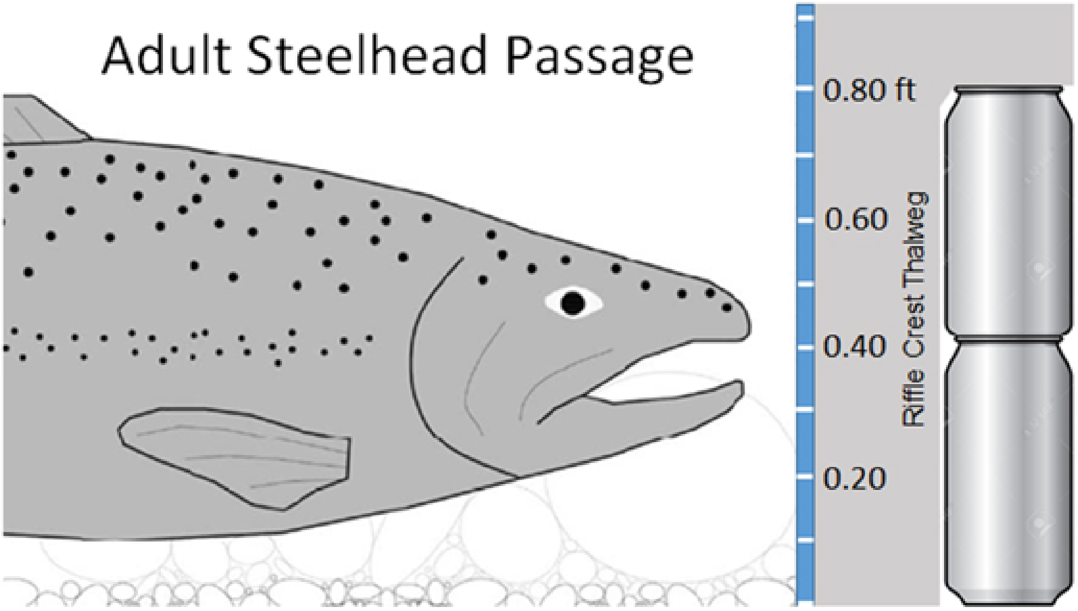
Friends of the Eel River Blockwater Investigation Final Memo

August 5, 2016



Prepared by: Alison O'Dowd & William Trush,

Humboldt State University River Institute

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SUMMARY

There is currently no quantitative method to guide the 2,500 ac-ft annual blockwater release from the Potter Valley Project into the Mainstem Eel River. The four blockwater releases between WY2012-WY2016 used a variety of strategies in attempts to assist outmigrating juvenile salmonids. This study compared impaired (with dams) and modeled unimpaired flow conditions in the Mainstem Eel River downstream of Cape Horn Dam to see how the flows could be managed to optimize juvenile salmonid habitat during the spring hydrograph recession limb. Annual hydrographs of measured impaired flows exhibited steeper spring recession limbs and lower flows earlier in the summer compared with modeled unimpaired annual flows. The unimpaired hydrograph may impact spring rearing habitat for salmonids (particularly Chinook salmon) in terms of fish mobility, habitat availability and quality, and riffle productivity (as related to invertebrates food resources). Analyses of riffle crest thalweg depths in the Mainstem Eel River over the spring and summer seasons showed that flows in the impaired hydrograph reached critical life history thresholds earlier in the season compared to the modeled unimpaired flows. We recommend the following: 1) for dam releases to allow highly productive riffle habitat to occur on the Mainstem Eel downstream of Van Arsdale reservoir, a release of a minimum of 80 cfs from Cape Horn Dam into early June would be needed for most years (as would occur in "Normal" (P=50%) years in an unimpaired scenario); 2) dam releases from Cape Horn Dam should release a minimum of 38 cfs in most water year types through mid- to late-June in order to maintain 'good' riffle habitat for rearing juvenile salmonids; and 3) a minimum well above 10.5 cfs should be maintained in the Mainstem Eel River below Van Arsdale reservoir through the entire summer in wet years, and through at least mid-August in "normal" years and mid-July in "dry" years. Blockwater releases can be used to help meet the above recommendations.

BACKGROUND

Potter Valley Project Background

The Potter Valley Project is an interbasin water transfer project that consists of two dams, a hydroelectric plant, and an eight-foot diameter diversion tunnel that pumps water from the Upper Mainstem Eel River to the East Branch of the Russian River in the Potter Valley. Pacific Gas and Electric Company (PG&E) has owned and operated the Potter Valley Project since 1930. Cape Horn Dam (the downstream dam that forms Van Arsdale Reservoir) and the diversion tunnel to the Potter Valley were completed in 1908 (PVID, 2015). Scott Dam was completed in 1922 and forms Lake Pillsbury approximately 19 km (12 miles) upstream of Cape Horn Dam. The storage capacity of Lake Pillsbury (74,000 acre-feet) is much larger than Van Arsdale Reservoir (700 acre-feet) and Lake Pillsbury/Scott Dam were designed to reliably release year-round water to Van Arsdale Reservoir for diversion to Potter Valley (NMFS, 2002). Water is released from Scott Dam to Cape Horn Dam and diverts a large portion of the flow from late-spring to early fall, while releasing only a small flow to the Mainstem Eel River (Figure 1). Flows can decrease significantly during dry years (e.g., the minimum required flow in summer 2015 was 9 cfs).

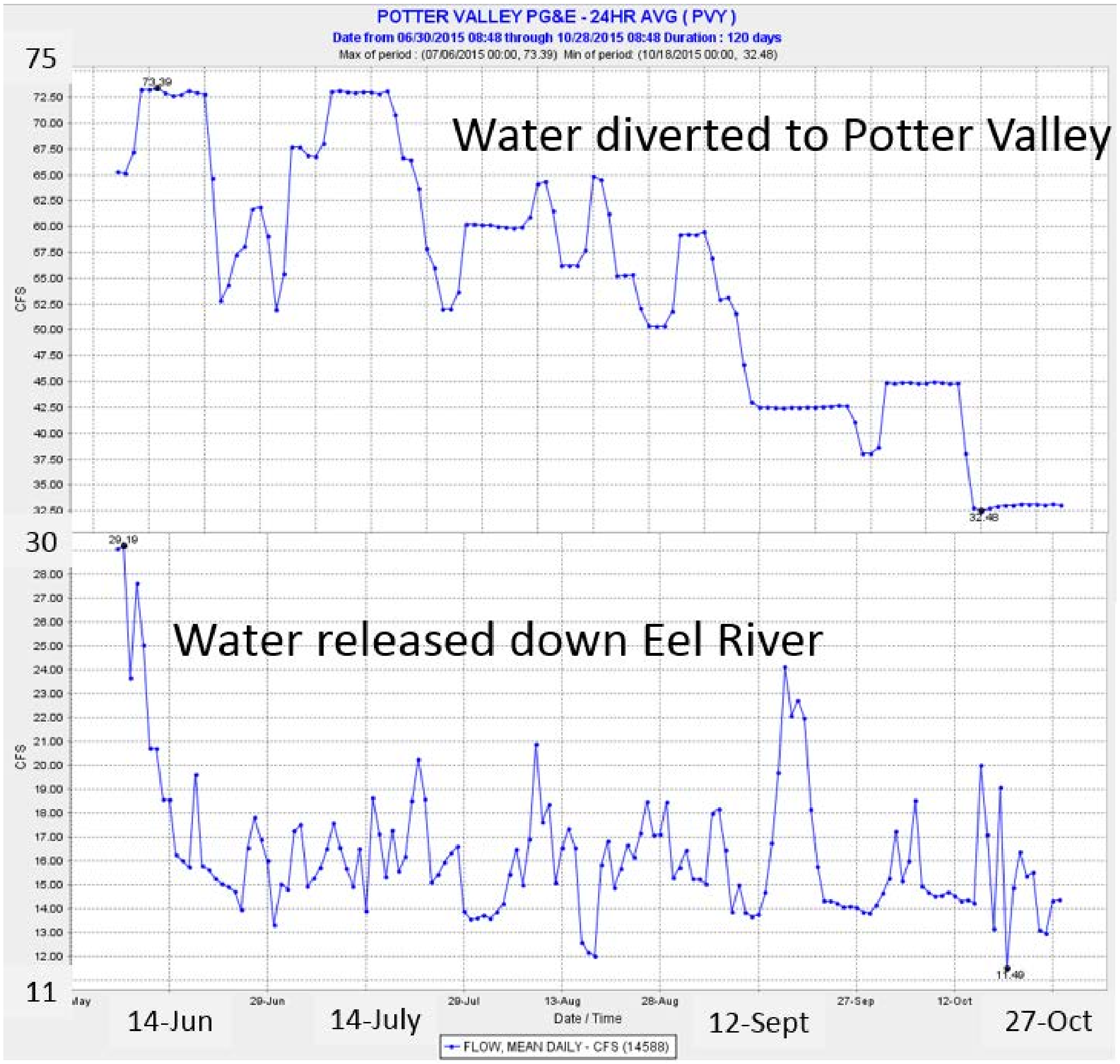


Figure 1. CDEC flow data compares water released from Van Arsdale down the Mainstem Eel River and the amount of water diverted to Potter Valley from mid-June to late October 2015. Graph created on CDEC website: http://cdec.water.ca.gov/cgi-progs/queryDgroups?s=PG2

Hydroelectric power is generated with water from the diversion tunnel that drops 450 vertical feet to the Potter Valley Powerhouse (PVID, 2015). The capacity of the hydroelectric plant is 9.4 megawatts. Scott Dam does not generate electricity and releases water from a needle valve near the base of the dam.

Anadromous Salmonids in the Eel River Basin

Several listed Evolutionarily Significant Units (ESUs) of anadromous salmonids can be found in the Eel River Basin including threatened Southern Oregon/Northern California Coasts (SONCC) Coho salmon (*Oncorhynchus kisutch)*, threatened California Coastal (CC) Chinook salmon (*O. tshawytscha*), and threatened Northern California (NC) steelhead (*O. mykiss*) (NMFS, 2002). It is estimated that these three ESUs have seen a dramatic population decline of approximately 97-99% compared to before the Potter Valley Project was built (USFS & BLM, 1995; NMFS, 2002; Yoshiyama & Moyle, 2010; NMFS, 2012).

Flow regime alteration by dams and other diversions is often considered the most serious and continuous threat to river ecosystem sustainability (Bunn, 2002; Poff et al., 1997). Dams alter the flow regime to optimize flood control, irrigation use, and hydropower production (Poff et al., 1997). Such alterations disrupt the dynamic equilibrium of movement of water and movement of sediment found in free-flowing rivers, having far reaching ecological effects (Poff et al., 1997). Flood control by dams reduces the occurrence of scouring floods in the winter (Power et al., 2015). This reduces the transport of fine sediment, which can result in burial of spawning gravels and the reduction of interstitial habitat for benthic invertebrates (Poff et al., 1997). During the summer, dams can both reduce or inflate baseflow. Reduced baseflow decreases habitat connectivity and strands aquatic organisms, as well as increases temperatures that can cause stress or mortality (Bunn, 2002). Dams often cause irregular flow releases that aquatic biota are not adapted to (Power et al., 2008). For example, catastrophic downstream drift of aquatic invertebrates can occur if irregular flows have enough velocity to dislodge them from rocks (Power et al., 2008). Small nymphs and invertebrates that cannot tolerate high velocities are underrepresented in aquatic communities below dams (Bunn, 2002). Trophic systems and food webs can also be affected by altered flow regimes, since flow alterations can have disproportionate effects on some groups of organisms over others, and groups of organisms are linked by trophic relationships (Poff et al., 1997; Power et al., 2008).

The Potter Valley Project has impacted anadromous salmonids in the Eel River Basin in several ways (Week, 1992). First, the streamflow released from both Scott Dam and Cape Horn Dam have changed the annual hydrograph of the Eel River compared with pre-project unimpaired flows. Modeling of the unimpaired hydrograph at Cape Horn Dam between 1977-2014 found that flow magnitudes in winter storms were diminished as well as late-spring, summer and early fall flows during wet years (E. Asarian, unpublished data, 2015). High winter storm flows are important as a stimulus for salmonids to migrate upstream (Smith, 1985; Lucas et al., 2001). Spring and summer flows are important for adult and juvenile salmonid outmigration and for summer rearing conditions (Northcote, 1984). Spring and early summer flows are also important for upstream migration of adult summer steelhead that enter rivers in late spring. The NMFS Biological Opinion (2002) stated that the Potter Valley Project, "...is by far the largest diversion and damming of Eel River flows, and has damaged habitat by lowering summer and early fall flows to the remaining stream below the Project... (Shapovalov 1939; CDFG 1965; USFS & BLM 1994; CDFG 1997)." The Biological Opinion also discusses that lower than unimpaired flows in spring and summer lead to a quicker formation of a downstream thermal barrier that may impact out-migration and over-summer rearing (NMFS, 2002).

Blockwater releases

The 2002 NMFS Biological Opinion requires Potter Valley Project operations to retain 2500 ac-ft annually (labeled 'blockwater') to be released when needed for anadromous salmonid adult upstream migration and/or juvenile downstream migration. However, blockwater has only been released four times since WY2002: in the spring of WY2012, late-summer WY2014, spring WY2015, and spring WY2016. The late summer WY2014 release was done at the end of the summer to try and prevent lethal high temperatures in the Mainstem Eel River and to move salmon downstream to more suitable habitat (Table 1 and Figure 2). The WY2015 spring blockwater release was "designed to encourage the outmigration of federally ESA-listed salmonids within the Eel River" (NMFS, 2015) between the two dams using three pulses of 60-93 cfs in late April and early/mid-May (Figures 3 & 4). The WY2016 spring blockwater release was meant "to encourage and enhance the emigration (outmigration) of federally ESA-listed salmonids within the Eel River." NMFS consulted with several stakeholders including the HSU River Institute, CalTrout, and CFWS to develop this blockwater release (Figure 5). The WY2016 spring release included a single pulse with a more gradual recession limb meant to replicate a late spring rain storm. The WY2016 blockwater release from Scott Dam was supposed to be a warm-water top release, so that flow and temperature would signal to Chinook salmon to outmigrate, but the release was unfortunately a cold water bottom release and therefore had very little impact on instream water temperatures between the two dams. Possibly for this reason, fisheries technicians at the Van Arsdale fish ladder reported no noticeable response of outmigrating Chinook associated with the WY2016 blockwater release.

Table 1. 2014 summer/fall blockwater release schedule (source: NMFS, 2014).

Date	Scott Dam Releases[1]	RPA required flow below Cape Horn	Blockwater release	Total flow (E-11)	Blockwater used	Water year
Aug. 15 – Sept. 15	78 cfs	3 cfs	22 cfs	25 cfs[3]	1,350 ac-ft	2013/14
Sept. 16 – Sept. 30	78-88 cfs	3 cfs	17 cfs	20 cfs[3]	610 ac-ft	2013/14
Oct. 1 – Oct. 11	88-110 cfs	3 cfs to 20 cfs[2]	1 cfs to 16 cfs	20 cfs[3]	179 ac-ft	2014/15

[1] Equals required minimum flows to Eel River, East Branch Russian River, and 50 cfs allocation to the PVID.
[2] Required minimum flow increases incrementally from 3 cfs on Oct. 1 to 25 cfs on Oct. 15 (NMFS 2002).
[3] Buffer water not required with total flow (E-11).

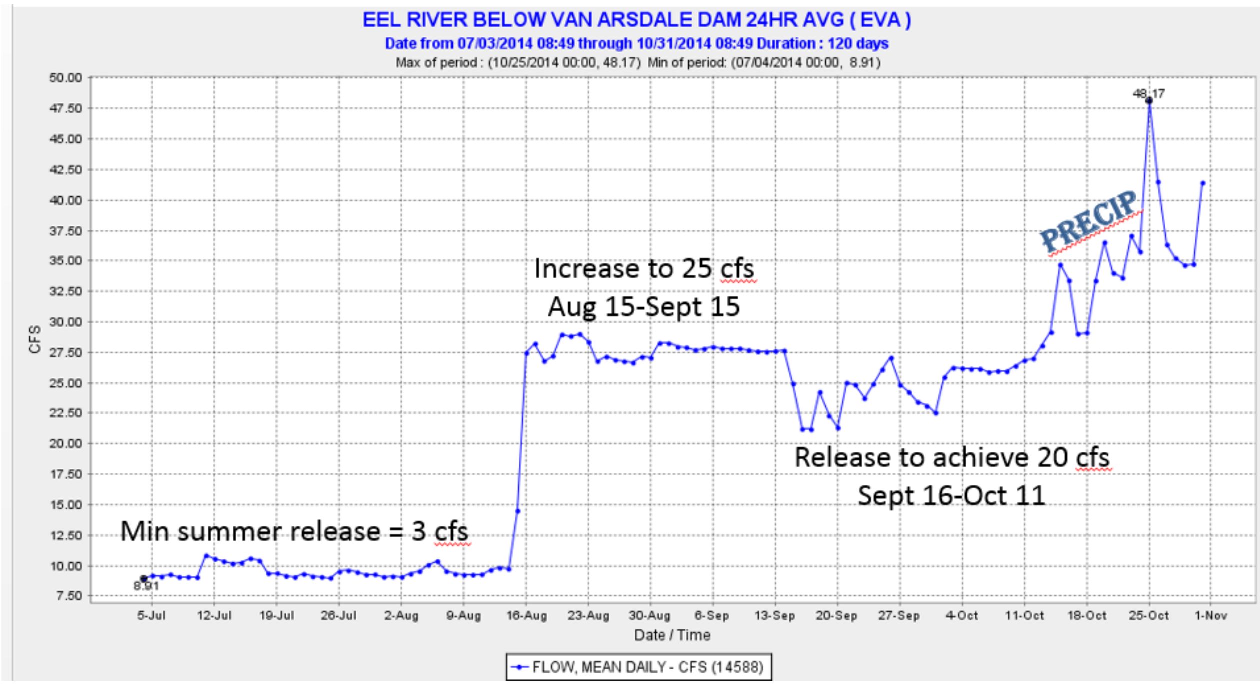


Figure 2. Summer 2014 blockwater release from Van Arsdale Reservoir (late summer/early fall release, Aug 15-Oct 11, 2014). Graph created on CDEC website: http://cdec.water.ca.gov/cgi-progs/queryDgroups?s=PG2

