Appendix A

Russian River Turbidity Assessment and Proposed Plan, Sonoma County and Mendocino County, California, Final Report with Addendum September 20, 2023
Prepared by San Francisco District, Environmental Services Branch

Russian River Turbidity

Assessment and Proposed Plan

Sonoma County and Mendocino County, California

San Francisco District
Environmental Services Branch

Final Report with Addendum
September 20, 2023

I. Introduction

The National Marine Fisheries Service's (NMFS) 2008 biological opinion (BO) assessing the effects of water supply, flood control operations, and channel maintenance activities conducted by the U.S. Army Corps of Engineers (USACE) and others on Endangered Species Act-listed salmonids (i.e., coho salmon (*Oncorhynchus kisutch*), steelhead (*O. mykiss*), and Chinook salmon (*O. tshawytscha*) in the Russian River watershed includes a term and condition #4 intended to reduce turbidity resulting from the project. Specifically, USACE was to collect turbidity data for 10 years at 5 new locations in addition to 3 existing U.S. Geological Survey (USGS) gages in the Russian River downstream of Coyote Valley Dam (CVD) and secondarily Warm Springs Dam (WSD). Deliverables were to include progress/annual reports and a final report documenting the data and analyses, and development and implementation of a plan to avoid or minimize project-related turbidity. However, all required data collection did not occur due to staff turnover and difficulties deploying and maintaining equipment. To date USACE has provided only limited reporting on progress and turbidity data analysis to NMFS. No avoidance or minimization plan has been developed.

This report is intended to document the turbidity data that has been collected in the Russian River for this project and provide data analysis and interpretation for selected years and locations. The report concludes with a proposed plan for addressing project-related turbidity impacts. The purpose of this report is to comply with the terms and conditions in the 2008 BO to the extent possible so that the information can be incorporated into the new biological assessment (BA) and BO expected in 2023.

II. Background

Coyote Valley Dam was constructed in 1958 on the East Fork of the Russian River approximately 1 mile upstream from where it joins the West Fork (Mendocino County; Figure 1; the West Fork often is called the Russian River mainstem but will be referred to as the West Fork in this report). The dam created Lake Mendocino for the purpose of regulating flows for flood control, power generation, and water supply (Levanthal 2010). Soon after construction was completed, periods of persistent turbidity were reported to occur in the Russian River downstream to Hopland and sometimes as far as Guerneville (Levanthal 2010). These increased levels of turbidity were thought to be detrimental to both fishing and fish populations. Seven possible sources contributing to elevated turbidity in the Russian River were identified early on by Ritter and Brown (1971) in discussion with various resource agencies, and an eighth concern was added to the list recently by NMFS:

1. Erosion during rainstorms;
2. Turbid water from the Eel River being diverted into the East Fork of the Russian River;
3. Turbid water persisting in Lake Mendocino due to slow settling of suspended sediment;
4. Elevated flow releases from Lake Mendocino causing increased erosion downstream;
5. Sand and gravel mining;

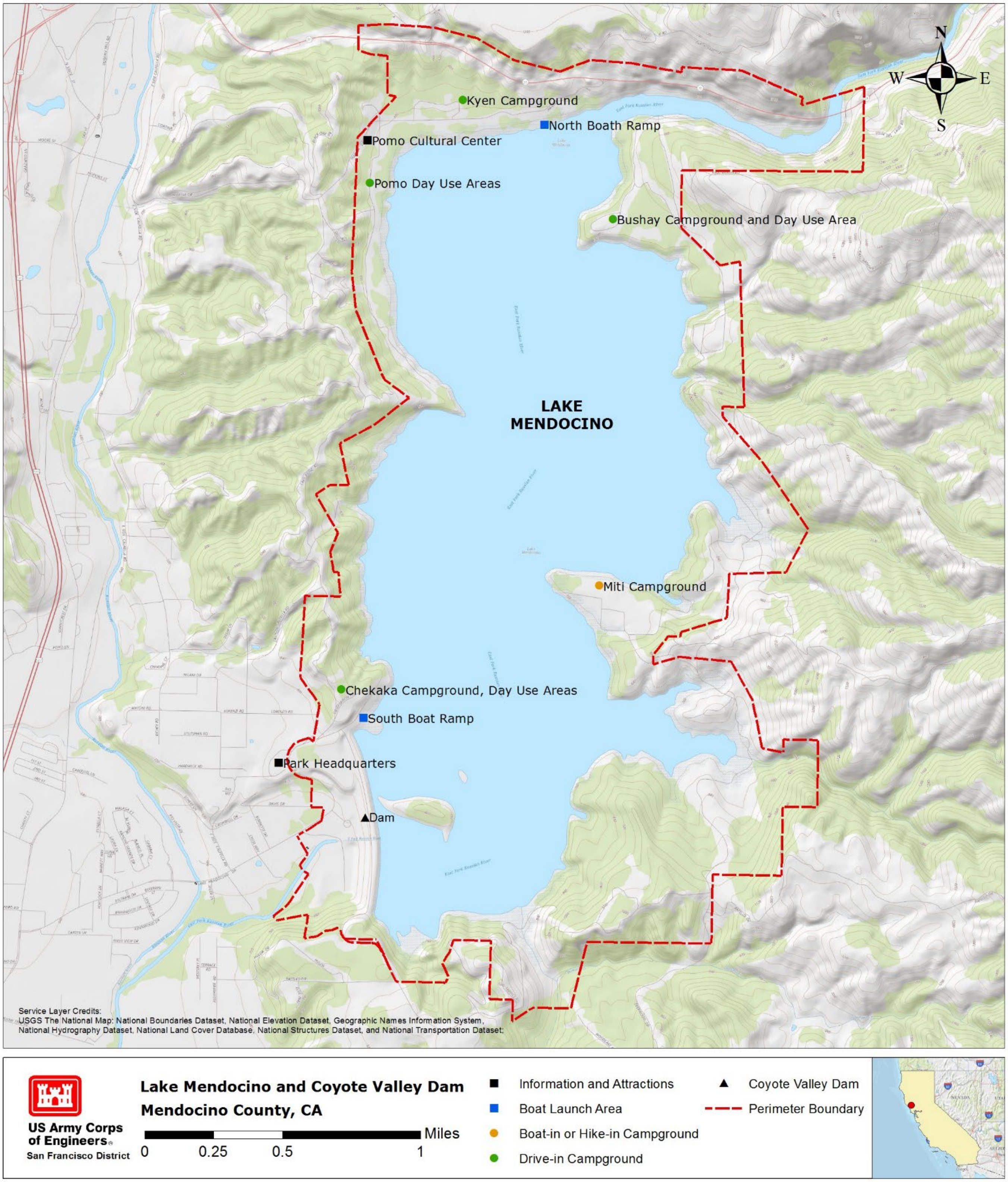

Figure 1. Map of Lake Mendocino showing CVD and channels of the east and west forks of the Russian River.

6. Other human activities causing increased erosion, such as road construction and logging;
7. Algal blooms and
8. Entrainment of fine sediments by release gates.

Recent discussions with staff from CDFW, NMFS, and Sonoma Water provide additional details about some of these issues. For example, suspended sediment migrates into Lake Mendocino from the East Fork particularly under winter flow conditions. The East Fork is noticeably more turbid than the West Fork in winter, and the issue was severe enough in 2020-21 that it negatively impacted water quality at the Coyote Valley Fish Facility (CVFF; Eric Larson, CDFW, pers. comm., April 29, 2021).

Lake Mendocino releases may contribute to algal blooms downstream especially when the lake turns over in the late fall and nutrients are mobilized from the bottom of the lake. Algal blooms occur in the lower reaches of the Russian River beginning in the Alexander Valley. Both flows and turbidity tend to be higher closer to CVD which may preclude algal blooms (Jeff Church, Sonoma Water, pers. comm., April 29, 2021).

Lake Mendocino has a "dead pool," where fine sediment deposits and later can be mobilized. Also, shoreline erosion in Lake Mendocino is exacerbated by recreational boating in summer, although that is not the main source of turbidity (Bob Coey, NMFS, pers. comm., April 29, 2021). Slumping of benthic sediments occurs around the outlet tower due to a suction or funnel effect toward the intake which can occur even at low instream flows (e.g., 30 cfs; Eric Larson, CDFW, pers. comm., April 29, 2021). Lake Mendocino flow releases therefore may contain elevated levels of suspended sediment at any time throughout the year. However, there are no clear temporal patterns to turbidity in the Russian River downstream of CVD especially during the dry season (e.g., summer) when turbidity is likely to be influenced by lake conditions. Turbidity may increase or decrease at different times within a dry season, perhaps in response to wind-driven or upwelling events on Lake Mendocino as well as the intensity of boat traffic as described above (Jeff Church, Sonoma Water, pers. comm., December 20, 2021). Also, increases in flow releases that reach a threshold may induce suction of fine sediment into release gates as flows ramp up over the summer to meet downstream demands (Tom Daugherty, NMFS, pers. comm., March 16, 2022).

The long-term trend is that turbidity in the Russian River has increased in the last 20 years, and there are no clear seasonal patterns to turbidity (Jeff Church, Sonoma Water, pers. comm., April 29, 2021). Potential adverse effects to listed salmonids in the Russian River include the following (Tom Daugherty, NMFS, pers. comm., April 29, 2021; Joe Dillon, NMFS, pers. comm., March 16, 2022):

- Impairment of feeding or detection of predators by rearing juveniles (spring/summer)
- Deposition of fines in spawning gravels (fall/winter)
- Toxicity/depletion of oxygen due to algal blooms (summer/fall)

III. Methods

Turbidity data available from USGS gauges and used in this analysis are shown below. Turbidity data collected by USACE as directed by the 2008 BO were obtained from an extensive search of CVD Operations and Planning staff files. The staff that collected the data are no longer working for the USACE San Francisco District, but current staff were able to find what they believe are all of the data. Upon review it was apparent that data were not collected at all locations required by the 2008 BO and were collected for fewer than 10 years at the remaining locations. Discussions with staff from CDFW, NMFS, and Sonoma Water resulted in the selection of the following data for analysis, with sensor locations shown in Figure 2:

- West Fork, Ukiah@Lake Mendocino Drive Bridge 2012-2014; USACE data collected near USGS gauge #11461000
- East Fork, Calpella (above Lake Mendocino) 2013-2018; USACE Data collected near USGS gauge #11461500; also 2019-2021 from the USGS gauge
- East Fork, Ukiah@Dam Outlet 2011-2018; USACE data collected near USGS gauge #11462000
- Hopland 2002-2021 (USGS gauge #11462500)
- Jimtown 2009-2021 (USGS gauge #11463682)
- Dry Creek@Lambert Bridge 2012-2021 (USGS gauge #11465240)

Data collected on the West Fork (upstream of the confluence with the East Fork) were intended as a control for CVD effects (Derek Acomb, CDFW, pers. comm., April 29, 2021). Jimtown in the Alexander Valley is thought to be the lower limit of observable turbidity influenced by CVD flow releases (Jeff Church, Sonoma Water, pers. comm., April 29, 2021). Although less of a concern, data collected on Dry Creek are intended to examine the effects of WSD releases on turbidity.

Large data gaps were apparent in both the USACE and USGS datasets, often in winter when gauges may have been damaged or removed during high flows. The Jimtown and Lambert Bridge gauges in particular were noted by USGS as having "low-flow records only" for most of the water years used in this analysis. Data gaps also occurred in summer at times. Additionally, unreasonably high values (i.e., up to 3,000 nephelometric turbidity units (NTU)) were recorded for some of the USACE data possibly due to the sensors being either out of the water or covered in bottom sediment (Josh Burkhead, USACE, pers. comm., July 21, 2021). To address this issue, all data greater than 930 NTU, the highest value recorded at the Hopland USGS gauge, were deleted from the analysis.

Log-transformed turbidity data were compared for each sensor location using summary statistics and ANOVA. Data also were compared over time to detect the seasonal effects of CVD flow releases on turbidity at locations downstream in the Russian River. The period from April 20, 2012, through August 1, 2014, was a particular focus because those were the dates for which data were available for the control reach, West Fork).

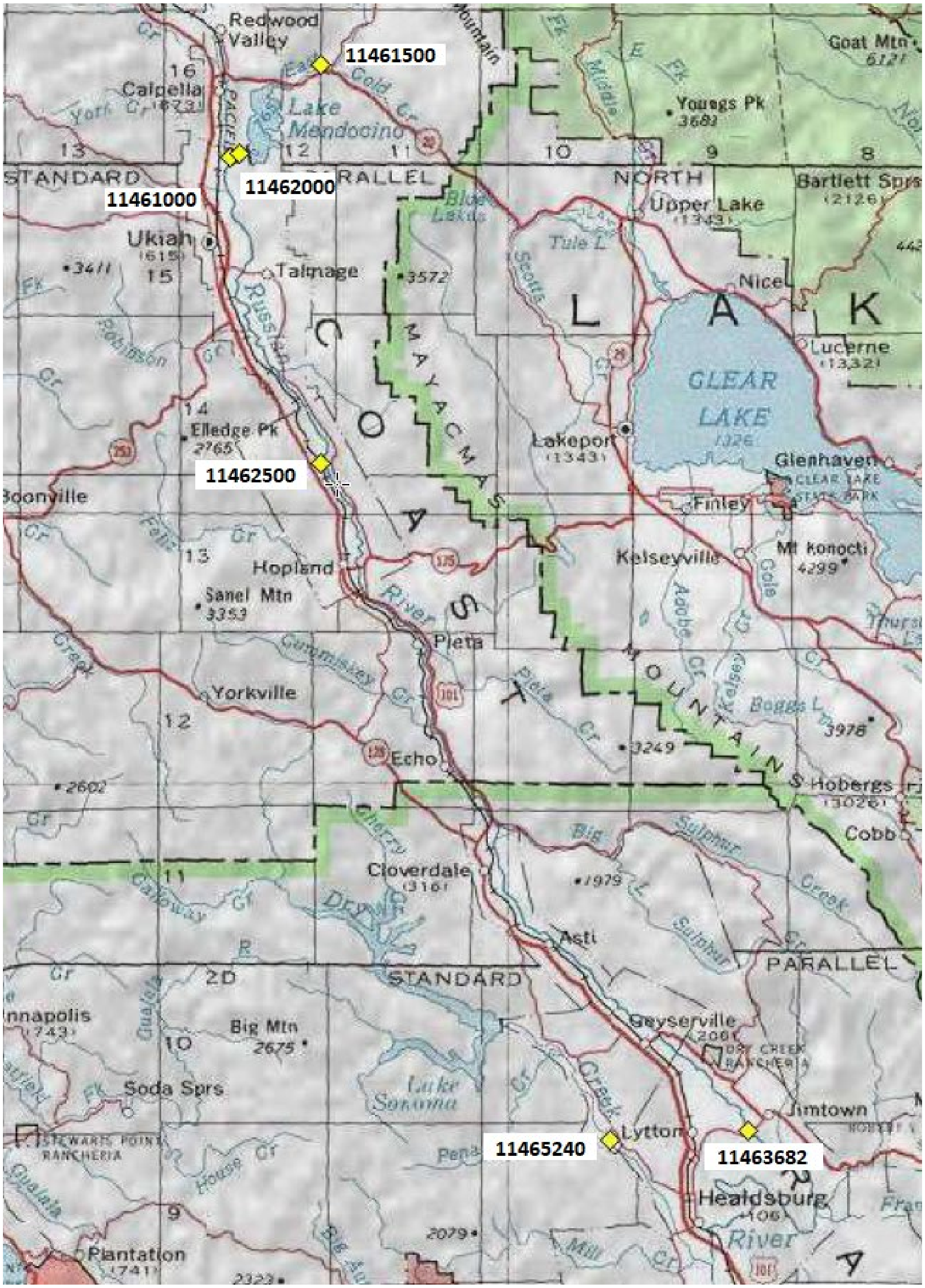

Figure 2. Six USGS gauge locations (yellow diamonds) and numbers (black, bold numerals on white background) where data was collected for this analysis.

We selected turbidity impact thresholds for impairment of feeding by juvenile salmonids and deposition of fines into spawning gravels using the models shown in Figure 1 and Figure 4, respectively from Newcombe and Jensen (1996) after converting turbidity measurements to suspended sediment concentration (SSC). The species used to develop these models are shown in Table 1. Specifically, we used their calculated values for a 1-day duration of exposure from the upper matrix of panel B of both figures. For the juvenile thresholds, we identified the percentage of days when 3 – 1,097 mg SS/L occurred to identify potential sub-lethal effects and greater than 1,097 mg SS/L occurred to identify potential lethal effects. For the spawning thresholds, we identified the percentage of days when 1 – 55 mg SS/L occurred to identify potential sub-lethal effects and greater than 55 mg SS/L occurred to identify potential lethal effects. Data were assessed seasonally at each of the six sensor locations.

Species		Figure/Model
Common Name	Scientific Name	Contributed to:
Lake whitefish	*Coregonus clupeaformis*	1
Mountain whitefish	*Prosopium williamsoni*	1
Brook trout	*Salvelinus fontinalis*	1
Lake trout	*Salvelinus namaycush*	1
Atlantic salmon	*Salmo salar*	1
Brown trout	*Salmo trutta*	1
Chinook salmon	*Oncorhynchus tshawytscha*	1
Sockeye salmon	*Oncorhynchus nerka*	1
Cutthroat trout	*Oncorhynchus clarkii*	1
Rainbow smelt	*Osmerus mordax*	1
Arctic grayling	*Thymallus arcticus*	1, 4
Chum salmon	*Oncorhynchus keta*	1, 4
Coho salmon	*Oncorhynchus kisutch*	1, 4
Steelhead	*Oncorhynchus mykiss*	1, 4
Rainbow trout	*Oncorhynchus mykiss*	1, 4
American shad	*Alosa sapidissima*	4
Atlantic herring	*Clupea harengus*	4
Pacific herring	*Clupea pallasii*	4
Lake herring (cisco)	*Coregonus artedi*	4
Striped bass	*Morone saxatilis*	4
White perch	*Morone ameicana*	4
Yellow perch	*Perca flavescens*	4

Table 1. Fish species used by Newcombe and Jensen (1996) to develop the models used to assess the effects of suspended sediment as shown in their Figure 1 (impairment of feeding by juvenile salmonids) and Figure 4 (deposition of fines into spawning gravels).

Note that there is substantial uncertainty with this simple analysis associated with the likelihood of either sub-lethal or lethal effects occurring and their intensity that may cause overestimation of adverse effects, especially for rearing juveniles. This is due in part to the large ranges of turbidity values included in both categories; clearly, adverse impacts are more likely to occur at the higher end of the ranges. Sub-lethal effects ranked by Newcombe and Jensen (1996) ranged from short-term to long-term reductions in feeding rates and feeding success, as well as minor to major physiological stress. However, a 2-hour period of reduction in feeding rate was considered to be "long-term." Additionally, consecutive days of exposure may be required to achieve adverse impacts and was not accounted for in this analysis. Even if effects were assessed over multiple days, Birtwell (1999), in reference to Newcombe and Jensen (1996), warns particularly that caution should be used when "assessing the effects of low concentrations (≤ tens of mg.L^{-1}) of suspended sediment over protracted periods of time." Fish responses to low levels of suspended sediment are expected to be more variable and have larger "scope for adaptation, tolerance, and resistance" (Birtwell 1999). Finally, the threshold between sub-lethal and lethal effects is not well defined and the minimum value was selected for analysis which may overestimate the likelihood of lethal effects. For example, in their investigation of 96-h LC50's for suspended sediment on juvenile coho salmon (i.e., the concentration of suspended sediment required to kill 50 percent of coho salmon in laboratory tests within 96 hours; LC denotes "lethal concentration), Servizi and Martens (1991) found that no coho salmon died in 96 hours in some trials when suspended sediment concentration was as high as 6,000 to 10,000 mg SS/L and temperatures were 7 to 14 ^{o}C. At 18 ^{o}C, no mortality was observed in 96 hours until suspended sediment concentration was raised to 3,000 mg SS /L (Servizi and Martens 1991). These values are much higher than the 1,097 mg SS/L lethal impact threshold identified from Newcombe and Jensen (1996), above. We also note that Newcombe and Jensen (1996) considered a reduction in growth rate as equivalent to a lower-ranked, lethal effect.

Because of the uncertainties described above we searched for alternative estimates of the lower ends of the sub-lethal and lethal impact ranges for juvenile salmonids. For sub-lethal effects, we selected 20 mg SS/L based on the studies of gill flaring/coughing responses by juvenile coho salmon to clear their gills conducted by Berg (1982; cited in Bash et al. 2001) and Servizi and Martens (1992). Gill flaring and coughing were denoted by Newcombe and Jensen (1996) as causing minor physiological stress in their ranking of sub-lethal effects. For lethal effects, we selected 2,000 mg SS/L based on the work of Servizi and Martens (1991) described above. We did not identify alternative thresholds for spawning due to the vulnerability of stationary eggs and larvae in redds to reductions in oxygen or smothering.

Linking turbidity data to algal blooms was not possible because algal blooms in the Russian River tend to be benthic rather than planktonic (Mike Thomas, Northern California RWQCB, pers. comm. August 27, 2021) and hence would be unlikely to be detected with turbidity measurements. Instead, we assessed temperature and turbidity data collected at the Dam Outlet and then oxygen data collected at the Hopland gauge along with flow, temperature, and turbidity because this was the closest gauge downstream of the Dam Outlet for which all of these data were available.

Relationships between turbidity and SS are watershed specific (Tananaev and Debolskiy 2014) but we could find no established relationship or data to develop one for the Russian River. We examined relationships for the North Santiam River (OR; Uhrich and Bragg 2006) and Freshwater Creek (Humboldt County, CA; Bray 2000). We selected the North Santiam River relationship for use with the Russian River data because of similar bank full discharges for the two rivers, and because both have dams with regulated flow releases. The North Santiam River is in the Cascade Range and is more forested than the Russian River. However, results greater than 100 NTU compared favorably with those for Freshwater Creek which drains directly into Humboldt Bay and is in the same coastal forest zone as the Russian River. Results less than 100 NTU yielded higher SSCs using the North Santiam River relationship compared to Freshwater Creek and hence were viewed as more conservative. The relationship between turbidity and SSC for the North Santiam River and used for the Russian River data discussed in this report is described by the following equation:

$$SSC = 1.75\ (\text{turbidity})^{1.04}$$

Using this equation, turbidity measurements yielding the juvenile sub-lethal and lethal threshold amounts of 3 and 1,097 mg SS/L are 1.7 and 490 NTU, respectively. Our alternative estimates for the juvenile sub-lethal and lethal thresholds (i.e., 20 and 2,000 mg SS/L, respectively) generated turbidity estimates of 10 NTU and 872 NTU, respectively. Turbidity measurements yielding the spawning sub-lethal and lethal threshold amounts of 1 and 55 mg SS/L are 0.6 and 28 NTU, respectively.

A final analysis was conducted where possible to quantify the effect of turbidity from the project compared to typical permit standards. The North Coast California Regional Water Quality Basin Plan states that “turbidity shall not be increased more than 20 percent above naturally occurring background levels. Allowable zones of dilution within which higher percentages can be tolerated may be defined for specific discharges upon the issuance of discharge permits or waiver thereof.“ We used the standard for California reported by Bash et al. (2001), which was 20% above “natural” turbidity, not to exceed 10 NTU. This analysis was conducted for all available data edited as described above. Additionally, we examined 10 NTU exceedances of the turbidity measured at West Fork by those measured at the Dam Outlet and Hopland for days when co-occurring data was measured.

IV. Results

Box and whisker plots of the log-transformed data (Figure 3) visually indicate that that overall, median turbidity was greatest at the Dam Outlet, followed by Hopland, Calpella, West Fork, and Jimtown in the Russian River, and Lambert Bridge on Dry Creek. Statistical analysis found that the means all are significantly different, except for West Fork and Jimtown which are not significantly different from each other.

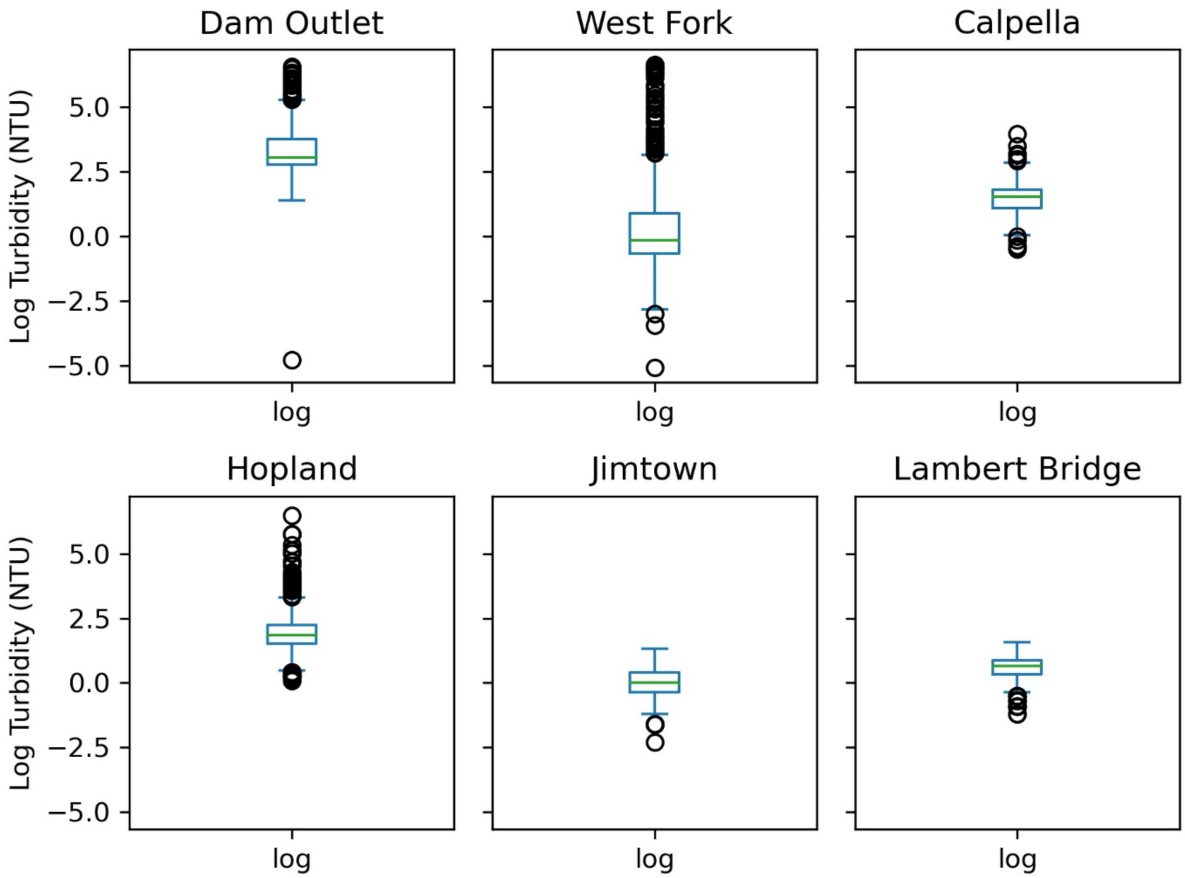

Figure 3. Box and whisker plots of turbidity data collected at five locations on the Russian River and one location on Dry Creek (Lambert Bridge). For each plot, the median is indicated by the horizontal line in the box, and the box represents the 25% to 75% interquartile range and hence spans 50% of the data. About 99.3% of the data are within the horizontal lines located at the end of the “whiskers.” The remaining 0.7% of the data (i.e., “outliers”) are depicted by circles.

