12C.7 Water Supply Forecasting in the Upper Klamath Lake Basin During the 2001 Drought

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1. INTRODUCTION

During water year 2001 the Upper Klamath Lake Basin experienced a near record drought. During water year 2001, the snowpack, the primary source of streamflow, peaked at approximately 55% of average in January 2001. By April 1, 2001 the observed snowpack had fallen to below the previously established record minimum of 27% of average. Based on the April 1st Natural Resources Conservation Service (NRCS) Water Supply Forecast of 31% of average streamflow for the April-September period, the Bureau of Reclamation cut off all irrigation water to over 75% of the irrigated agriculture in the Klamath Basin. This affected 170,000 acres (68,800 hectares) of farmland. The decision based on the endangered species act supported biological opinion by the, Fish and Wildlife Service, the National Marine Fisheries Service and court action was historic and made immediate national headlines.

2. KLAMATH BASIN OVERVIEW

The Klamath River originates at Upper Klamath Lake in Oregon and flows in a southwesterly direction, through the Cascade Range and the Klamath Mountains, and discharges to the Pacific Ocean (Figure 1.). The Upper Klamath Basin encompasses approximately 8,000 square miles (20,700 square kilometers) and is located in south-central Oregon and northeastern California. The Oregon part of the basin (more than 5,600 square miles – 14,500 square kilometers) lies primarily in Klamath County with smaller parts in Jackson and Lake Counties. The California part of the basin (more than 2,300 square miles – 5,960 square kilometers) lies in Modoc and Siskiyou Counties. (USGS, 2001)

2.1 Geography

The Klamath Basin spans parts of the Sierra-Cascade Mountain province to the west and the Basin and Range province to the east. Down faulted valleys and fault block mountains of the Basin and Range province terminate against the Cascade Mountains (Illian, 1970). In the upland areas of the basin to the north, the Wood and Williamson Rivers originate from the eastern flank of Mount Mazama (Crater Lake). To the east, the Sprague and Lost Rivers flow westward from more arid parts of the basin. The California portion of the basin to the south is characterized by closed lake basins that are more typical of the Basin and Range Province.

2.2 Climate

The Klamath Basin climate is characterized by hot, dry summers and wet winters with moderate to low temperatures. Annual basin precipitation totals range from 15 inches (38.1 centimeters) at valley floors to more than 70 inches (178 centimeters) in the Cascade Mountains. Sixty to seventy percent of the precipitation occurs from October through March. An average of about 4 inches of rain falls during the period from April through September (Oregon State Climatologist; Oregon State Water Resources Board, 1971; Illian, 1970).

3.0 WATER SUPPLY FORECASTING

In the Klamath Basin, water supply forecasting is a critical component needed to manage irrigation water resources for the basin. The basin consists of many hundreds of acres of farms and ranches, which mainly grow alfalfa, potatoes, and hay. All crops and grazing is irrigated in the area. The basin also has an important National Wildlife Refuge for migrating birds, including critical habitat for Bald Eagles.

The largest lake in the basin, Upper Klamath Lake has an endangered fish species of Shortnose and Lost River Sucker fish that is resident to the lake. Downstream of this lake in the lower reaches of the Klamath River are endangered salmon spawning and rearing areas. All of these critical resources require water at a certain volume, velocity and quality to meet these species needs. Unfortunately the wildlife needs compete for the same limited water as the irrigated agriculture in the watershed.

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3.1 Klamath Basin Data Collection Networks

Water supply volumes are forecast at five locations in the Klamath. As shown in Figure 1, snowpack and climate information from 19 SNOTEL sites, six manual snow courses and four aerial snow depth markers are located in the Klamath Basin region. Of the 19 SNOTEL sites in the region, thirteen are used to create the water supply forecast from January to June every year. The stations located are listed in Table 1. Two of the 19 SNOTEL sites have been augmented with soil temperature and soil moisture sensors to assess snowmelt runoff productivity during the spring snowmelt.
The SNOTEL sites report snow water content, cumulative seasonal precipitation, snow depth, maximum, minimum and current temperature every six hours which are posted to the NWCC webpage www.wcc.nrcs.usda.gov.

3.2 History of Forecasting Water Supplies in the West:

Since the early 1900s, seasonal streamflow volume forecasts for western basins have been created and used by those dependent on spring snowmelt runoff. Water supply forecasting began by comparing the snowpack in the mountains to the subsequent volume of water produced by the snow in the spring in the Sierra Nevada mountains in order to determine the water supply for the city of Reno, Nevada.

