MODELING SEDIMENT TRANSPORT DYNAMICS AND EVALUATING FLOODING RISKS IN THE YUBA AND FEATHER RIVERS, CALIFORNIA, FOLLOWING MODIFICATIONS TO ENGELBRIGHT AND DAGUERRE POINT DAMS

Technical Report

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Habitat Conservation Division

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Executive Summary

1. Introduction

Englebright Dam on the Yuba River is not equipped with fish passage facilities and is identified in the National Marine Fisheries Service (NMFS) Draft Central Valley Recovery Plan as one of the dams where fish passage would contribute to recovery of the Central Valley Spring-run Chinook Evolutionarily Significant Unit (ESU) and the Central Valley Steelhead Distinct Population Segment (DPS) (NMSF 2012). Daguerre Point Dam, also on the Yuba River, is equipped with two fish ladders, but they are substandard and do not adequately provide upstream anadromous fish passage over a full range of flows.

NMFS is investigating whether reintroduction of spring-run Chinook salmon and steelhead into the historic watersheds of the upper Yuba River is feasible; and if so, where and how can reintroduction be implemented. NMFS has previously commissioned studies of anadromous fish passage and habitat potential in the Yuba River. These studies include an extensive habitat assessment model for the upper Yuba River watershed and a conceptual engineering study to develop alternatives for upstream and downstream fish passages at Englebright and Daguerre Point Dams.

This study focused on erosion of sediment in the impoundment areas and deposition of sediment downstream of the dams following the removal or modification of Englebright and Daguerre Point dams as means to facilitate upstream fish passage. The study reaches include: Englebright Dam impoundment, Yuba River downstream of Englebright Dam, and Feather River between Yuba River and Sacramento River confluences, examining the following five alternatives:

1. a full removal of Englebright Dam under the Tunneling and Rapid Release Alternative by blasting open a tunnel at the base of the dam to drain the lake before removing the dam;
2. a full removal of Englebright Dam under the Staged Removal Alternative by removing the dam top-down in 10 stages over a 10-year period;
3. notch Englebright Dam to a crest elevation of 131 m (431 ft), constructing a fish ladder to allow fish passage through the remaining 51 m (170 ft) of the dam;
4. notch Englebright Dam to a crest elevation of 140.2 m (460 ft), constructing a fish ladder to allow fish passage through the remaining 60 m (200 ft) of the dam; and
5. a full removal of Daguerre Point Dam.

Engineering details of dam removal or modification are not provided in this report. A companion study by Gathard Engineering Consulting (GEC) provides preliminary engineering designs for the removal or notching of the two dams and associated modifications (such as fish passage and water diversion facilities).
2. Approach

Dam Removal Express Assessment Models (DREAM-1 and DREAM-2) were used for modeling sediment transport following the removal or modification of the two dams, and the Army Corps of Engineers HEC-RAS model was used to estimate changes in flood elevations following the removal of Englebright Dam. DREAM models and their predecessors and sister models (i.e., early versions of the models and models that differ only in sediment transport equations, which were selected based on composition of sediment deposit) have been used for simulation of large sediment pulse movement in rivers, including sediment transport following dam removal for many projects. Example case studies include: mining waste disposal in Ok Tedi – Fly River system in Papua New Guinea (Cui and Parker 1999); Soda Springs Dam removal study on the North Umpqua River in Oregon (Stillwater Sciences 1999); Marmot Dam removal on the Sandy River, Oregon (Stillwater Sciences 2000; Cui and Wilcox 2008; Cui et al. in press); Saeltzer Dam removal on Clear Creek, California (Stillwater Sciences 2001); landslide sediment evolution in the Navarro River, California (Sutherland et al. 2002; Cui and Parker 2005); Iron Gate, Copco 1, Copco 2, and J.C. Boyle Dam removal on the Klamath River, California and Oregon (Stillwater Sciences 2004; Stillwater Sciences 2008); Simpkins and Bloede Dam removal on the Patapsco River, Maryland (Stillwater Sciences 2010); Harvey Diversion Structure removal on Santa Paula Creek, California (Stillwater Sciences 2012a); and Vern Freeman Dam removal on the Santa Clara River, California (Stillwater Sciences 2013).

In addition to these practical projects, DREAM-1 and DREAM-2 models were also examined with flume experiments and proved to produce excellent results without or with minimal model calibrations (Cui et al. 2008). More details of the Dam Removal Express Assessment Models can be found in Cui et al. (2006a, 2006b). A HEC-RAS model was developed based on an existing version for the Feather River Basin that was developed by US Corps of Engineers under the post-1997 flood cross sections (ACOE 2011). For post-dam-removal flooding risk evaluations, we transferred the sediment deposition predicted with the sediment transport model to the existing cross sections and input the modified cross sections into the HEC-RAS model to simulate water surfaces in the Yuba River and the Feather River. Hypothetical HEC-RAS modeling scenarios included a flow event equal to the flood of 2 January 1997 (approximately a 50-year recurrence interval event in the Yuba and Feather rivers) occurring under the following sediment deposition scenarios: (a) when deposition of released sediment peaks in the Yuba River; (b) when the majority of the sediment from Englebright Lake reaches the Feather River; and (c) when the Yuba and Feather rivers reach the new quasi-equilibrium profile following reestablishment of sediment supply and transport continuity at the Englebright Dam site.

3. Major Conclusions

Examinations of a full removal of Daguerre Point Dam with DREAM-2 indicate that erosion of impoundment deposits would extend for approximately 3 km upstream of the dam while sediment deposition would be limited to within approximately 3 km downstream of the dam. Because of the limited extent and magnitude of sediment deposition following Daguerre Point Dam removal, increased flooding risk is not expected. Relatively high suspended sediment concentration (potentially reaching several thousand mg/l for a day at Daguerre point Dam, decreasing in the downstream direction) was predicted following a full removal of Daguerre Point Dam.

Two engineering alternatives were examined with the DREAM-1 model for a full removal of Englebright Dam: a Tunneling and Rapid Release Alternative that opens a tunnel at the base of
the dam to drain the lake and release sediment prior to dam removal, and a Staged Removal Alternative that notches sections of the dam from the top in layers over a 10-year period.

Modeling results for the Tunneling and Rapid Release Alternative indicate that a tunnel of $3 \times 3$ m ($10 \times 10$ ft) or larger would allow a quick drawdown of Englebright Lake (within about a week) and help to maintain a low lake level during the winter high flow season for efficient erosion of sediment deposited in the reservoir, thereby minimizing the period of high suspended sediment concentration to within approximately a one year period. A smaller-sized tunnel may extend the time needed to release the reservoir deposit, resulting in the undesired effect of high suspended sediment concentration over multiple years without producing other benefits such as substantially reducing the thickness of sediment deposition downstream of the dam.

DREAM-1 and HEC-RAS modeling was conducted for the Tunneling and Rapid Release Alternative assuming that the tunnel would open on the 15th of November to start Englebright Lake drawdown. Stillwater Sciences (2008, 2009) recommended a similar reservoir draw down schedule for the removal of four dams on the Klamath River so that the primary period of increased suspended sediment concentration would occur during the winter high flow season when suspended sediment concentrations are occasionally high under natural conditions.

DREAM-1 and HEC-RAS modeling results for the Tunneling and Rapid Release Alternative with a $3 \times 3$ m ($10 \times 10$ ft) tunnel indicate that:

- Daily averaged suspended sediment concentration in the Yuba River would increase by more than 100,000 mg/l for short durations on multiple occasions and exceed 10,000 mg/l for an extended period of time over the first year following the opening of the tunnel but become similar to background conditions in the second year following tunnel opening.

- A substantial amount of sediment would be deposited in the Timbuctoo Bend Reach approximately 4 – 9 km downstream of Englebright Dam, starting a few months following Englebright Lake drawdown and flushing out of the reach in 1 to 2 years once the majority of the Englebright Lake deposit is transported downstream. The maximum potential deposition is approximately 8 m near the upstream end of the reach, decreasing to approximately 5 m near the downstream end of the reach. Sediment deposition in the reach lasts for a shorter duration if the initial drawdown occurs in a dry year as Englebright Lake can be kept at a low level during the winter high flow season, resulting in more efficient erosions of the reservoir deposit.

- A substantial amount of sediment (potentially up to 10 m thick at times under certain hydrologic conditions) would be deposited in the Yuba River a short distance upstream of the Feather River confluence. HEC-RAS model results indicate this deposition would increase the water surface level by approximately 1.1 to 1.3 m in a 13-km reach (24 – 37 km downstream of Englebright Dam) during a flood event equal in magnitude to the 2 January 1997 event (a 50-yr recurrence interval event). Model simulations at this flood magnitude indicate that approximately 1.6 km of Yuba River levees (roughly between 27.8 and 29.4 km downstream of Englebright Dam) that would not be overtopped under the current conditions could be overtopped under the simulated Englebright Dam removal scenario unless they were raised by approximately 1.5 m. Depending on hydrologic
conditions following dam removal, substantial sediment deposition (on the order of 3 to 5 m) may persist for three to five years, while the extreme sediment deposition (on the order of 7 to 10 m) may occur during the first three years following dam removal. The probability of having a 50-year flood event or larger to occur over a three year period is 0.059. For comparison, the probability of a 100-year flood event or larger to occur over a 100 year period, which is the risk associated with development on 100-year floodplains, is 0.634.

- A substantial amount of sediment (up to 3.5 m thick at times) would be deposited in most of the Feather River over approximately an eight year period, increasing the water surface level up to 0.45 m in a 35-km reach (27 – 62 km downstream of Englebright Dam) during a flood event similar to that of 2 January 1997. Levees in a 10-km reach (52 – 62 km downstream of Englebright Dam) that were either overtopped or close to overtopping under the current condition could be overtopped in a flood similar to the January 1997 flood following Englebright Dam removal unless they were raised by approximately 0.5 m. The probability of having a 50-year flood event or larger to occur over an eight year period is 0.149.

- The eventual reestablishment of sediment transport continuity at Englebright Dam following dam removal would result in long-term, persistent channel aggradation in Feather River downstream of Yuba River confluence by approximately 2 m and increase water surface elevation during a 2 January 1997 flood event by a maximum of 0.3 m for a 33-km reach of the Feather River (29 – 62 km downstream of Englebright Dam). The maximum increase in water surface elevation during a 2 January 1997 flood event is within 0.2 m for the majority of this reach. The predicted bed elevation following reestablishment of sediment transport continuity at the Englebright Dam site is lower than the predicted pre-Oroville Dam historical river bed.

DREAM-1 simulation of the Tunneling and Rapid Release Alternative with a $3 \times 4.5$ m ($10 \times 15$ ft) tunnel produced similar results as those for a $3 \times 3$ m ($10 \times 10$ ft) tunnel. We recommend using as large a tunnel [minimum $3 \times 3$ m ($10 \times 10$ ft)] as practically possible (e.g., not so large as to create an undesired flood when the tunnel is opened) to draw Englebright Lake down quickly and to maintain a low lake level during winter high flow season as a means to minimize the duration of high suspended sediment concentration.

DREAM-1 simulation indicates that a 10-year Staged Removal Alternative would significantly reduce the thickness of sediment deposited in the Yuba River, including the Timbuctoo Bend Reach (approximately 4 – 9 km downstream of Englebright Dam) and the reach immediately upstream of Feather River confluence. The Staged Removal Alternative, however, does not reduce sediment deposition in the Feather River. The Staged Removal Alternative also creates high suspended sediment concentration (> 5,000 mg/l) almost every year over the 10-year period when the dam is being removed.

DREAM-1 simulation indicates that the partial removal alternative (notching) of Englebright Dam to 131.4 m (431 ft) or 140.2 (460 ft) elevation would increase suspended sediment concentration in the Yuba River over the short-term (within 2 to 6 months) but would not result in channel aggradation in the Yuba and Feather rivers.
To summarize, a removal or modification of Daguerre Point Dam would not result in flooding or biological concerns because it does not create long-lasting (i.e., more than a day) high suspended sediment concentration, nor would it result in widespread channel aggradation. For Englebright Dam, increased flooding risks associated with a full removal of the structure could potentially be reduced by taking precautionary measures prior to commencement of dam removal. Primary identified mitigation measures are to raise the levees in a 1.6-km reach in the Yuba River by approximately 1.5 m, and raise the levees in a 10-km reach in the Feather River by approximately 0.5 m. Dredging a portion of the sediment prior to dam removal or diverting sediment to the gold fields area may also reduce the amount of sediment deposition in various reaches, and thus, reducing the impact to flooding risks and spawning habitat. Engineering feasibility and effectiveness of these potential measures, however, are not investigated in this study.
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1 INTRODUCTION

The Yuba River is a major tributary of the Feather River in California’s Sacramento River basin, which formerly supported a large population of salmon. Many hydro modifications (e.g., modifications to channel cross sections and floodplain, ship channel dredging, gold and aggregate mining, flood control, water diversion) in the catchment have changed flow and sediment regimes, and altered habitat of the once populous salmon runs. Perhaps the construction of Harry L. Englebright Dam (Englebright Dam hereafter) provided the most damage to the salmon population as it completely blocked the upstream migration of fish to spawning and rearing areas in the upper watershed. Englebright Dam is a 85-m (280-ft) tall concrete arch dam located approximately 38 km (23.5 river miles) upstream of Yuba River’s confluence with the Feather River (i.e., at river mile [RM] 23.5) constructed by the California Debris Commission (CDC) in 1941 to trap sediment mobilized by hydraulic mining in the upper watershed (Figure 1). No fish ladder exists at Englebright Dam, and the base of Englebright Dam is the upstream limit for anadromous fish passage, confining three ESA-listed threatened species (spring Chinook salmon, steelhead, and green sturgeon) to the remaining lower river habitats below the dam. In addition to Englebright Dam, CDC also constructed the 7.3-m (24-ft) tall Daguerre Point Dam 18 km (11.2 miles) upstream of the Feather River confluence (RM 11.2) in 1906 for mining debris trapping, which was rebuilt in 1964 following flood damage. Daguerre Point Dam is equipped with two fish ladders, but they are substandard and do not adequately provide upstream anadromous fish passage over a full range of flows1. The dam and its associated water diversions are also thought to be increasing the incidence of predation of juvenile salmonids because of alterations of hydraulic conditions in the riverine environment (Richard Wantuck, per. comm., May 2013).

Englebright Dam is identified in the National Marine Fisheries Service (NMFS) Draft Central Valley Recovery Plan as one of the dams where fish passage would contribute to recovery of the Central Valley Spring-run Chinook Evolutionarily Significant Unit (ESU) and the Central Valley Steelhead Distinct Population Segment (DPS) (NMSF 2012). Currently several hydropower relicensing actions are underway in the upper Yuba watershed. In the context of these relicensing actions, as well as for recovery planning of anadromous fish species listed under the Endangered Species Act, NMFS has sponsored a series of studies to determine whether reintroduction of spring-run Chinook salmon and steelhead into the historic watersheds of the upper Yuba River is feasible, and if so, where and how reintroduction can be implemented.

The sediment transport study herein focused on erosion of sediment in the reservoir impoundment areas and deposition of sediment downstream of the dams following the removal of, or modification to Englebright and Daguerre Point dams as means to facilitate upstream fish passage. The study reaches include: Englebright Dam impoundment, Yuba River downstream of Englebright Dam, and Feather River between Yuba River and Sacramento River confluences. The study focuses on erosion of sediment in the impoundment areas and deposition of sediment downstream of the dams following dam modifications. A separate study (GEC 2013) provides engineering details of the Englebright Dam and Daguerre Point Dam modification alternatives. The GEC (2013) report and this technical report complement each other and should be examined together when analyzing the different aspects of dam removal or modification options.

Field data were not collected during this study and the analyses and modeling inputs are all based on existing information such as published papers and technical reports, USGS hydrologic station records, and aerial and Google Earth photographs.

Figure 1. Schematic map of the study area, showing the study reaches in black and other rivers in grey.
2 OVERVIEW OF GEOMORPHIC CONDITIONS RELEVANT TO SEDIMENT TRANSPORT MODELING IN THE STUDY REACHES

Longitudinal profiles of the Yuba River, South Fork Yuba River, and Feather River in the study reach show a typical upward concave profile with decreasing channel gradient in the downstream direction (Figure 2). Most of the study reach is unconfined, with active channel widths varying between approximately 120 and 200 m (Figure 3).

Figure 2. Longitudinal profiles of the study reaches, including Yuba River, South Fork Yuba River, and Feather River. Yuba River and South Fork Yuba River pre-Englebright-Dam profiles were thalweg elevations derived from digitized 1939 USGS topographic map (Snyder et al. 2004b); Yuba River and South Fork Yuba River 2001 profiles are the thalweg elevations of the USGS bathymetric surveys (Childs et al. 2003); Yuba River profile downstream of Englebright Dam represents 2009 thalweg elevation (Wyrick and Pasternack 2011); Feather River profile represents 1997 thalweg elevation (based on Army Corps of Engineers [ACOE] HEC-RAS studies, ACOE 2011). Dashed line in Yuba River immediately downstream of Englebright Dam represents data gap.

The Yuba River experienced a period of intensive hydraulic mining in the 19th century, producing large quantities of debris that once choked the channel with sediment up to 40 m thick in certain reaches of the watershed (Gilbert 1917; James 1989). The termination of hydraulic mining in the late 19th century and construction of dams throughout the watershed in the 20th century, however, have cut off almost all the coarse sediment supply to the Lower Yuba River...
(i.e., Yuba River downstream of Englebright Dam to the Feather River confluence), resulting in continued channel degradation (Figure 4) (Ghoshal et al. 2010, Ayres Associates 1997; Pasternack 2008). The Timbuctoo Bend, located at approximately 4 – 9 km downstream of Englebright Dam, for example, has degraded approximately 0.5 to 1.5 m, depending on geomorphic unit (e.g., pools, riffles and secondary channels), between 1999 and 2006 (Pasternack 2008). Without coarse sediment supply from the upper watershed, channel degradation in the Lower Yuba River is likely to continue, although likely at a rate decreasing with time primarily due to the gradual coarsening of the channel bed.

