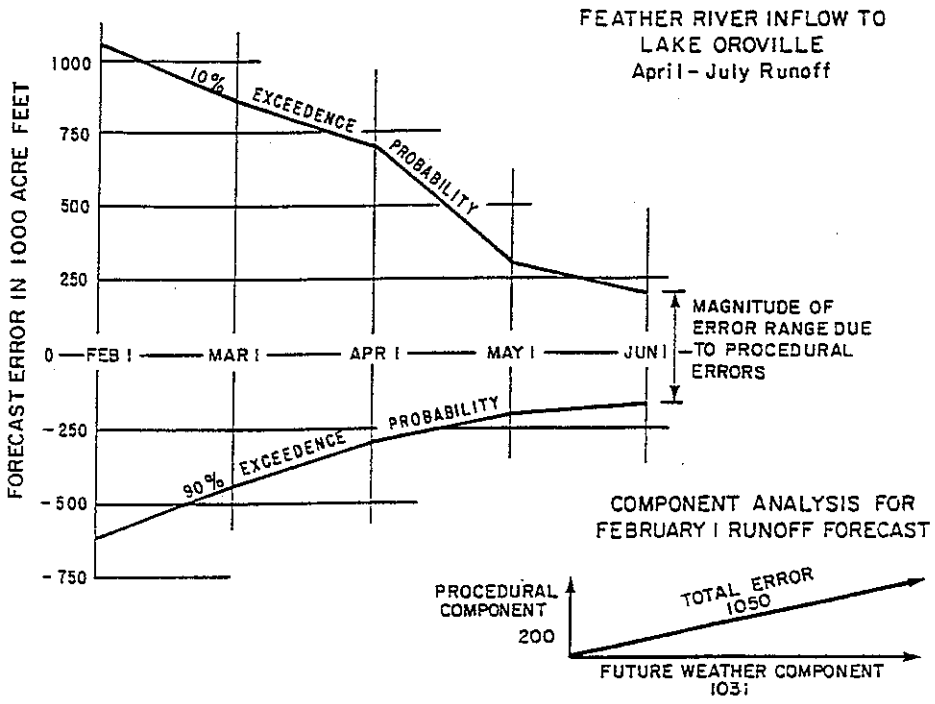

Figure 1. FEATHER RIVER 80% RANGE FORECAST ERROR DIAGRAM

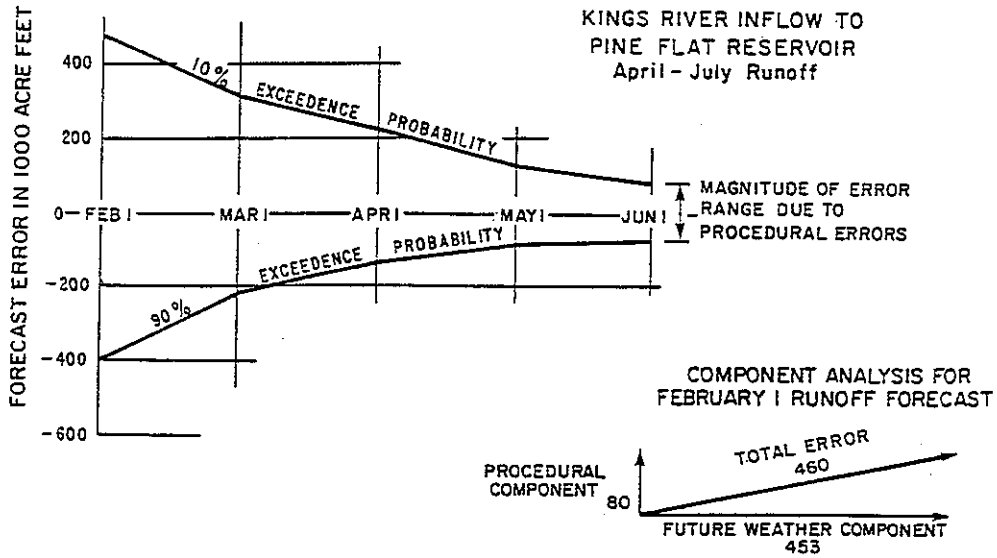

Figure 2. KINGS RIVER 80% RANGE FORECAST ERROR DIAGRAM

However, weather forecasts extending a few days into the future do not help much in water supply forecasting. The obvious need is to greatly improve medium and long range weather forecasts. Some research on this is underway. But if acceptable results are obtained, how might these uncertain forecasts be used? Some suggestions are offered herein.