Figure 4 provides some additional insight to the results. The log-transformed data appear normally distributed at all sites except for Lambert Bridge, which is more skewed to the right. However, the means differ as described above and hence, the distributions shift accordingly. The Dam Outlet, Hopland, and West Fork all had log turbidity values greater than 5 (i.e., measured turbidity greater than 148 NTU). However, the frequency of these values is much greater for the Dam Outlet. West Fork had many log turbidity values that were negative (i.e., measured turbidity less than 1 NTU), and Jimtown and Lambert Bridge had several as well.

Caveats associated with the data and previous analyses are illustrated by Figure 5, which shows histograms of all available, edited turbidity data from all sites. Regular data gaps from the USGS gauges located at Jimtown and Lambert Bridge primarily in winter and spring are evident. USGS may remove the gauges during these seasons to avoid damage from high flows. Turbidity measured at these locations during presumably lower flow summer and fall seasons was quite low, i.e., always in the lower end of the sub-lethal impact range. Additionally, direct comparisons between inflow turbidity to Lake Mendocino from the East Fork at Calpella and outflow turbidity from the Dam Outlet generally are not possible due to data gaps (i.e., 2014-2015 at Calpella, and 2016-2018 at the Dam Outlet). There is some indication that higher turbidity occurred at Calpella in winter and spring 2018 than from Dam Outlet releases during that period. An additional observation is that turbidity levels at Hopland appear to increase in winter and spring with a regularity that occurs at no other station and does not clearly track the turbidity measured at the Dam Outlet. This could be due to the influence of tributaries between the CVD and the Hopland gauge or other within-reach sources of turbidity such as resuspension of sediment or bank failures (Joe Dillon, NMFS, pers. comm., March 30, 2022).

Closer examination of the approximately 2-year period from April 20, 2012, through August 1, 2014, for which data was available for the West Fork control reach again found data gaps at Jimtown and Lambert Bridge, and also at Calpella (Figure 6). Turbidity measurements did not exceed 5 NTU at Jimtown and Lambert Bridge and rarely exceeded 20 NTU at Calpella. However, turbidity measurements in winter and spring at these locations were limited. Elevated turbidity levels occurred at the Dam Outlet, Hopland, and West Fork in winter and spring 2012-2013 and 2013-2014, presumably during high flows. For these measurements, Hopland more closely tracked West Fork likely because controlled flood control releases were made at the Dam Outlet.

Water temperature data was available for the Dam Outlet from 2011 through 2015 and followed a regular annual pattern (Figure 7). However, no clear relationship between temperature and turbidity can be discerned. Turbidity peaks occurred on the ascending and descending limbs of the temperature peaks, and also appeared quite independent of temperature especially in 2014. More data (from 2002 to 2021) was available for Hopland, so we compared turbidity with flow, temperature, and DO for that site (Figure 8). All of these variables were notably cyclical and largely varied by season. Due in part to the large data set, correlation coefficients (Table 2) all are highly significant ($P < 0.001$). Turbidity was always highest in winter and spring and is most

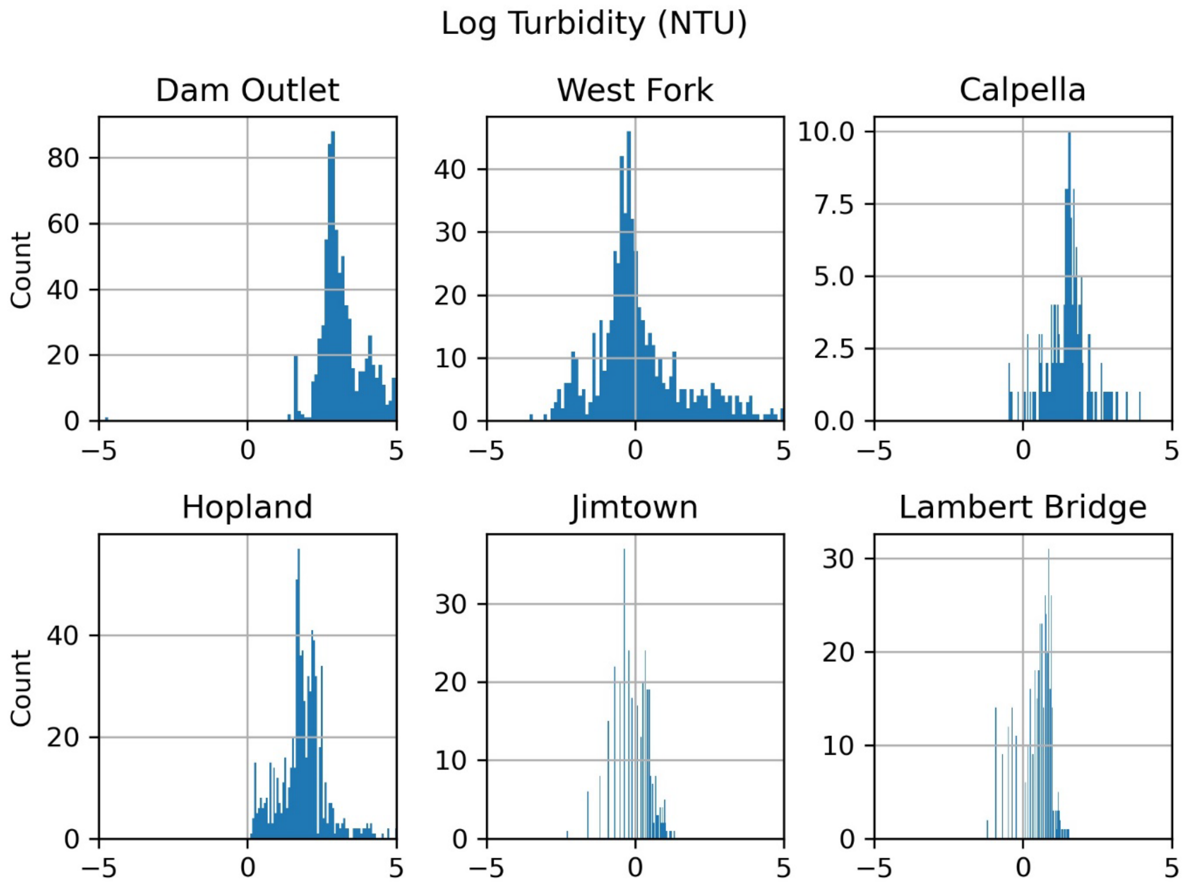

Figure 4. Counts of turbidity data measurements collected at five locations on the Russian River and one location on Dry Creek (Lambert Bridge). Negative log values indicate that measured turbidity was less than 1 NTU.

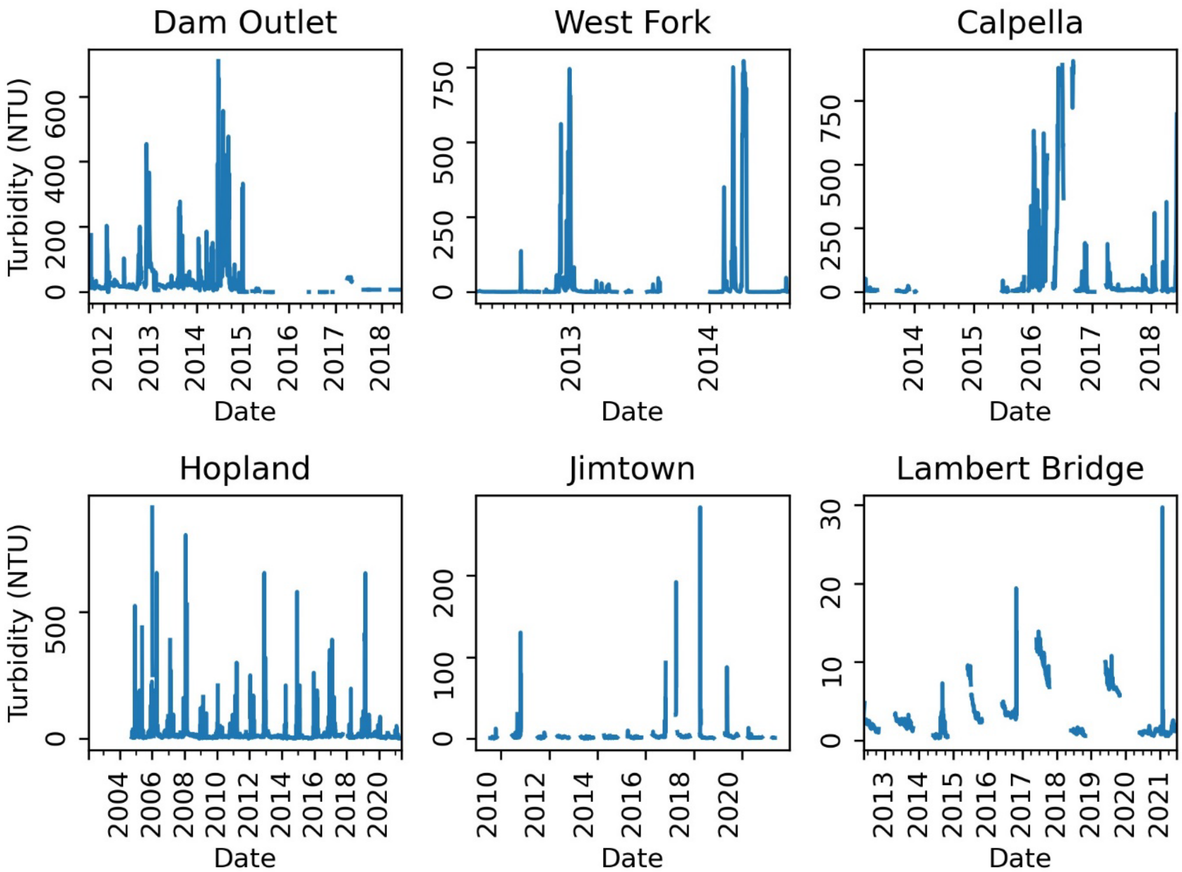

Figure 5. Turbidity measurements collected at five locations on the Russian River and one location on Dry Creek (Lambert Bridge). Year tick marks on the x-axis correspond with January 1.

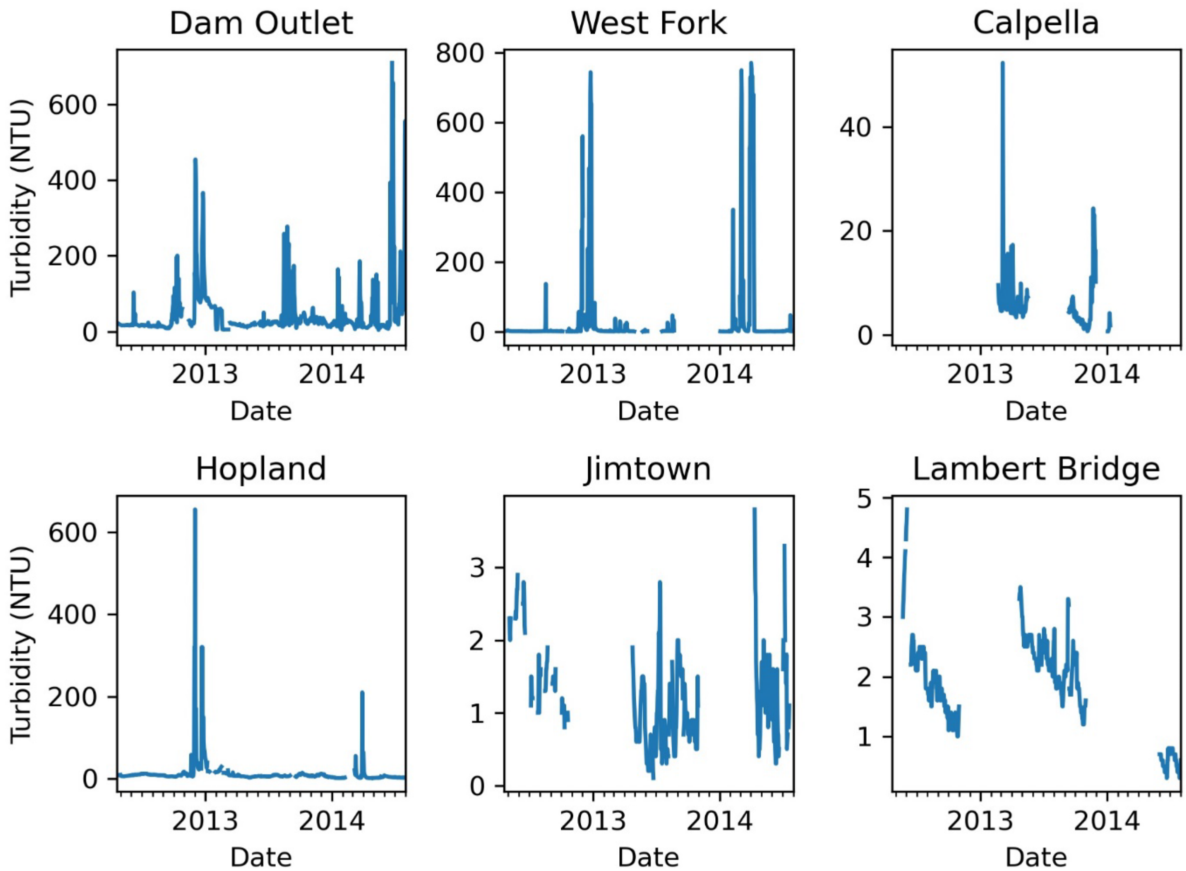

Figure 6. Turbidity measurements collected at five locations on the Russian River and one location on Dry Creek (Lambert Bridge) from April 20, 2012, through August 1, 2014. Year tick marks on the x-axis correspond with January 1.

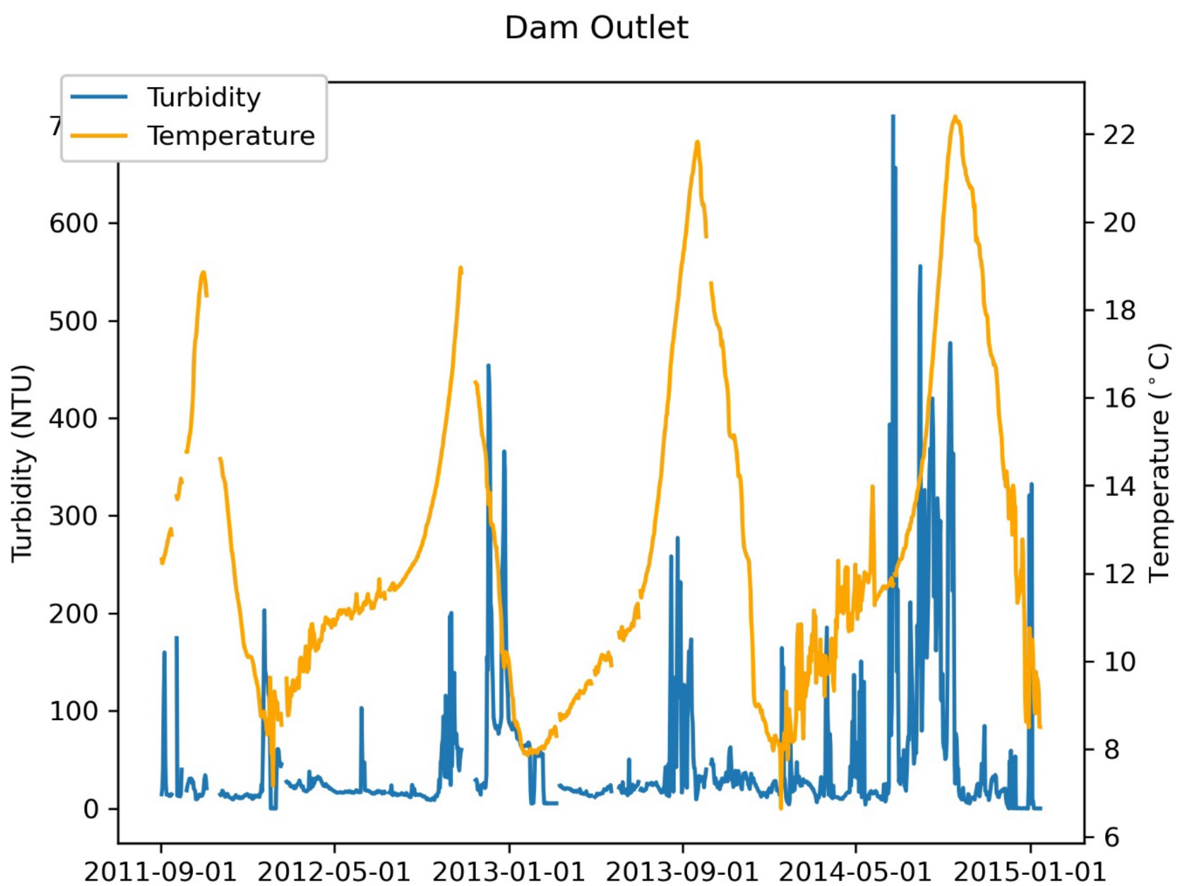

Figure 7. Turbidity and water temperature measured at the Coyote Valley Dam Outlet on the East Fork of the Russian River.

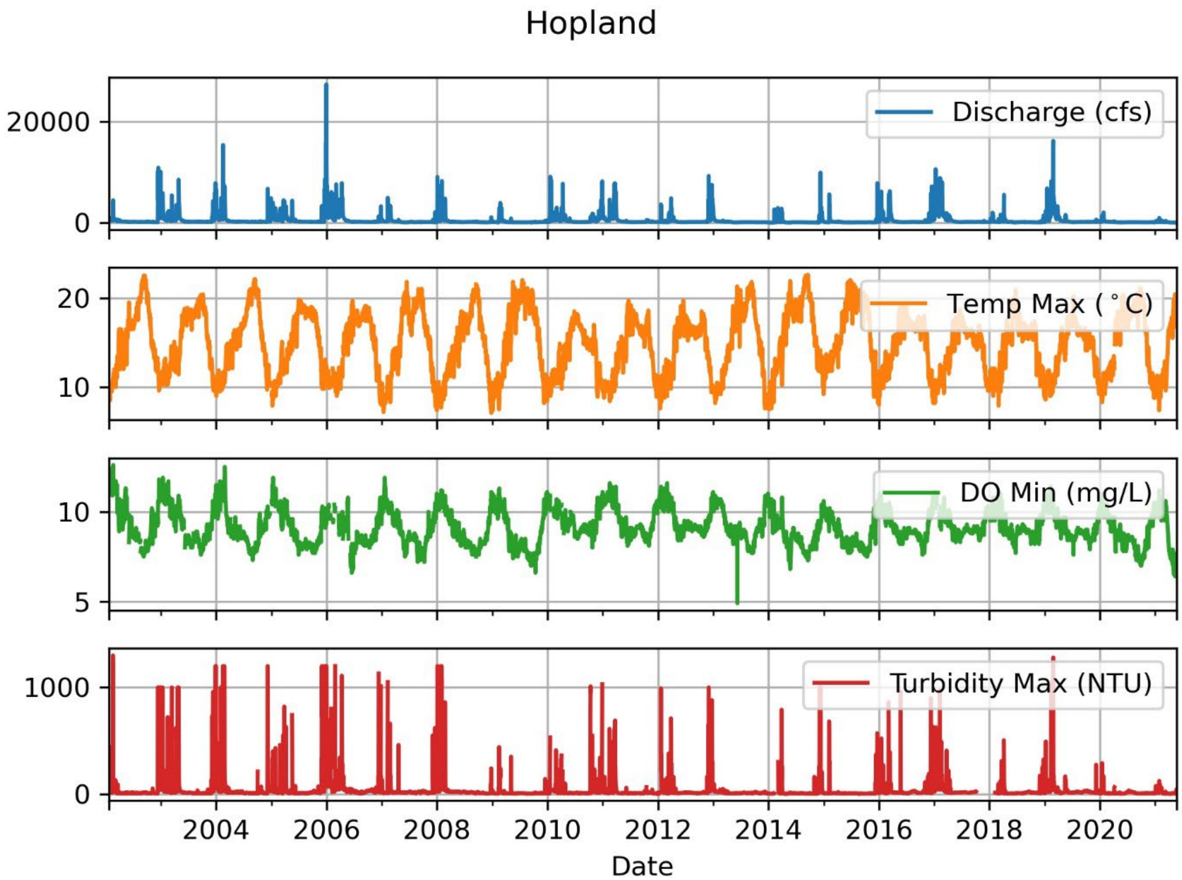

Figure 8. Discharge, temperature, dissolved oxygen, and turbidity measured at Hopland on the Russian River. Year tick marks on the x-axis correspond with January 1.

strongly positively correlated with flow. Therefore, the additional positive correlation with DO and negative correlation with temperature are to be expected. There is no clear impact of turbidity on temperature or DO evident from these data.

Pearson Correlation r values				
	Discharge (cfs)	Temp Max (^oC)	DO Min (mg/L)	Turbidity Max (NTU)
Discharge (cfs)	1	-0.315034427	0.376801931	0.766591976
Temp Max (^oC)	-0.315034427	1	-0.879578671	-0.248269677
DO Min (mg/L)	0.376801931	-0.879578671	1	0.274190286
Turbidity Max (NTU)	0.766591976	-0.248269677	0.274190286	1

Table 2. Pearson correlation coefficients (r-values) for discharge, temperature, DO, and turbidity measurements collected on the Russian River at Hopland from 2002 to 2021. All correlations are highly significant ($P < 0.001$).

Turbidity impact threshold exceedance levels for rearing juvenile salmonids are summarized by season in Table 3 using the sub-lethal and lethal thresholds obtained from Newcombe and Jensen (1996). Calpella is included in the analysis as an example of a location unaffected by project impacts, even though juvenile salmonids from the lower Russian River cannot access the habitat there. Potential sub-lethal turbidity levels were consistently high during all seasons for the Dam Outlet, Hopland, and Calpella (i.e., from 79 to 100 percent, 98 to 100 percent, and 76 to 98 percent of monitoring days, respectively). Interestingly, the percent of days reaching sub-lethal turbidity levels at Hopland was higher in all seasons compared to the Dam Outlet or Calpella. No turbidity data were available for Jimtown in the winter, but sub-lethal turbidity levels occurred from 63 to 81 percent of the days there, and similarly from 64 to 88 percent of the days at Lambert Bridge. Only the West Fork had notably lower sub-lethal turbidity levels (i.e., from 32 to 53 percent of monitoring days).

Potential lethal turbidity levels for rearing juveniles occurred much less often than sub-lethal levels. They occurred most often at Calpella (i.e., 3 to 14 percent of monitoring days) in all seasons. The Dam Outlet achieved lethal turbidity levels on 2 to 9 percent of monitoring days. The four other stations had at least one season when lethal turbidity levels did not occur.

Other than the occurrence on 8 percent of the days at West Fork in the winter and spring, lethal turbidity levels occurred on 2 percent of the days or less at West Fork and Hopland. Lethal turbidity levels did not occur at all at Jimtown or Lambert Bridge. Using the less conservative (i.e., considered less likely to cause adverse effects), alternative threshold values for rearing juveniles (Table 4) reduced the percentage of days estimated as having adverse effects from turbidity at the Dam Outlet very little. In contrast, potential sub-lethal effects at Hopland and Calpella were estimated to occur on 16 to 35 percent fewer days, and those at Jimtown and Lambert Bridge by 62 to 75 percent fewer days. Potential lethal effects always occurred on the same or a smaller percentage of days at all sites compared to the thresholds obtained from Newcombe and Jensen (1996). Consequently, any reductions in potential sub-lethal effects were due to the percentage of days which had turbidities ranging from 1.7 to 10 NTU (i.e., the increase of the alternative minimum threshold to 10 NTU compared to the 1.7 NTU minimum threshold from Newcombe and Jensen (1996).

	Season											
	Winter			Spring			Summer			Fall		
Gage	Days Count	% Sublethal	% Lethal	Days Count	% Sublethal	% Lethal	Days Count	% Sublethal	% Lethal	Days Count	% Sublethal	% Lethal
Dam Outlet	349	79%	3%	428	100%	0%	328	81%	9%	451	86%	2%
Hopland	788	98%	2%	957	99%	0%	874	100%	0%	834	99%	0%
Calpella	217	76%	10%	282	89%	8%	160	85%	14%	319	96%	3%
West Fork	144	53%	8%	195	32%	8%	187	36%	0%	78	38%	1%
Jimtown	0	0%	0%	412	81%	0%	704	63%	0%	550	77%	0%
Lambert Bridge	90	76%	0%	140	64%	0%	832	88%	0%	549	83%	0%

Table 3. Number of days for which turbidity data was available, and the percent of days that had turbidity measurements of 1.7 to 490 NTU and greater than 490 NTU, which represent potential sub-lethal and lethal thresholds, respectively, obtained from Newcombe and Jensen (1996) for rearing juvenile salmonids.