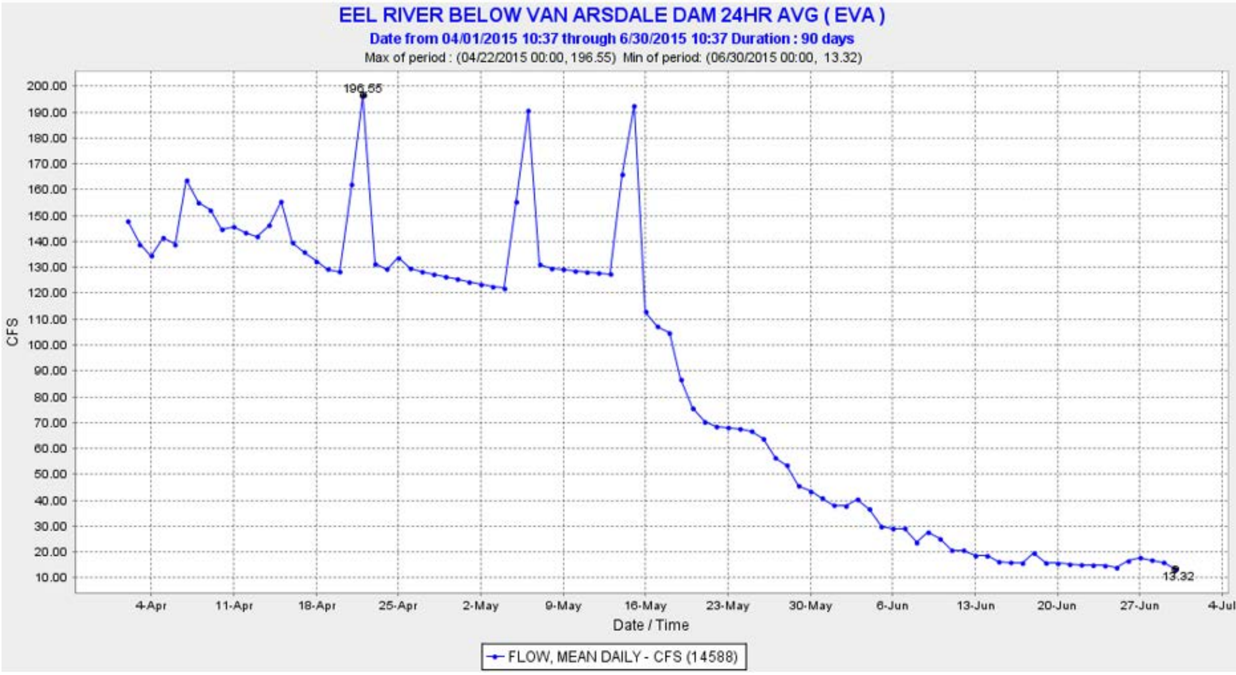


Figure 3. Spring WY2015 blockwater release from Van Arsdale Reservoir shows three pulses in April/May intended to flush fish out from between the two dams. Graph created on CDEC website: http://cdec.water.ca.gov/cgi-progs/queryDgroups?s=PG2

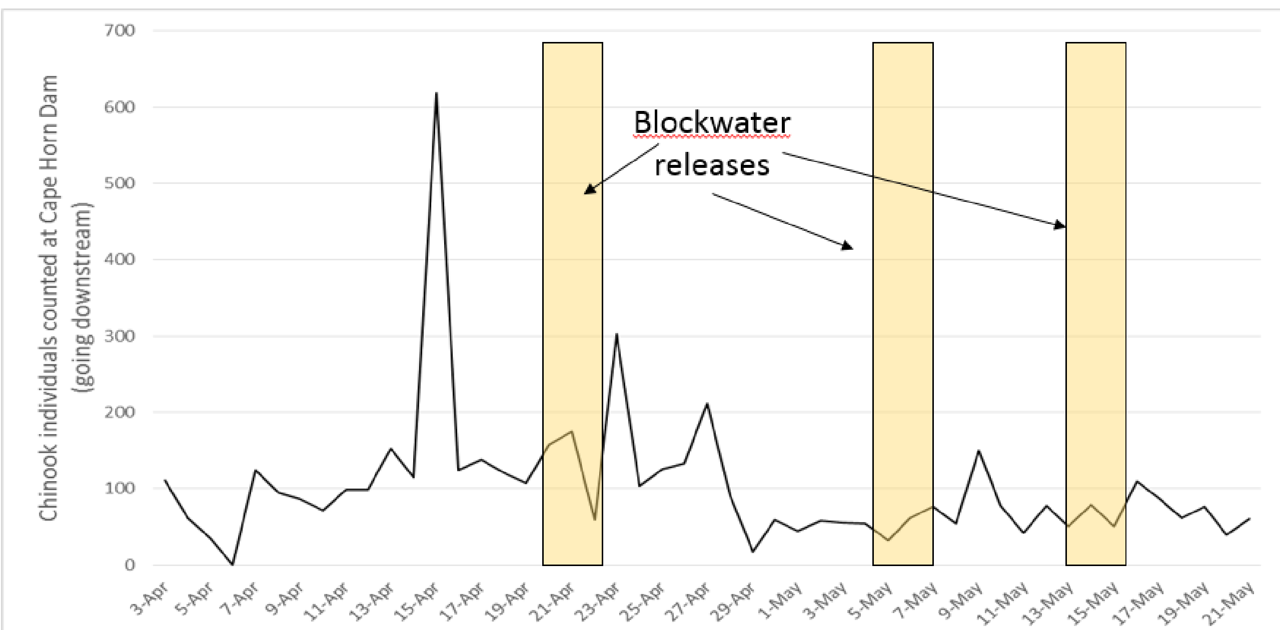


Figure 4. Chinook salmon individuals counted going downstream through Cape Horn Dam between April 3, 2015 and May 21, 2015. The yellow blocks indicates the time periods of blockwater pulse releases.

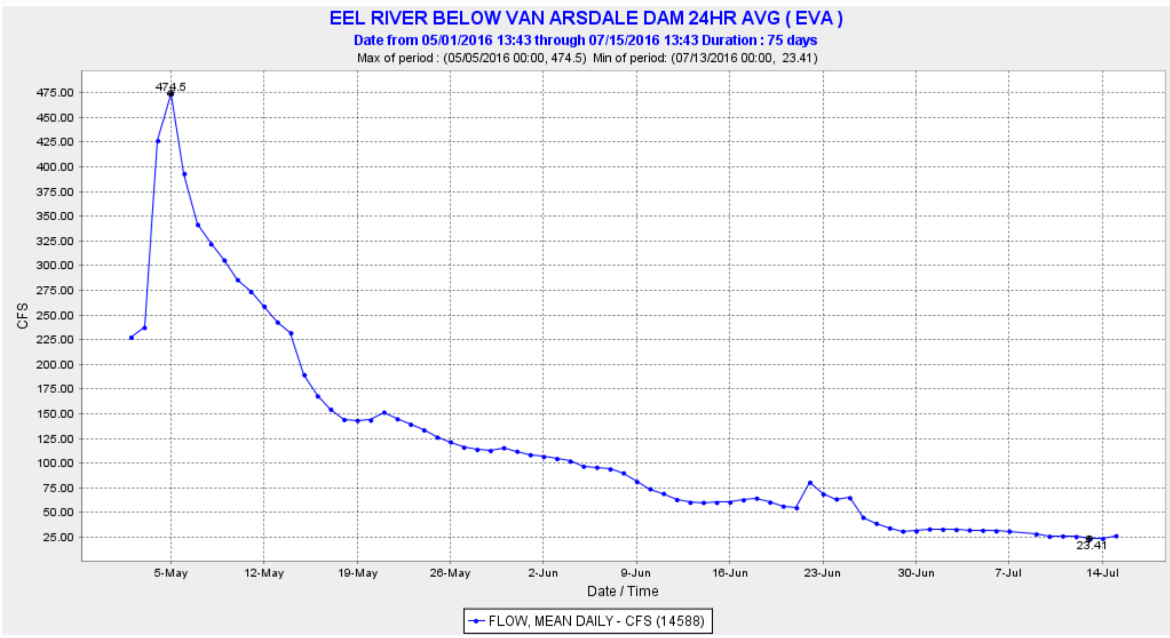


Figure 5. Spring WY2016 blockwater release from Van Arsdale Reservoir shows a single pulse in early May with a longer, gradual recession limb intended to flush fish out from between the two dams. The small increase in flow on June 22, 2016 was for PG&E maintenance reasons. Graph created on CDEC website: http://cdec.water.ca.gov/cgi-progs/queryDgroups?s=PG2

Modeled Unimpaired Flows

Unimpaired flows were modeled by Eli Asarian (Riverbend Sciences) to show what the natural hydrograph would have looked like over time at Van Arsdale if the Potter Valley Project was not in place (E. Asarian, 2015, unpublished data). The estimated unimpaired flows between WY1977 and WY2014 show a gradual decline in streamflow between March and September (Figure 6). In contrast, the impaired hydrographs between WY1977 and WY2014 show a sharp drop-off in flow by the end of June even in the wettest years (Figure 7).

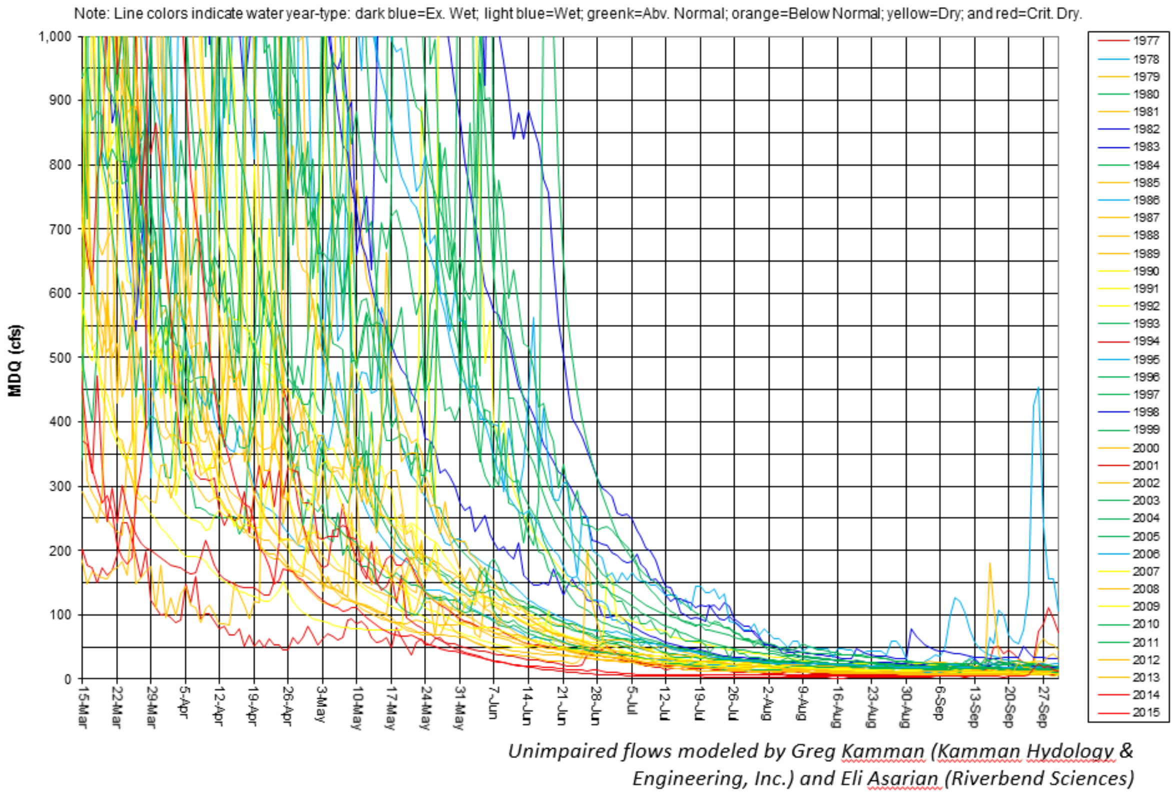


Figure 6. Estimated **unimpaired** flow below Van Arsdale (WY1977-WY2014). Unimpaired flows were modeled by Greg Kamman (Kamman Hydrology Engineering, Inc.) and Eli Asarian (Riverbed Sciences).

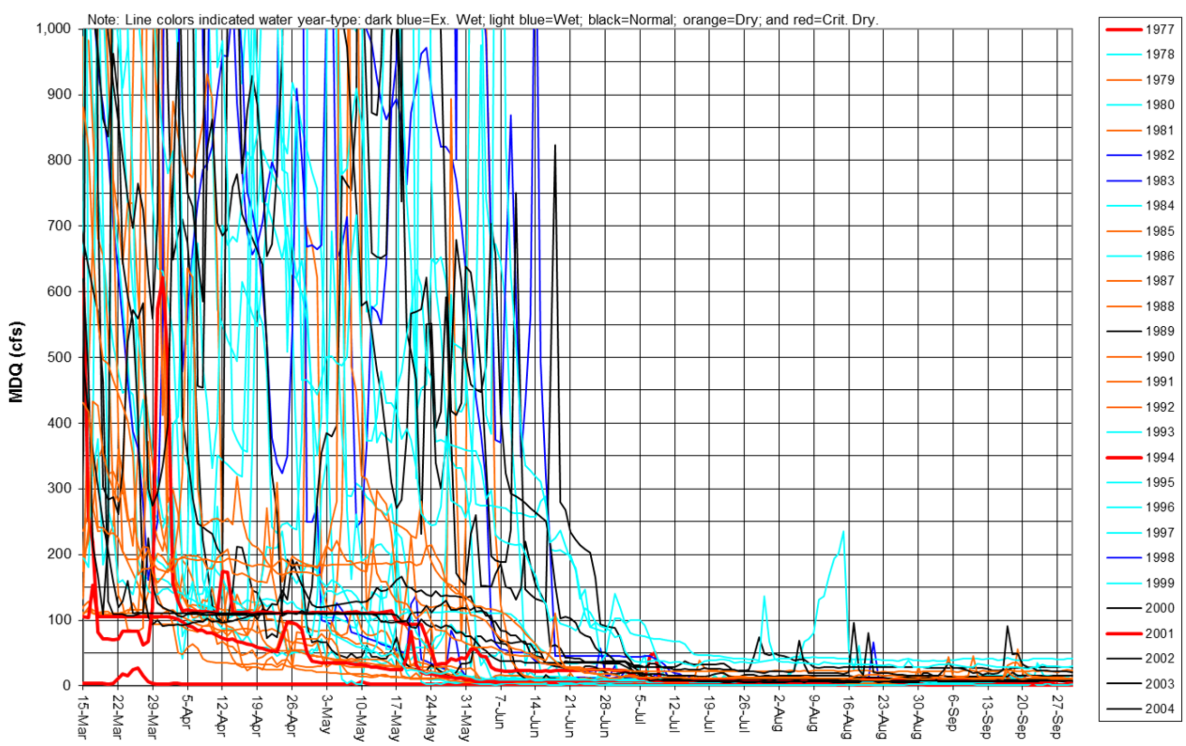


Figure 7. Measured **impaired** flow below Van Arsdale (WY1977-WY2011). Source: CDEC website.

To guide future blockwater releases, this project sought to develop a better understanding of how the unimpaired Eel River ecosystem functioned by asking the question: What were interannual unimpaired conditions in the Mainstem Eel River for smolts heading downstream before the dams were built? In addition, we explored how the dam releases manifest in terms of flow and riffle crest depths related to salmonid mobility, habitat availability/quality, and riffle productivity in the Mainstem Eel River downstream to the confluence with Outlet Creek.

Site Description

Field data were collected from two reaches along the Mainstem Eel River January-September 2015. The first site (Hearst site) was located 550 m upstream of the steel bridge in the town of Hearst and downstream from Emandal Farm (Figure 8). This site incorporates 300 km^2 of additional watershed area from Van Arsdale. The second site (Outlet Creek site) was located just upstream of the confluence with Outlet Creek (Figure 8). The Hearst and Outlet sites are 18.5 km and 48.5 km downstream from Cape Horn Dam, respectively.

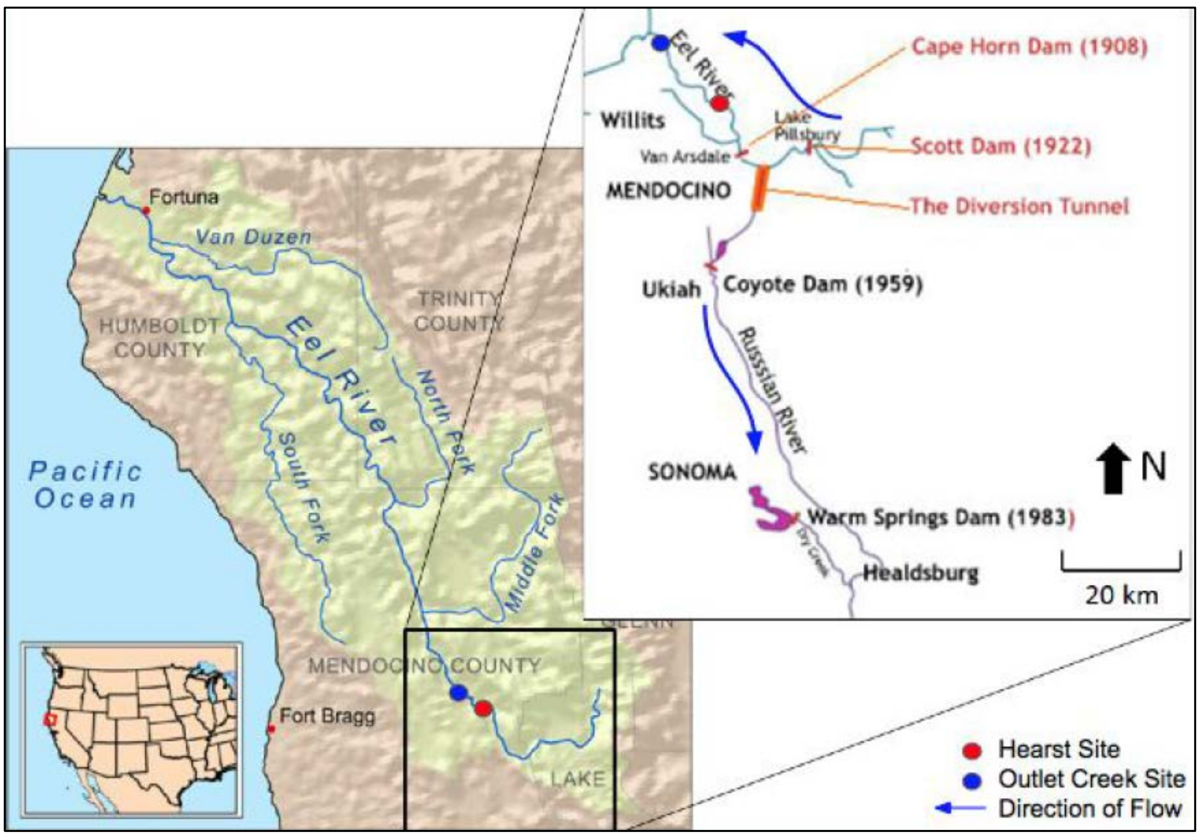


Figure 8. Eel River watershed with location of study sites indicated by red (Hearst) and blue (Outlet) circles. Inset map shows Potter Valley Project components (Cape Horn Dam, Scott Dam, and diversion tunnel to the Russian River). Eel River watershed map created by Kmusser – self-made based on USGS data. Source of inset map: NMFS, 2002.

Hydrograph and Stream Channel Analysis

Data from the CDEC website (http://cdec.water.ca.gov) were used to observe the flows released from Lake Pillsbury and Van Arsdale reservoirs over time and compare them with the flow measurements made at the study sites.