Figure 3 shows a bar chart of the statistical distribution of winter precipitation for Canyon Dam, a northern Sierra station about 1,400 meters in elevation in the Feather River basin at Lake Almanor about 150 kilometers north of Sacramento. The seasonal amounts of precipitation are ranked from highest to lowest. The listing is then divided into thirds or terciles. The highest third, above 590 mm, is the upper tercile and the lowest third, below 430 mm, is then the lower tercile. In between is the middle tercile which has the smallest quantitative range.

Some long range weather forecasts are simply wet or dry which usually means above or below median. A more useful forecast would be to prescribe which tercile future precipitation will be. Obviously, it would be best if the forecaster could specify percentiles, but that seems to be far beyond current skills.

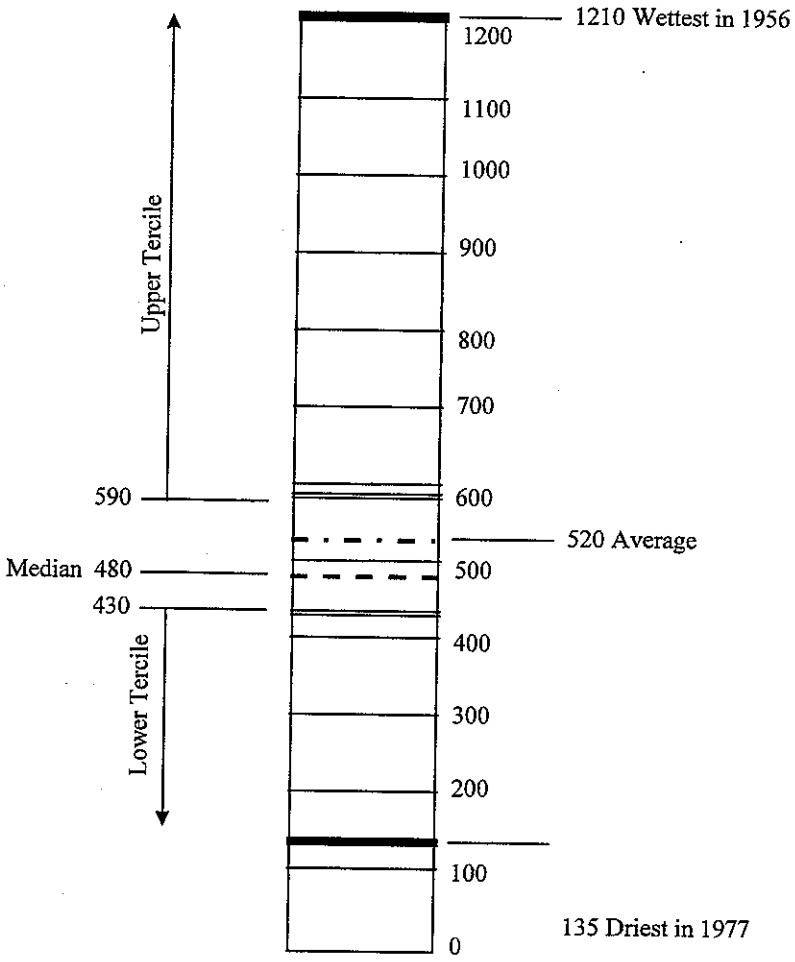

Figure 3. Distribution of winter season precipitation at Canyon Dam December through February. Amounts in mm (1947-1986).

FORECAST SKILL

In order to use a long range weather forecast, initially one has to evaluate the skill of the long range forecast, whether for one month or for 3 months. (Monthly units are convenient because much of historical data is monthly.) A widely used method is to rate the skill of a forecaster by a simple skill score computation. This is the ratio of correct forecasts over the total number of forecasts after allowing for the number of correct forecasts expected from chance. The formula is:

$$S = \frac{R - E}{T - E}$$

Where:

S = Skill score (often multiplied by 100 to give percent)
R = number of correct forecasts
T = total number of forecasts
E = number of forecasts expected to be correct based on climatology.