The Lower Yuba River is gravel-bedded all the way to its confluence with the Feather River. Yuba River upstream of Englebright and South Fork Yuba River were gravel-bedded prior to construction of Englebright Dam. Sediment accumulation behind Englebright Dam, however, is generally sand- and silt-sized material with a very small fraction of gravel (Snyder et al. 2004a, 2006). The Feather River within the study reach is sand-bedded.

Similar to the Yuba River, the Feather River experienced channel aggradation during the hydraulic mining era and subsequent degradation following the termination of hydraulic mining in the late 19th century and construction of Oroville Dam in 1968. The reach near the Yuba River confluence (i.e., upstream end of FR-4, Figure 5), for example, is observed to have experienced 3 – 10 m (10 – 30 ft) of channel degradation between the mid-1920s and mid-1960s.
Figure 4. Yuba River longitudinal profile (thalweg) between 1899 and 1992. Diagram reproduced from Ayres Associate (1997). 1 mile = 1.609 km; 1 ft = 0.3048 m.

Figure 5. Feather River longitudinal profile (thalweg) between 1909 and 1997. Diagram reproduced from CADWR (2004b). 1 mile = 1.609 km; 1 ft = 0.3048 m; Yuba River confluence is at the upstream end of FR-4.
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3 RELEVANT HYDROLOGIC RECORDS IN THE WATERSHED

There are a number of USGS hydrologic stations within or near the study reach in the Yuba River watershed and the Feather River. Based on the period of record, we selected seven stations to use for hydrologic analysis and modeling input (Table 1). Daily discharge data from one or a combination (i.e., addition or subtraction) of two of these stations are used to represent the daily discharge at a particular location in the study reach as indicated in Table 2 below.

<table>
<thead>
<tr>
<th>Station Number</th>
<th>Station Name</th>
<th>Period of Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>USGS 11417500</td>
<td>South Yuba River at Jones Bar near Grass Valley</td>
<td>WY1941 – 2010</td>
</tr>
<tr>
<td>USGS 11419000a</td>
<td>Yuba River at Smartsville</td>
<td>WY1904 – 1941</td>
</tr>
<tr>
<td>USGS 11418000a</td>
<td>Yuba River below Englebright Dam near Smartsville</td>
<td>WY1942 – 2010</td>
</tr>
<tr>
<td>USGS 11421000</td>
<td>Yuba River near Marysville (below Daguerre Dam)</td>
<td>WY1944 to present</td>
</tr>
<tr>
<td>USGS 11407150</td>
<td>Feather River near Gridley</td>
<td>WY1965-1998</td>
</tr>
<tr>
<td>USGS 11425000</td>
<td>Feather River near Nicolaus</td>
<td>See note b below</td>
</tr>
<tr>
<td>USGS 11391150</td>
<td>Sutter Bypass near Nicolaus</td>
<td>See note c below</td>
</tr>
</tbody>
</table>

a. USGS 11418000 is a relocation of USGS 11419000 following Englebright Dam construction. They are located close to each other.

b. Available 1 April 1942 through 30 September 1983, extended to WY 1998 with the aid of USGS 11407150, see Appendix A for details).

c. Available 1 October 1959 through 31 March 1980, extended to WY 28 May 2012 with the aid of USGS 11389500 Sacramento River near Colusa, see Appendix A for details).

Table 2. Daily discharge representation used for each sub-reach within the modeling domain.

<table>
<thead>
<tr>
<th>Sub-reach within the study reach</th>
<th>Representative daily discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Fork Yuba River</td>
<td>USGS 11417500</td>
</tr>
<tr>
<td>Yuba River upstream of South Fork Yuba River confluence</td>
<td>USGS 11418000 subtracting USGS 11417500</td>
</tr>
<tr>
<td>Yuba River between South Fork Yuba River confluence and Daguerre Point Dam</td>
<td>USGS 11418000</td>
</tr>
<tr>
<td>Yuba River downstream of Daguerre Point Dam</td>
<td>USGS 11421000</td>
</tr>
<tr>
<td>Feather River between Yuba and Bear River confluences</td>
<td>USGS 11407150 plus USGS 11421000</td>
</tr>
<tr>
<td>Feather River between Bear River and Sutter Bypass confluences</td>
<td>USGS 11425000a</td>
</tr>
<tr>
<td>Feather River between Sutter Bypass and Sacramento River confluences</td>
<td>USGS 11425000 plus USGS 11391050b</td>
</tr>
</tbody>
</table>

a. Gage data at USGS 11425000 (Feather River near Nicolaus, CA) record terminated on 30 September 1983. Discharge at the station is extended to beyond 30 September 1983 using correlation with USGS 11407150 (Feather River near Gridley) daily discharge record (Appendix A).

b. Gage data at 11391050 (Sutter Bypass nr Nicolaus, CA) terminated on 31 March 1980. Discharge at the station is extended to beyond 31 March 1980 using correlation with USGS 11389500 (Sacramento River near Colusa, CA) daily discharge record (Appendix A).
Fifteen water years were selected randomly from the available daily discharge data for model input (Table 3), among which three typical years were selected to represent “wet” (1997), “average” (1989), and “dry” (1981) conditions (year types based primarily on annual runoff with references to annual peak flow exceedance probabilities at USGS 11419000 and 11418000). Daily flow records at selected USGS stations for these years are provided in Figure 6.

The 2 January 1997 flood is the second largest flood event in the recorded history of the Yuba and Feather River basins with a slightly higher than 50-year recurrence interval peak discharge (i.e., with exceedance probability slightly lower than 0.02) (Figure 7). In the absence of a flood risk assessment standard and/or guidance from regulating agencies for dam removal projects, we selected the 2 January 1997 flood event to evaluate the potential increase in flooding risks associated with the project. This is likely an overly conservative approach due to the relatively short duration of the potentially increased flood risks associated with the sediment deposition, as discussed later in Section 12.4. Additional analysis can be conducted in the future if a flood risk assessment standard or guidance is established.

Table 3. Peak flow and annual runoff exceedance probabilities of the fifteen years randomly selected for modeling purposes, based on the hydrologic record from WY 1903 to 1941 at USGS gage 11419000 (Yuba River at Smartville) and from WY 1942 to 2011 at USGS gage 11418000 (Yuba River below Englebright Dam near Smartsville); the three typical “wet”, “average”, and “dry” years presented in Figure 6 are shaded.

<table>
<thead>
<tr>
<th>Year No</th>
<th>Water Year</th>
<th>Year Type</th>
<th>Annual Runoff (million m³)</th>
<th>Exceedance Probability</th>
<th>Annual Peak (m³/s)</th>
<th>Exceedance Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1997</td>
<td>Wet</td>
<td>3817</td>
<td>0.140</td>
<td>4360</td>
<td>0.019</td>
</tr>
<tr>
<td>2</td>
<td>1981</td>
<td>Dry</td>
<td>857</td>
<td>0.925</td>
<td>100</td>
<td>0.916</td>
</tr>
<tr>
<td>3</td>
<td>1989</td>
<td>Average</td>
<td>1884</td>
<td>0.570</td>
<td>740</td>
<td>0.477</td>
</tr>
<tr>
<td>4</td>
<td>1994</td>
<td></td>
<td>940</td>
<td>0.888</td>
<td>50</td>
<td>0.972</td>
</tr>
<tr>
<td>5</td>
<td>1967</td>
<td></td>
<td>3114</td>
<td>0.308</td>
<td>1240</td>
<td>0.280</td>
</tr>
<tr>
<td>6</td>
<td>1996</td>
<td></td>
<td>3191</td>
<td>0.290</td>
<td>1430</td>
<td>0.178</td>
</tr>
<tr>
<td>7</td>
<td>1977</td>
<td></td>
<td>370</td>
<td>0.991</td>
<td>30</td>
<td>0.991</td>
</tr>
<tr>
<td>8</td>
<td>1986</td>
<td></td>
<td>3224</td>
<td>0.271</td>
<td>2830</td>
<td>0.084</td>
</tr>
<tr>
<td>9</td>
<td>1990</td>
<td></td>
<td>872</td>
<td>0.907</td>
<td>60</td>
<td>0.963</td>
</tr>
<tr>
<td>10</td>
<td>1985</td>
<td></td>
<td>1003</td>
<td>0.841</td>
<td>160</td>
<td>0.879</td>
</tr>
<tr>
<td>11</td>
<td>1980</td>
<td></td>
<td>3323</td>
<td>0.224</td>
<td>1190</td>
<td>0.308</td>
</tr>
<tr>
<td>12</td>
<td>1998</td>
<td></td>
<td>1085</td>
<td>0.262</td>
<td>100</td>
<td>0.589</td>
</tr>
<tr>
<td>13</td>
<td>1982</td>
<td></td>
<td>4689</td>
<td>0.037</td>
<td>1420</td>
<td>0.187</td>
</tr>
<tr>
<td>14</td>
<td>1988</td>
<td></td>
<td>815</td>
<td>0.944</td>
<td>50</td>
<td>0.981</td>
</tr>
<tr>
<td>15</td>
<td>1971</td>
<td></td>
<td>2648</td>
<td>0.383</td>
<td>420</td>
<td>0.673</td>
</tr>
</tbody>
</table>
Figure 6. Daily discharge records within the study reach for three typical water years. (a). Wet year (WY 1997); (b). Average year (WY 1989); and (c) Dry year (WY 1981)
Figure 7. Peak flow in the Feather River near Oroville, based on USGS Station #11407000 peak flow record (WY 1902 - 2009), and Yuba River downstream of Englebright Dam, based on USGS Stations #11418000 (WY 1942 - 2011) and #11419000 (WY 1904 - 1941) peak flow records. The exceedance probability values in the diagram are based on Weibull plotting position.
4 IMPOUNDMENT DEPOSITS BEHIND ENGLEBRIGHT DAM

The bathymetric surveys and coring campaigns conducted by USGS in 2001 and 2002 (Childs et al. 2003; Snyder et al. 2004a, 2004b, 2006) provided sufficient information to characterize the volume and composition of Englebright Lake reservoir deposits for sediment transport modeling purposes (Figure 8).

![Figure 8. Longitudinal profiles of the Englebright Dam impoundment area, including Yuba River and South Fork Yuba River. Pre-Englebright-Dam profiles were thalweg elevations derived from digitized 1939 USGS topographic maps (Snyder et al. 2004b); Yuba River and South Fork Yuba River 2001 profiles are the thalweg elevations of the USGS bathymetric surveys (Childs et al. 2003).](Image)

According to the analysis of Snyder et al. (2004b), there were approximately 26 million metric tons (t) of material in Englebright Lake deposits in 2001, of which 64.7 to 68.5% is sand and gravel. This represents an average accumulation rate of 426,000 t/yr over the 61-year period (1941–2001) of reservoir operation. The bottomset bed of the deposit is primarily fine sediment (i.e., silt and clay, or sediment with particles finer than 0.063 mm), while the topset bed of the deposit is coarse sediment (i.e., sand and gravel, or sediment with particles coarser than 0.063 mm) (Figure 9), which is a typical stratification of deposits in large reservoirs (e.g., Vanoni 1975). The coarse sediment fraction increases in the upstream direction (Table 4). Deep core #1 located at 0.5 km upstream of Englebright Dam, for example, contains 11% coarse sediment and 89% fine sediment; however, at approximately 8.1 km upstream of Englebright Dam at deep core #8, coarse sediment increases to 72% at the surface and 43% near the bottom of the deposit.
Table 4. Depth averaged coarse (> 0.063 mm) and fine (< 0.063 mm) sediment fraction in the deposit, based on data provided by Noah Snyder and summarized in Snyder et al. (2004a).

<table>
<thead>
<tr>
<th>Core #</th>
<th>Distance from Englebright Dam (km)</th>
<th>Depth from Deposit Surface</th>
<th>Average Fraction of Sand and Coarser</th>
<th>Average Fraction of Silt and Finer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>Entire deposit</td>
<td>0.11</td>
<td>0.89</td>
</tr>
<tr>
<td>6</td>
<td>2.5</td>
<td>Entire deposit</td>
<td>0.22</td>
<td>0.78</td>
</tr>
<tr>
<td>4</td>
<td>5.4</td>
<td>Entire deposit</td>
<td>0.30</td>
<td>0.70</td>
</tr>
<tr>
<td>7</td>
<td>6.2</td>
<td>&lt; 25.0 m</td>
<td>0.64</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 25.0 m</td>
<td>0.32</td>
<td>0.68</td>
</tr>
<tr>
<td>9</td>
<td>7.3</td>
<td>&lt; 12.5 m</td>
<td>0.86</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 12.5 m</td>
<td>0.34</td>
<td>0.66</td>
</tr>
<tr>
<td>8</td>
<td>8.1</td>
<td>&lt; 20.0 m</td>
<td>0.72</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 20.0 m</td>
<td>0.43</td>
<td>0.57</td>
</tr>
<tr>
<td>2</td>
<td>10.5</td>
<td>&lt; 1.0 m</td>
<td>0.97</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 1.0 m*</td>
<td>0.79</td>
<td>0.21</td>
</tr>
</tbody>
</table>

* No sample was taken, assumed to be the average of the top layer of cores 9 and 8 above.

The grain size distributions of the Englebright Lake deposit from seven bulk samples within the top 1 m of the deposit surface collected during the USGS 2002 campaign are presented in Figure 10 (Noah Snyder, per. comm. 24 April 2012). The coarser portion of these samples (Figure 10b) should provide good representation of the sand and gravel fraction in Englebright Lake deposit downstream of Core #2 (Figure 9). Sediment deposited upstream of Core #2 is coarser than the grain size distributions presented in Figure 10. Snyder et al. (2004a) estimated that gravel fractions in the upper reservoir deposits can be significantly higher than what was shown in the samples presented in Figure 10, potentially elevating the gravel fraction of the overall reservoir...
deposit to approximately 20%. For modeling purposes, we used the average grain size distribution of the samples presented in Figure 10 for model input and did not explicitly account for the coarser sediment size distribution in the upper reservoir deposit. Following the current scientific understanding of how different sized sediment particles move through river systems (e.g., Cui and Wilcox 1998), research on sediment pulse movement (e.g., Lisle et al. 2001; Cui et al. 2003a, 2003b), and observations of sediment transport following Marmot Dam removal on the Sandy River, Oregon (Cui et al. in press), we are confident that the gravel particles in the upper reservoir deposit (i.e., > 10 km upstream of Englebright Dam) will lag in downstream transport behind the sand and silt fraction, and will not reach the Lower Yuba River (i.e., Yuba River downstream of Englebright Dam) until all the sand and silt has evacuated out of the reservoir area, due to the attenuation of gravel transport through the more than 10 km long reach before reaching Englebright Dam. Attenuation of gravel transport and particle abrasion while transporting through more than a 10 km long river reach before reaching Englebright Dam provides additional physical basis for why the magnitude of gravel deposition downstream of Englebright Dam will be minimal once it reaches the Lower Yuba River. Gravel deposition in the Sandy River in Oregon following Marmot Dam removal, for example, was limited to within 2 km downstream of the main impoundment gravel deposit while minimal gravel deposition was observed beyond the 2-km depositional zone four years after dam removal (Cui et al. in press). The volume of gravel particles in the upper Englebright Lake deposit is comparable to that in the Marmot impoundment deposit, and hydrologic and geomorphic conditions of the two rivers are also fairly similar. As a result, it is reasonable to expect the primary gravel deposition following Englebright Dam removal will be focused within a few kilometers of the upper reservoir deposit, which is still within the reach upstream of the current Englebright Dam site. Over time the gravel particles will transport to the Lower Yuba River; however, since this gravel influx will lag far behind the sand and silt wave following initial dam removal, the impact from the gravel will likely only benefit the system as it supplements spawning gravel and reduces the rate of channel degradation.

The size distribution of the fine portion (< 0.063 mm) of the reservoir deposit does not influence modeling results because particles that fine will certainly transport as washload with minimal chance to settle onto the channel bed once eroded from the deposit following dam modifications. The silt portion of the deposit is included in the calculation of suspended sediment concentration.
Figure 10. Grain size distributions from seven bulk samples near surface (within 1 m of the deposit surface) at Cores #1, 6, 4, 7, 9, 8 and 2 (colored lines) and their average (thick black line), based on grain size data provided by Noah Snyder (per. comm., 24 April 2012). (a) Full grain size distributions; (b) Grain size distributions excluding silt and clay (i.e., < 0.063 mm).
5 IMPOUNDMENT DEPOSITS BEHIND DAGUERRE POINT DAM

Entrix, Inc. (2003) estimated that there is approximately 3.5 million m$^3$ (4.6 million cubic yards) of sediment deposited behind Daguerre Point Dam (bulk volume). Historic accounts report that sediment completely filled the reservoir to the current bed level following the 1911 flood one year after dam construction in 1910 (Hunerlach et al. 2004), implying that the volume of sediment stored behind Daguerre Dam is relatively small compared to the river’s capacity to transport sediment. We estimate the maximum amount of possible sediment erosion following Daguerre Point Dam removal is approximately 1.8 million m$^3$ (2.4 million cubic yards) (assuming a triangular deposit of 4 km long, 150 m wide, and 6 m deep just upstream of the dam), which is approximately half of the estimated deposit volume by Entrix, Inc. (2003) (Figure 11).

![Longitudinal profile of the Yuba River near Daguerre Point Dam, constructed based on 2009 thalweg elevations of Wyrick and Pasternack (2011).](figure11.png)

Grain size distributions of the impoundment deposit behind Daguerre Point Dam are available from six drill holes scattered within 2 km of the dam with depths up to 10.8 m collected by USGS in August 2001 (Hunerlach et al. 2004) (Figure 12). A review of the location of the drill holes and grain size at different depths revealed that it is not possible to develop a map of spatial dependent grain size distribution map such as that developed for Marmot Dam deposit on the Sandy River, Oregon (Squier Associate 2000). As a result, an average of the grain size
distributions presented in Figure 12 is used to model the sediment transport dynamics in the case simulating Daguerre Point Dam removal.