Since the West has a Mediterranean climate, winter precipitation (snow) accounts for 75-85 percent of the surface water supply for the following spring and summer months. In order to maximize this seasonal runoff reservoirs were constructed to extend the availability of the spring runoff. Water managers have become reliant on streamflow forecasts of the amount of water that they will receive that year to manage reservoirs for competing uses. Agriculture, municipalities, recreation, fish and wildlife and other water uses rely on the forecasts to provide an early warning of the amount of water they will receive that year.

Accurate forecasts of the amount of water that the in-stream flow and reservoir systems will receive in any given year can be predicted with reasonable accuracy up to six months in advance. The accuracy increases as the snowpack builds until the most accurate streamflow forecast can be determined by April 1st. After that time, the accuracy will remain the same, or decrease depending on the variability of late spring rain and snowfall in that basin.

3.3 Role of NRCS Snow Surveys and Water Supply Forecasting in the Klamath Basin:

NRCS began water supply forecasting for the Upper Klamath Lake in the Klamath Basin in 1936. Early forecasts relied on snow course measurements in the eastern Cascades and the mountains within the basin to determine spring and summer runoff. Nine SNOTEL stations in the basin came on line in the early 1980s. During the last few years, the Bureau of Reclamation has funded the installation and annual maintenance of five new sites in the basin that are near important snow courses used in water supply forecasting. In the past, forecasts were coordinated with the National Weather Service (NWS) River Forecast Center in Portland, Oregon and have been coordinated with the NWS office in Sacramento, California since the 1980s. Five forecasts are made by the NRCS for the basin as shown in Table 2. Three are coordinated with the NWS, the other two are solely the NRCS distribution.

The Bureau of Reclamation (BOR) relies on the NRCS forecast and forecast products to manage the reservoirs and distribute water in the basin. The forecasts are the basis of management software run to make decisions in the basin. The forecast includes a range of confidence based on the accuracy of the forecast procedure used to calibrate the basin.

Basin stakeholders have agreed that the BOR will use the 70 percent probability exceedance level. In other words, the NRCS provides the BOR with a volume forecast of water that will be equaled, or exceeded 70 percent of the time based on the available data and procedure used to generate the forecasts.

3.4 Streamflow Forecasting Techniques:

The water supply forecasts are based on the statistical relationship between the historic snowpack and subsequent spring and summer streamflow in a watershed. The statistics rely on a principal components regression technique that determines the data elements and stations that optimize the results from equations used to predict streamflow volumes (Garen, 1992). The result is a more robust equation that includes stations that may represent unique climate or geographic areas in the basin.

Once the equations are built, they are tested using a "jack-knife" technique that cross validates the equation. This technique uses the period of record to build the regression coefficients and withholds each year of observed record and generates a forecast for the known streamflow volume for that particular year. A correlation coefficient determined and is used to calculate the water supply forecasts confidence limits that the water manager can choose based on the acceptable level of risk associated for a specific water management operation.

4. WATER YEAR 2001

For several years Klamath Basin water rights have been over-allocated, requiring nearly 135% of average streamflow to fill all the rights. Within the last few years, enforcing the endangered species needs alone required much higher quality water than has been available. One estimate for this combined need was nearly 190% of the average flow. Thus, in almost every year, the needs of all the competing water needs would not be met. The water year 2000 spring and summer streamflow was nearly average and several junior water rights were not met, though reservoir carryover was used for meeting some needs.

4.1 Fall 2000 Antecedent Conditions:

The fall of 2000 was much drier than average. October precipitation was about 98% of average. November fell short at 38% of average and December came in at 46% of average. So going into the snow season the cumulative fall precipitation was a dismal 52% of average. The snowpack was nearly the same for January 1st at 50% of average.

4.2 2001 Klamath Basin Winter Snowpack:

As shown in Figure 2., January and February remained very dry with less than a 60% of average snowpack basin wide. The cumulative mountain precipitation also remained low, below 60% of average, with includes the October through December precipitation. Though low, these were not the low of record, which was slightly below 20% of average.

March and April, the final time that recovery and snowpack building can occur, came and left little rain or snow. The snowpack fell even more in March, with higher than average temperatures easily melting the thin snowpack. The April 1st snowpack was below the record minimum at 27% of average. Precipitation in March was slightly better than earlier in the year, with 62% of average recorded for the basin.

