DRAFT TECHNICAL MEMORANDUM

Date:	January 20, 2015
To:	Barry O' Regan, KSN, Inc.
From:	Chris Campbell, MS; Sridhar Ponangi, PE; Chris Bowles PhD, PE
Project:	14-1036 – Knights Landing Outfall Gates Fish Exclusion Project
Subject:	Historic Flow Analysis

The purpose of this Technical Memorandum (TM) is to review historic flows though Knights Landing Outfall Gates (KLOG) and characterize the existing operation during significant floods. This analysis is important for understanding the potential operational affects of the proposed Alaskan Weir during flood stages and informing the flood impact analysis.

KNIGHTS LANDING OUTFALL GATES OPERATION

Flow through KLOG is controlled by eight 66-inch and two 42-inch screw operated slide gates on the Colusa Basin Drain (Colusa Drain) side, and by eight 66-inch and two 42-inch combination flap and slide gates on the Sacramento River side. The configuration provides for control of flows in either direction and allows automatic outflows from Colusa Drain at lower stages in the Sacramento River (see Figure 1).

The operation of the gates is primarily to protect the lower Colusa Basin from backwater of the Sacramento River during floods and to help control water levels in Colusa Drain for irrigation and drainage. The riverside slide gates remain in the closed position year round with the flap gates active (Russell Eckman, Superintendent, Sacramento Maintenance Yard, pers. comm., January 2015). The flap gates discharge water if the Colusa Drain stage is higher than the Sacramento River stage and prevent reverse flow when the Sacramento River stage is higher. The amount of discharge through the gates depends on the number of gates open and the height of gate openings. The riverside slide gates are opened (raised) only for maintenance. Screw operated gates at the upstream end are operated to maintain required pool elevation, currently at 25.5 ft USED (23.73 ft, NAVD88), during irrigation season based on local interests.

In 2012, DWR rehabilitated the KLOG structure to replace the gate flaps, seals, and assemblies. Additionally, outdated motor controllers and nonfunctional water level sensors were replaced. The new control system and other existing water level sensors along the Sacramento River provide greater flexibility in the operation of the gates to protect Colusa Basin Drain from the backwater effects of the

Sacramento River and maintain the required pool elevation on the Colusa Drain side for irrigation. The rehabilitation project has no impact to the operations of the structure.

HISTORIC FLOW ANALYSIS

An analysis of the KLOG historic flow record[1], available from Water Data Library gauge Colusa Basin Drain at Knight's Landing (A02945), was undertaken to characterize the existing operation of KLOG during significant floods. In addition, flow and stage data from the following gauges (see Figure 1) was obtained and evaluated as a part of the analysis:

- Gauged stage (A02200) Sacramento River at Knights Landing
- Gauged stage (A02495) Colusa Drain at Knights Landing
- Gauged and estimated[2] flow (A02939) Ridge Cut Slough @ Knights Landing

Figures 2, 3, 4 and 5 show the flow and stage data for four historic flood events (1986, 1997, 2006, 2011) when the stage in Sacramento River near Knights Landing exceeded 37.0 ft USED (35.7 ft NAVD88). This monitor stage is defined as the water level corresponding to "flood" or "high water period" flows (USACE, 1957). The figures confirm that the DWR calculated flow data is consistent with the operations of KLOG whereby a positive head difference between the Colusa Drain and Sacramento River results in flow through the structure and a negative head prevents any flow through the structure due to the sealed flap gates.

During these flood events, the stage in the Sacramento River was consistently higher than Colusa Drain at the peak of the flood wave, resulting in no flow through the KLOG structure. However, at far ends of the rising and/or falling limbs, there are instances where Colusa Drain water levels are higher than the stage in Sacramento River resulting in flow (up to 1,370 cfs during the 4 historic floods) through the KLOG structure. The maximum flow through KLOG based on historic record is 2,220 cfs.

Table 1 summarizes the period and duration of flood wave and gate operation for the historic flood events. Also summarized is the period and duration when flow occurs through KLOG structure during the rising and falling limbs of the flood events, and the maximum daily flows during such periods.

[1] Flow calculations at KLOG are based on flow conditions caused by the gate and flap gate settings of each gate relative to the head difference of the stage of the gauge on Colusa Basin Drain (upstream of the gates) and that of the Sacramento River at Knights Landing gauge (downstream of the gates) (Huckabay, 2012).
[2] Flows for Ridge Cut Slough prior to gauge installation (Dec 2006) estimated by cbec (unpublished).

