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Memorandum

Date:	3 August 2020
To:	Michael Bowen, California State Coastal Conservancy
From:	Jacob Krall, Project Engineer Rob Annear, Senior Principal Anju Wicke, Senior Principal
Subject:	Review of Conceptual Approach to Scott Dam Removal and Sediment Management Geosyntec Project Number: WR2851

INTRODUCTION

This memorandum reviews work by McBain Associates (McBain; 2020) and McBain and Princeton Hydro (2019) regarding sediment volume calculations, review of the dam removal literature, and applications to Scott Dam and Lake Pillsbury. Additional context and complexity was also incorporated from dam removal literature. This review focused on the methodology and conceptual aspects of the McBain work rather than the computations.

REVIEW OF CONCEPTUAL APPROACH TO SCOTT DAM REMOVAL AND SEDIMENT MANAGEMENT

Calculations of Trapped Sediment Volume

A review was conducted on calculations of sediment volumes trapped behind Scott Dam (McBain, 2020). Based on the analysis, two separate methods were used:

- Differencing between a 2015 Digital Terrain Model (DTM) provided to McBain by Pacific Gas and Electric Company (PG&E) and a 1922 DTM created from a 10-foot contour map. The differencing was conducted only within a boundary such that valley walls were not included in the calculation. McBain calculated a sediment volume of 22 million cubic yards using this method.
- Calculating the volume between the maximum water surface elevation (WSE) and the 1922 DTM sediment surface, then calculating the volume between the maximum WSE and the

2015 DTM, then finding the difference between the two values. McBain calculated a sediment volume of 20.5 million cubic yards using this method.

While back-up data files with calculations were not available, the methodology used by McBain appears sound. This would represent on average 218,000 to 234,000 cubic yards (cy) of deposition within Lake Pillsbury per year between 1921 and 2015. This compares with an estimated annual deposition of 328,000 cy between 1921 and 1959 based on a United States Geological Survey study (Porterfield and Dunnam, 1964). There is no evidence that flows (and thus sediment loads) were higher in the 1921 to 1959 period compared with the more recent decades. However, reduced trap efficiency over time as a reservoir fills with sediment is expected, so these values are not necessarily inconsistent, though there is some uncertainty with each of the volume estimates.

In addition to the two estimates described above, McBain calculated the volume difference between the 2015 and 1922 DTMs within the active channel as it appears on the 1922 contour map to estimate the volume of trapped sediments within the active channel. McBain estimated that there are 12 million cy of trapped sediments within the active channel as it was defined in 1922. This is a useful calculation that suggests approximately 55-59% of the sediment could be mobilized following dam removal (12 million cy compared with 20.5-22 million cy). However, as discussed in the next section, this should be thought of as a high-end estimate of the mobilization that is likely to occur after dam removal.

Dam Removal Literature And Implications for Scott Dam Removal

A key part of the McBain (2019) presentation is drawing lessons from past dam removals and evaluating lessons learned that can be applied to Scott Dam and Lake Pillsbury.

The presentation focuses on the width of the impoundment relative to the width of the channel and the depth of the trapped sediments. Other characteristics that have been shown to be important in determining the fate of trapped sediments following dam removals, including the cohesion of the trapped sediments, and the volume of trapped sediments relative to the sediment transport in a typical year, were not evaluated. The presentation specifically drew lessons from the dam removal as they apply to the mainstem Eel River, Salmon Creek and Rice Fork. Figure 1 shows a map of these tributaries from McBain (2019). Each tributary is discussed separately below.

Figure 1. Map of Lake Pillsbury showing tributaries. Taken from McBain (2019).

Eel River Mainstem

The Eel River mainstem is a wide impoundment with sediment depths much greater than the bankfull channel depth. The McBain presentation equates this scenario to the Glines Canyon Dam on the Elwha River in Washington State. The presentation notes that a significant percentage of the impounded sediments were mobilized downstream through a process where the channel downcuts into the trapped sediments and creates a wide meander belt through the former impoundment.

Rice Fork

The Rice Fork arm has a narrow, confined impoundment approximately equal in width to the channel. The McBain presentation draws lessons for this case from the Condit Dam on the White Salmon River in Washington State. The presentation says that these scenarios often transport 100% of their impounded sediments. Our understating is that approximately 70% of the impounded sediments were mobilized in the first year following the removal of the Condit Dam. Furthermore, there are cases where a narrow impoundment has had as low as 30% of its impounded sediments mobilized. So, while the Rice Fork does have a key characteristic—a narrow impoundment—that is consistent with rapid erosion of the majority of trapped sediments, it also has cohesive sediments (12.7% clay and 65.8% silt based on Geosyntec Consultants, Inc. [Geosyntec], 2020) and it is uncertain that a staged removal of the dam would yield to rapid full mobilization.