	Season											
	Winter			Spring			Summer			Fall		
Gage	Days Count	% Sublethal	% Lethal	Days Count	% Sublethal	% Lethal	Days Count	% Sublethal	% Lethal	Days Count	% Sublethal	% Lethal
Dam Outlet	349	76%	1%	428	89%	0%	328	88%	2%	451	87%	1%
Hopland	788	72%	1%	957	61%	0%	874	68%	0%	834	66%	0%
Calpella	217	56%	5%	282	73%	4%	160	65%	11%	319	61%	3%
West Fork	144	32%	4%	195	13%	8%	187	4%	0%	78	10%	0%
Jimtown	0	0%	0%	412	11%	0%	704	0%	0%	550	2%	0%
Lambert Bridge	90	2%	0%	140	0%	0%	832	27%	0%	549	19%	0%

Table 4. Number of days for which turbidity data was available, and the percent of days that had turbidity measurements of 10 to 872 NTU and greater than 872 NTU, which represent potential sub-lethal and lethal alternative thresholds, respectively, from those obtained from Newcombe and Jensen (1996) for rearing juvenile salmonids.

When examining turbidity impact thresholds obtained from Newcombe and Jensen (1996) for salmonid eggs and larvae in redds (Table 5), Hopland again had a greater percentage of days in all seasons with sub-lethal impacts compared to either Calpella or the Dam Outlet (i.e., 65 to 92 percent, 59 to 84 percent, and 20 to 43 percent, respectively). Calpella is included in the analysis as an example of a location unaffected by project impacts, even though spawning adult salmonids from the lower Russian River cannot access the habitat there. In this case, however, West Fork also had a greater percentage of days in all seasons with sub-lethal impacts (i.e., 56 to 90 percent) than occurred at the Dam Outlet, and Jimtown and Lambert Bridge had the highest percentages of all (i.e., 93 to 99 percent and 99 to 100 percent, respectively). These results can be explained by the very low impact thresholds, which resulted in sub-lethal impacts at a minimum occurring on most days at West Fork, Jimtown, and Lambert Bridge whereas impacts at the Dam Outlet tended to move out of the sub-lethal category and into the lethal category. Lethal impact thresholds were exceeded on more than 50 percent of days in all seasons at the Dam Outlet, followed by Calpella, Hopland, and West Fork (51 to 70 percent, 16 to 41 percent, 8 to 35 percent, and 3 to 23 percent, respectively). As suggested by the high percentages of sub-lethal impacts, Jimtown and Lambert Bridge had low levels (i.e., 0 percent of days in most seasons) of lethal impacts.

Gage	Season											
	Winter			Spring			Summer			Fall		
	Days Count	% Sublethal	% Lethal	Days Count	% Sublethal	% Lethal	Days Count	% Sublethal	% Lethal	Days Count	% Sublethal	% Lethal
Dam Outlet	349	31%	54%	428	43%	56%	328	20%	70%	451	37%	51%
Hopland	788	65%	35%	957	82%	18%	874	92%	8%	834	84%	16%
Calpella	217	59%	41%	282	60%	39%	160	79%	21%	319	84%	16%
West Fork	144	56%	23%	195	65%	17%	187	90%	3%	78	69%	6%
Jimtown	0	0%	0%	412	93%	7%	704	98%	0%	550	99%	1%
Lambert Bridge	90	99%	1%	140	100%	0%	832	100%	0%	549	100%	0%

Table 5. Number of days for which turbidity data was available, and the percent of days that had turbidity measurements of 0.6 to 28 NTU and greater than 28 NTU, which represent potential sub-lethal and lethal thresholds, respectively, obtained from Newcombe and Jensen (1996) for spawning (i.e., salmonid eggs and larvae in redds).

Finally, comparisons of the turbidity at West Fork (i.e., a reach unaffected by project activities) with all other stations showed 10 NTU or greater exceedance only at the Dam Outlet (Table 5). West Fork indeed had the lowest median turbidity measured, and 20 percent exceedances (i.e., values greater than 0.84 NTU + 0.168 NTU = 1.008 NTU) occurred at all other stations except Jimtown. Note that Calpella also is unaffected by the activities of this project but is influenced by turbidity from the Pacific Gas and Electric Company's Potter Valley Project (California Department of Water Resources (CDWR) 1976). Many stream segments in Potter Valley are deeply incised likely resulting in bank erosion, and deteriorated road conditions in the upper watershed also could be a potential chronic contributor of sediment in the system (Joe Dillon, NMFS, pers. comm., March 30, 2022).

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Location	Median Log Turbidity (NTU)	Median Turbidity (NTU)
West Fork	-0.18	0.84
Calpella	1.54	4.7
Dam Outlet	3.04	20.9
Hopland	1.84	6.3
Jimtown	0	1.0
Lambert Bridge	0.64	1.9

Table 6. Median turbidities measured at five locations on the Russian River, and one location on Dry Creek (Lambert Bridge). The median log values correspond with those shown in Figure 3.

Turbidity data for West Fork, the Dam Outlet, and Hopland co-occurred on a total of 477 days over a period of approximately 800 days from 2012 through 2014 (Figure 9). For these days, turbidity measured at the Dam Outlet was >= 10 NTU over the West Fork 85% of the time (404 days) and Hopland was >= 10 NTU over the West Fork 14% of time (69 days). Pearson correlation coefficients for turbidity at these locations and corresponding P-values are shown in Table 6.

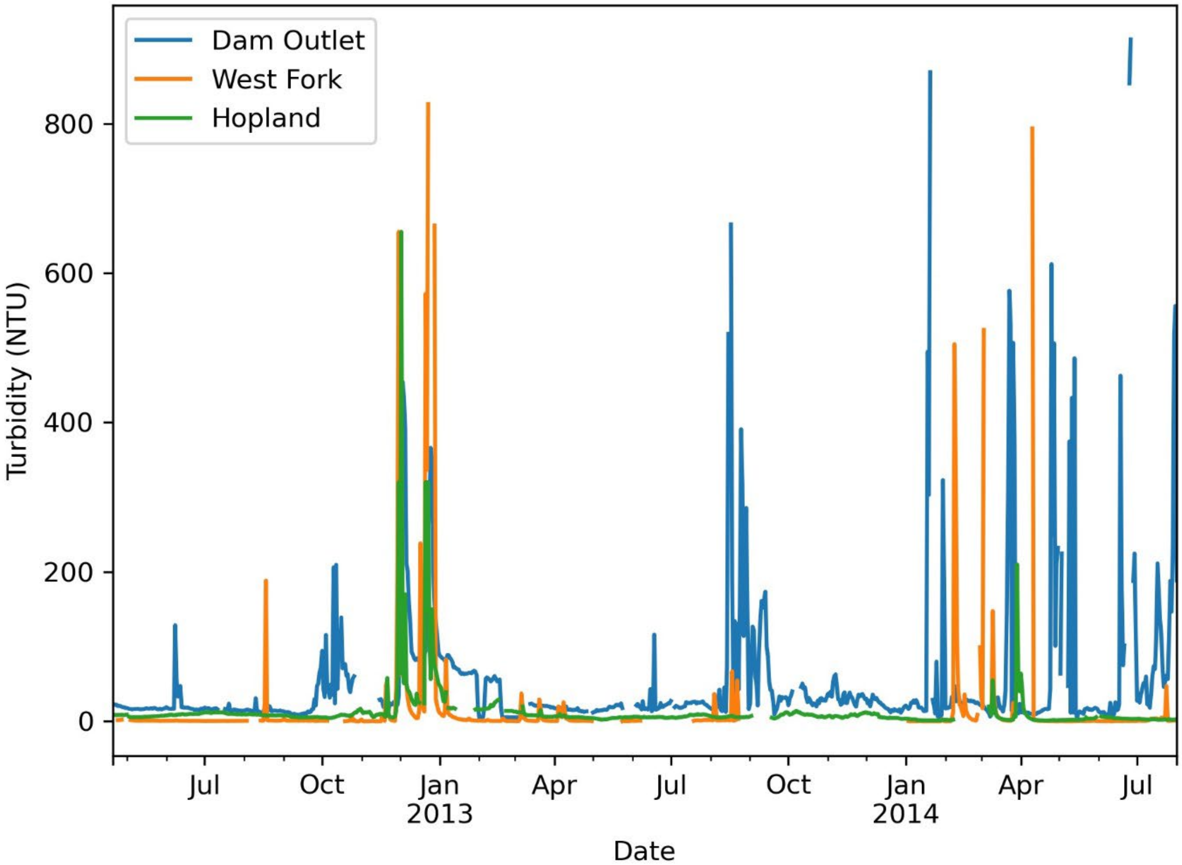


Figure 9. Co-occurring turbidity measurements obtained at the West Fork, Dam Outlet, and Hopland stations on 477 days from March 2012 through July 2014. Note that large gaps in the data occur particularly for West Fork in fall/winter 2013/2014.

Pearson correlation r values			
	West Fork	Dam Outlet	Hopland
West Fork	1	0.090429	0.772386
Dam Outlet	0.090429	1	0.07538
Hopland	0.772386	0.07538	1

Table 7. Pearson correlation coefficients (r-values) for turbidity measurements collected on the Russian River at West Fork, Dam Outlet, and Hopland on 477 days in 2012 through 2014. The West Fork-Hopland correlation is highly significant ($P < 0.001$). The West Fork-Dam Outlet correlation, although small, is significant (($P < 0.05$).

Discussion

This study compared turbidity levels at six stations in the Russian River watershed located in the East Fork both upstream and downstream of Lake Mendocino/CVD, in the West Fork upstream of the East Fork confluence, in the Russian River mainstem downstream from where the West Fork and East Fork join, and in Dry Creek downstream of Lake Sonoma/WSD. We examined the results from five perspectives: (1) total number and statistical distribution of turbidity measurements; (2) variation of turbidity with time (i.e., seasons and years); (3) correlation of turbidity with flow, temperature, and DO levels; (4) turbidity impact threshold exceedances by season; and (5) comparisons of turbidity measured at West Fork and Calpella, which are unaffected by project activities, with all other stations.

On average, turbidity levels were greatest at the Dam Outlet, followed by Hopland, Calpella, West Fork, Lambert Bridge, and Jimtown (Figure 3). Means for stations in the Russian River (i.e., excluding Lambert Bridge on Dry Creek) all were statistically significantly different. The results are not surprising based on anecdotal evidence and past studies (e.g., Ritter and Brown 1971; Levanthal 2010) indicating elevated turbidity in the Russian River comes from CVD flow releases and which was the motivation for this study. Hopland and Jimtown are approximately 12 miles and 44 miles, respectively, downstream from the Dam Outlet. Although the generally normal distributions of the data suggest a consistent influence of turbidity from Dam Outlet releases at these locations (Figure 4), these data were not necessarily collected during similar time periods. Jimtown is thought to be the limit of the influence of added turbidity from CVD (Jeff Church, Sonoma Water, pers. comm., April 29, 2021). Therefore, it is not surprising the average turbidity levels at Jimtown and Lambert Bridge on Dry Creek were the lowest observed and were not significantly different from each other. Although monitoring the effects of WSD releases on turbidity levels in Dry Creek was included in the term and condition of NMFS's 2008 BO, Lake Sonoma and WSD have not been noted as a concern for contributing to downstream turbidity in any earlier studies.

The East Fork Russian River upstream of Lake Mendocino, where Calpella is located, receives flow from the Eel River at Potter Valley (Ritter and Brown 1971; note that as of 2023 PG&E's Potter Valley Project may be decommissioned and Scott Dam removed, so future inputs of flow from the Eel River into the East Fork are uncertain). The suspended sediment load in the Eel River was reported as the highest in the nation for its size (Brown and Ritter 1971), and likely contributes to the elevated turbidity observed at Calpella. In contrast the West Fork has been observed to be much less turbid than the East Fork, but still periodically exhibits high turbidity, likely from winter storms (Bachand et al. 2010; see additional discussion below).

Extensive comparison of turbidity measurements at Calpella and the Dam Outlet by year and season (Figure 5) was not possible due to data gaps. However, there is some suggestion that higher turbidity may have occurred at Calpella in winter and spring 2018 than from Dam Outlet releases during that period. Bachand et al. 2010 also compared turbidity values for Calpella and Dam Outlet for the years 1977-1982 and 2009-2010. In contrast, they found that turbidity was not statistically different between the two sites, and that seasonal trends at the Dam Outlet tracked those at Calpella. Their analysis indicated that turbidity values at the Dam Outlet tended to be higher and remain high for longer periods than at Calpella. Declines in turbidity at the Dam Outlet tended to lag those at Calpella (Leventhal 2010). Data also were available to add the West Fork to the comparison for the months of April through November. In all cases for these months, the median turbidity was highest at the Dam Outlet, followed by Calpella, and finally the West Fork (Bachand et al. 2010).

In this study, turbidity levels at Hopland appear to increase in winter and spring with a regularity that occurs at no other station and does not clearly track the turbidity measured at the Dam Outlet. Overall, it is difficult to discern from these data the influence of turbidity levels at the Dam Outlet on the levels measured downstream at Hopland and Jimtown. This is in part explained by the complex relationship between flow and turbidity in the Russian River. Specifically, although there is a positive relationship between flow and turbidity in the Russian River (i.e., much higher turbidity occurs during winter storm flows), turbidity downstream of CVD does not clearly decline after winter storms subside (Levanthal 2010).

Turbidity data collected at Hopland therefore agree with the findings of Bachand et al. (2010), who detected nine distinct high flow events (>3000 cfs) that occurred at West Fork and Hopland during the period from January through April 2010. They state that during this period, "flows downstream of the confluence of the East and West Fork were dominated by storm events along the West Fork." This occurred because winter flow from the Dam Outlet was regulated to less than 600 cfs and more typically to less than 300 cfs. Bachand et al. (2010) found that under high flow conditions, total suspended solid concentration (SSC) was significantly higher and more variable in the West Fork compared to the East Fork. However, SSC was significantly higher in the East Fork under low flow conditions. Therefore, summer flows in the Russian River downstream of the East Fork confluence are expected to be dominated by Dam Outlet releases and higher than the very low flows that would be expected to occur in the absence of CVD (Bachand et al. 2010). The point of Levanthal (2010) above, however, is that turbidity releases at the Dam Outlet are related to something other than flow such as factors controlling resuspension of sediment in Lake Mendocino.

When examining turbidity levels more closely for the years 2013-2014 as part of this study (i.e., the period for which data for the West Fork control site were available; Figure 6), it is clear that winter turbidity levels at Hopland more closely tracked those at West Fork rather than the Dam Outlet. This is not surprising given the discussion above. However, photos supplied by NMFS and taken by J. McKeon at and just downstream of the convergence of the East Fork and West Fork definitely show higher turbidity in the East Fork and its downstream effects (Figures 8-10, respectively). These photos were taken on "February 3, 2010, approximately 3-4 days following a storm in the Russian River basin." It is unclear how far downstream these effects extend, and why they are not detected either at Hopland or at Jimtown. However, they do coincide with the observation of Levanthal (2010) that turbidity downstream of CVD does not quickly decline following winter storms.

Elevated turbidity also was evident at the Dam Outlet in summer and fall 2013 but was not evident downstream at Hopland. These limited data suggest that some minimum flow may be required to carry turbidity downstream. If flow is too low, then suspended sediment causing turbidity could settle out fairly rapidly, i.e., the effects of turbidity from Dam Outlet releases may not extend as far downstream as expected. This could, by providing clearer water to downstream locations, contribute to the benthic blue green and green algal blooms that occur there.

Turbidity at the Dam Outlet showed no clear relationship with temperature (Figure 6), and flow and DO data were not available for this location. In contrast, turbidity at Hopland was positively correlated with flow and DO, and negatively correlated with temperature (Figure 7). All four variables clearly were cyclic and seasonal, with higher turbidity measurements corresponding to the higher flows in winter and spring, and the corresponding lower temperatures and higher DO levels that would be expected during those seasons. Potential impacts of turbidity such as increasing water temperature through heat absorption by suspended sediment particles and decreasing DO through the reduction of light transmission and photosynthesis (Kjelland et al. 2015) could not be detected, possibly due to the strong seasonal correlations. Additionally, these data provided no insight regarding the potential impacts of releases from the Dam Outlet following the fall turnover of Lake Mendocino and resultant nutrient inputs that could contribute to algal blooms downstream (Jeff Church, Sonoma Water, pers. comm., April 29, 2021). A finer analysis using past operations data on flow releases from Lake Mendocino and closer examination of the above variables within seasons may be needed to investigate these issues further.

Impact threshold exceedance for juvenile rearing is of most interest in spring and summer, and at the Dam Outlet, Hopland, and Jimtown compared with the West Fork. For these seasons, the sub-lethal threshold from Newcombe and Jensen (1996; Table 3) was exceeded most often at the Dam Outlet and Hopland (i.e., averaging above 90 percent of days) followed by Jimtown (i.e., averaging about 70 percent of days) and then West Fork (i.e., averaging about 35 percent of days). Sub-lethal threshold exceedances actually were slightly greater for Hopland than the Dam

Outlet, but this is because a small percentage of lethal threshold exceedances occurred at the Dam Outlet, but none occurred at Hopland. For the alternative sub-lethal thresholds (Table 4), exceedances at the Dam Outlet remained about the same but occurred less often at Hopland (i.e., averaging about 65 percent of days). Exceedances at West Fork declined by an additional 20 to 32 percent (i.e., to an average of about 8 percent of days) and those at Jimtown declined to the extent that their frequency of occurrence was similar to West Fork (i.e., to an average of about 5 percent of days).

Both analyses indicate that turbidity associated with Dam Outlet flows in spring and summer exceeds sub-lethal thresholds much more often (i.e., about 50 to 80 percent more days) than occurs at West Fork. However, both the Dam Outlet and West Fork each also had a small percentage of lethal threshold exceedances under both scenarios, whereas Hopland and Jimtown had none. Other than for the Dam Outlet, the comparison of the two thresholds (i.e., 1.7 to 490 NTU (Newton and Jensen 1996) versus 10 to 872 NTU (alternative)) yielded different results for sub-lethal exceedances; potential sub-lethal effects were detected on a minimum of about 25 percent fewer days using the alternative values.

The high percentage of days with sub-lethal impact exceedance at the Dam Outlet under both thresholds is a concern in that feeding by rearing juveniles may be impeded most days in the spring and summer. However, there is uncertainty about how far downstream these effects extend from the Dam Outlet. Some additional turbidity data was collected in 2012 – 2013 and 2015 -2018 by USACE near USGS gauge # 11462080 in the Russian River near Talmage, located approximately 7.5 miles upstream of Hopland. Examination of this data may provide additional information about the effects of turbidity from the Dam Outlet on downstream locations. Also, examination of the days when exceedances occurred both at the Dam Outlet and Hopland but not at West Fork may provide insight on the conditions required to cause downstream impacts, especially if combined with CVD operations data.

The impact thresholds for spawning (i.e., eggs and larvae in redds; Newcombe and Jensen 1996) are of interest primarily in fall and winter, and again at the Dam Outlet, Hopland, and Jimtown compared with the West Fork. In this case, potential lethal effects occurred often enough to be of concern not only at the Dam Outlet, but also at Hopland and West Fork. Threshold exceedances indicate that turbidity from releases at the Dam Outlet potentially could cause lethal effects to eggs and larvae on about 50 percent of days in the fall and winter. At all locations potential lethal effects were more likely to occur in the winter than in the fall, although there was no data for Jimtown in the winter. Potential lethal effects occurred on 51 percent, 16 percent, and 0 percent of days in the fall at the Dam Outlet, Hopland, and Jimtown, respectively, and 6 percent at West Fork. The likelihood of potential lethal effects in winter increased to 55 percent and 35 percent at the Dam Outlet and Hopland respectively, and 20 percent at West Fork. The caveat when examining these data is that for eggs and larvae in redds to be impacted, suspended sediment must settle out and smother eggs and larvae or otherwise reduce oxygen levels in redds. The extent to which this occurs probably depends on the flow and habitat conditions measured on a finer scale near each redd, and also the number of consecutive days that impact thresholds are exceeded. Collecting microhabitat data in spawning locations of concern may provide additional insight on the extent of true lethal impacts.

Median turbidity measured at the Dam Outlet was an order of magnitude greater than that measured at West Fork, which is considered the control site as it is unaffected by project activities (Table 5). Median turbidity values at all other stations exceeded the turbidity at West Fork by at least 10 percent. Additionally, turbidity measured at the Dam Outlet and Hopland was >= 10 NTU over the West Fork 85% and 14% of the 477 days, respectively, when data was available for all three locations. This last analysis perhaps provides the strongest evidence of the impact of turbidity released by the Dam Outlet on conditions in the Russian River because of the direct comparison of data collected on the same days. The caveat is that data collected over this relatively brief time period may be influenced by drought or other conditions affecting flows.

Figure 8. Photo taken by J. McKeon on February 3, 2010, at the confluence of East Fork and West Fork Russian River showing much higher turbidity in the East Fork.

Figure 9. Photo taken by J. McKeon on February 3, 2010, just downstream of the confluence of East Fork and West Fork Russian River showing the effects of the much higher turbidity in the East Fork.

Figure 10. Photo taken by J. McKeon on February 3, 2010, about 400 feet downstream of the confluence of East Fork and West Fork Russian River showing the near complete mixing and dominance of the much higher turbidity in the East Fork.

V. Summary

The multiple analyses described in this report clearly have identified higher levels of turbidity released from the Dam Outlet at CVD than typically occur under the non-project conditions exemplified by turbidity measurements collected at West Fork. However, the mechanisms controlling the turbidity from Dam Outlet releases and the extent of downstream effects remain unclear. Well-defined differences in turbidities are evident from the comparisons of all available, edited data for all six sites. Although these data generally were normally distributed with significantly different means, they were not all collected on the same days or even in the same years. Therefore, despite turbidity being clearly highest at the Dam Outlet followed by Hopland, then Jimtown, and lowest at West Fork, turbidity effects from CVD releases on downstream locations and additive effects to those at West Fork remain difficult to quantify, even though these results confirm over 70 years of anecdotal observations and informal assessments. The pattern of turbidity impact threshold exceedances was less clear but still occurred more often (i.e., on a greater percentage of days) at the Dam Outlet and Hopland versus Jimtown and West Fork. These data were assessed by season, but again often were not collected on the same days or in the same years. Perhaps the best comparison concerns the reduced set of turbidity data for West Fork, the Dam Outlet, and Hopland collected on the same 477 days during 2012 – 2014. As described in the results and discussion pertaining to typical permit standards, turbidity measured at the Dam Outlet was >= 10 NTU over the West Fork 85% of the time (404 days) and Hopland was >= 10 NTU over the West Fork 14% of time (69 days). These data are shown in Figure 9 and suggest that additional intra-seasonal analysis incorporating CVD operations data may be helpful in identifying the timing, sources, and mechanisms controlling the releases of turbidity from the Dam Outlet.

The assessment of turbidity measurements collected at the six stations over time (i.e., years; Figures 5 and 6) in this report were markedly unclear in distinguishing the downstream effects of turbidity measured at West Fork and the Dam Outlet. In particular, turbidity measurements at Hopland appeared to be more correlated with those at West Fork than at the Dam Outlet, even though both West Fork and the Dam Outlet periodically exhibited similarly high turbidity levels. This pattern may have been influenced by controlled flows through the Dam Outlet, release timing, and data gaps. Correlation of the turbidity at Hopland with the West Fork would be typically limited to winter and storm flow events, whereas summer values are more correlated with Dam Outlet releases, especially in drier years and summer/fall, when the West Fork goes dry before reaching the confluence (Jeff Church, Sonoma Water, pers. comm. December 23, 2021). Also, seasonal correlations of turbidity with flow, temperature, and DO may preclude detection of more subtle relationships among these variables. Additional finer-scale, intra-seasonal analysis of these data using CVD operations information again may be useful for identifying the mechanisms controlling the complicated relationships involving turbidity over space and time in the Russian River (see section VI. Proposed Plan, below).

VI. Proposed Plan

Introduction

The previous analysis has shown that CVD releases turbidity and suspended sediment from Lake Mendocino into the Russian River. Our data indicate that the turbidity effects from CVD likely override the non-project conditions emanating from the West Fork. This typically occurs at lower flows but may occur as flows recede after winter storm events as well during ordinary low flow periods that typically occur in the summer and fall. Mechanisms other than flow, such as turbidity currents and wind resuspension of sediment in Lake Mendocino as suggested by Leventhal (2010) also may play a key role. As indicated above, the NMFS (2008) biological opinion (BO) required the development and implementation of a plan to avoid or minimize project-related turbidity from water supply and flood control operations that involve Lake Mendocino storage and CVD releases. As this has not yet occurred, additional investigation into the mechanisms controlling project turbidity and potential solutions have been incorporated into the project description of the new (2023) biological assessment (BA) along with avoidance and minimization measures.

Background—Lake Mendocino and Existing CVD Facilities and Operations

A description of Lake Mendocino and existing CVD facilities and operations is included in the Lake Mendocino Master Plan (USACE 2019) and quoted below with footnotes removed:

"*Reservoir* The Lake Mendocino reservoir comprises approximately 1,956 acres in Coyote Valley, with a gross pool capacity of 122,500 acre-feet. The East Fork of the Russian River, which originates in the Eel River watershed, flows into Lake Mendocino. A majority of the inflow into Lake Mendocino is regulated by the Potter Valley powerhouse diversion tunnel. Future reductions in this diversion could significantly impact the lake level. The reservoir is owned in fee by USACE.

Embankment The CVD is a compacted, impervious, earth filled embankment that was constructed in zones, comprising impervious clay and silt materials. The earthen embankment is 160 feet high and has a crest length of 3,500 feet.

Spillway The spillway for CVD is located 0.6 miles upstream from the left abutment of the dam embankment. There is an approach channel, an un-gated concrete ogee spillway control section, and a discharge channel. The spillway is approximately 1,300 feet long and 200 feet wide.