Figure 12. Grain size distributions of samples obtained from six drill holes up to 10.8 m deep in August 2001 by USGS in the Daguerre Point Dam impoundment reach within 2 km of the dam. Diagram is created based on data presented in Hunerlach et al. (2004); the black thick line represents the average of all the available data and is used for model input.
6 SEDIMENT SUPPLY TO THE STUDY REACH

The long-term average rate of sediment supply from the upper Yuba River watershed is approximately 426,000 t/yr based on 61 years of sediment accumulation in Englebright Lake between 1941 and 2001, among which 64.7% - 68.5% (or approximately 276,000 – 292,000 t/yr) is sand and gravel (Snyder et al. 2004b). The current rate of sediment supply, however, is most likely lower than that for the reason that much of the debris from hydraulic mining has already transported into Englebright Lake in the early years following Englebright Dam closure. Construction of dams in the watershed after Englebright Dam closure in 1941 may also have lowered sediment supply rate into the Englebright Lake, but the impact from that is believed to be small.\footnote{The following dams were constructed after Englebright Dam closure in 1941: New Bullards Bar Dam on the North Fork Yuba River (1969), Log Cabin Dam on Oregon Creek (1969); Jackson Meadow Dam on the Middle Fork Yuba River (1969), and Our House Dam on the Middle Fork Yuba River (1969). Log Cabin and Our House dams are relatively small diversion dams without much storage capacity and both pass some percentage of sediment downstream when they are full of sediment (their reservoirs are intermittently dredged) and thus, should not have a significant impact on sediment supply to Englebright Lake. Jackson Meadow Dam controls a very small contributing catchment area, and thus, its influence on sediment supply is small. New Bullards Bar Dam traps all the North Fork Yuba River sediment supply, but North Fork Yuba River was not heavily disturbed by hydraulic mining and thus, has a much lower sediment production rate compared to the Middle Fork and South Fork Yuba rivers. In addition, the original Bullards Bar Dam was in place a short distance upstream of the current New Bullards Bar Dam site prior to the construction of New Bullards Bar and Englebright dams, which was trapping sediment from the North Fork Yuba River during the entire period over which Englebright accumulation rates were calculated.}

Based on the record between WY 1965 and 1993 at USGS Station #11407150 Feather River near Gridley (\textbf{Figure 13}), annual suspended sediment transport ranges between 4,200 and 3,304,000 t/yr, with the maximum value occurring during WY 1965 (\textbf{Figure 14}), which is one of the wettest years in the basin and was prior to the closure of Oroville dam. The average suspended sediment transport rate in the Feather River near Gridley based on the record above is 223,000 t/yr, and 95,800 t/yr if only post-Oroville Dam closure in the record (WY 1969 through 1993) is considered. Significant reduction of sediment supply in the Feather River has occurred due to closure of Oroville Dam in 1968. CADWR (2004a) estimated that there was approximately 35 million m$^3$ of sediment deposited (bulk volume) in Lake Oroville in 2002, which translates to approximately 41.6 million tons of sediment if we use the same bulk density as that of the Englebright Lake deposit where 21,890,000 m$^3$ was converted to 26 million tons (Childs et al. 2003; Snyder et al. 2004b). That equates to more than 1.2 million t/yr (or about 4 times the annual amount trapped by Englebright Dam) of sediment from the upper Feather River is trapped by the dam rather than entering the Feather River and the portion of the modeling study reach downstream of the Feather and Yuba rivers’ confluence.

Application of the DREAM-1 model requires a value of the supply rate of bed material load, which is generally sediment in the sand range that can be transported as bedload and suspended load during floods. An estimate of bed material load in the Feather River was calculated during a zeroing process through trial-and-error in the DREAM-1 model so that the estimated bed material load from the upstream Feather River results in a modeled longitudinal profile similar to that observed in the field.
Figure 13. Suspended sediment record at USGS Station #11407150 Feather River near Gridley between WY 1965 and 1993.

Figure 14. Suspended sediment transport record at USGS Station #11407150 Feather River near Gridley between WY 1965 and 1993.
7 DAM REMOVAL EXPRESS ASSESSMENT MODELS (DREAM)

7.1 Overview

Dam Removal Express Assessment Models (DREAM-1 and DREAM-2) were used for modeling sediment transport following the removal or modification of the two dams. DREAM-1 and DREAM-2 models and their predecessors and sister models (i.e., early versions of the models and models that differ only in sediment transport equations, which were selected based on composition of sediment deposit) have been used for simulation of large sediment pulse movement in rivers, including sediment transport following dam removal for many projects. Example case studies include: mining waste disposal in Ok Tedi – Fly River system in Papua New Guinea (Cui and Parker 1999); Soda Springs Dam removal study on the North Umpqua River in Oregon (Stillwater Sciences 1999); Marmot Dam removal on the Sandy River, Oregon (Stillwater Sciences 2000; Cui and Wilcox 2008; Cui et al. in press); Saeltzer Dam removal on Clear Creek, California (Stillwater Sciences 2001); landslide sediment evolution in the Navarro River, California (Sutherland et al. 2002; Cui and Parker 2005); Iron Gate, Copco 1, Copco 2, and J.C. Boyle Dam removal on the Klamath River, California and Oregon (Stillwater Sciences 2004; Stillwater Sciences 2008); Simpkins and Bloede Dam removal on the Patapsco River, Maryland (Stillwater Sciences 2010); Harvey Diversion Structure removal on Santa Paula Creek, California (Stillwater Sciences 2012); and Freeman Dam removal on the Santa Clara River, California (Stillwater Sciences 2013). In addition to these practical projects, DREAM-1 and DREAM-2 models were also examined with flume experiments and proved to produce excellent results without or with minimal model calibrations (Cui et al. 2008). More details of the Dam Removal Express Assessment Models can be found in Cui et al. (2006a, 2006b).

DREAM-1 was designed for simulation of sediment transport dynamics in rivers following dam removal where the sediment deposit in the reservoir is composed primarily of non-cohesive sand-sized sediment. It simulates the transport and deposition of sand-sized sediment and is applicable to rivers with any combination of sand-bedded, gravel-bedded, and bedrock reaches downstream of the dam. Because DREAM-1 does not simulate the transport of gravel, it treats the gravel-beds downstream of the dam and the pre-dam historical gravel beds upstream of the dam as immobile — fine sediment either passes through or deposits onto the gravel-bedded surface and potentially transforms it into a sand-bedded reach if the sand deposit becomes sufficiently thick. For flow parameter calculations, the model applies a standard backwater equation (e.g., Chaudhry 1993) for low Froude numbers (i.e., Froude numbers < 0.9, see Cui et al. 2006a for details) and applies a quasi-normal flow assumption (i.e., friction slope is identical to local bed slope; see Cui and Parker 2005) for high Froude numbers. The model applies Brownlie’s (1982) bed material equation for calculating sediment transport capacity and considers the transport of particles coarser than 0.063 mm (i.e., sand and coarser) as one unit for mass conservation calculations, and considers particles finer than 0.063 mm in diameter as wash load that is assumed unable to redeposit onto the channel bed once released into the water column following erosion of the reservoir deposit. Further, it is assumed that reservoir erosion is governed by the mobilization of sand and coarser sized particles. At any cross section, eroding the reservoir deposit down to a given elevation by mobilizing sand and coarser particles will also result in the release of all the finer particles (i.e., finer than 0.063 mm) above that elevation.

DREAM-1 model requires the following input parameters: initial channel profile that consists of an immobile bed and a layer of sand deposit over the immobile bed in the reservoir and downstream reaches, channel cross-sections simplified as rectangles with widths equal to the
active channel width, daily average water discharge values, the rate and grain size distribution of sediment supply, and the downstream base-level control (i.e., either downstream water surface elevation or fixed bed elevation). Model output includes the erosion and deposition of sediment within the reservoir and downstream reaches, sediment fluxes, and daily-averaged total suspended sediment concentrations (TSS) along the river in response to the specified water discharge and sediment supply conditions.

**DREAM-2** was designed for simulation of sediment transport dynamics in rivers following dam removal where at least the top layer of the sediment deposit in the reservoir is composed primarily of gravel and coarser sediment. It simulates the transport and deposition of gravel and sand and is applicable to rivers with any combination of gravel-bedded and bedrock reaches downstream of the dam. For flow parameter calculations, the DREAM-2 model applies a standard backwater equation identical to that of DREAM-1 model. DREAM-2 model applies the surface-based bedload equation of Parker (1990) for calculating transport capacity of gravel and coarser sediment (i.e., particles coarser than 2 mm) and Brownlie’s (1982) bed material equation for calculating transport capacity of sand-sized sediment (i.e., particles between 0.0625 and 2 mm). Sediment in the silt and clay range (i.e., particles finer than 0.0625 mm) is treated as wash load that is assumed unable to redeposit onto the channel bed once released into the water column following erosion of the sediment deposit upstream of the dam. Furthermore, the model assumes that the erosion of reservoir deposit is governed by the mobilization of gravel-sized and coarser particles, and thus eroding the deposit down to a given elevation by mobilizing gravel and coarser particles will simultaneously result in the release of all the finer particles (i.e., sand, silt and clay).

The model requires the following input parameters: a) initial channel profile, including the elevation of a non-erodible bed and the thickness of a layer of sediment deposit over the non-erodible bed; b) initial grain size distributions of the sediment deposit upstream and downstream of the modeled structure; c) channel cross-sections simplified as rectangles with widths equal to the active channel width; d) daily average water discharge values; e) the rate and grain size distribution of sediment supply; and, f) the downstream base-level control (i.e., either downstream water surface elevation or fixed bed elevation). Model output includes the evolution and the thickness of sediment deposits in reaches upstream and downstream of the structure, sediment fluxes, and daily-averaged total suspended sediment concentrations along the river in response to the specified water discharge and sediment supply conditions.

For the present study, DREAM-1, with revisions discussed below, is used to simulate sediment transport dynamics in the Yuba and Feather rivers following modifications to Englebright Dam because Englebright Lake deposit is primarily sand and finer sediment, DREAM-2 is used to simulate sediment transport dynamics in the Yuba River following the removal of Daguerre Point Dam because the reservoir deposit contains a substantial amount of gravel.

### 7.2 Revisions to DREAM-1 for Modeling Removal or Modification of Englebright Dam

Two revisions were made to allow the DREAM-1 model to simulate sediment transport dynamics in the Yuba and Feather rivers following Englebright Dam modification: a) a modification was made to the reservoir erosion module to allow erosion of sediment deposits from both the Yuba River and South Fork Yuba River; and b) an inner boundary condition was added at the Englebright Dam site to allow for the simulation to follow the designed flow and sediment transport conditions.
release. The modification to DREAM-1 model to allow for erosion of sediment deposits from both the Yuba and the South Fork Yuba rivers involves adding a sediment conservation module at a river junction similar to that of Cui and Parker (1999). The inner boundary condition at the Englebright Dam site is discussed in more detail later in this report.
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8 ZEROING PROCESSES

A zeroing process is required to model sediment transport following dam removal using DREAM-1 or DREAM-2 models. The DREAM-1 zeroing process was conducted for the Lower Yuba River downstream of Englebright Dam and Feather River between Yuba and Sacramento River confluences; DREAM-2 zeroing process is conducted for the Lower Yuba River downstream of Englebright Dam. Due to the gravel-bedded nature of the Lower Yuba River and zeroing sediment supply from the upper Yuba River, DREAM-1 zeroing process is effective only for the Feather River reach (i.e., no simulated change is expected for the Lower Yuba River during the zero process runs).

The zeroing process runs for both models used the discharge record for the 15 water years given in Table 3 for model input (and in that order, and only the first 10 years for DREAM-2 zero processing run, as discussed below). Years were cycled back to the first year after every 15 years for the DREAM-1 run that lasted for more than 15 years.

![Figure 15. Comparison of DREAM-1 post-zeroing longitudinal profile with the observed longitudinal profile. Model validation through zero run applies only to the Feather River reach (downstream of 40 km) in this case because Yuba River is gravel-bedded and there is zero sediment supply from the upper Yuba River. Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam.](image)

DREAM-1 zeroing process simulated the current condition for 120 years, which resulted in a quasi-equilibrium profile (Figure 15 and Figure 16). It is worth reiterating that in a DREAM-1 simulation, a gravel deposit is treated as non-erodible, which explains the lack of channel
degradation in the Yuba River (i.e., between 0 and 40 km in Figure 15). As a result, the above DREAM-1 zeroing process provided model calibration only for the sand-bedded Feather River, and the sand transport over the gravel-bedded Yuba River remains uncalibrated. Field data for sand transport over a gravel-beded river is very difficult to find, because there is minimal attenuation of sand transport and deposition of sand en masse over a gravel-beded river under typical natural conditions. DREAM-1 performance with sand transport over a gravel-beded river reach simulating sediment transport following dam removal was successfully tested by Cui et al. (2008), who simulated sand pulse transport over a gravel-beded channel under forced pool-riffle morphology in a laboratory flume and numerically replicated the experiments with the uncalibrated DREAM-1 model, which produced an excellent match between the model and observations.

Figure 16. Simulated channel aggradation and degradation with DREAM-1 model at selected locations under current conditions. Note that lines not visible in the diagram all overlapped at zero change in bed elevation.

The DREAM-1 simulated post-zeroing profile and the observed profile are very close to each other, with the modeled profile smoother than the observed (Figure 15). A smoother than observed longitudinal profile is typical for numerically modeled profiles because models cannot capture all the local variations present in the field. Figure 16 shows the DREAM-1 modeled channel aggradation and degradation at selected locations along the river, indicating that there is local channel aggradation or degradation from year to year, but cumulatively over time, the river is in a quasi-equilibrium state.

Primary input parameters for the DREAM-1 zeroing process include: zero sand and gravel supply to the Yuba River at Englebright Dam (due to Englebright Lake trapping) and 225,250 t/yr long-term average sand supply rate from the upstream Feather River to the study reach. The latter
value was obtained via trial-and-error in the zeroing process run until a longitudinal profile similar to the observations was obtained (Figure 15). As presented earlier, the recorded long-term average post-Oroville Dam suspended sediment transport rate at Gridley station (between WY 1969 and 1993) was 95,800 t/yr. Given a 225,250 t/yr long-term average sand supply rate and assuming that the majority of the recorded 95,800 t/yr suspended sediment at Gridley station was silt and clay, the ratio of sand to silt and clay in the Feather River is approximately 1:0.43. The sand and gravel to silt and clay ratio in Englebright Lake deposit is between 1:0.54 and 1:0.45 based on data provided in Childs et al. (2003) and Snyder et al. (2004b). Therefore, the 225,250 t/yr Feather River sand supply rate seems reasonable.

DREAM-2 zeroing process simulated the current condition of the Yuba River for 10 years. The DREAM-2 post-zeroing process profile is shown in Figure 17 in comparison with the observed longitudinal profile. The DREAM-2 zeroing process was run for only 10 years because the river is still actively degrading (Pasternack 2008), and running the model for too long would produce a post-zeroing process profile too deviated from the observed longitudinal profile.

The simulated continued active channel degradation can be seen in Figure 18, indicating up to 0.6 m of cumulative channel degradation over the 10-year simulation period. This rate is similar to the observations reported in Pasternack (2008), according to which pools and secondary channels incised 1.45 m and 1.53 m, respectively, over a 7-year-period (1999 to 2006), and riffles incised at least 0.54 m over the same 7-year-period, especially when compared with the observed
rate of riffle incision (because riffles are high points that define the overall river longitudinal profile).

Figure 18. Simulated channel aggradation and degradation with DREAM-2 model at selected locations under current conditions, showing continued active channel degradation due to sediment entrapment by upstream dams. Note no change in bed elevation is produced at 20 km because it is located immediately upstream of Daguerre Point Dam.
9 MODELING DAGUERRE POINT DAM FULL REMOVAL

Due to the small amount of sediment deposited in the Daguerre Point Dam impoundment, it was expected that removal or modification of the dam would result in minimal sediment deposition downstream and minimal increase in suspended sediment concentration. Only three runs were conducted to explore sediment transport dynamics for the case of a full removal of Daguerre Point Dam in one season (i.e., the alternative commonly known as “blow-and-go” scenario).

Run DP-1 (DP denotes Daguerre Point). Hydrological conditions for the first two years of Run 1 simulation are a dry year (WY 1981 shown in Figure 6c) followed with a wet year (WY 1997 shown in Figure 6a). Simulated longitudinal profiles following Daguerre Point Dam removal indicate minimal channel degradation on a cross-section averaged basis (i.e., the amount of channel degradation averaged over the entire active channel width – a similar definition applies to cross-section averaged channel aggradation) during the first year due to low flow in the river (Figure 19). The river quickly approaches a post-dam-removal equilibrium profile during the second year (a wet year) following the occurrence of high flow events. Modeling results indicate that only a small amount of sediment deposition will occur within approximately 3 km downstream of Daguerre Point Dam.

It should be noted that the lack of channel erosion during the first year following dam removal does not imply that fish passage will not be reestablished until after a wetter year. First of all, the minimal erosion shown in Figure 19 was an artifact of an artificially smoothed profile: the initial profile modeled at the vicinity of the dam was less steep than actual field conditions because the modeling used a relatively large grid spacing (0.5 km, and a finer mesh near the dam would have resulted in a slope too steep that would cause numerical instability). It is expected that rapid erosion of the impoundment deposit at the dam site will occur following dam removal regardless of the magnitude of river discharge and will reduce the cross-sectionally averaged channel slope to a value similar to that of the 1-year simulation shown in Figure 19. Secondly, the simulated profiles shown in Figure 19 are cross-sectionally averaged, and the actual erosion of the impoundment deposit following dam removal will form gully-like channels near the dam site with a thalweg much deeper than the averaged bed elevation shown. As a result, we expect fish passage reestablishment soon after Daguerre Point Dam removal even if the dam is removed during a dry year.

Run DP-2. Hydrologic conditions for the first two years of Run 2 simulation were an average year (WY 1989 shown in Figure 6b) followed with a wet year (WY 1997 shown in Figure 6a). The river quickly approached a post-dam-removal equilibrium profile during the second year (a wet year) once high flow events occurred Figure 20. Modeling results indicate that only a small amount of sediment will be deposited within approximately 3 km downstream of Daguerre Point Dam.

