Technical Memo

Date: Monday, November 09, 2015

Project: Camp Far West Hydroelectric Project (FERC No. 2997)

Subject: Bear River Hydrology Methods

Background

One of the fundamental inputs to an operations model is the hydrology dataset. While the shape of a daily hydrograph is important for some projects, those with more flexible reservoir storage are less sensitive to the daily fluctuations of the inflow. In the case of the existing and proposed projects on the Bear River, a longer-term volume (i.e. weekly to monthly) is be the most important element of the hydrology in order to obtain statistically valid model results.

In the relicensing of Nevada Irrigation District's (NID) Yuba-Bear Hydroelectric Project (FERC No. 2266) and Pacific Gas and Electric Company's (PG&E) Drum-Spaulding Project (FERC No. 2310), hydrology was developed for the inflow to reservoirs on the upper Bear River, extending to NID's Rollins Dam. The methods are briefly described in a memo to relicensing participants dated March 16, 2010. The hydrology dataset was later extended to include the Bear River reach from Rollins Dam down to the normal high water mark of NID's Lake Combie. The extension of the hydrology below Rollins Dam was done for environmental analysis of the river reach, and not for operations, and did not have any gage-summation (volumetric) component. The Yuba-Bear hydrology was used as a starting point but was modified to allow extension down to Camp Far West dam.

Methods

Gage Summation

Hydrology was computed using gage summation accounting down to Rollins Reservoir. It was computed as the sum of the change in storage at Rollins Reservoir, Dutch Flat Afterbay, and PG&E's Drum Afterbay, plus the gaged/estimated outflows (Nevada Diversion, Bear River Canal, Bear River, Lower Boardman Canal/Release Point, and Rollins Reservoir estimated evaporation), minus the basin inflows (Drum Canal and South Yuba Canal Spill Gates, Lake Valley Canal, and Towle Canal). The use of twelve separate measurements to produce an account of volume in the Bear River Basin creates a high potential for short-term (i.e. daily and weekly) imprecision and noise, which was expected to cancel out in the longer-term volumetric calculations. A particular problem noted in the 2010 memo was the lack of Towle Diversion data prior to WY 1993. Relicensing participants came to a resolution about this problem by using average monthly Towle Diversions from WY 75-92 to develop a full period-of-record time series of monthly volumes.

A considerable effort has already been completed to create an account of unimpaired natural monthly inflow into Rollins Reservoir, but the record is incomplete. Table 1 summarizes the different time periods of the gage-summation and the data gaps.

Table 1. Rollins gage summation data availability

Start Date	End Date	Description
10/1/1975	1/1/1993	No storage record for Dutch Flat Afterbay and Drum Afterbay, Synthetic time series for Towle Diversion to 10/1/1992
1/2/1993	9/30/2005	Complete records for all flows in/out of Bear River basin
10/1/2005	9/30/2008	Missing data for Nevada Diversion and Lower Boardman Canal

In order to increase the utility of the volumetric record, several changes were made. First, the Towle diversion was re-synthesized using the following formula:

> *Inflow to Alta Forebay (YB-117) plus Canyon Creek below Towle Diversion (YB-282) minus Canyon Creek above Towle Diversion (YB-280), all multiplied by 0.829.*

This formula was created using a linear regression when Towle Canal data were available, and performs better than the annual average Towle diversion because it appears a significant decrease in diversions was made in 1990.

The second change was to attempt to better account for basin imports coming into Bear Valley. Previously, only the measured spills from the Drum (YB-137) and South Yuba (YB-139) Canal Waste gates were used to account for imported water. The records for these waste gates are poor and infrequently updated. In lieu of these two time series, an account of imports was made by subtracting the "expected" natural Bear Valley flow from the measured flow at YB-198 (USGS 11421710). The "expected" natural Bear Valley flow was a straight drainage-area proration (times 0.129) from the Pilot Creek above Stumpy Meadows gage, which is a very close match in elevation range.