Table 1. Flows and Gate Operations during historic flood events

Flood Event	Period	Number of days	Date of flood peak	Maximum Daily Flow, cfs	Gate Operation[3]
1986 Flood					
Flood wave[1]	Feb 12, 1986 – May 02, 1986	80	Feb 20, 1986		data not available
Flow [2] during rising limb	Feb 12, 1986 - Feb 13, 1986	2		519	
Flow[2] during falling limb	April 4, 1986 - May 02, 1986	29		774	
1997 Flood					
Flood wave[1]	Dec 04, 1997 – Mar 16, 1997	103	Jan 03, 1997		data not available
Flow[2] during rising limb	Dec 06, 1997 - Dec 07, 1996	2		147	
Flow[2] during falling limb	None	0		0	
2006 Flood					
Flood wave[1]	Dec 17, 2005 – Feb 24, 2006	70	Jan 02, 2006		7 – 66" gates open approximately 1.25 ft on Dec 17 and 18; 7 – 66" gates opened approx. 4.5 ft on Dec 19; 7 - 66" gates fully open starting Dec 20, 2005 through June 19;
Flow[2] during rising limb	Dec 17, 2005 – Dec 20, 2005	4		1,370	
Flow[2] during falling limb	none	0		0	
2011 Flood					
Flood wave[1]	Mar 14, 2011 – May 04, 2011	52	Mar 26, 2011		All gates closed on Mar 14 and 15; On Mar 16, 6 – 66-inch gates

					open approximately 0.5 foot; On Mar 17, 5 – 66-inch gates open approximately 5.25 ft and 1 - 66-inch gate open 4.8 ft; On Mar 18, 4- 66" gates open approximately 5.25 ft and 2 - 66" gate open 2 ft; Mar 19 to Apr 27, 4 - 66" gates mostly open and 1 - 66" gate slightly open 0.25 feet; Apr 28 – May 04, open gates transition to fully closed
Flow[2] during rising limb	Mar 14, 2011 – Mar 15, 2011	2		0.9	
Flow[2] during falling limb	none	0		0	
Notes: [1] Flood wave refers to stage in Sacramento River as recorded at Sacramento River at Knights Landing (A0220) gauge [2] Historic flow record, available from Water Data Library gauge Colusa Basin Drain at Knight's Landing (A02945) [3] Gate opening data from DWR's North Region Office					

PRELIMINARY ASSESSMENT OF POTENTIAL IMPACTS DUE TO INSTALLATION OF ALASKAN WEIR

When the stage in Sacramento River is higher than the stage in Colusa Drain, which is typical of four historic observations (see Figures 2, 3, 4, and 5), there is no flow through the KLOG. Therefore, the proposed Alaskan Weir would have an insignificant impact on flow and stage in the Sacramento River and the Yolo Bypass.

However, when flow passes through KLOG, the weir could result in additional head loss given that it is located in the turbulent zone of KLOG, which provides an opportunity for small additional flow into the Yolo Bypass through Knights Landing Ridge Cut (KLRC). Although, a significant portion of the leading and trailing stages in the Sacramento River typically result in zero flow through the KLOG, there are instances occurring 1 -3 weeks prior to and following the flood peaks where flow passes through KLOG (see Table 1).

Hydraulic Model

To inform the preliminary hydraulic assessment, cbec truncated the CVFED RAS model down to the limits of the KLOG channel (between the Ridge Cut Slough and the Sacramento River), using observed water level data and gate operations to verify the performance of the gates in the CVFED RAS model. Two periods, January 30, 2010 - February 20, 2010 and January 08, 2011 - January 14, 2011, when the gate operations were fairly constant (six 66-inch gates fully open) were modeled.

In addition, the following changes were made to the CVFED RAS model to improve model performance:

- KLOG gates were represented as culverts instead of rectangular gates to enable the flap gate option that would prevent reverse flow when stage in the Sacramento River is higher than stage in Colusa Drain.
- Inverts for gate openings were modified based on spring line elevation (NRS, 2014) and diameter of the gate opening. The invert for 66-inch gates was set at 16.75 ft-NAVD88 and the invert for 42-inch gates was set at 17.75 ft-NAVD88.
- To account for the head loss through flap gates, given that HEC-RAS cannot account for this loss directly, the entrance loss coefficients and culvert lengths were adjusted so modeled flows were similar to DWR's published flows. Figure 5 shows the DWR published flows and the modeled flows in 2011. Figure 6 shows the same comparison for the modeled period in 2010.
- The proposed Alaskan weir was incorporated into the model by cbec to account for head loss, and to assess the potential flow reduction through KLOG. The reduction in flow through KLOG indicates additional flux into the Yolo Bypass.

In HEC-RAS, the Alaskan Weir pickets (typically 1-inch in diameter) and openings (1.625-inch wide) were represented as multiple culvert openings through an embankment. The top of the weir was set to 25 ft-NAVD88 based on the preliminary design configurations provided by KSN, Inc. Due to memory and processing limitations of the HEC-RAS software, roughly 80% of the weir openings were included in the model while the remaining flow area was blocked off. This represents a conservative configuration whereby the head loss and the additional flow to Yolo Bypass are slightly over estimated.

Results

Table 2 shows the preliminary results of estimated additional flows to Yolo Bypass via KLRC due to the proposed Alaskan Weir during the two periods modeled.