Run DP-3. A wet year (WY 1997 shown in Figure 6a) was used as the hydrologic conditions for the first year of Run 3. Simulated longitudinal profiles following Daguerre Point Dam removal are presented in Figure 21, showing that the river quickly approached a post-dam-removal equilibrium profile once high flow events occurred. Modeling results indicate that only a small amount of sediment deposition will occur within approximately 3 km downstream of Daguerre Point Dam.
Figure 19. Simulated channel response following a full removal of Daguerre Point Dam with DREAM-2 model for Run DP-1, which used a discharge record from a dry year (WY 1981) as the first year and a wet year (WY 1997) as the second year for model input. (a). Average bed elevation; and (b) cumulative change in average bed elevation.
Figure 20. Simulated channel response following a full removal of Daguerre Point Dam with DREAM-2 model for Run DP-2 that used a discharge record from an average year (WY 1989) as the first year and a wet year (WY 1997) as the second year for model input. (a) Average bed elevation; and (b) cumulative change in average bed elevation.
Figure 21. Simulated channel response following a full removal of Daguerre Point Dam with DREAM-2 model for Run DP-3 that used a discharge record from a wet year (WY 1997) as the first year for model input. (a) Average bed elevation; and (b) Cumulative change in average bed elevation.
Modeling results for the three runs indicate that there is potentially a few thousand mg/l (8,000 mg/l maximum) increase in daily-averaged suspended sediment concentration immediately downstream of Daguerre Point Dam (Figure 22, Figure 23, and Figure 24) that last for a day. A 8,000 mg/l suspended sediment concentration is approximately 6 times the maximum observed suspended sediment concentration during flood based on observations at USGS Station #11407150 (Feather River near Gridley, CA) (Figure 13).

Increased flooding risk is not expected following a full removal of Daguerre Point Dam because of the limited extent and magnitude of sediment deposition following dam removal, and because sediment deposition would smooth out a longitudinal profile that is currently broken up by the existence of Daguerre Point Dam.

Because a one-time full removal of Daguerre Point Dam is the worst-case-scenario in terms of channel aggradation and potential increase in suspended sediment concentration downstream of Daguerre Point, we expect any modification of the dam (e.g., lowering the dam, notching the dam, etc.) should result in channel adjustment less than presented in Figure 19, Figure 20, and Figure 21 and smaller increase in suspended sediment concentration than presented in Figure 22, Figure 23, and Figure 24.

**Figure 22.** Simulated increase in daily-averaged suspended sediment concentration (compared to just downstream of Englebright Dam) for the first three 30-day periods following Daguerre Point Dam removal for Run DP-1. The appearance of high suspended sediment concentration never exceeded a single day.
Figure 23. Simulated increase in daily-averaged suspended sediment concentration (compared to just downstream of Englebright Dam) for the first three 30-day periods following Daguerre Point Dam removal for Run DP-2. The appearance of high suspended sediment concentration never exceeded a single day.

Figure 24. Simulated increase in daily-averaged suspended sediment concentration (compared to just downstream of Englebright Dam) for the first three 30-day periods following Daguerre Point Dam removal for Run DP-3. The appearance of high suspended sediment concentration never exceeded a single day.
Note that a removal of Daguerre Point Dam will result in a lowered water surface elevation for several kilometers of the river reach upstream of the dam site, making water diversion operations using the existing intakes located there nonfunctional. One potential solution is to extend the intakes further upstream to make up the lost head, but selection of new intake points should not rely solely on the modeled bed profiles because the predicted longitudinal profile upstream of a dam, which is dependent on information currently buried and mostly unknown, is intrinsically unreliable (Cui et al. 2011). Selection of new intake locations should use the predicted profiles as references and build adequate safety factors, to ensure that future water surface elevations at potential new diversion intake locations do not fall below the designed levels due to channel degradation beyond the model predictions.
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10 MODELING FULL REMOVAL OF ENGLEBRIGHT DAM

Two engineering alternatives are identified as potentially feasible for the full removal of Englebright Dam (GEC 2013):

1). Open a tunnel at the base of the dam for rapid drawdown of lake level; remove the dam in the summer dry season after drawdown (referred to as Tunneling and Rapid Release Alternative, hereafter). This method was used in the recent Condit Dam removal project on the White Salmon River in Washington.

2). Notch the dam down in steps, until the entire dam is removed (referred to as Staged Removal Alternative, hereafter). This method is currently being used on the Elwha River dam removal project in Washington.

10.1 Tunneling and Rapid Release

Once a tunnel is open, Englebright Lake level will drop, allowing the reservoir deposit to be eroded and released to the downstream reach. The dam structure will separate the reaches upstream and downstream of Englebright Dam prior to its removal. As a result, an inner boundary condition at the Englebright Dam site is needed to specify the lake level and discharge released to the river downstream. To do so, we developed Englebright Lake storage and discharge capacity curves (Appendix B), which, in combination with daily averaged inflow into the lake, are used to feed into a water conservation model developed specifically for this project. The model routes the flow through the Englebright Lake, deriving Englebright Lake level (Figure 25) and daily averaged discharge released to the Yuba River downstream of Englebright Dam (Figure 26) as a function of time. The output serves as a DREAM-1 modeling inner boundary condition.

A management and subsequent modeling decision must be made as to when to open up the tunnel at the base of Englebright Dam for sediment release, which may substantially increase the suspended sediment concentration in the Yuba and Feather rivers. Different life stages of the listed species (spring-run Chinook salmon, fall-run Chinook salmon, steelhead, and green sturgeon) are present in the Yuba and Feather rivers almost year-round (Table 5). As a result, it is not possible to release the sediment without impacting at least one species.

Table 5. Primary timing of spring-run Chinook salmon, steelhead, and green sturgeon presence in the Yuba and Feather rivers, based on NMFS (2012) and Stillwater Sciences (2012b).

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<th>Fish Type</th>
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<td>Green sturgeon</td>
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Based on the research of Stillwater Sciences (2008, 2009) on the Klamath River dam removal project, we have assumed that the tunnel will be open on the 15th of November. The main reason
for choosing this date was to have the sediment released as close to winter high flow season as possible. Opening the tunnel any time after this date presents additional risk of an early winter high flow occurring during the time the tunnel is scheduled to be blasted open, complicating the dam removal process.

Simulated Englebright Lake levels and discharges through Englebright Dam are presented in Figure 25 and Figure 26, respectively, for three typical hydrological years assuming a) one 3 × 3 m (10 × 10 ft) tunnel at the base of the dam is opened on the 15th of November; and b) Englebright Lake level was kept at 160 m prior to the opening of the tunnel, showing that the draw down was completed within approximately one week.

![Figure 25](image-url)

**Figure 25.** Simulated Englebright Lake level following opening a 3 × 3 m (10 × 10 ft) tunnel at the base of Englebright Dam on November 15 for three typical water years, assuming drawdown starts from the normal lake level.

Sediment would start flushing out of Englebright Lake as soon as the tunnel is opened. Englebright Lake level would remain low in a dry year similar to that of WY 1981, but in a wet year similar to WY 1997 or an average year similar to WY 1989, Englebright Lake would refill during winter high flow events (Figure 25). During the time of Englebright Lake refill, minimal flushing of Englebright sediment deposit would occur because bed shear stress within the majority of the Englebright Lake area would become minimal due to the high lake level. As a result, a dry year during the year of Englebright Lake drawdown would be more efficient than a wet year in flushing out the lake deposit.

Nine runs (Runs 1 through 6 and 17, 18 and 19) were conducted to examine the Tunneling and Rapid Release alternative with the assumptions stated above and different combinations of hydrological conditions (Appendix D). Selected runs are presented below to illustrate the sediment transport dynamics in the Yuba River and the Feather River. In addition, three more
runs (Runs 1a, 2a, and 3a) were conducted to examine the effects of varying engineering details prior to the opening of the tunnel that result in changes to Englebright Lake drawdown prior to the opening of the tunnel (Section 10.3).

![Simulated daily averaged discharge released to the Yuba River downstream of Englebright Dam following opening a 3 × 3 m (10 × 10 ft) tunnel at the base of Englebright Dam on November 15 for three typical water years, assuming drawdown starts from the normal lake level.](image)

**Figure 26.** Simulated daily averaged discharge released to the Yuba River downstream of Englebright Dam following opening a 3 × 3 m (10 × 10 ft) tunnel at the base of Englebright Dam on November 15 for three typical water years, assuming drawdown starts from the normal lake level.

In Run 1, the tunnel at the base of Englebright Dam is opened on the 15th of November in a wet year (WY 1997), followed with a dry year (WY 1981) and an average year (WY 1989). The dam is then assumed removed during the summer following the opening of the tunnel.

The Timbuctoo Bend Reach, located approximately 4 – 9 km downstream of Englebright Dam, is a primary spawning habitat for spring- and fall-run Chinook salmons. The model predicts that there will be significant sediment deposition in the Timbuctoo Bend Reach (generally within 8 m and briefly reaching 11.5 m at the upstream end of the reach; and up to 5 m at the downstream end of the reach), for about 2 years (i.e., from approximately 0.5 yr to 2.5 yr in Figure 30) (Figure 27, Figure 29, Figure 30, and Figure 31). The thickness of sediment deposition in the Yuba River generally decreases and duration increases in the downstream direction (Figure 27) with the exception of a short reach just upstream of the Feather River confluence where more sediment deposition is predicted due to the backwater effect from the Feather River (Figure 30). The magnitude of sediment deposition at the end of Year 1 increases to a maximum of approximately 4.5 m just upstream of the Feather River confluence due to backwater effect from the Feather River, and decreases in the downstream direction in the Feather River (Figure 29). The suspended sediment concentration stays high (exceeds 10,000 mg/l for an extended period of time) for approximately one year following lake level drawdown and may reach approximately 100,000 mg/l at its peak (Figure 31).
Figure 27. Simulated longitudinal profiles of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 1. Diagram is presented to provide a general view of sediment erosion and deposition. Details of the reach upstream of Englebright Dam are presented in Figure 28 and details of the reach downstream of Englebright Dam are presented in Figure 29. Note, Yuba-Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 28. Simulated erosion of Englebright Lake deposit during lake level drawdown and dam removal for Run 1. Note, the South Fork Yuba River enters the profile at approximately -10.5 km (the steeper, high elevation profile).
Figure 29. Simulated change in bed elevation in the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 1. Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 30. Simulated change in bed elevation at selected locations of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 1.

Note: Timbuctoo bend = 4 - 9 km
Figure 31. Simulated increase in daily-average suspended sediment concentration (above background) at selected locations of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 1.
Model runs for the Tunneling and Rapid Release Alternative using different combinations of hydrologic conditions during the dam removal process produced similar magnitude and patterns of sediment deposition and suspended sediment concentrations. Differences are primarily in the timing of the maximum sediment deposition and peak suspended sediment concentration (Figure 32 and Figure 33). Run 2, for example, started with a dry year (WY 1981) followed by a wet year (WY 1997) and an average year (WY 1989). Because of the low flow during the drawdown process for this run, Englebright Lake level remains low over the entire winter following opening of the tunnel (Figure 25), allowing the lake deposit to be eroded and released to the downstream reach more quickly than in Run 1, which started lake level drawdown in a wet year (WY 1997).

As a result, the duration of significant sediment deposition in the Timbuctoo Bend Reach for Run 2 extends for less than one year (Figure 32), which is shorter than that of Run 1 (Figure 30). Similar to Run 1, high suspended sediment concentration last for approximately one year for Run 2 (exceeds 10,000 mg/l for an extended period of time), with peak suspended sediment concentration higher than 100,000 mg/l and (Figure 33).

We have used the 2 January 1997 peak flow as a prototype to examine potential flood risks. Run 2 produces the highest sediment deposition in the Yuba River just upstream of the Feather River confluence at the time the event occurred, which can potentially increase flood risks to Marysville and Yuba City. A substantial amount (up to 10 m) of sediment is deposited just upstream of the Yuba/Feather River confluence (Figure 34) as a result of the backwater effect from the Feather River, which prevents sediment from being transported efficiently to the Feather River. Note that the predicted up to 10 m sediment deposition in the Yuba River just upstream of the Yuba/Feather River confluence occurs only if a large flood event such as that of 2 January 1997 occurs, which produces a significant backwater effect on the Yuba River (i.e., water surface in the Feather River is so high that it drowns the lower most reach of the Yuba River), resulting in lower shear stress within this backwater affected reach that encourages sediment deposition. The combination of sediment released from Englebrit Lake deposit quickly transports downstream due to the high flow event and reduced shear stress in the lower most reach of the Yuba River due to backwater effect from the Feather River produces the simulated large amount of sediment deposition presented in Figure 34. Large transitional sand deposits in the mouths of smaller rivers entering a larger river having a large range of water surface fluctuations are likely common even under natural conditions because of backwater effects. For example, we have observed a large sand dune (estimated to be taller than 2 m) deposited in Gordon Creek, a small tributary (< 45 km² catchment) of the Sandy River, Oregon just upstream of its confluence with the Sandy River during a field visit, which almost completely disappeared when we revisited the site a few months later. Sediment deposition such as shown in Figure 34 as a result of downstream backwater effect does not result in similar magnitude of water surface elevation increase, as demonstrated in Section 12.3 below with HEC-RAS water surface profile modeling.

Results of model runs with a smaller tunnel indicate that there is no apparent advantage to intentionally slowing down the release of the lake deposit in order to reduce the thickness of sediment deposition in the Yuba and Feather rivers. In Run 15, for example, a 2 × 2 m (6 × 6 ft) tunnel was used to drawdown Englebright Lake over a 10-year drawdown period. The prolonged drawdown in Run 15 produced magnitude and patterns of sediment deposition similar to those of a 3 × 3 m (10 × 10 ft) tunnel and a slightly longer period of increased suspended sediment concentration (Figure 35 and Figure 36). Model runs with a larger tunnel produced similar magnitude and deposition patterns and suspended sediment concentration compared to a 3 × 3 m (10 × 10 ft) tunnel (Figure 37 and Figure 38), suggesting that constructing a tunnel larger than 3 × 3 m (10 × 10 ft) is acceptable as long as it is not so large as to produce an undesired flood event
when it is initially opened. Another advantage of a larger outlet is that it allows woody debris buried in the lake deposit to pass through the dam more easily.
Figure 32. Simulated change in bed elevation at selected locations of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 2.
Figure 33. Simulated increase in daily-average suspended sediment concentration (above background) at selected locations of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 2.
Figure 34. Simulated bed profiles for Run 2 following Englebright Dam removal before and after 2 January 1997 flood event which occurred in the second year following Englebright Lake drawdown. Note, Yuba – Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 35. Simulated change in bed elevation at selected locations of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 15, 2 × 2 m (6 × 6 ft) tunnel, 10-year drawdown before dam removal.

Note: Timbuctoo bend = 4 - 9 km
Figure 36. Simulated increase in daily-average suspended sediment concentration (above background) at selected locations of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 15, 2 × 2 m (6 × 6 ft) tunnel, 10-year drawdown before dam removal.
Figure 37. Simulated change in bed elevation at selected locations of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 20, $3 \times 4.5$ m ($10 \times 15$ ft) tunnel, 6-month drawdown before dam removal.
Figure 38. Simulated increase in daily-average suspended sediment concentration (above background) at selected locations of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 20, 3 × 4.5 m (10 × 15 ft) tunnel, 6-month drawdown before dam removal.
10.2 Staged Removal Alternative

The inner boundary condition for the Staged Removal Alternative is established by assuming (a) daily average outflow is identical to that of the inflow into Englebright Lake; and (b) an Englebright Lake level that results in critical depth over the overflow section (i.e., notched section) of the dam, such that (Henderson 1966)

\[ q_w = \frac{2}{3} H \sqrt{\frac{2}{3} g H} \]  

(1)

In which \( q_w \) denotes discharge per unit width over the notched section of the dam; \( H \) denotes water depth over the notched section of the dam; and \( g \) denotes acceleration of gravity. Equation (1) provides the water surface elevation at the Englebright Dam site based on the discharge in the river for that day.

It is expected that sediment transport dynamics in the Yuba and Feather rivers for a Staged Removal Alternative is similar to that of Tunneling and Rapid Release Alternative if the dam was notched down quickly, such that the lake deposit can be released downstream over a similar duration as the Tunneling and Rapid Release Alternative. Because the Tunneling and Rapid Release Alternative is likely more economical to implement than a Staged Removal Alternative, notching the dam down quickly to produce similar results as Tunneling and Rapid Release Alternative is not expected to be desirable. As a result, we focused on notching the dam over a much longer duration for the Staged Removal Alternative in our modeling exercises to explore if it provides any advantages (such as decreased thickness of sediment deposition downstream of the dam) over the Tunneling and Rapid Release Alternative. We selected to notch the dam to the ground level in 10 steps over 10 years (one notch per year, but with varying depth of notching) in all our model runs for the Staged Removal Alternative. Notching the dam down to the ground level over a shorter period can be inferred from the results of the model runs (i.e., results will be between Tunneling and Rapid Release Alternative and the 10-year Staged Removal Alternative), and notching the dam down to the ground level in more than 10 years is likely not viable due to practical and economical concerns (i.e., cost of remobilization for deconstruction, and delayed establishment of fish passage).

A total of 5 runs (Runs 7 through 11) were conducted for a 10-year, 10-step staged removal, examining different depths of the initial notch and subsequent annual notching depth under different hydrological combinations (Appendix D). Modeling results indicate that overall sediment deposition thickness and patterns and suspended sediment concentration are less sensitive to combination of hydrological conditions unless results are compared on a year by year basis (i.e., results from one run in a particular year are likely similar to results from another run in a different year that has a similar hydrological condition, although results from both runs for the same year are likely not similar due to different hydrological conditions). Run 11, which notched the dam to an elevation of 110 m (360.9 ft) in the first year, followed by an additional 2.2 m (7.2 ft) each year in the next eight years and remove the remaining dam in the 10th year, seems to minimize the thickness of sediment deposition in the Feather River compared to runs with different notching rates. Results for Run 11 are presented in Figure 39, Figure 42, Figure 43, Figure 44, and Table 6 below.
Figure 39. Predicted longitudinal profiles in the Yuba and Feather rivers for Run 11 during a 10-year staged removal of Englebright Dam. Diagram provides a general view of sediment erosion and transport. Details of the evolution of lake deposit are presented in Figure 40, and details of the sediment deposition and erosion in the Feather River and part of the Yuba River downstream of Englebright Dam are presented in Figure 41. Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 40. Predicted evolution of Englebright Lake deposit for Run 11 during a 10-year staged removal of Englebright Dam.
Figure 41. Predicted longitudinal profiles in the Feather River and part of the Yuba River for Run 11 during a 10-year staged removal of Englebright Dam. Only a small amount of sediment deposition was simulated in the Yuba River between 0 and 26 km downstream of Englebright Dam (Figure 42). Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 42. Simulated change in bed elevation in the Yuba and Feather rivers for Run 11 during and after a 10-year staged removal of Englebright Dam. Note, Yuba-Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 43. Simulated change in bed elevation at selected locations of the Yuba and Feather rivers for Run 11 during and after a 10-year staged removal of Englebright Dam.
Figure 44. Simulated suspended sediment concentration at two locations in the Yuba River for Run 11 during a 10-year staged removal of Englebright Dam. (a) Immediately downstream of Englebright Dam; and (b) at Daguerre Point Dam. Diagrams are presented to show the general patterns of suspended sediment concentration. Statistics of the suspended sediment concentration are provided in Table 6.
Table 6. Number of days the increased daily average suspended sediment concentration is within various ranges for Run 11 during a 10-year staged removal of Englebright Dam.