Field Methods

Physical measurements. Field sites were visited eight times between January and September 2015 (1/15/15, 4/18/15, 5/28/15, 6/8/15, 6/22/15, 7/19/15, 8/12/15, and 9/13/15). Six cross-sections were established at the Hearst site starting at the upstream end of the reach at the riffle crest and ending downstream of the riffle in the adjacent pool. At each cross-section an elevational profile was taken using standard surveying equipment (stadia rod, level, tripod, tapes). Stream velocities were measured at each point along the cross-section in order to measure small-scale variability in velocity across the channel and to calculate discharge (Figure 9). The elevation of the water surface was also measured over time to be able to plot the water surface on the cross sections at a variety of flows.

Figure 9. Humboldt State University undergraduate Environmental Resources Engineering majors Faith Neff and Dustin Revel measure velocity and an elevational profile along a cross section at the Hearst site on 1/15/15. Photo by A. O'Dowd.

Each of the six cross-sections was plotted along with the water surface elevation at the six measured flows. The hydraulic geometry of each flow was calculated to quantify the usable habitat for each (Figure 10). See Appendix A for all six cross-section graphs and Appendix B for photographs of the Hearst riffle during several flows.

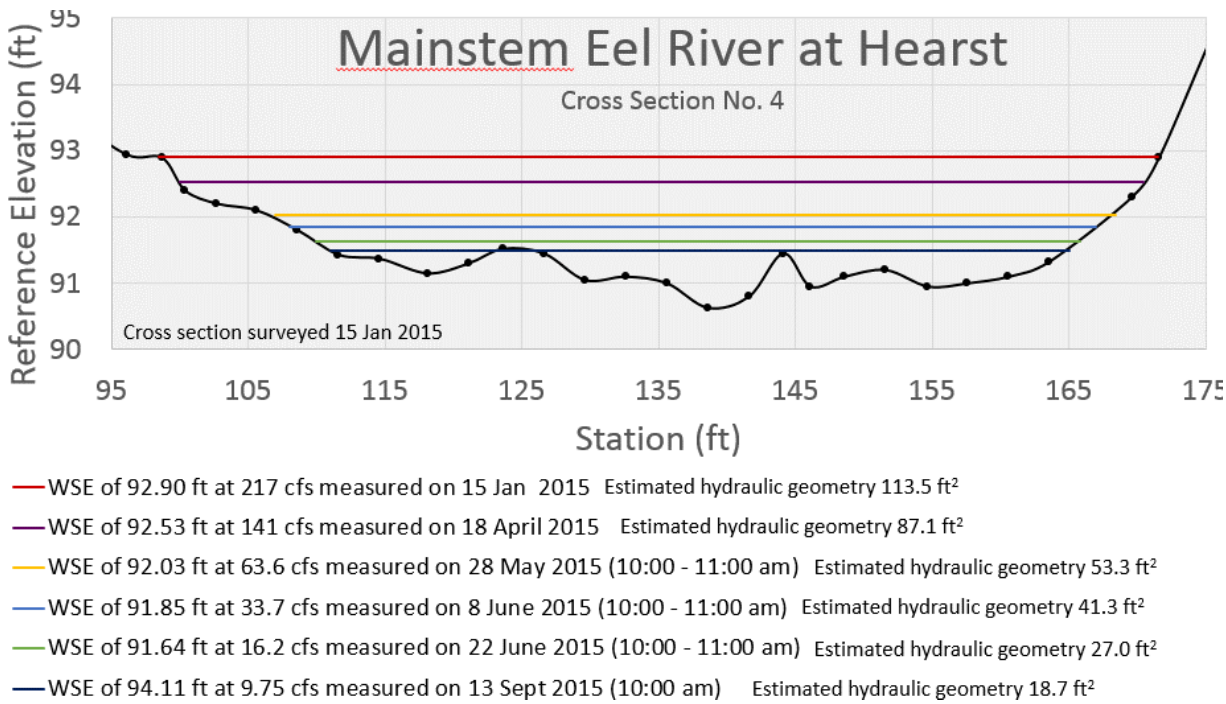


Figure 10. Cross-section 4 at Hearst on the Mainstem Eel River. The water surface elevation and hydraulic geometry are indicated for six measured flows between January and September 2015.

Discharge

Discharge measurements made at the Hearst and Outlet Creek sites (and one measurement just upstream of the confluence with the Middle Fork Eel) were compared to dam releases from Van Arsdale over time. Table 2 shows a summary of discharge measurements taken at both the Hearst and Outlet sites January-September 2015.

Table 2. Discharge measurements (cfs) taken at three locations on the Main Stem Eel River between January and September 2015. Van Arsdale flow data were downloaded from the CDEC website (http://cdec.water.ca.gov).

Site	1/15/2015	4/18/2015	5/28/2015	6/8/2015	6/22/2015	7/19/2015	8/12/2015	9/13/2015
Van Arsdale*	194.28	132.26	53.53	23.65	15.04	15.57	15.09	14.69
Hearst site	217.4	141.4	63.63	33.7	16.19			9.75
Outlet site					19.25	14.9	15.92	10.96
Middle Fork						12.84		

*Flow release data from Van Arsdale were downloaded from the CDEC website.

This study also sought to pinpoint when the reach between Van Arsdale Reservoir and our study reaches would switch from a gaining reach (i.e., higher flows occur downstream of dam because of tributary and watershed inputs during wetter times of year) to a losing reach (i.e., lower flows occur downstream of dam due to lesser tributary inputs, and losses to groundwater and evaporation at drier times of year). Our data indicate that the reach between Van Arsdale Reservoir in the Hearst study site went from a gaining reach in June and to a losing reach by mid-September 2015 (Figure 11).

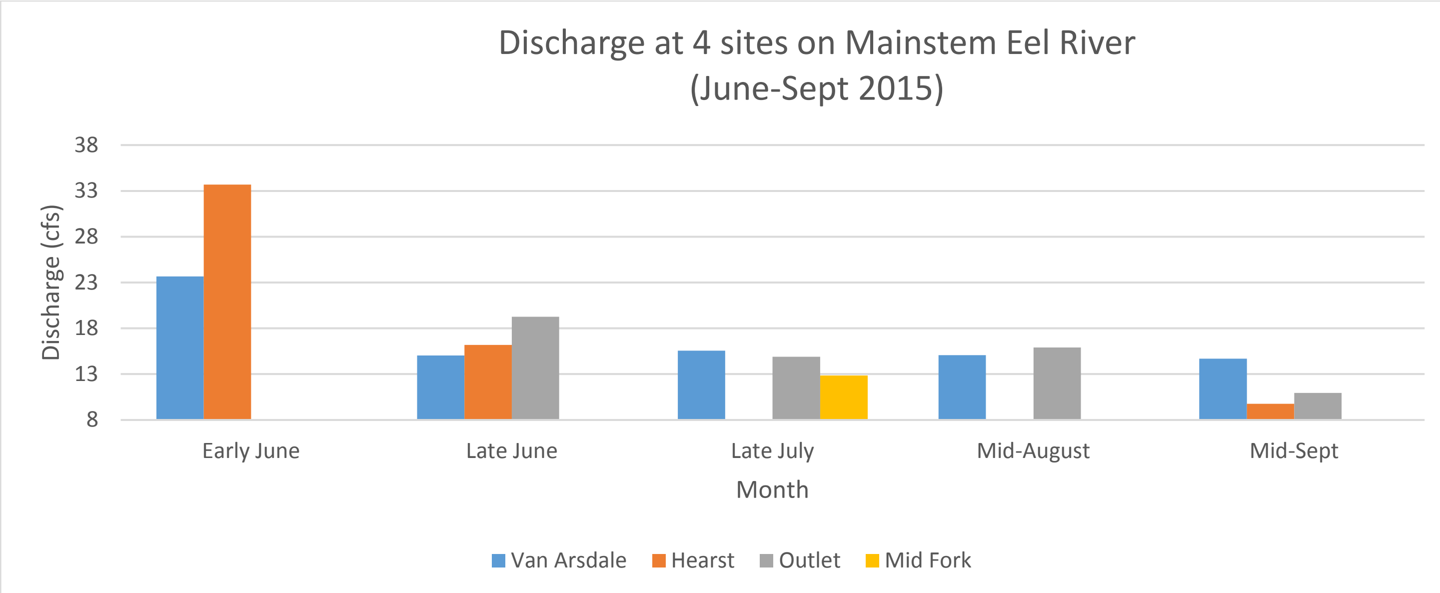


Figure 11. Discharge at four sites on the Main Stem Eel River between early June and mid-September 2015 to determine when the river went from being a gaining reach to a losing reach. Discharge measurements were not made at the Hearst site in July or August.

Riffle crest and flow relationships

This study examined the link between riffle crest thalweg (RCT) depth and discharge to help determine what a given dam release would mean in terms of salmonid mobility, habitat, and riffle productivity. First, we determined four riffle crest depths that would represent thresholds important to salmonid life history and then related those riffle crest depths to discharge at the Hearst site (Table 3). One way to visualize a minimal riffle crest depth for steelhead/Coho adult passage (0.8 feet) is contrast body height of an adult steelhead next to a given riffle crest depth (Figure 12).

Table 3. Riffle crest depth and flow thresholds related to salmonid passage and riffle productivity.

Riffle crest thalweg depth (feet)	Estimated Discharge (cfs)	Salmonid life history link
0.2	3	Threshold for minimal riffle-pool connectivity
0.4	10.5	Threshold for functionally connected riffles and downstream juvenile/smolt passage
0.8	38	Threshold for steelhead/Coho adult passage and good riffle habitat
1.2	80	Threshold for Chinook adult passage and highly productive riffle habitat

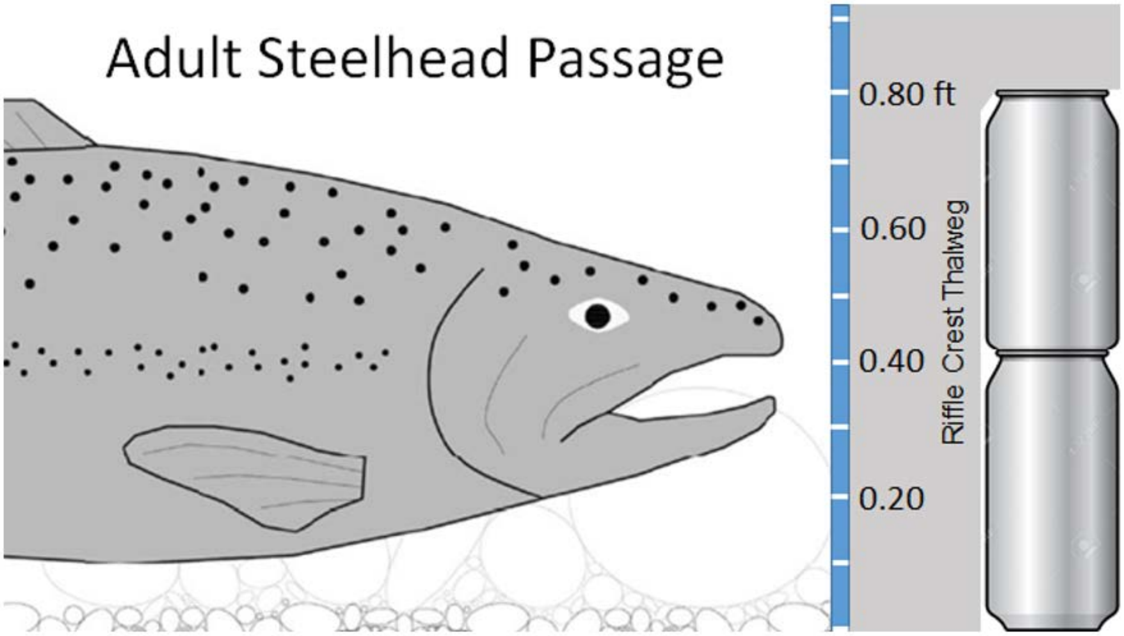


Figure 12. Body height of adult steelhead next to a riffle crest height of 0.80 feet indicates the minimum depth needed for adult passage at a riffle crest.

A rating curve was created using USGS flow and stage data recorded on the Mainstem Eel River at Hearst in WY1911 (Figure 13). WY1911 was used to construct the rating curve because it had an adequate number of flow and stage measurements available. The rating curve equation ($y = 0.1127x^{0.5394}$) was used to convert modeled unimpaired flow data into riffle crest thalweg (RCT) depths at this site. Riffle crest thalweg depths were then plotted as a 'spaghetti graph' in which each water year was plotted separately on the same graph for both the impaired (Figure 14) and unimpaired flows (Figure 15). Annual hydrographs were color-coded to show extremely wet, wet, above normal, below normal, dry and critically dry years. An image of a juvenile salmonid and the four biologically-relevant RCT depth thresholds from Table 3 were superimposed onto these graphs to show when and how often these thresholds would have been crossed in WY1977-WY2014 in an unimpaired (no dam, Figure 14) and impaired (Figure 15) scenario.

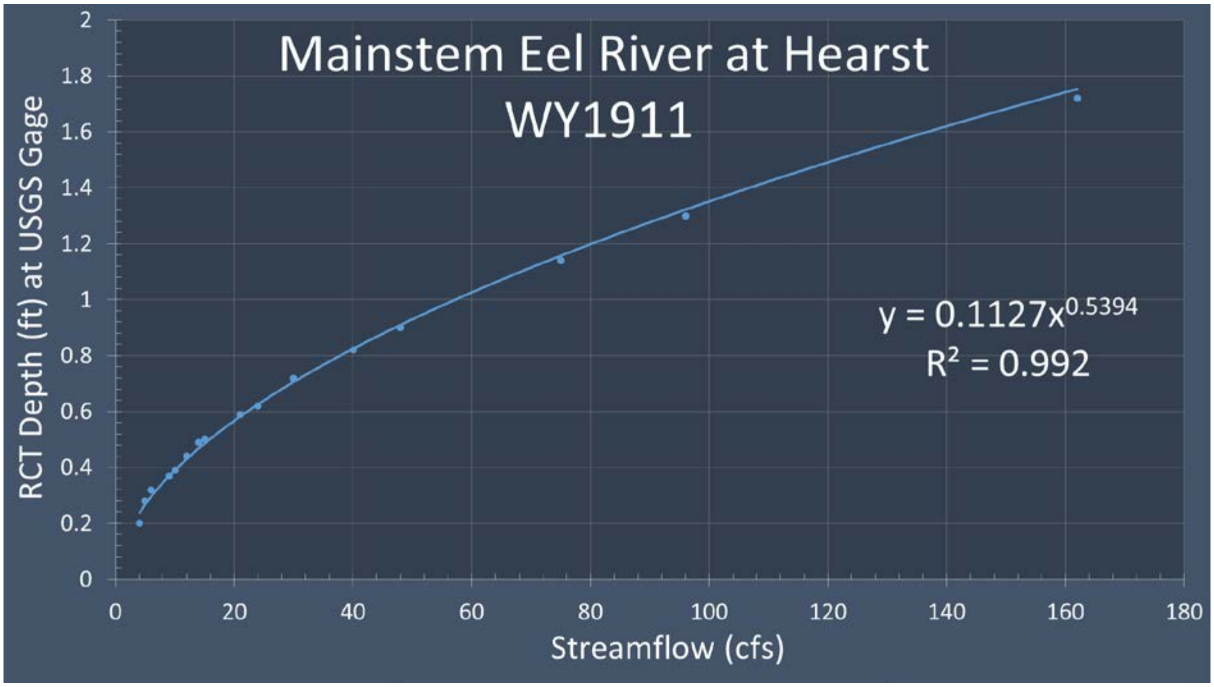


Figure 13. Riffle crest rating curve for the Mainstem Eel River at Hearst (WY1911).

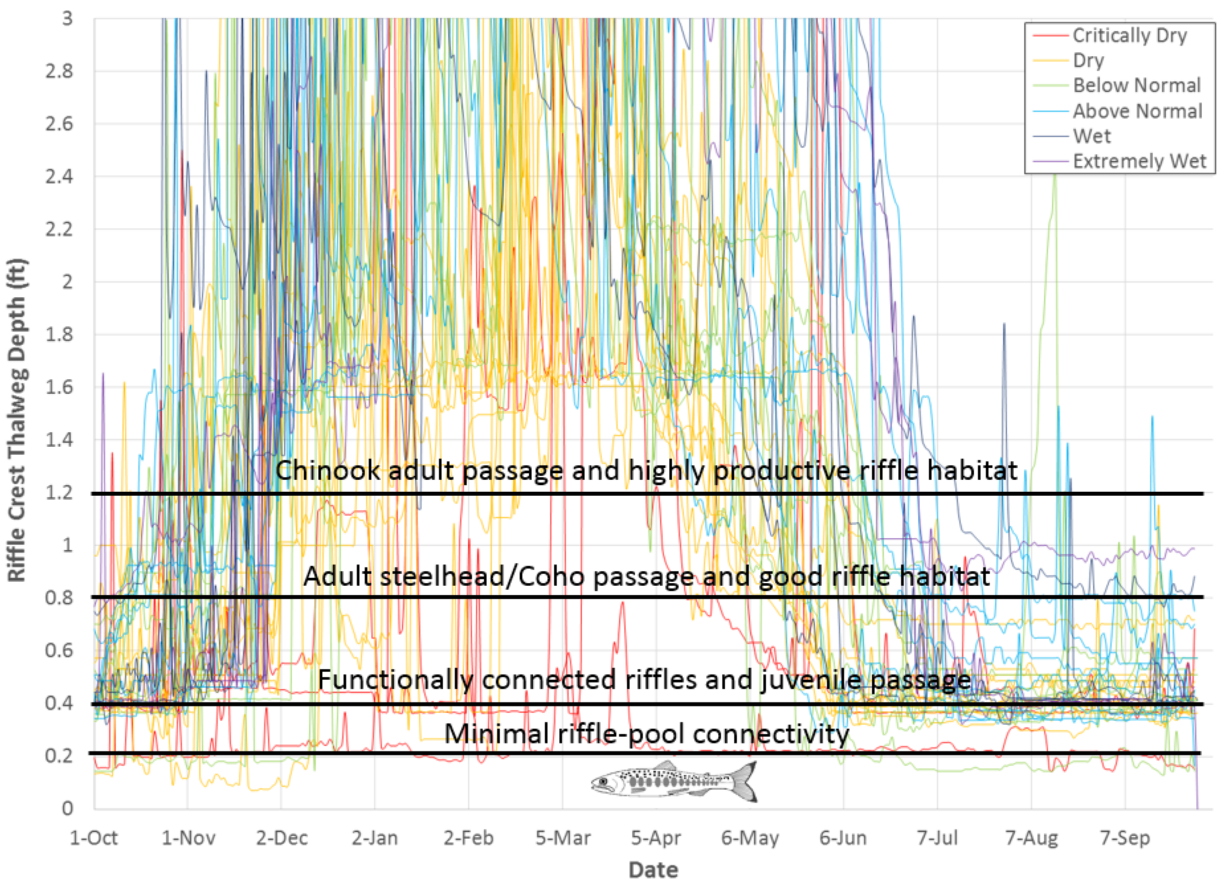


Figure 14. Riffle crest thalweg depths (based on **impaired** flow releases from Cape Horn Dam) on the Mainstem Eel River at Hearst (WY1977-WY2011).