For example, if forecasting is in terciles, and there are 30 total forecasts, we would expect 10 to be correct just on the basis of chance. If the forecaster got 20 correct, this means the person was able to correctly predict 10 of the remaining 20 events and his skill score would be 50 percent. The skill score has a possible range of -50% (all forecasts wrong) to 100% (all forecasts right).

APPLICATION

In water supply application, two runoff forecasts were made. Both forecasts use hydrologic data to the date of forecast. The first one was conventional, assuming median future precipitation with the corresponding 80 percent probability range. The second forecast assumed the weather forecaster was correct. The long range forecast precipitation was used for the projected period of forecast (three months in this case). If the precipitation season extended past the weather forecast, the historic median would be used for the remaining months of the water year.

A similar approach was used for the 80 percent probability range. This required assigning probability spreads to the long range forecast. At this time there is not enough skill or track record for a consistent long range forecast method to do so accurately. For forecasts which use terciles, we ranked the historical forecast period amounts from high to low; then chose a one-third segment centered on the forecasted amount. Thus the 80 percent range was compressed to match the reduced tercile span. For example, a three part long range scheme would forecast wet, near-normal, and dry categories. If forecasted to be wet, the conventional probability curve was compressed to fit into the upper third of the historic record and the 10 percent exceedence figure was near the wettest year of record while the 90 percent exceedence was just above the top third tercile point.

The second forecast was then blended with the conventional one by shifting toward the long range weather forecast product to the extent of its skill score. If the skill score was 50 percent, this would mean half way on percentiles of runoff. For example, if the conventional runoff forecast fell in the 40th percentile and the forecast produced by the long range weather forecast was in the 80th percentile, the experimental blend would be the 60th percentile number. Similar blending would be done for the 80 percent range limits. The result is not only a runoff forecast slanted in the direction of the long range forecast, but a smaller probability range than conventional early season forecasts.

For 15 years, beginning in 1977, the California Department of Water Resources encouraged a long range seasonal weather forecasting effort by Scripps Institution of Oceanography in San Diego. Their forecasts were based mainly on sea surface temperatures, upper air atmospheric pressure patterns, and surface temperature patterns over North America. Principal scientists were Drs. Jerome Namias and Daniel Cayan. Quarterly forecasts were provided for fall, winter, spring, and summer. The fall season is September through November, winter is December through February, and so forth. The winter season, on average, accounts for half the annual precipitation and is