Outlet Works The outlet works for Lake Mendocino comprise an approach channel, intake tower, conduit, outlet chute, and an outlet channel. The approach channel extends from the East Fork of the Russian River to the concrete intake structure. The reinforced concrete intake tower is located immediately upstream from the CVD, and is accessible via the dam crest. The tower contains a machinery room, shaft, and a control house. There are three 5 feet by 9 feet hydraulic slide gates located in the control tower. The outlet chute includes a drop structure and stilling basin, and the outlet channel is about 50 feet wide and protected by riprap.

Hydro power The Lake Mendocino Hydroelectric Power Plant (LMHPP), Federal Energy Regulatory Commission (FERC) Project No. 2841 , was completed in December 1986. The FERC issued a license to the City of Ukiah in 1982 to generate hydroelectric power through the CVD. The LMHPP is owned and operated by the City of Ukiah, and is an external facility at the base of the CVD. The City of Ukiah has a 50-year FERC license, issued in 1982, for project operation.

Operation of the LMHPP stalled in 1998 due to the minimum flow requirements for the protection of several fish species downstream, as required by the National Marine Fisheries Service (NMFS). NMFS required that minimum flows be maintained on the river to protect certain fish species, resulting in an inoperable hydroelectric plant based on its design. The City of Ukiah made alterations to the design of the LMHPP and operations of the power plant were resumed in January 2007. The hydroelectric facility was designed to produce three megawatts of power during times of acceptable water flows, which comprises about 10% of the City of Ukiah's overall power production."

Investigation Needs and Focus

The proposed investigation would require the expertise of key Lake Mendocino/CVD operations personnel from USACE and SW, who have knowledge of the bathymetry and temperature, turbidity, and dissolved oxygen profiles of Lake Mendocino (see additional discussion below) as well as operation of the three 5 ft x 9 ft gates and other facilities, limitations of current facilities and operations, and additional data needs. The USACE has convened a technical advisory committee (TAC) which is seeking both to better define the problem to be addressed and to prioritize potential solutions. For example, some suggestions that may better define the problem include the following:

- Develop a conceptual model for the processes leading to both episodic and chronic turbidity impacts as they may require different solutions (Levanthal 2010);
- Modeling sediment distribution and transport in Lake Mendocino and how they relate to the design and operation of the Dam outlet infrastructure so that potential modifications may be identified (Levanthal 2010);
- Increase understanding of the dynamics of turbidity in the Russian River, including organic vs. inorganic material (Jeff Church, Sonoma Water, pers. comm., April 29, 2021); modeling likely would be useful to address this task as well.

At least two solutions to address CVD turbidity impact that have been proposed previously:

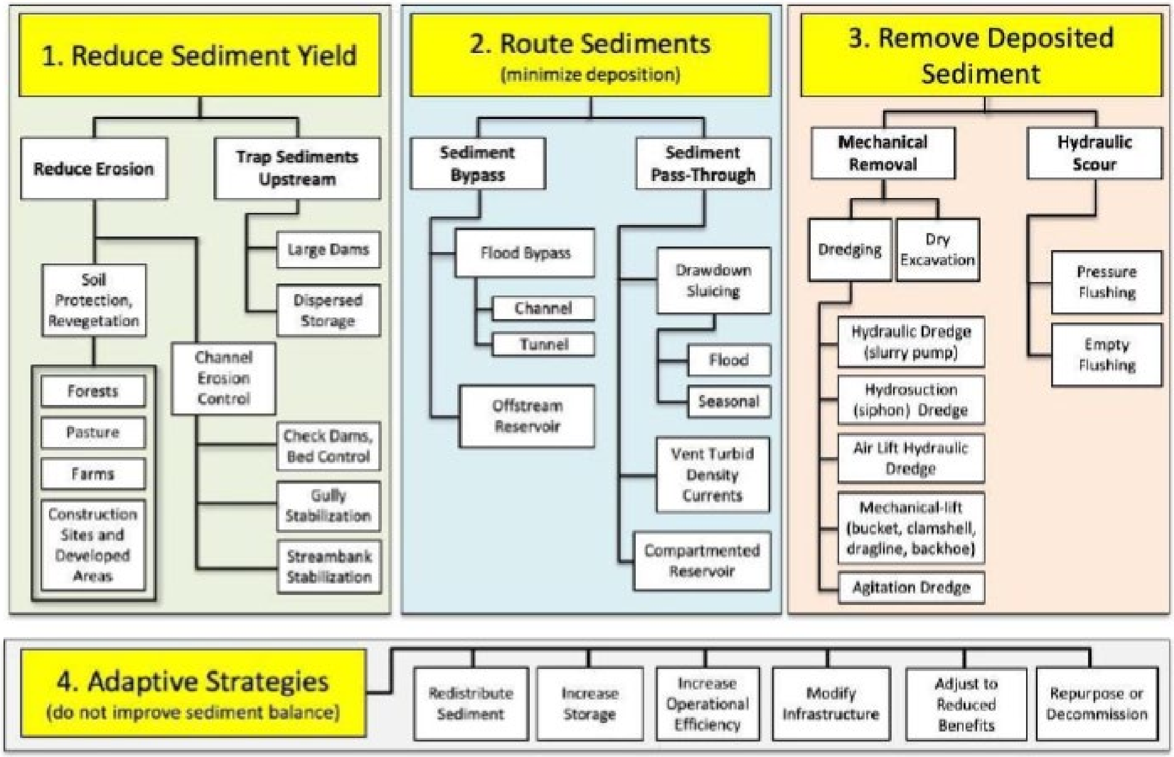
1. *Dredging Lake Mendocino.* As of 2010, USACE estimated that 7.2 million cubic yards of sediment would need to be removed from Lake Mendocino at a cost of $150 million dollars if the sediment is contaminated as expected (Levanthal 2010). Additional costs for maintenance dredging likely would be required as well.

However, recent work (Morris 2020; WEDA 2021) has identified a variety of dredging methods and other techniques that can be used to remove sediment from reservoirs (Figure 11). Additionally, there are completely different approaches that may be employed to alleviate the problem of reservoir sedimentation (and in this case, project-related turbidity impacts). These include reducing sediment yield from upstream sources, routing sediment around instead of through the reservoir, and implementing adaptive strategies that do not involve changing the volume of sediment in the reservoir (Figure 11). The applicability of this broader suite of techniques to addressing the sediment problem in Lake Mendocino could be investigated further by the TAC.

2. *Moving or modifying the CVD outlet.* This solution would be categorized as an “adaptive strategy” as described by Morris (2020) and WEDA (2021). Levanthal (2010) states that “the location of the outlet works at the bottom of the reservoir appears to exacerbate the problem of turbidity and downstream water quality.” He suggests that modifying the outlet infrastructure to take water higher up in Lake Mendocino could be an alternative to consider. Resource agency discussion on April 29, 2021, indicated that multiple vertical discharge locations should be considered because there may be a “sweet spot” where turbidity is low but cold water still occurs for release.

   Temperature and turbidity profiles of Lake Mendocino are available to compare over seasons and years. Other parameters, such as dissolved oxygen, are measured as well. In 2021 (Figure 12), temperature was uniform at all lake depths in March and from September through November due to seasonal turnover, except for being warmer at the surface. This means that water could have been drawn from locations with up to 40 NTU less turbidity at depths from about 10 to 25 feet compared to the bottom with no effect on temperature. In the month of June from 2015 through 2021 (Figure 13), the coldest water generally was available at a depth of 40 feet or greater. If water could have been drawn from 40 feet instead of from the very bottom of the lake, turbidity would have been reduced by approximately 10 NTU in 2 of 6 years, i.e., in 2016 and 2019, with little improvement occurring in the remaining years. The frequency of occurrence, stability, and vertical location of this low temperature, low turbidity sweet spot in Lake Mendocino could be investigated further by the TAC perhaps through modeling to determine if discharging water from different locations in the water column could be used effectively to reduce project-related turbidity impacts.

Further refinement of potential solutions and additional considerations were suggested by NMFS and the North Coast RWQCB at a meeting on March 22, 2022. Staff from NMFS indicated that developing a table from the Lake Mendocino temperature and turbidity profiles described may



Source: Morris 2020

Figure 11. Classification of methods to manage reservoir sedimentation. From WEDA (2021); their Figure 4.

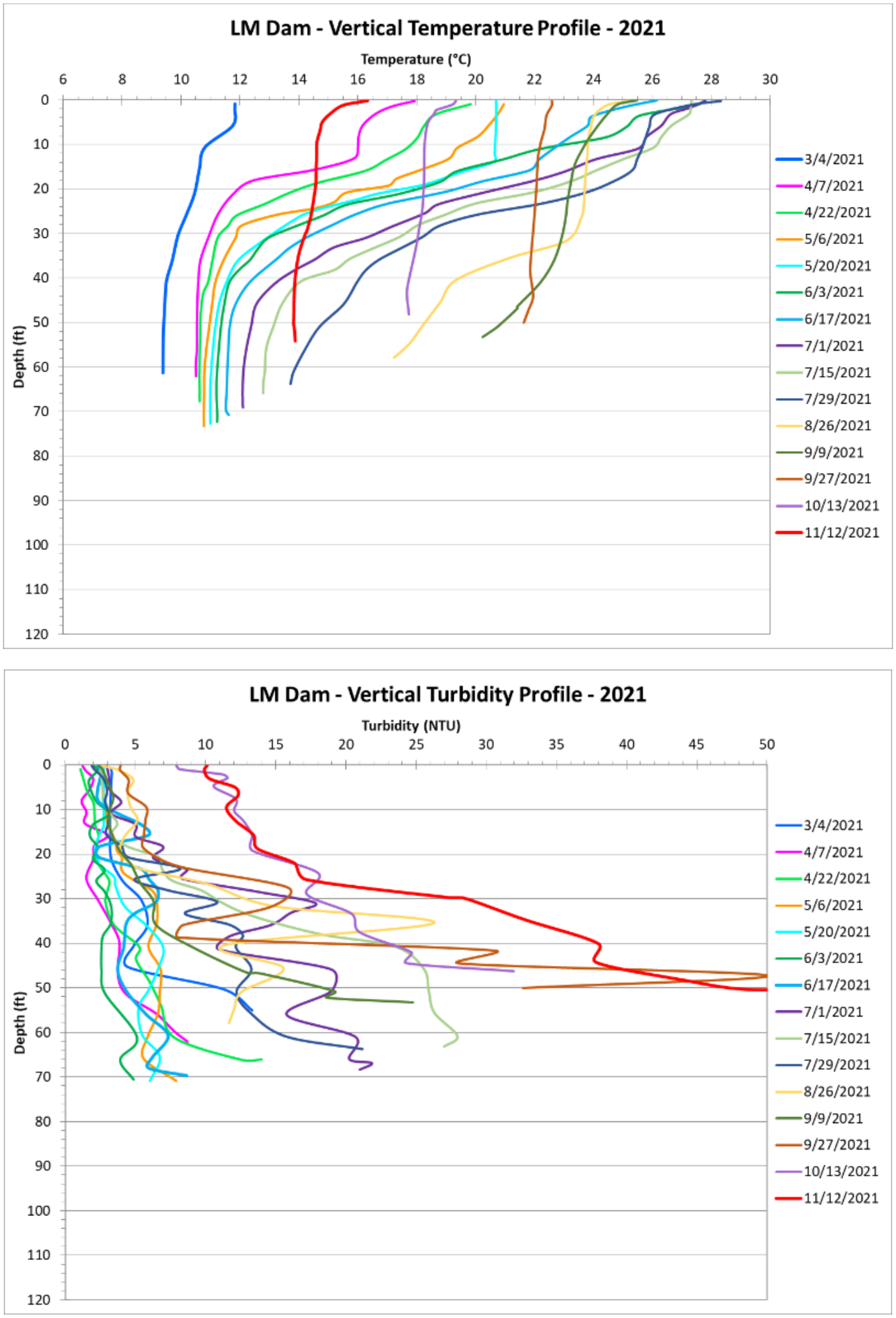
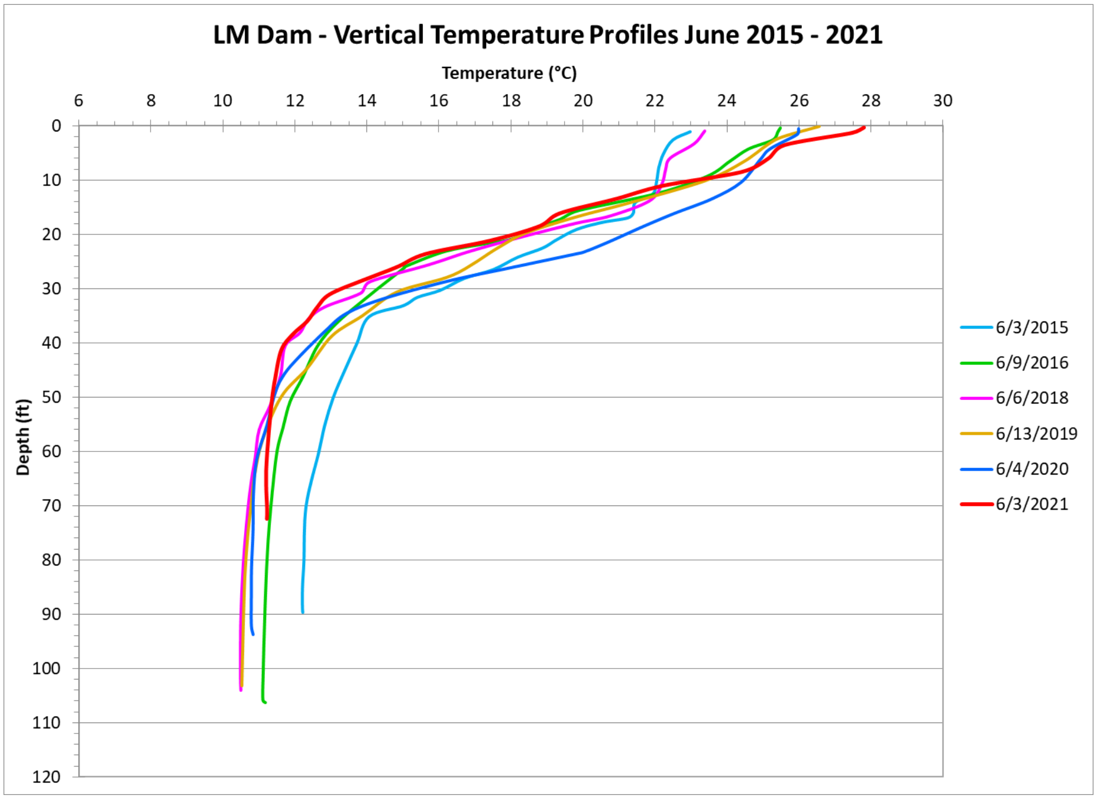


Figure 12. Bi-weekly depth profiles of temperature (top) and turbidity (bottom) in Lake Mendocino for March through November 2021. Profiles courtesy of Jeff Church, Sonoma Water.



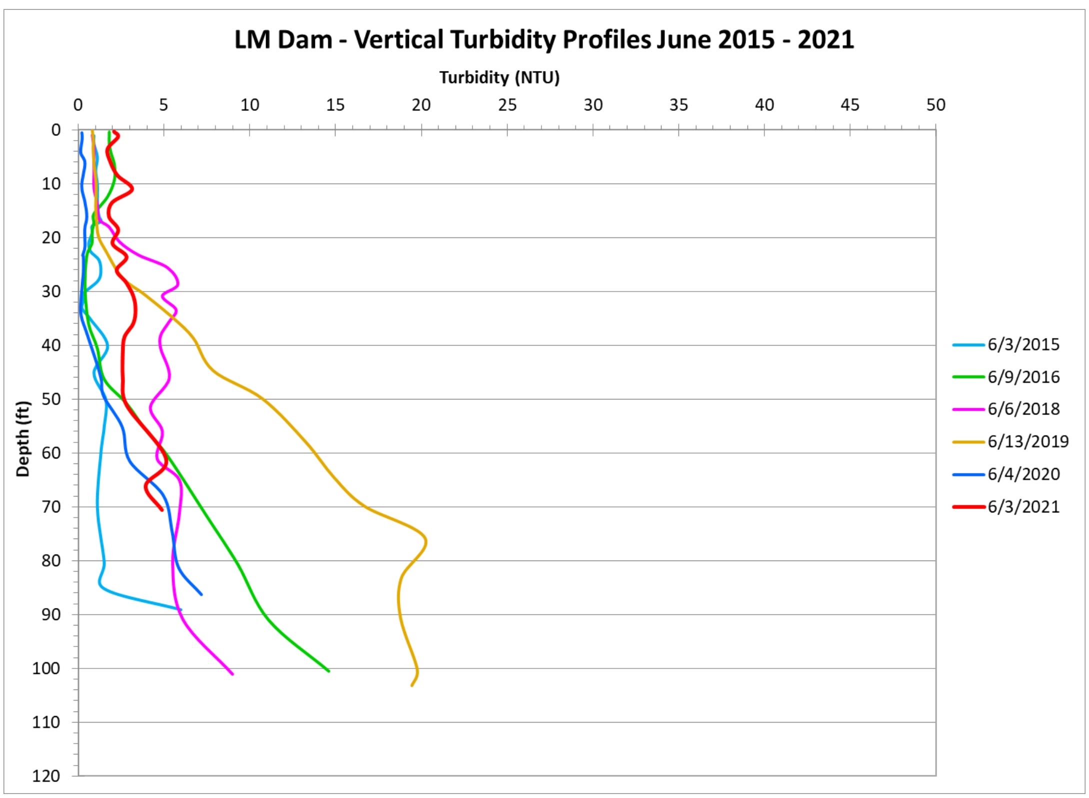


Figure 12. June depth profiles of temperature (top) and turbidity (bottom) in Lake Mendocino for the years 2015 through 2021. Profiles courtesy of Jeff Church, Sonoma Water.

be useful for comparing the advantages of drawing water from different levels in the water column. A creative proposition was that not all flow may need to be treated in order to achieve a measurable reduction in turbidity downstream from CVD. Land adjacent to CVD is an open field that once was a small borrow pit and is owned by USACE. Staff from NMFS suggested that a wetland water treatment system (e.g., using Cheto sand) potentially could be located there to filter some of the water from Lake Mendocino. To assess whether this would be a viable solution, the TAC would need to determine the treatment volume required to effect a change in turbidity downstream, likely through modeling.

Targeted suction dredging in Lake Mendocino also was suggested for locations where sediment is deposited near the intake. Additionally, intentionally disturbed sediment could simply be allowed to flush downstream at times when elevated turbidity levels may be less impactful to ESA-listed salmonids. Updated bathymetry measurements and modeling may allow the potential effectiveness of this solution to be assessed.

Upstream sediment source control was discussed and ranged from filtering the inflow to CVFF to reducing the turbidity generated by the PG&E's Potter Valley project and its transfer of water from the Eel River to the East Fork Russian River. Staff from the North Coast RWQCB also stated that disconnecting roads from streams in the upper Russian River watershed would be beneficial as the practice has been shown to reduce the duration of elevated turbidity levels in other watersheds.

The NMFS confirmed support for establishing "no wake zones" near the CVD outlet structure to reduce shoreline erosion/slumping. This would be a relatively small, inexpensive change to lake management that could partially address the turbidity problem and be implemented fairly quickly. We note that Lake Mendocino has been closed to boating in recent years due to low water levels from drought with no obvious reduction of turbidity in CVD releases, but effects may differ when lake levels are higher. Including turbidity inputs from Lake Sonoma and WSD in the investigation also was supported. Finally, NMFS staff expects that turbidity monitoring will be continued, hence the TAC likely will need to develop an updated turbidity monitoring plan. Monitoring should include the collection of data to develop flow-turbidity and/or turbidity-SS relationships for the Russian River watershed downstream of both Lake Mendocino and Lake Sonoma.

PROPOSED PLAN (PROJECT DESCRIPTION FROM THE 2023 BIOLOGICAL ASSESSMENT)

The following plan is from section 3.2.2.4 of the 2023 BA:

"**Lake Mendocino Turbidity Management**

Elevated levels of turbidity remain a persistent condition in Lake Mendocino and in reaches of the Russian River downstream. Earlier efforts by USACE attempted to analyze turbidity levels and potential impacts at a series of sampling stations downstream of the reservoir, but the need for additional information such as Russian River-specific flow-turbidity and turbidity-suspended sediment rating curves has become apparent.

Turbidity Technical Advisory Committee

To determine mitigation actions for elevated turbidity levels, USACE has formed a technical advisory committee (TAC) including fishery biologists and water quality specialists. The TAC has been charged with both better defining the magnitude of the problem specifically as it affects ESA-listed species and advising USACE on potential solutions. The problem to be addressed will focus on reducing measurable turbidity effects to ESA-listed salmonids to acceptable levels. Defining what these acceptable levels are will be necessary to determine when a solution has been successfully implemented. The USACE identified initial TAC members from NMFS, CDFW, and the North Coast RWQCB and held a TAC kickoff meeting in February 2023 and a second meeting in July 2023. The USACE presented some initial discussion topics (e.g., problem definition, acceptable turbidity targets, the concept of "baseline" turbidity, etc.) to the TAC and drafted a Memorandum of Understanding (MOU) for the TAC. However, USACE now anticipates that the TAC will utilize an existing MOU involving these same agencies.

By September 23, 2023, USACE will issue a final turbidity report analyzing the collected turbidity data collected at Gauge Numbers 11461000 (West Fork, Ukiah at Lake Mendocino Drive Bridge), 11461500 (East Fork, Calpella), 11462000 (East Fork Russian River downstream of Coyote Valley Dam), 114625000 (Hopland), 1146382 (Jimtown), 11465240 (Dry Creek at Lambert Bridge) and transmit the final turbidity report to the TAC. Additionally, USACE will enlist the assistance of two TAC-approved peer reviewers of TAC recommendations and products who have expertise with turbidity and/or suspended sediment dynamics in reservoirs and rivers impacted by dams. Additional description of anticipated TAC activities is included below.

Turbidity Monitoring

The USACE will conduct turbidity monitoring at the following sites:

1. East Fork Russian River downstream of Coyote Valley Dam (Gauge No. 11462000), continuously by August 31, 2023;

2. Dry Creek downstream of Warm Springs Dam (Gauge No. 11465000), continuously by August 31, 2023; and

3. West Fork Russian River at Lake Mendocino Drive Bridge (Gauge No. 11461000), intermittently by October 15, 2023, and continuously by December 31, 2023.

The USACE has proposed conducting turbidity monitoring at the following two additional sites:

1. Lake Mendocino; in the thalweg with data collection at 20-foot intervals and at 5 feet off the bottom; and

2. The mainstem Russian River at Talmage, at or near USGS gauge (Gauge No. 11462080), if a cooperative agreement can be reached with USGS and private landowner(s).

The TAC has been apprised of the proposed monitoring locations and given the opportunity to suggest alternative locations for (4) and (5). The USACE will document the status of all turbidity monitoring by September 23, 2023. Turbidity monitoring is expected to begin at the last two sites or alternatives by December 31, 2023, pending any necessary agreements or permit requirements.

Additionally, USGS collects daily discharge, temperature, and turbidity data at two other locations of interest:

1. East Fork Russian River approximately 1 mile upstream of Lake Mendocino near Calpella (Gauge No. 11461500); and

2. Mainstem Russian River mainstem approximately 13 miles downstream of CVD near Hopland (Gauge No. 11462500).

The USACE will summarize the turbidity data from the above seven locations by water year (i.e., from October 1 through September 30) and present it in an annual report submitted on the following December 31 to the TAC and NMFS for review. The USACE plans to submit the initial annual report on December 31, 2024, and continue the submittals for a minimum of five years. Should an extension of the December 31 deadline be necessary in any given year, a request for the extension will be submitted to NMFS in writing with a justification one week prior to the deadline.

Short-term Implementation Actions

To avoid or minimize impacts to ESA-listed salmonids, USACE proposes to relate flow inputs to Lake Mendocino, release ramping rates, gate positions, etc. to turbidity measurements at the CVD outlet in an effort to determine operational scenario(s) that minimize the release of turbidity to the Russian River. Some flexibility in ramping rates is anticipated. The “best” operational scenario(s) will be determined and implemented within the constraints of the CVD WCM and O&M manual. USACE will meet with the TAC to plan these activities and review existing data within 1 year of the date of the biological opinion.

The following activities are proposed to better define the turbidity issues related to releases from CVD, including:

- Develop flow-turbidity curves, turbidity-suspended sediment curves, or other appropriate rating curves specifically for the Russian River;
- Develop and refine a conceptual model for the processes leading to both episodic and chronic turbidity impacts;

- Model sediment distribution and transport in Lake Mendocino and how they relate to the design and operation of the Dam outlet infrastructure; and

- Increase understanding of turbidity dynamics in the Russian River, including organic versus inorganic material.

USACE anticipates that the research to develop the rating curves will be conducted by a university graduate student, and that modeling will be conducted by the USACE Engineering Research and Development Center. USACE will present draft scopes of work, proposals, etc. for this work to the TAC for review and comment within 1 year of the date of the biological opinion. Due to the lead time required for approval and funding of these efforts, USACE expects the work to begin approximately three years from the date of the biological opinion. Results will be presented to the TAC for use in assessing the proposed solutions to the turbidity problem, below.

Long-term Implementation Actions

Potential solutions proposed by NMFS and others for reducing turbidity in and downstream from Lake Mendocino include the following:

- Dredge Lake Mendocino, including using targeted suction dredging near the outlet works or other areas from which sediment may be mobilized;

- Modify CVD infrastructure (e.g., the dam itself, outlet works, etc.) to allow variable water release locations, depending on conditions;

- Divert a portion of the CVD outflow into a biofilter; and

- Reduce sediment input to Lake Mendocino from upstream sources.

These sorts of complex solutions would require authorization and funding separate from the current flood control and water supply project. Additionally, there is substantial uncertainty about their potential effectiveness and which, if any, could or should be implemented. The USACE intends to pursue funding under section 216 of the Flood Control Act of 1970 (P.L. 91-611) for a reconnaissance level study of this issue to begin within three years of the date of the biological opinion. The TAC will provide input and review the results of this study, and USACE will determine a path forward potentially leading to implementation of one or more solutions if appropriate, pending authorization and funding.”