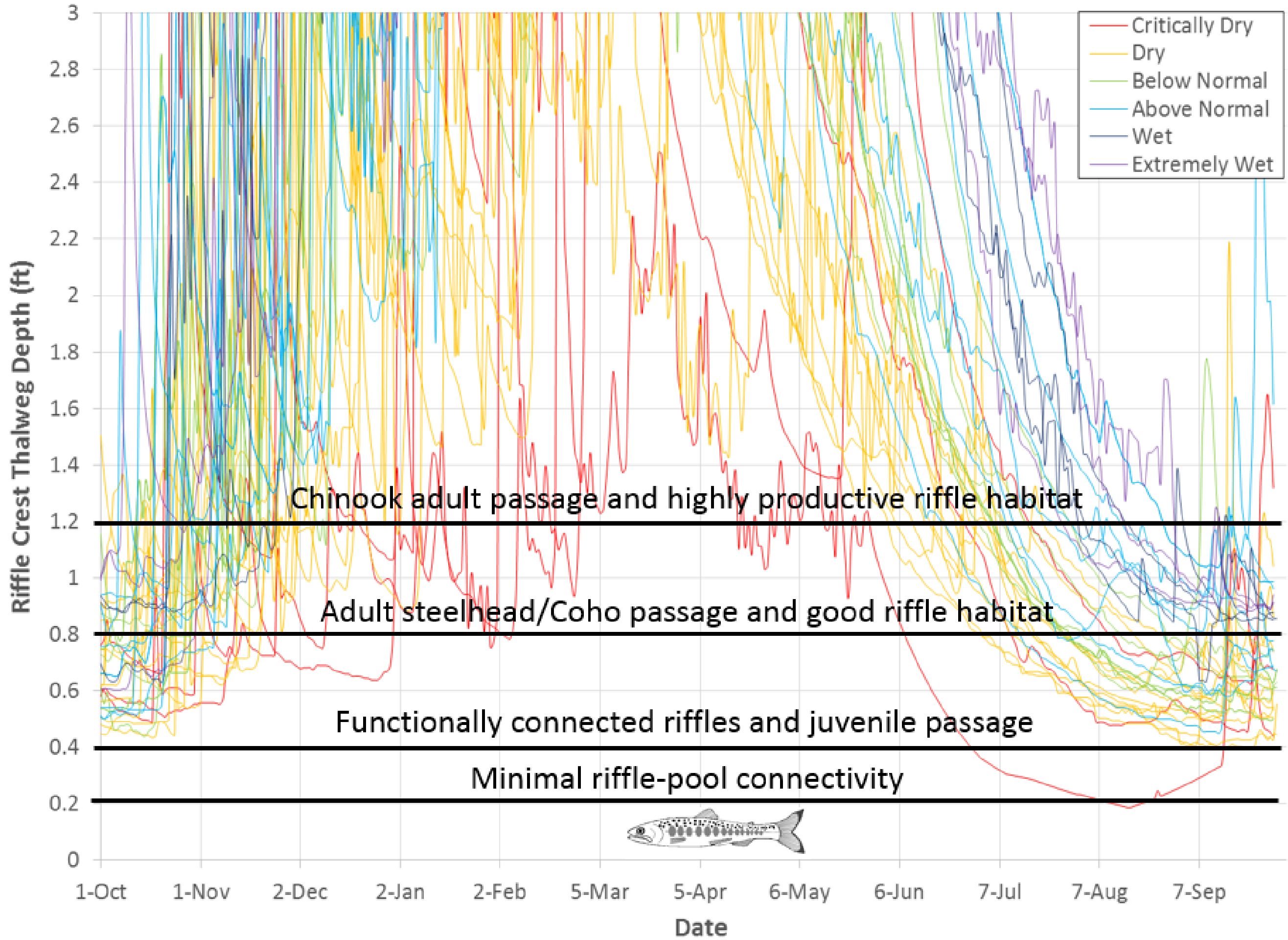


Figure 15. Estimated **unimpaired** riffle crest thalweg depths on the Mainstem Eel River at Hearst (WY1977-WY2014).

An annual runoff percent exceedance graph was created using the modeled unimpaired runoff data. Total runoff (cfs) for each water year was calculated and then converted to total acre-feet per year (Figure 16). Years were ranked from wettest to driest years by total acre-feet (Table 4). The percent exceedance values (P) were used to examine at the time of year when the four riffle crest thalweg thresholds were crossed.

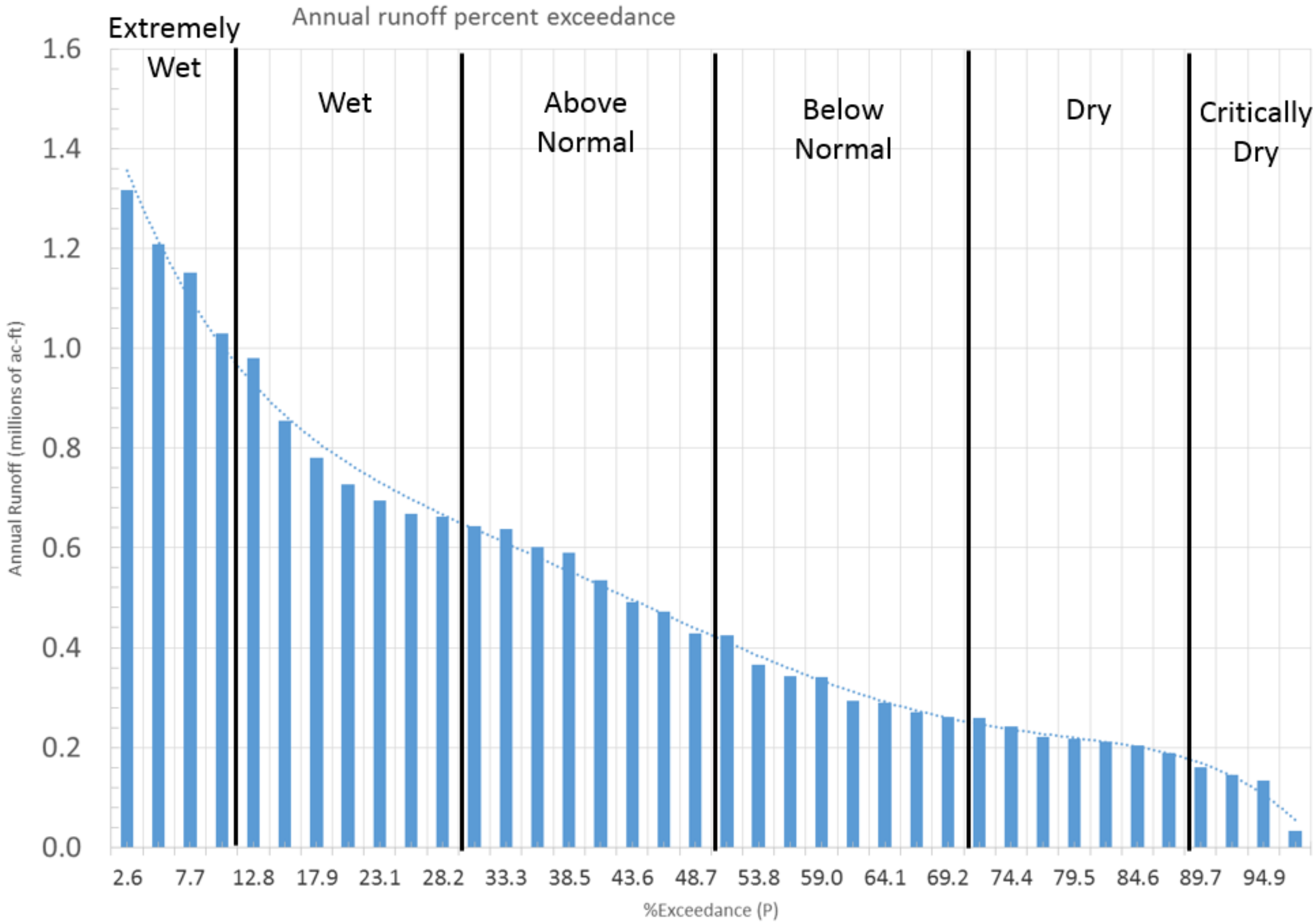


Figure 16. Annual runoff percent exceedance curve based on unimpaired flow data at Van Arsdale with categories from ‘extremely wet’ to ‘critically dry’.

Table 4. Ranks of water years based on modeled unimpaired flow data converted to acre-feet per year (WY1977-WY2014).

Water Year	Rank	%P	Acre-ft/yr	Water year type
1983	1	2.6	1,316,909.3	Extremely wet
1998	2	5.1	1,208,398.7	Extremely wet
1982	3	7.7	1,151,785.3	Extremely wet
2006	4	10.3	1,028,865.5	Wet
1995	5	12.8	980,563.8	Wet
1986	6	15.4	853,926.4	Wet
1978	7	17.9	780,958.1	Wet
1980	8	20.5	727,736.6	Wet
1996	9	23.1	695,125.1	Wet
1997	10	25.6	669,118.9	Wet
2011	11	28.2	663,424.3	Wet
1993	12	30.8	644,198.6	Above Normal
1984	13	33.3	638,215.8	Above Normal
1999	14	35.9	601,644.9	Above Normal
2003	15	38.5	590,075.8	Above Normal
2004	16	41.0	535,380.0	Above Normal
2005	17	43.6	491,085.7	Above Normal
2010	18	46.2	473,184.6	Above Normal
2002	19	48.7	427,936.4	Above Normal
2000	20	51.3	424,291.0	Below Normal
1989	21	53.8	366,152.8	Below Normal
2008	22	56.4	342,402.1	Below Normal
2013	23	59.0	340,456.5	Below Normal
1988	24	61.5	294,015.2	Below Normal
1979	25	64.1	289,269.4	Below Normal
2012	26	66.7	270,456.3	Below Normal
1985	27	69.2	260,499.5	Below Normal
1981	28	71.8	258,338.7	Dry
1987	29	74.4	242,720.5	Dry
1992	30	76.9	221,835.4	Dry
2007	31	79.5	218,237.2	Dry
2009	32	82.1	211,082.5	Dry
1990	33	84.6	203,716.4	Dry
1991	34	87.2	188,480.5	Dry
2001	35	89.7	159,448.3	Dry
1994	36	92.3	144,803.9	Critically Dry
2014	37	94.9	133,654.3	Critically Dry
1977	38	97.4	33,286.8	Critically Dry

Using Flow and Riffle Crest Thresholds to Guide Performance Measures

Four graphs were created to show the date of each water year between WY1977-WY2014 when a riffle crest depth threshold was crossed during the spring recession limb. The first graph (Figure 17) shows that in ‘extremely wet’ years (P<10%) the riffle crest thalweg depth (RCT) was ≥1.2 feet until July and in “Normal” (P=50%) years this RCT depth persisted generally into early June. Therefore, for dam releases to allow highly productive riffle habitat to occur on the Mainstem Eel downstream of Van Arsdale reservoir, a release of a minimum of 80 cfs from Cape Horn Dam into early June would be needed for most years (as would occur in “Normal” (P=50%) years in an unimpaired scenario).

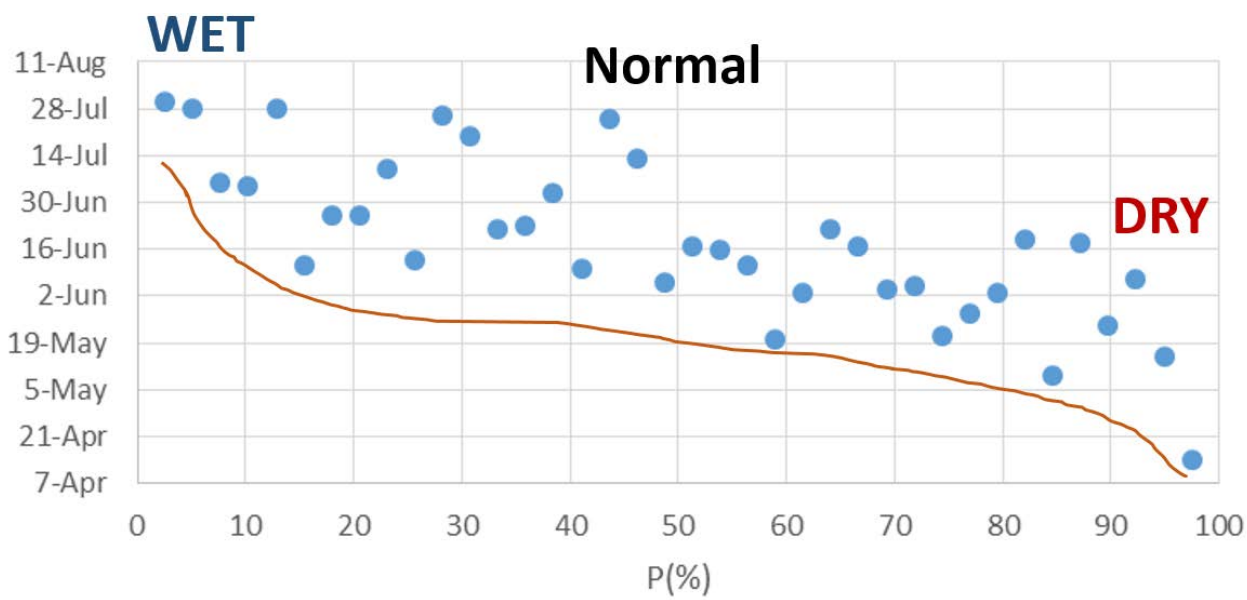


Figure 17. The date when the riffle crest thalweg (RCT) depth crossed a threshold of less than 1.2 feet during the spring recession limb of the modeled **unimpaired** flow at Van Arsdale (WY1977-WY2014). The orange line shows the lower boundary of these dates.

The measured impaired (with dams) flow record shows that the 1.2 foot RCT depth was crossed as early as April in both wet and dry years prior to the 2002 Biological Opinion (Figure 18). In WY2002-WY2014, the 1.2 ft threshold was often not crossed until early-June to mid-July. This reflects the fact that more recent management of flow releases from Van Arsdale have allowed for 80 cfs until early June. However, in drier years (e.g. WY2013 and WY2014) the flow release dropped below 80 cfs earlier (in mid- to late-May).

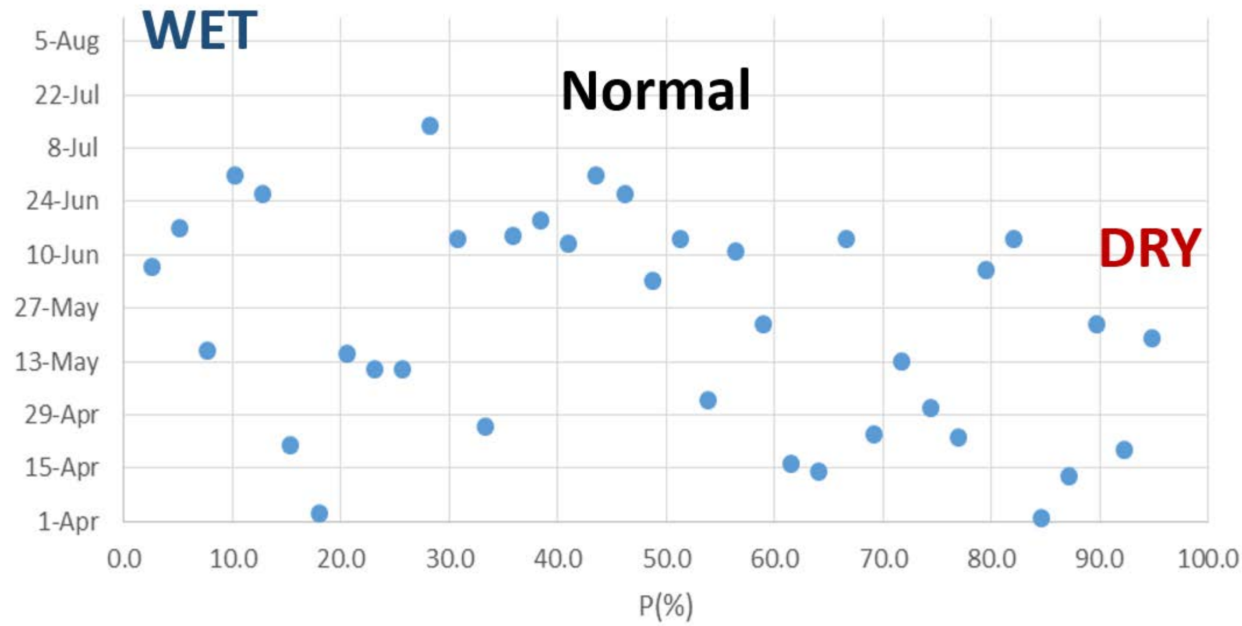


Figure 18. The date when the riffle crest thalweg (RCT) depth crossed a threshold of less than 1.2 feet during the spring recession limb of the **impaired** flow at Van Arsdale (WY1977-WY2014). It should be noted that during WY1977 the RCT never was above 1.2 for the entire year, so this data point was omitted from the graph. Source: CDEC website (http://cdec.water.ca.gov/).

Moreover, in the modeled unimpaired flow data a riffle crest depth of 0.8 ft (for 'good' riffle habitat) was maintained in "wet" (P<10%) years until mid-July and early-August (Figure 19). In "Normal" years the riffle crest depth was >0.8 feet until mid- to late-June. Therefore, dam releases from Cape Horn Dam should release a minimum of 38 cfs in most years through mid- to late-June in order to maintain 'good' riffle habitat for rearing juvenile salmonids.

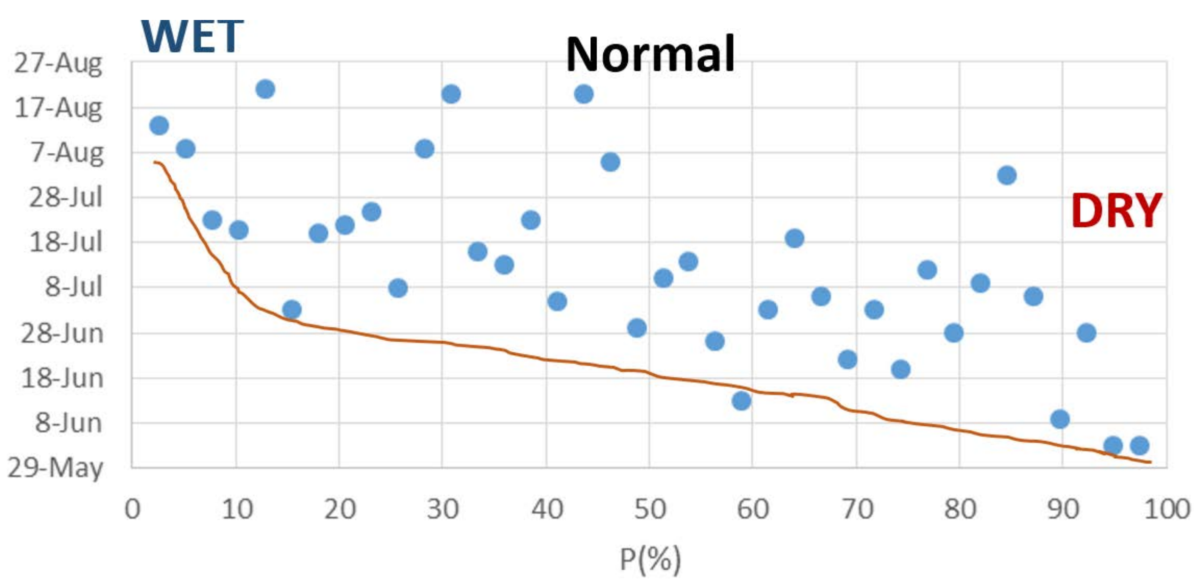


Figure 19. The date when the riffle crest thalweg (RCT) depth crossed a threshold of less than 0.8 feet during the spring recession limb of the modeled **unimpaired** flow at Van Arsdale (WY1977-WY2014). The orange line shows the lower boundary of these dates.