The April basin precipitation amount was an even larger improvement at 90% of average, bringing the seasonal precipitation to 54% of average. After April, the snow accumulation season is over in the Klamath Basin and the dry season begins. Only during an unusually cold spring and wet spring will significant snow event affect the water supply volumes.

In May 2001 the snowpack showed very little change from April at 28% of average, and by June 2001 the snowpack was gone. The May precipitation was not any better than April at about 54% of average.

4.3 2001 Klamath Basin Water Supply Forecasts:

The water supply volume forecasts for the Klamath Basin were as dismal as the hydromet data. The January forecasts for the five streamgages in the basin ranged from 54% to 70% of average. The Klamath Lake inflow forecast was 67% of average as shown in Figure 3.

This gave the Bureau of Reclamation, Fish and Wildlife Service and National Marine Fisheries Service early warning of the drier than average conditions in the basin, and potential for very little water for the competing uses. The Bureau of Reclamation is legally mandated to use a conservative estimate of the Upper Klamath reservoir water supply forecast volumes. The 70% exceedance probability provides the necessary guidance for managing the Klamath Basin. This probability value provides a water supply volume that can be expected to be exceeded 70% of the time. This volume is less than the 50%, or most probable value, that is the most widely used.

In February the most probable forecasts dropped further due to diminished snowpack to range between 37% and 61% of average at the 5 points. In March, volume forecasts dropped to between 29% and 53% of average.

In April the forecasts reacted strongly to the continued lack of snowpack and precipitation. These low forecast volumes required analysis of the historic records to decide how low the streamflow might go given the extreme and persistently low snowpack and precipitation in the basin. The April

1 forecasts dropped to the 6% to 39% of average range. These forecast volumes generated significant interest from all Klamath Basin stake holders.

Based on the April 1st NRCS Water Supply Forecast, the Bureau of Reclamation cut off irrigation water to over 75% of the irrigated agriculture in the Klamath Basin. This affected 170,000 acres of farmland. The decision based on the endangered species act supported biological opinion by the, Fish and Wildlife Service, the National Marine Fisheries Service and court action was historic and made immediate national headlines.

What was an extremely dry year became a political crisis when the basin did not have enough water to supply all the needs. Three endangered species, each with competing water needs, vied with irrigation agriculture for critical water rights within the basin.

The May water supply volume forecasts did rebound somewhat in response to mid-April precipitation. Higher than expected streamflow also contributed to the improvement of the forecast. The forecasts increased to 13% to 40% of average, still very dry. In June, the forecasts increased very slightly again, mostly in response to the increased observed streamflow during May. The forecasts were then ranging from 8% to 41% of average.

4.4 Natural Flow observations for 2001 and Forecast Accuracy:

The observed streamflow at the five water supply streamgages verified within the accuracy of the forecasts. The errors involved in the forecasts include gage measurement accuracy at USGS and BOR streamgages, precipitation network errors, snow measurement errors from SNOTEL, manual and aerial makers, and the accuracy of the forecast equation in relating the data to streamflow.
The most probable (50%) Upper Klamath Lake forecast volume issued on April 1st was 130 KAF (1,600,000 cubic meters) (31% of average) for the period April to July. The observed volume for that period was 185.5 KAF (2,290,000 cubic meters) (44% of average).

5. OPPORTUNITIES FOR IMPROVEMENT

Improvements in water supply volume accuracy can be made for the basin. Better geographic data collection coverage in specific areas is needed and the BOR has shown interest in funding additional SNOTEL sites. Improved streamflow diversion measurements are critical when determining natural flow. Because Klamath Lake has a very large surface area and shallow depths, its surface elevation is subject to wind effects that can influenced the true volume of water stored in the lake. More accurate lake level measurement would facilitate improved water supply calibrations. The forecasts are only as accurate as the data and improving the data collection at all levels would enhance the forecast.

The BOR funded for two forecast model studies performed by the CH2M HILL Engineering that concluded that the forecasts are fairly accurate, and would be difficult to improve with any hydrologic model. The National Water and Climate Center has concluded that additional analysis and updated forecast equations that include the most current data, including weather, streamflow and lake data from other agencies would be beneficial. The installation of an additional three to five SNOTEL sites ($20,000.00 each site with an annual maintenance cost of $2,000 per site) and additional staffing would be an excellent first step.

6. References

Garen, D. C. (1992). Improved techniques in regression-based streamflow volume forecasting. Journal of Water Resources Planning and Management, American Society of Civil Engineers, 118(6), 654-670.

Illian, J. R., 1970, Interim report on the ground water in the Klamath Basin, Oregon: Salem, Oregon State Engineer, 110 p.