Even with these adjustments, there are some months with negative volume, and some months with unusually high volumes. These errors can be caused by poor gage ratings, lack of storage accounting at Dutch Flat Afterbay and Drum Afterbay, or un-gaged accretion/leakage from the canals. HDR completed a *reconstruction* of Bear River monthly volumes using nearby unimpaired monthly volumes. The goal of this approach is to more accurately estimate the monthly volumes of months when the Rollins gage summation is very uncertain or irregular.

A reconstruction of monthly volumes was created using monthly volumes from three unimpaired USGS gaged basins nearby: Cosumnes River at Michigan Bar (USGS 11335000), Oregon Creek above Log Cabin (USGS 11409300), and Slate Creek above Diversion Dam (USGS 11413300+11413250). To estimate the monthly volumes, a linear regression was made comparing each of the gages monthly volumes to those of the Bear River above Rollins. The Cosumnes basin and Slate Creek basin both have a larger snowmelt component than the Bear River, so monthly multipliers were developed to reshape the volumetric record, shown in Table 2. Figure 1 shows the regressions used to reconstruct the Rollins monthly volume record.

Table 2. Average monthly multipliers used to reconstruct monthly volumes

Basin	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Cosumnes	1.62	1.49	1.64	1.19	1.16	1.02	0.93	0.64	0.57	0.87	1.32	3.42
Slate	0.89	0.82	1.13	1.34	1.36	1.05	0.81	0.41	0.35	0.61	0.86	2.15

