Appendix 3.3-A

Reconnaissance Level Geomorphic Assessment Technical Memorandum

Hydrology | Hydraulics | Geomorphology | Design | Field Services

TECHNICAL MEMORANDUM

Date:	August 10, 2015
To:	Chris Fritz (PBI)
From:	John Stofleth, Denise Tu, Chris Campbell
Project:	14-1026 Oroville Wildlife Area Flood Stage Reduction Project
Subject:	Reconnaissance Level Geomorphic Assessment

cbec has been requested by Peterson Brustad Inc. (PBI) to conduct a geomorphic assessment of the Feather River corridor in the vicinity of the Oroville Wildlife Area (OWA) D-Unit to support the Flood Stage Reduction (FSR) Project. The goal of this reconnaissance level geomorphic assessment was to develop a better understanding of potential project related impacts to the local sediment regime and water quality within the study reach. The reconnaissance level geomorphic assessment includes approximately 8 miles of the Feather River starting upstream of the OWA D-Unit inlet weir to approximately half a mile downstream of the dredge tailings (Figure 1).

1 OWA FSR PROJECT SUMMARY

The OWA encompasses 11,869 acres of the lower Feather River corridor just downstream of the city of Oroville. The upstream boundary of the OWA is located along Hwy 162 (RM 63.9) and extends approximately 11.5 miles downstream to RM 53.7 (Figure 1 and Figure 2). Within the OWA, there is a weir system that diverts flood waters into the OWA D-Unit with the purpose to reduce downstream flood stages; however, the weir system is not functioning as designed. The original weir design intended to divert approximately 80,000 cubic feet per second (cfs) from the main channel into the OWA D-Unit during the peak of the 200-year event to reduce peak stages downstream through attenuation. However, analysis has indicated that the current weir configuration only diverts approximately 40,000 cfs during the peak of the 200-year event (SBFCA 2015). The goal of the OWA FSR Project is therefore to improve the current OWA weir system (Figure 3) to meet the original design capacity, thereby reducing downstream flood stages, and to also improve ecosystem functions within the OWA D-Unit by increasing the frequency and duration of low flow inundation.

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2 HISTORIC INFLUENCES

A unique sequence of historic anthropogenic activities has impacted the sediment regime, hydraulics and hydrology of the lower Feather River. Between 1898 and 1918, gold mining in the form of hydraulic and dredge mining drastically altered the morphology of the Feather River and its adjacent floodplains (Figure 4). Approximately 100 million cubic yards of sediment are estimated to have been mined in the Feather River between 1849 and 1909 (WET 1991). Early dredge technology could mine less than 1,000 cubic yards/day and was later replaced with dredge technology with the ability to mine up to 15,000 cubic yards/day (Stevens 2006).

In addition to the mining activities, there was also a dramatic increase in sediment load delivered to the system as a result of land use changes including timber harvesting, agriculture, and urbanization (CSU Chico 2003, DWR OFRT, 2004a). In the 1800s and 1900s, timber harvesting and intensive grazing occurred in the upper Feather River watershed. These land use changes contributed to the influx of sediment to the system at the turn of the century and influenced flood control projects of the 1900s. Comparative vegetation mapping in the upper Central Valley between 1900, 1945, 1960, and 1995 revealed that a majority of riparian vegetation and natural habitat was lost to agriculture and urban development with an approximate conversion of 48% by 1945, 54% by 1960 and 62% by 1995 (CSU Chico 2003).

Major floods of the early to mid 1900s greatly affected the growing towns of Oroville, Marysville and Yuba City. As a result, Oroville Dam was a major component of the California State Water Project with preliminary work starting in 1957 (Mathews 2014). Construction began in 1962 with the spillway completed in 1968 (WET 1991). An estimate of 7,000 acres of Feather River dredge tailings (Figure 5), to include the present day OWA D-Unit (or Borrow Area D), were used in the 1950s and 1960s in the construction of the dam (Stevens 2006). Bucket-wheel excavators moved material at a rate of 5,700 tons/hour. At the transfer station, the Oroville Dam train, a 40 car train with each car's capacity at 110 ton, enabled workers to move gravel from the borrow area 12 miles up to the dam site (Mathews 2014). Today, the remaining dredge tailings within the OWA along the Feather River continue to be mined for commercial gravel.

With the cessation of hydraulic mining in the early 1900s, and the construction of dams through the middle of the 20th century, the supply of sediment to the system was dramatically reduced. As a result of the reduced supply and extensive levee projects, dredging, and channelization, a period of channel incision occurred from the early to mid 20th century, after which the channel began to rest upon pre-hydraulic mining era deposits, which are significantly more resistant to erosion. The extensive aggradation followed by incision has dramatically reduced the frequency and duration of floodplain inundation that persisted prior to the hydraulic mining era. While bed incision has arrested in the last 20 to 30 years, lateral bank erosion is an ongoing concern and is controlled by the composition of the river banks and the supply of sediment from the watershed below the major reservoirs (Ayres, 1997).

3 WATER QUALITY

As a result of historic gold mining in the region, high levels of mercury are a water quality concern for Sacramento River and its tributaries. DTMC (2002) reported that an estimated 61 kg/year load is generated from runoff and erosion of historic gold mine sites of the American River and Feather River watersheds (calculated from mass loads for the American River and Feather River watersheds). For the lower Feather River at Nicholas (below the confluence with the Yuba and Bear Rivers) the average annual total mercury mass loads were attributed to mining activity, native soils and springs with the highest concentration from mining activity at 38 kg/yr. The bioaccumulation of mercury within fish varies depending on factors such as species, age, environmental parameters including pH, temperature, suspended sediment loads and geomorphology (DTMC 2002, Domagalski, et al. 2000, Klasing et al. 2006). In particular, on the lower Feather River, mercury levels in fish have been attributed to dredge tailing fields within the Feather River watershed (DTMC 2002, Klasing et al. 2006). The National Water-Quality Assessment (NAWQA) Program recorded some of the highest levels of mercury in streambed sediment (1995 and 1997) for the Sacramento River Basin along the Feather River with the highest concentrations along the Bear and Yuba Rivers (Domagalski, et al. 2000).

Although high levels of mercury in the lower Feather River have been attributed to dredge tailings in the Feather River watershed, which includes the Feather, Yuba and Bear Rivers, the relative proportion of mercury derived from the OWA study reach has not been documented. Given that the overall size of the OWA dredge tailings that are exposed to river flow is relatively small compared to that of the Yuba and Bear Rivers, it stands to reason that the proportion of its contribution to mercury loads is small relative to these tributaries. However, changes to reach scale hydraulics associated with the FSR project will have the potential to alter flow velocities and the sediment regime within the main channel and the D-Unit floodplain. As such, these changes have the potential to alter the loading (increase or decrease) of mercury stored in the tailings to the lower Feather River. Analysis of this potential is presented in the following sections of this memorandum.

4 HYDROLOGY

The hydrologic regime of the lower Feather River has changed significantly with completion of Oroville Dam in 1968. Currently, there are two hydrologically distinct sections within of the OWA study reach. Upstream of the Thermalito Afterbay Outflow (RM 58.5) is considered the low flow reach dictated by water released from the Fish Barrier Dam (RM 66.5). Minimum flows of at least 600 cfs are maintained to achieve favorable fish habitat conditions in the low flow reach between RM 58.5-66.5 (DWR OFRT, 2004a). The majority of low flows released from Oroville Dam are diverted into the Thermalito Forebay for hydro electricity production and released downstream at the Thermalito Afterbay outflow. Thermalito Afterbay outflows generally meet an instream flow requirement of 1,700 cfs from October through March and 1,000 cfs from April through September (DWR OFRT, 2004a).

Two USGS gages on the lower Feather River were used to examine differences in the hydrologic regime for pre- and post-dam construction. The historic USGS gage station at Oroville (USGS # 11407000) shows both natural pre-dam (1902-1987) hydrology and post-dam (1986-2013) hydrology through the low flow reach. The historic USGS gage station at Gridley (USGS # 11407150) records the total flow downstream of the Thermalito Afterbay for water years 1965- 1998. A comparison between daily average discharge by month shows the changes in the hydrologic regime on the Feather River (Figure 6). The lower Feather River pre-dam (black) exhibited low flows in the summer and snowmelt dominated flows in the spring. In contrast, the seasonal extremes are much more muted in post-dam flows (yellow) where the highest flows occur in the winter and higher low flows in the summer are released to manage water supply and water quality. The post-dam low flow reach (green) flows remain fairly constant throughout the year to meet the minimum requirements downstream of the Fish Barrier Dam. The largest post-dam flood events occurred in 1986, 1997, and 2006 (Figure 7). The peak flow event at Gridley in 1986 was 150,000 cfs and in 1997 was 160,300 cfs. The 2006 peak flow event at the Oroville gage was recorded at 65,600 cfs through the low flow reach.

DWR OFRT (2004e) study also indicated that there is a hydraulic connection (subsurface / hyporheic) between the Feather River and some of the ponds within the OWA. This connection is dependent upon many variables such as elevation, proximity to the river channel, physical characteristics (e.g., porosity) of the channel and ponds. Of the four ponds sampled, two have exhibited a strong hydraulic connection with the Feather River.

5 GEOMORPHOLOGY

5.1 REACH RECONNAISSANCE

The 8 mile OWA study reach is located along the Feather River between RM 59.5 and 52.7 (Figure 1). It is a gravel/cobble bed river with banks comprised of dredge tailings. cbec conducted qualitative observations of bank composition and erosion. These observations verified existing geology (Figure 8 and Table 1) and soils (Figure 9 and Table 2) findings presented in existing publications such as WET (1991) and DWR OFRT (2004a). The banks throughout much of the study reach are comprised of armored gravel/cobble dredge tailings. Bank erosion along the downstream portions of the study reach show the presence of cohesive and erosion resistant Modesto formation deposits (Figure 10). cbec staff visually observed fining of bed material from the upstream to the downstream extent with armoring of bed material throughout the reach.

Table 1. Geology classification table.

Geology	Symbol
Alluvium (Holocene)	Qa
Basin Deposits, Undivided (Holocene)	Qb
Modesto Formation, Lower Member (Pleistocene)	Qml
Modesto Formation, Upper Member (Pleistocene)	Qmu
Red Bluff Formation (Pleistocene)	Qrb
Riverbank Formation, Lower Member (Pleistocene)	Qrl
Riverbank Formation, Upper Member (Pleistocene)	Qru

Stream Channel Deposits (Holocene)	Qsc
Turlock Lake Formation (Pleistocene)	Qtl
Ione Formation (Eocene)	Ti
Lovejoy Basalt (Miocene)	Tl
Laguna Formation (Pliocene)	Tla
Man Made Materials - Dredge Tailings and Other Disturbed Ground	t

Table 2. Soils classification table.

Soil Name	Soil Code
Boga-Loemstone , 0 to 1 percent slopes	0
Cherotable-Elsey , 2 to 15 percent slopes	1
Coalcanyon-Rock outcrop, cliffs-Talus-Coonhollow , 30 to 200 percent slopes	2
Columbia, 0 to 2 percent slopes, frequently flooded	3
Dam	4
Dumps, excavated material	5
Duric Xerarents-Eastbiggs , 0 to 1 percent slopes, leveled	6
Duric Xerarents-Oroville , 0 to 1 percent slopes, leveled	7
Eastbiggs loam, 0 to 2 percent slopes	8
Eastbiggs-Galt , 0 to 3 percent slopes	9
Esquon-Neerdobe , 0 to 1 percent slopes	10
Gianella fine sandy loam, 0 to 1 percent slopes, frequently flooded	11
Gianella fine sandy loam, 0 to 1 percent slopes, occasionally flooded	12
Gianella fine sandy loam, 0 to 1 percent slopes, rarely flooded	13
Gianella loam, 0 to 1 percent slopes, occasionally flooded	14
Gianella loam, 0 to 1 percent slopes, rarely flooded	15
Gridley taxadjunct loam, 0 to 2 percent slopes	16
Kimball loam, 1 to 3 percent slopes	17
Liveoak sandy clay loam, 0 to 2 percent slopes	18
Liveoak sandy loam, 0 to 2 percent slopes	19
Neerdobe clay loam, 0 to 1 percent slopes	20
Oroville-Thermalito-Fernandez-Thompsonflat complex, 0 to 9 percent slopes	21
Perkins gravelly loam, 0 to 2 percent slopes	22
Pits	23
Pits, gravel	24
Riverwash, 0 to 2 percent slopes frequently flooded	25
Rock outcrop-Thermalrocks-Campbellhills , 2 to 15 percent slopes	26
Thermalrocks-Beatsonhollow taxadjunct-Rock outcrop , 2 to 30 percent slopes	27
Thompsonflat loam, 15 to 30 percent slopes	28
Thompsonflat loam, 2 to 15 percent slopes	29
Thompsonflat-Oroville , 0 to 9 percent slopes	30
Vistarobles-Redding , 0 to 9 percent slopes	31
Water	32

Wilsoncreek-trainer loams, 0 to 2 percent slopes, occasionally flooded	33
Xerorthents, Tailings and 0 to 50 percent slopes	34
Xerorthents, tailings-Urban land complex, 0 to 2 percent slopes	35

Established trees and riparian scrub are present along the lower extent of the riverbank with the upper bank consisting of exposed dredge tailings (Figure 11). At higher flows, the unvegetated dredge tailings likely serve as a sediment source based on the steep slopes and bank retreat (erosion) relative to the lower vegetated banks.

Within the OWA D-Unit floodplain, cbec staff observed a mix of vegetated low lands and remnant dredge tailings. Most of the dredge tailings served as source material for construction of the Oroville Dam, hence the low relief within the OWA D-Unit. The OWA D-Unit remnant dredge tailings are comprised of gravel and cobbles with a fine sand matrix. This fine sand matrix was not observed on the surface of the tailing piles near the river (banks), indicating that the fine sediment on the surface of the riverbank tailings has been mobilized and transported to downstream reaches during high flow events. Full georeferenced photo documentation can be found in the Google Earth KML provided in Appendix A.

5.2 SEDIMENT TRANSPORT AND SEDIMENT SIZE ANALYSIS

Hydraulic and dredge mining caused a rapid influx of sediment to the system prompting extensive aggradation of the Feather River channel into the late 1800s. Hall (1880) estimated 18 million cubic yards of piedmont deposits were deposited between Oroville and Marysville. A reduction in sediment load occurred with the decline of hydraulic mining and with the construction of Oroville dam, which allowed channel incision to ensue into the latter half of the 20th century.

DWR OFRT (2004d) study demonstrated a dramatic shift in sediment supply with the construction of Oroville Dam. For example, the pre-dam construction daily mean suspended sediment discharge at the Oroville gage was 3,264 tons/day at an average discharge of 5,790 cfs for water years 1902-1962. The daily mean suspended sediment discharge post-dam construction was 42.5 tons/day at an average discharge of 1,062 cfs for water years 1968-1975. A total sediment load of 3,750 tons/ day is estimated to enter Lake Oroville, which results in a deficiency of 50 million tons in the lower Feather River between 1967 and 2004.

With the sediment loads from the upper watershed being trapped in Oroville dam, sediment from historic dredge tailing fields below the dam likely provide the predominant source of sediment along portions of the lower Feather River during high flow events. As with hydrology, there are two distinct sediment transport reaches within the OWA study reach: (1) the low flow reach above the Thermalito Afterbay outflow; and (2) downstream of the Thermalito Afterbay outflow. WET (1991) and DWR OFRT (2004d) both documented decreased transport of sediment in the low flow reach, which correlates with the heavily armored bed and the lack of an upstream sediment supply. DWR OFRT (2004d) model results (based on Fluvial 12) also show a coarsening of gravel over time within the low flow reach, leading to unsuitable salmon spawning habitat due to an armored bed and lack of finer sediment. WET (1991) further demonstrated a downstream fining of sediment size within the high flow reach, suggesting that the dredge tailings serve as a sediment source downstream of the Thermalito Afterbay outflow (upper high flow reach).

cbec supplemented existing findings by measuring the particle size distribution of surficial bar deposits along the 8 mile study reach (Figure 12 and Figure 13). Four sediment samples were analyzed digitally using field photos processed using Sedimetrics Digital Gravelometer (http://www.sedimetrics.com/). Results show a fining of sediment through the study reach, which supports the existing findings of WET (1991) and DWR OFRT (2004d). The low flow reach (location 73 and 79) showed D_{50} ranging between 47.3 and 83.6 mm. Downstream of the OWA D-Unit outlet weir (location 75), D_{50} is 23.9 mm, and at the downstream limits of the OWA study reach (location 77), D_{50} is 16.1mm.

5.3 BANKLINE ANALYSIS

Migration rates are highly variable along the Feather River due to the heterogeneity of material present along various reaches (WET 1991). In the OWA study reach, analysis of DWR OFRT (2004c) historical bankline analysis shows a relatively narrow meander belt and relatively low rates of bank migration. Post-dam construction bankline analysis indicates an average migration rate of 13.5 acres per year. These rates can be attributed to the decrease in frequency of peak flow events and the river being entrenched in armored dredge tailings. DWR OFRT (2004c) could not calculate erosion rates at cross sections between RM 58.9 and 61.9 due to historic gold dredging and present day gravel mining. However, the study suggests that banks comprised of stable, coarse dredge material may be slowing the bank erosion processes in the low flow reach. Downstream of the OWA study reach, where there is an absence of dredge tailing, post-dam erosion rates have increased. For example, just downstream of the study reach at RM 52.1, DWR OFRT (2004c) calculated a pre-dam erosion rate of 9.7 ft/year compared to a post-dam erosion rate of 16.2 ft/year.

Similarly, sediment transport model results (based on Fluvial 12) in DWR OFRT (2004d) showed little lateral channel movement within the low flow reach above the Thermalito Afterbay outflow. Model results also suggest higher bank erosion downstream of the Thermalito Afterbay outflow. Long term model results suggest that planform movement within the study reach will gradually decrease with time as finer sediments are transported downstream with no replenishment from an upstream source, allowing for channel armoring (coarsening) to continue.

To supplement existing analyses, cbec staff conducted historical bankline (DWR OFRT 2004b) comparison using banklines delineated for 1909, 1956, 1967, and 1986 overlaid with a 2012 aerial photo (Figure 14). Four specific locations within the OWA study reach were examined in-depth for planform changes: (1) at the inlet weir; (2) downstream of Thermalito Afterbay outflow; (3) downstream of the outflow weir; and (4) along the meander bend near the downstream extents of dredge tailings.

Gold mining at the turn of the century greatly altered channel form near the current OWA inlet weir (Figure 15). Between 1909 and 1967, the channel has become progressively wider with right and left bank bars forming sometime between 1956 and 1967. Very little planform changes have occurred after the construction of Oroville Dam. The current day left bank has been the same since 1956, presumably controlled by stable dredge tailings along the left bank. The right and left bank bars between 1986 and 2012 are nearly the same, which is likely a result of channel armoring within the low-flow reach.

Downstream of the Thermalito Afterbay outflow (Figure 16), anthropogenic activities such as gold and gravel mining are likely the most significant factors impacting channel morphology prior to dam construction. In 1909, the Feather River was a single threaded river channel, but by 1956, a mid-channel tailing pile is visible on aerial photos between RM 58.3 and 57.4. Based on field observations, this mid-channel tailings pile is composed of armored dredge tailings and likely resulted from gold mining and/or gravel extraction. Between 1956 and 1967, the mid-channel tailings pile had grown slightly on the upstream and downstream ends where alluvial deposits have contributed to the size of the bar. Post-dam construction, the mid-channel bar and channel form have not changed significantly. The 1967, 1986 and 2012 banklines are very similar through this reach.

Downstream of the present day OWA D-Unit outlet weir (Figure 17), the river was fairly active before the completion of Oroville Dam. The 1909 banklines show a multi-threaded channel with a backwater channel bordering the OWA D-Unit. Generally, the channel increased its width as the channel eroded the left bank on the outside of the meander bend. The formation of mid-channel bars at the downstream end began to establish in 1952; by 1967, this area had grown into a substantial bar feature. After the construction of Oroville Dam, the river is still fairly active along the outside of the meander bend with the formation of backwater features and bars partially attributed to return flows through the outlet weir. The mid-channel bar at the downstream end has also increased in size since the 1967 delineation and migrated downstream. The lack of dredge tailings bounding this portion of the river has allowed for typical meander migration patterns to persist, which is a sign that the river has sufficient capacity to transport its sediment supply.

Along the downstream extent of the dredge tailing fields the river is active along a meander bend (Figure 18). Between 1909 and 1967 the channel has grown wider, deposition occurred on the inside right bank and erosion occurred along the left bank, creating a more prominent meander bend. Post-dam construction banklines indicate continual changes to the channel form, albeit at a slower rate. Aggradation along the right bank has created a stable right bank bar unchanged since 1986. Coming out of the meander bend the left bank has not changed since 1967. Bank movement is limited in this reach by erosion resistant Modesto Formation (Figure 8) as shown in Figure 11. There is still erosion along the outside of the meander bend near RM 54.7, but for the most part channel widths have stayed the same since 1986.

Generally, there has been little to no planform changes following dam construction in the low flow reach upstream of the Thermalito Afterbay outfall, where stable armored dredge tailings and bed material confine river movement. This indicates that the low flow reach is transport limited and that lateral movement into dredge tailings may not be a source of sediment to downstream reaches. The downstream fining sequence observed in the high flow reach downstream of the Thermalito Afterbay outfall likely indicates that tailings along the river banks are serving as a sediment source during high flow events. Although there has been little change to the channel geometry in recent years, it is likely that high flow events that inundate the unvegetated tailings along the upper bank allow this sediment to be mobilized on these steep unstable slopes.

5.4 THALWAG PROFILE ANALYSIS

cbec staff compared river thalwegs between the 1909 (DWR OFRT 2004b), 1999 (USACE 1999), and 2010 (CVFED 2010) profiles (Figure 19). All profiles were standardized to a vertical datum of NAVD 88 and river miles per the Comprehensive Study (USACE, 2002). cbec used a best fit polynomial line to compare thalweg profiles between Fish Barrier Dam to Gridley Bridge:

- Between 1909 and 1999, the river thalweg degraded an average of 6.5 ft. Most degradation occurred just downstream of the Fish Barrier Dam.
- Between 1999 and 2010, the bed profile remained relatively unchanged with the exception of localized erosion and deposition. Localized erosion occurred between the Fish Barrier Dam and Hwy 162 of up to 4.5 ft (avg. 2.9) (but conditional depending on the quality of the 1999 bathymetry (Figure 22)), with the only significant flows occurring during the 2006 flood. Localized pool deposition following the 1997 flood occurred upstream of the OWA D-Unit inlet weir near present day gravel mining (RM 61.5) and near the Modesto Formation outcrop (RM 54.3).

5.5 CROSS SECTIONAL ANALYSIS

DWR OFRT (2004b) cross section analysis indicated little change in the channel geometry within the OWA study reach between 1970 and 1996. Between Hwy 162 and the Thermalito Afterbay (RM 63.9 and 58.5) only localized changes due to gravel extraction were observed. Downstream of the Thermalito Afterbay outflow, 1 to 4 feet of localized channel degradation was observed.

DWR OFRT (2004b) also compared cross sections between 1992 and 2002 to capture the effects of the 1997 flood event. In general, between Hwy 162 and the Thermalito Afterbay outflow, monitored cross sections exhibited aggradation and widening in the main channel and significant changes to morphology of secondary/side channels.

cbec compared 1999 (USACE 1999) and 2010 (CVFED 2010) cross sections as an effort to quantify more recent changes to channel morphology (Figure 20). The floodplain topography in 1999 was surveyed using photogrammetry while LiDAR was used in 2010, which likely accounts for some of the differences observed in the floodplain topography. Additionally, the 2010 survey was generally conducted at a higher resolution in the main channel, which attributes to some of the observed differences. This timeframe captures the effects of the 2006 flood event. Overall, a varying degree of morphological change was evident and dependent upon the location of the cross section relative to the erodibility of the bed and bank material even though there were minimal changes in the thalweg profile.