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Cover Photo: Flood control release from Coyote Valley Dam (Lake Mendocino) in 2016. Photo by J.D. Hardesty. https://www.spn.usace.army.mil/Media/Images/igphoto/2001486359/

ADDENDUM

This addendum is intended to address NMFS's comment on the draft turbidity report questioning the data quality because USACE measurements of Dam Outlet Turbidity show little correlation with Dam Outlet flow or Hopland turbidity or flow, even though the latter three parameters all show substantial correlation.

Introduction

Reasonable and Prudent Measure #4 of the 2008 biological opinion did not require USACE to measure flow or correlate turbidity with flow, although it was acknowledged in subsequent meetings between USACE and NMFS (e.g., April 29, 2021) that this would be desirable. We expect turbidity generally to be positively correlated with flow, but other studies have shown that the relationship between flow and turbidity can be complex at lower flows as well as in watersheds that are managed (Dunlop et al. 2009; Yalaletdinova et al. 2018; Wang and Steinschneider 2022). Furthermore, elevated turbidity from CVD releases has been noted as being a concern in two specific situations during wet and dry periods, respectively: (1) when flows from the West Fork have declined following winter rainstorms but flood control releases from CVD continue, and (2) when summer flows, although lower than winter flows, are driven by CVD releases alone as is typical. Our understanding is that turbidity may be released from CVD due to mechanisms other than simple flow volume, e.g., due to suction of fine sediment into release gates as flows ramp up (Tom Daugherty, NMFS, pers. comm., March 16, 2022).

That said, obtaining quality turbidity data on the Russian River below CVD and elsewhere has been a challenge and the data quality issue identified by NMFS likely is real. Regarding the 2009-2010 turbidity data collected by the graduate student referenced in NMFS's comments, according to Levanthal (2010) she indicated that most of the data "were unusable due to problems with fouling of the probe, datalogger issues, and damage to the wires caused by mice." As stated in the present USACE report, "unreasonably high values (i.e., up to 3,000 nephelometric turbidity units (NTU)) were recorded for some of the USACE data (at the Dam Outlet and elsewhere) possibly due to the sensors out of the water or covered in bottom sediment (Josh Burkhead, USACE, pers. comm., July 21, 2021)". To address this issue, all data greater than 930 NTU, the highest value recorded at the Hopland USGS gauge, were deleted from the analysis." In retrospect, it is likely this simple attempt to address the data quality issue was insufficient.

The NMFS's comments also noted the opposite case which also may be problematic i.e., that "on the other hand, some turbidity values are low (or zero) when the dam (flow) releases are high." We know of no straightforward method to select data for elimination to correct this issue, and so have chosen to address NMFS's comments by examining shorter time periods and specific scenarios that match the two situations of concern described above.

Methods

To address the data quality issue, USACE conducted additional analysis focused on turbidity comparisons that were obtained when West Fork flows were at least 10 cfs or greater or 10 percent of the CVD flow or greater. This approach eliminated a large number of 0 or 1 NTU measurements obtained during periods when little or no flow was measured in the West Fork (i.e., typically, but not always, in the summer and fall). We also inspected the turbidity data for both Dam Outlet and especially West Fork for believability/usability, i.e., that turbidity appeared to *track changes in flow at least loosely*. Data were examined post hoc for correlations between flow and turbidity at all sites, and between Hopland turbidity and turbidity at West Fork and Dam Outlet. Spearman correlations were used due to known spikes in the data and expected non-normality. Turbidity data is available only for 2012 - 2014 for the West Fork, so those are the years for which comparisons between West Fork and Dam Outlet are made. The USACE separately addressed flow and turbidity from CVD during low flow periods (i.e., when West Fork flow measured less than 10 cfs or less than 10 percent of Dam Outlet flow) over a longer period, i.e., 2012 - 2017, which is the primary period focused on in NMFS's comments.

For the low flow analysis, we only present data for which there is a significant positive correlation between Hopland and Dam Outlet turbidity, Dam Outlet flow and turbidity, or Calpella Flow and Dam Outlet turbidity. For all analyses, USACE ensured that turbidity measurements greater than 930 NTU were removed from the data set for the West Fork and CVD as stated in the original report. These high turbidity measurements are considered faulty (but see brief discussion in several locations below); the 930 NTU cutoff was used because that was the highest turbidity recorded at Hopland by the USGS for the original period of the data analyzed. Finally, when available, we used approved flow data obtained directly from USGS (i.e., NWISWeb) because data obtained by the California Department of Water Resources from NWISWeb and uploaded to the California Data Exchange Center server contains discrepancies introduced by the transfer process (Christine O'Neil, USGS, pers. comm., June 21, 2023). Consequently, the flow data shown the figures below especially for Hopland may differ slightly from the flow shown in NMFS's figures.

<u>Fall and Winter</u>

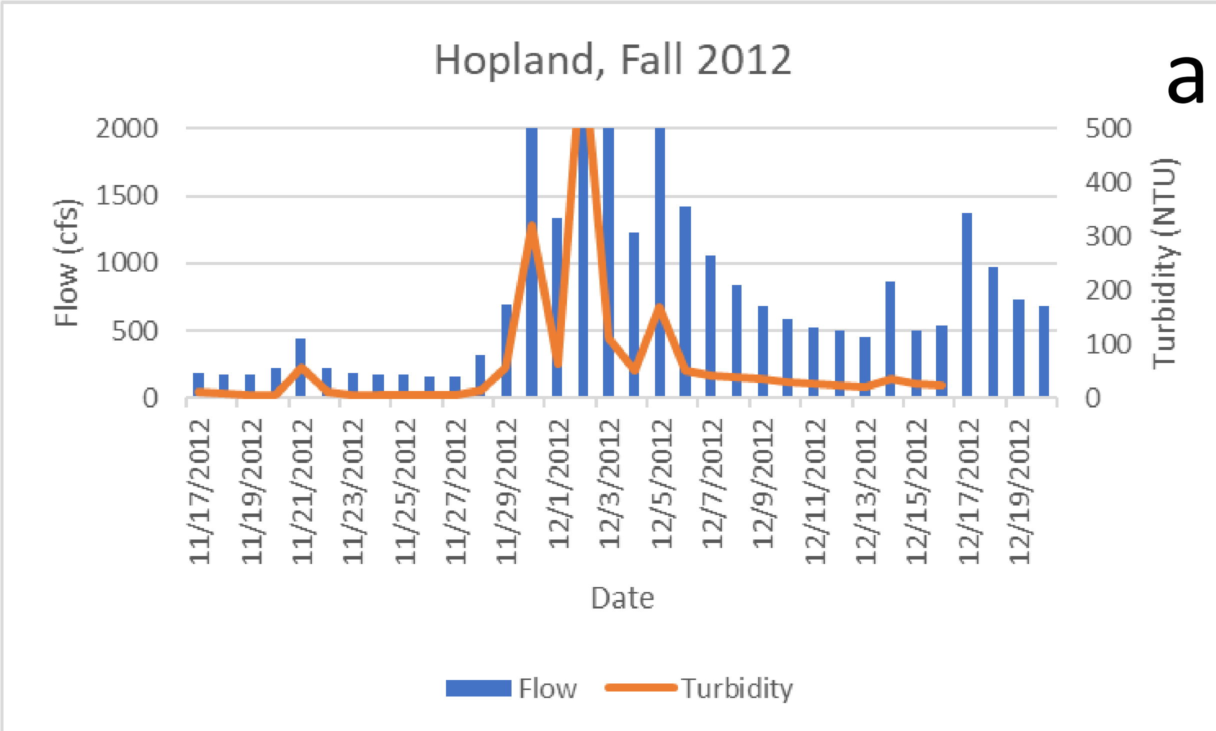
Although the fall season often is dry, fall 2012 was not so we are including fall 2012 with our discussion of winter 2012-13 and winter 2014. In fall 2012 median turbidity was 26 NTU at Hopland, 13 NTU at West Fork, and 82 NTU at CVD outlet. However, maximum recorded turbidity was 655 NTU at West Fork versus 454 NTU at CVD outlet. In winter 2012-13 median turbidity was 17 NTU at Hopland, 2 NTU at West Fork, and 58 NTU at CVD outlet, but maximum recorded turbidity was 826 NTU at West Fork versus 366 NTU at CVD outlet. In winter 2014, median turbidity was 6 NTU at Hopland, 12 NTU at West Fork, and 24 NTU at CVD outlet, but the maximum recorded turbidity was much higher at West Fork than CVD outlet (524 vs 47 NTU). We note that these maxima and other spiking turbidity levels could have been errors in the data. However, they were not uncommon and often (but not always) were correlated with flow. Future monitoring should determine whether these spikes actually occur.

Periodic elevated flows indicate that storms occurred during fall 2012 and the winters of 2012-13 and 2014. Simple inspection of flow and turbidity suggest that two storms occurred in fall 2012. Flow and turbidity were strongly correlated at both Hopland (Spearman's rho = 0.92; $p < 0.001$; Figure 1a) and West Fork (Spearman's rho = 0.91; $p < 0.001$; Figure 1b). Flow at West Fork was as low as 10 cfs in early November and as high as 7499 cfs during the largest storm at the beginning of December, but generally was about 200 to 400 cfs with turbidity measuring about 5 to 15 NTU after the storms by the end of fall (i.e., December 20, 2012). Flow at the CVD outlet was similar by the end of fall (i.e., generally about 200 to 300 cfs), but turbidity tended to be higher (i.e., about 80 to 90 NTU; Figure 2a). This partially corresponds to the first scenario of concern described above—although West Fork and Dam Outlet flows were similar after storm flows subsided, turbidity measured at the Dam Outlet was consistently higher.

Hopland turbidity was strongly correlated with West Fork turbidity (Spearman's rho = 0.81; $p < 0.001$) and moderately correlated with Dam Outlet turbidity (Spearman's rho = 0.64; $p < 0.001$), but flow and turbidity at the Dam Outlet in fall 2012 were not significantly correlated (Spearman's rho = 0.04; p = 0.42). However, it has been reported that Dam Outlet turbidity may be linked to Calpella flow and turbidity. Indeed, Calpella flow and Dam Outlet turbidity (Figure 2b) were moderately correlated (Spearman's rho = 0.66; $p < 0.001$). A time lag can be observed around December 5, i.e., Dam Outlet turbidity increased after elevated Calpella flows began to subside. This is consistent with the observation by Levanthal (2010) that declines in turbidity at the Dam Outlet tend to lag those at Calpella. However, no turbidity data are available for Calpella during this period so we could not examine that relationship directly. The lag could be accounted for if turbid water passing Calpella requires time to cycle through Lake Mendocino, or if high flow passing Calpella causes scour and resuspension of sediment as it enters Lake Mendocino, which then requires time to travel downstream. Note that this period leads directly into winter 2012-13, which is discussed next.

The only storm of winter 2012-13 began just prior to Christmas 2012. Flow and turbidity were again strongly correlated at both Hopland (Spearman's rho = 0.83; $p < 0.001$; Figure 3a) and West Fork (Spearman's rho = 0.92; $p < 0.001$; Figure 3b). Turbidity at West Fork declined to about 10 NTU within 10 days of the storm and continued declining to about 5 NTU by mid-January and about 1 NTU by the end of January. Flow in the West Fork also declined during this period from a high of 3,928 cfs to about 30 cfs. In contrast, increased flow at the CVD outlet was delayed until a few days after Christmas and then remained high through about New Years Day 2013 (Figure 4a). Although flow declined to about 150 cfs in the first week of January and remained at 140-150 cfs for the rest of the winter, turbidity at the CVD outlet following the storm declined to about 80, then 70, then 60 NTU through January, and then was somewhat erratic with periods of about 50-60, then 5, and finally 20-25 NTU at the end of the winter in March. Hopland turbidity was moderately correlated with West Fork turbidity (Spearman's rho = 0.55; $p < 0.001$) and strongly correlated with Dam Outlet turbidity (Spearman's rho = 0.76; $p < 0.001$), but flow and turbidity at the CVD outlet again were not significantly correlated (Spearman's rho = 0.14; p = 0.11). Calpella flow and turbidity at the CVD outlet were correlated even more strongly this time (Spearman's rho = 0.85, $p < 0.001$; Figure 4b). In this case, there was no time lag between the Calpella flow increase and increased turbidity being measured at the Dam Outlet. This is a good illustration of the first scenario of concern identified above in that both Dam Outlet flow and turbidity remained high long after West Fork flow and turbidity had declined post-storm.

A different pattern was evident in winter 2014 when flow in the West Fork was too low to make a comparison with the Dam Outlet except for February and March when two storms occurred. Little turbidity data was available for Hopland, yet flow and turbidity were again strongly correlated (Spearman's rho = 0.96; $p < 0.001$ Figure 5a). West Fork flow and turbidity also were again strongly correlated (Spearman's rho = 0.92; $p < 0.001$) and responded as expected to storms with notable increases and then decreases in both parameters; by the end of winter, West Fork flow was about 50 cfs and turbidity was 2 NTU (Figure 5b). In contrast, flow and turbidity at the CVD outlet generally were about 20 cfs and 25 NTU, respectively, and were relatively stable throughout the entire period (Figure 6a). In this case, Hopland turbidity was strongly correlated with West Fork turbidity (Spearman's rho = 0.99; $p < 0.001$) but moderately *negatively* correlated with Dam Outlet turbidity (Spearman's rho = -0.52; $p < 0.05$). This negative correlation and the moderate positive correlation of flow and turbidity at the Dam Outlet (Spearman's rho = 0.46; $P < 0.01$) likely occurred because there was little overall variance in either parameter at the Dam Outlet. Similarly, Calpella flow and Dam Outlet turbidity were moderately *negatively* correlated (Spearman's rho = -0.43; $p < 0.01$; Figure 6b). Inspection of Figure 6b suggests little influence of inflow from Calpella on turbidity released from the Dam Outlet which is different than occurred in fall 2012 or winter 2012-13. Winter 2014 is a good illustration of the second scenario of concern identified above which is thought to apply primarily to dry periods occurring in summer/fall. Presumably, flood control releases were not necessary, and flow was kept low at the Dam Outlet to increase water supply storage, yet turbidity following storms remained high compared to the West Fork.



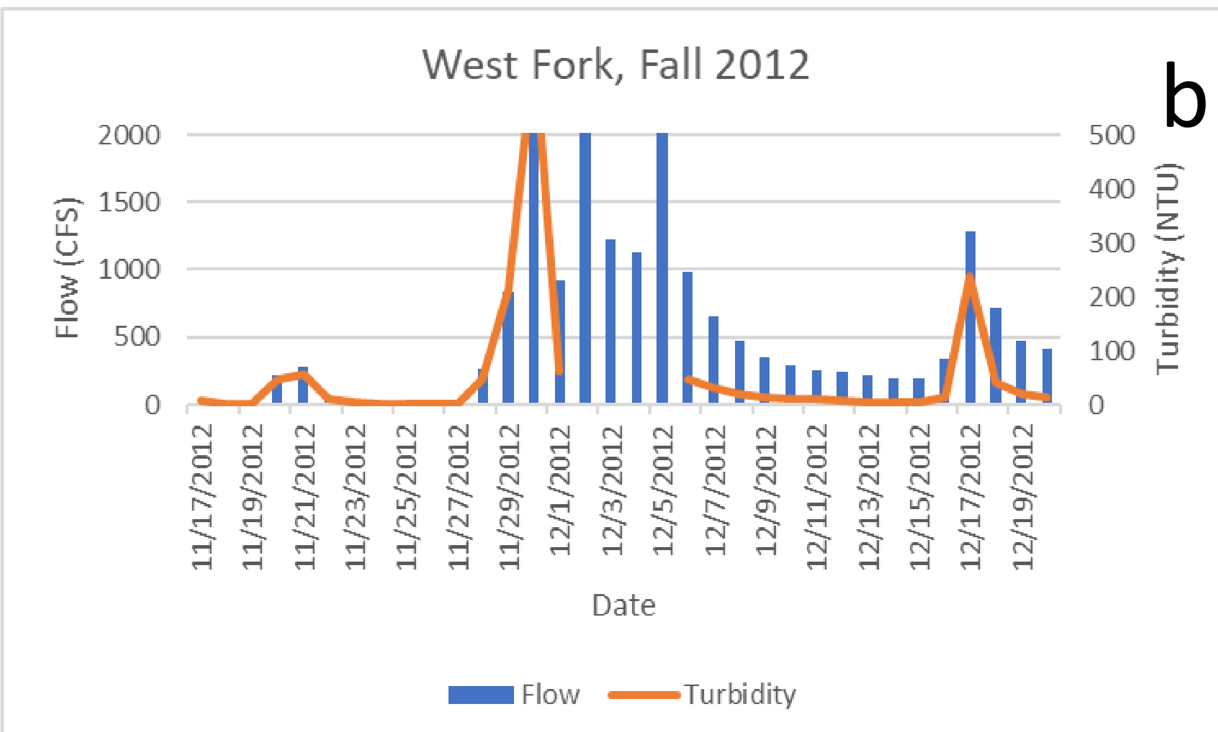
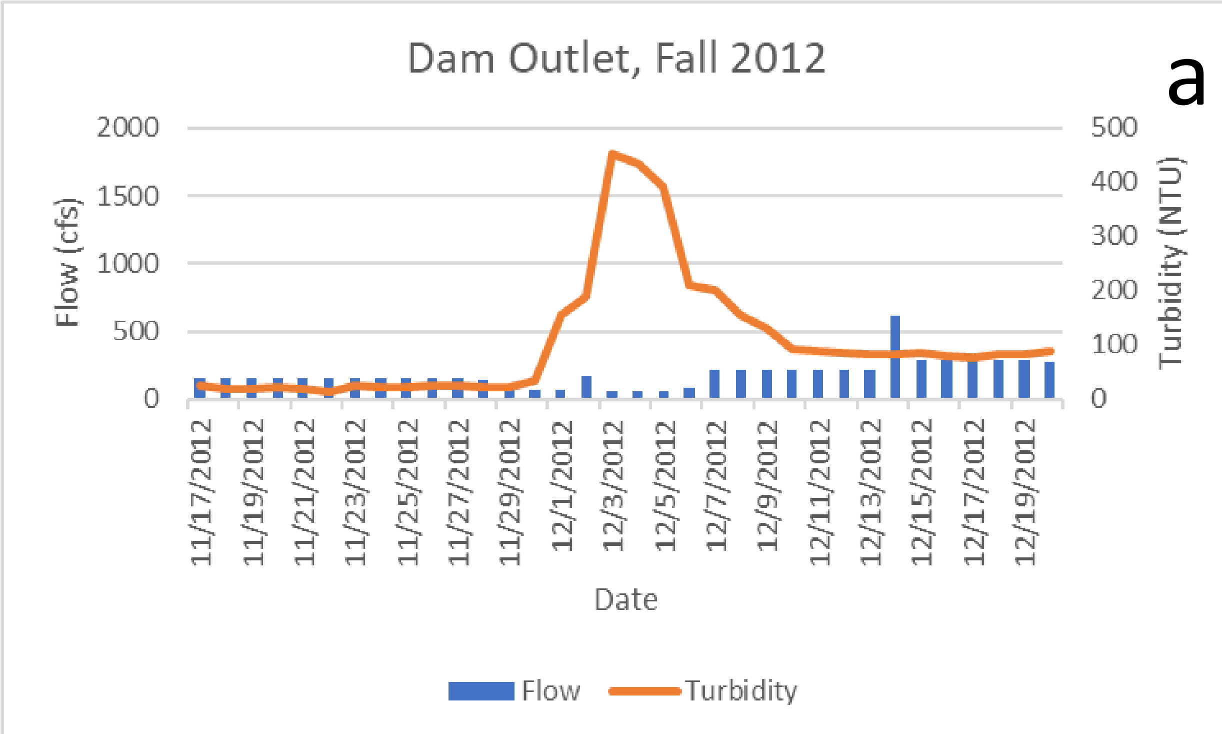


Figure 1. Flow vs. turbidity on the Russian River at Hopland (a) and West Fork (Lake Mendocino Drive Bridge; b) from November 17 through December 20, 2012.



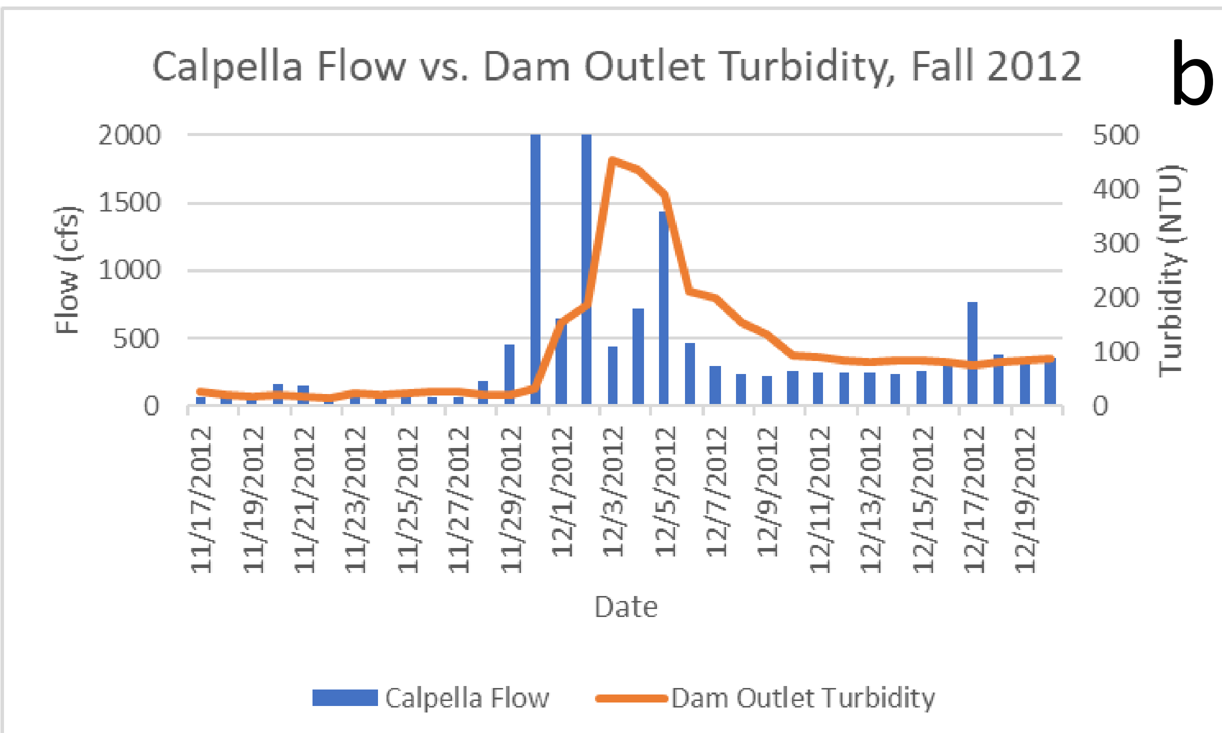
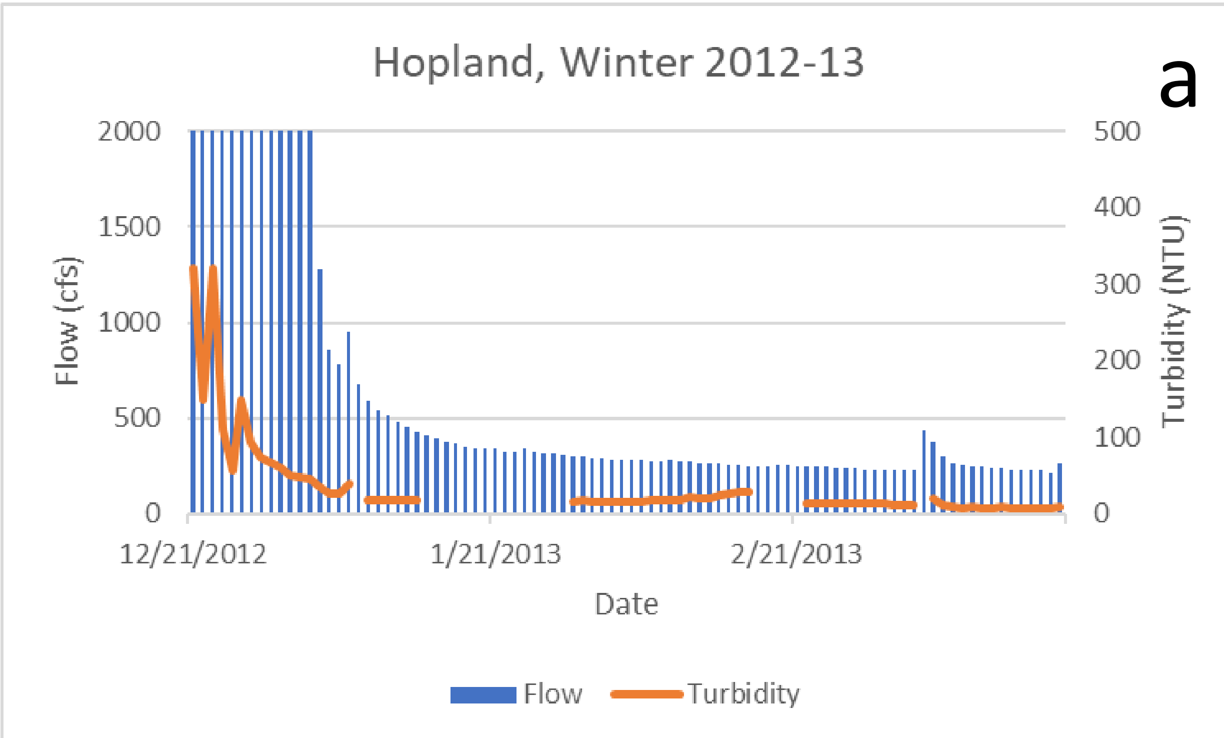


Figure 2. Flow vs. turbidity at Dam Outlet (East Fork Russian River; a) and Calpella flow vs. Dam Outlet turbidity (East Fork Russian River; b) from November 17 through December 20, 2012.