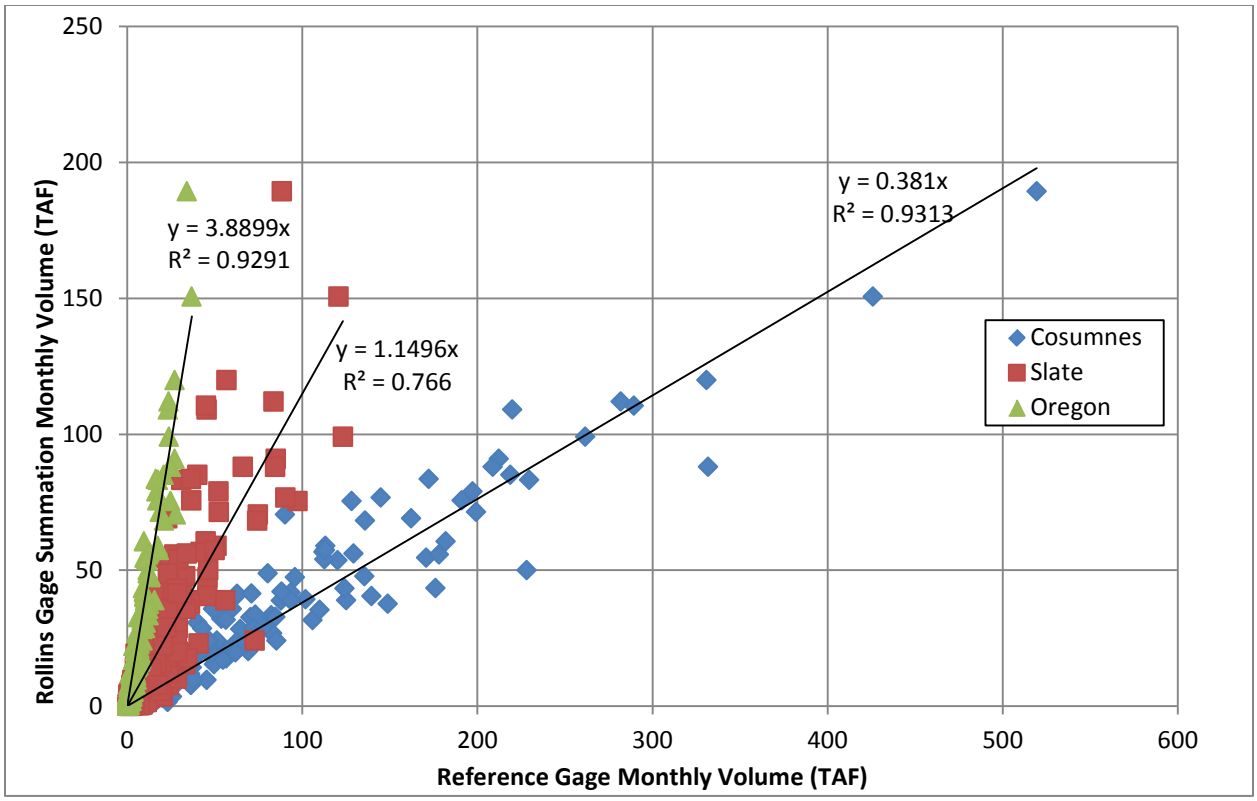


Figure 1. Monthly volume regressions used for Rollins Volume reconstruction

There is some geographic variability in the amount of precipitation received during large storms. This is why the volume reconstruction includes one gage to the north and one to the south. When the predicted volumes are averaged from the north and south basins, a better fit is produced to the measured volumes. The Cosumnes and Oregon basins were used from Water Year 1976 through 2000, and the Cosumnes and Slate basins were used from water year 2001 through 2008. The final volumetric reconstruction is shown in Figure 2, and the full period of record reconstructed monthly and annual volumes are shown in Table 3. The reconstructed volumes could either be used for the full period of record, or they could be used only to replace months of the Rollins gage summation record that appear to be anomalous compared to gage-proration estimates.