United States Geological Survey, Upper Klamath Basin Ground Water Study, http://oregon.usgs.gov/projs_dir/or180/

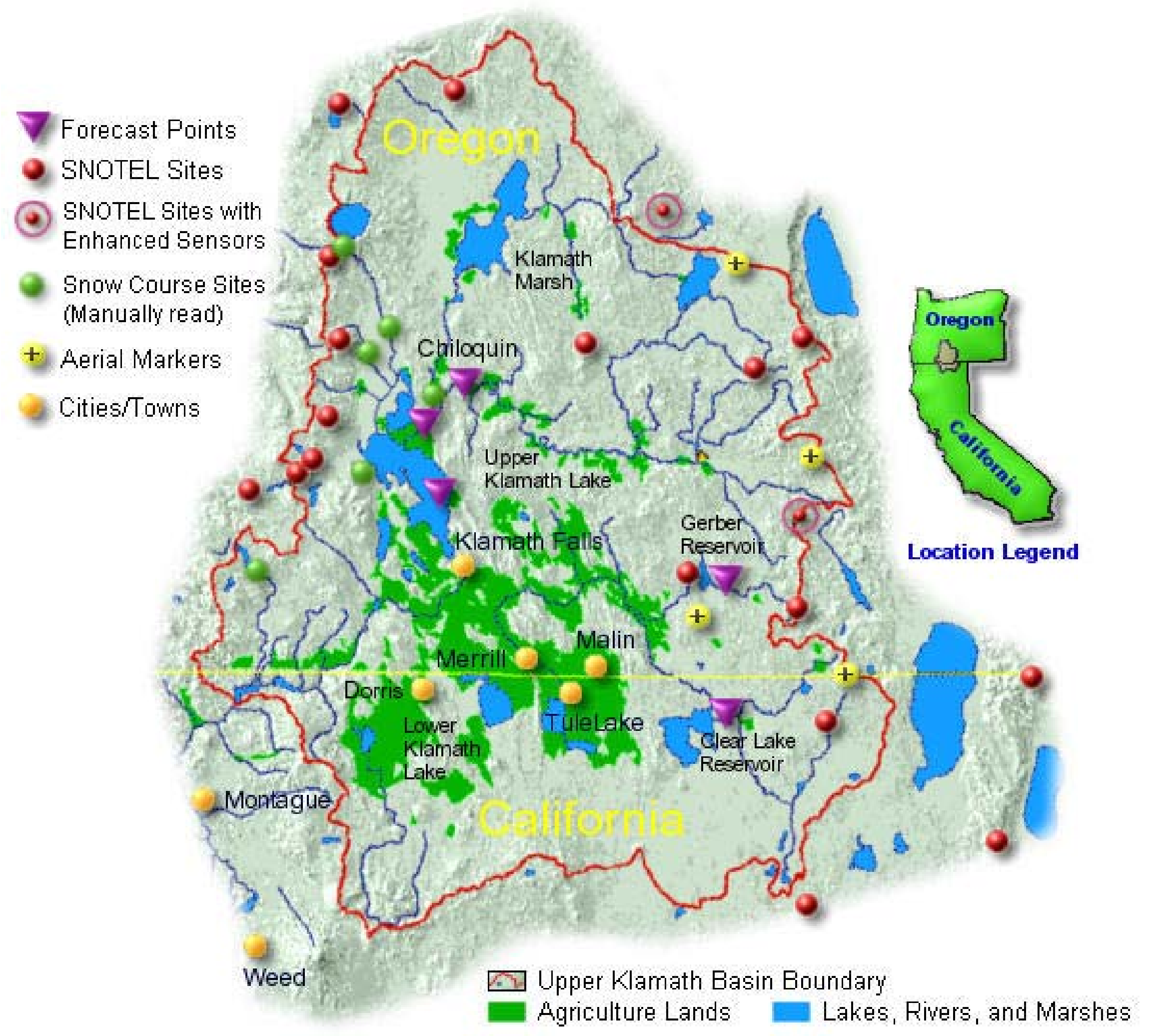

Figure 1. Klamath Basin with Data Collection and Water Supply Forecast Points

Based on Mountain Data from NRCS SNOTEL Sites
As of SUNDAY: APRIL 1, 2001

BASIN Data Site Name	ELEV. (Ft)	SNOW WATER EQUIVALENT Current	Average	% Avg	TOTAL PRECIPITATION Current	Average	% Avg
KLAMATH							
SUMMER RIM	7100	8.1	18.7	43	12.7	20.6	62
SEVENMILE MARSH	6200	9.8	31.9	31	24.6	50.3	49
COLD SPRINGS CAMP	6100	5.0	32.3	15	21.8	46.6	47
ANNIE SPRINGS	6020	16.0	-M	*	28.8	-M	*
FOURMILE LAKE	6000	7.1	30.1	24	21.1	42.6	50
STRAWBERRY	5760	.0	4.3	0	10.6	17.1	62
QUARTZ MOUNTAIN	5700	.0	.7	0	7.5	17.6	43
DIAMOND LAKE	5315	2.0	12.1	17	18.7	37.8	49
BILLIE CREEK DIVIDE	5300	5.7	20.5	28	24.7	41.6	59
CROWDER FLAT	5200	.0	-M	*	6.2	-M	*
TAYLOR BUTTE	5100	.0	2.0	0	8.6	17.0	51
GERBER RESERVOIR	4850	.0	-M	*	6.4	-M	*
CHEMULT ALTERNATE	4760	.0	5.8	0	10.0	21.8	46
Basin wide percent of average				24			51

Table 1. April 1, 2001 Klamath Basin snowpack and precipitation analysis.