In contrast, the impaired flow record shows that the 0.8 foot RCT depth was crossed as early as late-April and early May in both wet and dry years (Figure 20). There were several years in which the flow was maintained at 38 cfs until mid- to late-June.

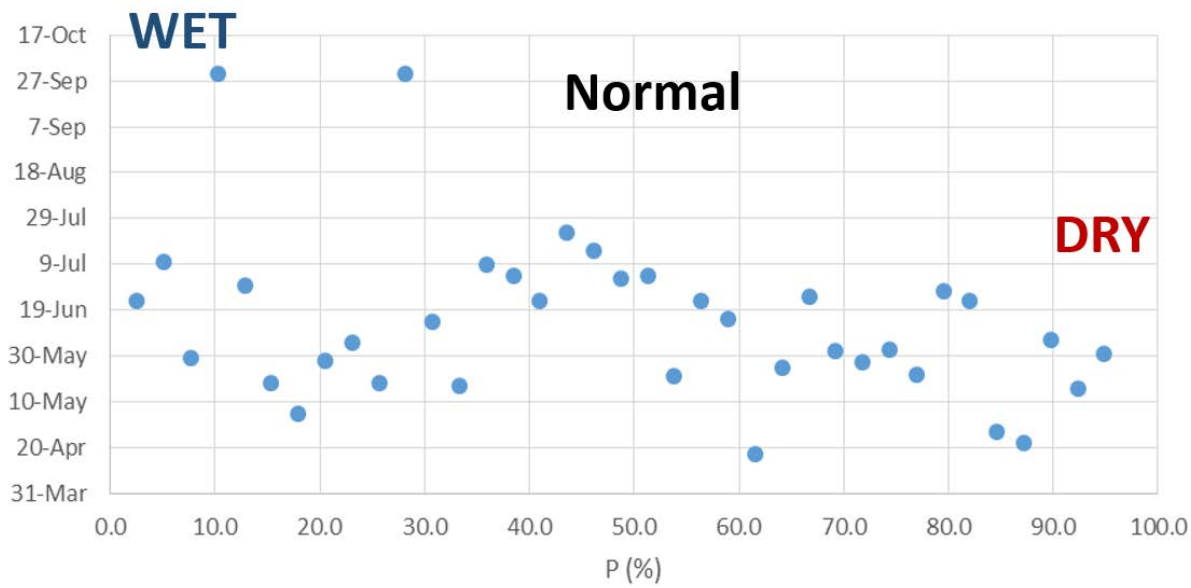


Figure 20. The date when the riffle crest thalweg (RCT) depth crossed a threshold of less than 0.8 feet during the spring recession limb of the **impaired** flow at Van Arsdale (WY1977-WY2014). It should be noted that during WY1977 the RCT never was above 0.8 for the entire year, so this data point was omitted from the graph. The two data points at 9/30 never dropped below 0.8 for the entire spring recession limb. Source: CDEC website (http://cdec.water.ca.gov/).

In most years between WY1977 and WY2014 the modeled unimpaired riffle crest depth never dropped below 0.4 feet (Q=10.5 cfs, Figure 21) and only in the driest year in the 38 year record (WY1977) did the riffle crest drop below 0.2 ft (3 cfs) (Figures 22). Based on these analyses it is recommended that a minimum well above 10.5 cfs be maintained in the Mainstem Eel River below Van Arsdale through the entire summer in wet years, and through at least mid-August in "normal" years and mid-July in "dry" years. It is also recommended that a minimum flow of 3 cfs maintained year-round even in the driest years in order to maintain minimal riffle-pool connectivity.

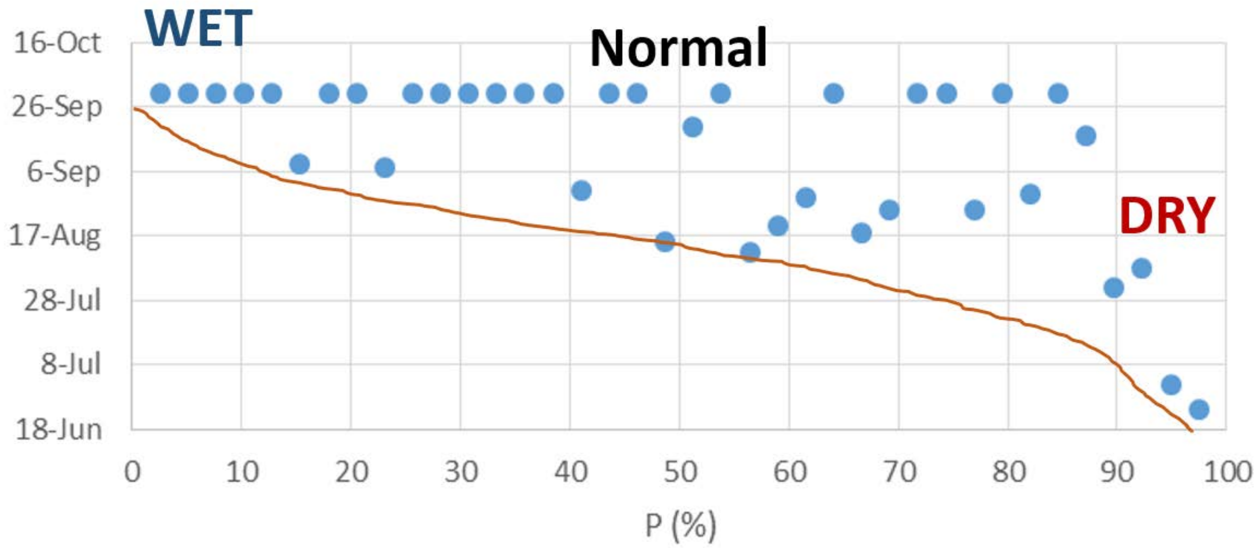


Figure 21. The date when the riffle crest thalweg (RCT) depth crossed a threshold of less than 0.4 feet during the spring recession limb of the modeled **unimpaired** flow at Van Arsdale (WY1977-WY2014). The orange line shows the lower boundary of these dates. All data points plotted on 9/30 indicate that the flow never caused the RCT to drop below the 0.4 threshold.

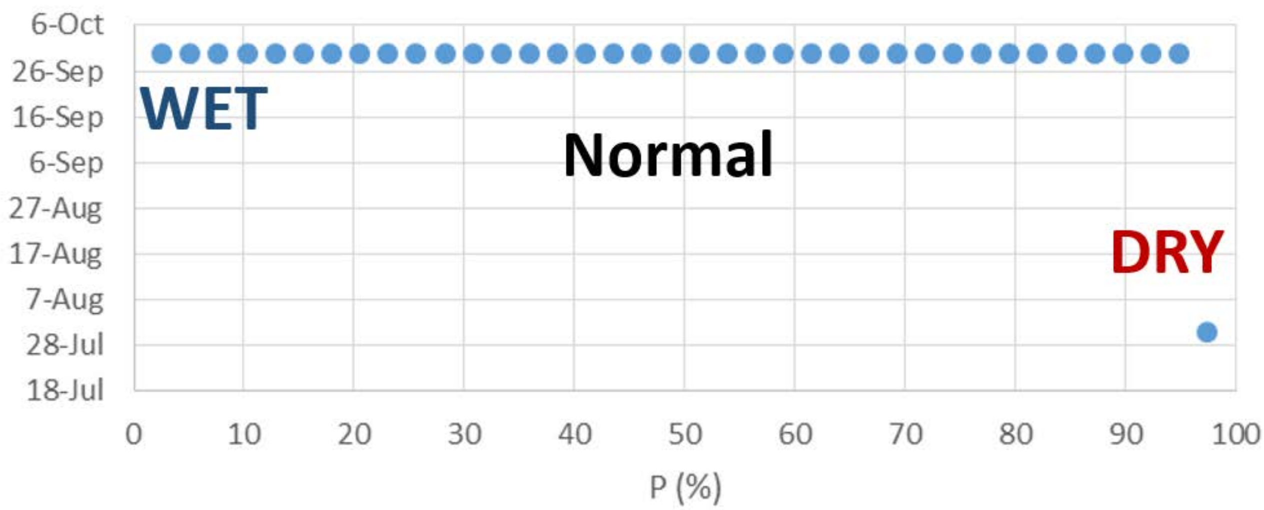


Figure 22. The date when the riffle crest thalweg (RCT) depth crossed a threshold of less than 0.2 feet during the spring recession limb of the modeled **unimpaired** flow at Van Arsdale (WY1977-WY2014). All data points plotted on 9/30 indicate that the flow never caused the RCT to drop below the 0.2 ft threshold. The threshold of 0.2 feet RCT was only crossed once during WY1977 and never between WY1977-WY2014.

In contrast, the impaired flow record shows that the 0.2 foot RCT depth was crossed as early as June and July in both wet and dry years (Figure 23). In most years the flow was maintained at >10.5 cfs for the entire summer. Minimum flow release requirements have helped keep flows above 10.5 cfs.

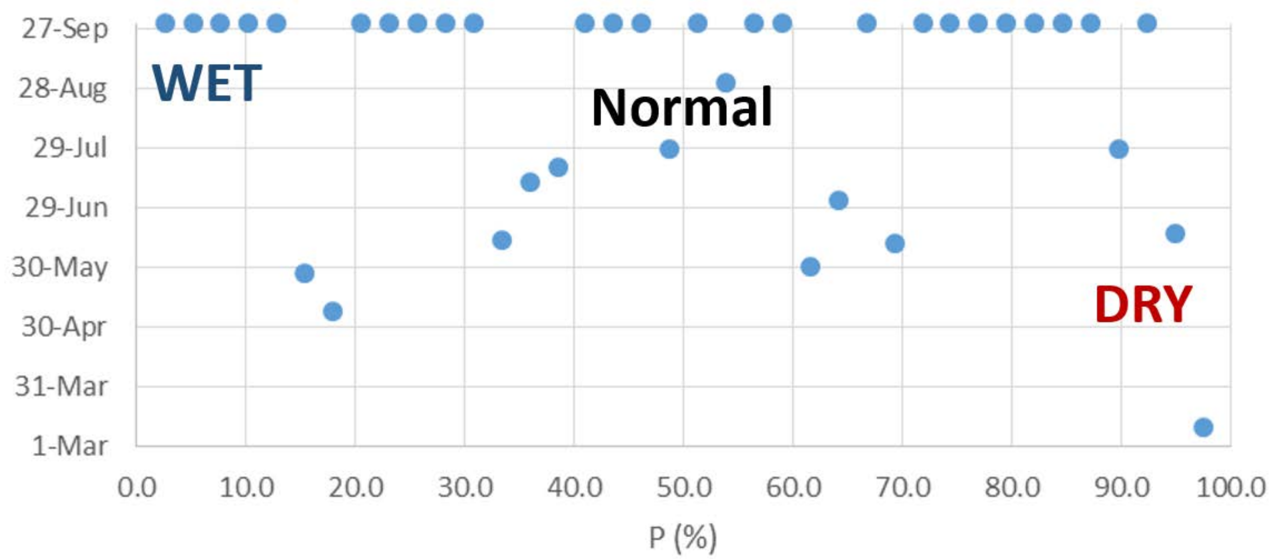


Figure 23. The date when the riffle crest thalweg (RCT) depth crossed a threshold of less than 0.4 feet during the spring recession limb of the **impaired** flow at Van Arsdale (WY1977-WY2014). The data points at 9/30 indicate that the RCT depth never dropped below 0.4 ft for the entire spring recession limb. Source: CDEC website (http://cdec.water.ca.gov/).

Analysis of Tomki Creek

Tomki Creek is a large tributary (200 sq-mi) to the Mainstem Eel River. The confluence of Tomki Creek with the Mainstem Eel is approximately 3.5 miles downstream of Cape Horn Dam.

To examine conditions for juvenile salmonids leaving significant tributaries in the spring, we looked at the spring recession limb of Tomki Creek to estimate the timing of when juveniles would leave Tomki Creek. Moreover, we matched up the timing of the receding hydrograph in Tomki Creek to estimate what flow conditions were like as salmon enter the Mainstem Eel River. For Tomki Creek to recede in flow before flow conditions significantly decline in the Mainstem Eel.

A rating curve for Tomki Creek was used to convert flow (cfs) to riffle crest depth (ft). USGS flow gage records on Tomki Creek (#11471800) from WY1963-WY1970 were used to examine when flow conditions became low (Figure 24). A RCT analysis shows that riffle crest depths dropped below 1.2 feet in mid-to late-March, below 0.8 feet in early- to late-April, below 0.4 feet in mid- to late-May, and 0.2 feet in mid-June to early-July (Figure 25). The flow at Tomki became zero anywhere from mid-July to mid-September. Therefore it appears that the Tomki Creek flows and RCT depths generally declined prior to that of the Mainstem Eel River.

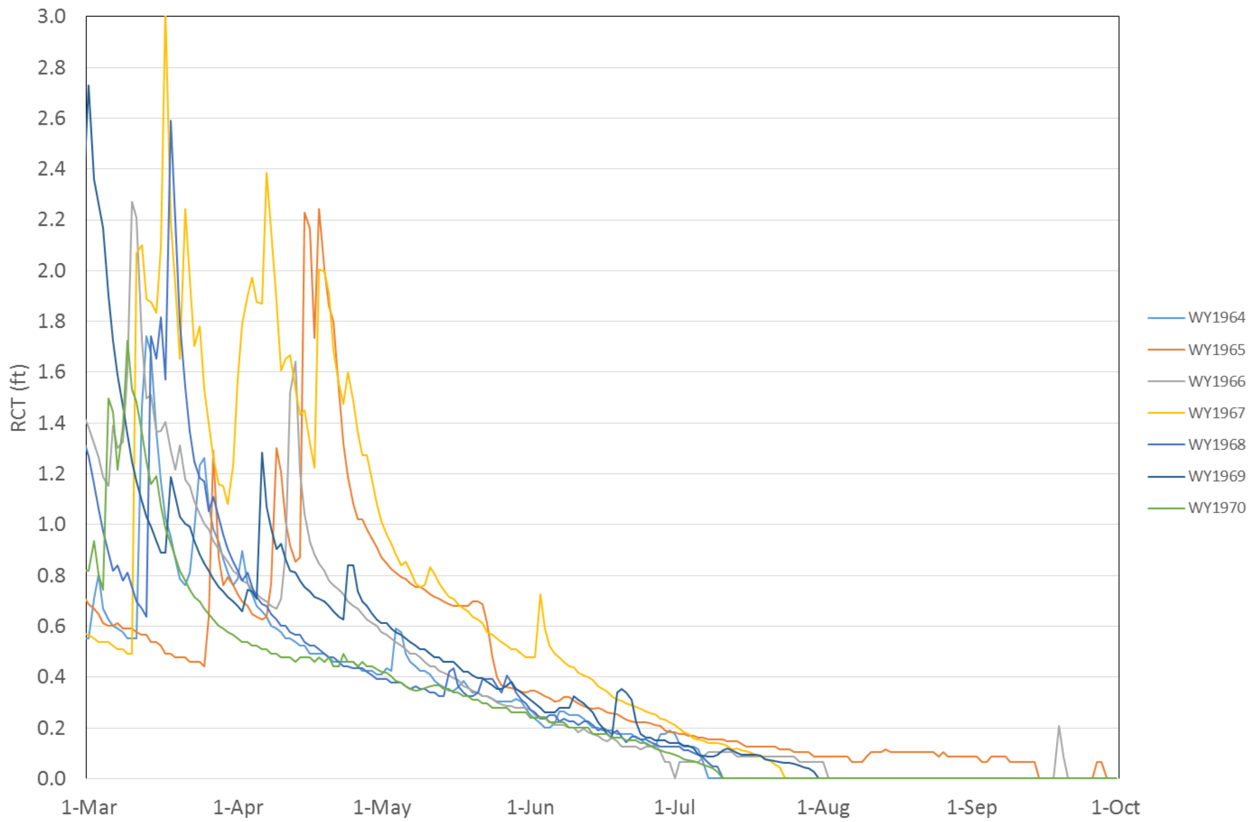


Figure 24. RCT depths (ft) in Tomki Creek during the spring recession limb WY1963-WY1970 (based on flow records from USGS gage #11471800).

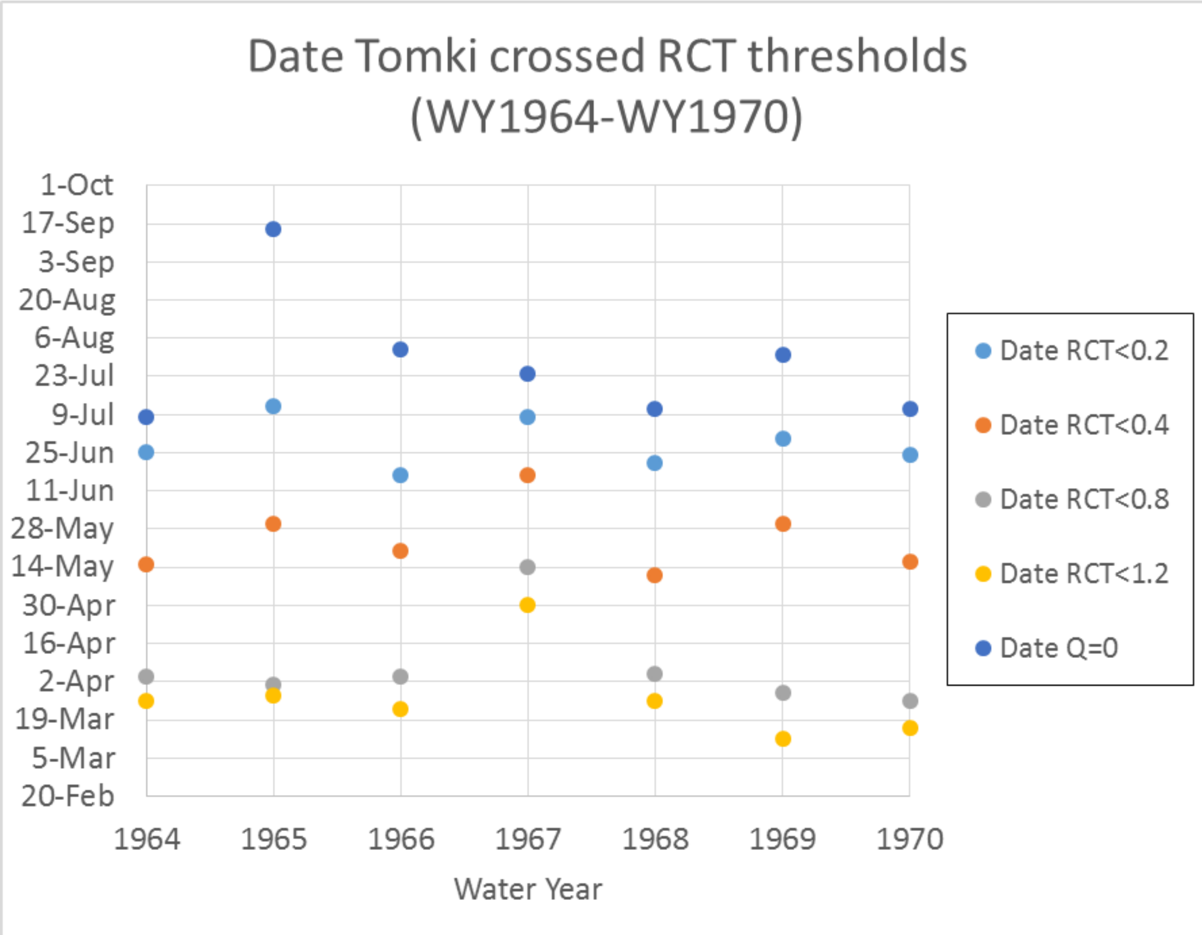


Figure 25. The points plotted in this graph indicate the date in which the RCT depths in Tomki Creek crossed RCT depth thresholds of 1.2, 0.8, 0.4, 0.2 feet and Q=0 in WY1963-WY1970 (based on flow records from USGS gage #11471800).