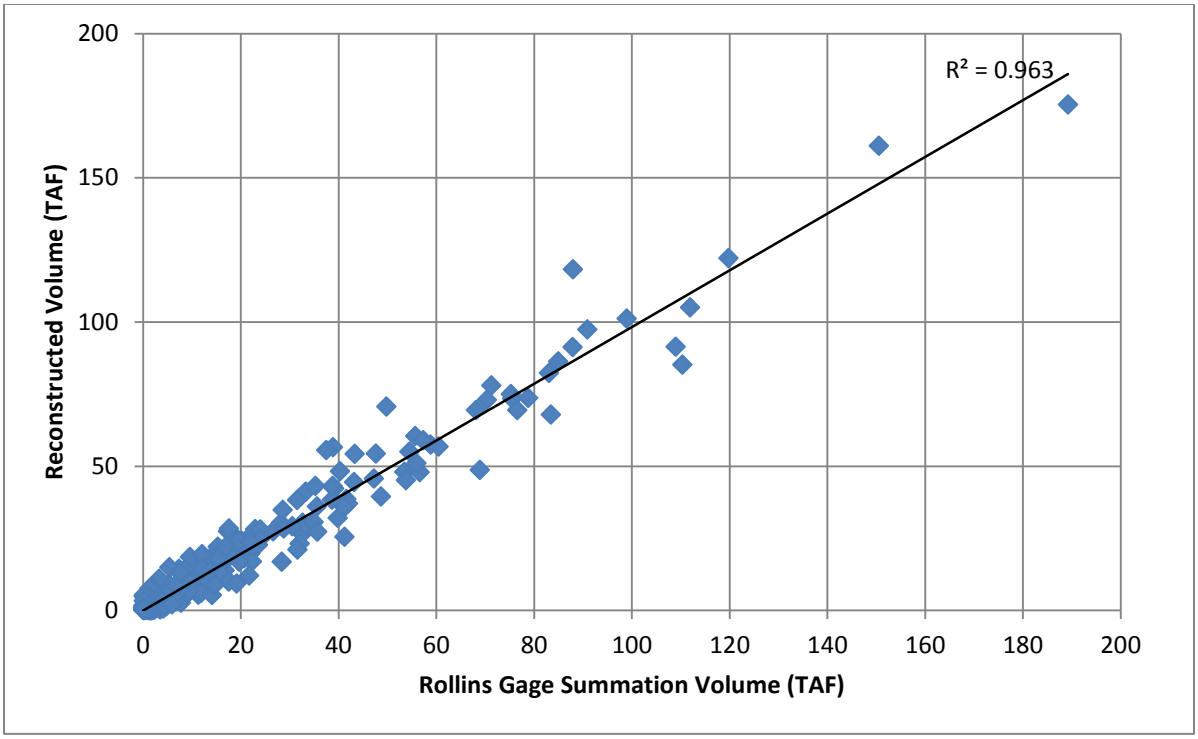


Figure 2. Reconstructed monthly volumes compared to gage summation method

Table 3. Rollins Reservoir reconstructed monthly volumes

WY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	*Total*
1976	3,076	4,071	3,838	2,757	5,227	9,186	6,318	2,648	843	316	639	823	*39,742*
1977	533	748	661	1,122	1,387	1,864	1,274	2,614	543	134	81	155	*11,114*
1978	162	1,244	12,262	57,551	30,366	45,803	42,401	15,688	3,945	1,535	551	2,241	*213,748*
1979	740	1,518	2,106	12,721	19,865	41,277	27,468	21,927	3,206	1,323	648	1,012	*133,812*
1980	1,881	4,479	9,210	97,446	73,722	38,639	18,139	10,646	4,077	2,198	982	1,346	*262,765*
1981	930	1,211	2,851	7,816	10,338	24,460	14,549	3,999	1,164	380	310	462	*68,469*
1982	2,610	27,937	75,025	55,144	78,049	60,520	91,469	21,043	4,565	2,480	1,326	3,721	*423,889*
1983	5,872	23,024	70,697	54,310	86,419	122,178	48,135	38,498	13,190	5,245	2,638	4,556	*474,762*
1984	3,053	48,338	118,330	30,498	26,595	29,263	17,003	9,340	2,709	1,171	972	1,576	*288,849*
1985	2,006	13,625	9,919	5,119	14,042	16,573	19,776	4,964	1,299	702	465	1,427	*89,918*
1986	997	3,965	10,699	22,146	161,145	56,838	15,967	6,677	2,382	1,136	761	2,336	*285,050*
1987	1,298	1,135	1,637	2,845	9,589	15,625	5,062	1,854	594	260	151	181	*40,233*
1988	371	939	7,957	13,967	6,245	7,266	4,887	3,321	1,219	347	100	78	*46,697*
1989	109	6,083	2,734	5,530	11,994	73,136	20,472	5,948	1,760	719	356	1,000	*129,840*
1990	2,355	2,781	2,042	7,552	7,354	18,926	8,579	6,363	5,800	1,079	415	394	*63,641*
1991	409	689	790	791	1,164	22,430	19,742	10,911	3,413	1,121	478	282	*62,219*
1992	1,004	1,438	1,851	2,739	22,718	18,689	8,977	2,236	752	545	179	127	*61,254*
1993	521	851	8,977	54,435	38,309	56,694	28,271	11,113	7,748	1,818	869	744	*210,350*
1994	861	995	3,686	2,817	8,457	12,180	5,461	3,988	958	354	135	123	*40,014*
1995	359	2,117	11,431	91,339	25,471	105,089	48,051	43,294	11,172	4,368	1,669	1,720	*346,081*
1996	922	977	8,246	30,746	69,511	45,250	32,163	29,297	6,032	2,222	1,105	1,670	*228,141*
1997	1,144	5,871	101,275	175,440	27,500	12,795	7,780	3,665	1,691	994	792	1,188	*340,137*
1998	1,421	3,185	6,238	59,126	82,435	55,664	43,206	34,972	18,654	5,243	2,260	3,309	*315,713*
1999	1,876	5,680	12,995	36,191	73,567	37,100	22,844	12,708	3,609	1,552	1,143	1,531	*210,796*
2000	1,006	2,343	2,794	24,140	67,940	39,533	17,663	9,888	2,679	1,200	712	1,778	*171,676*
2001	1,765	1,695	2,847	3,438	6,928	17,516	14,006	5,248	665	480	364	835	*55,787*

WY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	*Total*
2002	501	2,799	12,214	22,793	18,172	23,233	19,594	5,446	1,383	620	444	834	*108,034*
2003	429	2,557	16,946	28,441	14,555	19,227	21,202	16,899	3,067	1,068	860	1,179	*126,431*
2004	466	1,306	12,688	10,014	27,337	28,128	15,087	4,066	947	567	407	867	*101,879*
2005	2,073	2,467	9,779	24,938	22,078	44,518	28,513	25,579	5,438	2,311	1,230	2,088	*171,012*
2006	1,086	2,006	69,490	51,110	35,943	48,770	85,307	24,260	4,623	2,049	1,475	2,619	*328,736*
2007	1,469	2,374	8,489	6,823	23,667	18,251	8,633	3,403	832	565	454	1,094	*76,054*
2008	1,176	955	2,167	8,957	9,389	13,861	13,337	6,941	1,222	572	358	643	*59,577*