Below is a summary of the cross section changes observed between 1999 and 2010 (Figures 21 to 34):

- **Cross section comparison 1, RM 66.8:** erosion along the toe of the left bank creating a slightly wider channel.
- **Cross section comparison 2, RM 64.8:** channel thalweg has degraded by up to 5 ft, , but conditional based on the low resolution of the 1999 bathymetry. Otherwise there is little to no change to the banks and floodplain.
- **Cross section comparison 3, RM 64.2:** up to 3 ft erosion along the toe of the right bank. There are no changes to the banks and differences within the floodplain are most likely due to lower resolution survey techniques associated with the 1999 topographic survey.
- **Cross section comparison 4, RM 63.8:** up to 5.5 ft of channel erosion with deposition along the left bank bar. Changes on the right bank may be due to implementation of erosion control measures (rock placement) observed during field reconnaissance.
- **Cross section comparison 5, RM 62.7:** up to 3 ft of erosion along the right bank toe, but conditional based on the low resolution of the 1999 bathymetry, with minimal change to the channel banks and floodplain.
- **Cross section comparison 6, RM 61.7:** up to 1ft of erosion within the channel thalweg, minor erosion of the left bank and up to 0.5 ft of deposition along the right bank bar.
- **Cross section comparison 7, RM 60.4:** channel aggradation of 2.5 ft and deposition along the right bank bar.
- **Cross section comparison 8, RM 59.9:** channel migration towards the left bank with aggradation along the right bank, but conditional based on the low resolution of the 1999 bathymetry.
- **Cross section comparison 9, RM 58.0:** aggradation along both channels. The left channel has aggraded up to 3 ft and the right channel has aggraded up to 4 ft. Both the banks and mid-channel bar show little to no change.
- **Cross section comparison 10, RM 57.7:** major channel change occurred along the left channel with up to 6 ft of aggradation. The right channel, mid-channel bar and banks have exhibited minimal change.
- **Cross section comparison 11, RM 56.5:** in-channel aggradation of up to 4 ft with minimal change to floodplain topography.
- **Cross section comparison 12**, **RM 54.4:** sediment deposition and erosion on the left bar.
- **Cross section comparison 13, RM 53.7:** channel migration towards the left bank with deposition along the right bank bar, but conditional based on the low resolution of the 1999 bathymetry.
- **Cross section comparison 14, RM 52.7:** little to no change within the channel and possible deposition along the left bank bar.

5.6 ANALYSIS OF PRELIMINARY MODEL RESULTS

In an effort to further quantify relative impacts to the local sediment regime and water quality within the OWA study reach, cbec examined preliminary model outputs from the TUFLOW hydraulic model currently under development by PBI. To facilitate the analysis, cbec compared model outputs between existing conditions and the 1000 ft weir alternative (addition of a 1000 ft rock gabion weir set to elevation 130 ft) for the 10- and 100-year flood events. It should be noted that alternatives for the FSR project currently consist of a 400 ft weir and the magnitude of associated hydraulic impacts are less than the 1000 ft alternative (see Table 3); however, for the purposes of this geomorphic assessment, the 1000 ft alternative was analyzed because there are opportunities for future projects that may expand the diversion to this size or larger. Because the TUFLOW model is comprised of 1D channels (i.e., Feather River) and 2D floodplains (i.e., OWA D-Unit), this limited our interpretation of model results at locations in the river in the vicinity of inlet and outlet weirs. For example, we could not interpret how increased flows out of the D-Unit interact with the river to increase cross channel flows. The overall goal of this analysis was to:

1) Determine if relative decreases in conveyance and flow velocity on the Feather River between the inlet and outlet of the OWA D-Unit are significant enough to reduced sediment supply to downstream reaches on the Feather River. Because the banks of the Feather River downstream of the Thermalito Afterbay are comprised of dredge tailings and have been found to provide a source of sediment and potentially mercury to downstream reaches (WET 1991). Potential downstream impacts as a result of the reduced supply may include increased rates of channel incision, bank erosion and a reduction in spawning gravels for salmonids. Potential benefits of a reduced supply/transport include less mercury loading and a reduction in the rate of channel armoring.
2) Determine if relative increases in conveyance and flow velocity through the OWA D-Unit floodplain will be significant enough to mobilize and transport fine sediment stored within mine tailings on the floodplain to the mainstem of the Feather River. Potential implications include transporting fine sediment to the Feather River that may potentially be contaminated with Mercury, thus degrading water quality on the Feather River.

Table 3. Peak flows through the D-Unit (per PBI preliminary model results)

Recurrence Interval	Existing	400 ft Weir Alternative		1000 ft Weir Alternative	
	Flow (cfs)	Flow (cfs)	Diff (cfs)	Flow (cfs)	Diff (cfs)
10-year	8,000	NA	NA	12,000	4,000
100-year	27,000	32,000	5,000	44,000	17,000

5.6.1 Specific Stream Power Comparison

Understanding the fundamental processes governing river form allows for the interpretation of dynamic channel behavior and effects that impacts have on natural river corridor function. River form is controlled by the relative rates of sediment supply to the channel and the ability of the channel to transport that imposed supply (the ‘transport capacity’). While quantitative metrics of sediment supply are difficult to prescribe, specific stream power provides a direct and quantitative index for transport capacity (Knighton, 1998).

Specific stream power is the unit rate at which energy is applied to the channel bed and banks and provides a quantitative measure of the ‘geomorphic energy regime’ throughout a river system. As such, it is closely related to processes of dynamic channel behavior (including lateral migration) and sediment transport regime and, therefore, provides a powerful insight as to observed spatial patterns of physical condition in river systems. Specific stream power, Ω, is defined as:

$$\Omega = \tau \cdot \nu \cdot \omega$$

where τ is the bed shear stress, ν is velocity, and ω is the width of the channel (Larsen et al, 2006). Reach-scale analysis of specific stream power, together with information on sediment input and storage, is an important element of the physical process model.

Cross section average specific stream power for the 10- and 100-year events were calculated on the Feather River between the D-Unit inlet and outlet weirs using preliminary TUFLOW model output[1] for both existing conditions and the 1000 ft weir alternative (Figures 35 and 36). Analysis of these results indicate an overall decrease in specific stream power is observed when Feather River discharges upstream of the inlet exceed approximately 140,000 cfs, with a maximum reduction of approximately 25% during the peak of the 100-year event. Under the 10-year event, a similar trend was observed with a decrease in specific stream power when mainstem flow exceed approximately 140,000 cfs, although the magnitude of the reduction was on the order of 8% during the peak of the event.

It is understood that tailing piles that comprise the banks of the Feather River act to serve as a source of sediment during high flow events, especially on the upper non-vegetated terraces. It is possible that the reduction in cross section average stream power will reduce the supply of sediment to downstream reaches. However, it should be noted that a 8% to 25% reduction in stream power for the 1000 ft weir alternative, which will be significantly smaller for the 400 ft weir alternative as flow increases through the D-Unit are less than one third of the increases for the 1000 ft weir alternative, may not necessarily correlate to a proportional reduction in sediment supply, as the erosional forces acting on the upper banks (supply) include a combination of complex geotechnical (slope-stability) and hydraulic processes that may not correlate as well as a typical stream power analysis would. It is possible that this reach has excess capacity (stream power) to transport sediment under existing conditions, and that even with a reduction in stream power associated with the proposed alternative, the reach may still have adequate capacity (stream power) to transport the sediment supply. That said, the reduction in stream power has the potential to slow the rate of channel armoring.

5.6.2 Velocity Comparison

Relative changes to the magnitude and spatial distribution of velocity were also examined between existing conditions and the 1000 ft weir alternative for the 10- and 100-year events. Figure 37 shows the velocity distribution at the peak of the 10-year event and the relative difference with the 1000 ft weir alternative. With the addition of 4,000 cfs from the river into the D-Unit , this graphic shows relative decreases of up to 0.5 ft/s on the Feather River between the inlet and the outlet weirs, increases of up to 2 ft/s within the OWA D-Unit near the inlet, and increases of up to 1 ft/s on the Feather River upstream of the inlet weir. Figure 38 shows the velocity distribution at the peak of the 100-year event

[1] Extracted from TUFLOW model outputs at cross sections: V73, V14, V17, V21, V25, V29

and the relative difference with the 1000 ft weir alternative. With the addition of 17,000 cfs from the river into the D-Unit, there are relative decreases of up to 2 ft/s on the Feather River between the inlet and the outlet weirs, increases of up to 2 ft/s within the OWA D-Unit near the inlet, and increases of up to 2 ft/s on the Feather River upstream of the inlet weir.

Within the OWA D-Unit, the largest increases in velocity were observed immediately downstream of the inlet weirs (2 ft/s), which gradually decrease moving downstream toward the outlet weir (0 to 0.5 ft/s). Velocity within downstream portions of the OWA D-Unit floodplain increased from approximately 0.25 ft/s under existing conditions to 0.65 ft/s with the alternative for the 100-year event. The increases in velocity for the 1000 ft weir alternative within upper portion of the OWA D-Unit floodplain downstream of the inlet weir are likely to mobilize both coarse and fine sediment locally and transport these sediments a relatively short distance before they fall out of suspension as the velocities slow significantly. The increases in velocity within the mid and lower portions of the OWA D-Unit floodplain under the 100-year event have the potential to mobilize and transport fine material that has been observed within the surface matrix of dredge tailings in this zone, a process that would reduce with time as fines are winnowed from the surface of the coarse matrix. It is possible, although not definitive given the nature of this screening level analysis, that these sediments could be transported through the OWA D-Unit outlet into the Feather River during large flood events. However, the potential to winnow fines from the coarse matrix will be greatly diminished under the 400 ft weir alternative as flow increases through the D-Unit are less than one third of the increases for the 1000 ft weir alternative. As shown by Figure 39, the 400 ft weir alternative velocity increases in the mid and lower portions of the OWA D-Unit are 0.1 ft/s. It should be noted, that efforts could be made to enhance attenuation and reduce velocities through the D-Unit floodplain to lower the potential for sediment movement into the Feather River. This effort could be included with restoration actions in the form of strategically placed plantings or topographic manipulations oriented perpendicular to the flow direction. Furthermore, development of 2D sediment transport model could be utilized to further quantify the potential for sediment mobility within the D-Unit and the effectiveness of proposed mitigation measures to limit mobility.

Velocity within the Feather River channel upstream of the D-Unit inlet weir were also examined in greater detail by plotting time series of the cross section average channel velocity (Figure 40). Here we see increases in velocity of approximately 2 ft/s during the peak of the 100-year event given a steeping of the local hydraulic gradient due to greater flows passing through the OWA D-Unit. However, the increases in velocity in the Feather River upstream of the inlet weir are of lesser concern as the baseline velocities for lower discharges (<80,000 cfs) are well in excess of the increased velocities that occur during the peak of the alternative condition (Figure 40).

5.6.3 Water Surface Elevation Comparison

Relative changes to the simulated water surface elevation on the Feather River between the D-Unit inlet and outlet weirs were examined between existing conditions and the 1000 ft weir alternative for the 10-, 25- and 100-year flood events. These changes were quantified to provide additional context to the changes in specific stream power and average channel velocity presented in the preceding sections. Figure 41 shows the difference in the water surface elevation at river station 58.02, which is the approximately half the distance between the D-Unit inlet and outlet weirs. The drop in the water surface elevation associated with the 1000 ft weir alternative increases incrementally with the larger magnitude flood events, with decreases of 0.5, 1.3 and 1.8 feet for the 10-, 25-, and 100-year events, respectively. Relative to the maximum flow depths of up to 30 feet for these flood events, these decreases are small and still manage to inundate the unstable slopes of the dredge tailings..

6 SUMMARY AND CONCLUSIONS

Based on a review of readily available information, limited field reconnaissance, and review of preliminary model results for one of the proposed alternatives, herein follows a summary of the presented information:

- The morphology of the lower Feather River has been largely affected by historic perturbations within the watershed that have significantly impacted both the sediment and hydrologic regime over the last 150 years. Land use change and hydraulic mining led to extensive channel and floodplain aggradation, which was followed by channel incision as a result of reduced sediment loads from the cession of mining and the construction of dams. The OWA has been dredged extensively and the morphology of the Feather River and adjacent floodplain within this area are dominated by dredge tailings.
- The morphology of Feather River upstream of the Thermalito Afterbay outfall is heavily armored due to significantly reduced sediment loads due to the presence of the Oroville Dam.
- A fining of sediment downstream of the Thermalito Afterbay outfall suggests that dredge tailings likely provide a source of fine sediment to the river. This trend has been further corroborated with the observed armoring of near-river dredge tailings (banks) as the fine sediment matrix has been transported to downstream reaches. It is likely that during very high flow events, slumping of non-vegetated tailings on the upper banks provides a source of fine sediment to the river.
- Elevated mercury levels in fish along the lower Feather River have been attributed to dredge tailing fields on the Bear, Yuba and upper Feather Rivers, with the highest concentrations along the Yuba and Bear Rivers(DTMC 2002, DWR OFRT, 2004a).
- Most of the study reach downstream of the Thermalito Afterbay outfall shows little to no planform changes in recent years due to the dredge tailing, which confine lateral river movement.
- The thalweg profile through the study reach has degraded approximately 6.5 ft from 1909 to 1999. Minor changes to the thalweg profile have occurred between 1999 and 2010.
- Cross sectional comparison between 1999-2010 show minor changes to the channel morphology through the study reach and generally represent localized evolution of pool-riffle development. Localized channel scour was observed above the Thermalito Afterbay outfall (RM 58.5), while channel aggradation and bar deposition was observed downstream of this location.
- Analysis of preliminary model results between existing conditions and the 1000 ft weir alternative for the 10- and 100-year flood events indicate a reduction of 8 to 25% in specific stream power on the Feather River between the OWA D-Unit inlet and outlet weirs during the

peak of the flood events. These reductions will be significantly smaller for the 400 ft weir alternative as flow increases through the D-Unit are less than one third of the increases for the 1000 ft weir alternative. This reach has also been found to serve as a sediment source to downstream reaches, so there is the potential to reduce downstream sediment supply given reductions in stream power associated with the project. It should noted that a 8% to 25% reduction in stream power may not necessarily correlate to a proportional reduction in sediment supply, either from the unstable slopes of dredge tailings to the river or from the river to downstream reaches, given the complexity of bank erosion (slope stability) and the uncertainties between sediment supply and sediment transport capacity that exist within this reach. That said, the reduction in stream power has the potential to slow the rate of channel armoring downstream of the D-Unit inlet weir.

- Analysis of preliminary model results between existing conditions and the 1000 ft weir alternative for the 10- and 100-year flood event indicate that increases in flow velocity within the OWA D-Unit floodplain range from 0 to 0.25 ft/s within the southern floodplain to 0.5 to 2 ft/s just downstream of the inlet weir. The increases in the vicinity of the inlet weir have the potential to mobilize and deposit sediment locally, whereas the increases in the southern floodplain during the 100-year event have the potential to winnow and transport fine sediments from within the coarse dredge tailings matrix to the mainstem of the Feather River. The winnowing of fines from the surface of the coarse matrix would be episodic and supply limited, and more so, the potential to winnow fines from the coarse matrix will be greatly diminished under the 400 ft weir alternative as flow increases through the D-Unit are less than one third of the increases for the 1000 ft weir alternative. However, strategic use of vegetative plantings and topographic manipulations associated with the proposed restoration actions could mitigate this potential by reducing velocities and increasing attenuation. The nature of this screening level analysis does not allow for these potential impacts to be precisely quantified. However, it is possible that the reductions of sediment delivery from the dredge tailings on the mainstem of the Feather River (due to a reduction in stream power) may be offset by the increase in sediment loadings from within the OWA D-Unit floodplain (due to increases in velocity). This also has implications for tradeoffs in potential mercury loadings between the dredge tailings in the river and the dredge tailings in the OWA D-Unit floodplain. Much of this depends on a future phase of the project to enhance the aquatic habitat function and value of the OWA D-Unit floodplain for fish and other wildlife.

Based on this summary of information and data uncertainty, and in consideration that the OWA FSR Project includes a 400 ft weir alternative and not the potential future 1000 ft weir alternative, the FSR Project would appear to minimally affect the hydraulics, geomorphology, and water quality of the Feather River relative to present day. Reductions in stream power on the Feather River between the inlet and outlet weirs may help to slow river armoring while not further diminishing the supply of sediment from the dredge tailings. Small increases in velocity through the D-Unit have the potential to winnow fines from the coarse matrix, but this will be limited due to fine sediment availability and future habitat enhancements within the D-Unit that also have the benefit of slowing flow velocities and stabilizing surface sediments.

If a future phase of the FSR Project includes expansion beyond the current 400 ft weir alternative, i.e., a 1000 ft weir alternative, then cbec recommends the use of sediment transport models to more definitively quantify the potential for geomorphic impacts to the Feather River and fine sediments within the OWA D-Unit floodplain to be mobilized and transported. A 1D sediment transport model such as Fluvial 12 from the DWR OFRT (2004d) study could be used to assess the long-term geomorphic impacts to the river within the OWA study reach to determine how reductions in overall stream power may affect sediment delivery rates and river armoring. A 2D sediment transport model such as SRH-2D or MIKE 21C could be used to assess relative changes in sedimentation patterns within and sediment delivery from the OWA D-Unit to the Feather River. This hydraulic analysis could also be used to optimize techniques that would serve to reduce sediment delivery through strategically placed vegetation and topographic manipulations as part of future habitat enhancements.

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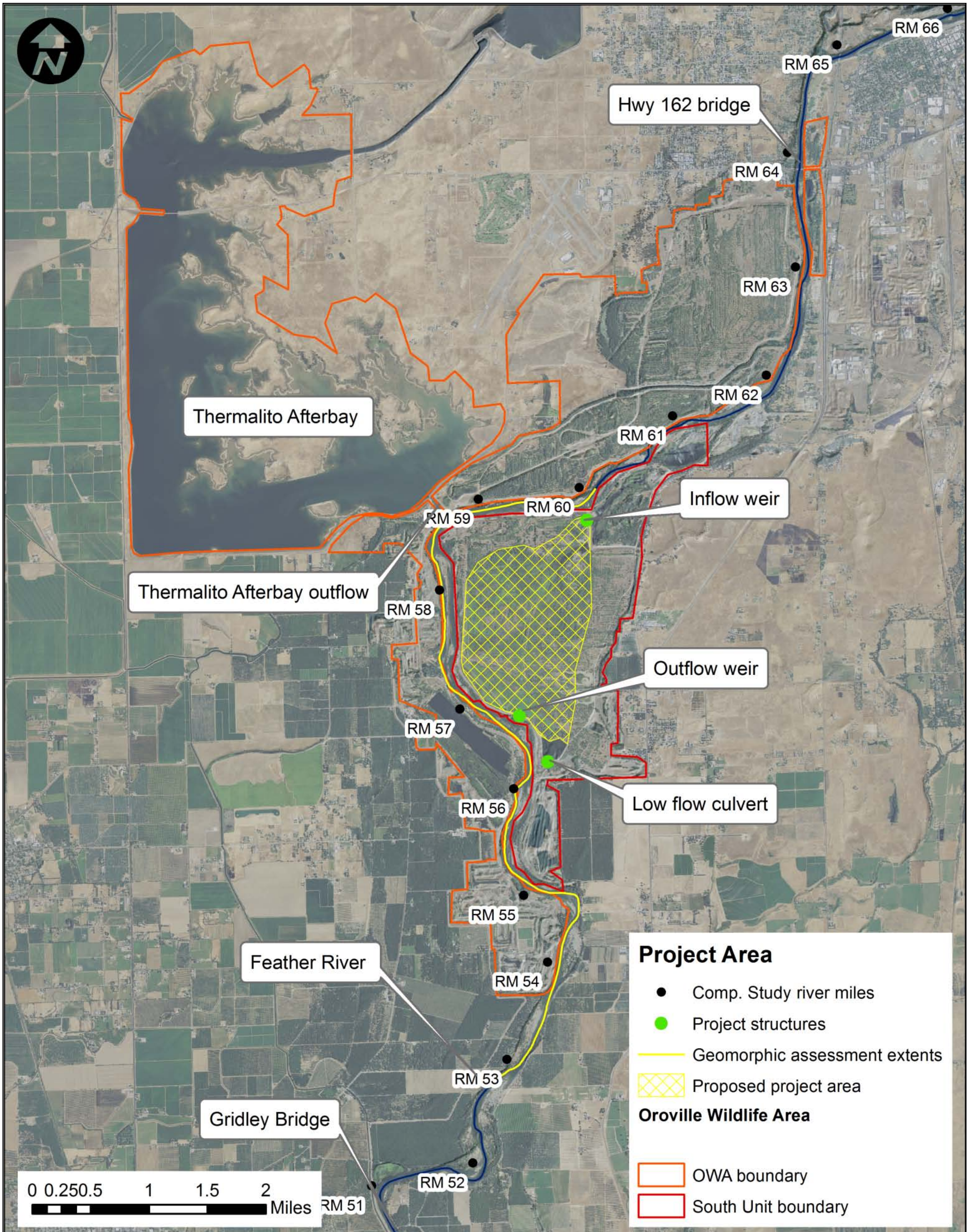
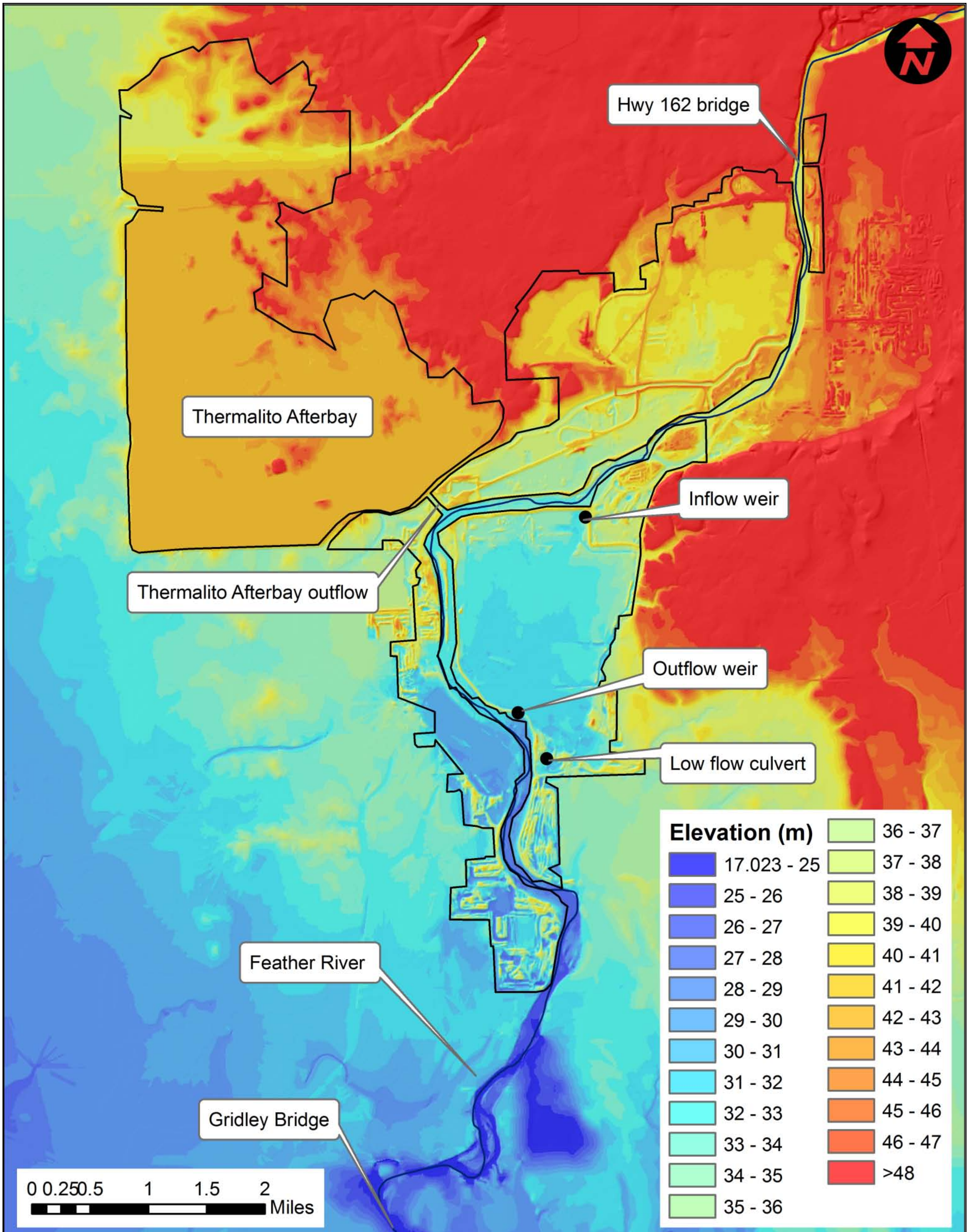
FIGURES