<table>
<thead>
<tr>
<th>Increased daily average suspended sediment concentration (mg/l)</th>
<th>1,000 to 5,000</th>
<th>5,000 to 10,000</th>
<th>10,000 to 50,000</th>
<th>50,000 to 100,000</th>
<th>&gt; 100,000</th>
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<td>14</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Year 2</td>
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<td>1</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Year 3</td>
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<td>7</td>
<td>7</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Year 4</td>
<td>104</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>0</td>
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<td>Year 5</td>
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<td>0</td>
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<tr>
<td>Year 6</td>
<td>44</td>
<td>6</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Year 7</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Year 8</td>
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<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Year 9</td>
<td>29</td>
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<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Run 11 applied the same hydrological sequence as Run 2, and thus, a direct comparison of results between Runs 11 and 2 is valid to examine the relative advantages and disadvantages of the 10-year Staged Removal Alternative and the Tunneling and Rapid Release Alternative.

Comparison of sediment deposition for Runs 11 and 2 (Figure 43 vs. Figure 32) indicates that a 10-year Staged Removal Alternative has the following two advantages compared to the Tunneling and Rapid Release Alternative:

- Reduced sediment deposition in the Timbuctoo Bend Reach (4 – 9 km downstream of Englebright Dam);
- Reduced sediment deposition in the Yuba River a short distance upstream of its confluence with the Feather River.

Comparison of suspended sediment concentration for Runs 11 and 2 (Figure 44 vs. Figure 33) indicates that the 10-year Staged Removal Alternative produced high suspended sediment concentration (e.g., > 5,000 mg/l) almost every year, and multiple times in some years, during the 10-year period when the dam is progressively notched down (Figure 44). The simulated total number of days with increased daily suspended sediment concentration above 5,000 mg/l for year 2, 3, 4, 5, and 6, for example, are 6, 14, 5, 17, and 10, respectively, for the 10-year staged removal for Run 11 (Table 6). In comparison, the high suspended sediment concentration as a result of dam removal occurs only during the first year for the Tunneling and Rapid Release Alternative (Figure 33).

The duration to notch the dam to the base can be reduced to shorter than the examined 10 years. Using a shorter time period to notch the dam down to its base is not examined with the model as
discussed earlier. The outcome of a shorter time period to notch the dam down to its base, however, is a straight forward interpolation of the Tunneling and Rapid Release Alternative and the 10-year Staged Removal Alternative: the thickness of sediment deposition will be lower than the Tunneling and Rapid Release Alternative but higher than a 10-year Staged Removal Alternative; and the period for elevated suspended sediment concentration will be longer than the Tunneling and Rapid Release Alternative but shorter than a 10-year Staged Removal Alternative. Notching the dam down in more than a 10-year period is not examined because such an option is likely not viable due to practical concerns (e.g., increased cost for remobilization, and delayed establishment of fish passage) as mentioned earlier.

10.3 Effects of Variations of Engineering Details to Modeling Results

A dam removal preliminary design was ongoing at Gathard Engineering Consulting (GEC) during model development and scenarios examinations. As such, the assumptions used in the modeling presented in this report may differ somewhat from the engineering design. Such variations in engineering details do not affect the general results in terms of sediment deposition downstream of Englebright Dam and flooding risks, because impacts from sediment deposition persists for multiple years, and the largest sediment deposition that can potentially cause flood risk concerns does not occur until the second year following dam removal. What the variations in engineering details do affect significantly is the timing of high suspended sediment concentration: an early drawdown of the lake level will result in earlier high suspended sediment concentration, as expected. To demonstrate these points, we conducted Runs 1a, 2a, and 3a using identical hydrological conditions to Runs 1, 2 and 3, respectively, and assumed that lake level decreases from 160 m (525 ft) on 1 June to 143 m (470 ft) on 15 November prior to the opening of the 3 × 3 m (10 × 10 m) tunnel. Simulated change in bed elevation for Run 2a (Figure 45), for example, is very similar to that of Run 2 (Figure 32), but high turbidity events prior to November 15 for Run 2a (Figure 46) are not present for Run 2 (Figure 33).

In addition to the possible engineering details discussed above, there may be other variations in dam removal engineering (such as a rapid successive notching instead of opening the tunnel at the base of the dam). It is expected that sediment deposition patterns and associated flooding risks will be similar to those discussed above, assuming the dam is removed within a short period of time (i.e., within a year), while the timing of high turbidity events could change.
Figure 45. Simulated change in bed elevation at selected locations of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 2a.

Note: Timbutcoo bend = 4 - 9 km
Figure 46. Simulated increase in daily-average suspended sediment concentration (above background) at selected locations of the Yuba and Feather rivers following Englebright Lake drawdown and dam removal for Run 2a. The dashed line marks the day the tunnel at the base of the dam is opened (November 15).
11 MODELING PARTIAL REMOVAL (NOTCHING) OF ENGLEBRIGHT DAM

GEC (2013) considered two potential final elevation options for partial removal (notching) of Englebright Dam: a) notch to a crest elevation of 131.4 m (431 ft) and construct new outlet and penstock for power generation; and b) notching to a crest elevation of 140.2 m (460 ft) and using the existing intake and penstock for power generation. In both cases, a fish ladder will be constructed for fish to pass over the remaining portion of the dam (51 and 60 m [170 and 200 ft] tall, respectively).

Eighteen model runs (Runs 22 through 39) were conducted to examine effects of partial removal using the three typical hydrological scenarios previously described and assuming that the Englebright Lake drawdown begins on April 1, October 1, and July 1. In all cases the deconstruction work starts immediately following the lake level drawdown to form a 6-m (20-ft) deep and 9-m (30-ft) wide notch, with the notch deepening an additional 6-m (20-ft) every following week until it reaches the designed crest elevation. The notch will then be widened to the entire cross section of the dam.

Modeling results indicate that suspended sediment concentrations would increase downstream of Englebright Dam during lake drawdown but there would be no discernible sediment deposition downstream of the dam for either of the two notching scenarios (Figure 47; Table 7). The elevated suspended sediment concentration following lake level drawdown is generally limited to 2 to 6 months.

It should be noted, however, that the DREAM-1 modeling assumed that fine sediment particles (silt and clay) cannot be redeposited onto the channel bed once they are entrained in the water column. This is likely an accurate assumption under most dam removal scenarios. In case of a partial removal of Englebright Dam, however, the model may over-predict the magnitude of suspended concentration, especially during the early stages of lake level drawdown when there is still a considerable water depth just upstream of the dam, allowing resettling of fine sediment particles that can reduce the suspended sediment concentration downstream of the dam. As a result, the increased suspended sediment concentration predicted with DREAM-1 model (Table 7) can be viewed as a worst-case scenario.
Figure 47. Simulated Increase in suspended sediment concentration for Run 35 that started drawdown on April 1, notching the dam to an elevation of 131.4 m (431 ft). Simulation used discharge record of water year 1985 (a randomly selection) between April 1 and September 30, followed by water year 1989 (the average year).
Table 7. Simulated suspended sediment concentration for notching runs, providing number of days within the first two years following Englebright Lake drawdown with increased suspended sediment concentration within certain ranges.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Notching Elevation</th>
<th>Drawdown Date</th>
<th>WY prior to 1 October</th>
<th>WY after 1 October</th>
<th>Maximum Increase in Suspended Sediment Concentration (mg/l)</th>
<th>Number of Days Within a 2-year Period Following Drawdown</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt; 100,000 mg/l</td>
<td>50,000 to 100,000 mg/l</td>
</tr>
<tr>
<td>22</td>
<td>131.4 m (431 ft)</td>
<td>1-Oct</td>
<td>n/a</td>
<td>1997 (Wet)</td>
<td>164,400</td>
<td>2</td>
</tr>
<tr>
<td>23</td>
<td>131.4 m (431 ft)</td>
<td>1-Oct</td>
<td>n/a</td>
<td>1989 (Average)</td>
<td>388,200</td>
<td>8</td>
</tr>
<tr>
<td>24</td>
<td>131.4 m (431 ft)</td>
<td>1-Oct</td>
<td>n/a</td>
<td>1981 (Dry)</td>
<td>93,500</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>140.2 m (460 ft)</td>
<td>1-Oct</td>
<td>n/a</td>
<td>1997 (Wet)</td>
<td>164,400</td>
<td>2</td>
</tr>
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<td>7</td>
</tr>
<tr>
<td>27</td>
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<td>n/a</td>
<td>1981 (Dry)</td>
<td>93,500</td>
<td>0</td>
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<tr>
<td>28</td>
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<td>1-Jul</td>
<td>1985</td>
<td>1997 (Wet)</td>
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<td>1997 (Wet)</td>
<td>312,700</td>
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<td>1-Jul</td>
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<td>1981 (Dry)</td>
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<td>1985</td>
<td>1997 (Wet)</td>
<td>160,800</td>
<td>3</td>
</tr>
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12 EVALUATION OF POTENTIAL INCREASE IN FLOODING RISKS DUE TO FULL REMOVAL OF ENGLEBRIGHT DAM

There is minimal channel aggradation in the Yuba and Feather rivers for a full removal of Daguerre Point Dam and a partial removal (notching) of Englebright Dam. As a result, we focus evaluation of flooding risks on a full removal of Englebright Dam. First, we put the predicted channel aggradation into a historical context through examination of historical channel profiles. We then predict a future equilibrium profile of the Yuba and Feather rivers due to the reestablishment of sediment transport continuity at Englebright Dam after all the excessive sediment accumulated in Englebright Lake has passed through the study reach. Finally we model and compared the potential water surface profiles for the 2 January 1997 peak flow event occurring under various conditions, including: historical pre-Oroville conditions, current existing conditions, post-Englebright Dam removal when sediment deposition peaks in the Yuba River, post-Englebright Dam removal when sediment deposition peaks in the Feather River, and post-Englebright Dam removal when a new equilibrium profile is realized in the Yuba and Feather rivers following reestablishment of sediment transport continuity at the Englebright Dam site.

12.1 Historical Perspective

A full removal of Englebright Dam releases the sediment deposit accumulated in Englebright Lake to the Lower Yuba River, resulting in channel aggradation (both temporary, transitional channel aggradation while the sediment pulse from dam removal passes through the system and long-term persistent aggradation due to reestablishment of sediment continuity at the Englebright Dam site) in the Yuba and Feather rivers. Here we put the simulated channel aggradation due to dam removal into a historical context to help us better understand the potential increase in flood risks.

As discussed briefly in Section 2, the Feather River experienced 3 – 10 m of channel degradation between the mid-1920s and the mid-1960s as the sediment pulse produced by hydraulic mining dissipated through the system and transported downstream (Figure 5), and similar channel degradation had occurred in the Yuba River (Figure 4). Note that predicted sediment deposition due to Englebright Dam removal in the Yuba and Feather rivers exceeds 3 – 10 m only briefly and within a short reach, and thus, it can be expected that the flood risks following Englebright Dam removal will not be significantly worse than those during the pre-mid-1920’s and would last for at most a few years.

Oroville Dam on the Feather River has trapped large amounts of sediment since its closure in 1968, reducing sediment supply to the study reach. As a result, it can be expected that the bed of the Feather River would have been higher if Oroville Dam were not constructed. Similarly, the Yuba River profile would also have been higher because of the higher base level in the Feather River. We have simulated a longitudinal profile of the Yuba and Feather rivers under the hypothetical “no Oroville Dam” condition. This profile was generated by running DREAM-1 model under pre-Oroville Dam sediment supply and hydrological conditions.

An estimate of “no Oroville Dam” sand supply in the Feather River to the study reach is straightforward. Approximately 1.2 million t/yr of sediment accumulation occurs annually in Lake Oroville (Section 6). Assuming a sand to silt and clay ratio of 1:0.43 (Section 8), we estimate that sand supply from the Feather River to the study reach would have been approximately
840,000 t/yr higher if Oroville Dam were not constructed. That is, the long-term averaged sand supply in the Feather River to the study reach under the hypothetical “no Oroville Dam” conditions would have been 1,063,000 t/yr (840,000 t/yr plus the current supply rate of 223,000 t/yr, see Section 6 for details).

An estimate of daily discharge in the Feather River within the study reach under the “no Oroville Dam” conditions is provided in Appendix C.

A longitudinal profile under a “no Oroville Dam” condition is simulated by running DREAM-1 model for 150 years using the “no Oroville Dam” sediment supply and hydrologic conditions. The Feather River and the downstream-most 2 km of the Yuba River would have been approximately 2.5 m higher than the current bed levels under the hypothetical “no Oroville conditions” (i.e., if Oroville Dam was not constructed) (Figure 48 and Figure 49).

Reestablishment of sediment transport continuity at Englebright Dam (either through dam removal or after the current Englebright Lake, with or without notching to the dam, is full of sediment) would result in channel aggradation in the same reach (discussed in more detail in Section 12.2 below).

Model runs for the 3 \times 3 m (10 \times 10 ft) Tunneling and Rapid Release Alternative with the 2 January 1997 flood event occurring in different years following Englebright Lake drawdown are conducted to find the highest potential sediment deposition in the Yuba and Feather rivers during such a flood event, and the results for these runs are presented in Figure 34 (Run 2, with 2 January 1997 event occurring in the second year following Englebright Dam removal), Figure 50 (Run 17, with 2 January 1997 event occurring in the third year following Englebright Dam removal), Figure 51 (Run 18, with 2 January 1997 event occurring in the third year following Englebright Dam removal), and Figure 52 (Run 50, with 2 January 1997 event occurring in the tenth year following Englebright Dam removal). Results from these runs suggest that

- Following Englebright Lake drawdown and Englebright Dam removal, large amounts of channel aggradation (up to 10 m) could occur in the Yuba River downstream of Englebright Dam in a high flood event such as that of 2 January 1997, with the sediment deposit moving downstream as a sediment pulse, potentially increasing flooding risks associated with the event (e.g., Figure 34, Figure 50, Figure 51). Considering the locations of Marysville and Yuba City, sediment deposition in a 15-km long reach immediately upstream of the Feather River confluence (i.e., approximately between 25 km and 40 km downstream of Englebright Dam) is of primary concern for potential flood risk. This is examined in more detail with HEC-RAS modeling in Section 12.3 below.

- While sediment deposition could occur in the Feather River during a high flood event such as that of 2 January 1997 following Englebright Lake drawdown and Englebright Dam removal, the aggraded Feather River bed elevation does not exceed that for the “no Oroville Dam” condition (e.g., Figure 52).
Figure 48. DREAM-1 simulated longitudinal profiles for the current conditions, hypothetical "no Oroville Dam" condition, and future condition once sediment transport continuity is reestablished at the Englebright Dam. Results for upstream of 30 km are not presented because the three results series are equal and completely overlap. Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 49. DREAM-1 simulated deviation of bed elevation from the current condition for the hypothetical "no Oroville Dam" condition and future condition once sediment transport continuity is reestablished at the Englebright Dam. Results upstream of 30 km are not presented because their values are all very close to zero (i.e., no deviation from the current condition). Note, Yuba – Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 50. Simulated bed profiles for Run 17 following Englebright Dam removal before and after 2 January 1997 flood event that occurred in the third year following Englebright Lake drawdown. Note, Yuba– Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 51. Simulated bed profiles for Run 18 following Englebright Dam removal before and after 2 January 1997 flood event that occurred in the fourth year following Englebright Lake drawdown. Note Yuba – Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 52. Simulated bed profiles for Run 19 following Englebright Dam removal before and after 2 January 1997 flood event that occurred in the 10th year following Englebright Lake drawdown. Note, Yuba – Feather River confluence is located at approximately 40 km downstream of Englebright Dam.

* Differences between profiles prior to and after 2 January 1997 flood event are not discernible in this diagram.
12.2 Long-Term Implications

Below we examine the long-term implications of reestablishment of sediment transport continuity either due to Englebright Dam removal or a complete filling of Englebright Lake with sediment (either under the current dam height or after the dam is notched to a lower level). We then examine the potential water surface level during a 2 January 1997 flood event with the HEC-RAS model in Section 12.3.

Following reestablishment of sediment transport continuity at the Englebright Dam site, long-term persistent channel aggradation is expected to occur in the Feather River and in the Yuba River within a short reach immediately upstream of the Feather River confluence. A future equilibrium profile under these conditions was simulated by running the DREAM-1 model under conditions similar to that of the zero run presented in Section 8 except that the sand supply rate from the upper Yuba River is increased from 0 to the estimated 284,000 t/yr (the average of 276,000 and 292,000 t/yr, see Section 6 for details) that would result due to reestablishment of sediment continuity at Englebright Dam. DREAM-1 model was run for 150 years to obtain a future quasi-equilibrium profile following reestablishment of sediment transport continuity at Englebright Dam (Figure 48 and Figure 49). Results shown in Figure 48 and Figure 49 indicate that the reestablishment of sediment transport continuity at the Englebright Dam site (a) will not result in channel aggradation in the majority of the Yuba River; (b) will result in channel aggradation in the downstream most 6-km of the Yuba River and the Feather River within the study reach (i.e., Feather River between Yuba and Sacramento rivers’ confluences). Results shown in Figure 48 and Figure 49 also indicate the future elevated bed elevation due to reestablishment of sediment transport continuity will be approximately 2 m, which is lower than that of the hypothetical no Oroville Dam conditions, suggesting that future flood risks due to long-term persistent channel aggradation following Englebright Dam removal would be slightly higher than the current condition but lower than the pre-Oroville Dam years. Note that the 276,000 – 292,000 t/yr sand supply from the upper Yuba River watershed is likely to be an overestimate for present-day and future conditions (see Section 6 for discussions), and thus, the future profile following reestablishment of sediment transport continuity at Englebright Dam is likely to be slightly lower than predicted.