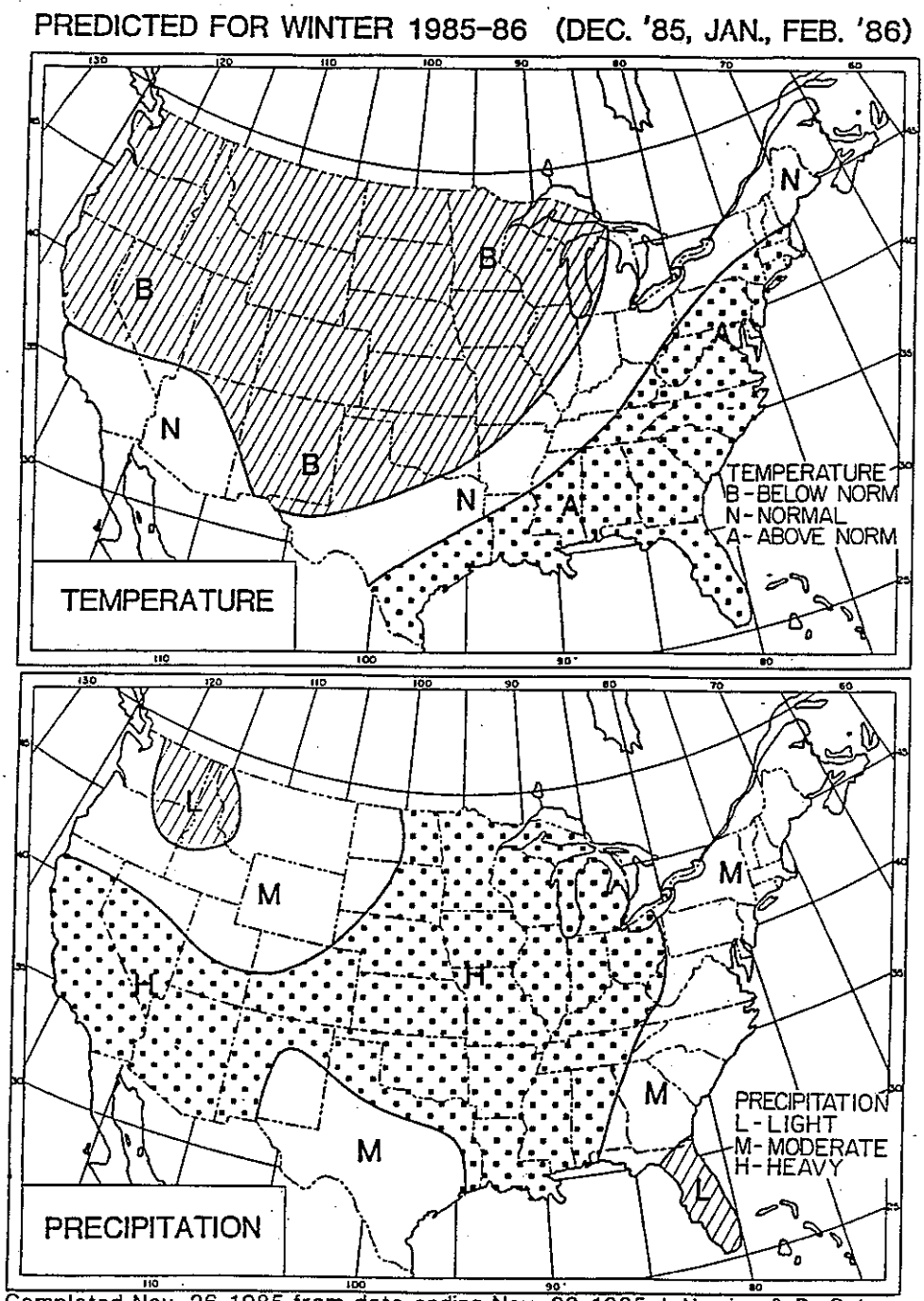

Figure 4. Example of Scripps Long Range Seasonal Forecast

Jerome Namias and Daniel Cayan. Quarterly forecasts were provided for fall, winter, spring, and summer. The fall season is September through November, winter is December through February, and so forth. The winter season, on average, accounts for half the annual precipitation and is therefore the most important for water supply. Nearly one quarter of the annual precipitation occurs during the fall season and slightly over one quarter during the spring quarter; the summer quarter is an insignificant 2 to 3 percent. A sample of one of their forecasts is shown on Figure 4.

RESULTS

A box chart, of which a sample is shown on Figure 5, was put together to evaluate the Scripps forecasts. The "x" is the forecast and the "o" is the observed precipitation tercile. The three rows are for the northern, central, and southern Sierra. Both symbols are in the same box when the observed precipitation matches the forecast. There are a couple of times when the amounts fell on the category transition, for example, northern Sierra in fall of 1985. We gave those half credit. For the 15 year period the skill scores for the fall quarter were -0.02; winter 0.20, spring 0.20 and summer 0. This indicates some skill for the winter and spring but none for the summer and fall. Of more consequence to a water project operator is a double miss, especially a forecast of wet which turned out to be dry, as in winter of 1987. Those happened in 19 percent of the winter cases, just slightly less than the 22 percent expected by chance. Of course, a more conservative forecaster could avoid a two class error by staying near the middle, but then the forecast would not be very useful in water operations.