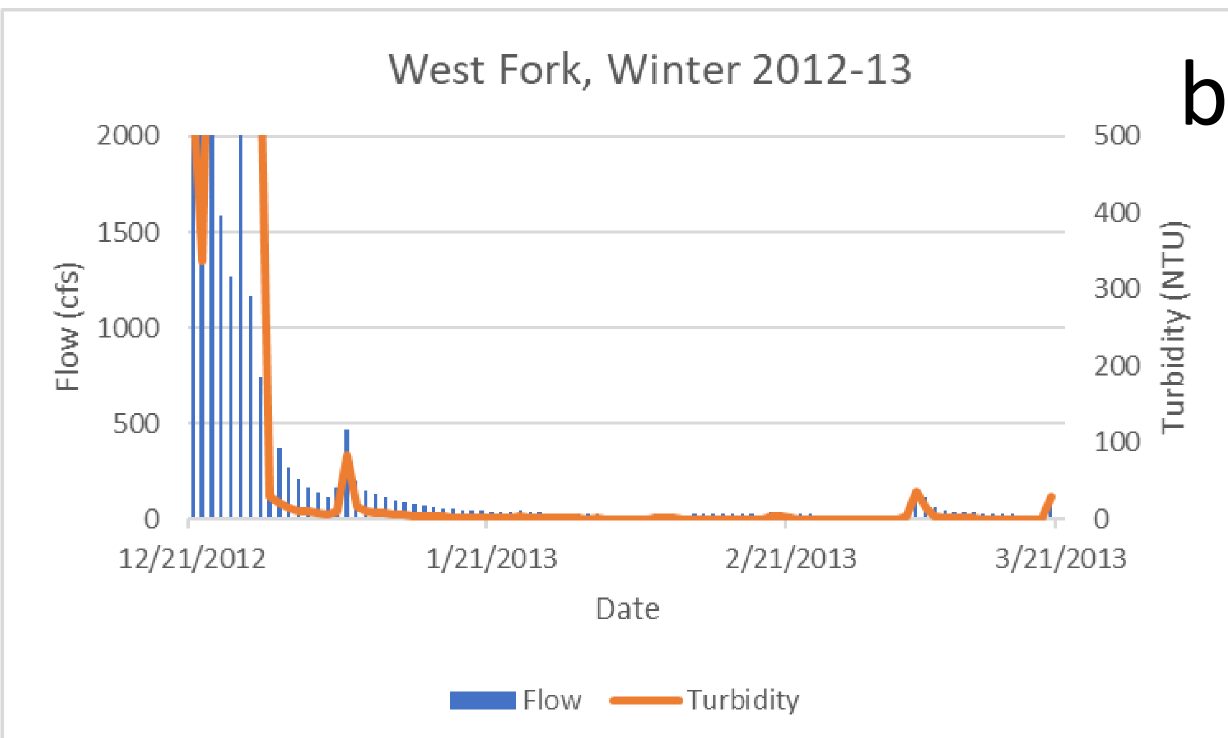
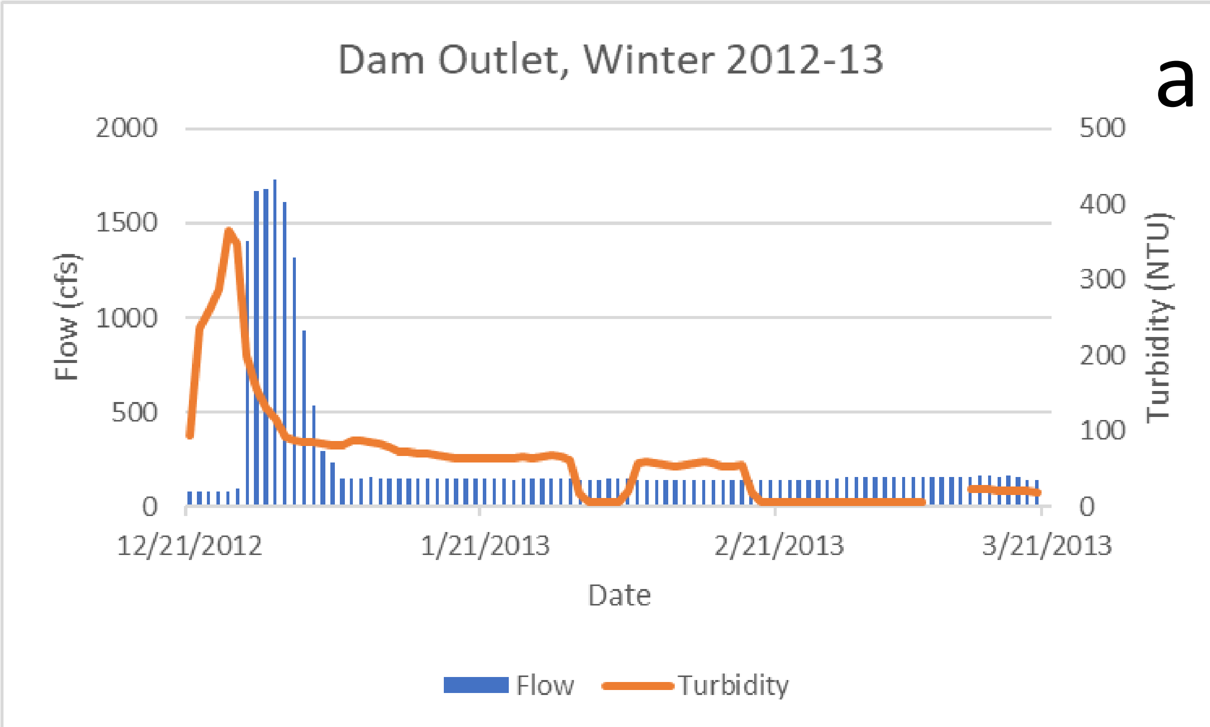


Figure 3. Flow vs. turbidity on the Russian River at Hopland (a) and West Fork (Lake Mendocino Drive Bridge; b) from December 21, 2012, through March 20, 2013.



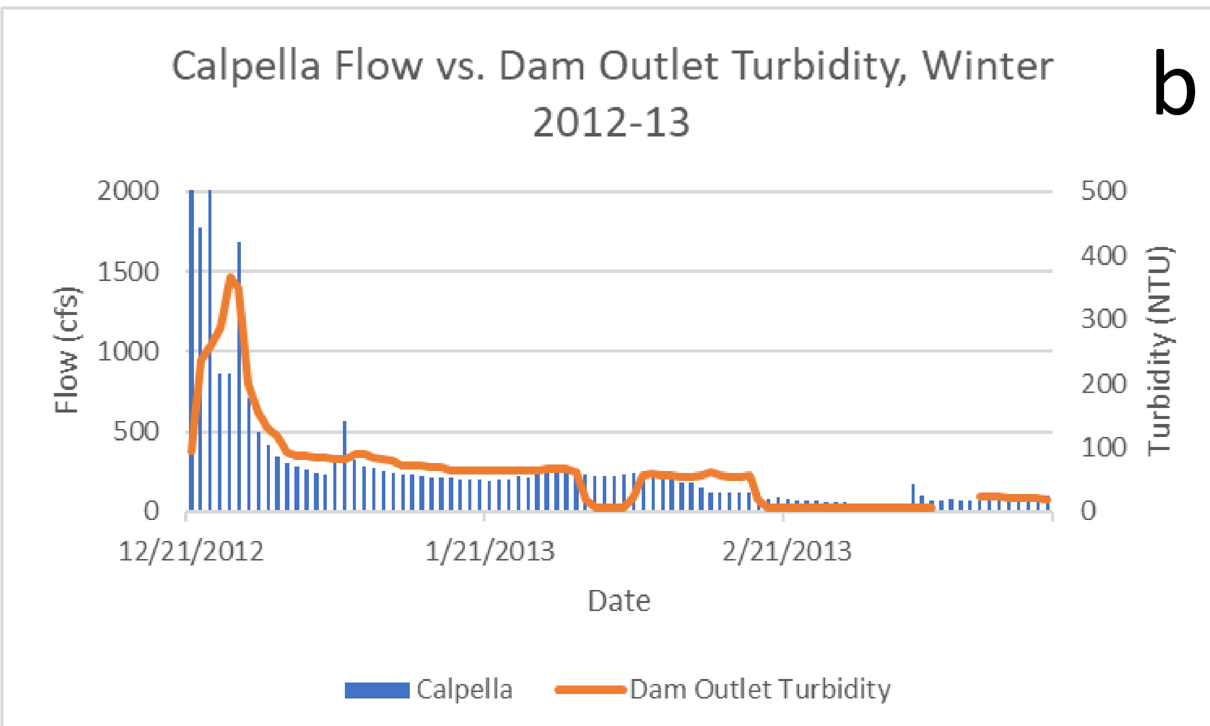


Figure 4. Flow vs. turbidity at Dam Outlet (East Fork Russian River; a) and Calpella flow vs. Dam Outlet turbidity (East Fork Russian River; b) from December 21, 2012, through March 20, 2013.

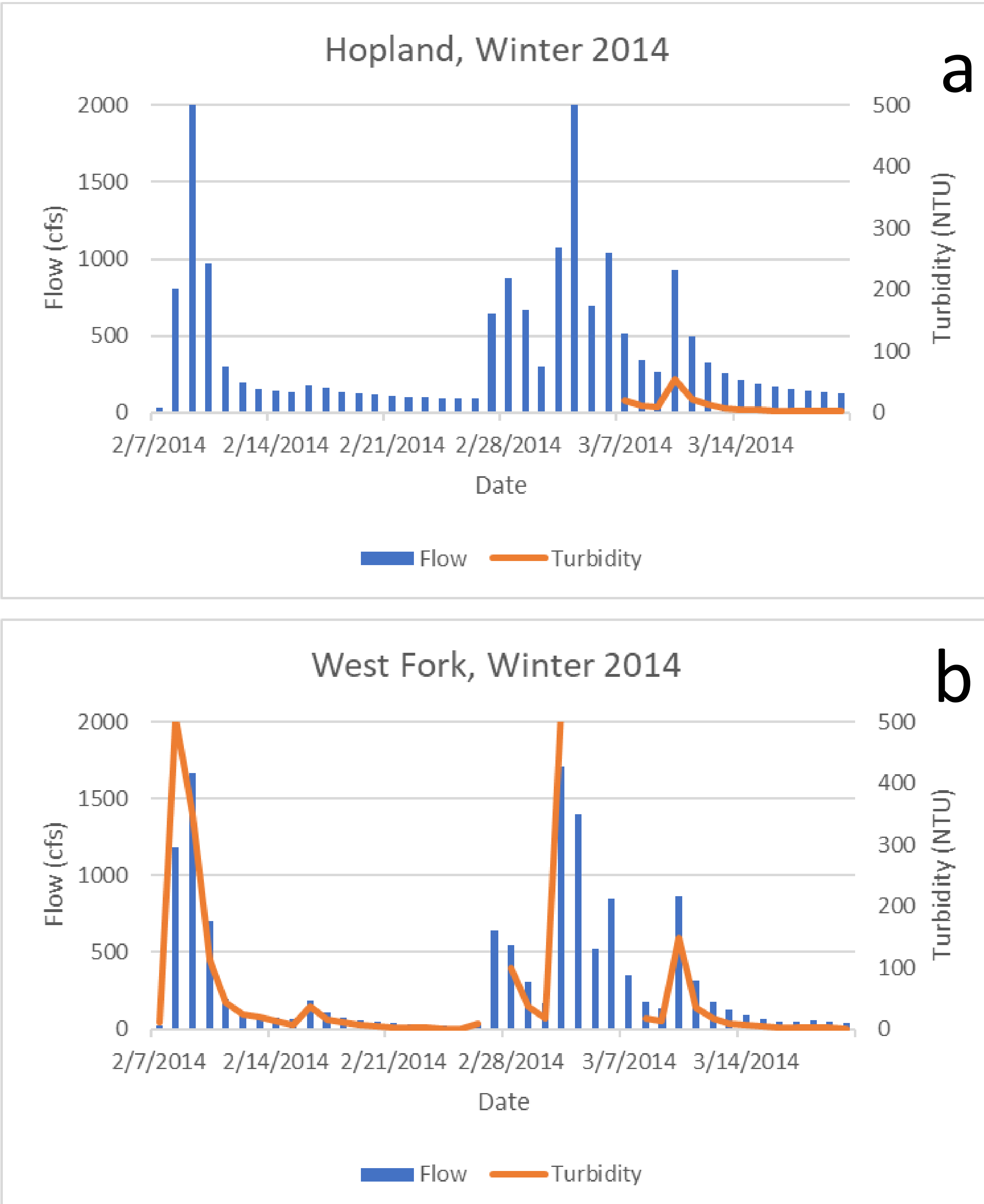
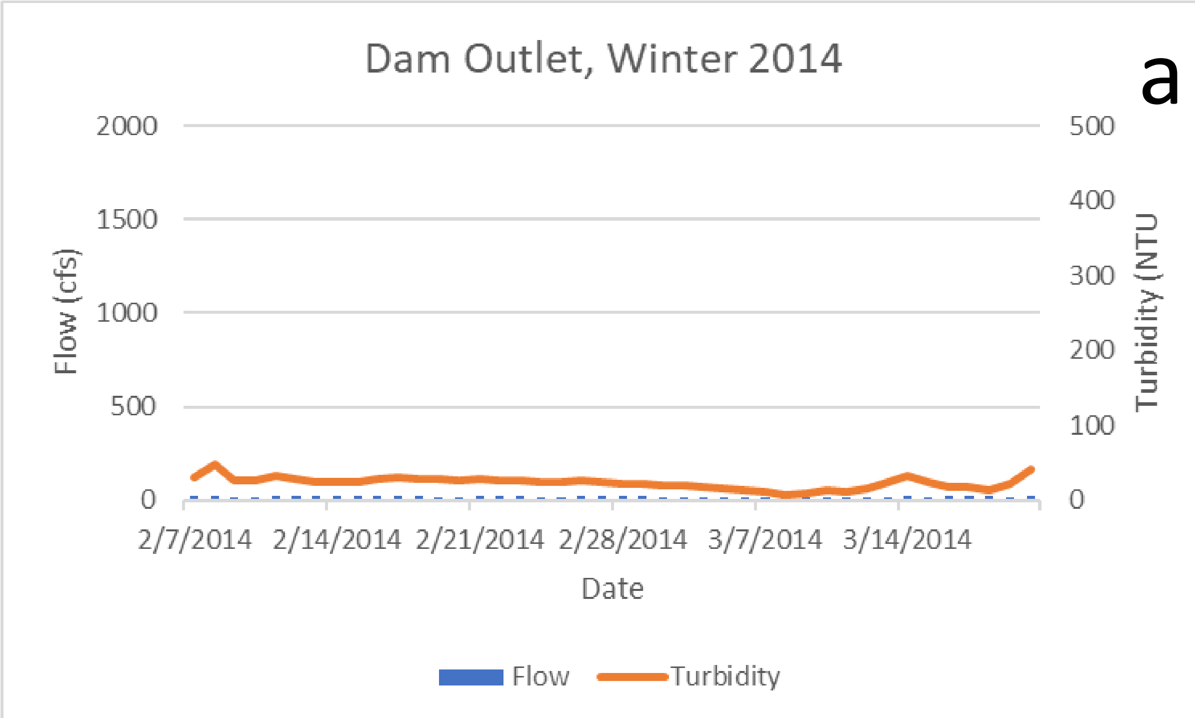


Figure 5. Flow vs. turbidity on the Russian River at Hopland (a) and West Fork (Lake Mendocino Drive Bridge; b) from February 7 through March 20, 2014.



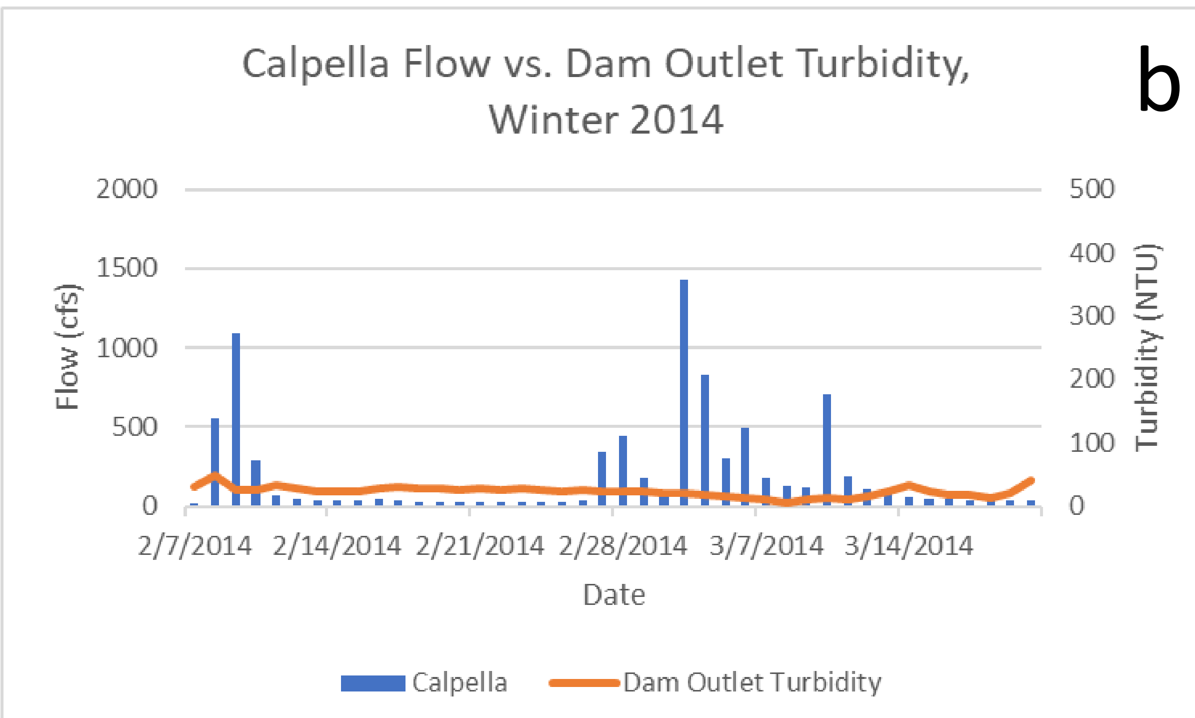


Figure 6. Flow vs. turbidity at Dam Outlet (East Fork Russian River; a) and Calpella flow vs. Dam Outlet turbidity (East Fork Russian River; b) from February 7 through March 20, 2014.

Spring

We also compared flow and turbidity for three spring periods (2012-14). In spring 2012 median turbidity was 7 NTU at Hopland, 1 NTU at West Fork, and 17 NTU at CVD outlet, and maxima were 9, 3, and 24 NTU respectively. In spring 2013 median turbidity was 6 NTU at Hopland, 1 NTU at West Fork, and 16 NTU at CVD outlet, and maxima were 15, 25, and 21 NTU, respectively. Turbidity data also were available for Calpella in spring 2013; the median and maximum were 5 and 17 NTU, respectively. In spring 2014, median turbidity was 2 NTU at Hopland, < 1 NTU at West Fork, and 16 NTU at CVD outlet. Due to a spring storm, maxima were 210, 793, and 612 NTU for Hopland, West Fork, and Dam Outlet, respectively. As occurred during the fall and winter period, maximum turbidity from the storm was higher for West Fork than the Dam Outlet.

In general, by the end of spring for all three years, flow in the West Fork declined to about 10-15 cfs and turbidity declined to about 1 NTU. At the CVD outlet, by the end of both spring 2012 and spring 2013 flow was relatively stable at about 115 and 100 cfs, respectively, as was turbidity at about 17 and 15 NTU, respectively. In 2012, flow and turbidity were not significantly correlated at Hopland (Spearman's rho = 0.10; p = 0.25; Figure 7a), but were strongly correlated at West Fork (Spearman's rho = 0.75; p < 0.001; Figure 7b) and Dam Outlet (Spearman's rho = 0.70; p < 0.001; Figure 8a), and moderately correlated for Calpella flow vs. Dam Outlet turbidity (Spearman's rho = 0.55; p < 0.001; Figure 8b). Hopland turbidity not correlated with West Fork turbidity (Spearman's rho = 0.02; p = 0.46) but moderately correlated with Dam Outlet turbidity (Spearman's rho = 0.62; p < 0.001). This corresponds to NMFS's expectation, and is not surprising since West Fork flow and turbidity were very low with little influence on downstream locations for the latter half of the period. In 2013, flow and turbidity were strongly correlated at Hopland (Spearman's rho = 0.73; p < 0.001; Figure 9a) and West Fork (Spearman's rho = 0.78; p < 0.001; Figure 9b), but not significantly correlated at Dam Outlet (Spearman's rho = -0.05; p = 0.36; Figure 10a) and weakly *negatively* correlated for Calpella flow vs. Dam Outlet turbidity (Spearman's rho = -0.25; p < 0.05; Figure 10b). Hopland turbidity moderately correlated with West Fork turbidity (Spearman's rho = 0.68; p < 0.001) and strongly correlated with Dam Outlet turbidity (Spearman's rho = 0.76; p < 0.001). The significant correlations are not particularly revealing and most likely are related to little variance in either parameter over the period examined. Conditions in spring 2012 and 2013 again are good illustrations of the second scenario of concern, although Dam Outlet flows generally were higher than those of winter 2014.

Spring 2014 was different in that a storm occurred around April 1st resulting in spikes in both flow and turbidity at Hopland and West Fork which would be expected. However, similar to winter 2014, flow at the CVD outlet was relatively stable but much lower at about 20 cfs throughout the period. In this case, however, several very large spikes in turbidity were recorded and flow and turbidity at Dam Outlet did not track well. It seems much more likely that the turbidity sensor was periodically out of the water due to the low flow resulting in faulty data compared to periods when higher flow occurred. As noted above, if the data are not faulty, they suggest factors other than flow alone may affect turbidity at the CVD outlet. In 2014, flow and turbidity were moderately correlated at Hopland (Spearman's rho = 0.58; p < 0.001; Figure 11a), strongly correlated at West Fork (Spearman's rho = 0.89; p < 0.001; Figure 11b), not significantly correlated at Dam Outlet (Spearman's rho = 0.11; p = 0.23; Figure 12a), and moderately *negatively* correlated for Calpella flow vs. Dam Outlet turbidity (Spearman's rho = -0.42; p < 0.01; Figure 12b). Hopland turbidity weakly correlated with West Fork turbidity (Spearman's rho = 0.31; p = 0.05) and weakly *negatively* correlated with Dam Outlet turbidity (Spearman's rho = -0.32; p < 0.05). The best representation of stable data when no turbidity spikes occurred at the Dam Outlet was from late March through late April 2014, when flow and turbidity generally measured about 17 – 21 cfs and 10 – 17 NTU, respectively (Figure 12a).

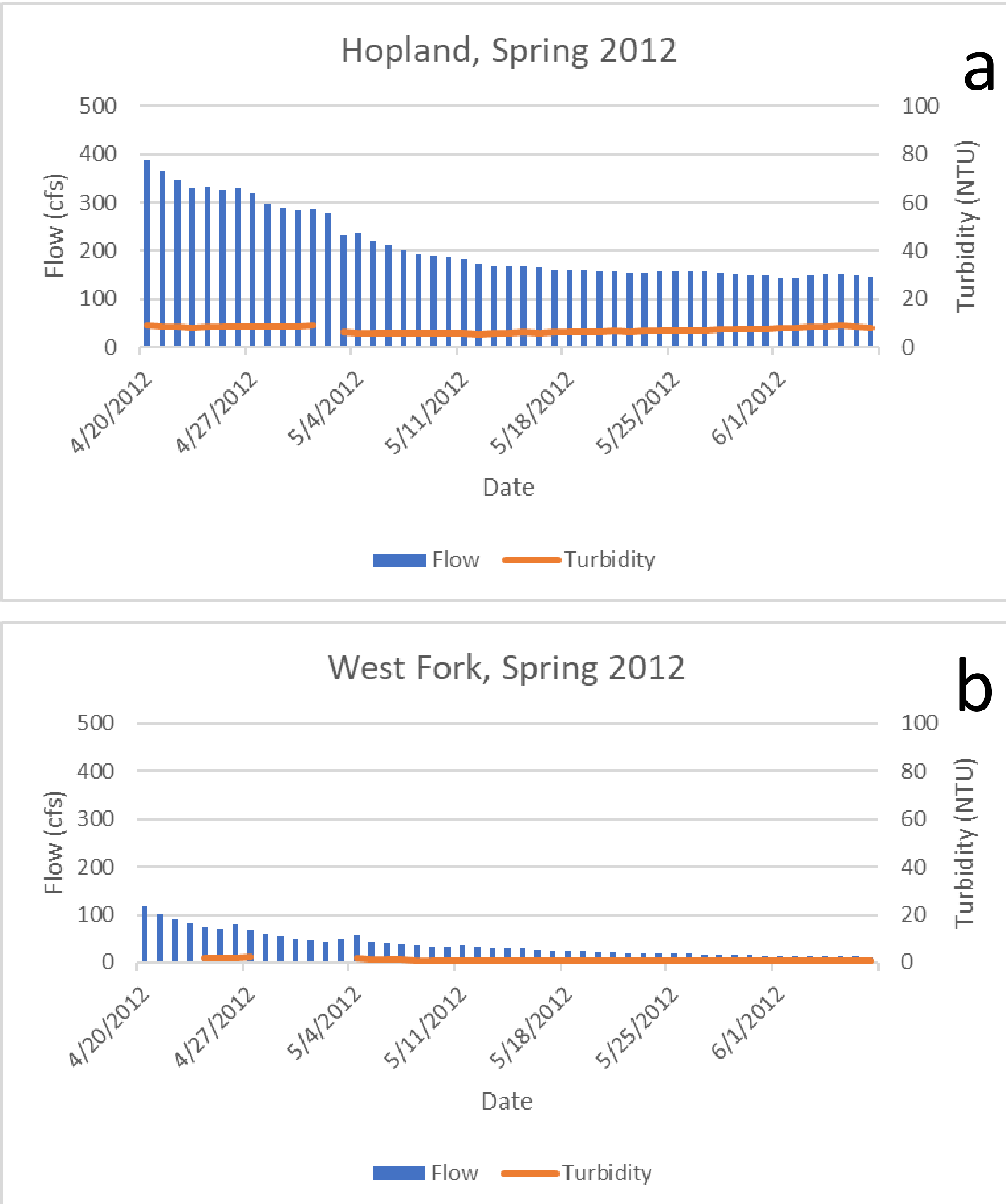


Figure 7. Flow vs. turbidity at Hopland (a) and West Fork (Lake Mendocino Drive Bridge; b) on the Russian River from April 20 through June 7, 2012. Start date is based on the availability of turbidity data for the West Fork. End date is when West Fork flow declined to less than 10 cfs or less than 10 percent of Dam Outlet Flow.