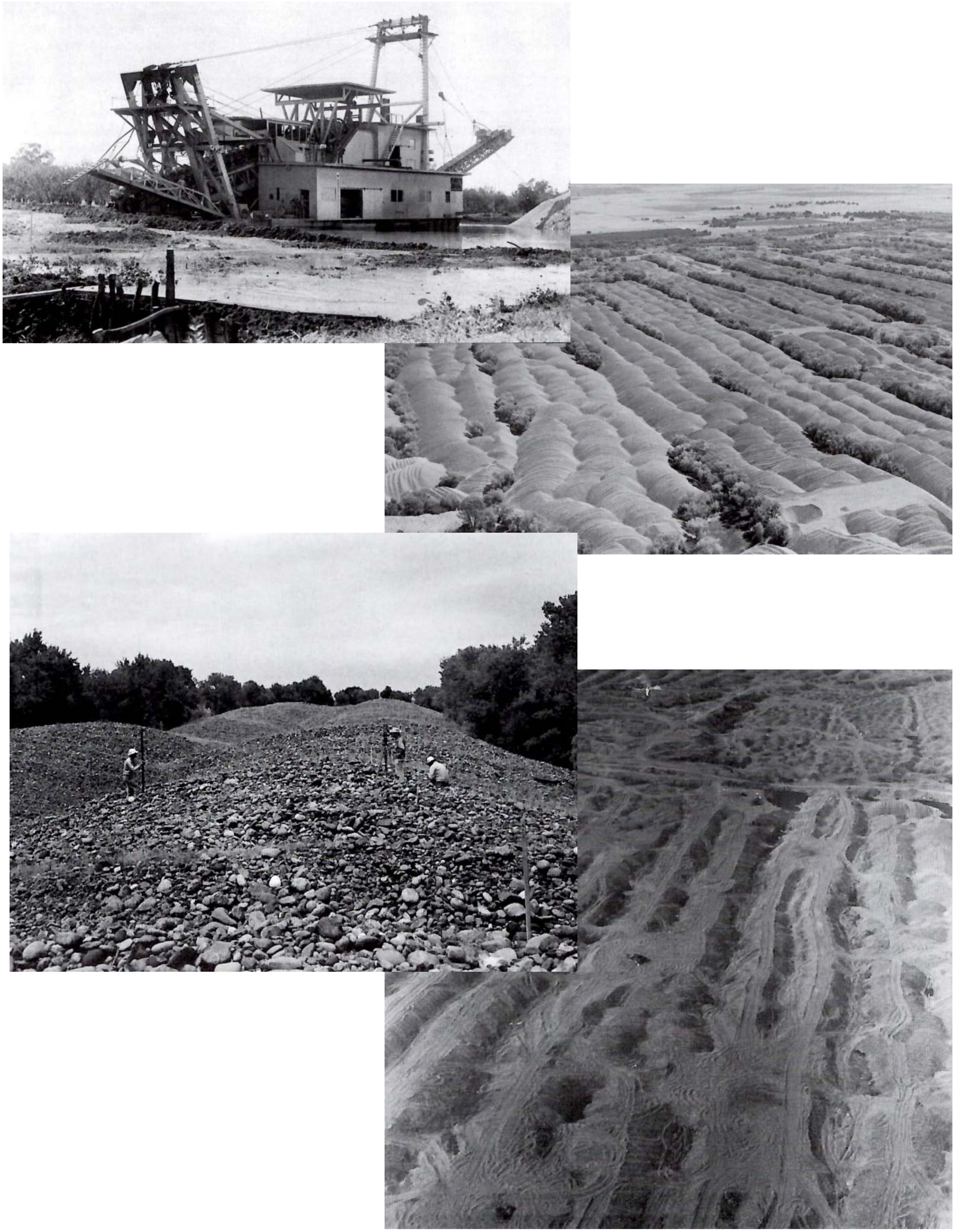


Notes: Background image-NAIP 2012	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Oroville Wildlife project area**
		Project No. 14-1026 | Created By: DT | **Figure 1**

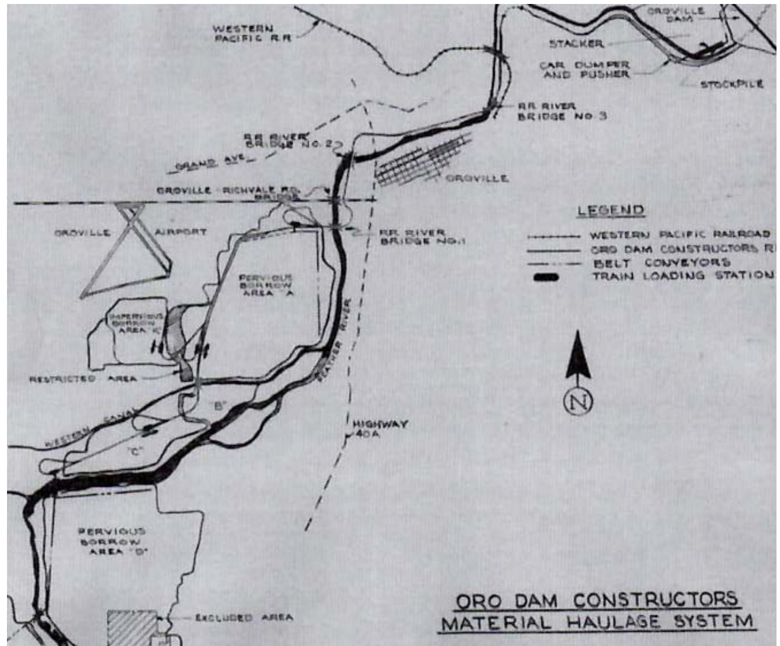


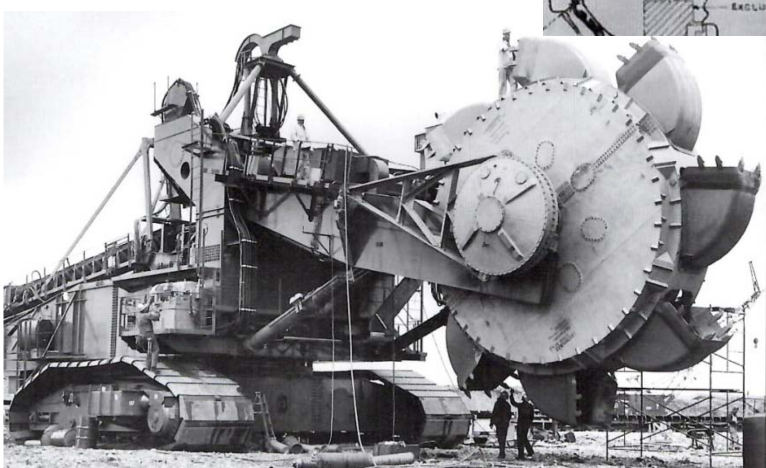
Notes: DEM- NRCS, 2014	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Oroville Wildlife project area elevations**		
		Project No. 14-1026	Created By: DT	**Figure 2**

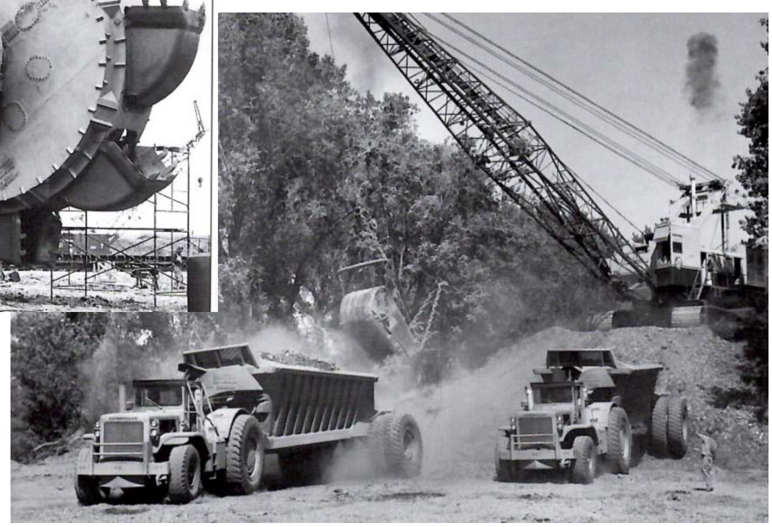
Notes:	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Inlet and Outlet Weir photos**		
		Project No. 14-1026	Created By: DT	**Figure 3**



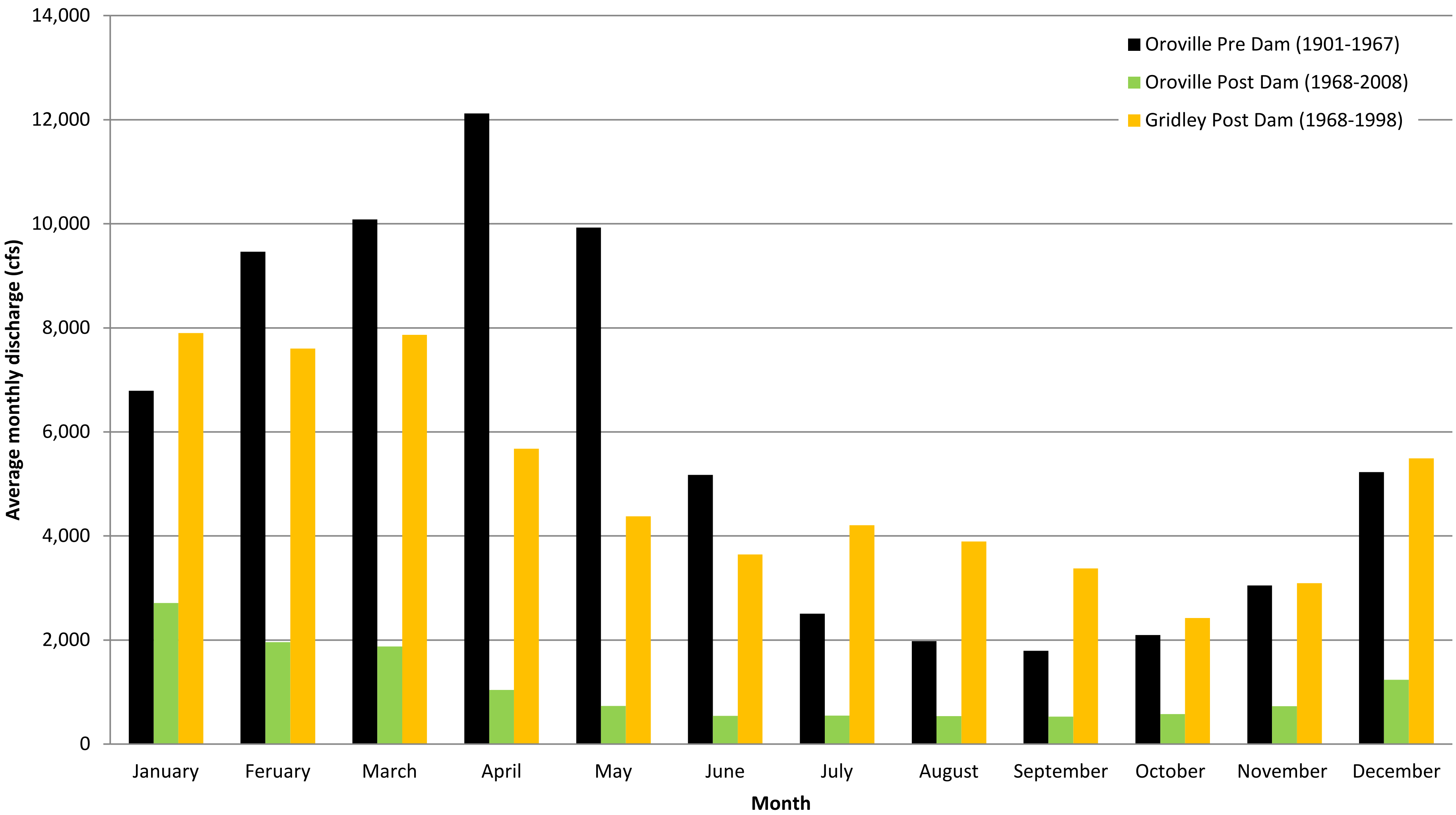
Notes: Adapted from Mathews (2014)	*Oroville Wildlife Area Flood Stage Reduction*	
	Gold dredging and dredge tailings fields	
Project No. 14-1026	Created By: DT	**Figure 4**







Notes: Adapted from Mathews (2014)		*Oroville Wildlife Area Flood Stage Reduction* **Gravel extraction operations for Oroville Dam**		
		Project No. 14-1026	Created By: DT	**Figure 5**



Notes: Computed from daily data-
USGS gage # 11407000 Feather River at Oroville, CA (Drainage area of 3,624 mi^2)
USGS gage # 11407150 Feather River at Gridley, CA (Drainage area of 3,676 mi^2)

cbec eco engineering

Oroville Wildlife Flood Stage Reduction

Pre- and post-dam average monthly flows

Project No. 14-1026 | Created By: DT | **Figure 6**

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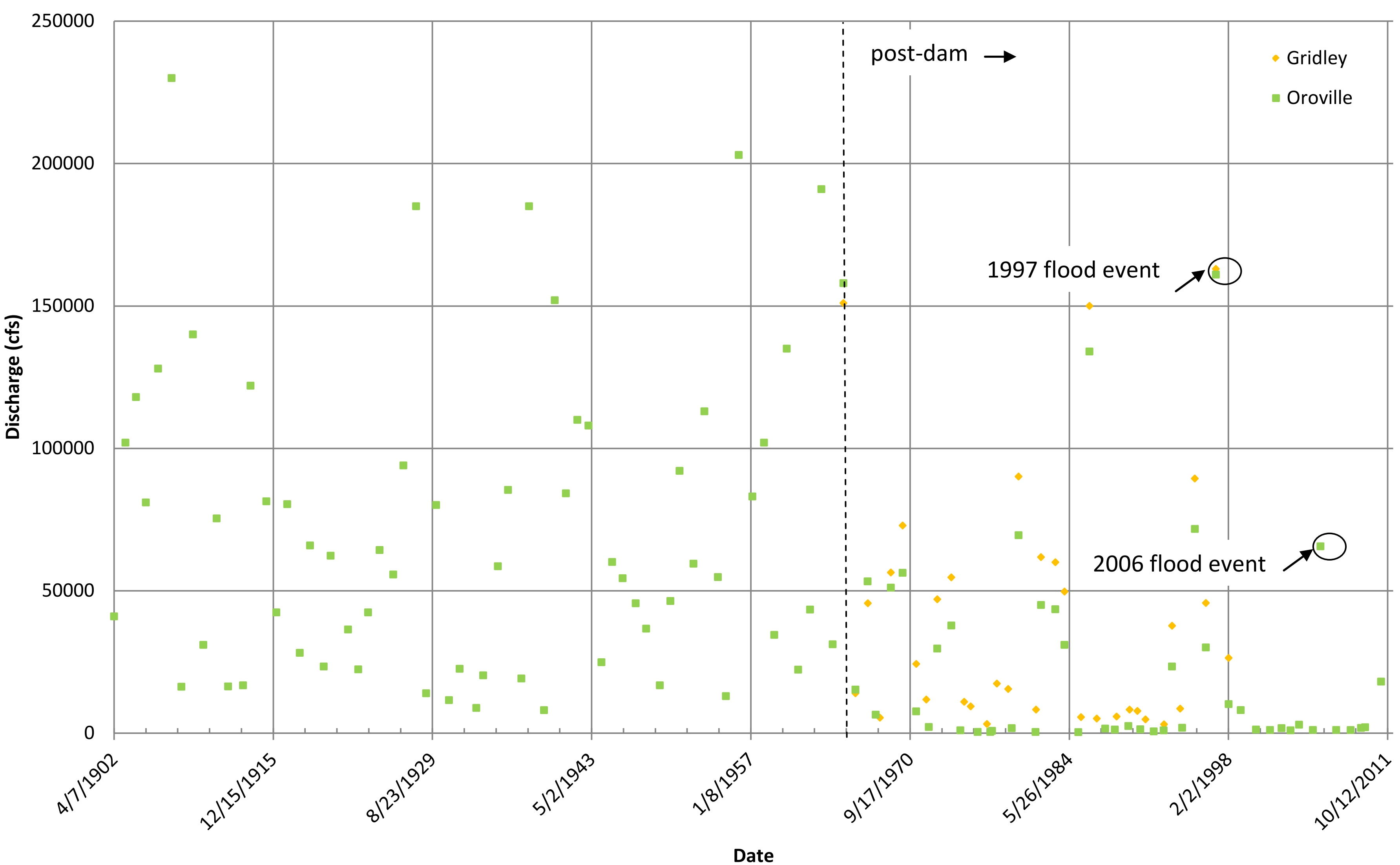
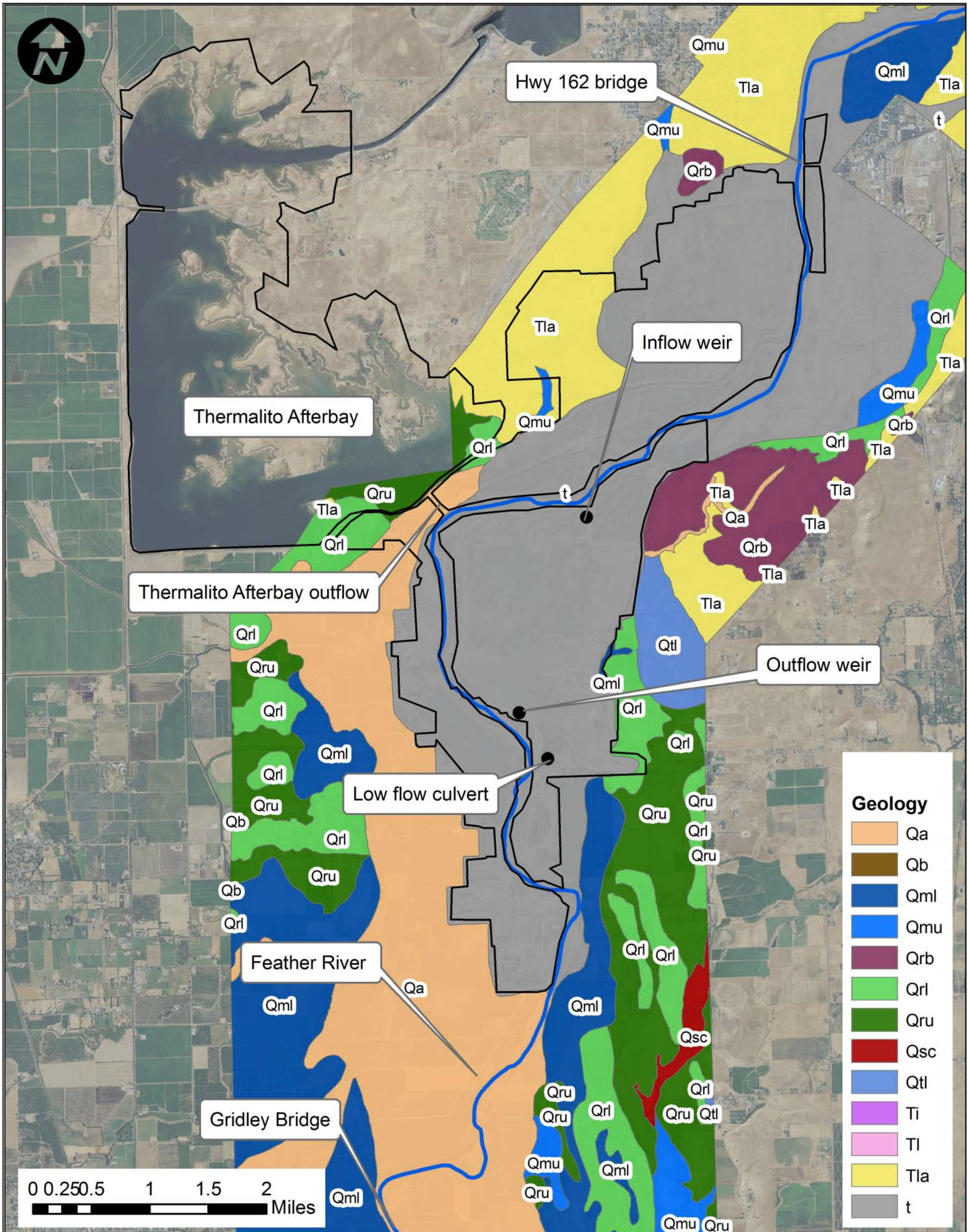
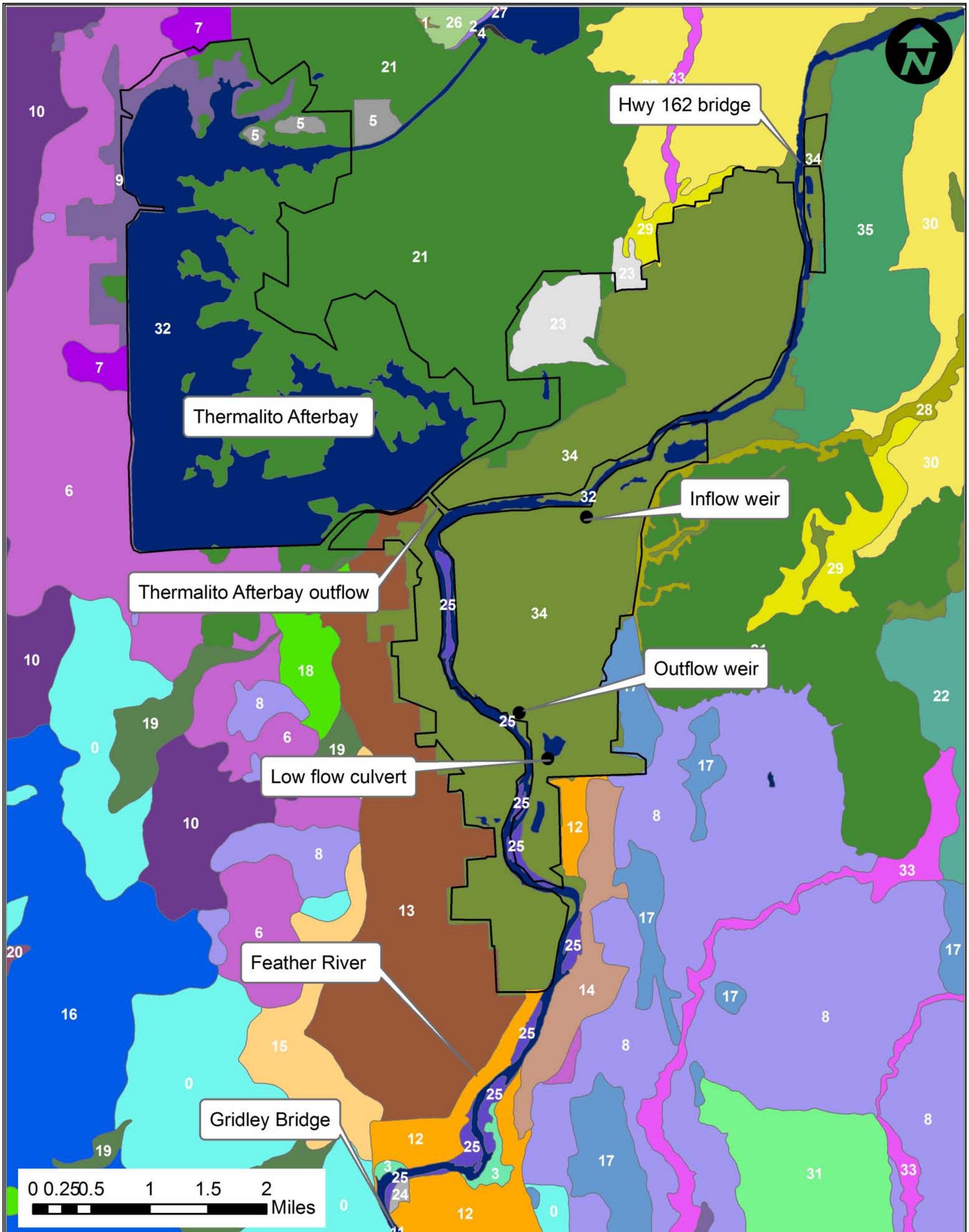