Table 2. Preliminary hydraulic model assessment of flow diversion to RCS due to fish exclusion weir

Date	Average Daily Flow through KLOG, cfs	Estimated additional daily flows to KLRC, cfs	Percentage of flow diversion due to the weir	Gate Operation
30 Jan, 2010	686	3.4	0.5%	6 gates (66-inch) fully open
31 Jan, 2010	1,277	3.9	0.3%	6 gates (66-inch) fully open
01 Feb, 2010	1,473	5.8	0.4%	6 gates (66-inch) fully open
02 Feb, 2010	1,560	10.1	0.6%	6 gates (66-inch) fully open
03 Feb, 2010	1,612	23.3	1.4%	6 gates (66-inch) fully open
04 Feb, 2010	1,621	34.6	2.1%	6 gates (66-inch) fully open
05 Feb, 2010	1,658	43.3	2.6%	6 gates (66-inch) fully open
06 Feb, 2010	1,097	3.1	0.3%	6 gates (66-inch) fully open
07 Feb, 2010	492	0.5	0.1%	6 gates (66-inch) fully open
08 Feb, 2010	374	2.0	0.5%	6 gates (66-inch) fully open
09 Feb, 2010	381	2.4	0.6%	6 gates (66-inch) fully open
10 Feb, 2010	544	3.1	0.6%	6 gates (66-inch) fully open
11 Feb, 2010	713	3.4	0.5%	6 gates (66-inch) fully open
12 Feb, 2010	1,022	6.6	0.6%	6 gates (66-inch) fully open
13 Feb, 2010	1,205	13.3	1.1%	6 gates (66-inch) fully open
14 Feb, 2010	1,266	28.4	2.2%	6 gates (66-inch) fully open
15 Feb, 2010	1,299	35.7	2.8%	6 gates (66-inch) fully open
16 Feb, 2010	1,306	35.6	2.7%	6 gates (66-inch) fully open
17 Feb, 2010	1,290	37.8	2.9%	6 gates (66-inch) fully open
18 Feb, 2010	1,219	38.6	3.2%	6 gates (66-inch) fully open
19 Feb, 2010	1,086	37.3	3.4%	6 gates (66-inch) fully open
20 Feb, 2010	981	37.4	3.8%	6 gates (66-inch) fully open
08 Jan, 2011	280	6.2	2.2%	6 gates (66-inch) fully open
09 Jan, 2011	477	7.5	1.6%	6 gates (66-inch) fully open
10 Jan, 2011	512	10.6	2.1%	6 gates (66-inch) fully open
11 Jan, 2011	578	12.3	2.1%	6 gates (66-inch) fully open
12 Jan, 2011	655	16.4	2.5%	6 gates (66-inch) fully open
13 Jan, 2011	657	15.2	2.3%	6 gates (66-inch) fully open
14 Jan 2011	586	14.3	2.4%	6 gates (66-inch) fully open

Results of the preliminary hydraulic assessment indicate that the additional flow to KLRC, due to the Alaskan Weir, is a small portion (< 5 percent) of flow through the KLOG. The head loss through the weir is 0.30 ft under maximum flow of 1,658 cfs through the KLOG on Feb 5, 2010 which appears reasonable given the conservative nature of the weir configuration as discussed before.

Using a conservative value of 5 percent, the estimated maximum daily flow diverted to Yolo Bypass during the four floods is as follows:

- 1986 flood: 38.7 cfs (5 percent of 774 cfs)
- 1997 flood: 8 cfs (5 percent of 147 cfs)
- 2006 flood: 69 cfs (5 percent of 1370 cfs)
- 2011 flood: 0.05 cfs (5 percent of 0.90 cfs)

The cumulative volume of additional flow to Yolo Bypass during the period of flood wave relative to the cumulative volume to Yolo Bypass over the Fremont Weir (CDEC station: FRE) is summarized below:

- 1986 flood: Fremont Weir flow data not available for comparison
- 1997 flood (Dec 04, 1997 – Mar 16, 1997): 16.3 ac-ft vs. 7,821,312 ac-ft (< 0.01 %)
- 2006 flood (Dec 17, 2005 – Feb 24, 2006): 334 ac-ft vs. 4,369,488 ac-ft (< 0.01 %)
- 2011 flood (Mar 14, 2011 – May 04, 2011): 0.10 ac-ft vs. 2,383,868 ac-ft (< 0.01 %)

Based on this assessment, the volume of flow diverted to Yolo Bypass is insignificant and should not affect peak stages during a flood.