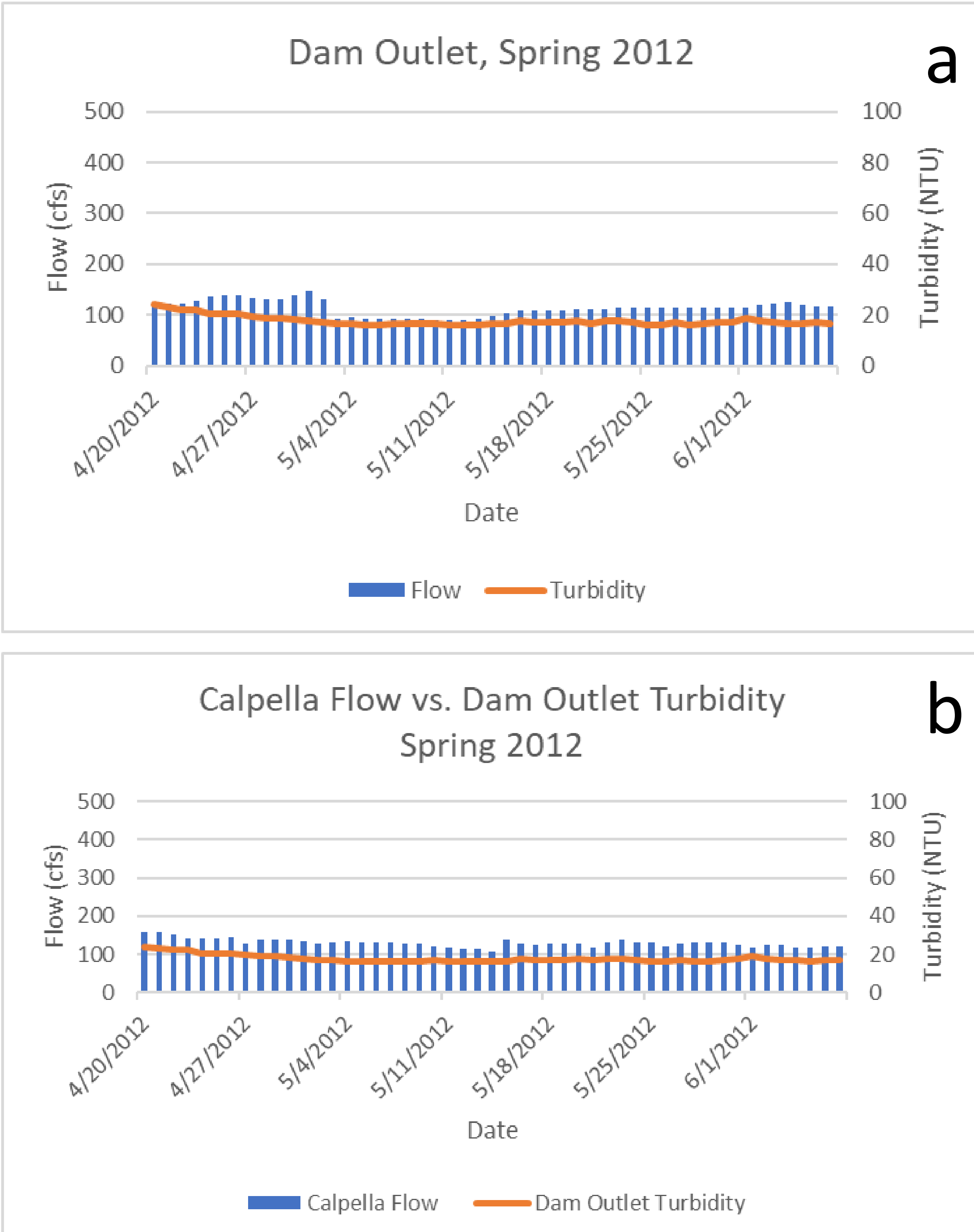
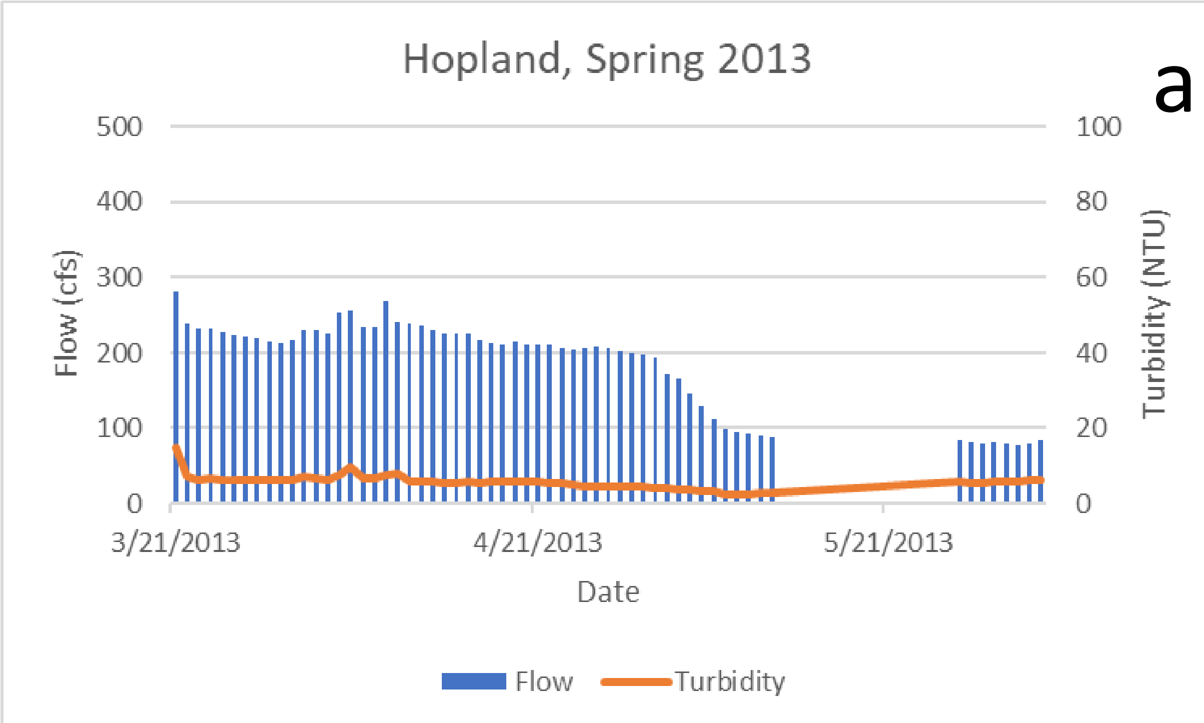


Figure 8. Flow vs. turbidity at Dam Outlet (East Fork Russian River; a) and Calpella flow vs. Dam Outlet turbidity (East Fork Russian River; b) from April 20 through June 7, 2012. As in Figure 7, start date is based on the availability of turbidity data for the West Fork. End date is when West Fork flow declined to less than 10 cfs or less than 10 percent of Dam Outlet Flow.



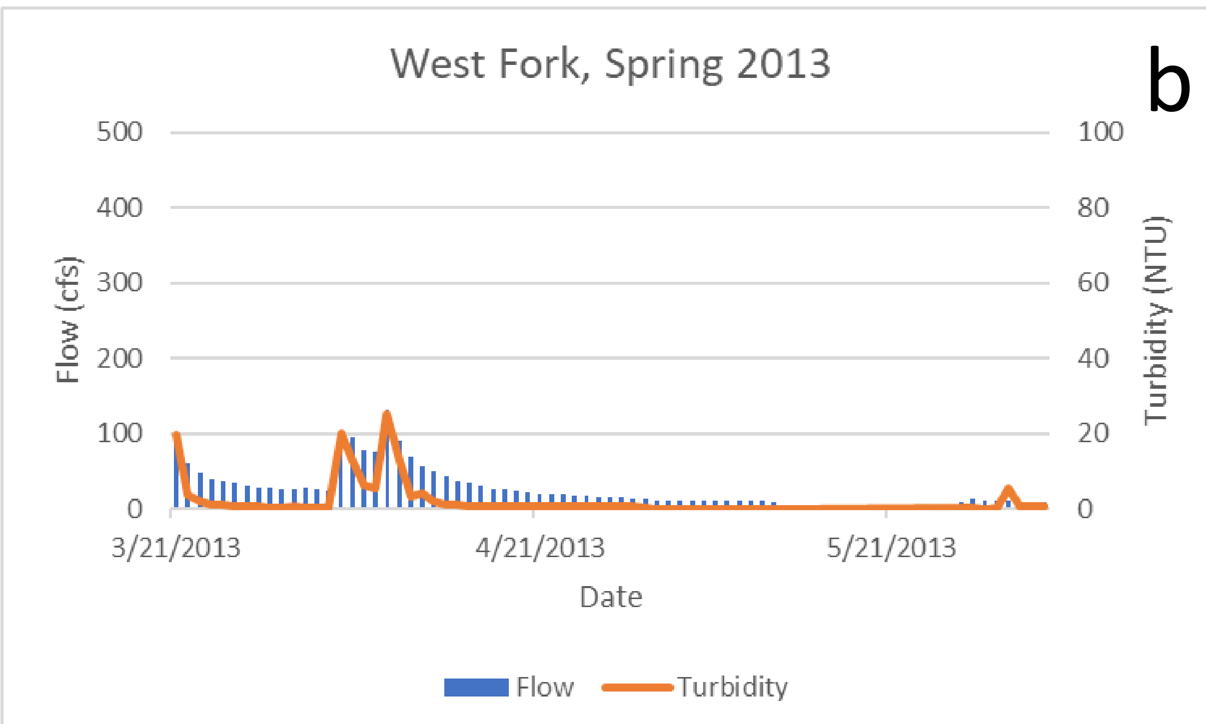


Figure 9. Flow vs. turbidity at Hopland (a) and West Fork (Lake Mendocino Drive Bridge; b) on the Russian River from March 21 through June 3, 2013. End date is when West Fork flow declined to less than 10 cfs or less than 10 percent of Dam Outlet Flow.

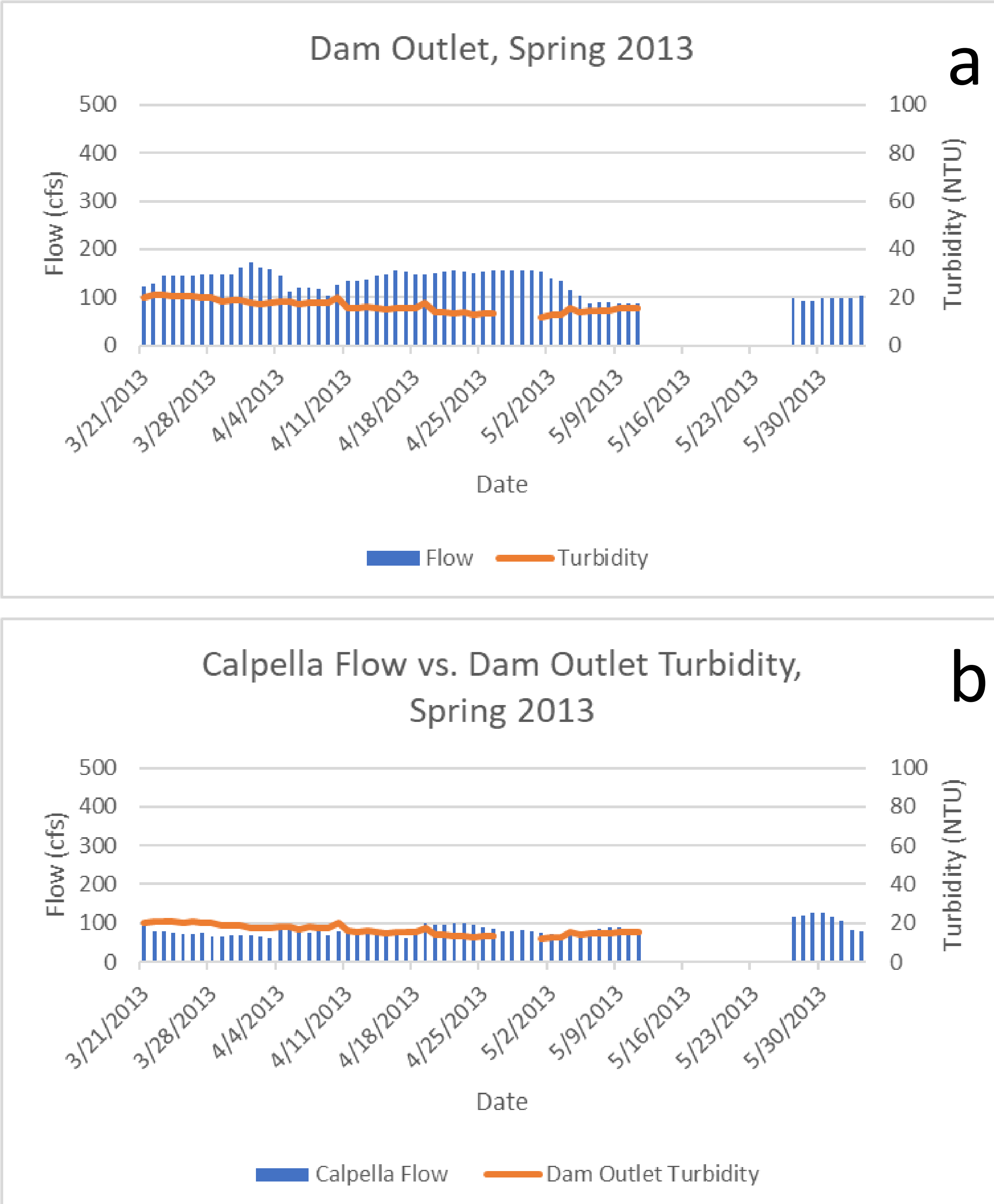
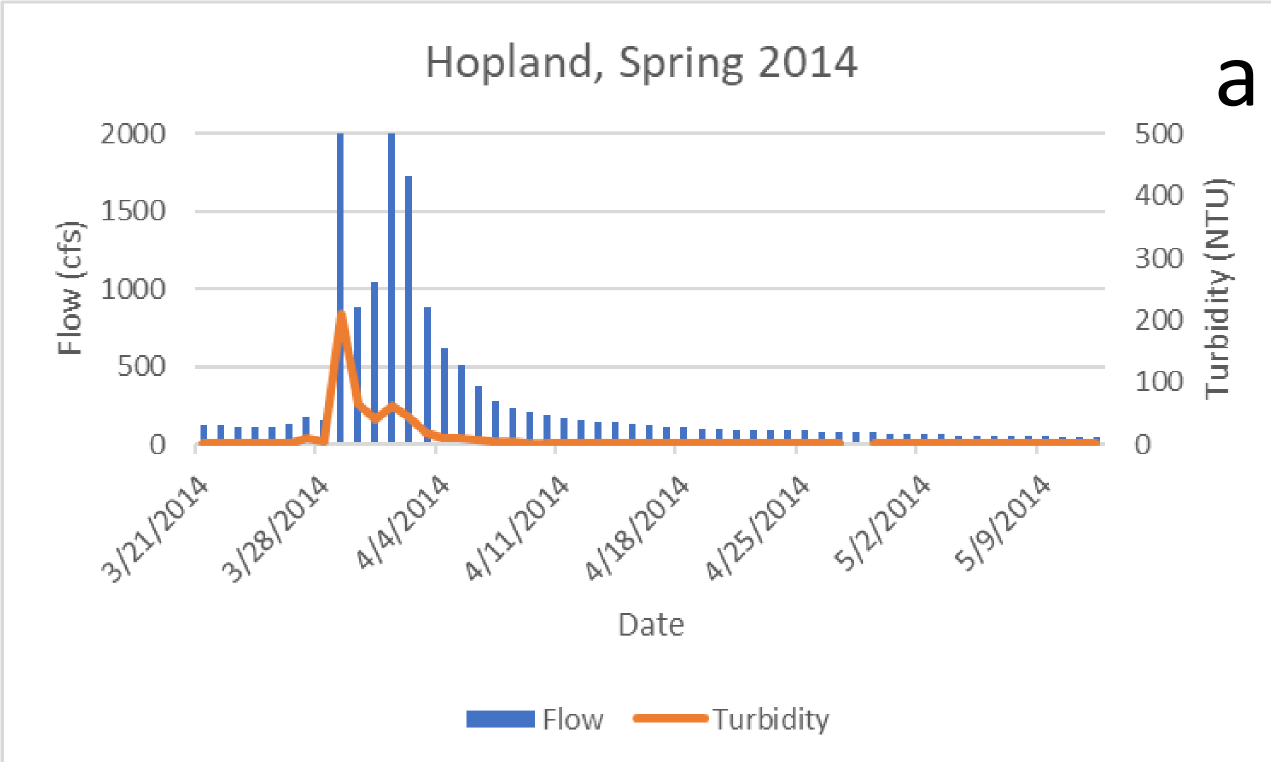


Figure 10. Flow vs. turbidity at Dam Outlet (East Fork Russian River; a) and Calpella flow vs. Dam Outlet turbidity (East Fork Russian River; b) from March 21 through June 3, 2013. As in Figure 9, end date is when West Fork flow declined to less than 10 cfs or less than 10 percent of Dam Outlet Flow.



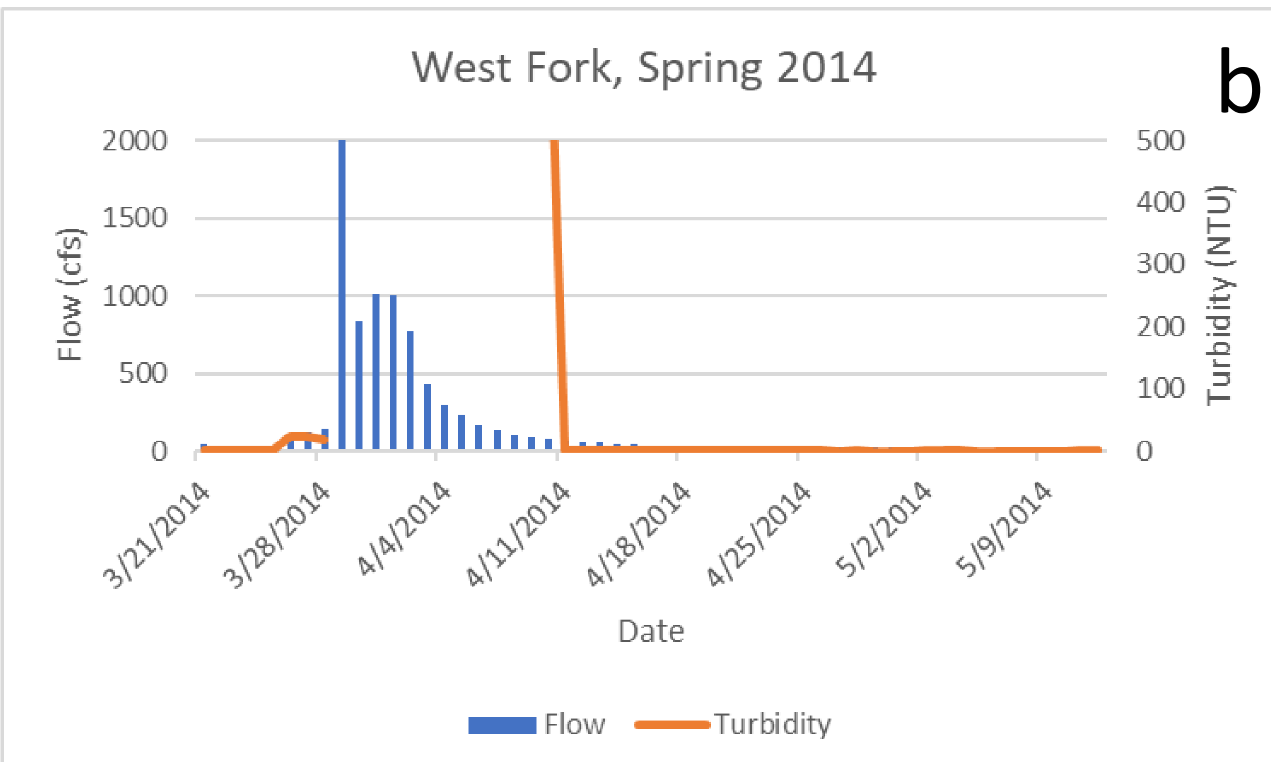
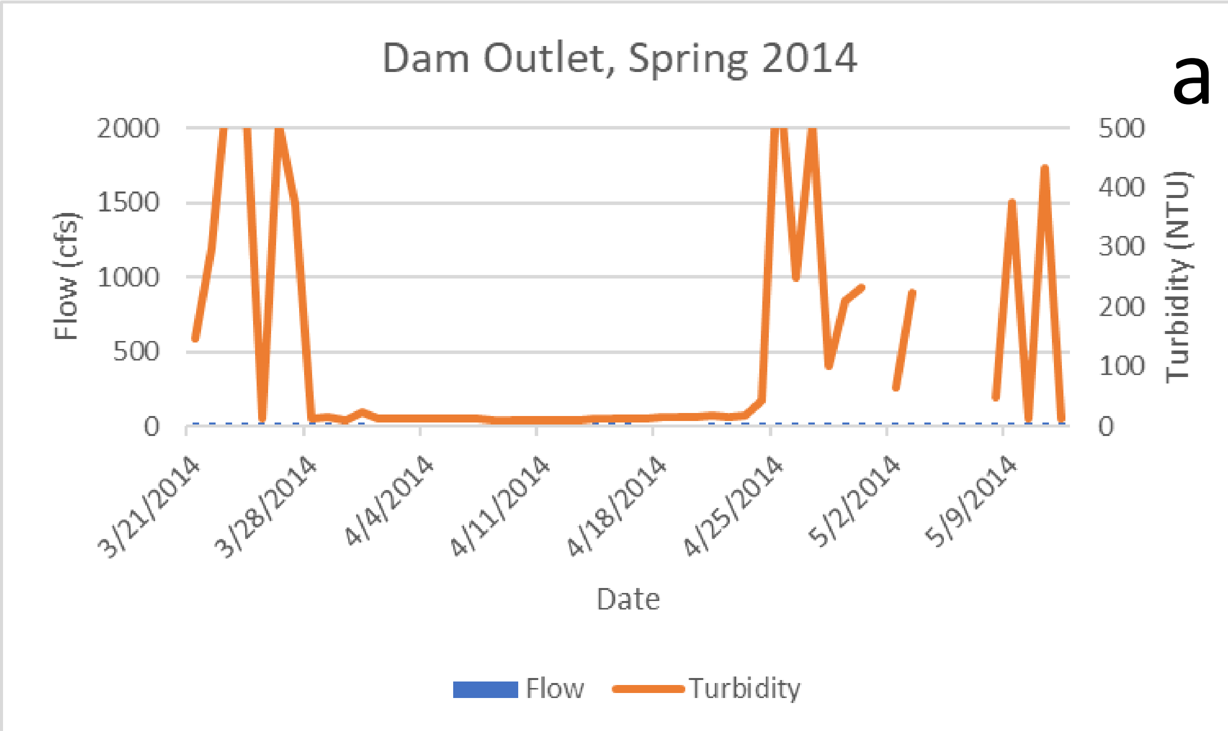


Figure 11. Flow vs. turbidity at Hopland (a) and West Fork (Lake Mendocino Drive Bridge; b) on the Russian River from March 21 through May 14, 2014. End date is when West Fork flow declined to less than 10 cfs or less than 10 percent of Dam Outlet Flow.



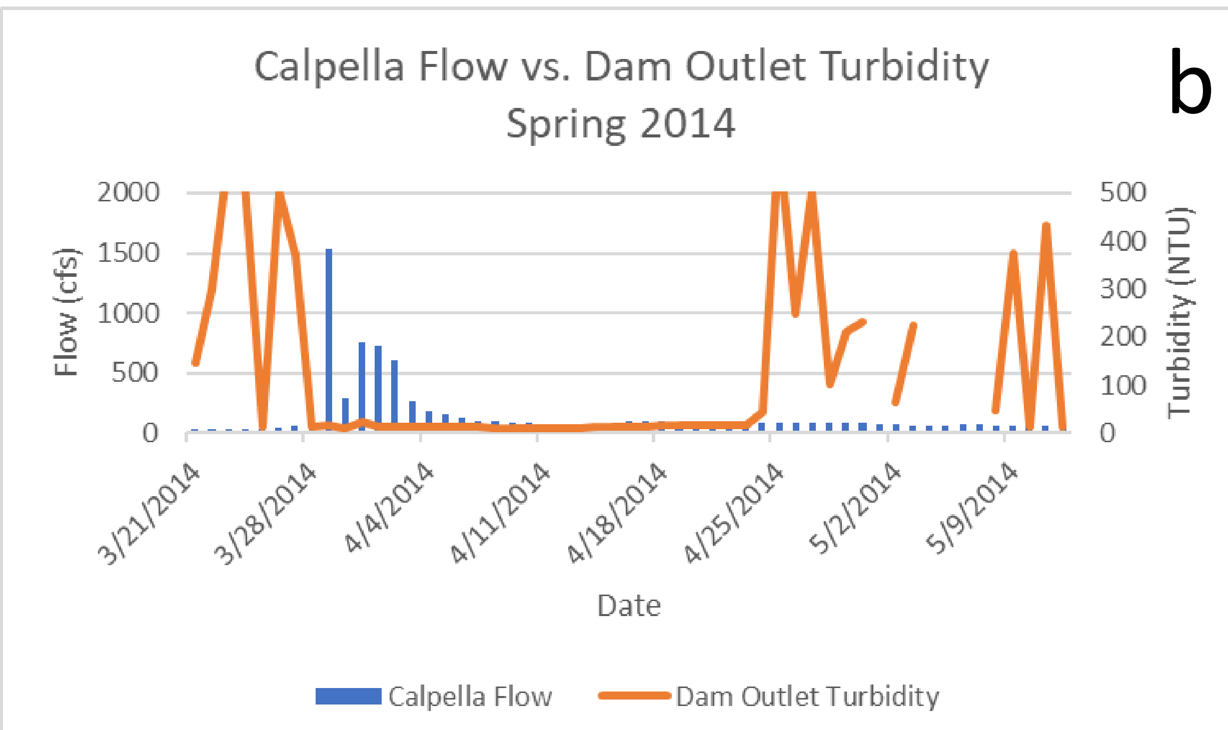


Figure 12. Flow vs. turbidity at Dam Outlet (East Fork Russian River; a) and Calpella flow vs. Dam Outlet turbidity (East Fork Russian River; b) from March 21 through May 14, 2014. As in Figure 11, end date is when West Fork flow declined to less than 10 cfs or less than 10 percent of Dam Outlet Flow.