Notes:	cbec eco engineering	*Oroville Wildlife Flood Stage Reduction* **Feather River post-dam peak flows**		
		Project No. 14-1026	Created By: DT	**Figure 7**



Notes: Background image- NAIP 2012, Geology - DWR OFRT 2004a. Refer to Table 1 for geology classes.	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Project area geology**		
		Project No. 14-1026	Created By: DT	**Figure 8**



Notes: Soils classification-SSURGO. Refer to Table 2. for soil classifications

Oroville Wildlife Area Flood Stage Reduction

Project area soils

Project No. 14-1026	Created By: DT	**Figure 9**

Notes: Left Bank at ~RM 54.6	cbec eco engineering	*Oroville Wildlife Flood Stage Reduction* **Modesto formation along downstream portion of the study reach**		
		Project No. 14-1026	Created By: DT	**Figure 10**

Notes: Taken from the left channel looking at the mid-channel bar along the right bank at RM 58.0	cbec eco engineering	*Oroville Wildlife Flood Stage Reduction* **Typical bank composition**	
		Project No. 14-1026	Created By: DT	**Figure 11**

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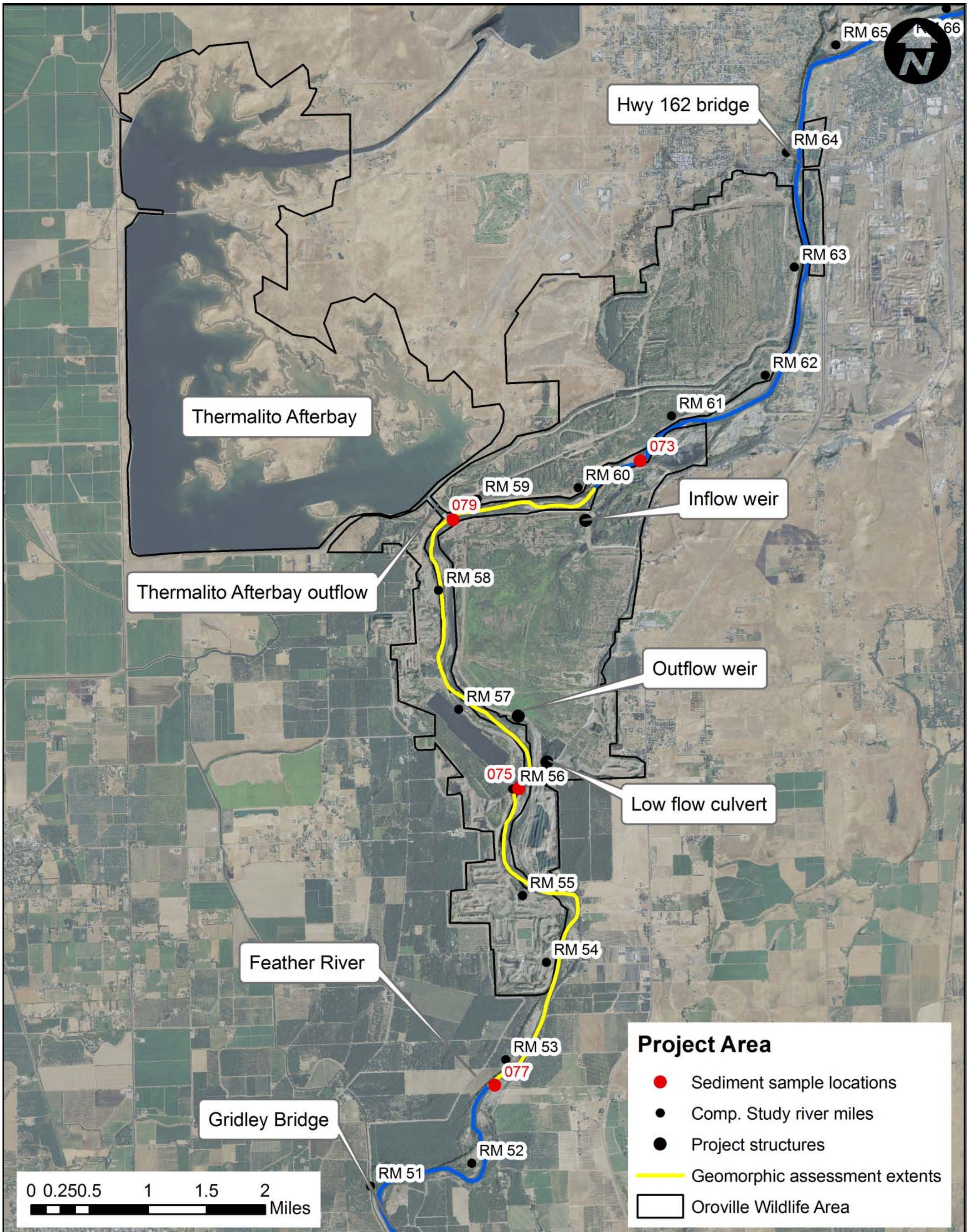
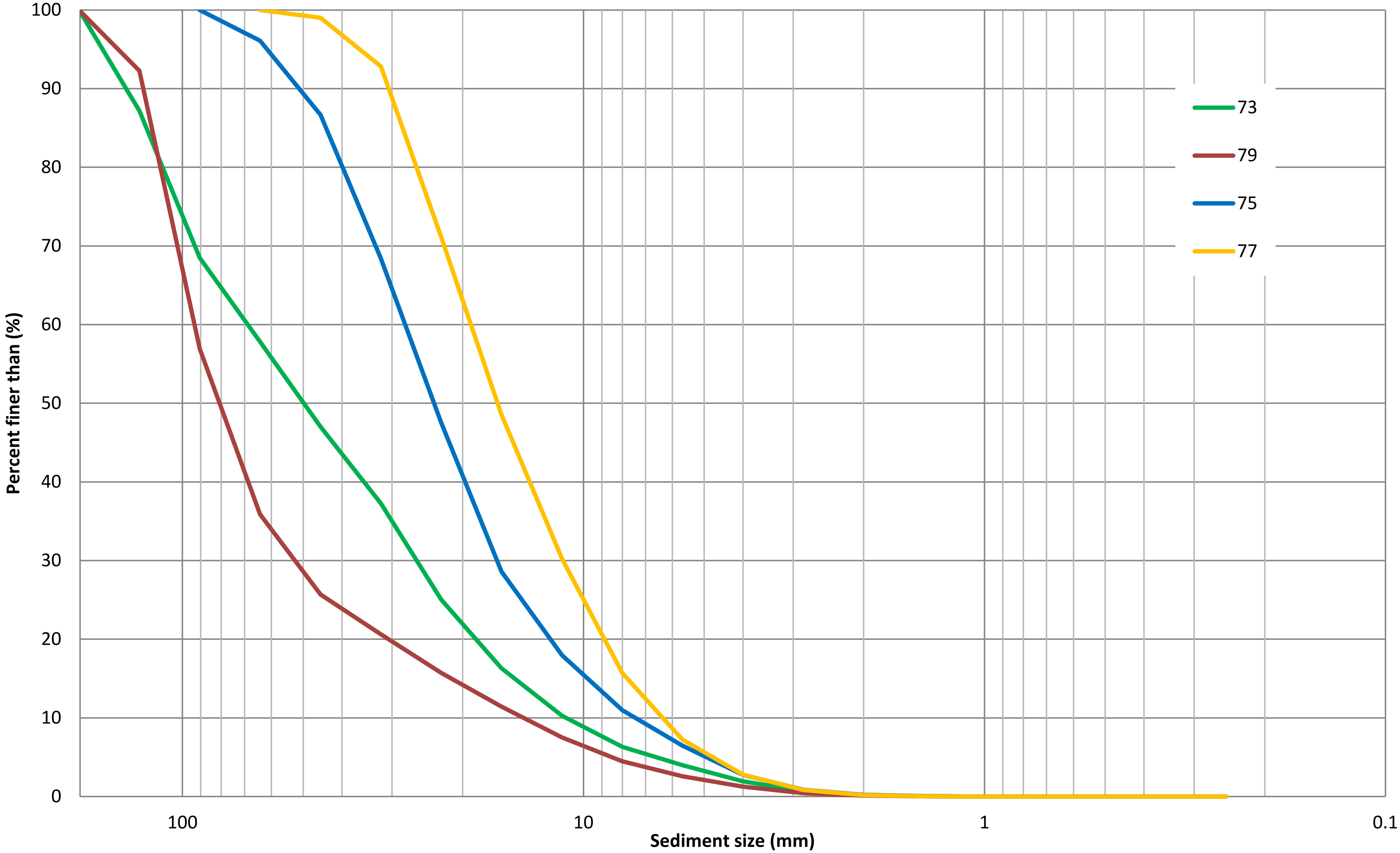
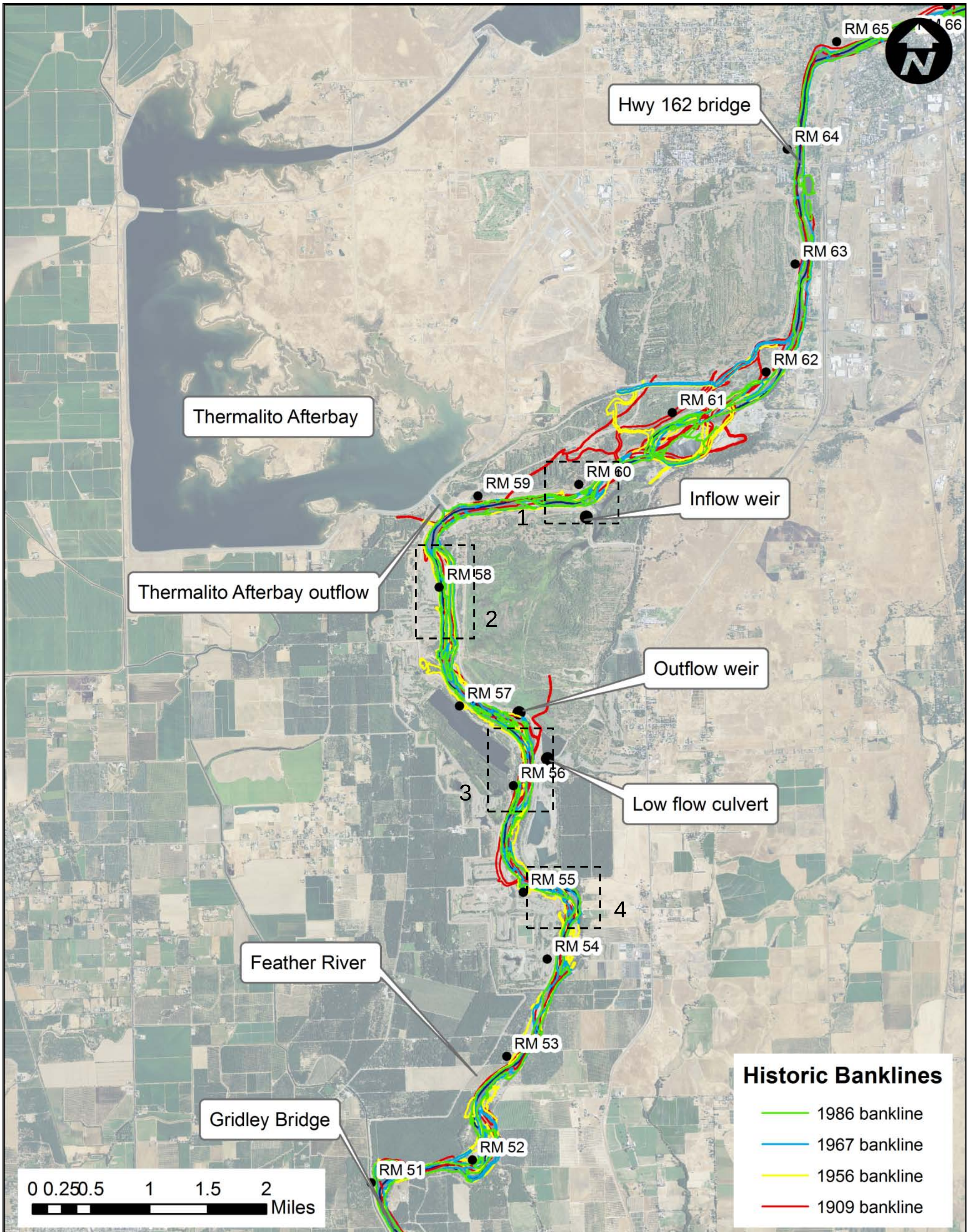


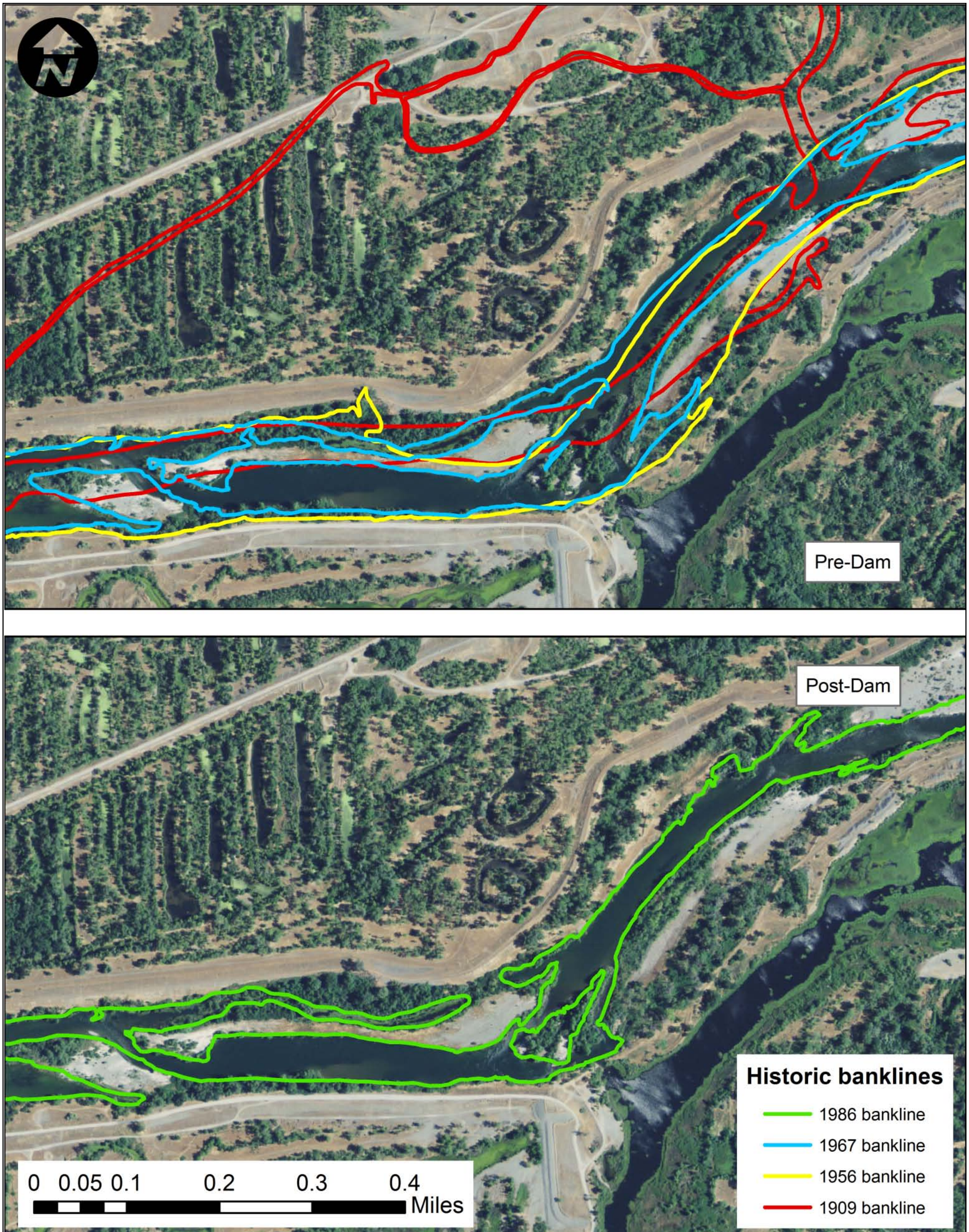
Notes: Background image-NAIP 2012	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Sediment sample locations**
		Project No. 14-1026 | Created By: DT | **Figure 12**



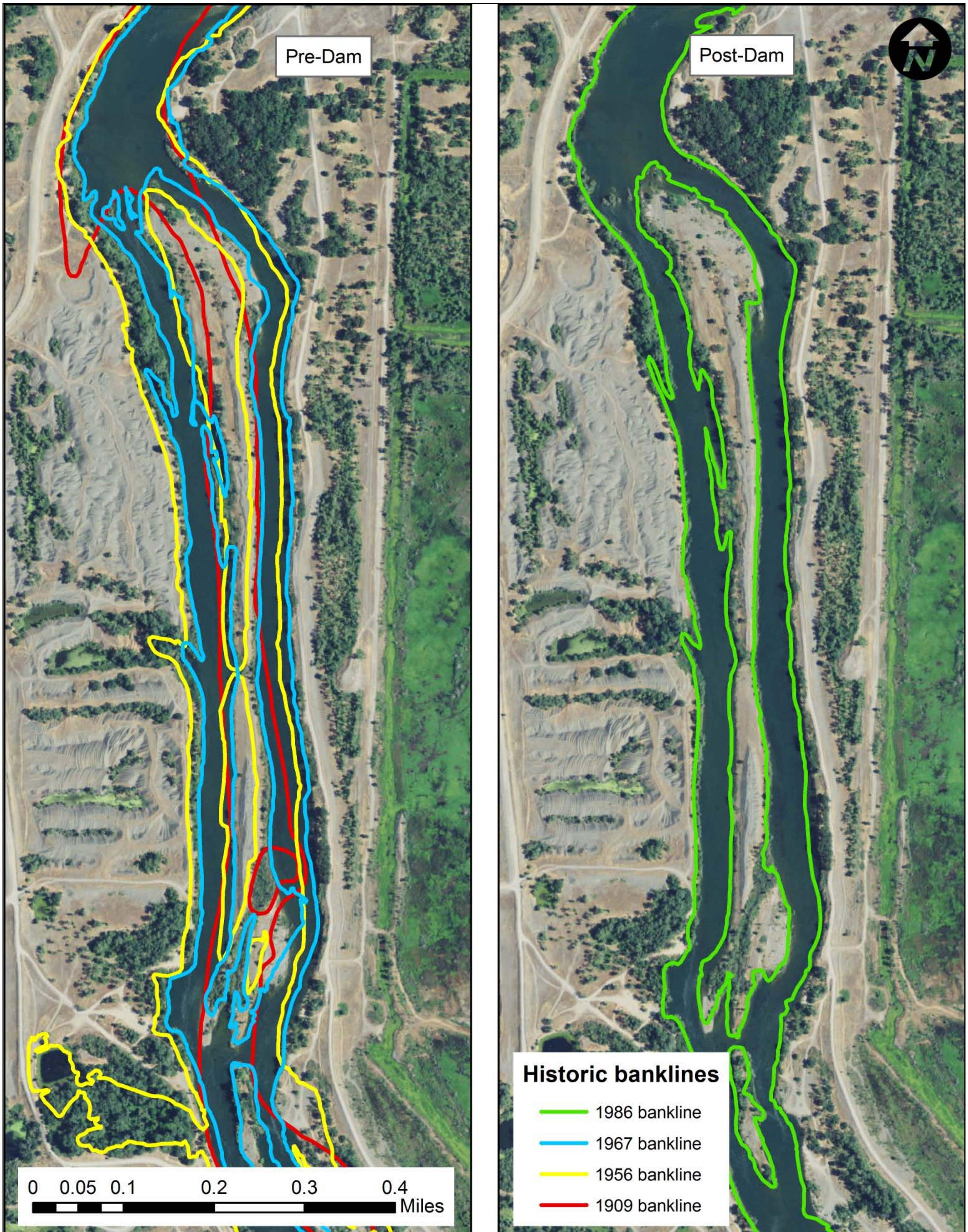
Notes:		*Oroville Wildlife Area Flood Stage Reduction*		
	cbec eco engineering	**Sediment Size Analysis**		
		Project No. 14-1026	Created By: DT	**Figure 13**



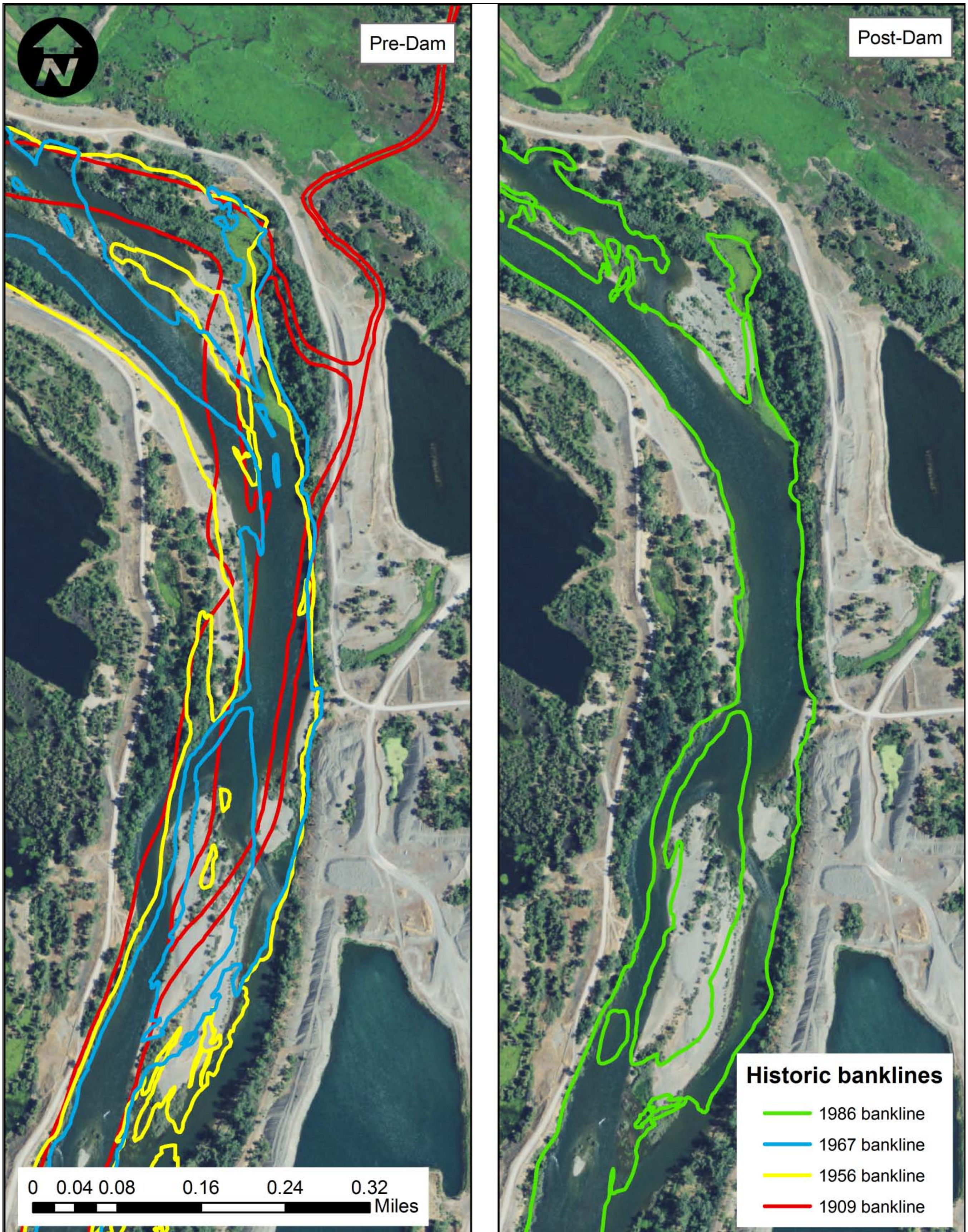
Notes: Background image-NAIP 2012, Bankline-DWR OFRT, 2004b	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Bankline overview map**		
		Project No. 14-1026	Created By: DT	**Figure 14**