However, the flow diversion estimates are preliminary and would depend on stage in Colusa Drain, stage in the Sacramento River and gate operations. Hydraulic model analysis of the 100-year flood would provide an accurate assessment of any potential impacts to flow and stage in Sacramento River and Yolo Bypass. To perform such an analysis, the following approach is proposed:

- CVFED Combined RAS model (includes Upper and Lower) will be used to simulate 100-year recurrence interval event. We will verify that the KLOG in the CVFED RAS model reflects the historic gate operation and modify as necessary. According to DWR, 1997 flood flows and stages represent 100-year flood hydrology in the Sacramento Basin. CVFPO 100-year flood hydrology will be obtained or compiled to inform the hydraulic model.
- We will verify that KLOG gauge flows simulated in the RAS model reasonably match observed operations.
- Additional head loss factor will be accounted for on the river side to reflect the Alaskan Weir under project conditions.
- Results from the 100-year flood model under existing and project conditions will be compared to check that the hydraulic impacts due to the proposed Alaskan Weir are insignificant for the duration of the 100-year flood, whereby small head losses result in slightly more water moving into the Yolo Bypass on the leading and trailing limbs of the flood wave. Comparisons will be made at key index points within the system.

REFERENCES

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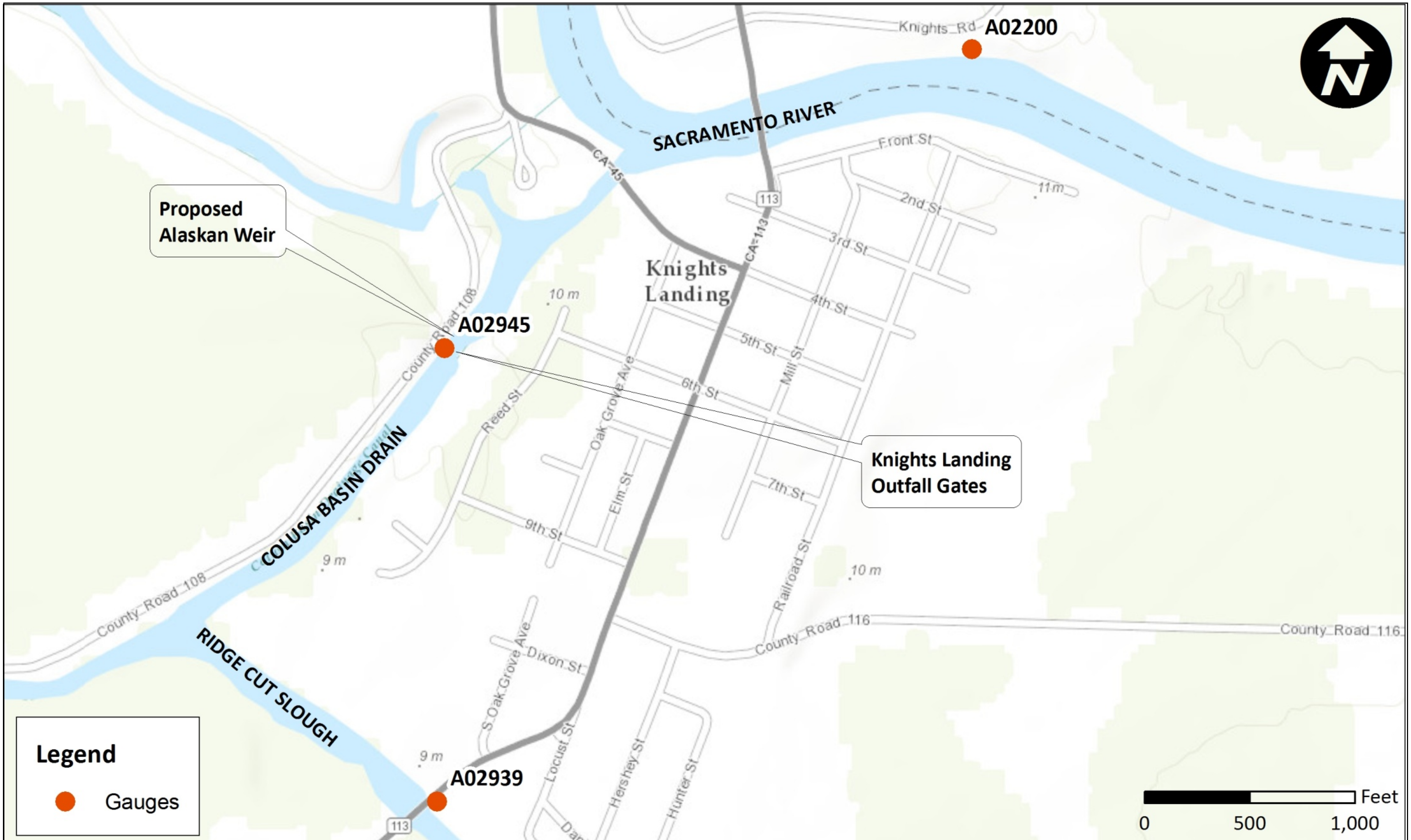

Notes:

Knights Landing Outfall Gates Fish Exclusion Project

Location of Gauges

Project No. 14-1036	Created By: SP	**Figure 1**

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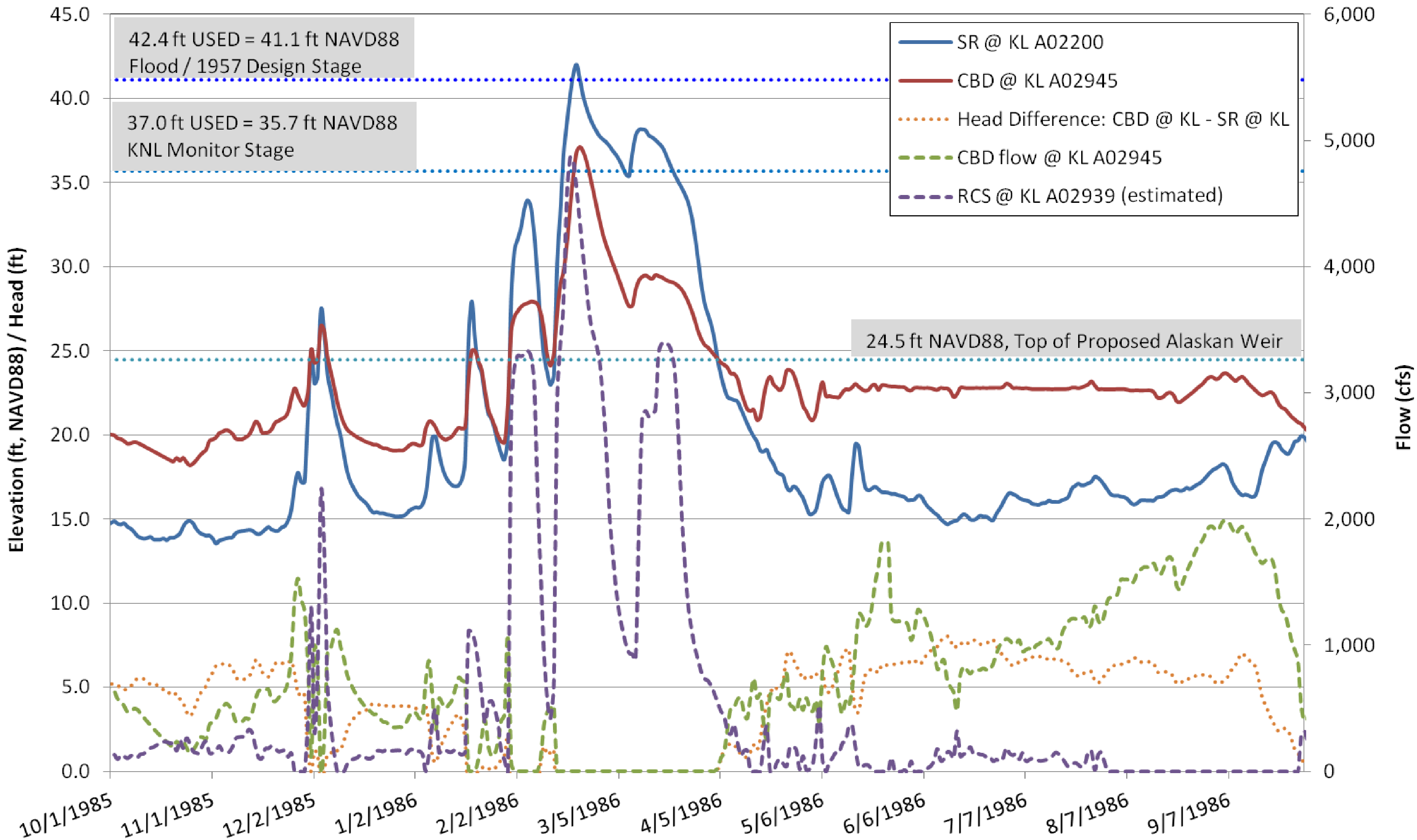