KLAMATH BASIN
Streamflow Forecasts - April 1, 2001

Forecast Pt Forecast Period	<=== Drier === Future Conditions === Wetter ===> ============== Chance of Exceeding * ============== 90% (1000AF)	70% (1000AF)	50% (Most Prob) (1000AF)	50% (% AVG.)	30% (1000AF)	10% (1000AF)	30 Yr Avg (1000AF)
CLEAR LK Net Inflow (2)							
APR-JUL	0.4	3.5	10.0	23	19.8	34	44
GERBER RESERVOIR net Inflow (2)							
APR-JUL	0.2	0.5	1.0	6	4.6	9.9	17.9
SPRAGUE R nr Chiloquin							
APR-JUL	2.0	31	52	26	73	104	200
APR-SEP	6.0	38	60	26	82	114	228
UPPER KLAMATH LK net Inflow (1)							
APR-JUL	8.0	82	130	31	178	283	422
APR-SEP	5.0	108	160	31	212	328	509
WILLIAMSON R nr Chiloquin							
APR-JUL	31	87	125	39	163	219	325
APR-SEP	47	108	150	38	192	253	391

* 90%, 70%, 30%, and 10% chances of exceeding are the probabilities that the actual flow will exceed the volumes in the table.
The average is computed for the 1961-1990 base period.
(1) - The values listed under the 10% and 90% Chance of Exceeding are actually 5% and 95% exceedance levels.
(2) - The value is natural flow - actual flow may be affected by upstream water management.