Notes: Background image-NAIP 2012, Bankline-DWR OFRT, 2004b	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Bankline comparison 1- inlet weir**
		Project No. 14-1026 | Created By: DT | **Figure 15**



Notes: Background image- NAIP 2012, Bankline- DWR OFRT, 2004b	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Bankline comparison 2- downstream of the Thermalito Afterbay**		
		Project No. 14-1026	Created By: DT	**Figure 16**

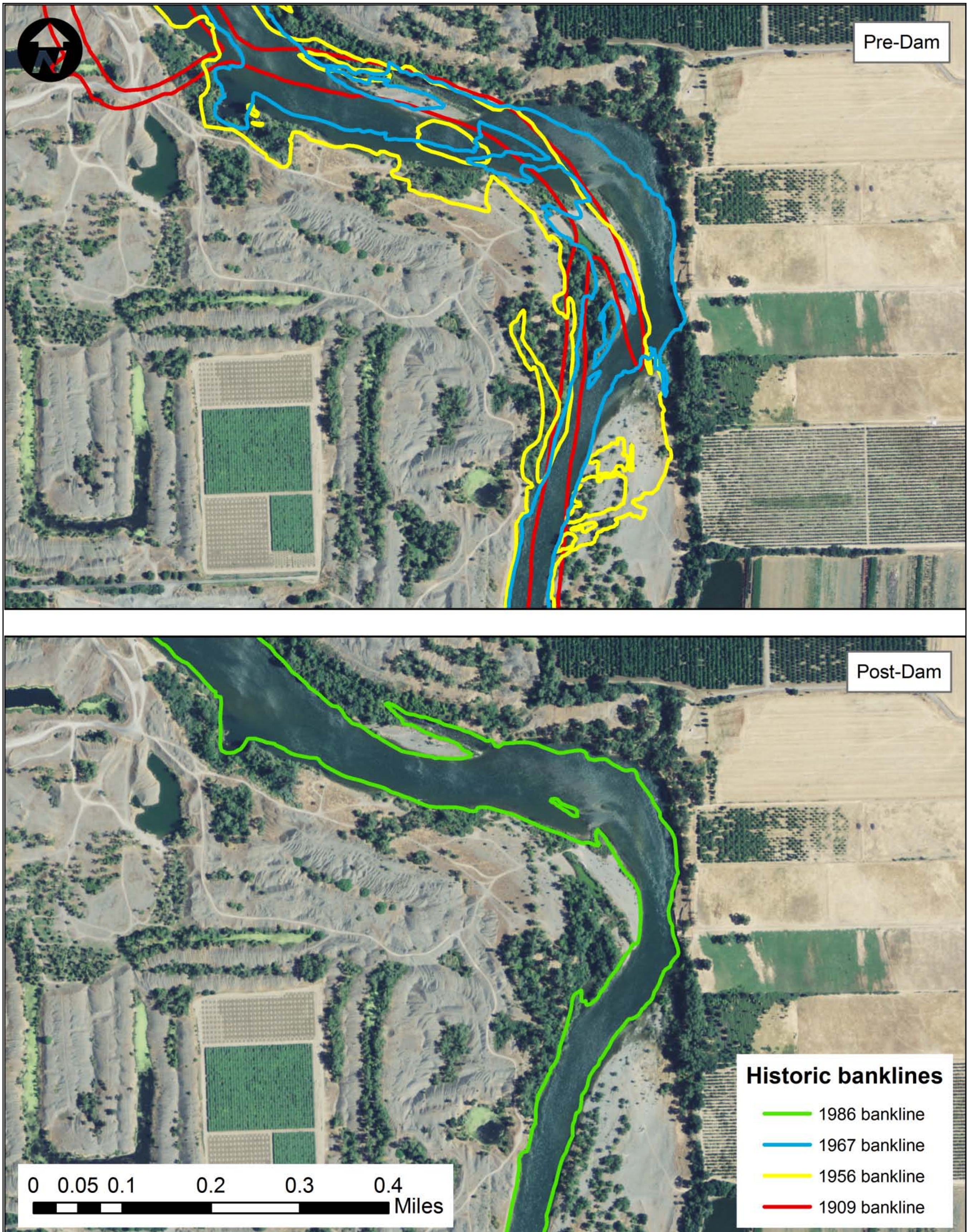


Notes: Background image- NAIP 2012, Bankline- DWR OFRT, 2004b

Oroville Wildlife Area Flood Stage Reduction

Bankline comparison 3- downstream of the outflow weir

Project No. 14-1026	Created By: DT	**Figure 17**



Notes: Background image- NAIP 2012, Bankline- DWR OFRT, 2004b	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Bankline comparison 4- meander bend along dredge tailings**
		Project No. 14-1026 | Created By: DT | **Figure 18**

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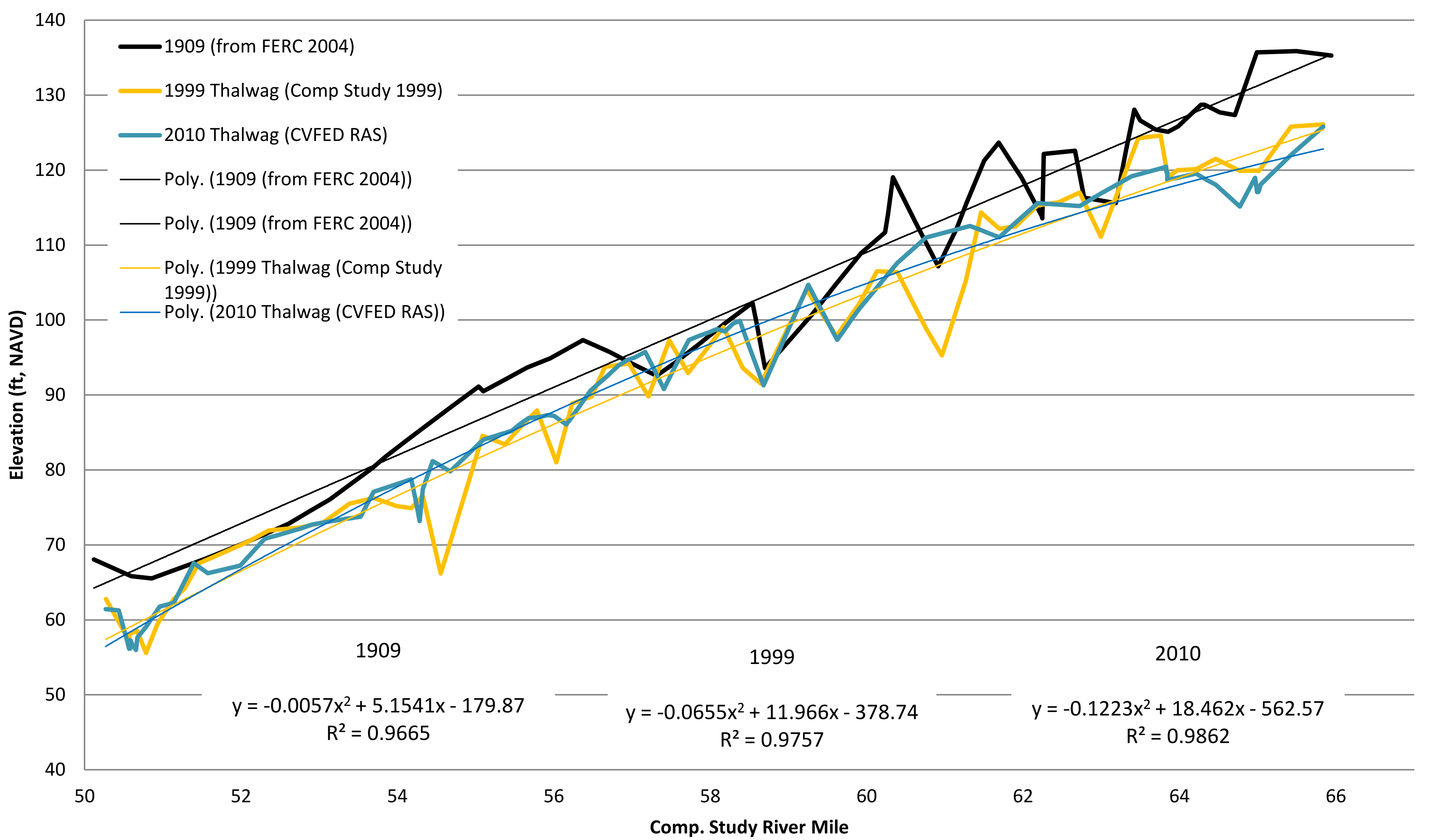


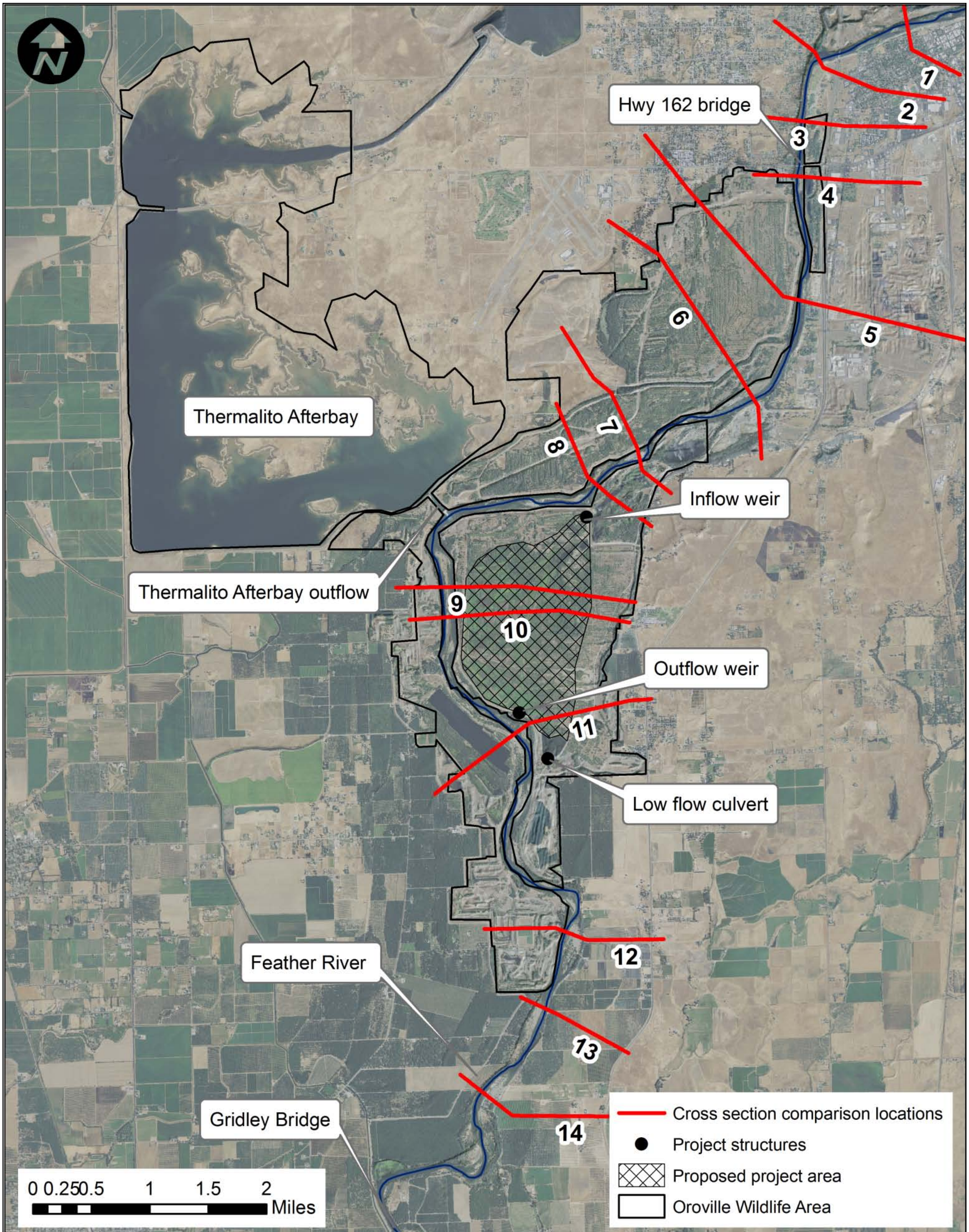
Notes:

cbec eco engineering

Oroville Wildlife Area Flood Stage Reduction

Thalwag profile comparison

Project No. 14-1026 | Created By: DT | **Figure 19**



Notes: Background image-NAIP 2012		*Oroville Wildlife Area Flood Stage Reduction* **Cross section comparisons**		
		Project No. 14-1026	Created By: DT	**Figure 20**

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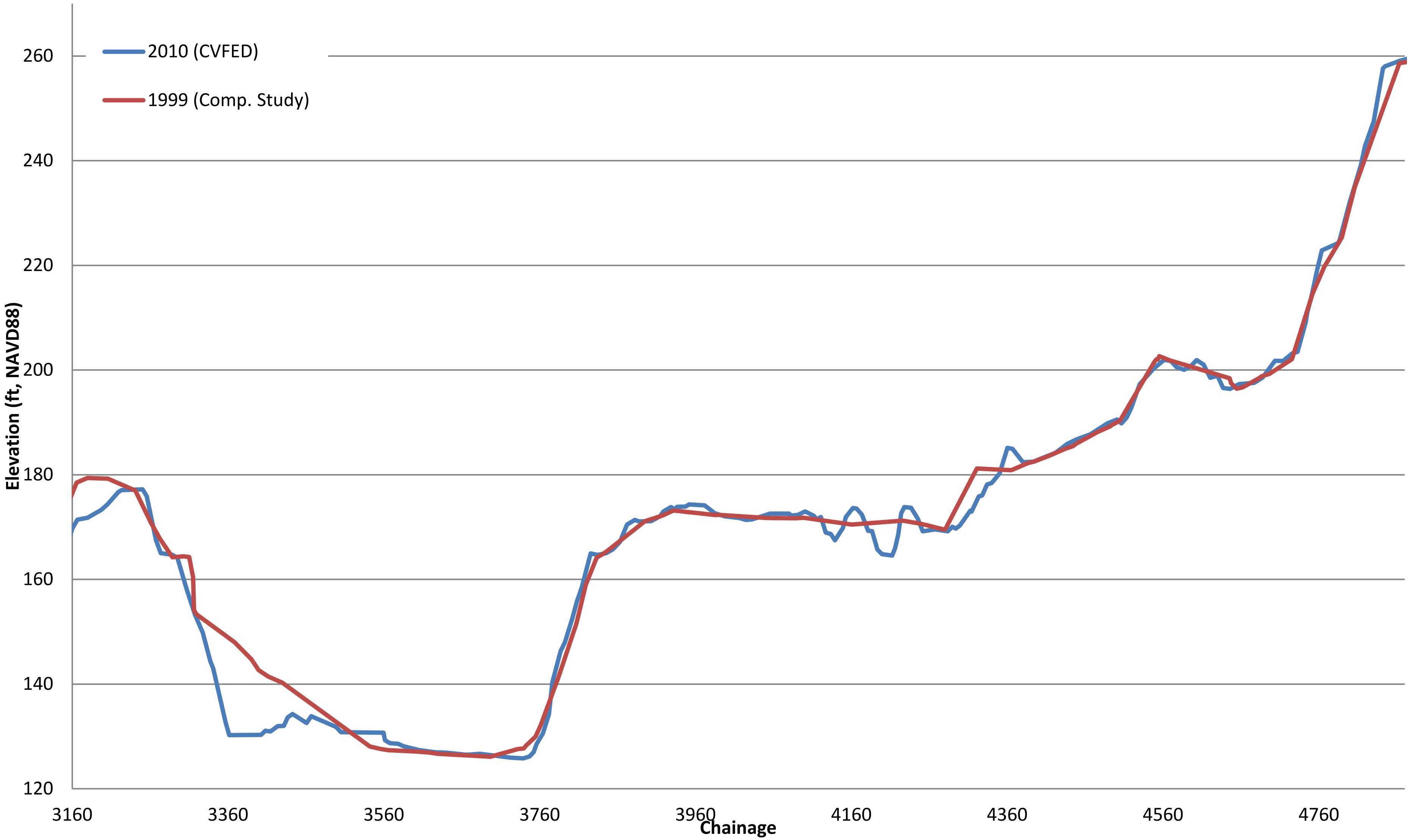

Notes:	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Cross section comparison 1, RM 65.8**		
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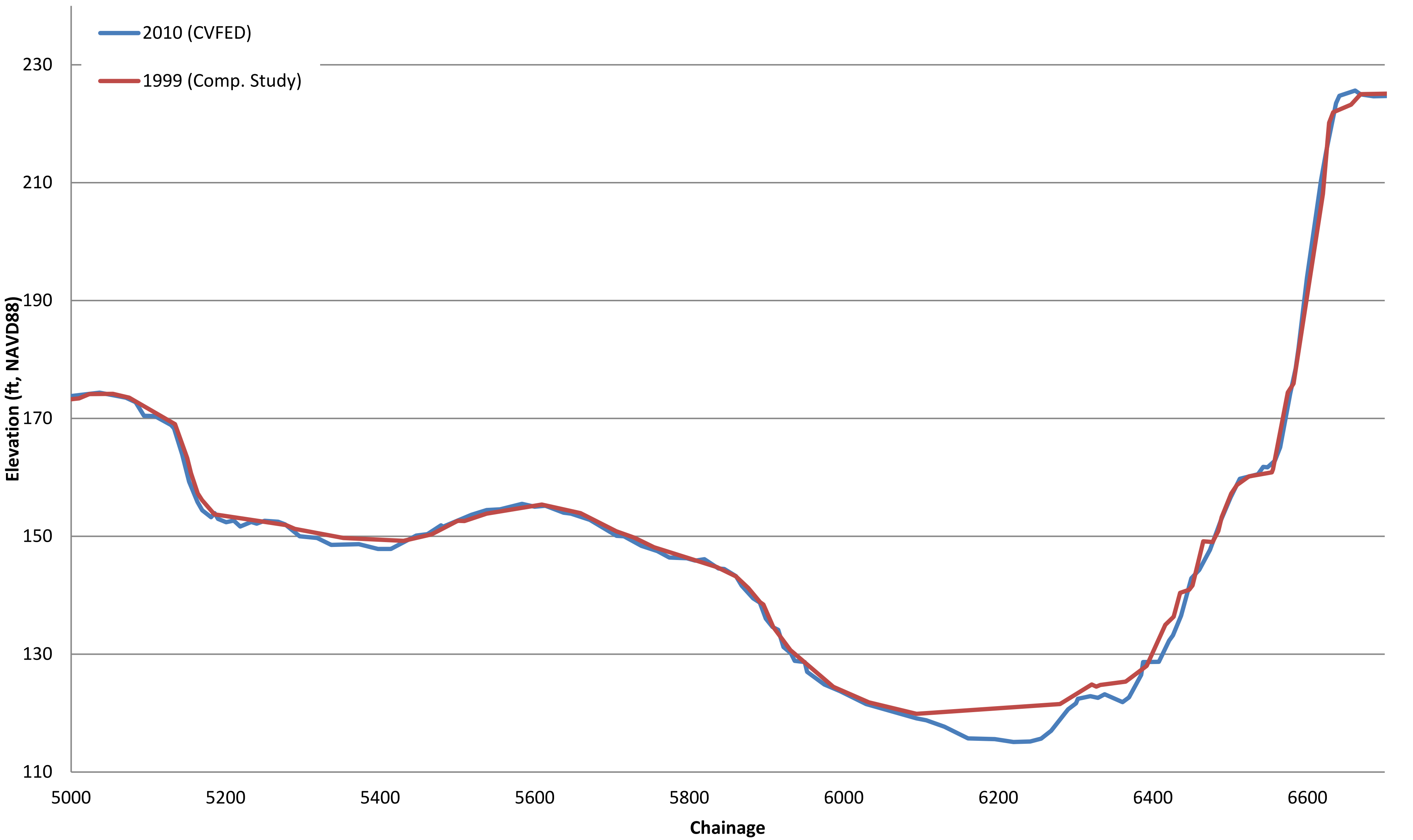
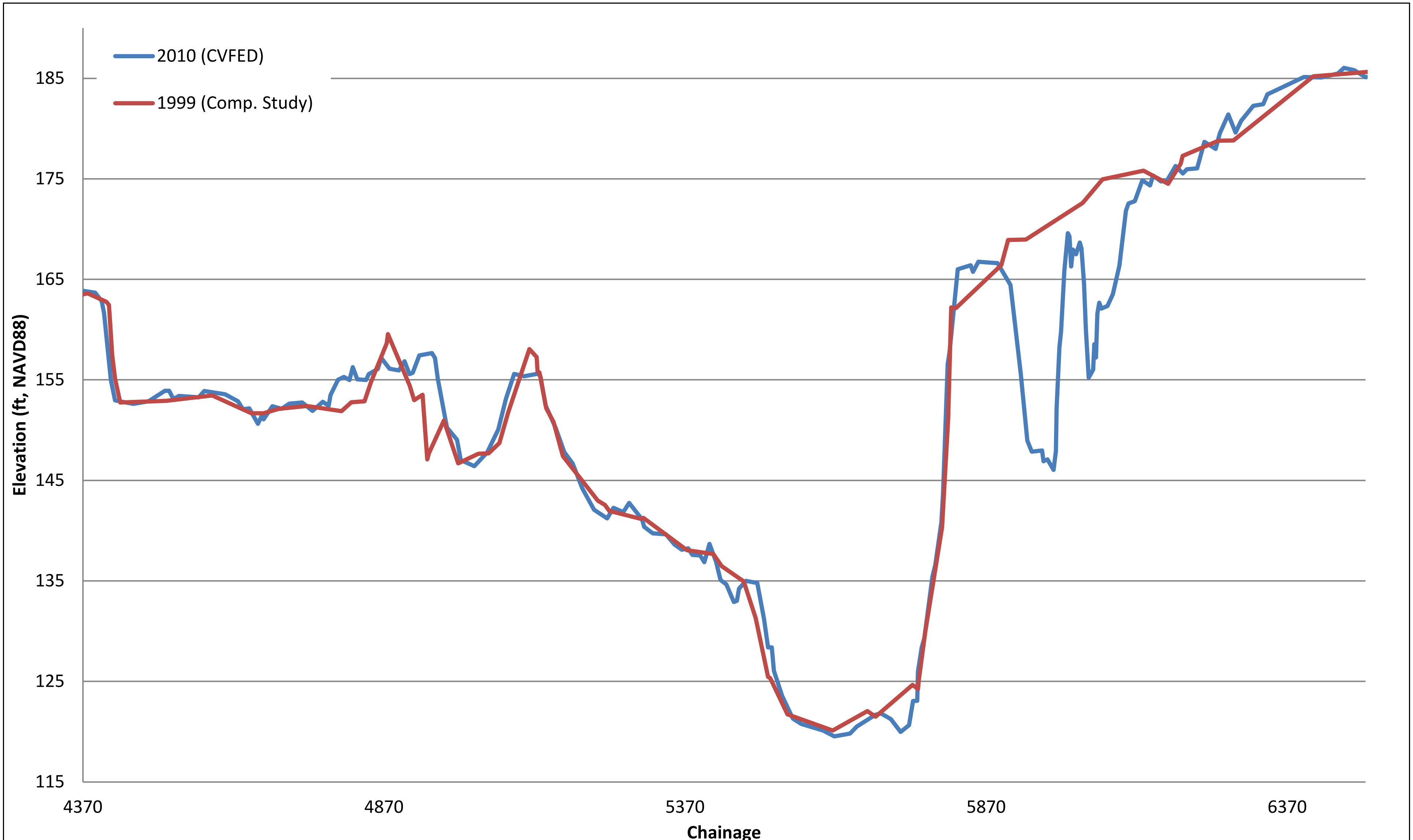


Notes:

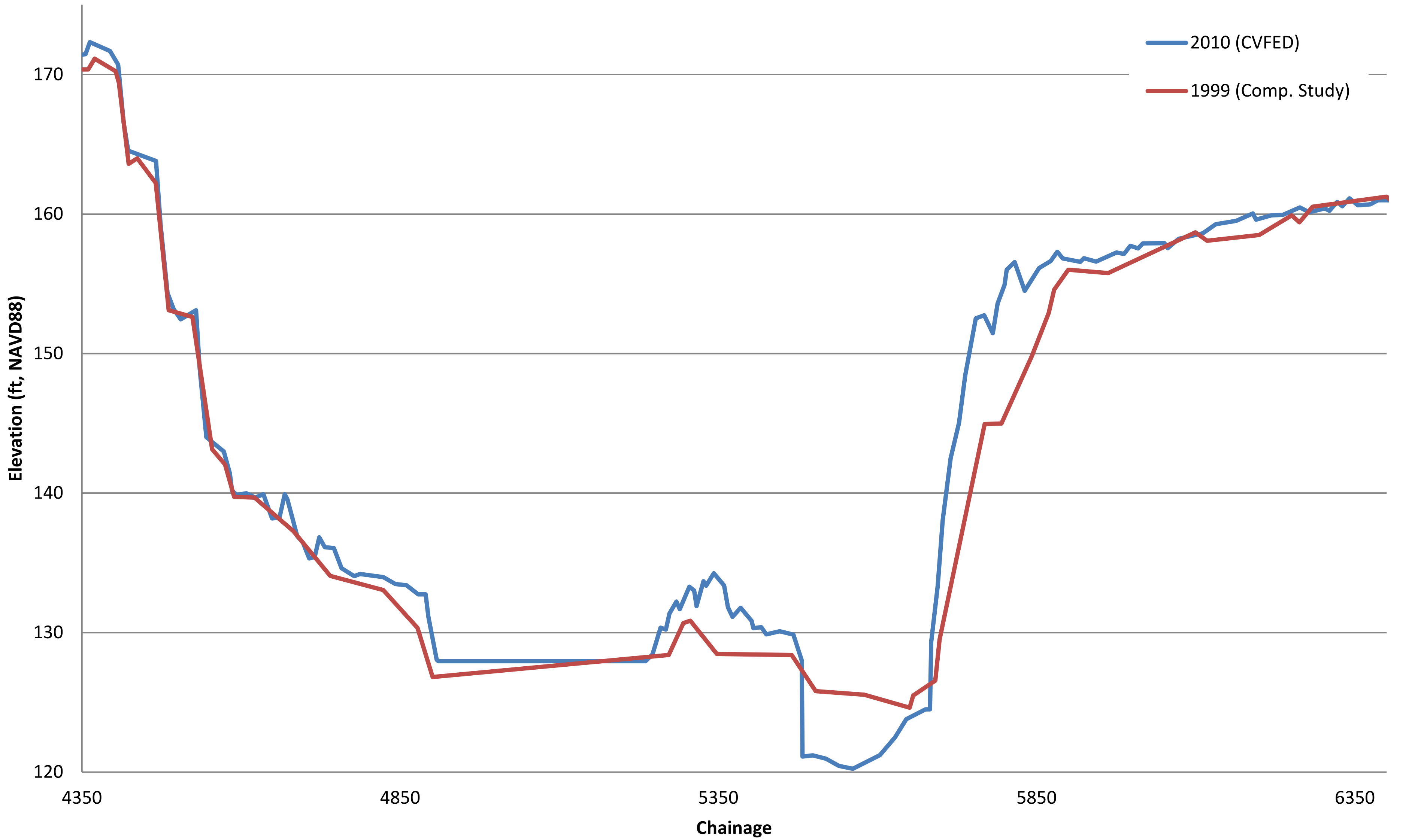
Oroville Wildlife Area Flood Stage Reduction

Cross section comparison 2, RM 64.8

Project No. 14-1026	Created By: DT	**Figure 22**



Notes:	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Cross section comparison 3, RM 64.2**		
		Project No. 14-1026	Created By: DT	**Figure 23**

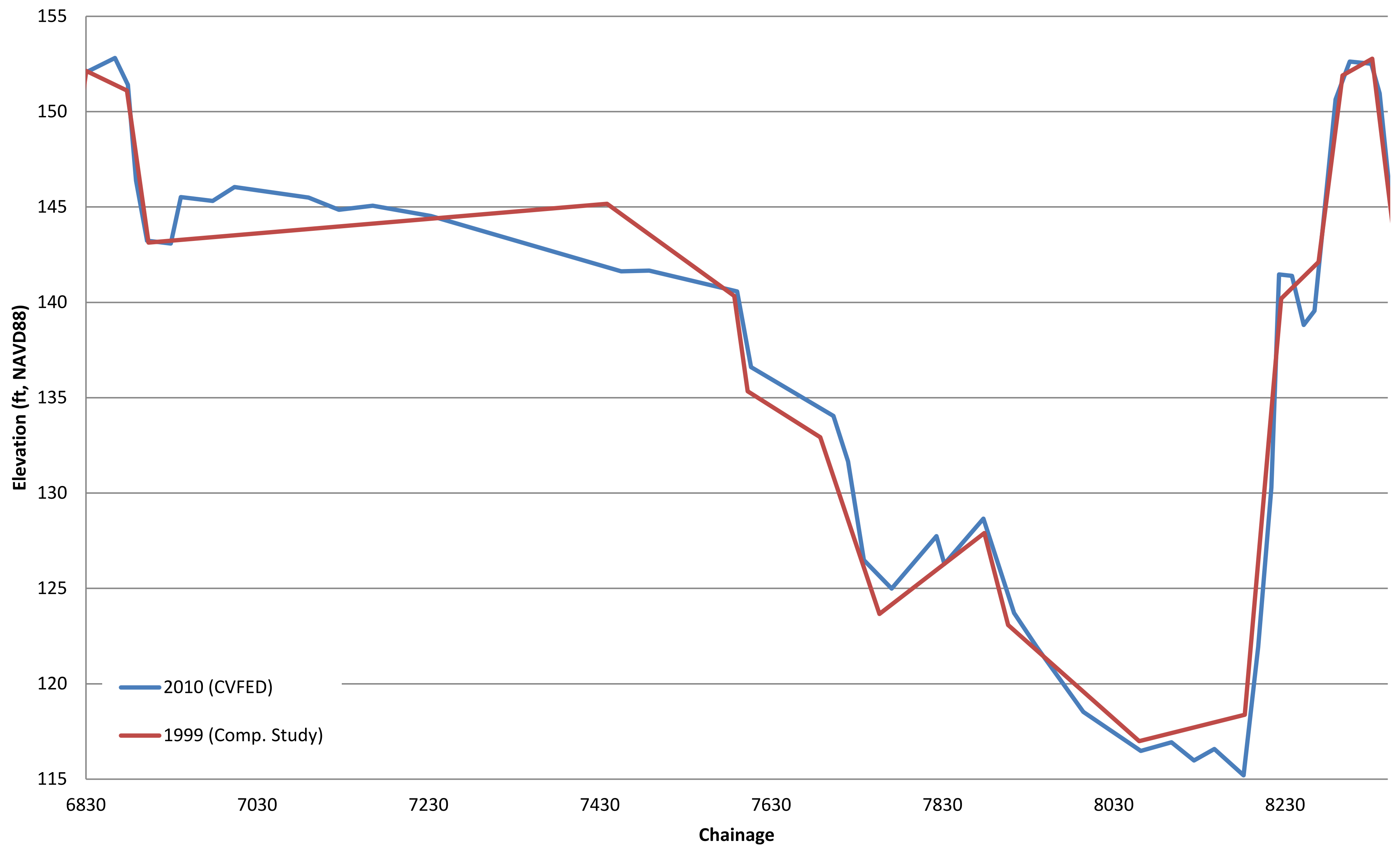


Notes:

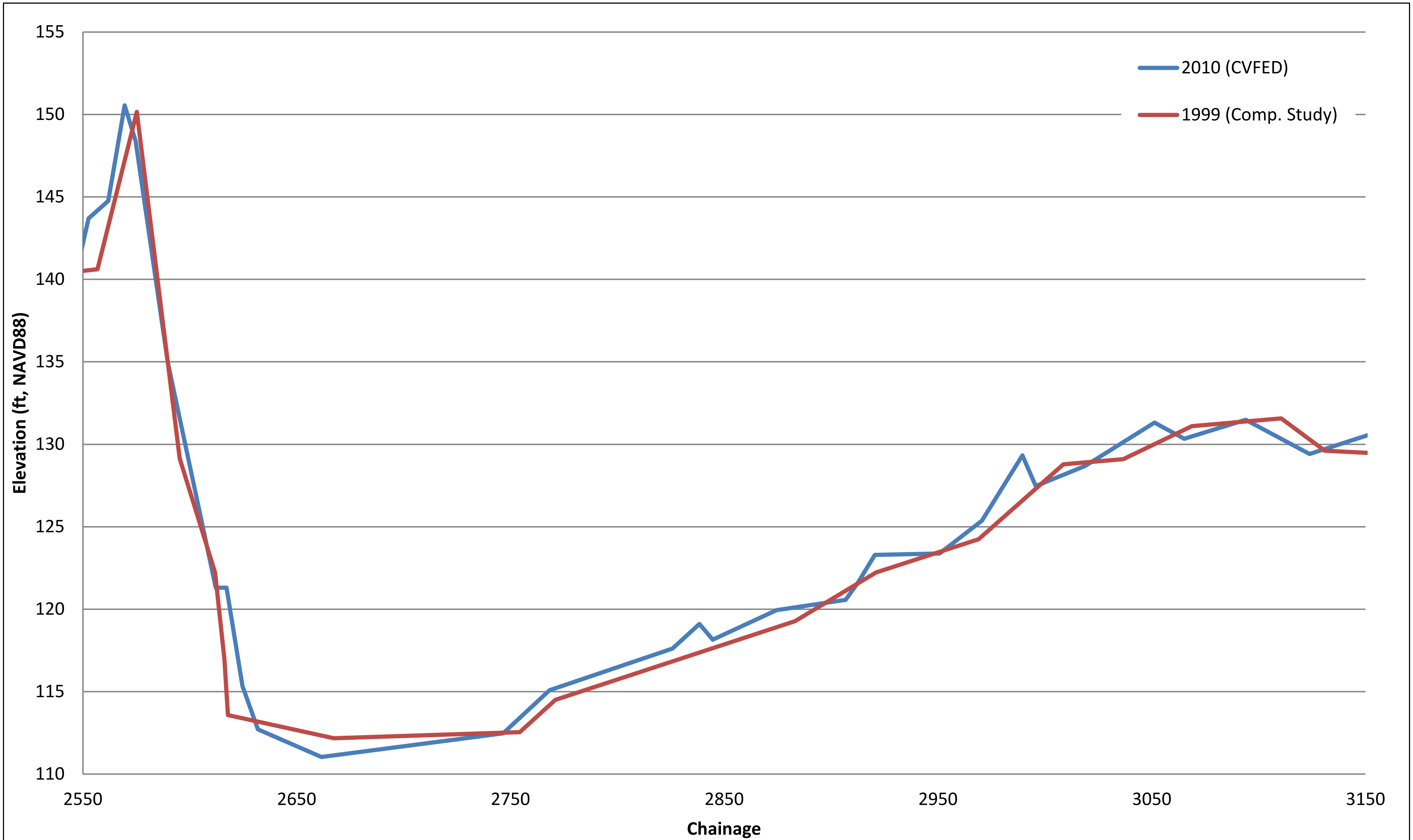
Oroville Wildlife Area Flood Stage Reduction

Cross section comparison 4, RM 63.8

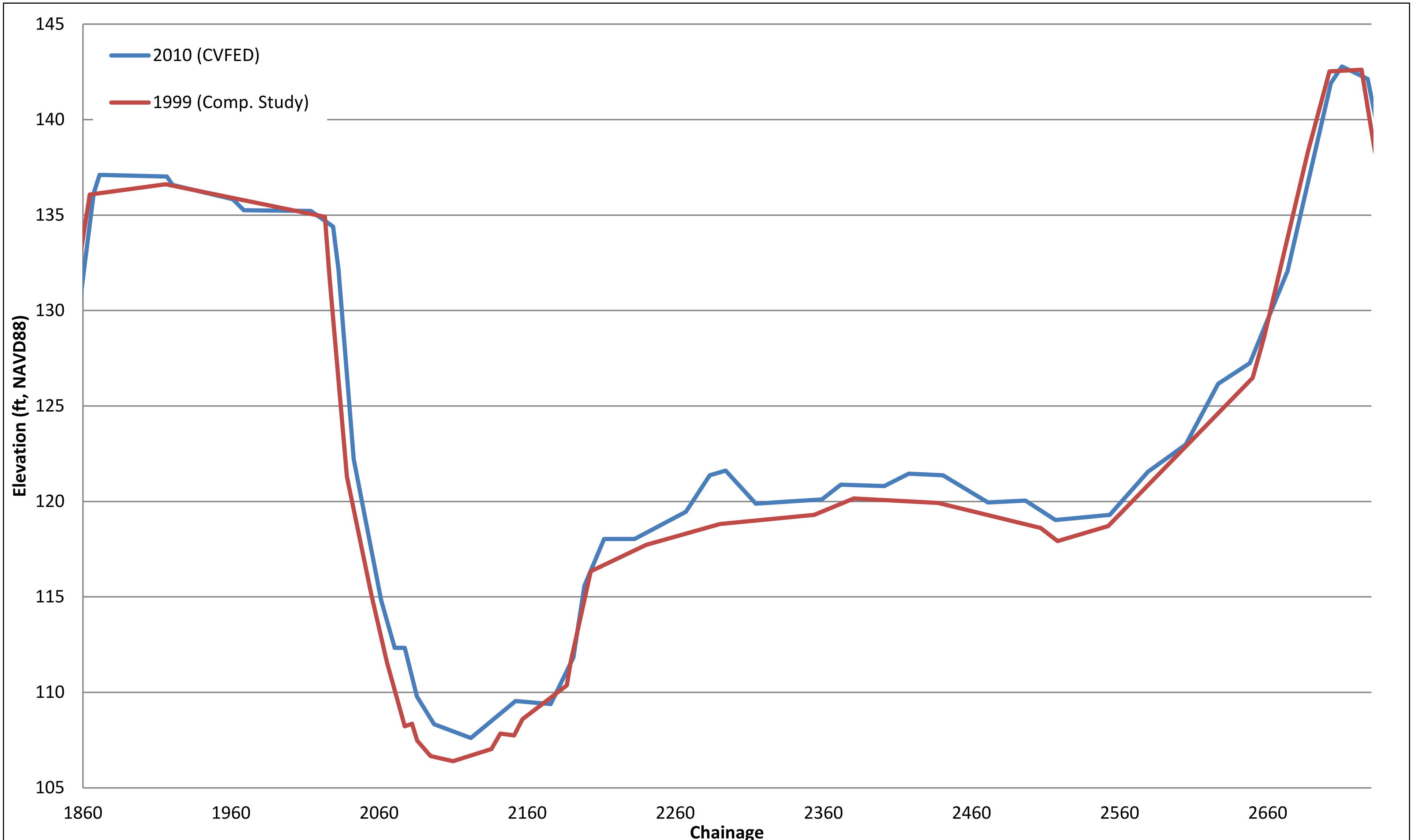
Project No. 14-1026 | Created By: DT | **Figure 24**



Notes:	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Cross section comparison 5, RM 62.7**		
		Project No. 14-1026	Created By: DT	**Figure 25**



Notes:	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Cross section comparison 6, RM 61.7**		
		Project No. 14-1026	Created By: DT	**Figure 26**

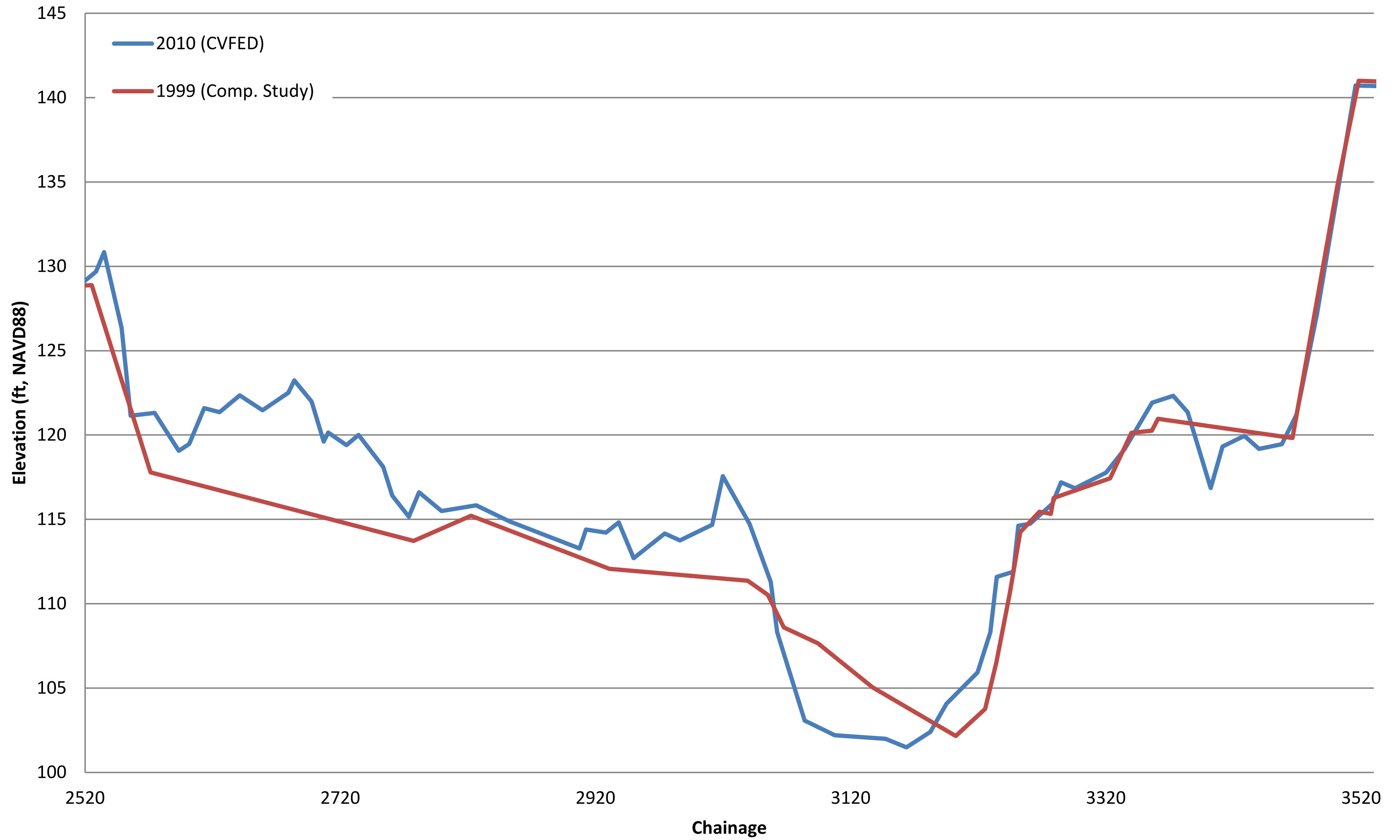


Notes:

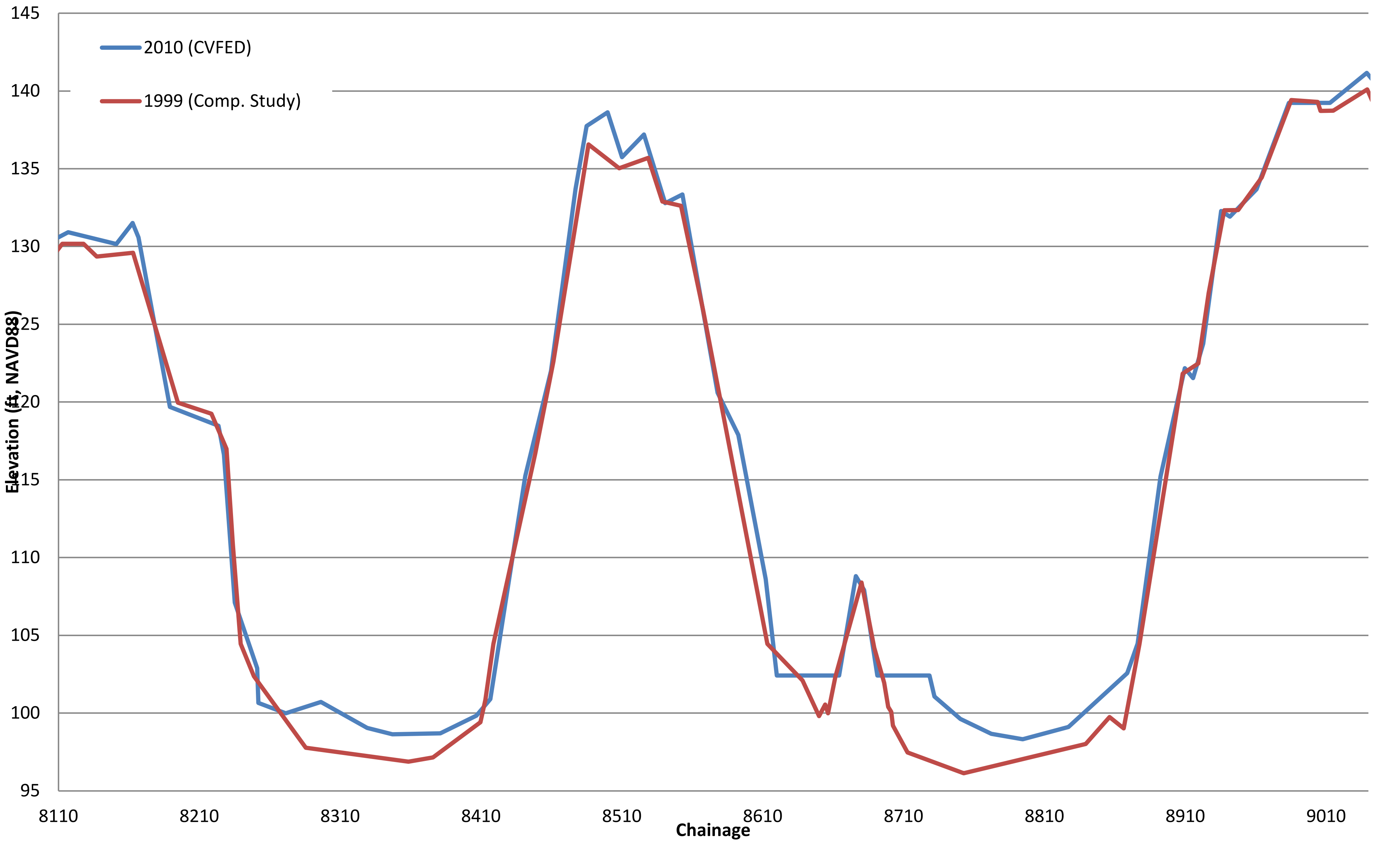
Oroville Wildlife Area Flood Stage Reduction