SEASON		FALL			WINTER			SPRING			SUMMER			L = Light M = Moderate H = Heavy
		L	M	H	L	M	H	L	M	H	L	M	H	
1982-83	Forecast		X				X			X	X			North Sierra
	Observed			O			O			O		O		
	Forecast		X				X			X	X			Central Sierra
	Observed			O			O			O		O		
	Forecast		X				X			X	X			South Sierra
	Observed			O			O			O			O	
1983-84	Forecast		X			X		X			X			North
	Observed			O		O			O				O	
	Forecast		X			X		X				X		Central
	Observed			O		O		O					O	
	Forecast		X				X	X				X		South
	Observed			O		O		O					O	
1984-85	Forecast		X				X		X			X		North
	Observed			O	O			O				O		
	Forecast		X				X			X		X		Central
	Observed			O	O			O				O		
	Forecast		X		O		X			X		X		South
	Observed			O					O			O		
1985-86	Forecast		X				X			X		X		North
	Observed		O				O		O		O			
	Forecast			X			X		X			X		Central
	Observed			O			O		O		O			
	Forecast			X			X		X			X		South
	Observed			O			O			O	O			
1986-87	Forecast		X				X			X			X	North
	Observed		O		O				O		O			
	Forecast		X				X		X				X	Central
	Observed	O			O			O			O			
	Forecast		X				X		X				X	South
	Observed	O			O				O			O		

Figure 5. Box chart comparing forecasted and observed precipitation by season.

Figure 6 shows the history of skill starting from the 5th year of the experiment in 1982. At that point the winter skills were an impressive 65 percent. By 1990, skills had dropped to around 30 percent, which is the threshold of usefulness in a 3 part forecasting scheme.

By mutual agreement, we decided in 1992 that it would be better to put aside the experimental early water supply forecast to await further developments in long range weather forecasting.

Table 1 shows the comparisons of conventional and experimental runoff forecasts for the water year on the Feather River, one of the 7 streams tested in the program. Since this is very early in the water (2 months into the season) ranges are wide. The best verification of the winter season long range forecast is the March 1 forecast which has the actual winter weather and the same median climatological future as assumed in the December 1 experimental forecasts.