12.3 HEC-RAS Modeling of 2 January 1997 Event

As presented in Section 3, the peak discharges at USGS #11418000 (Yuba River below Englebright Dam near Smartsville, CA), USGS #11421000 (Yuba River nr Marysville, CA), and USGS #11407150 (Feather River near Gridley, CA) for the 2 January 1997 event was 4,360 m³/s (154,000 cfs), 4,600 m³/s (161,000 cfs), and 4,616 m³/s (163,000 cfs), respectively. Analysis conducted in Section 3 indicates that there was no flow in Sutter Bypass and minimal flow in Bear Creek on that particular date. As a result, the following peak discharges are used to represent the Yuba and Feather Rivers within the study reach to examine the 2 January 1997 event (Table 8).

A HEC-RAS model obtained from the Army Corps of Engineers (ACOE 2011) includes the entire Feather River basin with its downstream end set at the Sacramento River I-5 bridge approximately 9.5 river miles downstream of the Sacramento - Feather River confluence. For this study, a modeling of the entire Feather River basin is not necessary because the primary potential
dam removal project impact to flood levels is limited to the Yuba River downstream of Englebright Dam and the Feather River downstream of the Yuba River confluence. While water surface levels in the Feather River immediately upstream of the Yuba River confluence are likely to be affected by the water surface levels of the study reach, its impact can be inferred from the results within the study reach. Sacramento River will likely receive some sediment deposition, but the magnitude is expected to be small, and thus, its impact to Sacramento River water levels is expected to be small. As a result, we constructed a sub-model using the ACOE’s model that included the Yuba River downstream of Englebright Dam and the Feather River downstream of the Yuba River confluence. A 2-mile reach of the Feather River just upstream of Yuba River confluence is also included to set the discharge correctly within the study reach. The downstream boundary of the HEC-RAS model is set at the Feather River – Sacramento River confluence.

### Table 8. Peak flow discharge at different reaches used for HEC-RAS modeling for the 2 January 1997 event.

<table>
<thead>
<tr>
<th>Sub-reach within the study reach</th>
<th>Peak discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yuba River between Englebright Dam and Daguerre Point Dam</td>
<td>4,360 m³/s (154,000 cfs)</td>
</tr>
<tr>
<td>Yuba River downstream of Daguerre Point Dam</td>
<td>4,600 m³/s (161,000 cfs)</td>
</tr>
<tr>
<td>Feather River between Yuba and Sacramento River confluences</td>
<td>8,960 m³/s (315,000 cfs)</td>
</tr>
</tbody>
</table>

A total of six runs were conducted, Runs FE-1 through FE-6, where “FE” denotes flood evaluation corresponding to the 2 January 1997 peak flow event under different conditions (Table 9).

No flood evaluation runs were conducted for bed profiles under the Staged Removal Alternatives and Partial Removal Alternatives. Full removal of Englebright Dam under the Staged Removal Alternative produces a smaller magnitude of sediment deposition compared to the Tunneling and Rapid Release Alternatives, and negligible sediment deposition is predicted for the partial removal alternative. Thus, increased flooding risks would be smaller in those scenarios relative to the Tunneling and Rapid Release Alternatives evaluated with the HEC-RAS model below.

The DREAM-1 model simplifies channel cross sections into rectangles while the HEC-RAS model uses full topography cross sections. As a result, channel aggradation predicted by the DREAM-1 model was translated into an equivalent area of aggradation within the cross sectional topography. The translation is carried out by assuming that a channel cross section will elevate from bottom up until the decreased channel cross section area matches the area of channel aggradation predicted in DREAM-1 model, as demonstrated in Figure 53. Also note that the actual pattern of sediment deposition over a cross section is not typically uniform as we assumed, but how the sediment is truly distributed does not affect the HEC-RAS modeling results because it is also a 1-dimensional model.
Figure 53. Schematic sketch illustrating how the thickness of sediment deposition predicted with DREAM-1 is translated into aggradation within the HEC-RAS cross sections.

Table 9. List of flood evaluation runs and their corresponding bed profiles

<table>
<thead>
<tr>
<th>Flood evaluation runs</th>
<th>Bed profile for the flood evaluation run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run FE-1</td>
<td>Current condition</td>
</tr>
<tr>
<td>Run FE-2</td>
<td>DREAM-1 Run 2 simulated 2 January 1997 profile occurring in the second year following Englebright Dam removal, Tunneling and Rapid Release Alternative</td>
</tr>
<tr>
<td>Run FE-3</td>
<td>DREAM-1 Run 17 simulated 2 January 1997 profile occurring in the third year following Englebright Dam removal, Tunneling and Rapid Release Alternative</td>
</tr>
<tr>
<td>Run FE-4</td>
<td>DREAM-1 Run 18 simulated 2 January 1997 profile occurring in the fourth year following Englebright Dam removal, Tunneling and Rapid Release Alternative</td>
</tr>
<tr>
<td>Run FE-5</td>
<td>DREAM-1 Run 19 simulated 2 January 1997 profile occurring in the tenth year following Englebright Dam removal, Tunneling and Rapid Release Alternative</td>
</tr>
<tr>
<td>Run FE-6</td>
<td>DREAM-1 Run 21a simulated future longitudinal profile following reestablishment of sediment transport continuity at the Englebright Dam site.</td>
</tr>
</tbody>
</table>
According to the simulated water surface profile for 2 January 1997 peak flow event (HEC-RAS Run FE-2 that employed DREAM-1 Run 2 longitudinal profile), the primary increase in water surface elevation due to Englebright Dam removal occurs in a 13-km reach between 24 and 37 km downstream of Englebright Dam where water surface elevation increases by approximately 1.1 to 1.3 m (maximum 2.3 m at one model node) (Figure 54 and Figure 55). The levee in a 1.6-km reach approximately 27.8 to 29.4 km downstream of Englebright Dam that would not have been overtopped under the current conditions would be overtopped under the modeled Englebright Dam removal condition. In addition, the HEC-RAS model indicates that the water surface overtops the levee between approximately 57 km and 66 km downstream of Englebright Dam under both the current and post-dam removal conditions.

HEC-RAS Runs FE-3 and FE-4 produced similar results as Run FE-2 with slightly lower water surface elevations compared to Run FE-2 and are not presented here.

HEC-RAS Run FE-5, which employed the DREAM-1 Run 19 longitudinal profile, examines increases in water surface elevation due to sediment deposition in the Yuba and Feather rivers following Englebright Dam removal during a 2 January 1997 flood event after the majority of the Englebright Lake deposit has been transported out of the Yuba River and into the Feather River 10 years following lake level drawdown (Figure 56 and Figure 57). Results in Figure 56 and Figure 57 indicate that water surface elevation would increase by up to a maximum of 0.45 m in a 35-km reach between 27 and 62 km downstream of Englebright Dam in the Yuba and Feather Rivers. The increased water surface elevation does not result in overtopping of the levees between 27 and 52 km downstream of Englebright Dam. Between 52 to 62 km downstream of Englebright Dam, the water surface elevation under the current condition is already close to overtop the levees, and the increase in water surface due to sediment deposition will overtop the levees at four computational nodes (Figure 56b). Similar to early runs, water surface overtops the levees between approximately 57 km and 66 km downstream of Englebright Dam under both the current and post-dam-removal conditions.

HEC-RAS Run FE-6 examines the increased water surface in the Yuba and Feather River after the study reach reaches a quasi-equilibrium condition following Englebright Dam removal (Figure 60). Water surface elevation would increase by up to a maximum of 0.3 m in a 33-km reach between 29 and 62 km downstream of Englebright Dam in the Yuba and Feather rivers under a 2 January 1997 flood event, and for more than 50% of that reach the increase is 0.2 m or less. As discussed earlier, the water surface level following reestablishment of sediment transport continuity at Englebright Dam should still be lower than the case if Oroville Dam was not constructed on the Feather River.
Figure 54. HEC-RAS modeling results for Run FE-2, which used DREAM-1 Run 2 simulated longitudinal profile during the 2 January 1997 peak flow event, in comparison with the same event under the current condition (Run FE-1). (a). The entire study reach; and (b). The reach with increased flood risks on the Yuba River (25 to 37 km downstream of Englebright Dam). Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam.

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Figure 54 (continue). HEC-RAS modeling results for Run FE-2, which used DREAM-1 Run 2 simulated longitudinal profile during the 2 January 1997 peak flow event, in comparison with the same event under the current condition (Run FE-1). (a). The entire study reach; and (b). The reach with increased flood risks on the Yuba River (25 to 37 km downstream of Englebright Dam). Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 55. HEC-RAS simulated increase in water surface elevation during a 2 January 1997 event following Englebright Dam removal under the condition of DREAM-1 Run 2. Note, Yuba -Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 56. HEC-RAS modeling results for Run FE-5, which used DREAM-1 Run 19 simulated longitudinal profile during the 2 January 1997 peak flow event that occurred in the tenth year after Englebright Lake drawdown, in comparison with the same event under the current condition (Run FE-1). Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam. (a). All affected reach; and (b) 50 - 70 km downstream of Englebright Dam.
Figure 56 (continued). HEC-RAS modeling results for Run FE-5, which used DREAM-1 Run 19 simulated longitudinal profile during the 2 January 1997 peak flow event that occurred in the tenth year after Englebright Lake drawdown, in comparison with the same event under the current condition (Run FE-1). Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam. (a). All affected reach; and (b) 50 - 70 km downstream of Englebright Dam.
Figure 57. HEC-RAS simulated increase in water surface elevation during a 2 January 1997 event that occurred in the tenth year following Englebright Lake drawdown under the condition of DREAM-1 Run 19. This diagram is scaled to be identical to that of Figure 55 to facilitate comparison. Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 58. HEC-RAS simulated water surface elevation during a 2 January 1997 event following reestablishment of sediment transport continuity at the Englebright Dam site as predicted with DREAM-1 Run 21b. A larger scale plot is presented in Figure 59 to compare the water surface of this run with that under the current conditions. Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 59. HEC-RAS simulated water surface elevation between 26 and 66 km downstream of Englebright Dam during a 2 January 1997 event following reestablishment of sediment transport continuity at the Englebright Dam site as predicted with DREAM-1 Run 21b. Note, Yuba – Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
Figure 60. HEC-RAS simulated increase in water surface elevation during a 2 January 1997 event following reestablishment of sediment transport continuity at the Englebright Dam site as predicted with DREAM-1 Run 21b. The diagram is scaled identically to Figure 55 and Figure 57 to facilitate comparison. Note, Yuba - Feather River confluence is located at approximately 40 km downstream of Englebright Dam.
12.4 Risk Analysis

As discussed earlier, the 2 January 1997 flood was approximately a 50-year recurrence interval flow (0.02 exceedance probability) in the Yuba and Feather rivers. We believe this flow provides a reasonable, if not overly conservative, event for a flood risk analysis. Based on modeling results for full Englebright Dam removal, significant sediment deposition may cause additional flooding concerns in the Yuba River near the Feather River confluence and in the Feather River a short distance downstream of the Yuba River confluence for the first three years following Englebright Dam removal (Figure 54 and Figure 56). As a result, a three year period should be used to evaluate Yuba River flood risks. In the Feather River, sediment deposition would occur both due to the release of Englebright Lake deposit and the reestablishment of sediment transport continuity at the Englebright Dam following dam removal. DREAM-1 model results indicate that there would be a transient deposit that peaks approximately 2 to 5 years following dam removal as the sediment pulse passes through the reach, and long-term, persistent channel aggradation relative to current conditions due to the increased upstream sediment supply. Modeling results indicated that it takes less than eight years for the system to reach a state close to the new quasi-equilibrium condition (Figure 32, Figure 35, Figure 37, Figure 43, and Figure 45). As a result, an eight year period should be used to evaluate Feather River flood risks associated with the transient sediment deposit in the Feather River. The objective of this study is to evaluate the flood risks associated with the transient sediment deposition due to the release of Englebright Lake deposit following dam removal, primarily on a comparative basis with the current conditions. A flood risk evaluation due to long-term, persistent channel aggradation in the Feather River will need to consider the infrastructure conditions and current flood protection management programs, which is out of the scope of work of this study. Below we focus on the flood risks in the Yuba and Feather rivers due to the transient sediment deposit due to Englebright Dam removal.

The probability of a flood event with similar or higher magnitude than the 2 January 1997 flood event to occur within the study reach in the Yuba River over a three year period (i.e., only the first three years following Englebright Dam removal is of concern) is 0.059 [= 1 - (1 - 0.02)³]. Similarly, the probability of a flood event similar or higher than the 2 January 1997 flood event to occur within the study reach in the Feather River over an eight year period (i.e., only the first eight years following Englebright Dam removal is of concern) is 0.149 [= 1 - (1 - 0.02)⁸]. The risk associated with probabilities of 0.059 and 0.149 over the duration of the dam removal process is significantly lower than a 100-year design criterion for typical flood protection projects with a 100-year design life expectancy, which has a 0.643 probability for an event similar or higher than the designed flood event to occur during the life of the project (Table 10).

Elevating the levees 1.5 m in a 1.6-km reach (approximately 27.8 to 29.4 km downstream of Englebright Dam) of the Yuba River should bring the flooding risks associated with Englebright Dam removal down to approximately the current level based on modeling results conducted for this study. In addition, levees in a 10-km reach of the Feather River between 52 and 62 km downstream of Englebright Dam may have to be elevated up to 0.4 m if the adjacent land needs to be protected to the same level as the Yuba River reach along Marysville and Yuba City. Dredging a portion of the sediment prior to dam removal or divert sediment to the gold fields area may also reduce the amount of sediment deposition in various reaches, and thus, reducing the impact to flooding risks and spawning habitat. Engineering feasibility of these potential measures, however, are not investigated in this study.
### Table 10. Comparison of flooding risks associated with the Englebright Dam removal project with typical flood protection projects.

<table>
<thead>
<tr>
<th></th>
<th>Potential duration of impact</th>
<th>Exceedance Probability</th>
<th>Probability of a similar or higher event to Occur during intended protection period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yuba River during Englebright Dam removal (50-yr event)</td>
<td>3(^a)</td>
<td>0.02</td>
<td>0.059 = [1-(1-0.02)^3]</td>
</tr>
<tr>
<td>Feather River during Englebright Dam removal (50-yr event)</td>
<td>8(^b)</td>
<td>0.02</td>
<td>0.149 = [1-(1-0.02)^8]</td>
</tr>
<tr>
<td>A typical flood protection project, with consideration of 100-year recurrence flow and 100 years project life</td>
<td>100(^c)</td>
<td>0.01</td>
<td>0.634 = [1-(1-0.01)^{100}]</td>
</tr>
</tbody>
</table>

\(^a\) Three years is evaluated because significant sediment deposition can potentially occur within the reach where increased Yuba River water surface elevation poses the highest additional flooding risk within a three year period following Englebright Lake drawdown;

\(^b\) Eight years is evaluated because significant sediment deposition can potentially occur in the Feather River following Englebright Dam removal, and model results predict at most 8 years before the system reaches a new equilibrium;

\(^c\) Typical flood protection projects consider property protection for a 100-year period.

This study represents initial efforts into investigating sediment transport and potential flooding risks associated with potential removal or modification of Englebright Dam; additional studies will be needed prior to any decision making regarding the fate of Englebright Dam. Additional studies should include more model runs to explore if other possible hydrological combinations may result in higher water surface elevations than those used in Runs FE-2 and FE-5.
13 SUMMARY

We have examined the sediment transport dynamics and flooding risks associated with the potential removal or modification of Daguerre Point Dam and Englebright Dam on the Yuba River with DREAM-1, DREAM-2, and HEC-RAS models.

Examinations of a full removal of Daguerre Point Dam with the DREAM-2 model indicate that erosion of impoundment deposits would extend for approximately 3 km upstream of the dam while sediment deposition would be limited to within approximately 3 km downstream of the dam. Because of the limited extent and magnitude of sediment deposition following Daguerre Point Dam removal, increased flooding risk is not expected. Modeling results indicate that there is potentially a few thousand mg/l increase in daily-averaged suspended sediment concentration immediately downstream of Daguerre Point Dam that last for a day, which is approximately 6 times the maximum observed suspended sediment concentration during flood in the basin.

Two engineering alternatives were examined with the DREAM-1 model for a full removal of Englebright Dam: a Tunneling and Rapid Release Alternative that opens a tunnel at the base of the dam to drain the lake and release sediment prior to dam removal, and a Staged Removal Alternative that notches sections of the dam from the top in layers over a 10-year period.

Modeling results for the Tunneling and Rapid Release Alternative indicate that a tunnel of 3 m (10 ft) or larger would allow a quick drawdown of Englebright Lake (in about a week) and help to maintain a low lake level during winter high flow season to allow for efficient erosion of the sediment deposit upstream of the dam, thereby minimizing the period of high suspended sediment concentration to within approximately a one year period. A smaller-sized tunnel may extend the time needed to release the sediment deposit, resulting in the undesired effect of high suspended sediment concentration over multiple years without producing other benefits such as meaningfully reducing the thickness of sediment deposition downstream of the dam.

DREAM-1 and HEC-RAS modeling was conducted for the Tunneling and Rapid Release Alternative assuming that the tunnel would open on the 15th of November to start Englebright Lake drawdown. Stillwater Sciences (2008, 2009) recommended a similar reservoir draw down schedule for the proposed removal of four dams on the Klamath River so that the primary period of increased suspended sediment concentration would occur during the winter high flow season when suspended sediment concentrations are occasionally high under natural conditions.