Cross section comparison 7, RM 60.4

Project No. 14-1026	Created By: DT	**Figure 27**

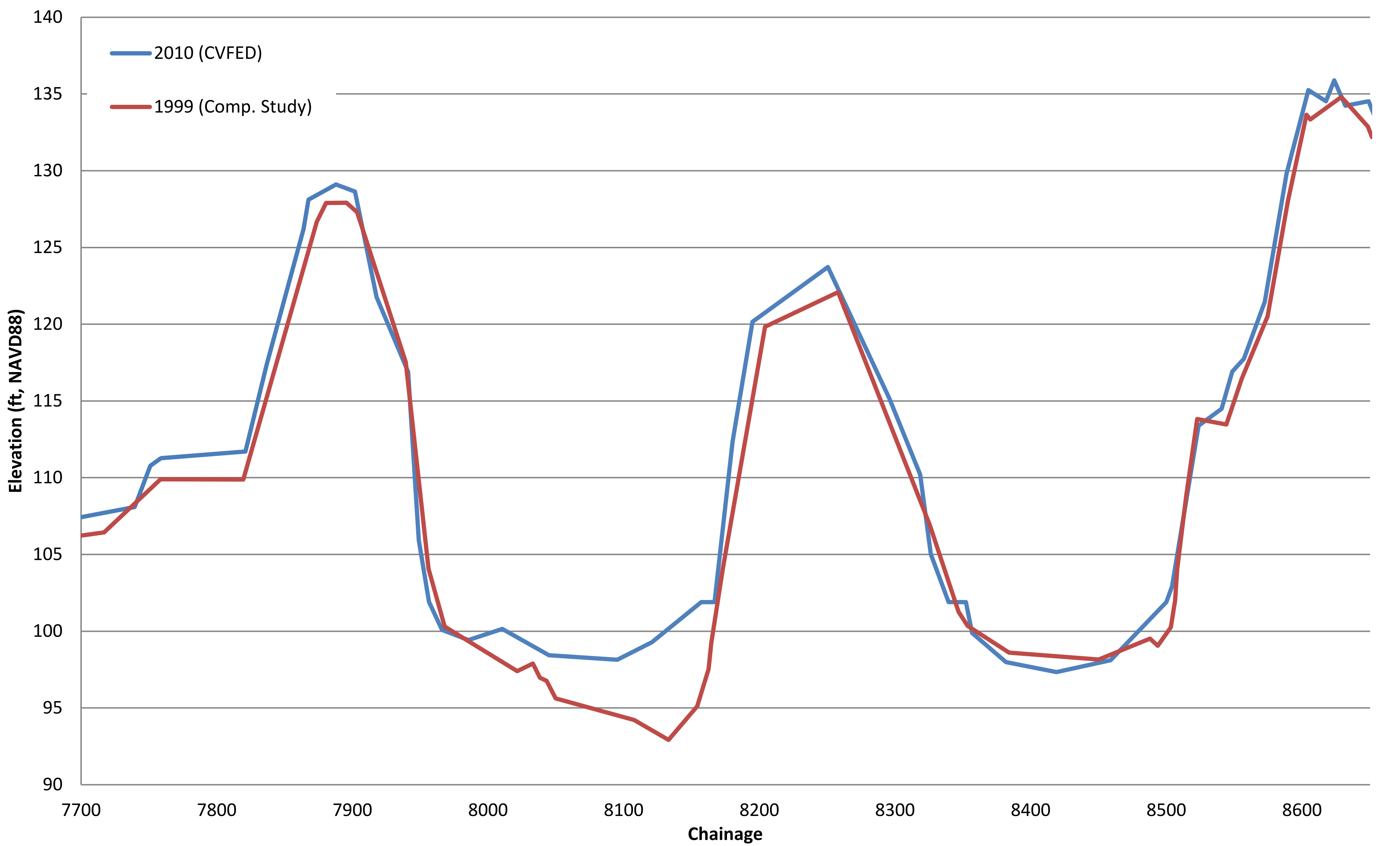


Notes:		*Oroville Wildlife Area Flood Stage Reduction* **Cross section comparison 8, RM 59.9**		
		Project No. 14-1026	Created By: DT	**Figure 28**

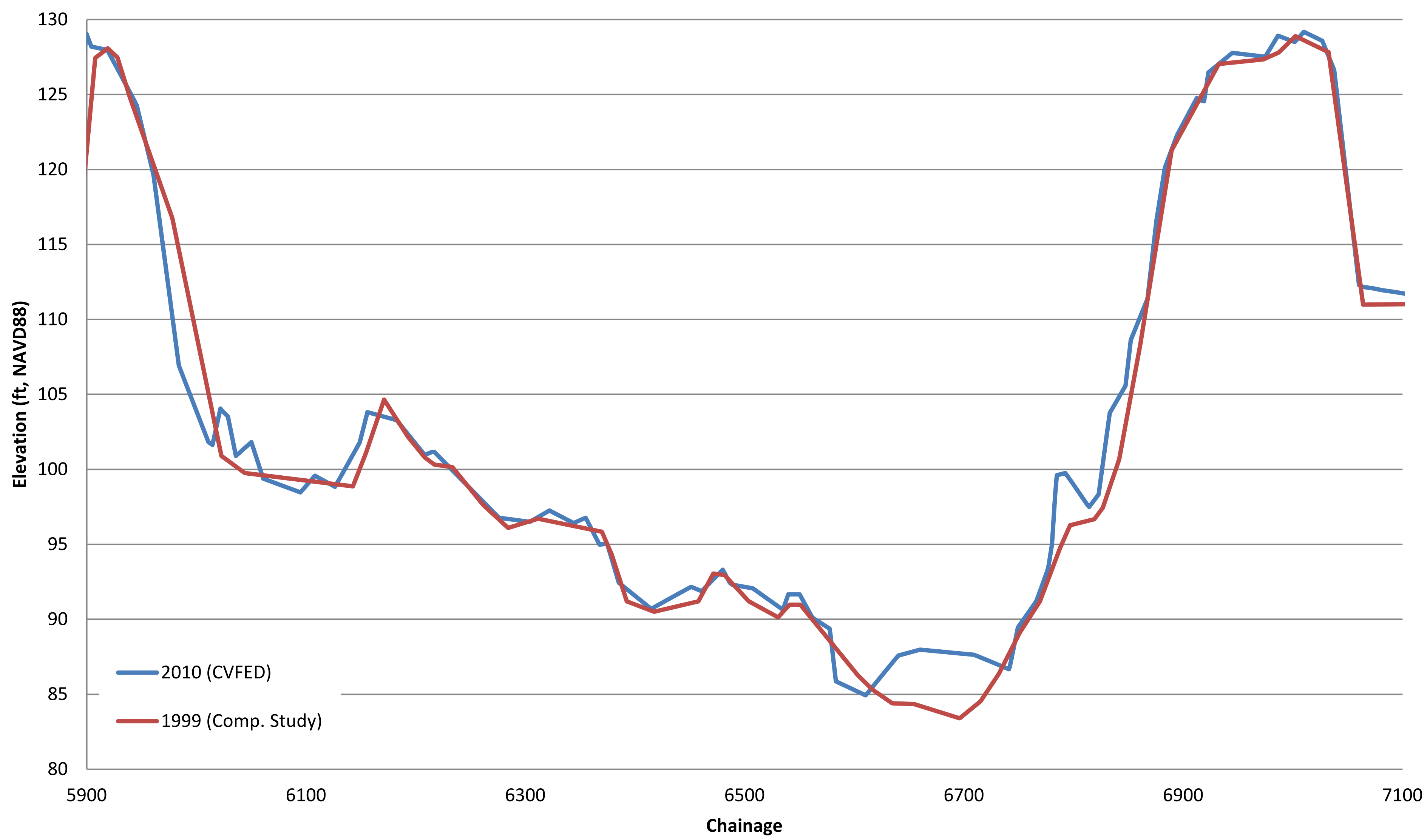


Notes:	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Cross section comparison 9, RM 58.0**		
		Project No. 14-1026	Created By: DT	**Figure 29**

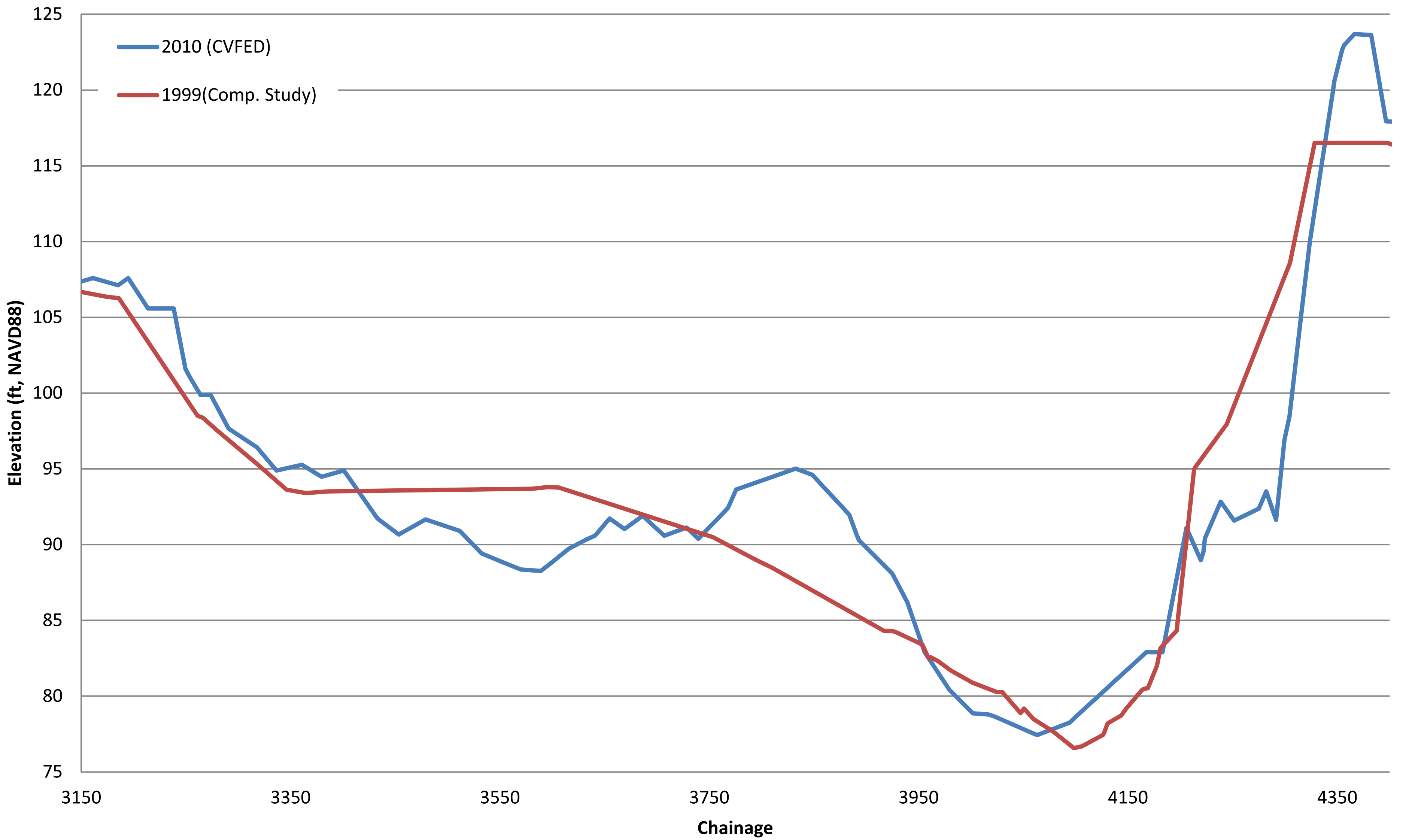
R:\Projects\14-1026_OWA_Flood_Reduction\Reporting\Figure Templates_v4\Figure Templates\Fig29_XS9.docx
7/13/2015



Notes:	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Cross section comparison 10, RM 57.7**
		Project No. 14-1026 | Created By: DT | **Figure 30**



Notes:		*Oroville Wildlife Area Flood Stage Reduction* **Cross section comparison 11, RM 56.5**		
		Project No. 14-1026	Created By: DT	**Figure 31**



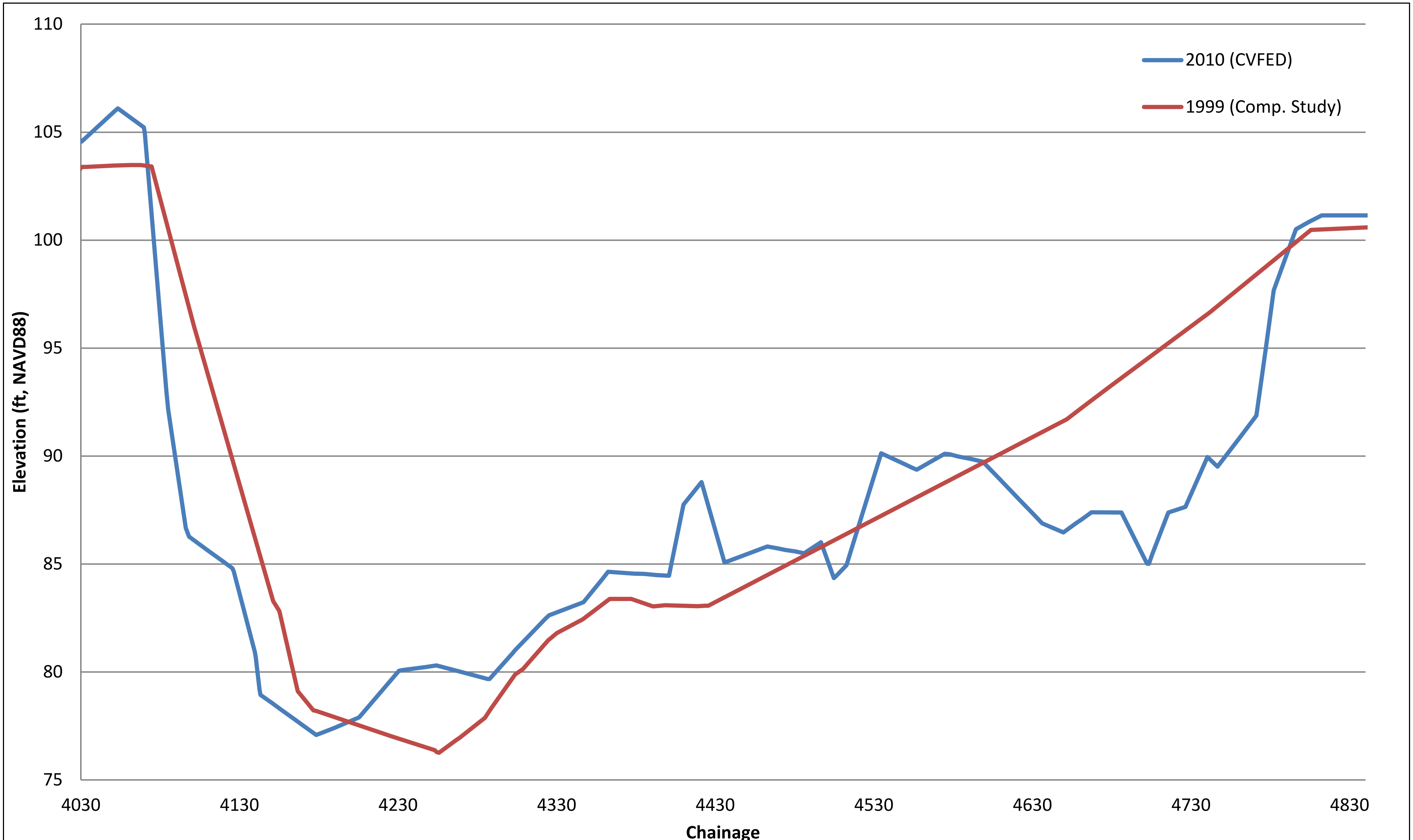
Notes:

Oroville Wildlife Area Flood Stage Reduction

Cross section comparison 12, RM 54.4

Project No. 14-1026	Created By: DT	**Figure 32**

R:\Projects\14-1026_OWA_Flood_Reduction\Reporting\Figure Templates_v4\Figure Templates\Fig32_XS12.docx
7/13/2015



Notes:	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Cross section comparison 13, RM 53.7**		
		Project No. 14-1026	Created By: DT	**Figure 33**

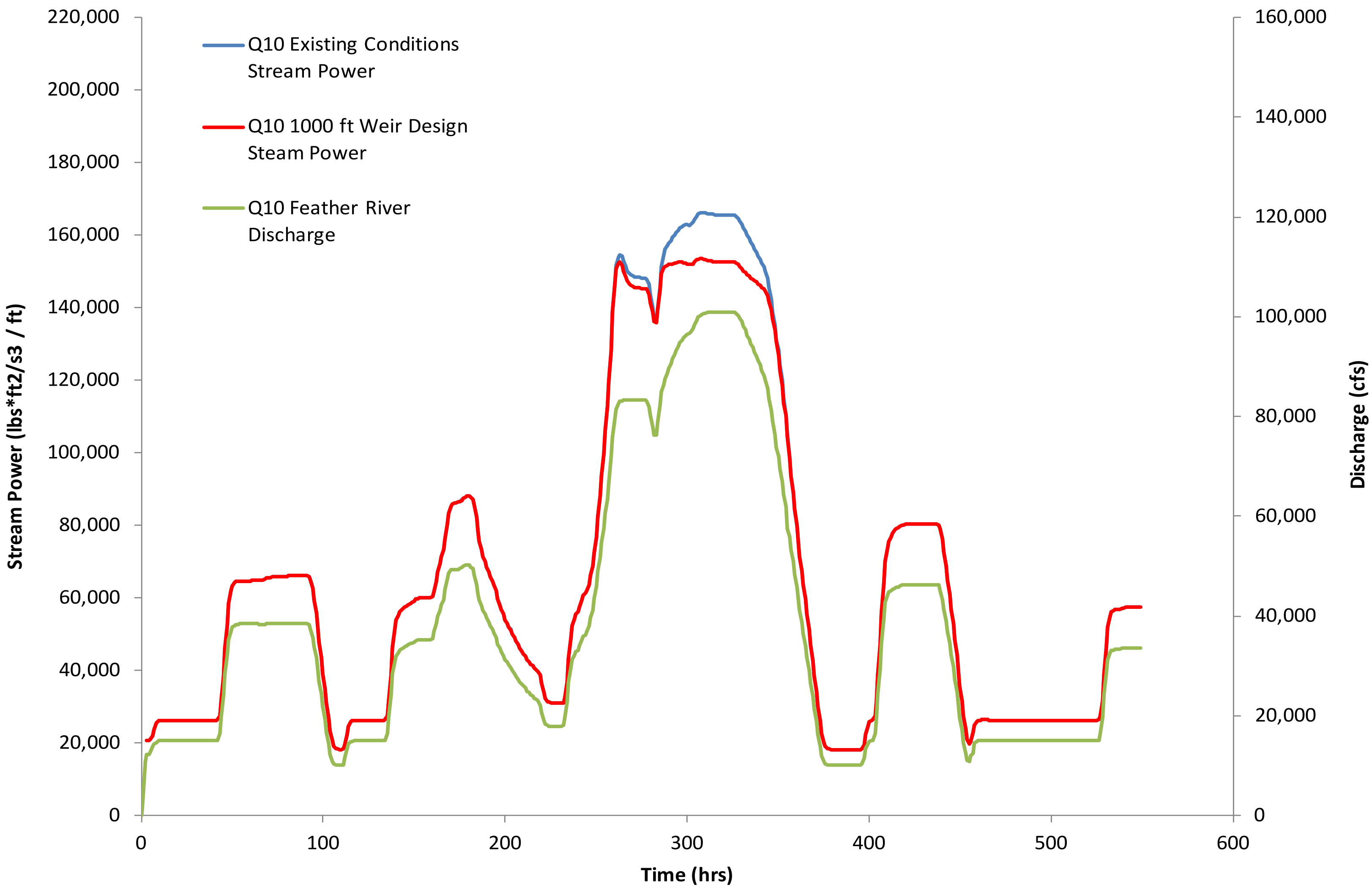
Notes:

cbec eco engineering

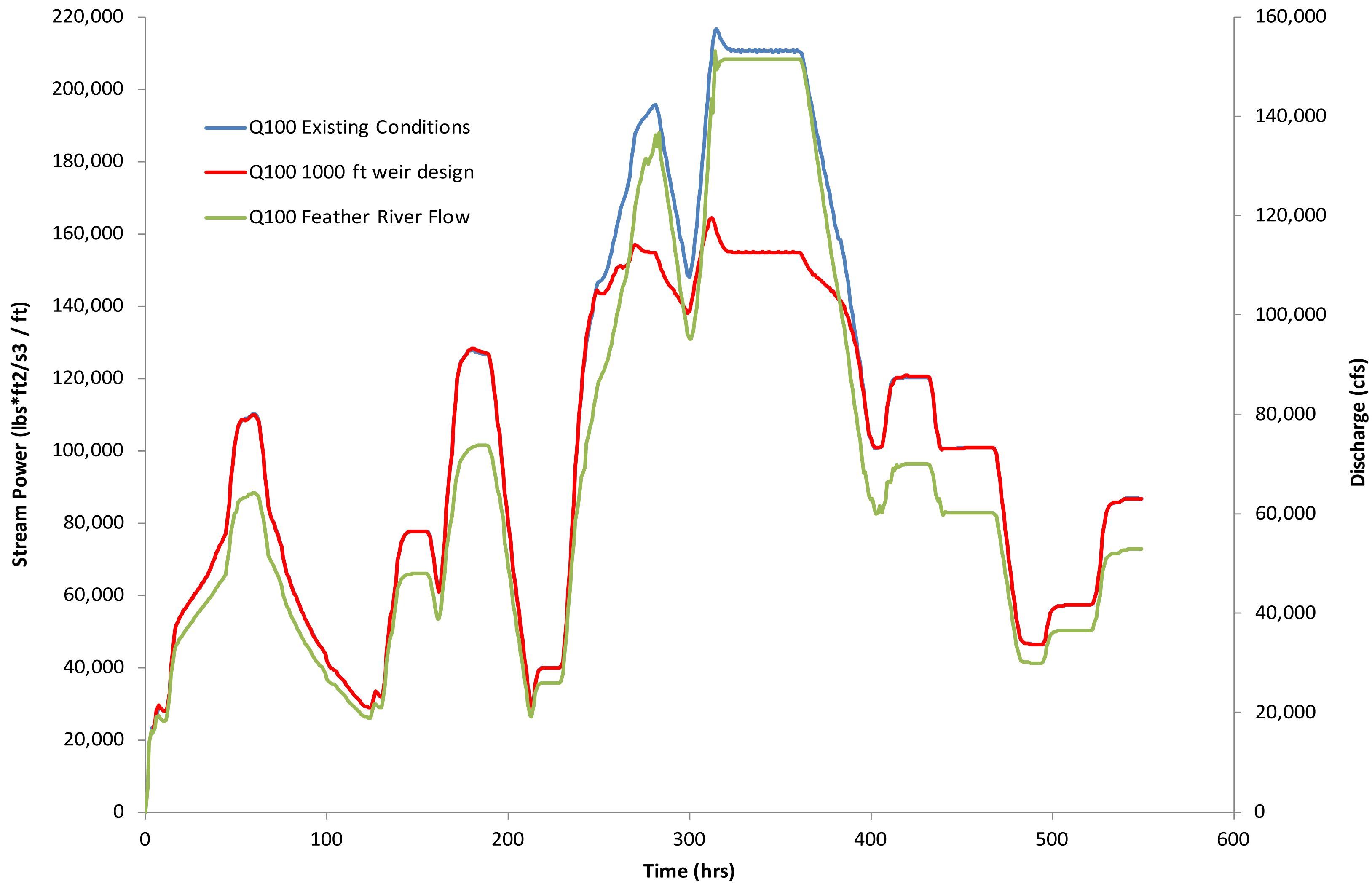
Oroville Wildlife Area Flood Stage Reduction

Cross section comparison 14, RM 52.7

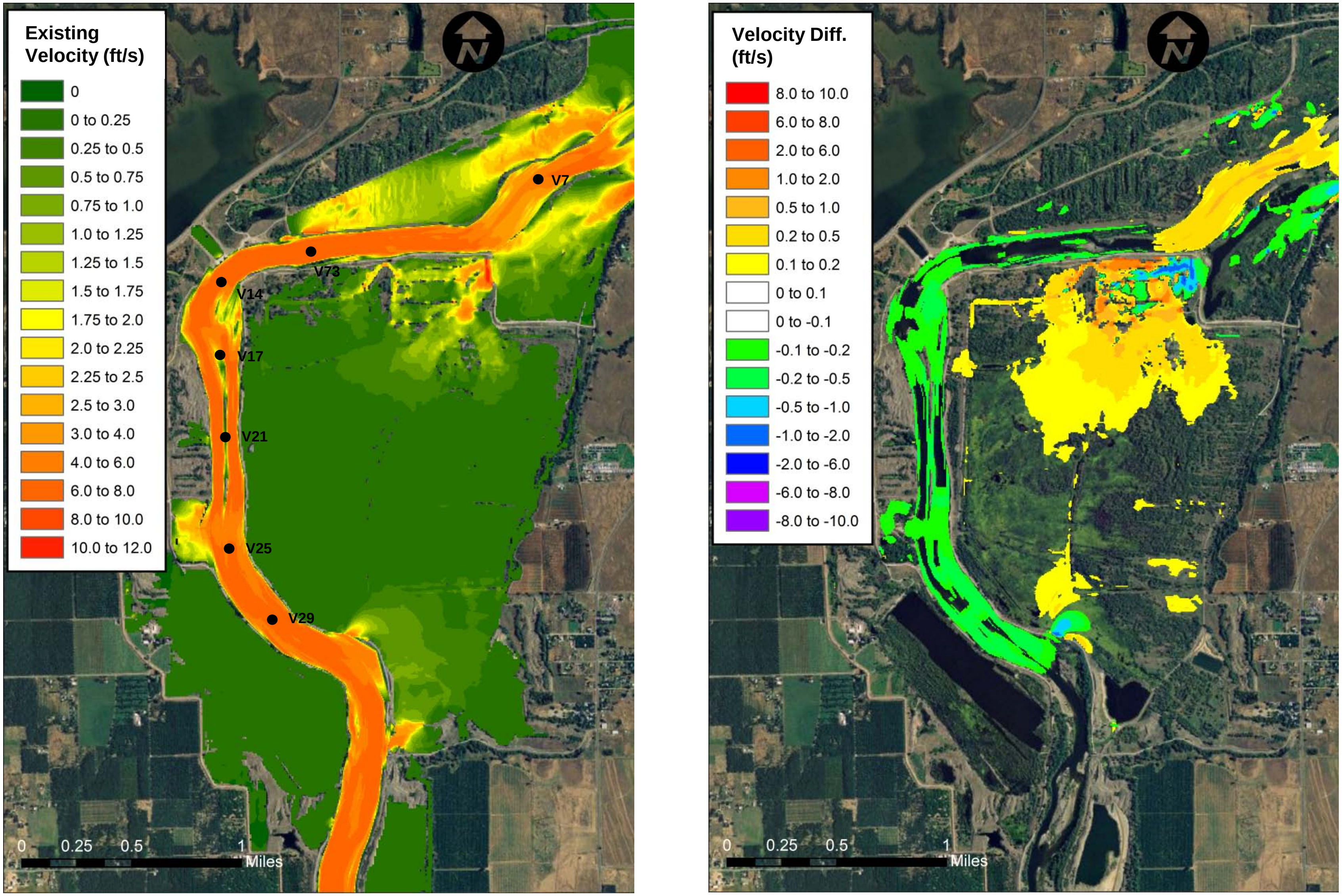
Project No. 14-1026	Created By: DT	**Figure 34**



Notes: Graphic includes the average stream power for existing conditions and the 1000 ft weir alternative on the Feather River between the inlet and outlet of the D-unit. Output derived from TUFLOW model at cross sections: V73, V14, V17, V21, V25 and V29.	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Main channel stream power between inlet and outlet – Q10**
		Project No. 14-1026 | Created By: DT | **Figure 35**



Notes: Graphic includes the average stream power for existing conditions and the 1000 ft weir alternative on the Feather River between the inlet and outlet of the D-unit. Output derived from TUFLOW model at cross sections: V73, V14, V17, V21, V25 and V29.	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Main channel stream power between inlet and outlet – Q100**
		Project No. 14-1026 / Created By: DT / **Figure 36**



Notes: Difference plot (right) represents differences in maximum velocity between the 1000 ft weir alternative and existing conditions. Positive values indicate an increase in velocity for the design alternative, whereas negative values indicate a reduction in velocity.