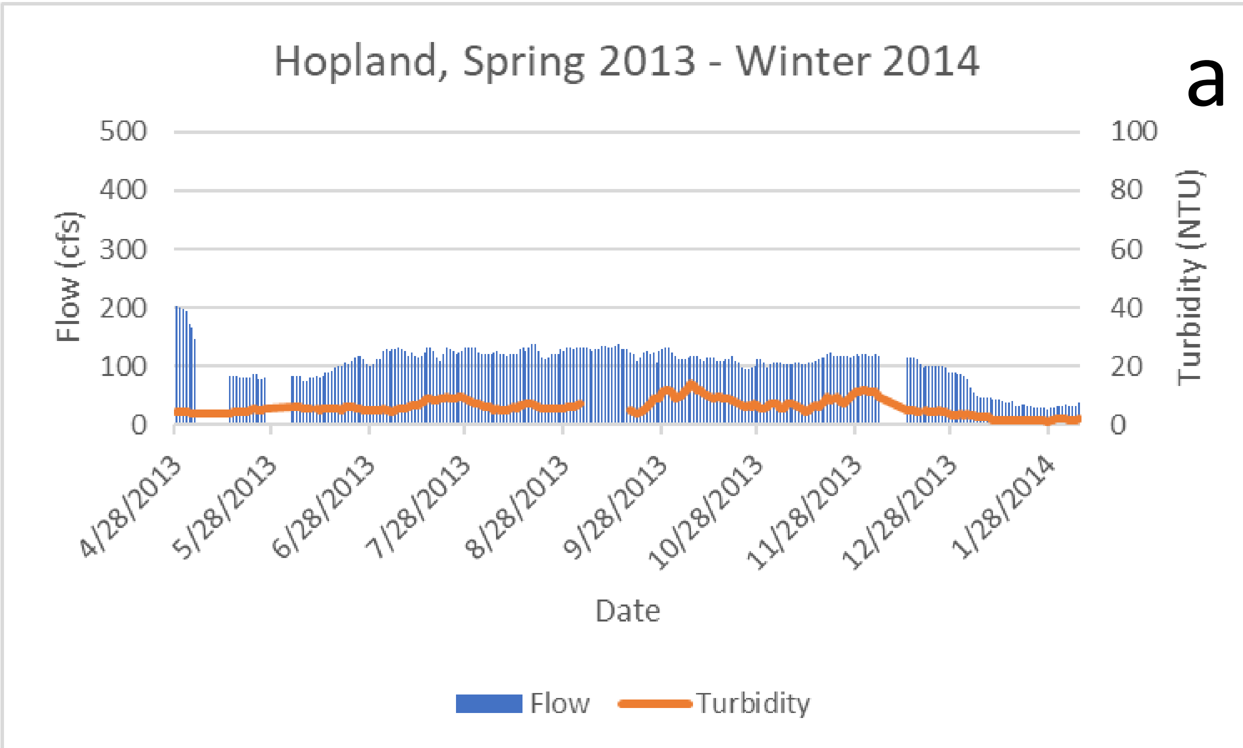
Summer and Other Low Flow Periods

We examined the summers of 2012-17 for dates when the West Fork contributed little or no flow to the Russian River (i.e., when West Fork flow was less than 10 cfs or less than 10 percent of Dam Outlet flow), and found that these periods continuously spanned all four seasons in some years. Specifically, spring 2013 through winter 2014 and spring through fall 2014 represented periods of extended low flow conditions in the Russian River (261 and 193 days, respectively), and that had significant positive correlations between Hopland and Dam Outlet turbidity, Dam Outlet flow and turbidity, or Calpella Flow and Dam Outlet turbidity. Median turbidity was 6 NTU at Hopland and 24 NTU at the Dam Outlet for the period from spring 2013 through winter 2014; maximum turbidity measured 14 and 869 NTU, respectively. For spring – fall 2014, median turbidity was 2 NTU at Hopland and 32 NTU at the Dam Outlet; maximum turbidity measured 7 and 912 NTU, respectively.

During the period from spring 2013 through winter 2014, flow and turbidity were moderately correlated at Hopland (Spearman's rho = 0.55, $p < 0.001$; Figure 13a), and weakly correlated at the Dam Outlet (Spearman's rho = 0.28, $p < 0.001$; Figure 13b) and for Calpella flow vs. Dam Outlet turbidity (Spearman's rho = 0.15, $p < 0.01$; Figure 14). Additionally, Hopland turbidity was moderately correlated with Dam Outlet turbidity (Spearman's rho = 0.42, $p < 0.001$). There appears to be some variance in turbidity at Hopland that could be related to the spikes at the CVD outlet after a delay accounting for the downstream transit time.

For spring – fall 2014, flow and turbidity were moderately correlated both at Hopland (Spearman's rho = 0.43, $p < 0.001$; Figure 15a), and at the Dam Outlet (Spearman's rho = 0.55, $p < 0.001$; Figure 15b), and weakly *negatively* correlated for Calpella flow vs. Dam Outlet turbidity (Spearman's rho = -0.27, $p < 0.001$; Figure 16). In this case Hopland turbidity was not significantly correlated with Dam Outlet turbidity (Spearman's rho = 0.01, $p = 0.47$). Hopland turbidity showed little variance despite the spikes in turbidity at the CVD outlet.

Spikes in turbidity are apparent at the Dam Outlet during both of the low flow periods despite the statistically significant positive correlations between flow (which was relatively stable) and turbidity at that location. Median flows for both periods were greater than 100 cfs, which would be expected to make it less likely for turbidity sensors to be out of the water or covered by sediment that had settled out compared to periods when CVD releases are very low such as during winter 2014 (Figure 6a) when flows typically were about 20 cfs. Again, we need to investigate these spikes further to determine if they are real.



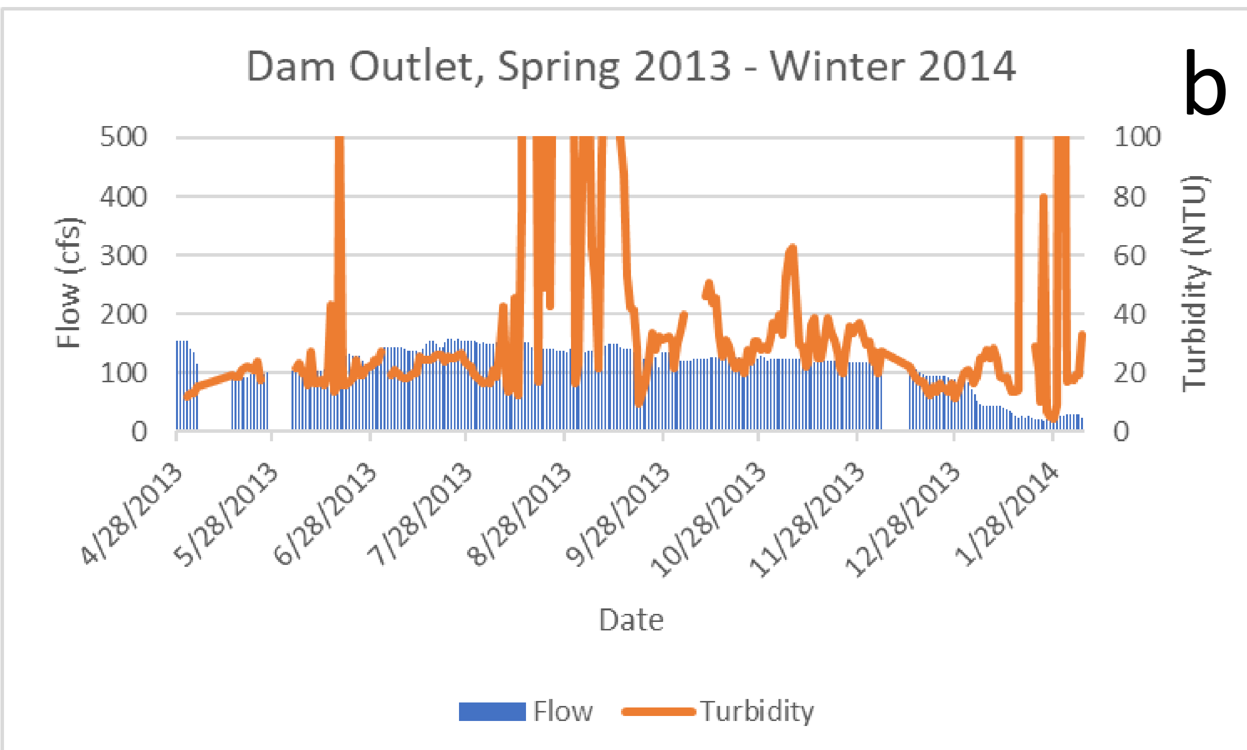


Figure 13. Flow vs. turbidity at on the Russian River at Hopland (a) and at the Dam Outlet on the East Fork Russian River Dam Outlet (b) from April 28, 2013, through February 6, 2014. The West Fork contributed little or no flow to the Russian River during this period.

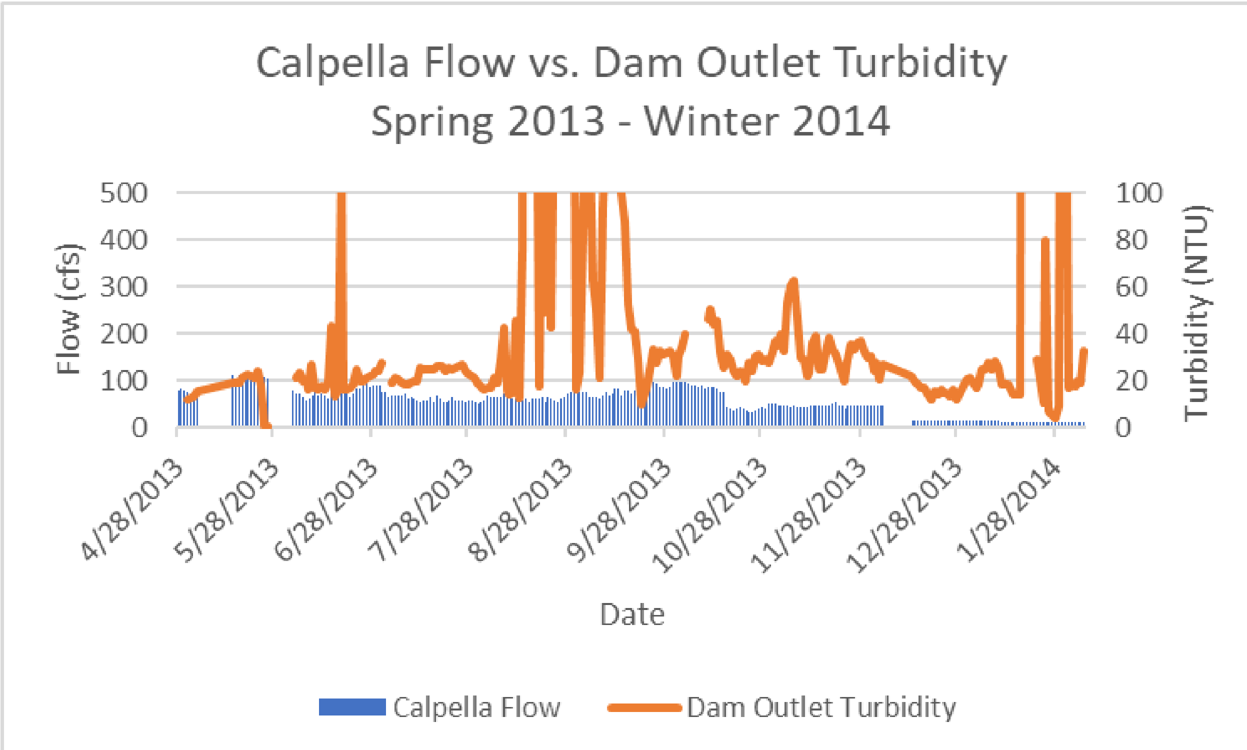


Figure 14. Calpella flow vs. Dam Outlet turbidity (East Fork Russian River) from April 28, 2013, through February 6, 2014.

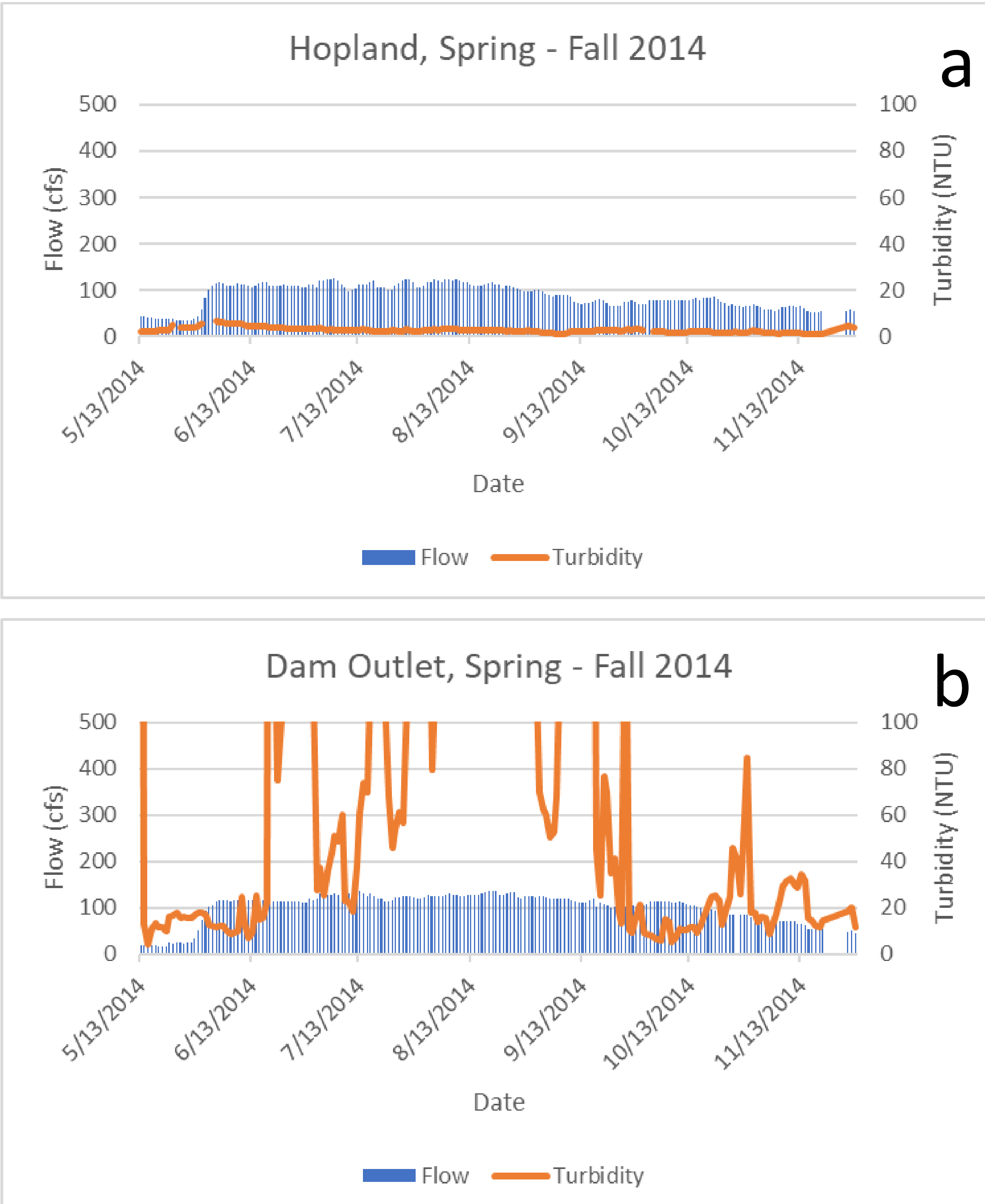


Figure 15. Flow vs. turbidity at on the Russian River at Hopland (a) and at the Dam Outlet on the East Fork Russian River Dam Outlet (b) from May 13 through November 28, 2014. The West Fork contributed little or no flow to the Russian River during this period.

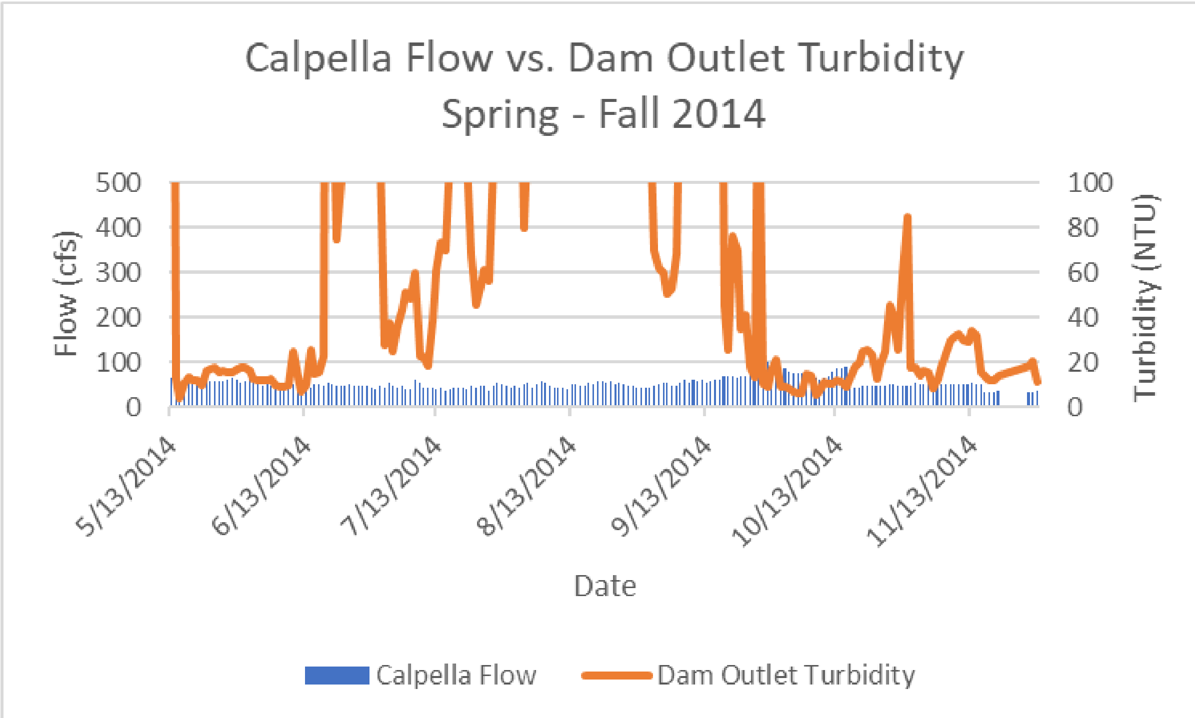


Figure 16. Calpella flow vs. Dam Outlet turbidity (East Fork Russian River) from May 13 through November 28, 2014.

Conclusion

The data analysis above provides some good examples of the flow and turbidity levels that have occurred at Hopland, West Fork, and the Dam Outlet (East Fork) in the Russian River in recent years. Table 1 shows some approximate flow and turbidity measurements (obtained by eye from the data spreadsheet and rounded off) that occurred when conditions stabilized post-storm in the fall, winter, and spring. These are intended to be representative of scenario of concern # 1 (i.e., when flows from the West Fork have declined following winter rainstorms but flood control releases from CVD continue). The stable periods lasted about 1 – 6 weeks between storms or no additional storms occurred in the winter; however, scenario of concern #2 could be entered into directly afterward if spring was also dry. As shown, post-storm flow releases from the Dam Outlet were lower than those in the West for in three of the six examples and so may not have been for “flood control.” However, in all cases turbidity was higher at the Dam Outlet that at West Fork.

	Hopland		West Fork		Dam Outlet		
	Flow (cfs)	Turbidity (NTU)	Flow (cfs)	Turbidity (NTU)	Flow (cfs)	Turbidity (NTU)	N
Fall 2012	500	25	200	5	300	85	9
Winter 2012-13 early	300	16	40	2	150	65	48
Winter 2012-13 late	240	8	30	1	160	23	19
Winter 2014	150	3	50	2	20	20	6
Spring 2014 early	150	2	50	1	20	10	5
Spring 2014 late	100	1	25	< 1	18	17	26

Table 1. Example flow and turbidity amounts on the Russian River at Hopland, West Fork, and at the Dam Outlet (East Fork) when flow and turbidity had stabilized following storm events. N is the approximate number of days of stable flow and turbidity.

We also have examples (again obtained by eye from the data spreadsheet and rounded off) of stable flow and turbidity levels that occurred during drier conditions, i.e., periods when there were no storms for the entire (spring) season. These are intended to be representative of scenario of concern #2, when Russian River flows were driven by CVD releases (Table 2). The stable periods lasted from about 2 – 6 weeks, and led right into the low flow period when West Fork flow was less than 10 cfs or less than 10 percent of Dam Outlet flow. The CVD flows in all cases were higher than those from the West Fork.

Overall, it is notable from Table 1 and Table 2 that West Fork turbidity was consistently very low at 1 – 2 NTU. In contrast, it appears that we can expect turbidity at the Dam Outlet to measure about 20 NTU under a variety of conditions, and when this occurs and flow inputs from the West Fork are low, we can expect the turbidity at Hopland to measure about 8 NTU or less. The highest turbidities for the Dam Outlet shown in Table 1 (85 and 65 NTU) both were correlated with the high flows entering Lake Mendocino at Calpella at that time (Figures 2b and 4b, respectively).

For the low flow periods examined (i.e., spring 2013 – winter 2014 (Figure 13b) and spring – fall 2014 (Figure 15b)), despite significant correlations occurring between flow and turbidity at Hopland and/or the Dam Outlet, or between Hopland turbidity and Dam Outlet turbidity, large spikes in the turbidity

	Hopland		West Fork		Dam Outlet		
	Flow (cfs)	Turbidity (NTU)	Flow (cfs)	Turbidity (NTU)	Flow (cfs)	Turbidity (NTU)	N
Spring 2012 early	300	8	70	2	135	20	19
Spring 2012 late	150	8	13	1	115	18	30
Spring 2013 early	215	6	30	1	150	19	43
Spring 2013 late	100	3	11	< 1	90	15	17

Table 2. Example flow and turbidity amounts on the Russian River at Hopland, West Fork, and at the Dam Outlet (East Fork) when flow and turbidity appeared to be stable, and no storm events occurred during the entire season.

data occurred at the Dam Outlet even though flow at the Dam Outlet was relatively stable at about 120 cfs for several consecutive weeks. Flow and turbidity at Hopland were relatively stable as well. Turbidity at the Dam Outlet was so erratic that no stable periods could be identified for that parameter. These spikes also occurred in spring 2014 (Figure 12a), but a 1-month period of stability occurred, and the observations are presented in Table 2 for early and late spring. These data spikes could be valid. In spring 2014 (Figure 12a), both the turbidity spikes and period of stability occurred when flow was consistently low (e.g., 20 cfs), so it is unclear why the sensor would suddenly be out of the water and read erroneously. Operations staff have visually observed a spike in turbidity when the tainter gate was moved into open position after a long period of disuse (Nick Malasavage, USACE Operations Chief, September 6, 2023). There were no abrupt data gaps that indicated the sensor had malfunctioned or been removed, and then replaced. This is generally true of both low flow periods as well when flow was consistently about 120 cfs or greater. Also, for spring 2013 – winter 2014 (Figure 13), there is some evidence that the turbidity spikes at the CVD outlet were (after a delay) detectable at Hopland.

In contrast, it is a concern that the spikes in turbidity measured at the Dam Outlet were not mirrored at all at Hopland in spring – fall 2014 (Figure 15), which suggests that some of the turbidity collected at the Dam Outlet could be faulty. There are no outfalls in this reach of the Russian River that might serve to add water and reduce turbidity in the Russian River during low flow periods when the West Fork contributes little or no flow to the Russian River (Don Seymour, Sonoma Water, pers. comm., September 6, 2023). It could be that under low flow conditions the suspended sediment responsible for the turbid conditions settles out before it reaches Hopland. Flows were somewhat lower at both Hopland and the Dam Outlet in spring – fall 2014 compared to spring 2013 – winter 2014. There could be a low flow threshold that was reached that allowed suspended sediment to settle out.

Various explanations have been proposed to account for the elevated turbidity occurring at the CVD outlet, and some of them, such as gate positions, are not flow-related. Therefore, the lack of consistent correlation between Dam Outlet flow and turbidity is not surprising. However, the turbidity sensors should be closely attended in future monitoring efforts to ensure that the lack of correlation and any sudden increases or decreases in turbidity are real.

We note that the periods of little or no contribution of flow from the West Fork were quite lengthy and comprised mostly of consecutive days for the years we initially explored for this analysis: 2012 – 184 days; 2013 – 223 days; 2014 – 230 days; 2015 – 243 days; 2016 – 162 days; and 2017 – 203 days. Hence, we do not expect that comparisons of West Fork and East Fork (CVD outlet) turbidity are possible for large portions of most years. We do expect tradeoffs with other parameters affecting fish habitat during these low flow periods, such as the flow amount itself (which may be mandated) and providing appropriate water temperatures.

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