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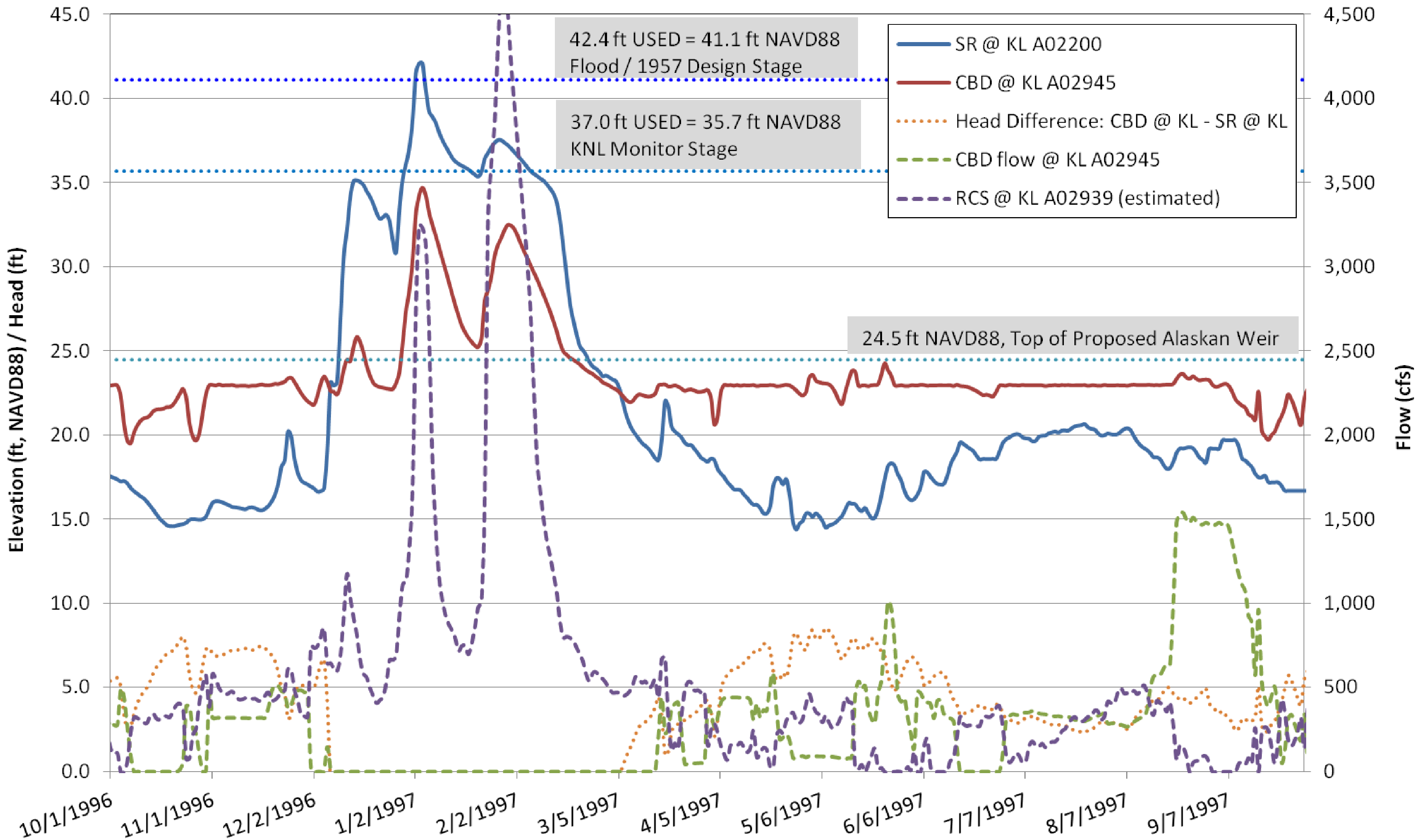
Knights Landing Outfall Gates Fish Exclusion Project

KLOG flow and stage data – water year 1986

Project No. 14-1036	Created By: SP	**Figure 2**



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Knights Landing Outfall Gates Fish Exclusion Project