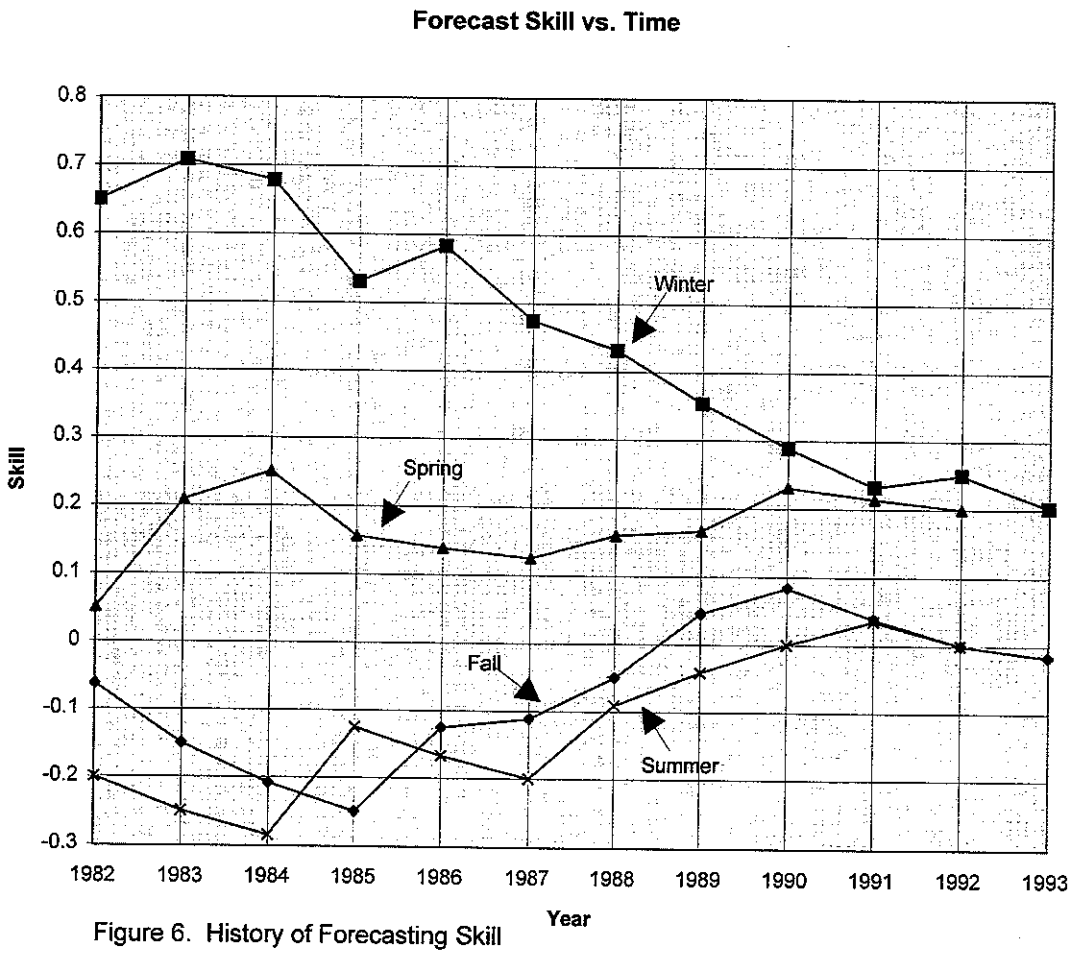

Figure 6. History of Forecasting Skill

TABLE 1
EXPERIMENTAL RUNOFF FORECASTS
Based on Scripps Long Range Winter Season Forecasts
In 1,000 Acre-Feet
Feather River
(1941-1990 Average Runoff = 4,620)

Forecasted in Early December

Water Year	Conventional Projection of Water Year Runoff			Experimental Projection of Water Year Runoff		
	Median Amount	Percent	80% Probability Range	Median Amount	Percent	80% Probability Range
1982	6600	143	4500 to 9500	7000	152	5800 to 9500
1983	5600	121	3100 to 8500	5900	128	4400 to 8800
1984	6400	139	3800 to 9200	6300	136	5000 to 8200
1985	5300	115	3100 to 8000	6300	136	4600 to 8600
1986	4100	89	2100 to 6800	4900	106	2800 to 6900
1987	3300	71	1800 to 6300	3900	84	2600 to 6400
1988	3300	71	1400 to 6100	3300	71	1900 to 5800
1989	4300	93	2300 to 7300	4700	102	2900 to 7300
1990	4000	87	2100 to 7000	4000	87	2400 to 6400
1991	2900	63	1300 to 5800	3000	65	1600 to 5700
1992	3000	65	1500 to 6300	2800	61	1400 to 5700

Forecast Verification

Water Year	March 1 Forecasted Runoff		Observed Runoff For Water Year	
	Amount	Percent	Amount	Percent
1982	7420	161	9000	195
1983	7660	166	9420	204
1984	6200	134	5770	125
1985	3070	66	2640	57
1986	6600	143	6720	146
1987	2300	50	2170	47
1988	2660	58	2010	44
1989	2470	53	3710	80
1990	2400	52	2140	46
1991	1200	26	2070	45
1992	2350	51	1950	42

CONCLUSIONS

At first the results looked very promising. For the first 5 years, 1982 through 1986, four of the experimental forecasts were closer to the actual. Then a 5 year series of generally incorrect winter forecasts gradually eroded the skill to less than threshold levels of usefulness. This illustrates the importance of a long run evaluation. Good streaks of forecasts occur often but skills can be expected to fluctuate over time.

One of the strongest forecasting signals is the warming of the eastern tropical Pacific known as El Niño. The 1982-83 event was very strong. Later in the decade, ocean signals were not as obvious. Current thinking, as exemplified by the efforts of the Climate Prediction Center of the U.S. National Weather Service, is that sometimes there is a usable weather forecast signal, often not. When one looks at their 3 to 15 month regular forecasts of precipitation, most of the area is labeled CP, climatological probability, and only relatively small portions have a wet or dry shift.

The strongest long range indicator seems to be the tropical Pacific ocean. The southern oscillation index, as measured by the sea level pressure difference between Tahiti and Darwin, does have an influence at a number of locations around the world. For example, an El Niño event tends to produce a warmer and drier than usual Pacific Northwest with a strong enough correlation so that it can be built into early season forecasts of runoff with some confidence. It has not worked for northern California.

Progress is being made in understanding the atmosphere and worldwide teleconnections. We should continue to monitor the work of the long range weather forecasters, evaluate their skill, and when it shows promise, try to apply such skills to early season water supply forecasting. The work described herein served as a catalyst for current climate diagnostic studies of the northern hemisphere and western North America.

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