Gage summation for the incremental volume into Combie Reservoir was attempted using data from Combie Storage (BR900), Bear R below Combie (BR300), Combie Phase I Canal (BR301) and Bear R below Rollins (YB 196). The resulting time series of monthly volumes did not resemble any natural pattern. It is suspected that unmeasured spills from the Bear River canal disturb the calculation. In addition there may also be a significant portion of the basin that is captured by the Bear River Canal and not spilled at times. Finally, the Bear R below Combie gage does not seem to match the high-flow rating of the Bear R below Rollins – there are times where both are in uncontrolled spill and the flow below Combie is much less than below Rollins. Because the volume moving through the basin is much larger than the natural runoff volume of the basin, it will be hard or impossible to estimate with the available measurements.

Gage summation for the Wolf Creek and total inflow to Camp Far West was not attempted due to a lack of data. It is unlikely that sufficient information is obtainable in order to develop a reliable volumetric record, due to numerous diversions to and from the Bear River drainage between Deer Creek and Auburn Ravine. It is recommended that the hydrology for the drainage area below Rollins use the same monthly scaling factors as the Rollins Basin.

Gage Proration

With the volumes of the Rollins basin decided by gage summation (or reconstruction), the streamflow gages used for proration of the Rollins basin are inconsequential. However, for the basins below Rollins, it is important to use the same gages for proration, to ensure that the monthly scaling factors produce consistent results. The gage-proration methods were applied to three basins using their cumulative drainage area: Rollins, Combie, and Camp Far West. Sub-basins can be computed and subtracted from the basin-total hydrology, as needed for the Camp Far West operations model.

HDR used a combined gage proration technique that incorporates data from several gages to cover gaps in data and provide a regional estimate of streamflow. The available gage records are summarized in Table 4.

Table 4. Unimpaired gages available for proration to Bear River

Name	Number	Start Date	End Date	Elevation Range (ft.)	Drainage Area (mi²)
Rollins Reservoir	N/A	10/1/1975	9/30/2008	2000-6000	103.6
Cosumnes R at Michigan Bar	11335000	10/1/1975	9/30/2008	250-7500	534.6
Oregon Cr abv Log Cabin Div.	11409300	10/1/1975	9/30/2000	2000-6000	23
S Honcut Cr near Bangor	11407500	10/1/1975	9/30/1986	500-3500	30.6
S Honcut Cr near Bangor	A05775 (DWR)	7/6/2006	9/30/2008	500-3500	30.6
Pilot Cr abv Stumpy Meadows	11431800	10/1/1975	9/30/2008	4250-6250	11.6
Deadwood Creek (sum)	11413320 +11413323 +11413326	10/1/1994*	9/30/2008*	3000-4000	5