KLOG flow and stage data – water year 1997

Project No. 14-1036	Created By: SP	**Figure 3**

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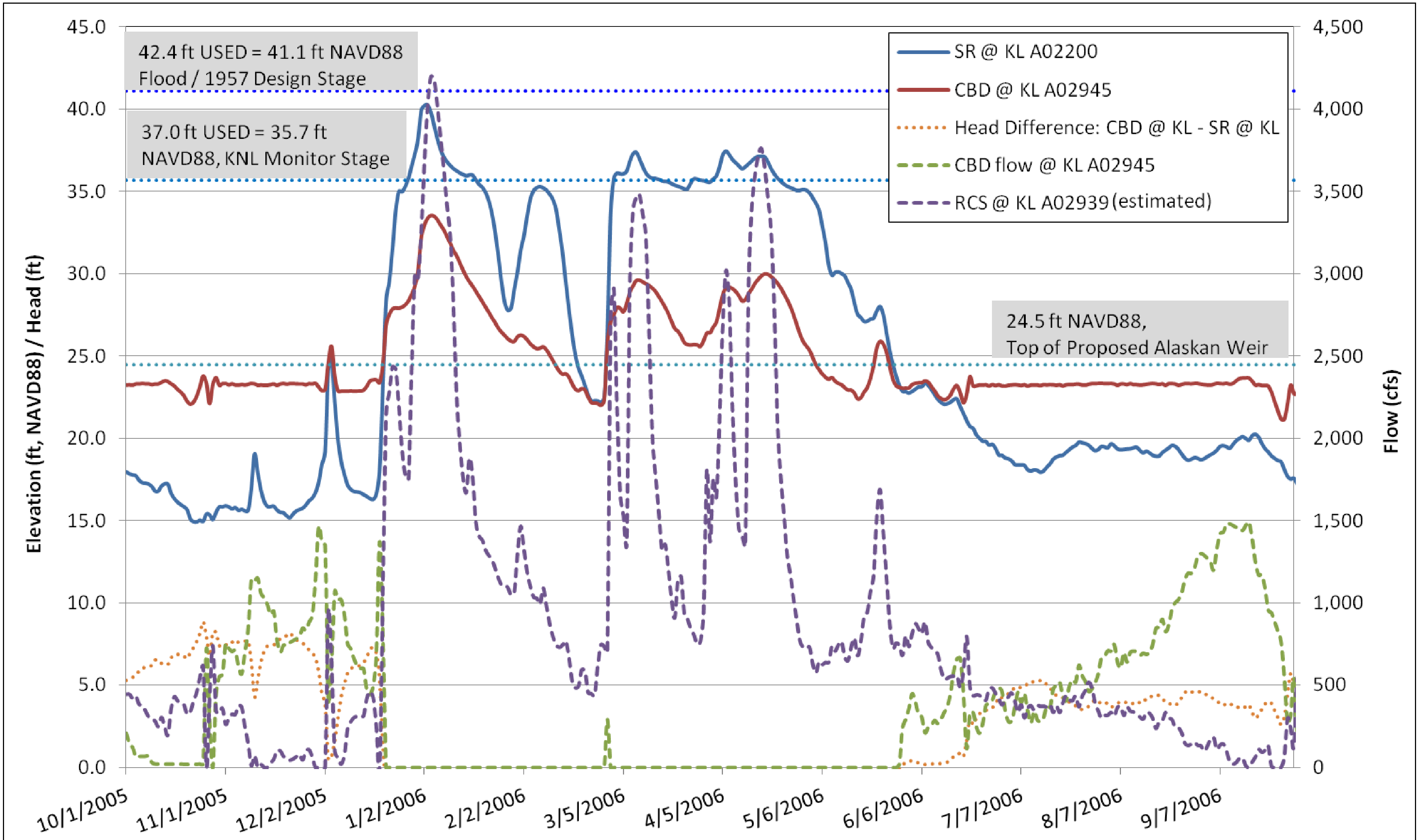
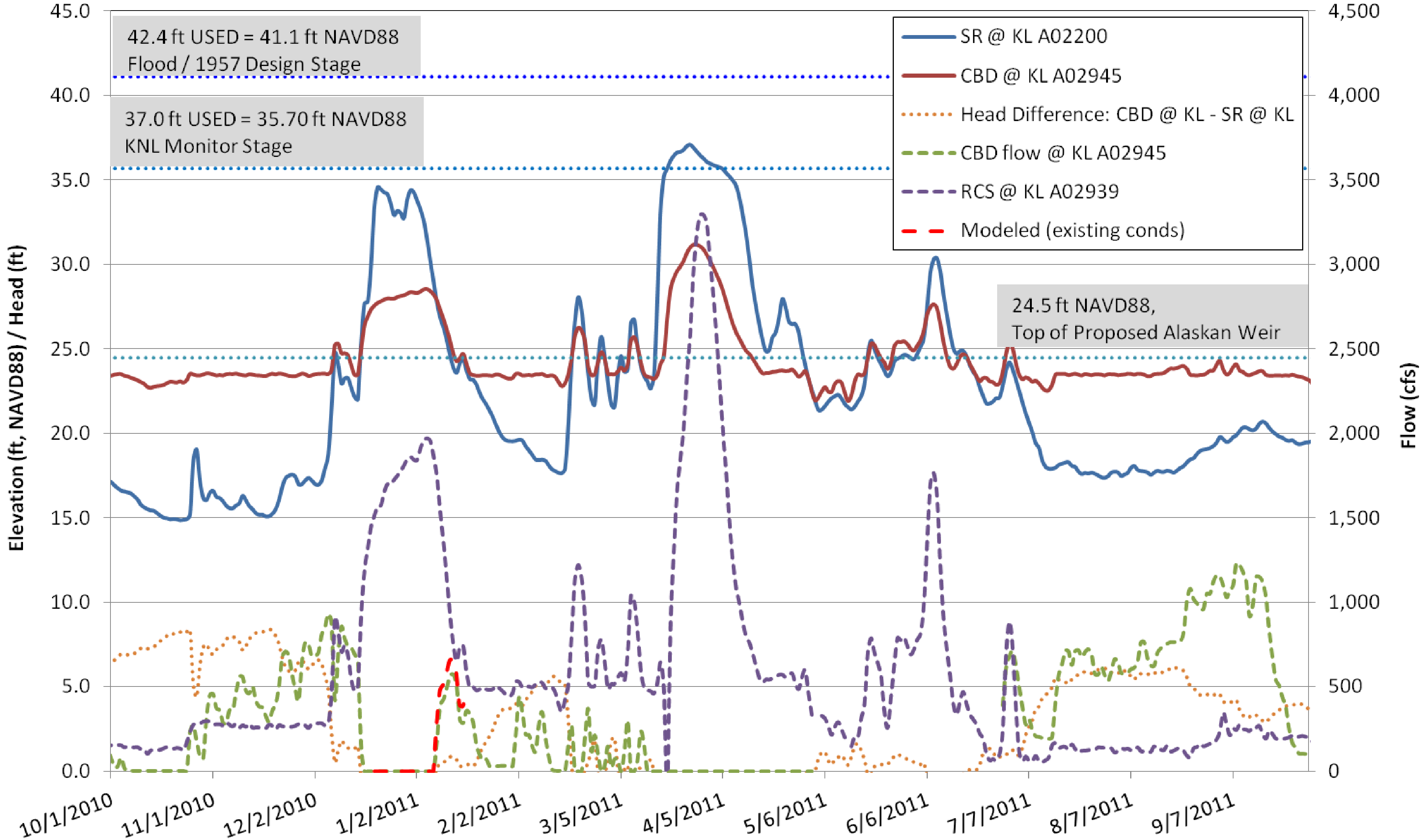
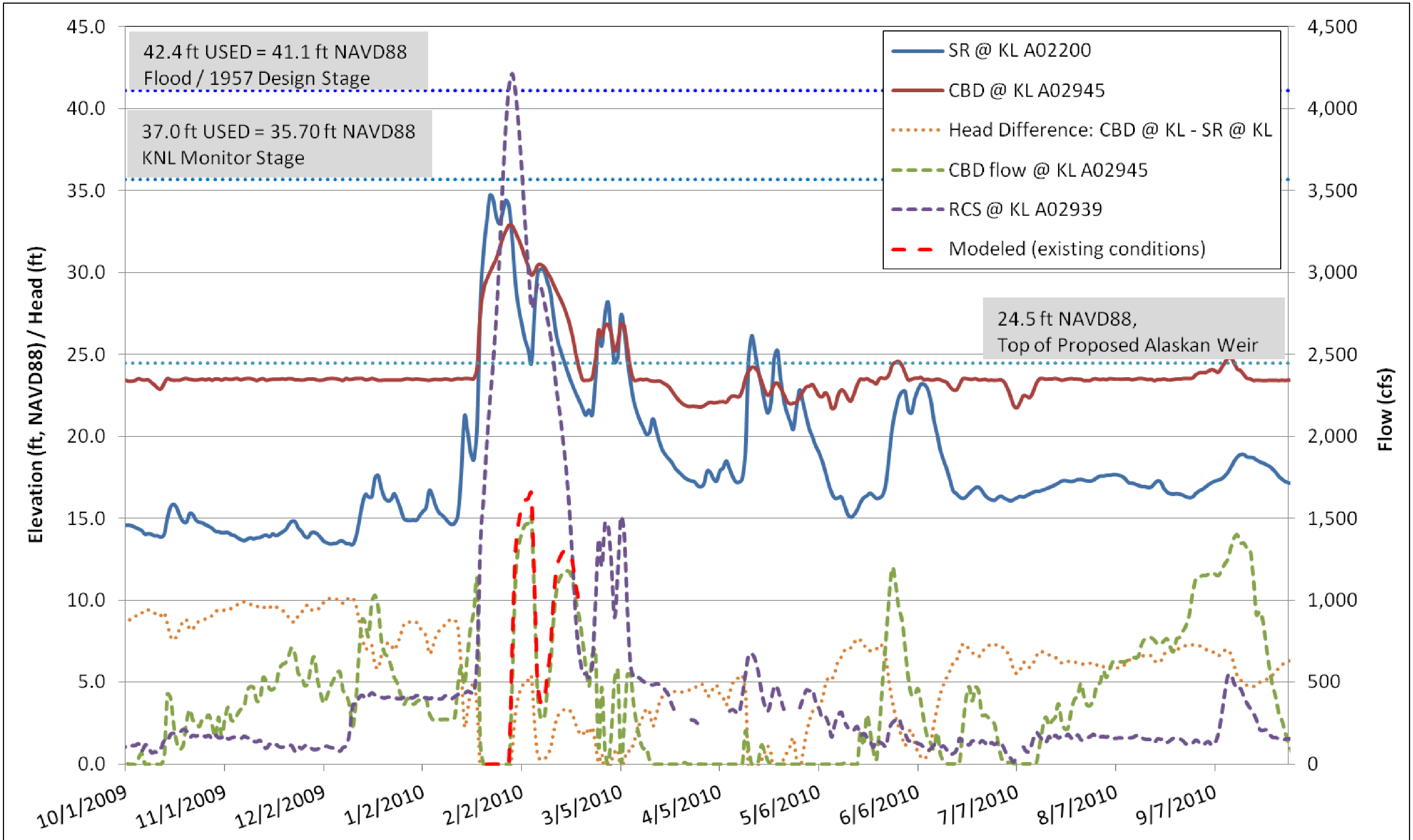


Notes:	cbec eco engineering	*Knights Landing Outfall Gates Fish Exclusion Project* **KLOG flow and stage data – water year 2006**		
		Project No. 14-1036	Created By: SP	**Figure 4**



Notes:	cbec eco engineering	*Knights Landing Outfall Gates Fish Exclusion Project* **KLOG flow and stage data – water year 2011**		
		Project No. 14-1036	Created By: SP	**Figure 5**



Notes:	cbec eco engineering	*Knights Landing Outfall Gates Fish Exclusion Project* **KLOG flow and stage data – water year 2010**		
		Project No. 14-1036	Created By: SP	**Figure 6**