Benthic Macroinvertebrate Assessment

At several of the field visits benthic macroinvertebrate samples were collected to observe how benthic invertebrate communities might change over the course of the summer season and relate this to flow releases from Cape Horn Dam. Invertebrate sampling was done using a standard D-frame that the 500 µm mesh (Figure 26) along a transect near the riffle crest perpendicular to the stream channel (Figure 27). Along each transect, three sampling areas within a single riffle were sampled by agitating the benthic substrate for one minute. The three samples were then composited. All samples were preserved in 95% ethanol in the field. In the laboratory, invertebrates were sorted from inorganic material and identified to Family using the dissecting microscope (10x-30x).

Figure 26. Humboldt State University undergraduate Environmental Science majors Rachel Klassen and Alder Gustafson use a D-frame net to sample benthic macroinvertebrates at the Hearst site riffle crest on 9/13/15. Photo by A. O'Dowd.

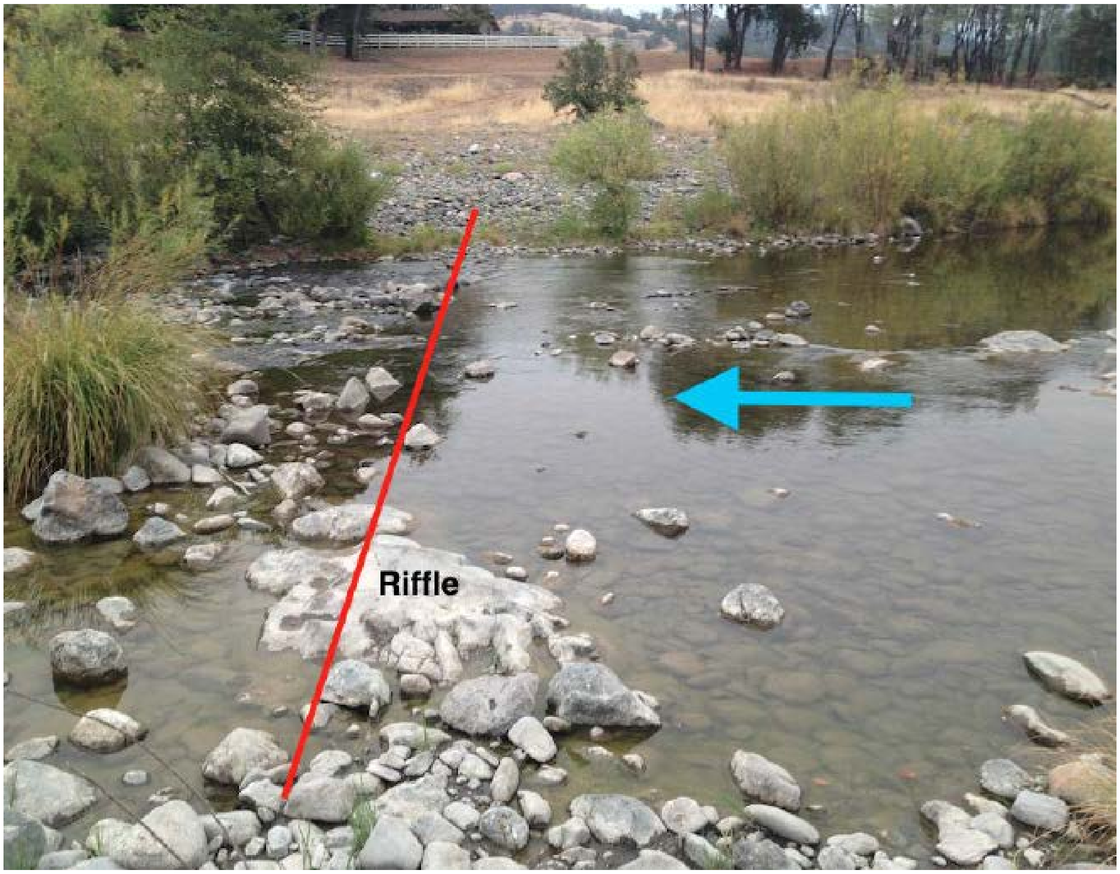


Figure 27. Hearst site riffle transect looking at right bank. Blue arrow indicates direction of flow. Photo taken by A O'Dowd 9/13/15.

The benthic macroinvertebrate study found that benthic invertebrate assemblages reflected good water quality overall, with low biotic index scores and high percentages of Ephemeroptera, Plecoptera, and Trichoptera (EPT) (Table 5). However, biotic condition and %EPT decreased over the summer season between June and September 2015, with a corresponding increase in percentage of tolerant invertebrates (Figures 28-30). The possible ecological reasons for this shift from sensitive to tolerant invertebrates include salmonid predation, benthic invertebrate life history/timing of emergence, invertebrate predation susceptibility, and hydrologic factors. A more rigorous study framework is needed to fully explain the complex relationship between flow and benthic macroinvertebrate community dynamics on the Eel River.

Table 5. Summary of benthic macroinvertebrate metrics calculated for Hearst and Outlet sites.

	Hearst (6/22/15)	Hearst (9/13/15)	Outlet (7/19/15)	Outlet (9/13/15)
Total number of Individuals	279	171	203	200
Taxa Richness	13	22	17	21
Index of Biotic Integrity	3.94	4.15	3.79	4.71
% EPT	67%	50%	67%	33%
% Dominance	35%	35%	47%	46%

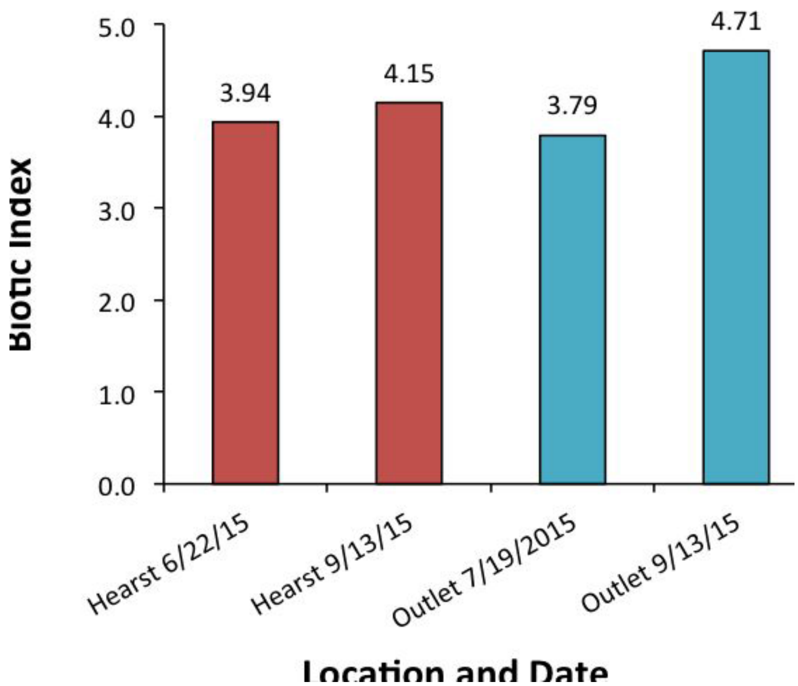


Figure 28. Biotic index for Hearst and Outlet sites.

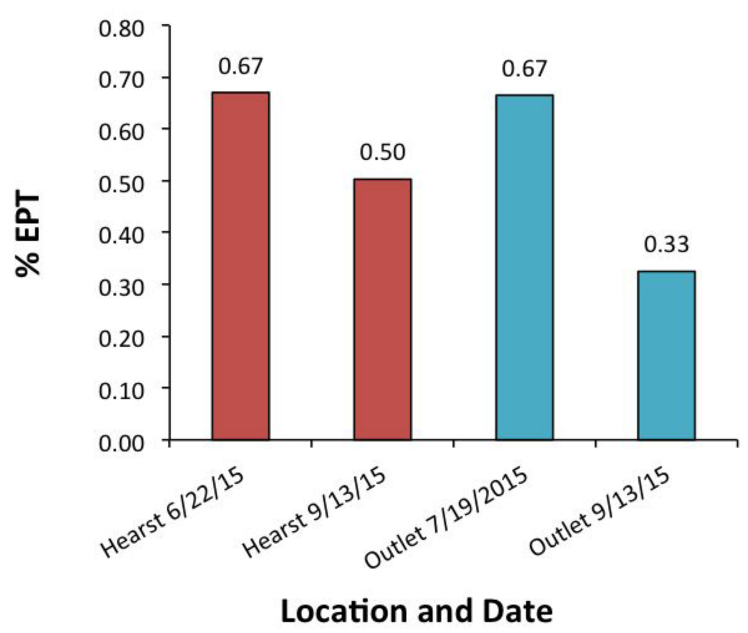


Figure 29. Percent EPT of taxa at Hearst and Outlet sites.

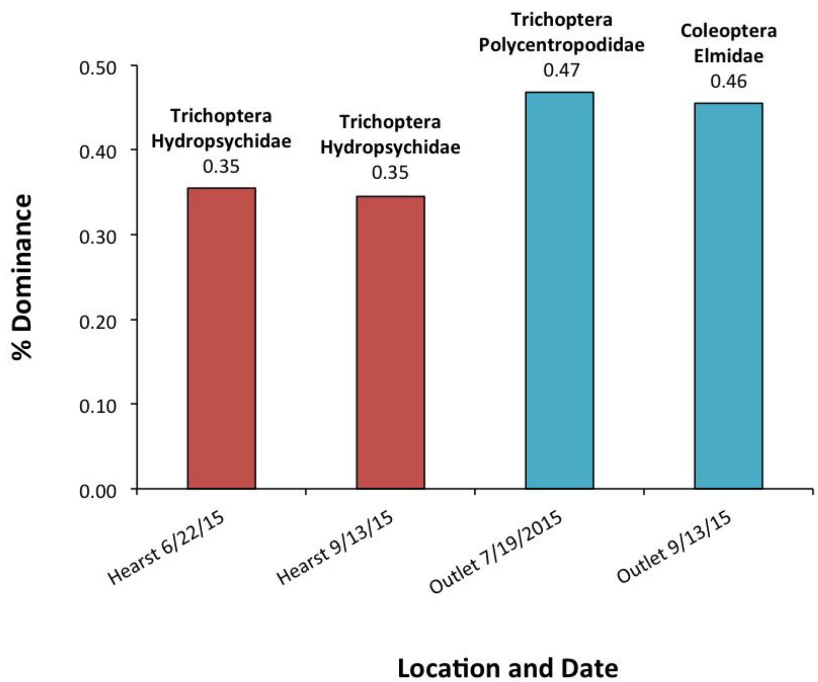


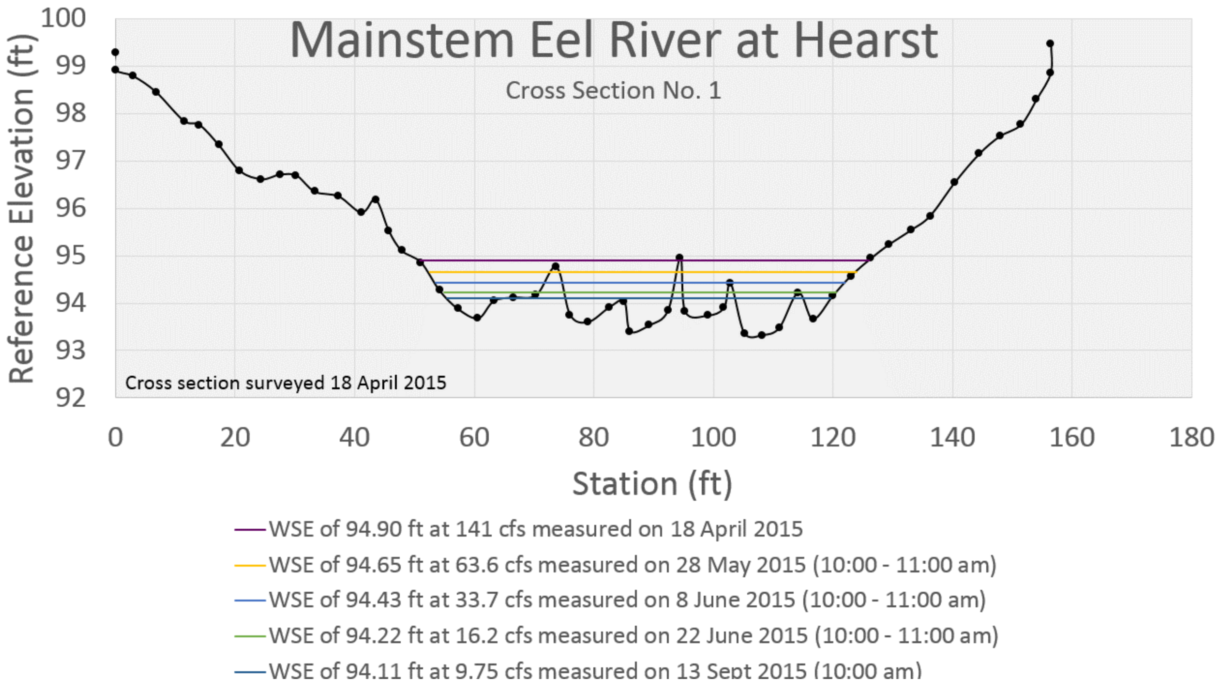
Figure 30. Percent dominance of taxa at Hearst and Outlet sites.

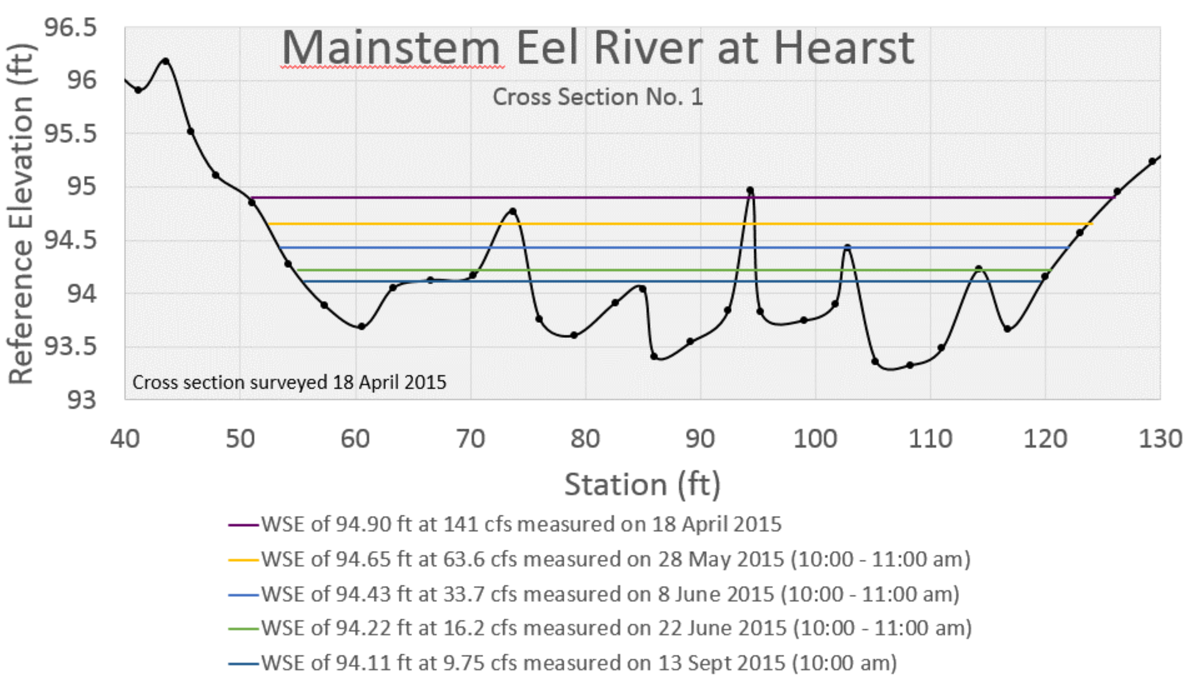
Recommended Future Studies

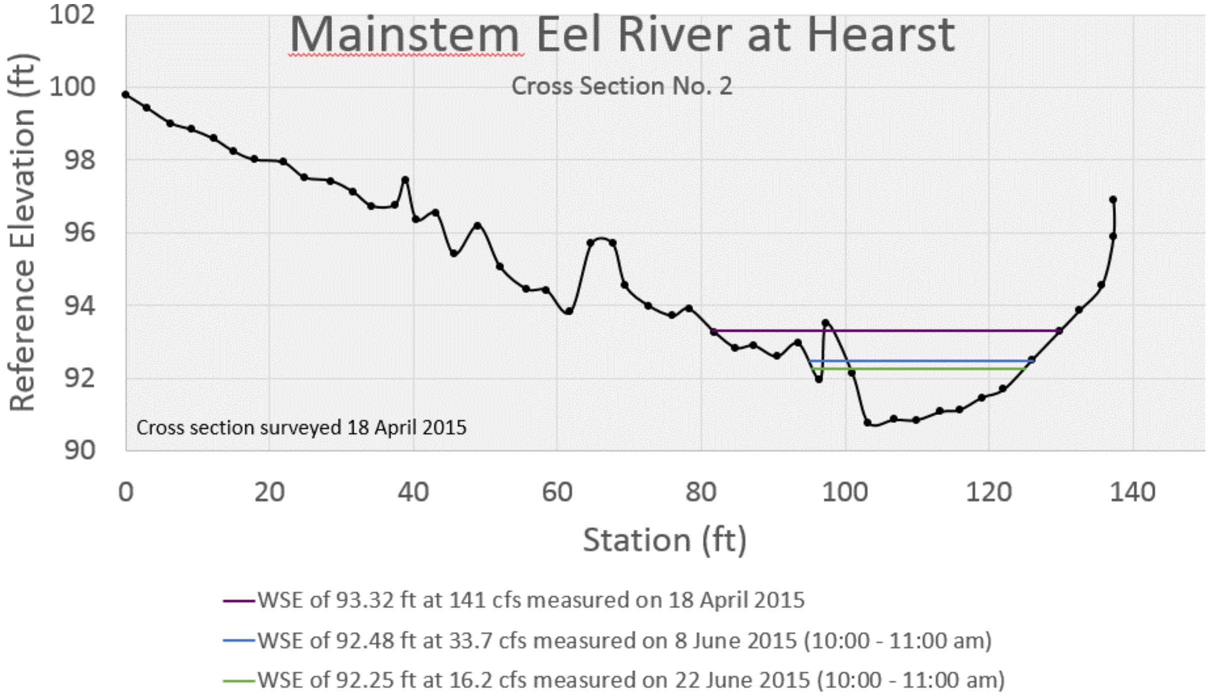
The next steps to further explore best management practices for blockwater releases include:

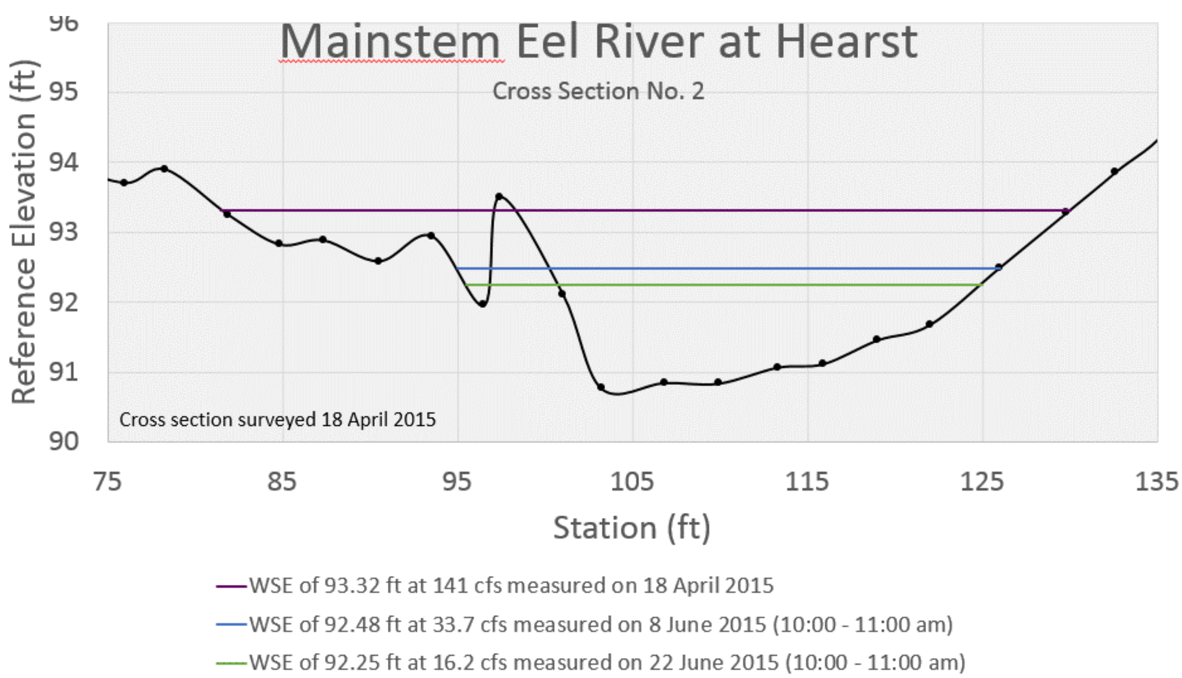
1) Create a temperature model that shows stream temperatures throughout the Mainstem Eel River during the spring recession limb of the hydrograph and through the summer and fall.
2) Install flow gages on the Mainstem Eel River or Rice Fork upstream of Scott Dam so the dynamics of the unimpaired hydrograph can be characterized. These gages can also be used as cues for blockwater releases
3) Conduct further flow, velocity, and biological measurements in the Mainstem Eel to better understand the relationship between flow, hydraulic connectivity, and riffle productivity during from spring to fall.
4) Develop a hydrologic model to examine relationships among groundwater, evaporation, and surface flow in the Mainstem Eel River to determine how flow releases from Cape Horn Dam manifest themselves downstream.

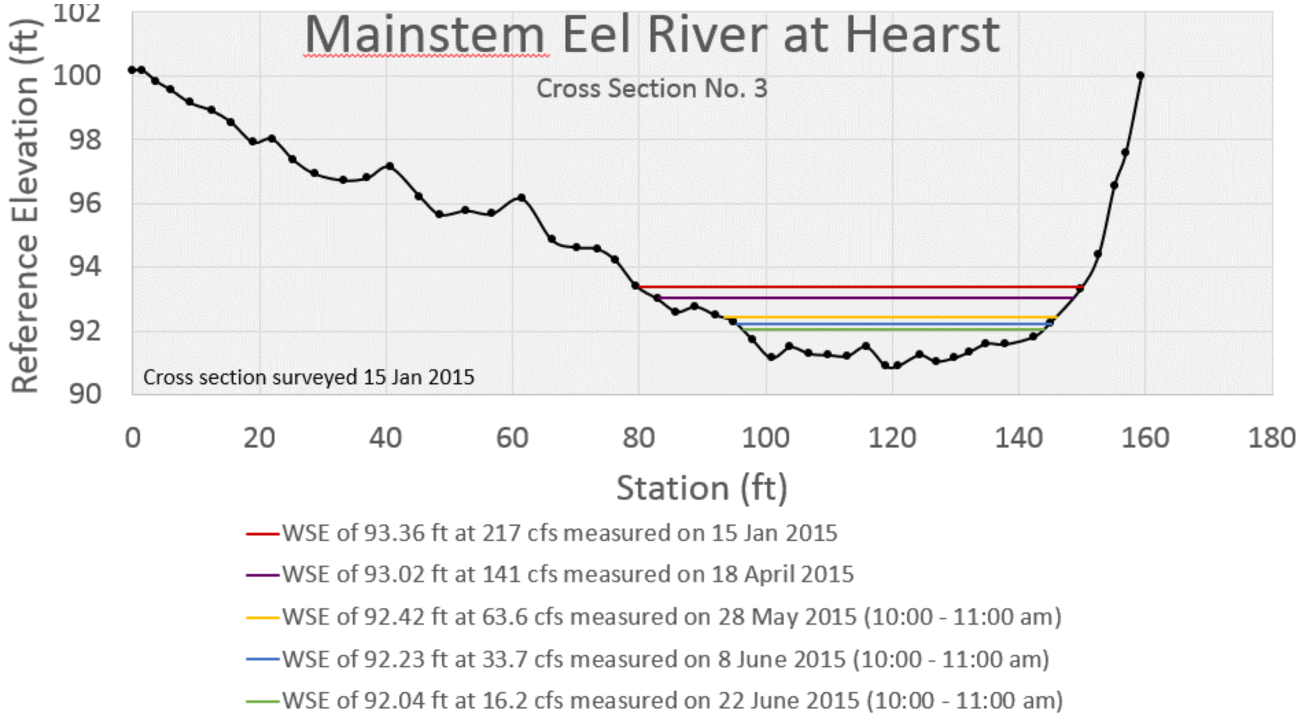
APPENDIX A. Six cross-sections with watershed surface elevation of each measured flow. For cross-section 4, the estimated hydraulic geometry (ft^2) was estimated using a HEC-RAS model. There are two plots of each cross-section: 1) the entire extent of the cross-section, 2) the cross-section just near the wetted width.

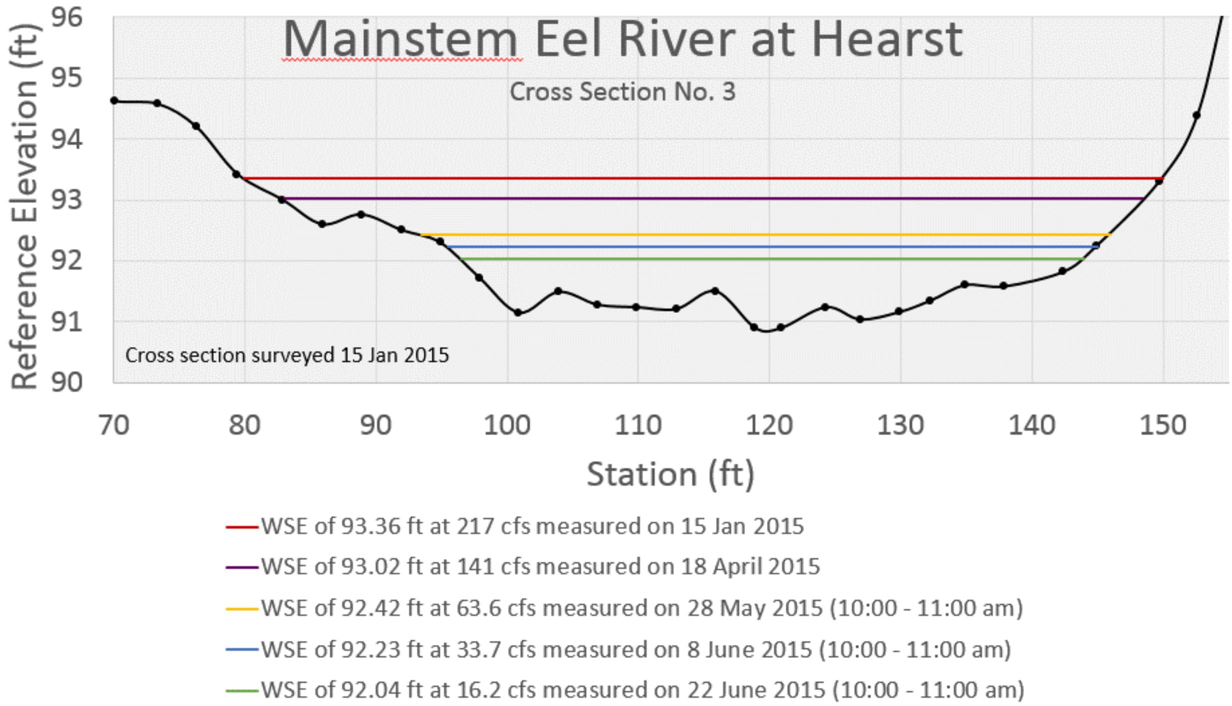


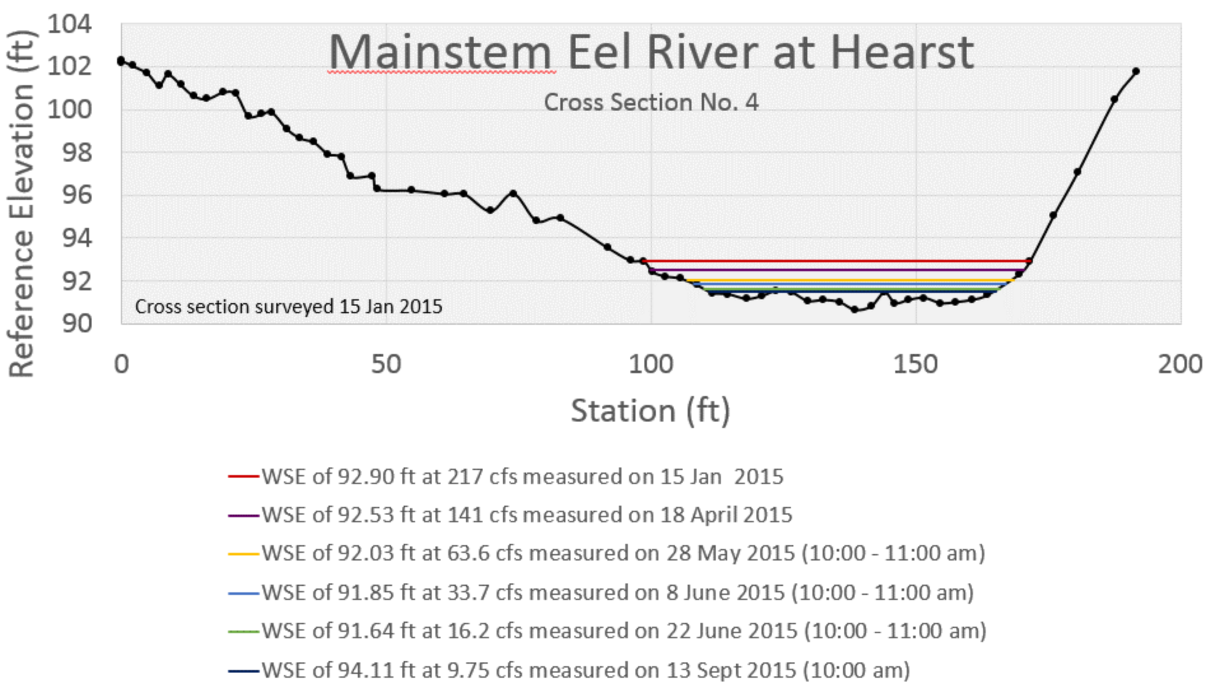


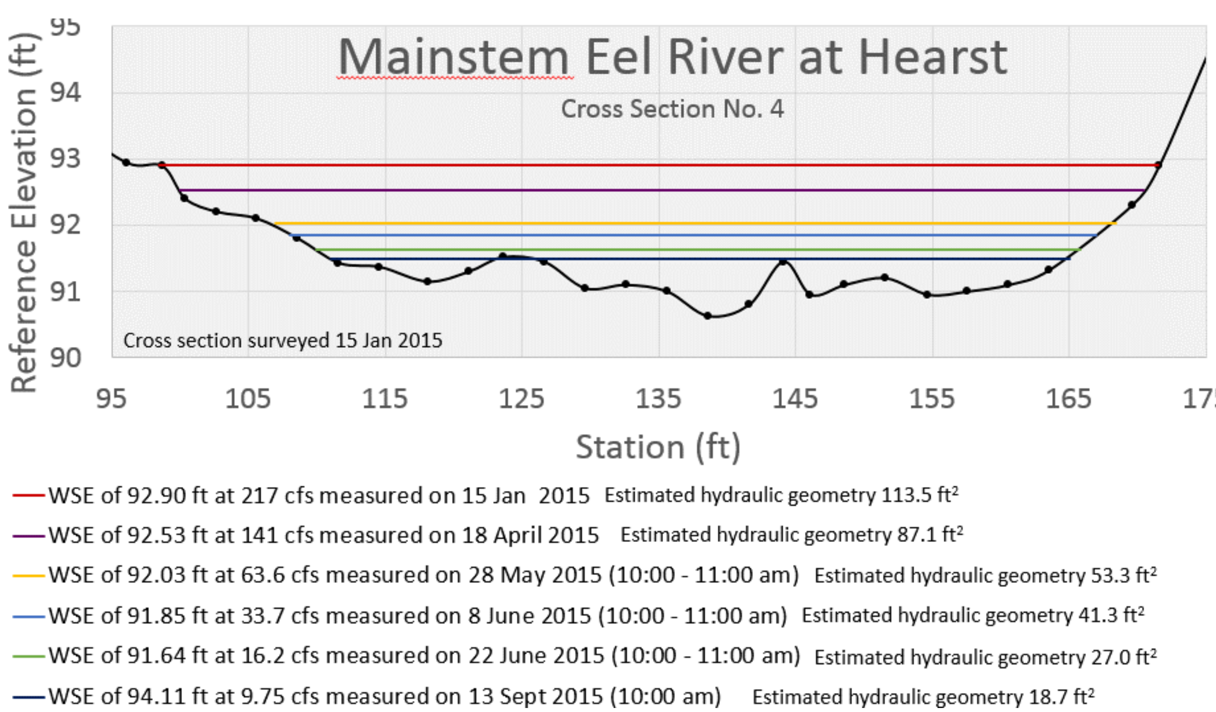

Mainstem Eel River at Hearst
Cross Section No. 2
Reference Elevation (ft)
102
100
98
96
94
92
90
Cross section surveyed 18 April 2015
0
20
40
60
80
100
120
140
Station (ft)
WSE of 93.32 ft at 141 cfs measured on 18 April 2015
WSE of 92.48 ft at 33.7 cfs measured on 8 June 2015 (10:00 - 11:00 am)
WSE of 92.25 ft at 16.2 cfs measured on 22 June 2015 (10:00 - 11:00 am)

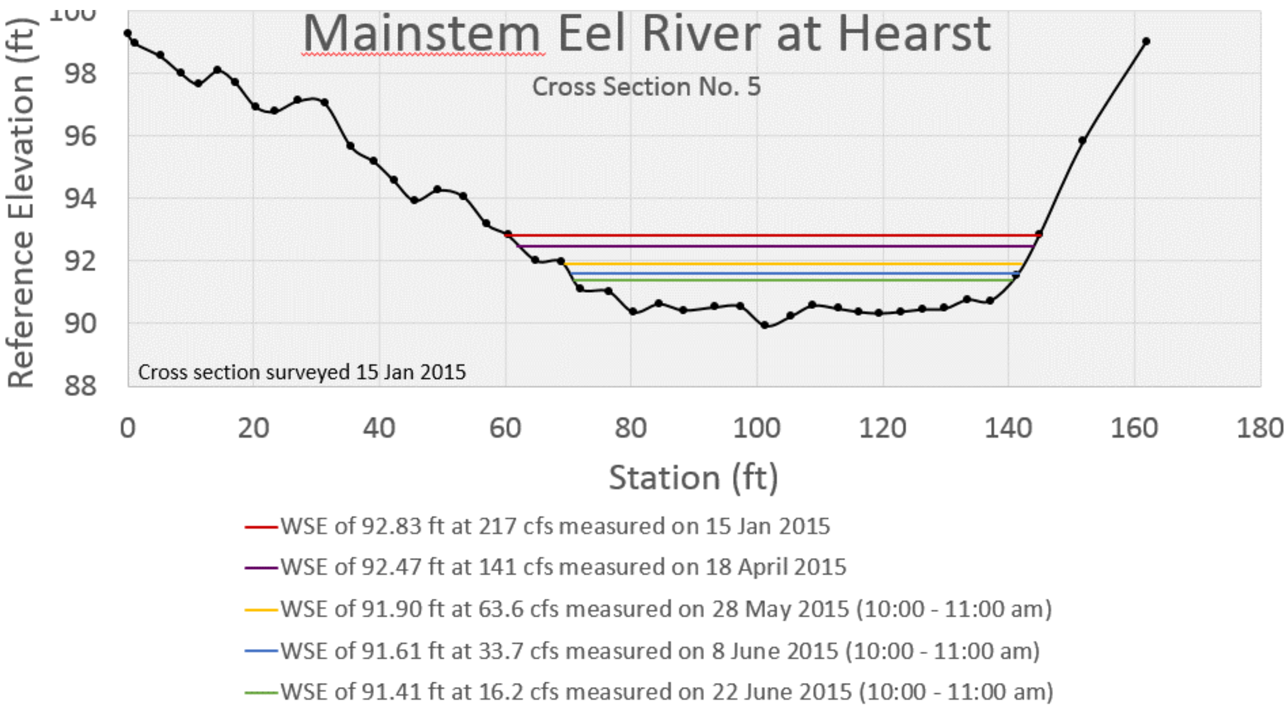

Mainstem Eel River at Hearst
Cross Section No. 2
Reference Elevation (ft)
96
95
94
93
92
91
90
Cross section surveyed 18 April 2015
75
85
95
105
115
125
135
Station (ft)
WSE of 93.32 ft at 141 cfs measured on 18 April 2015
WSE of 92.48 ft at 33.7 cfs measured on 8 June 2015 (10:00 - 11:00 am)
WSE of 92.25 ft at 16.2 cfs measured on 22 June 2015 (10:00 - 11:00 am)