DREAM-1 and HEC-RAS modeling results for the Tunneling and Rapid Release Alternative with a 3 m (10 ft) tunnel indicate that:

- Daily averaged suspended sediment concentration in the Yuba River would briefly increase by more than 100,000 mg/l multiple times and exceed 10,000 mg/l for an extended period of time over the first year following the opening of the tunnel but become similar to background conditions in the second year following tunnel opening.
- A substantial amount of sediment would be deposited in the Timbuctoo Bend Reach approximately 4 – 9 km downstream of Englebright Dam, starting a few months following Englebright Lake drawdown and dissipating in 1 to 2 years once the majority of the Englebright Lake deposit flushes downstream. The maximum deposition is
approximately 8 m near the upstream end of the reach, decreasing to approximately 5 m near the end of the reach. Sediment deposition in the reach lasts for a shorter duration in model scenarios where the drawdown occurs in a dry year as Englebright Lake can be kept at a level low, resulting in more efficient lake deposit erosion.

- A substantial amount of sediment (potentially up to 10 m thick at times under certain hydrologic conditions) would be deposited in the Yuba River a short distance upstream of the Feather River confluence, increasing the water surface level by approximately 1.1 to 1.3 m in a 13-km reach (24 – 37 km downstream of Englebright Dam) during a flood event of magnitude of the 2 January 1997 event (a 50-yr recurrence interval event). Approximately 1.6 km of the Yuba River levees (roughly between 27.8 and 29.4 km downstream of Englebright Dam) that would not be overtopped under the current conditions could be overtopped under the simulated Englebright Dam removal scenario unless they were raised by approximately 1.5 m.

- A substantial amount of sediment (up to 3.5 m thick at times) would be deposited in most of the Feather River, increasing water surface levels up to 0.45 m in a 35-km reach (27 – 62 km downstream of Englebright Dam) during a flood event similar to that of 2 January 1997. Levees in a 10-km reach (52 – 62 km downstream of Englebright Dam) that are predicted to overtop or be close to overtopping under existing conditions without dam removal could be overtopped in a flood similar to the January 1997 flood following Englebright Dam removal unless they were raised by approximately 0.5 m.

- The eventual reestablishment of sediment transport continuity at Englebright Dam following dam removal would result in long term persistent channel aggradation in the Feather River downstream of Yuba River confluence by approximately 2 m and increase water surface elevation during a 2 January 1997 flood event by up to a maximum of 0.3 m of a 33-km reach (less than 0.2 m for the majority of the reach) of the Feather River (29 – 62 km downstream of Englebright Dam). It is predicted that the aggradation following reestablishment of sediment transport continuity at the Englebright Dam site would not compensate for the degradation due to trapping of sediment behind the Oroville Dam.

DREAM-1 simulations of the Tunneling and Rapid Release Alternative with a $3 \times 4.5$ m ($10 \times 15$ ft) tunnel produced similar results as those for a $3 \times 3$ m ($10 \times 10$ ft) tunnel. We recommend using as large a tunnel [at minimum $3 \times 3$ m ($10 \times 10$ ft)] as practically possible (e.g., not so large as to create an undesired flood when the tunnel is opened) to draw Englebright Lake down quickly and to maintain a low lake level during winter high flow season as a measure to minimize the duration of high suspended sediment concentration.

DREAM-1 simulation indicates that a 10-year Staged Removal Alternative would significantly reduce the thickness of sediment deposited in the Yuba River, including the Timbuctoo Bend Reach (approximately 4 – 9 km downstream of Englebright Dam) and the reach immediately upstream of the Feather River confluence. The Staged Removal Alternative, however, does not reduce sediment deposition in the Feather River. It also creates a relatively high suspended sediment concentration (> 5,000 mg/l) almost every year over the 10-year period when the dam is being removed.
DREAM-1 simulations indicate that the partial removal alternative (notching) of Englebright Dam to 131.4 m (431 ft) or 140.2 (460 ft) elevation would increase suspended sediment concentration in the Yuba River over the short-term (within 2 to 6 months) but would not result in channel aggradation in the Yuba and Feather rivers.

To summarize, a removal or modification of Daguerre Point Dam would not result in flooding or biological concerns because it does not create long-lasting (i.e., more than a day) high suspended sediment concentration, nor would it result in widespread channel aggradation. Increased flooding risks associated with a full removal of Englebright Dam could be minimized by raising levees in some reaches, and taking other preventive or mitigation measures. These include a 1.6-km reach in the Yuba River where the levee may need to be raised by approximately 1.5 m, and a 10-km reach in the Feather River where the levee may need to be raised by up to 0.5 m. The Feather River channel longitudinal profile following dam removal would still be lower than the level if Oroville Dam had not been constructed.
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14 REFERENCES


California Department of Water Resources (CADWR) 2004a. Effects of project operations on geomorphic processes upstream of Oroville Dam, Oroville Facilities Relicensing, FERC Project No. 2100, Draft Final Report SP-G1, April.


Appendix A. Extension of Daily Discharge Record for Modeling Input

Daily discharge record at USGS 11425000 (Feather River near Nicolaus, CA) and USGS 11391050 (Sutter Bypass near Nicolaus) are needed as model input to represent discharge in different segments of the studied reaches. Both stations, however, terminated recording in the early 1980s. We extended the daily discharge record beyond the observed period of record using daily discharge records at other USGS stations as described below.

A.1 USGS 11425000 Feather River near Nicolaus, CA

The daily discharge record at USGS 11425000 between 1 October 1964 and 30 September 1983 is correlated with the daily discharge record at USGS 11407150 (Feather River near Gridley, CA), as shown in Figure 61, and a linear equation is used to extend the discharge record at USGS 11425000.

\[ Q_{\text{Feather at Nicolaus}} = 1.6855Q_{\text{Feather at Gridley}} + 227 \]  

(A-1)

![Figure 61. Correlation of daily average discharge between USGS 11425000 (Feather River near Nicolaus, CA) and USGS 11407150 (Feather River at Gridley, CA).]

Note that discharge unit is cfs in Equation (A-1).
A.2 USGS 11391050 Sutter Bypass near Nicolaus, CA

Daily discharge record at USGS 11391150 between 1 October 1959 and 31 March 1980 is correlated with the daily discharge record at USGS 11389500 (Sacramento River near Colusa, CA), as shown in Figure 62, and a fourth order polynomial equation is used to extend the discharge record at USGS 11391150.

\[
Q_{\text{Sutter at Nicolaus}} = \frac{8.02 \times 10^{-14} Q^4_{\text{Sacramento at Colusa}} - 3.7103 \times 10^{-9} Q^3_{\text{Sacramento at Colusa}} + 64.935 Q^2_{\text{Sacramento at Colusa}} - 8.02 \times 10^{-14} Q_{\text{Sacramento at Colusa}} + 986}{8.02 \times 10^{-14}} \tag{A-2}
\]

Figure 62. Correlation of daily average discharge between USGS 11391150 (Sutter Bypass near Nicolaus, CA) and USGS 11389500 (Feather River at Gridley, CA).

Note that discharge unit is cfs in Equation (A-2).
Appendix B. Englebright Lake Storage Curve and Lake level discharge capacity Curve with $3 \times 3 \text{ m (10} \times 10 \text{ ft)}$ tunnel at the base of the dam

Englebright Lake storage curve is calculated based on pre-Englebright Dam topographic data derived from digitized 1939 U.S. Army Corps of Engineers topographic map (Snyder et al. 2004b) and provided in Figure 63 below.

![Englebright Lake Storage Curve](image)

**Figure 63.** Englebright Lake storage capacity curve calculated based on pre-Englebright-Dam topographic data derived from digitized 1939 USGS topographic map (Snyder et al. 2004b).

The following outlets are available for flow to pass through Englebright following blasting open a $3 \times 3 \text{ m (10} \times 10 \text{ ft)}$ tunnel at the base of the dam:

- $3 \times 3 \text{ m (10} \times 10 \text{ ft)}$ tunnel with base elevation at 90 m. Discharge capacity of the tunnel is calculated assuming a discharge coefficient\(^3\) of 0.60 (e.g., Davis 1942).
- Narrows 1 penstock, with 20.7 m\(^3/\text{s}\) maximum capacity at normal Englebright Lake level (160 m), intake invert elevation at 137.2 m, and downstream water surface elevation at 86.9 m (rough estimate). Discharge for Narrows 1 is calculated assuming discharge is proportional to the square root of total head.

---

\(^3\) Defined as $Q_w/(A\sqrt{2gH})$, in which $Q_w$ denotes discharge through the tunnel; $A$ denotes tunnel area; $g$ denotes acceleration of gravity; and $H$ denotes water head (i.e., lake level minus downstream water surface elevation).
Narrows 2 penstock, with 96.3 m$^3$/s maximum capacity at normal Englebright Lake level (160 m), intake invert elevation at 133.8 m, and downstream water surface elevation at 88.4 m (rough estimate). Discharge for Narrows 2 is calculated assuming discharge is proportional to the square root of total head.

Overflow spillway with crest elevation at 160.6 m and overall width 137.2 m. Discharge over the spillway is calculated with a discharge coefficient$^4$ of 0.49 (converted from Equation 6-15 in Henderson 1966).

The lake level discharge curve for all the four outlets as calculated above is provided in Figure 64 below.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure64.png}
\caption{Englebright Lake level vs. discharge capacity through Englebright Dam following blasting open of a 3 $\times$ 3 m (10 $\times$ 10 ft) tunnel at the base of Englebright Dam.}
\end{figure}

$^4$ Defined as $q_w/(\sqrt{2gH})$, in which $q_w$ denotes discharge per unit width over the notched section; $g$ denotes acceleration of gravity; and $H$ denotes water head over the notched section (i.e., lake level minus crest elevation of the notched section).
Appendix C. Adjustment of Feather River Discharge data for Modeling of Pre-Oroville Dam Condition to Account for the Oroville Dam Construction

In order to simulate sediment transport dynamics under the hypothetical condition that Oroville Dam was never constructed, post-Oroville Dam discharge records in the Feather River need to be adjusted to account for the presence of Oroville Dam. This was accomplished in the following steps.

1. Developing pre-Oroville Dam period (10/1/1901 through 9/30/1967) and post-Oroville Dam period (10/1/1967 through 9/30/2011) flow duration curves based on daily discharge record at USGS 11407000 (Feather River at Oroville, CA) (Figure 65).

![Flow duration curves at USGS 11407000 (Feather River at Oroville, CA) for pre-Oroville Dam period (10/1/1901-9/30/1967) and post-Oroville Dam period (10/1/1967-9/30/2011).](image)

**Figure 65.** Flow duration curves at USGS 11407000 (Feather River at Oroville, CA) for pre-Oroville Dam period (10/1/1901-9/30/1967) and post-Oroville Dam period (10/1/1967-9/30/2011).

2. Establish pre-Oroville Dam and post-Oroville Dam discharge relation, assuming that a post-Oroville Dam discharge with a certain exceedance probability value would have had a pre-Oroville Dam discharge corresponding to the same exceedance probability, and from which the difference between pre- and post-Oroville Dam discharges is calculated. For example, pre- and post-Oroville Dam periods discharge corresponding to an exceedance probability of 0.5 are 81.3 and 17.5 m³/s, respectively, and from that, we establish that for a given date with a post-Oroville Dam period daily discharge of 17.5
m$^3$/s, the discharge in the Feather River in the study reach would have been 68.3 m$^3$/s (≈ 81.3-17.5 m$^3$/s) higher if Oroville Dam was not constructed. The relation between daily average discharge at USGS 11407000 and decreased discharge in the Feather River downstream of the Oroville Dam developed with this assumption is presented in Figure 66 below, which is used to adjust the discharge record in the Feather River for simulation of the sediment transport dynamics under the hypothetical “no Oroville Dam” scenario.

![Figure 66](image)

**Figure 66.** Relation between post-Oroville Dam daily average discharge at USGS 11407000 (m$^3$/s) and decreased daily average discharge in the Feather River downstream of Oroville Dam due to operation of Oroville Dam.

Note that the “no Oroville Dam” discharge generated with the approach above may not be completely correct if viewed as a time series because it is not a direct correlation of pre- and post-Oroville Dam discharge series, but cumulatively it should produce a good approximation of the correct flow duration curve under “no Oroville Dam” conditions. Because long-term sediment transport modeling does not depend closely on when different magnitude of flows occur but depend more on the cumulative durations of different magnitude of flows, the flow series generated with the above approach should provide sufficient model input for sediment transport modeling of “no Oroville Dam” conditions.
Appendix D. List of Sediment Transport Model Runs Conducted during this Study

Lists of DREAM-1 and DREAM-2 runs conducted during the study are provided in Table 11 and Table 12, respectively.

Table 11. List of DREAM-1 runs conducted during the study.

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Discharge for Input</th>
<th>General Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>n/a</td>
<td>Randomly combination</td>
<td>Zeroing process to simulate the current condition in the Yuba River and the Feather River, as presented in the report.</td>
</tr>
<tr>
<td>Seven preliminary runs not numbered</td>
<td>Varied</td>
<td>Experimental model runs to explore the potentially feasible Englebright Dam removal alternatives and to have an initial understanding of how to best examine the sediment transport dynamics with the model. Results of the preliminary runs are not presented in the report.</td>
</tr>
<tr>
<td>Run 1</td>
<td>W+D+A+Random Series</td>
<td>Examining sediment transport dynamics under different hydrologic combinations for Tunneling and Rapid Release Alternative for Englebright Dam removal with a 3 by 3 m (10 by 10 ft) outlet with one year drawdown before dam removal. Only selected runs are presented in the report.</td>
</tr>
<tr>
<td>Run 2</td>
<td>D+W+A+Random Series</td>
<td></td>
</tr>
<tr>
<td>Run 3</td>
<td>A+W+D+Random Series</td>
<td></td>
</tr>
<tr>
<td>Run 4</td>
<td>W+W+D+Random Series</td>
<td></td>
</tr>
<tr>
<td>Run 5</td>
<td>D+D+A+Random Series</td>
<td></td>
</tr>
<tr>
<td>Run 6</td>
<td>A+A+D+Random Series</td>
<td></td>
</tr>
<tr>
<td>Runs 1a, 2a, 3a</td>
<td>Identical to Runs 1, 2, and 3, respectively, except in engineering details that result in slightly different drawdown timing schedules.</td>
<td></td>
</tr>
<tr>
<td>Run 7</td>
<td>W+D+A+Random Series</td>
<td>Notch dam in 10 stages over a 10 year period. Initial stage remove to 120 m during the first year, followed by 3.3 m each year for the next 8 years, removal remaining structure in year 10.</td>
</tr>
<tr>
<td>Run 8</td>
<td>D+W+A+Random Series</td>
<td></td>
</tr>
<tr>
<td>Run 9</td>
<td>A+W+D+Random Series</td>
<td></td>
</tr>
<tr>
<td>Run 10</td>
<td>W+D+A+Random Series</td>
<td>Notch dam in 10 stages over a 10 year period. Initial stage remove to 110 m during the first year, followed by 2.5 m each year for the next 8 years, removal remaining structure in year 10.</td>
</tr>
<tr>
<td>Run No.</td>
<td>Discharge for Input</td>
<td>General Description</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Run 11</td>
<td>W+D+A+Random Series</td>
<td>Notch dam in 10 stages over a 10 year period. Initial stage remove to 110 m during the first year, followed by 2.2 m each year for the next 8 years, removal remaining structure in year 10.</td>
</tr>
<tr>
<td>Run 12</td>
<td>D+A+W+Random Series</td>
<td>Examining sediment transport dynamics under different hydrologic combinations for Tunneling and Rapid Release Alternative for Englebright Dam removal with a 2.4 by 2.4 m (8 by 8 ft) outlet with two years drawdown before dam removal. Only selected runs are presented in the report.</td>
</tr>
<tr>
<td>Run 13</td>
<td>A+D+W+Random Series</td>
<td>Tunneling and Rapid Release Alternative for Englebright Dam removal with a 1.8 by 1.8 m (6 by 6 ft) outlet with 10 years drawdown before dam removal.</td>
</tr>
<tr>
<td>Run 14</td>
<td>A+W+W+Random Series</td>
<td>Tunneling and Rapid Release Alternative for Englebright Dam removal with a 1.5 by 1.5 m (5 by 5 ft) outlet with 10 years drawdown before dam removal. Modeling terminated in 200 weeks due to numerical instability.</td>
</tr>
<tr>
<td>Run 15</td>
<td>Wet year in the 10th year</td>
<td>More runs for 3 by 3 m (10 by 10 ft) outlet with one year drawdown before dam removal (i.e., extension of Runs 1 through 6) in an attempt to find the highest sediment deposition in different reaches of interest during the 2 December 1997 50-yr event.</td>
</tr>
<tr>
<td>Run 16</td>
<td>Wet year in the 11th year</td>
<td>Examining future quasi-equilibrium condition following reestablishment of sediment transport continuity at the Englebright Dam site.</td>
</tr>
<tr>
<td>Run 17</td>
<td>A+D+W+Random Series</td>
<td>Examining a hypothetical condition in case Oroville Dam was not constructed in the Feather River and with Englebright Dam in place, as presented in the report.</td>
</tr>
<tr>
<td>Run 20</td>
<td>D+W+A+Random Series</td>
<td>Examining a wet year in the 10th year</td>
</tr>
<tr>
<td>Run 21a</td>
<td>Randomly combination</td>
<td>Notching Englebright Dam to 431 ft in November.</td>
</tr>
<tr>
<td>Run 21b</td>
<td>Randomly combination</td>
<td>Notching Englebright Dam to 431 ft in November.</td>
</tr>
<tr>
<td>Run 22</td>
<td>Notch during a wet year</td>
<td>Notching Englebright Dam to 431 ft in November.</td>
</tr>
<tr>
<td>Run 23</td>
<td>Notch during an average year</td>
<td>Notching Englebright Dam to 431 ft in November.</td>
</tr>
<tr>
<td>Run 24</td>
<td>Notch during a dry year</td>
<td>Notching Englebright Dam to 431 ft in November.</td>
</tr>
<tr>
<td>Run No.</td>
<td>Discharge for Input(^a)</td>
<td>General Description</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Run 25</td>
<td>Notch during a wet year</td>
<td>Notching Englebright Dam to 460 ft in November.</td>
</tr>
<tr>
<td>Run 26</td>
<td>Notch during an average year</td>
<td></td>
</tr>
<tr>
<td>Run 27</td>
<td>Notch during a dry year</td>
<td></td>
</tr>
<tr>
<td>Run 28</td>
<td>Notch during a wet year</td>
<td>Notching Englebright Dam to 431 ft in July.</td>
</tr>
<tr>
<td>Run 29</td>
<td>Notch during an average year</td>
<td></td>
</tr>
<tr>
<td>Run 30</td>
<td>Notch during a dry year</td>
<td></td>
</tr>
<tr>
<td>Run 31</td>
<td>Notch during a wet year</td>
<td>Notching Englebright Dam to 460 ft in July.</td>
</tr>
<tr>
<td>Run 32</td>
<td>Notch during an average year</td>
<td></td>
</tr>
<tr>
<td>Run 33</td>
<td>Notch during a dry year</td>
<td></td>
</tr>
<tr>
<td>Run 34</td>
<td>Notch during a wet year</td>
<td>Notching Englebright Dam to 431 ft in April.</td>
</tr>
<tr>
<td>Run 35</td>
<td>Notch during an average year</td>
<td></td>
</tr>
<tr>
<td>Run 36</td>
<td>Notch during a dry year</td>
<td></td>
</tr>
<tr>
<td>Run 37</td>
<td>Notch during a wet year</td>
<td>Notching Englebright Dam to 460 ft in April.</td>
</tr>
<tr>
<td>Run 38</td>
<td>Notch during an average year</td>
<td></td>
</tr>
<tr>
<td>Run 39</td>
<td>Notch during a dry year</td>
<td></td>
</tr>
</tbody>
</table>

Total number of DREAM-1 runs: 48

\(a\) W = wet year (WY 1997); A = average year (WY 1989); D = dry year (WY 1981); and Random Series = year no. 4 through no. 15 listed in Table 3.
Table 12. List of DREAM-2 runs conducted during the study.