*Water Years 2005 and 2006 are missing

Summary and Recommendation

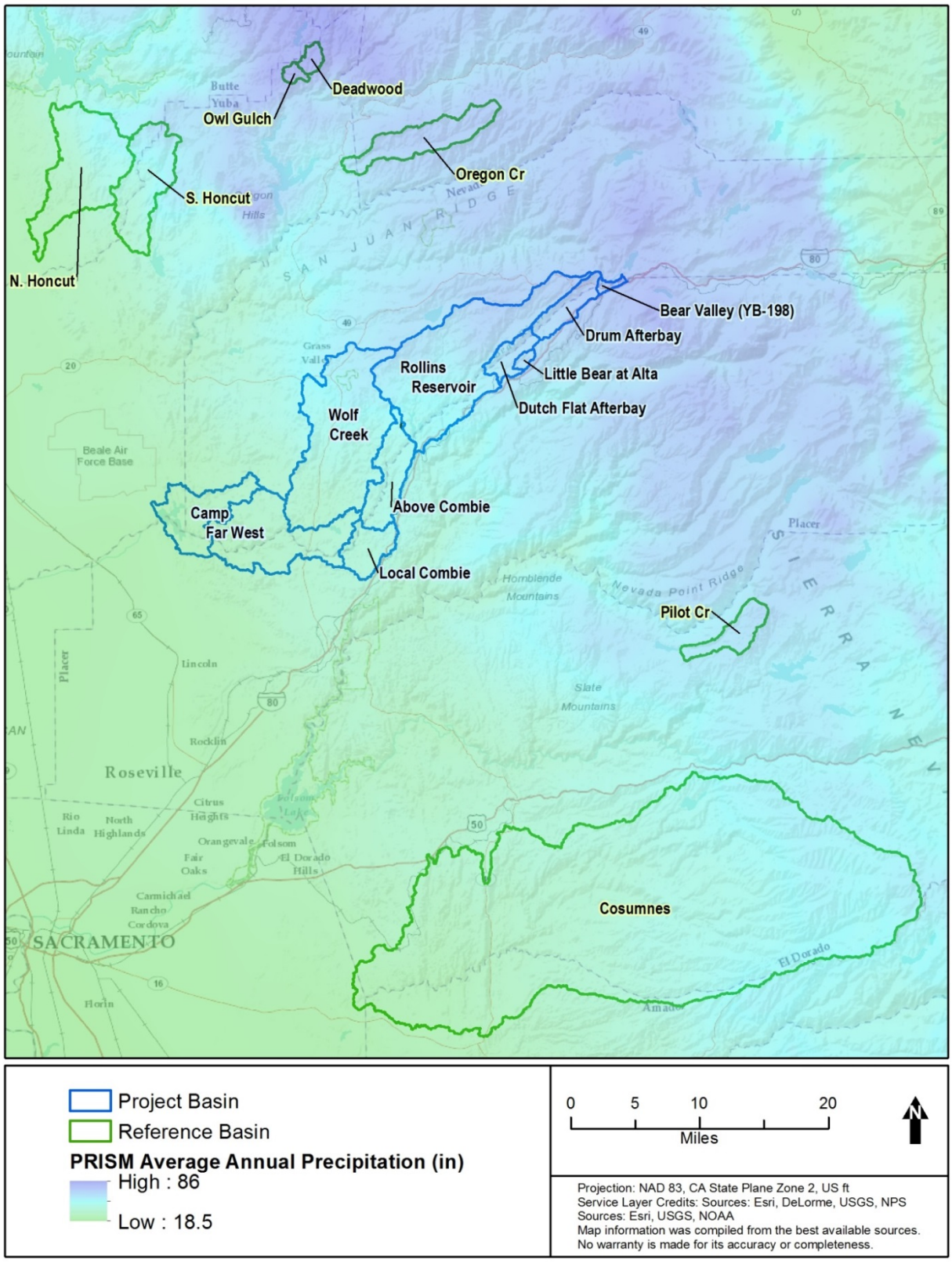
Hydrology for the Bear River was previously developed for the relicensing of upstream hydroelectric projects. It was developed using gage proration with two high elevation (>4,250 ft) gages, and applied to the Rollins basin which goes down to about 2,000 feet elevation. Relicensing Participants reviewed and agreed upon the hydrology methodology and time series. While volumes were important, they were not the focus – it was created for environmental analysis.

The purpose of this study was to extend the Bear River hydrology down to 250 feet elevation for the Camp Far West Hydroelectric Project relicensing process. If reliable monthly volumes were available and computable from the lower elevation basins, the relicensing hydrology could simply be used as-is and appended with the lower basins. However, because the lower elevation hydrology requires a different mix of gages for proration, and because the monthly volumes must be tied to the Rollins basin monthly volumes, a consistent hydrology dataset was re-developed for the whole Bear River.

HDR has therefore proceeded with the gage proration approach described above. This approach utilizes historical data from the Slate Creek, Oregon Creek and Cosumnes River watersheds to construct an aggregated monthly hydrology that provides the most consistent representation of the entire Bear River watershed for the purposes of an unimpaired hydrologic dataset.

LIST OF ATTACHMENTS

Regional Watershed Map (with reference basins used in unimpaired hydrology development)



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