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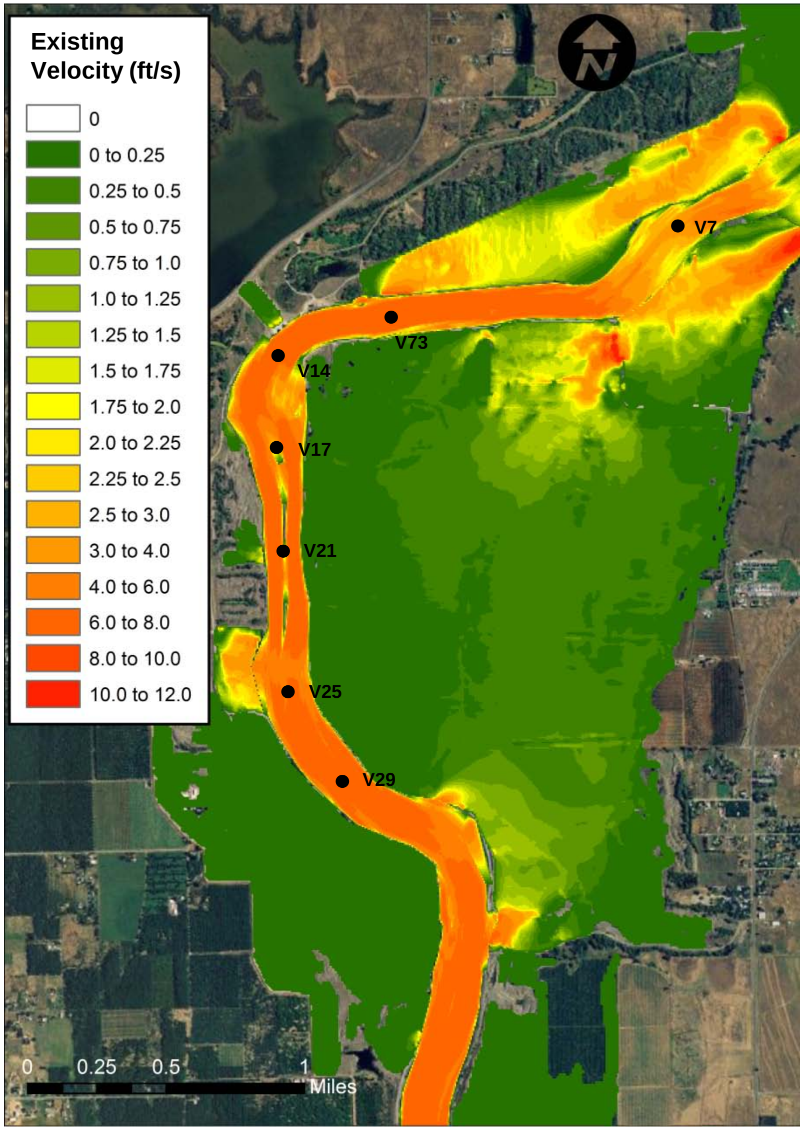
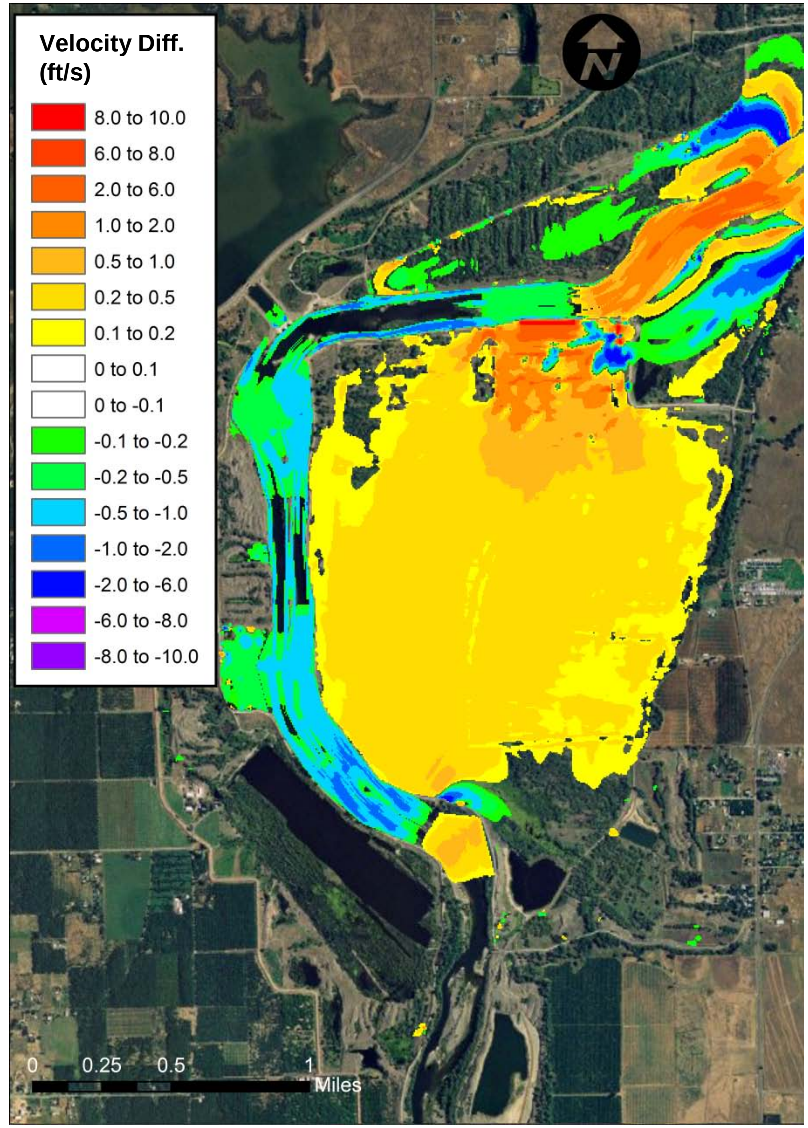
Oroville Wildlife Area Flood Stage Reduction

10-year peak velocity comparison

Project No. 14-1026	Created By: CMB	**Figure 37**



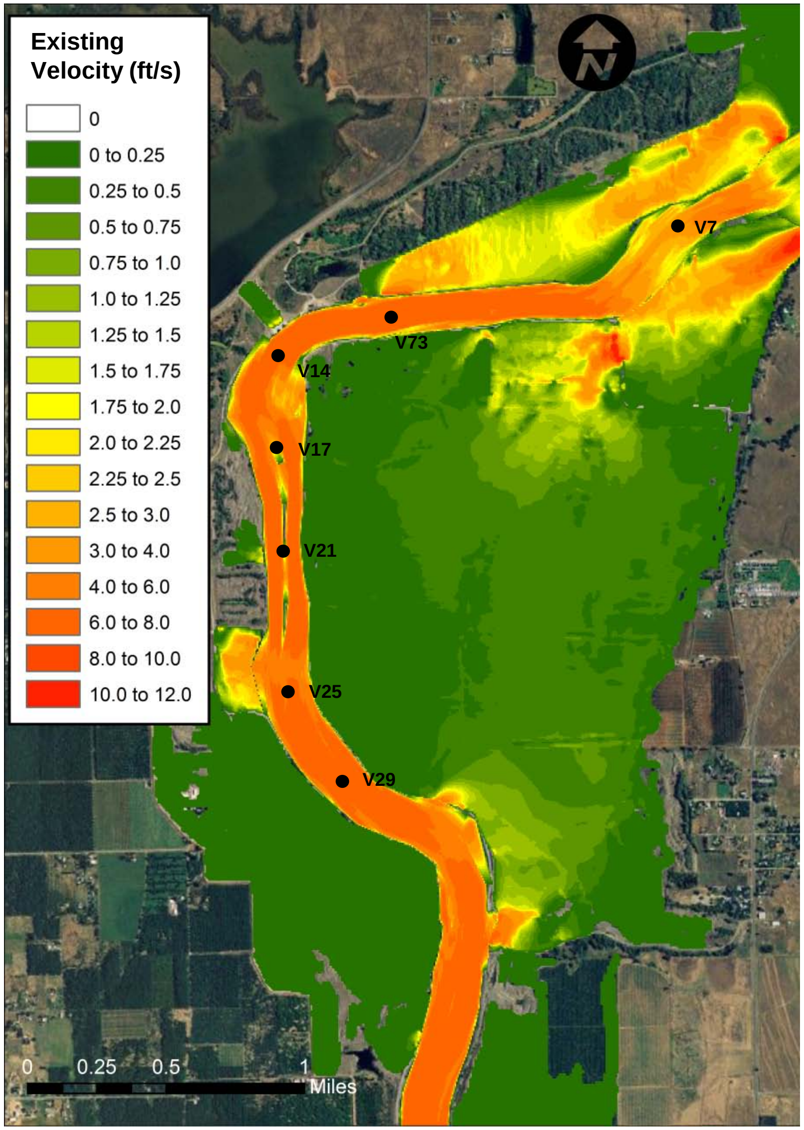


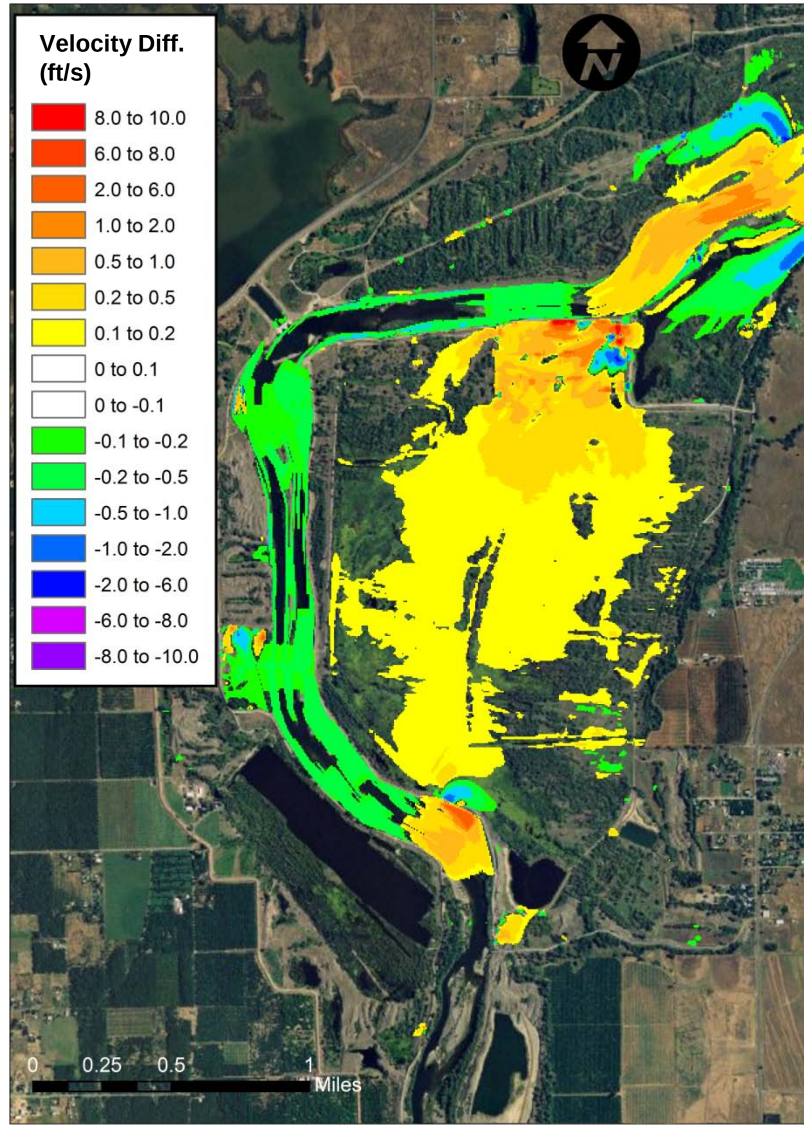
Notes: Difference plot (right) represents differences in maximum velocity between the 1000 ft weir alternative and existing conditions. Positive values indicate an increase in velocity for the design alternative, whereas negative values indicate a reduction in velocity.

Oroville Wildlife Area Flood Stage Reduction

100-year peak velocity comparison

Project No. 14-1026	Created By: CMB	**Figure 38**





Notes: Difference plot (right) represents differences in maximum velocity between the 400 ft weir alternative and existing conditions. Positive values indicate an increase in velocity for the design alternative, whereas negative values indicate a reduction in velocity.

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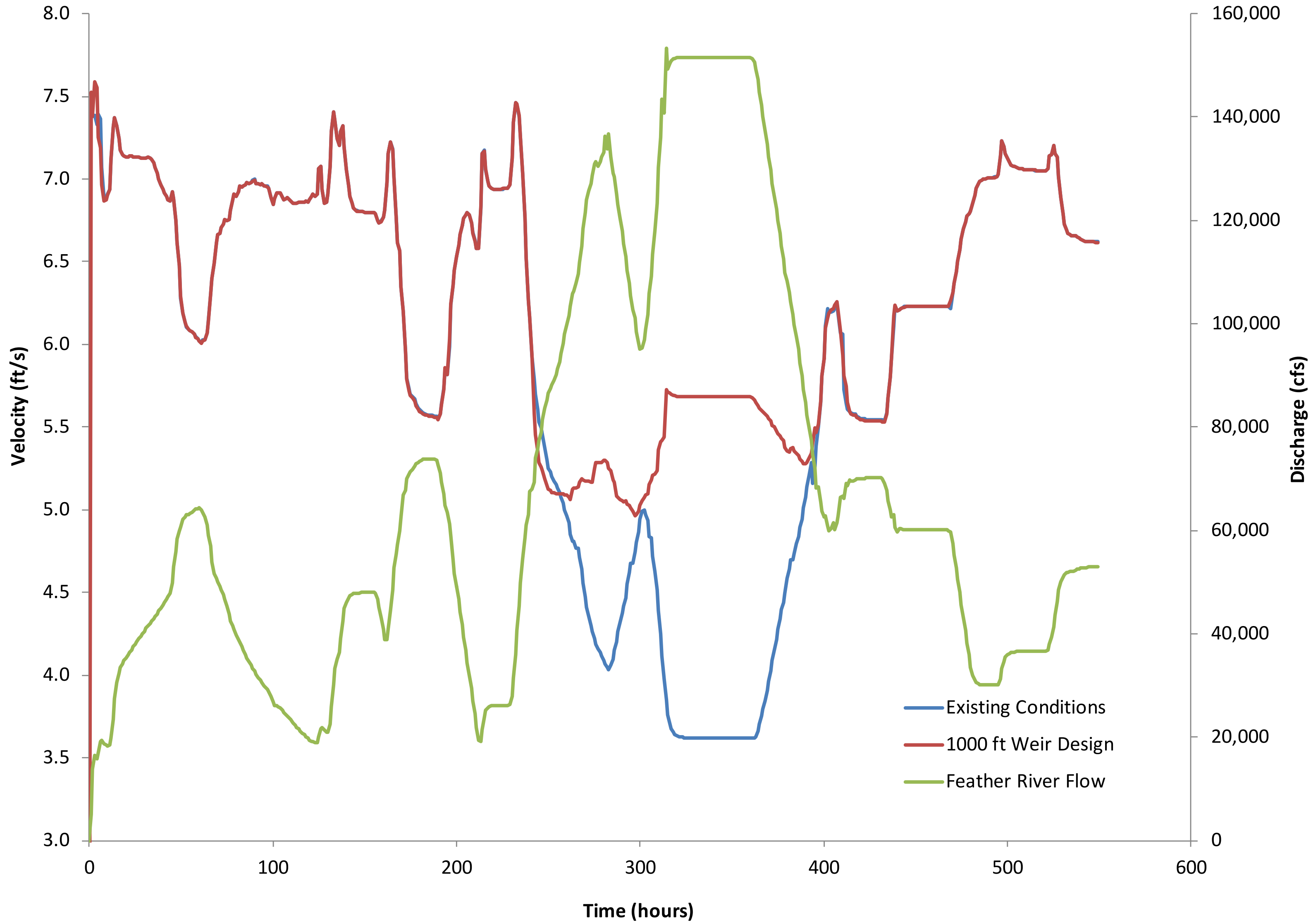
Oroville Wildlife Area Flood Stage Reduction

100-year peak velocity comparison

Project No. 14-1026	Created By: CMB	**Figure 39**

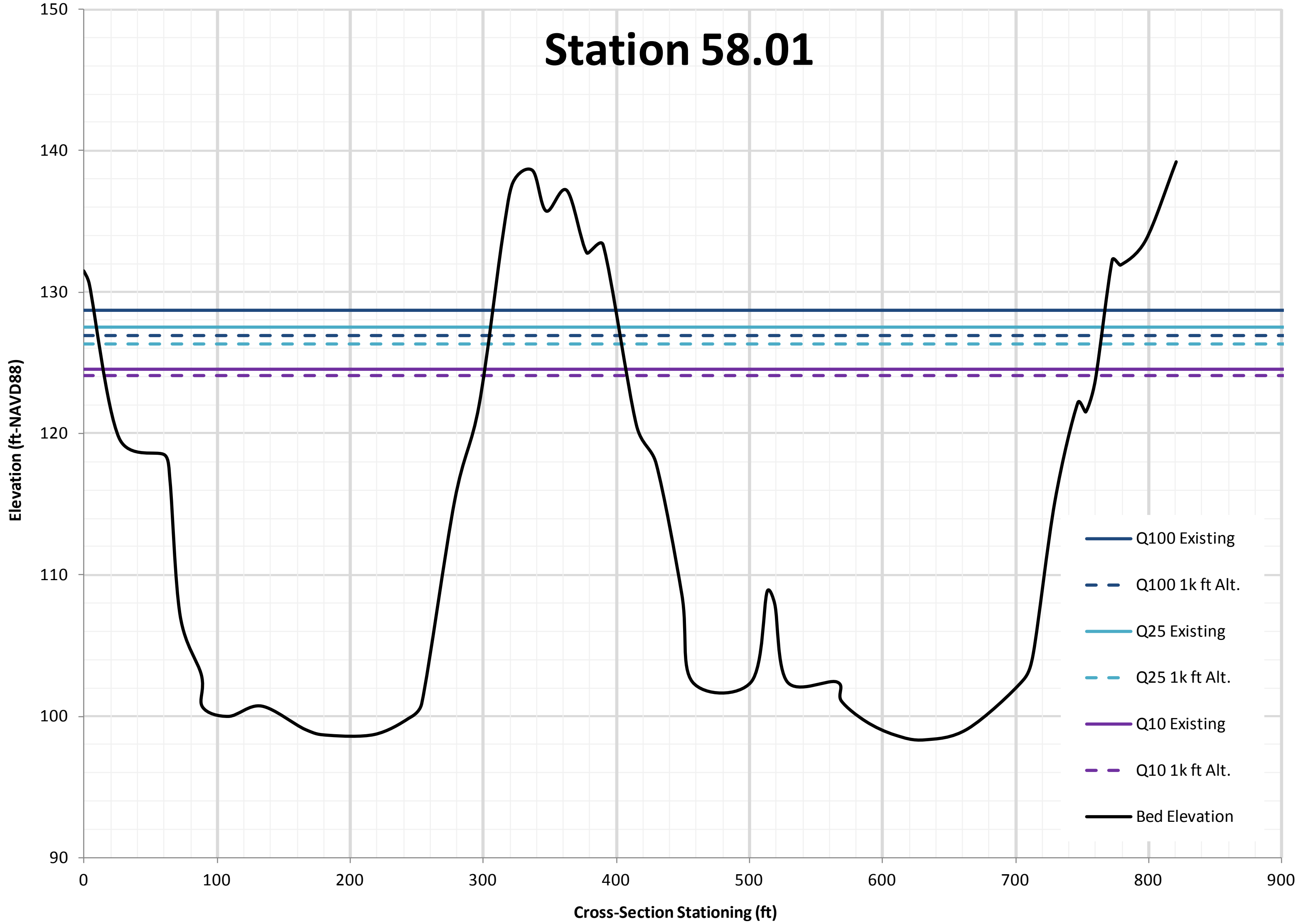


Notes: Graphic represent the main channel velocity for existing conditions and the 1000 ft weir alternative upstream of the inflow weir. TUFLOW velocity data extracted from 1D cross section V7.

Oroville Wildlife Area Flood Stage Reduction

Main channel velocity upstream of inflow weir

Project No. 14-1026	Created By: DT	**Figure 40**



Notes: Graphic includes the peak water surface elevation for existing conditions and the 1000 ft weir alternative on the Feather River between the inlet and outlet (Station 58.01) of the D-unit. Output derived from TUFLOW model results.	cbec eco engineering	*Oroville Wildlife Area Flood Stage Reduction* **Peak water surface elevation comparison**
		Project No. 14-1026	Created By: JS	**Figure 41**

APPENDIX A

RECONNAISSANCE LEVEL GEOMORPHIC ASSESSMENT PHOTOS