<table>
<thead>
<tr>
<th>Run no.</th>
<th>Discharge for Inputa</th>
<th>General Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>n/a</td>
<td>Random combination</td>
<td>Zeroing process to simulate the current condition in the Yuba River, as presented in the report.</td>
</tr>
<tr>
<td>Run DP-1</td>
<td>D+W+A+Random Series</td>
<td>Examining sediment transport dynamics under different hydrologic combinations for a full removal of Daguerre Point Dam, as presented in the report.</td>
</tr>
<tr>
<td>Run DP-2</td>
<td>A+W+D+Random Series</td>
<td></td>
</tr>
<tr>
<td>Run DP-3</td>
<td>W+D+A+Random Series</td>
<td></td>
</tr>
</tbody>
</table>

Total number of DREAM-2 runs: 4

a. W = wet year (WY 1997); A = average year (WY 1989); D = dry year (WY 1981); and Random Series = year no. 4 through no. 15 listed in Table 3.
Appendix E. Peer Review Comments and Author Responses

Dr. Noah Snyder, Associate Professor from the Department of Earth and Environmental Sciences, Boston College provided peer review to this report. Major comments from Dr. Snyder and our responses are summarized below. Minor comments and edits are incorporated into the final report without further documentation. Dr. Snyder’s original review comments are attached following the summary. We thank Dr. Snyder for his careful review and constructive comments.

Comment on Section 4 In several places (e.g. p.4), the report refers to the “very small fraction of gravel” stored in the reservoir. However, Snyder et al. (2004b) estimated that the reservoir contained ~20% gravel and coarser sediment (grain size > 2 mm in diameter). As discussed on p. 10-11 of that paper, the gravel content is a major source of uncertainty in the reservoir sediment grain size estimate because of the difficulty in sampling the coarse upstream deposit. This technical report uses grain size distributions of sand and gravel portions of representative samples from the top 1 m of reservoir sediment studied by Snyder et al. (2004a and 2004b) as model inputs. Judging by Figure 9b, this results in <10% of the deposit in the gravel size range. It may be worth considering whether a somewhat higher overall gravel fraction in Englebright Lake would influence the project findings with respect to timing, duration and magnitude of downstream aggradation.

Response We have made major revisions in Section 4 to address this comment, include: a) we acknowledged in the text that there are more gravel particles in the upper Englebright Lake deposit; b) we provided a discussion of how the additional gravel particles will be transported downstream; and c) we provided a discussion about why the transport of gravel from the upper Englebright Lake will have no negative impact to the Lower Yuba River.

Comment on Section 7 (a) The Dam Removal Express Assessment Models are excellent choices for this type of analysis. DREAM-1 focuses on sand-dominated impoundments, and DREAM-2 is for gravel impoundments. How does the gravel in the impoundment (e.g., Figure 9b and Snyder et al. 2004b) get treated in the DREAM-1 model? Is it transported with the sand, or does it remain in the impoundment? This is discussed a bit further in the context of the zeroing process (section 8), but it merits some further explanation in this section. (b) In section 7.2, how is the sediment supply in the Yuba River supply upstream of Englebright Dam (section 6) is apportioned between the mainstream and South Yuba forks in the model? Is this important?

Response (a) See our response to the previous comment above. (b) The partitioning of sediment supply from the Yuba and South Fork Yuba rivers has no effect on sediment transport modeling results as discussed below. In short-term modeling, the amount of sediment supply is negligibly small compared to the amount of sediment in the reservoir deposit, making the sediment supply unimportant. For long-term modeling as a result of reestablishing sediment continuity, all the dynamic geomorphic responses occur in the Feather River and the downstream most few kilometers of the Yuba River, making the specific upstream source of the sediment supply unimportant as long as the combined rate of sediment supply is estimated reasonably.

Comment on Section 10.1] These scenarios appear to be reasonable. The only question I have is whether the DREAM-2 would yield any important differences. Might DREAM-2 runs result
in more long-lived aggradation in the downstream locations than the sand-focused DREAM-1 runs?

[Response] Our response to the comment on Section 4 above answered this question.

[Comment on Section 12.1] The second paragraph in section 12.1 is somewhat confusing. First, the first sentence should refer to the Feather River, not the Yuba River. Second, it would be worth reminding the reader here of the studies of measuring channel degradation in the Yuba River channel downstream of Englebright Dam cited in section 2.

[Response] Revised as suggested.

[Comment on Section 12.2] It would be useful to see exactly the same suite of figures for Run 2 as are presented for Run 11.

[Response] We have considered the suggestion. The presentations for Run 11 are very similar to that of Run 2, except that the results are reported at different years following dam removal. This is necessary because duration of the impact from the two runs are quite different, making it very difficult to report the results in exactly the same style.

[Other notes] The reference of Cui et al. (2012) cited in the early draft and in Dr. Snyder’s review comments is now cited as Cui et al. (in press) in the final report.
Dr. Noah Snyder’s Review Comments

Peer review of Stillwater Sciences (2013). Modeling sediment transport dynamics and evaluating flooding risks in the Yuba and Feather rivers, California, following modifications to Englebright and Daguerre Point dams

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February 2013

INTRODUCTION

This review focuses on the question: do the methods and modeling approaches used by in this technical report by Stillwater Sciences provide a reasonable evaluation of sediment transport and flood risk after potential modification of the dams on the lower Yuba River? As I understand the context of the report, the Stillwater Sciences team conducted their analyses based on existing data, new data collection was beyond the scope of the project. Below I present my comments organized section by section, followed by a few specific comments and a summary statement.

COMMENTS

1. Introduction
   No specific comments; see the summary statement below.

2. Overview of geomorphic conditions...
   This section includes compilations of existing data on longitudinal profile changes in the lower Yuba and Feather rivers (Figures 2 and 4). These datasets are important because they are inputs to the sediment transport modeling. They are the best available in terms of quality control and assurance. The profiles of the Yuba River mainstem and South Fork within Englebright Lake may have changed somewhat since 2001 due to continued deposition in the reservoir, but I suspect this additional sediment would not have much effect on the model results.

3. Relevant hydrologic records...
   This section reviews hydrologic records, and identifies the flood event (1/2/1997) to be used for flood risk analyses, as well as representative wet, dry and average years to be used as model inputs (Table 3). These choices appear reasonable.

4. Impoundment deposits behind Englebright Dam
   In several places (e.g., p. 4), the report refers to the “very small fraction of gravel” stored in the reservoir. However, Snyder et al. (2004b) estimated that the reservoir contained ~20% gravel and coarser sediment (grains > 2 mm in diameter). As discussed on p. 10-11 of that paper, the gravel content is a major source of uncertainty in the reservoir sediment grain size estimate because of the difficulty in sampling the coarse upstream deposit. This technical report uses grain size distributions of the sand and gravel portions of representative samples from the top 1 m of reservoir sediment studied by Snyder et al. (2004a and 2004b) as model inputs. Judging by Figure 9b, this results in <10% of the deposit in the gravel size range.
It may be worth considering whether a somewhat higher overall gravel fraction in Englebright Lake would influence the project findings with respect to timing, duration and magnitude of downstream aggradation.

5. Impoundment deposits behind Daguerre Point Dam
   As discussed in the first paragraph of this section, Daguerre Point Dam impounds far less sediment than Englebright Dam, and the fact that the reservoir filled in about one year indicates that the quantity of sediment stored is not particularly significant to the lower Yuba River geomorphology. I note from Figure 11 that the Daguerre Point impoundment deposit is ~50% gravel. This high fraction of coarse sediment (compared to Englebright Lake) is unsurprising because the dam has much less influence on the river velocity.

6. Sediment supply to the study reach
   The first paragraph (and footnote) of this section includes a discussion of the likelihood that the long-term average sediment supply is an overestimate for several reasons, including time since hydraulic gold mining and construction of dams upstream. Snyder et al. (2006) present evidence for a ~25% drop in sediment deposition rate in the reservoir since 1970, and hypothesize similar reasons for the decline.

   The approach used to estimate sediment supply on the Feather River appears reasonable, based on existing data.

7. Dam removal express assessment models
   The Dam Removal Express Assessment Models are excellent choices for this type of analysis. DREAM-1 focuses on sand-dominated impoundments, and DREAM-2 is for gravel impoundments. How does the gravel in the impoundment (e.g., Figure 9b and Snyder et al., 2004b) get treated in the DREAM-1 model? Is it transported with the sand, or does it remain in the impoundment? This is discussed a bit further in the context of the zeroing process (section 8), but it merits some further explanation in this section.

   In section 7.2, how is the sediment supply in the Yuba River supply upstream of Englebright Dam (section 6) apportioned between the mainstem and South Yuba forks in the model? Is this important?

8. Zeroing processes
   The first paragraph of this section suggests that the DREAM-2 process was used for the Yuba River, but later in the section it apparent that both models were used. This could be clarified via minor revisions to the first paragraph.

   In the first full sentence on page 23 (“The sand to silt and clay ratio in Englebright Lake deposit is between 1:0.54 and 1:0.45 based on data provided in Childs et al. (2003) and Snyder et al. (2004b).”) it may be worth clarifying that these are the sand+gravel to silt+clay ratios.

9. Modeling Daguerre Point Dam full removal
   Given the small size of Daguerre Point Dam, the model findings that its removal has a modest effect on the Yuba River geomorphology are unsurprising.

10. Modeling full removal of Englebright Dam
    10.1 Tunneling and uncontrolled release
    This section investigates the effects of opening a tunnel at the base of Englebright Dam, with a full reservoir drawdown and sediment release. The report develops a reasonable set of scenarios for how this might occur, including considering the rate that the lake would empty, and the best date to do this based on the release of suspended sediment downstream. The scenarios depend quite a bit on the hydrology
after the tunneling happens, because during a wet year the lake would refill, minimizing downstream sediment flushing.

The report includes figures from model scenarios to illustrate the range of possible downstream responses. In this section, the Figures 23-27 show the effects of Run 1 (wet year after tunneling) and Figures 28-30 show Run 2 (dry year after tunneling). This approach serves to contrast the different scenarios. These scenarios suggest deposition of significant (>5 m deep), temporary (<10 years) sand deposits in several parts of the lower Yuba River after sediment release from Englebright Dam. This kind of response has been observed in other dam removal studies (e.g., Cui et al., 2012). In the last part of this section, the report considers the effects of a smaller tunnel opening, and reaches the conclusion that such a modification is probably not desirable.

These scenarios appear to be reasonable. The only question I have is whether the DREAM-2 would any yield important differences. Might DREAM-2 runs result in more long-lived aggradation in downstream locations than the sand-focused DREAM-1 runs?

10.2 Staged removal alternative
This section focuses on scenarios in which Englebright Dam is removed in 10 steps over 10 years, focusing on Run 11, which has a notching scenario that minimizes sand deposition in the Feather River. The comparison between Runs 2 and 11 discussed at the end of this section nicely encapsulates the pros and cons of the two dam-removal alternatives: tunneling yields more downstream deposition, while staged removal yields more prolonged high suspended sediment concentrations. These end members will give decision makers useful information about the two dam removal alternatives. It might be worth expanding this section able to better illustrate this comparison, including emphasizing that the timing of deposition is different between the two scenarios (later in Run 11). For example, it would be useful to see exactly the same suite of figures for Run 2 as are presented for Run 11 (Figures 35-40).

10.3 Effects of variations of engineering details...
No comments.

11. Modeling partial removal (notching) of Englebright Dam
This section focuses on scenarios where Englebright Dam is lowered, but not removed completely. It is reasonable to assume that lowering the dam crest to 131-140 m elevation would result in little transport of impounded sand and gravel downstream of the dam, because this dam height leaves sufficient space to store most of the impounded sediment.

12. Evaluation of potential increase in flooding risks...
12.1 Historical perspective
The main purpose of this section is to place the potential aggradation associated with Englebright Dam modifications in the context of ongoing degradation in the lower Yuba and Feather river channels due to the cessation of hydraulic mining and dam construction. The basic findings are that the amount of potential aggradation is less than the historical degradation, which appears to be a reasonable conclusion based on direct observations and modeling.

The second paragraph in section 12.1 is somewhat confusing. First, the first sentence should refer to the Feather River, not the Yuba River. Second, it would be worth reminding the reader here of the studies of measuring channel degradation in the Yuba River channel downstream of Englebright Dam cited in section 2.

12.2 Long-term implications
No comments.
12.3 HEC-RAS modeling of 2 January 1997 event
This section applies the DREAM-1 results to an existing HEC-RAS flood model for the study area developed by the US Army Corps of Engineers. HEC-RAS is the “industry standard” flood model. To apply the aggradation indicated by the various DREAM-1 runs used for the flood analysis, the authors distribute the modeled sediment into the more detailed HEC-RAS cross sections, as illustrated by Figure 49. This is a reasonable way to link these two models. Overall, the analysis presented in this section focuses on the uncontrolled release scenarios with maximum aggradation in the lower Yuba River. These are “worst-case” scenarios, which is prudent. The specific findings with respect to specific stretches of levees on the Yuba and Feather rivers will likely warrant further analysis, particularly if the recommendation to raise the levees goes forward.

12.4 Risk analysis
This section translates the model findings with respect to aggradation and subsequent flood enhancement to a formal risk assessment, and places it in context of a standard risk analysis for a 100-year project design. This analysis is necessarily simplified, and the section closes with a paragraph listing appropriate caveats and suggestions for further study.

13 Discussion and Conclusions
This section reviews the key findings of the project and makes a few recommendations that are justified by the model results presented. See the summary statement below.

MINOR GRAMMATICAL SUGGESTIONS
Note: I did not do an extensive review of the writing and grammar. Below are a few minor errors that I noticed.

p. 58: Third paragraph is missing a period at the end of the last sentence.

p. 61: In the third line of the first paragraph, “no” should be “on”.

p. 68: The colon at the end of the first paragraph in section 12.3 should be a period. In the last line on the page, “is” should be “are”.

p. 73: Where is the left levee in the second part of Figure 50?

p. 78: The right levee is not labeled in the Figure 55 legend.

p. 80: Extra period in the second paragraph of section 12.4.

Appendix B: The 1939 map mentioned in the first paragraph was from the U.S. Army Corps of Engineers, not the USGS.

Appendix D: Runs 1a-3a are not included in Table 11.

SUMMARY STATEMENT
This report uses the best available geomorphic, sedimentologic and hydrologic data as inputs to computer models to study the effects of modifications to the dams on the lower Yuba River. The sediment transport work uses DREAM-1 and DREAM-2, which are the state-of-the-art models for evaluating sediment transport after dam removal. As the report explains, these models have been used successfully to make
predictions in a variety of other settings. For example, a field test before, during and after the Marmot Dam removal in Oregon by Cui et al. (2012) demonstrated that the models performed reasonably well and, if anything, overestimated downstream aggradation in some reaches following dam removal. The Cui et al. (2012) manuscript includes an extensive “lessons learned” section that influenced the approaches used in this project. I am not aware of any comparable sediment transport models that combine the relative ease of application (not requiring more detailed hydrologic, hydraulic, geomorphic and/or sedimentologic surveys and calibrations) with DREAM’s history of field and laboratory testing. The flood risk analysis is based on an existing hydraulic model for the study area developed by the U.S. Army Corps of Engineers, and is therefore presumably well-tested by previous studies. The report’s focus on exploring the range of expected downstream responses to a range of dam modification scenarios, over a range of time horizons, is well justified because it presents a spectrum of possible responses, including likely worst cases in terms of aggradation and flood risk. The report appropriately mentions that these models cannot capture all possible responses, and that additional focused studies may be warranted in the future if plans for modification to the lower Yuba River dams go forward.

As detailed in the comments above on sections 4, 7, 8 and 11, the report would benefit from further justification of and explanation for the use of the sand-focused DREAM-1 for the Englebright Dam removal scenarios, given that the impoundment deposit is approximately 20% gravel (Snyder et al. 2004b). It appears that the report uses a grain-size distribution that likely underestimates the coarse fraction in the impoundment (Figure 9b), and therefore some attention should be given to whether this difference may be important in terms of the timing, magnitude and duration of downstream deposition. One possibility might be to add some runs using DREAM-2 to the Englebright Dam analysis (perhaps in a manner similar to that used by Cui et al., 2012), although this may be beyond the scope of the present project.

Overall, I find this report to be a well-presented first analysis of the sediment transport and flood risk implications of modifications to the lower Yuba River dams. My only substantial suggestion is related to the gravel stored in Englebright Lake described above. I also note that little attention is given to changes that can be expected to occur in the Yuba River within the present Englebright Lake after dam removal or lowering. This is beyond the scope of the project, but may be another aspect worth considering in the future. These caveats aside, this report presents a clear and reasonable guide for future decisions associated with Yuba River management, in particular by identifying ranges of possible responses and places where additional focused analyses may be necessary.