Table 2. April 1, 2001 Klamath Basin Water Supply Forecasts

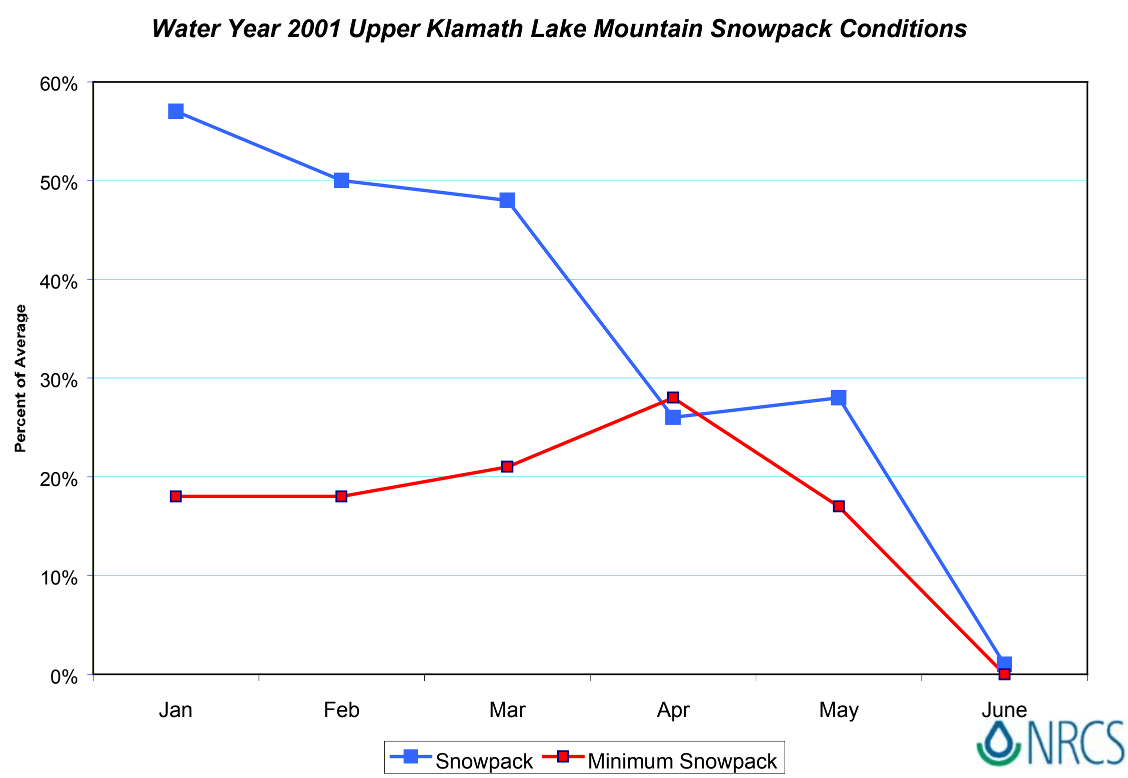

Figure 2. Klamath Basin Snowpack Conditions- Spring 2001

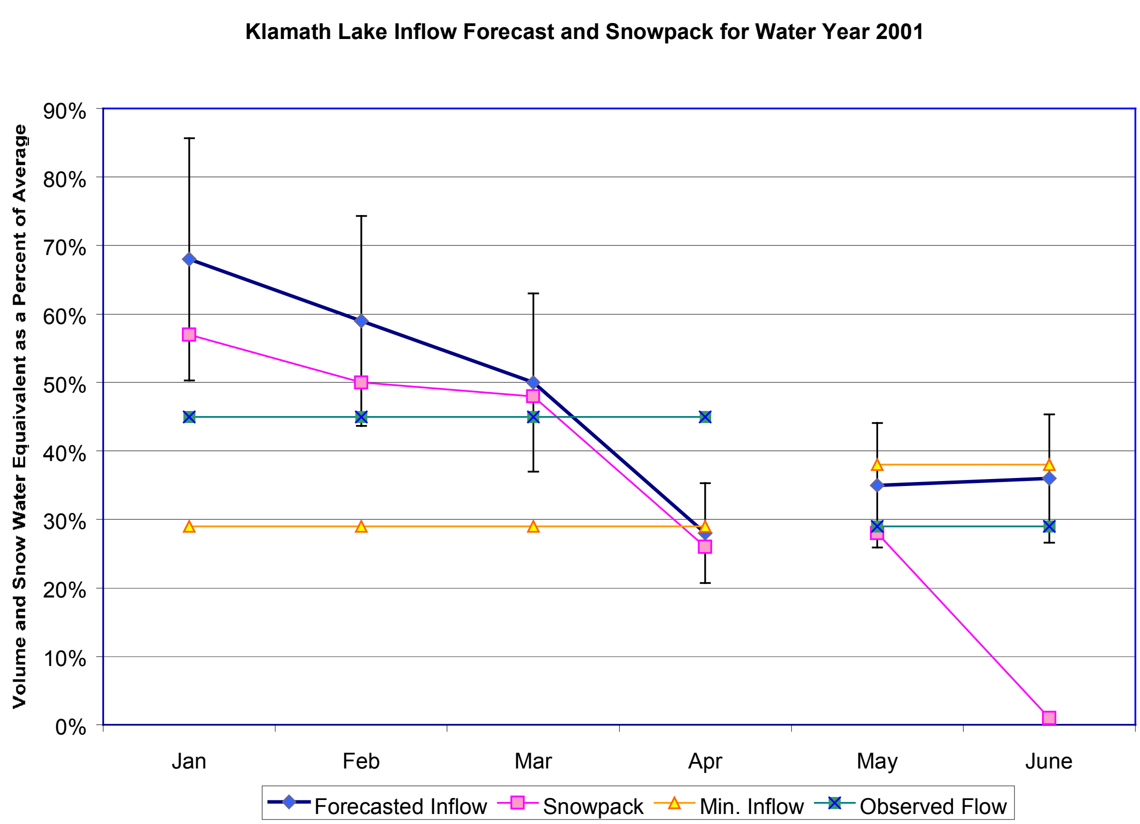

Figure 3. Klamath Basin Water Supply Forecasts – Spring 2001