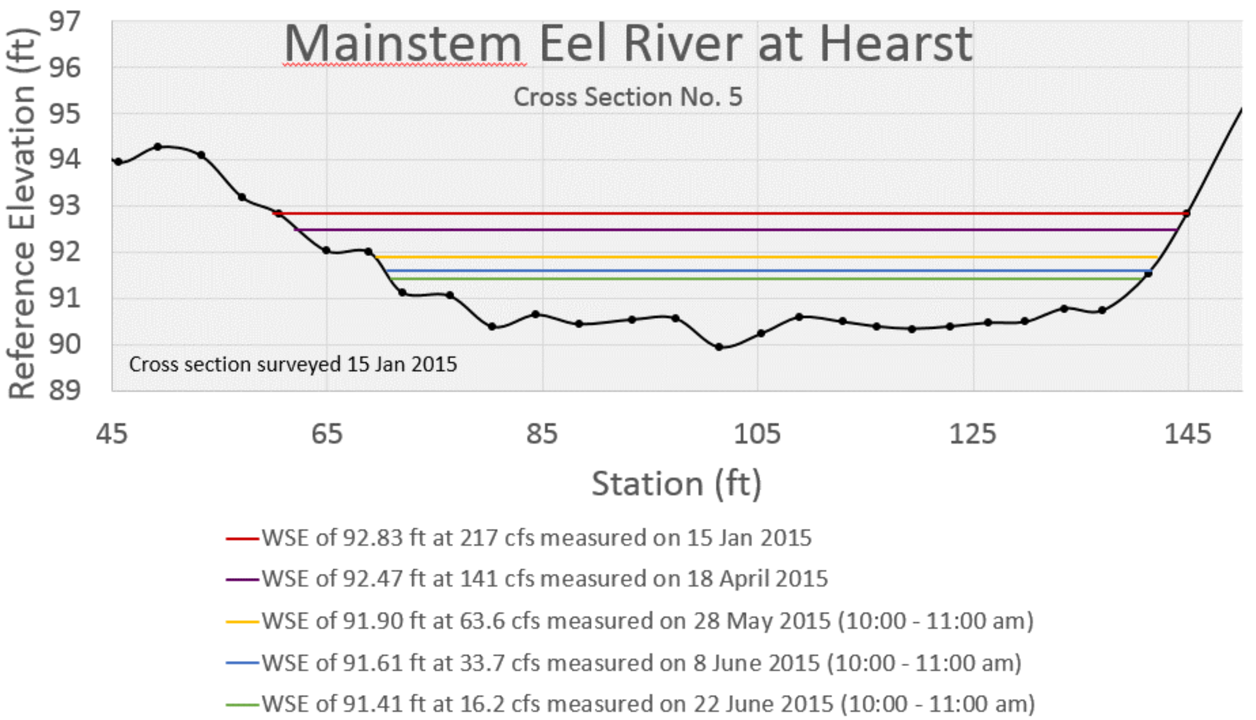

Mainstem Eel River at Hearst
Cross Section No. 3
Cross section surveyed 15 Jan 2015
Reference Elevation (ft)
102
100
98
96
94
92
90
0
20
40
60
80
100
120
140
160
180
Station (ft)
WSE of 93.36 ft at 217 cfs measured on 15 Jan 2015
WSE of 93.02 ft at 141 cfs measured on 18 April 2015
WSE of 92.42 ft at 63.6 cfs measured on 28 May 2015 (10:00 - 11:00 am)
WSE of 92.23 ft at 33.7 cfs measured on 8 June 2015 (10:00 - 11:00 am)
WSE of 92.04 ft at 16.2 cfs measured on 22 June 2015 (10:00 - 11:00 am)

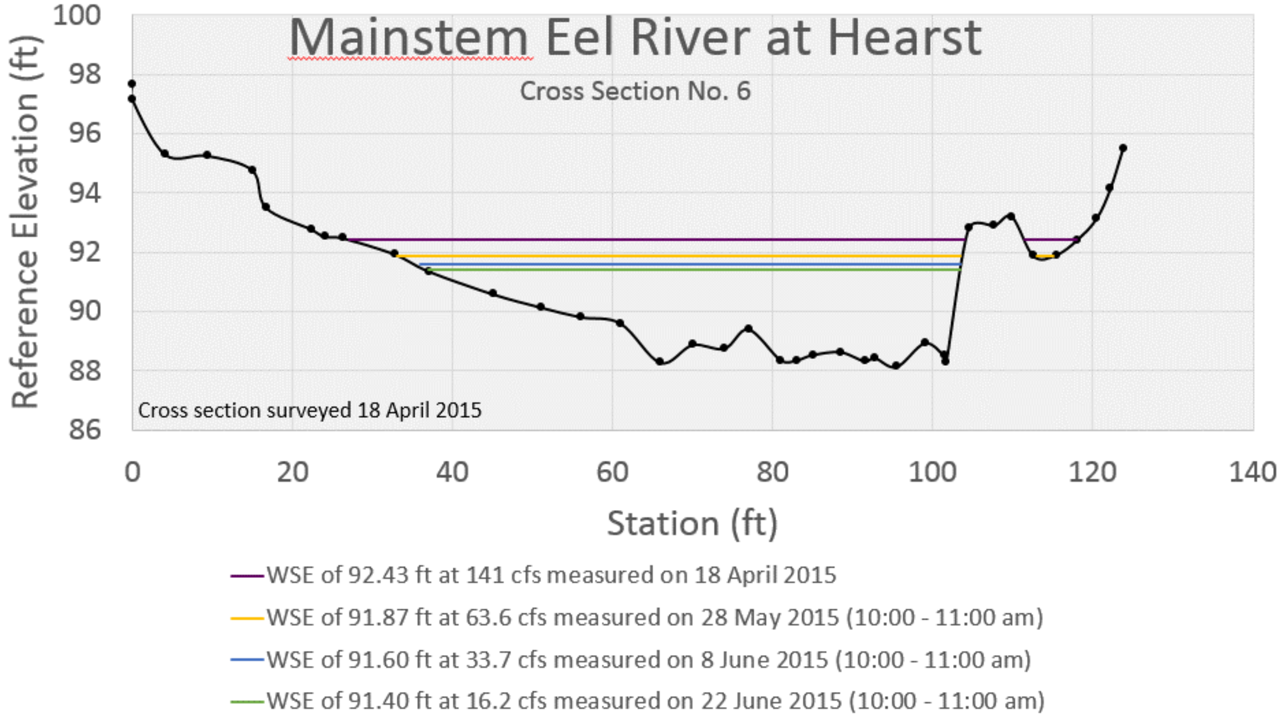

Mainstem Eel River at Hearst
Cross Section No. 3
Cross section surveyed 15 Jan 2015
Reference Elevation (ft)
96
95
94
93
92
91
90
70
80
90
100
110
120
130
140
150
Station (ft)
WSE of 93.36 ft at 217 cfs measured on 15 Jan 2015
WSE of 93.02 ft at 141 cfs measured on 18 April 2015
WSE of 92.42 ft at 63.6 cfs measured on 28 May 2015 (10:00 - 11:00 am)
WSE of 92.23 ft at 33.7 cfs measured on 8 June 2015 (10:00 - 11:00 am)
WSE of 92.04 ft at 16.2 cfs measured on 22 June 2015 (10:00 - 11:00 am)

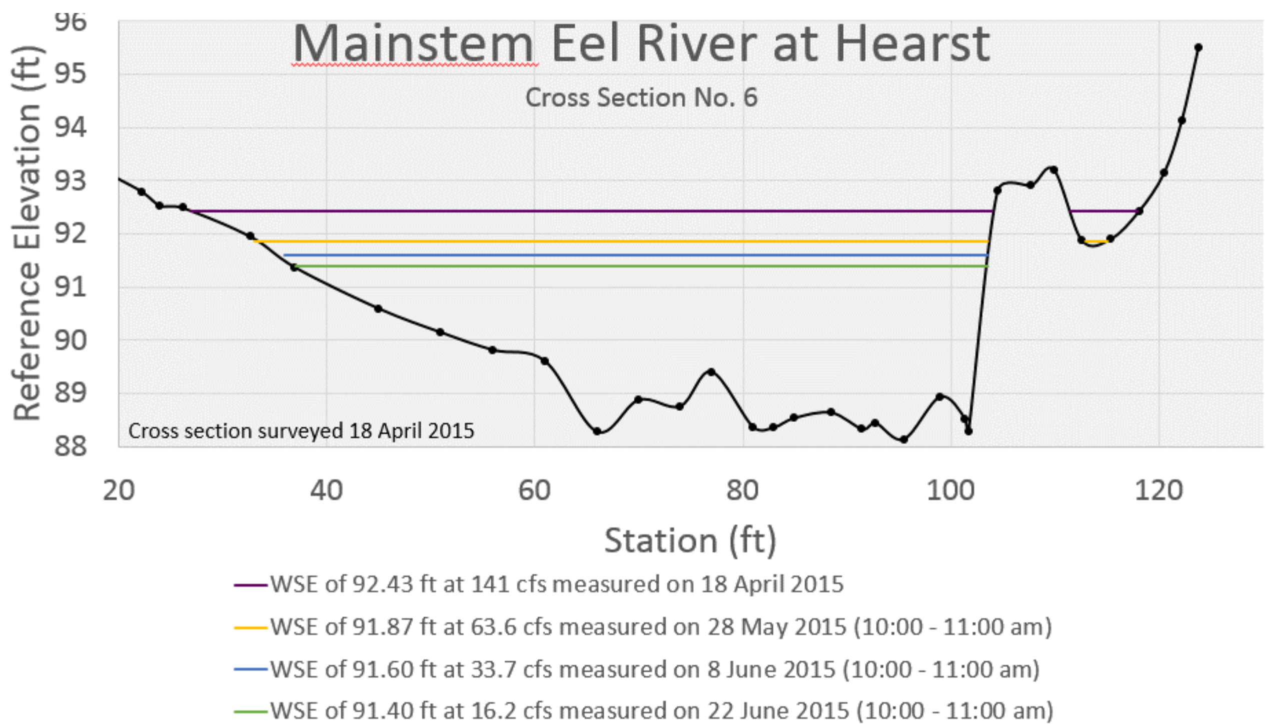

Mainstem Eel River at Hearst
Cross Section No. 4
Cross section surveyed 15 Jan 2015
Reference Elevation (ft)
Station (ft)
104
102
100
98
96
94
92
90
0
50
100
150
200
WSE of 92.90 ft at 217 cfs measured on 15 Jan 2015
WSE of 92.53 ft at 141 cfs measured on 18 April 2015
WSE of 92.03 ft at 63.6 cfs measured on 28 May 2015 (10:00 - 11:00 am)
WSE of 91.85 ft at 33.7 cfs measured on 8 June 2015 (10:00 - 11:00 am)
WSE of 91.64 ft at 16.2 cfs measured on 22 June 2015 (10:00 - 11:00 am)
WSE of 94.11 ft at 9.75 cfs measured on 13 Sept 2015 (10:00 am)


Mainstem Eel River at Hearst
Cross Section No. 4
Cross section surveyed 15 Jan 2015
Reference Elevation (ft)
Station (ft)
94
93
92
91
90
95
105
115
125
135
145
155
165
WSE of 92.90 ft at 217 cfs measured on 15 Jan 2015 Estimated hydraulic geometry 113.5 ft²
WSE of 92.53 ft at 141 cfs measured on 18 April 2015 Estimated hydraulic geometry 87.1 ft²
WSE of 92.03 ft at 63.6 cfs measured on 28 May 2015 (10:00 - 11:00 am) Estimated hydraulic geometry 53.3 ft²
WSE of 91.85 ft at 33.7 cfs measured on 8 June 2015 (10:00 - 11:00 am) Estimated hydraulic geometry 41.3 ft²
WSE of 91.64 ft at 16.2 cfs measured on 22 June 2015 (10:00 - 11:00 am) Estimated hydraulic geometry 27.0 ft²
WSE of 94.11 ft at 9.75 cfs measured on 13 Sept 2015 (10:00 am) Estimated hydraulic geometry 18.7 ft²


Mainstem Eel River at Hearst
Cross Section No. 5
Reference Elevation (ft)
Station (ft)
Cross section surveyed 15 Jan 2015
WSE of 92.83 ft at 217 cfs measured on 15 Jan 2015
WSE of 92.47 ft at 141 cfs measured on 18 April 2015
WSE of 91.90 ft at 63.6 cfs measured on 28 May 2015 (10:00 - 11:00 am)
WSE of 91.61 ft at 33.7 cfs measured on 8 June 2015 (10:00 - 11:00 am)
WSE of 91.41 ft at 16.2 cfs measured on 22 June 2015 (10:00 - 11:00 am)


Mainstem Eel River at Hearst
Cross Section No. 5
Reference Elevation (ft)
Station (ft)
Cross section surveyed 15 Jan 2015
WSE of 92.83 ft at 217 cfs measured on 15 Jan 2015
WSE of 92.47 ft at 141 cfs measured on 18 April 2015
WSE of 91.90 ft at 63.6 cfs measured on 28 May 2015 (10:00 - 11:00 am)
WSE of 91.61 ft at 33.7 cfs measured on 8 June 2015 (10:00 - 11:00 am)
WSE of 91.41 ft at 16.2 cfs measured on 22 June 2015 (10:00 - 11:00 am)

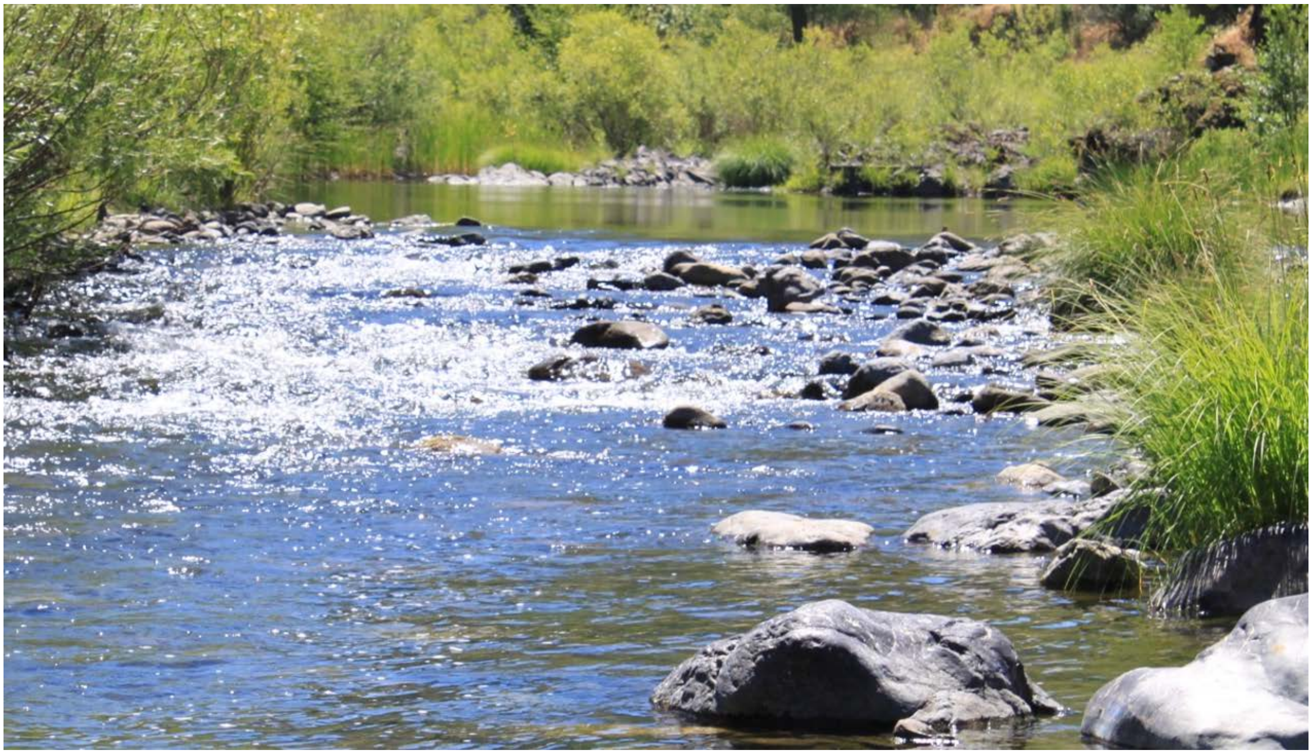

Mainstem Eel River at Hearst
Cross Section No. 6
Reference Elevation (ft)
Station (ft)
Cross section surveyed 18 April 2015
WSE of 92.43 ft at 141 cfs measured on 18 April 2015
WSE of 91.87 ft at 63.6 cfs measured on 28 May 2015 (10:00 - 11:00 am)
WSE of 91.60 ft at 33.7 cfs measured on 8 June 2015 (10:00 - 11:00 am)
WSE of 91.40 ft at 16.2 cfs measured on 22 June 2015 (10:00 - 11:00 am)


Mainstem Eel River at Hearst
Cross Section No. 6
Reference Elevation (ft)
Station (ft)
Cross section surveyed 18 April 2015
WSE of 92.43 ft at 141 cfs measured on 18 April 2015
WSE of 91.87 ft at 63.6 cfs measured on 28 May 2015 (10:00 - 11:00 am)
WSE of 91.60 ft at 33.7 cfs measured on 8 June 2015 (10:00 - 11:00 am)
WSE of 91.40 ft at 16.2 cfs measured on 22 June 2015 (10:00 - 11:00 am)

APPENDIX B. Photos of the Hearst riffle at four streamflows.

Hearst riffle (Van Arsdale release = 29 cfs), 10/14/2014.

Hearst riffle (Van Arsdale release = 194.28 cfs, measured flow = 238.4 cfs), 1/15/2015.



Hearst riffle (Van Arsdale release =15.04 cfs, measured flow = 16.03 cfs), 6/22/2015.

Hearst riffle (Van Arsdale release =14.69 cfs, measured flow = 9.75 cfs), 9/13/2015.

ACKNOWLEDGEMENTS

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