Salmon Creek/North Arm

Salmon Creek, part of the North Arm of Lake Pillsbury which also includes Squaw Valley Creek, is a wide impoundment relative to the channel and has shallow sediment depth. The McBain presentation draws lessons for this scenario from the removal of the Tannery Brook Dam in New Hampshire. In the case of Tannery Brook, most of the impounded sediment did not mobilize. This is consistent with the dam removal literature for this type of impoundment.

It is instructive to plot Eel River, Rice Fork, and Salmon Creek on several plots obtained from syntheses of dam removal literature. Figure 2 is a figure reproduced from Warrick et al. (2015) with lines indicating Eel River, Rice Fork, and Salmon Creek. The figure indicates that past phased removals have exported 10-40% of the impounded sediment (a). The second panel shows that the ratio of width of the deposit to width of the channel has been important in past removals (b), suggesting that 50-70% of the impounded sediment at the Rice Fork would be expected to be exported, compared with approximately 10% for the mainstem Eel River and approximately 10-20% for Salmon Creek/North Arm. The third panel (c) finds a relationship between the ratio of average bed slope to the width ratio plotted in (b) and the fraction eroded; this relationship would predict approximately 70% erosion efficiency for Rice Fork, 10-40% for the mainstem, and approximately 10% for Salmon Creek/North Arm. This compares with the estimated 55-59% estimated removal based on McBain (2020) and is consistent with the McBain work being an upper bound estimate on the post-removal erosion.

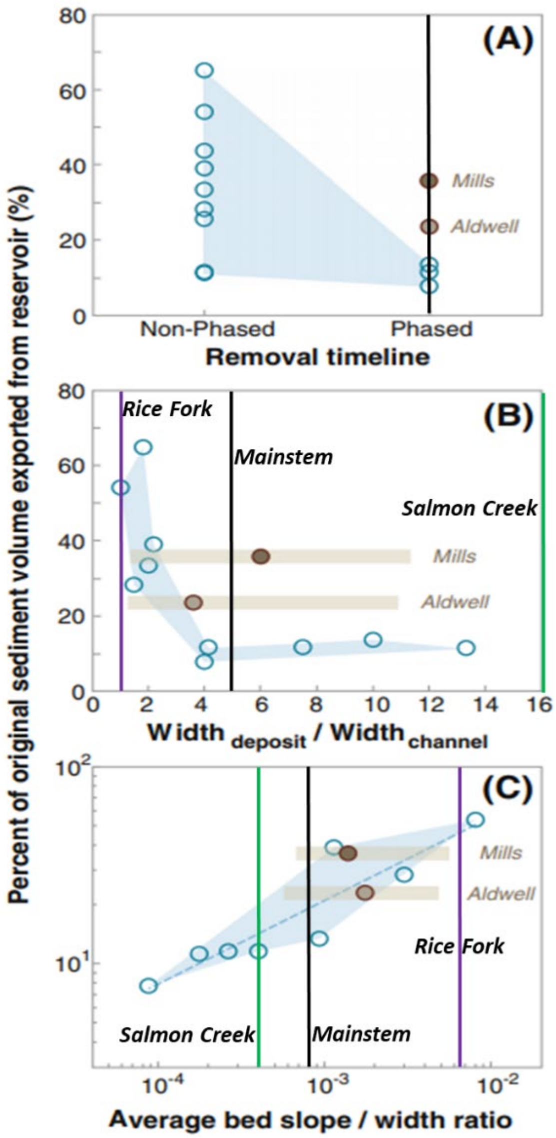

Figure 2. Modified from Warrick et al. (2015). Scatter plots of percent of sediment volume transported downstream as a function of removal timeline (phased or non-phased), ratio of impoundment width to channel width and ratio of bed slope to deposit/channel width. The y-axis represents erosion in the first two years for Mills and Aldwell (Glines Canyon and Elwha Dams, respectively) and longer-term erosion for the other dams.

Figure 3 shows another scatterplot comparing past dam removals, modified from Major et al. (2017). The x-axis represents the amount of sediment trapped behind the dam and the y-axis represents two different dimensionless ratios:

- V* is the ratio of reservoir sediment volume to estimated volume of sediment transported in a year (annual sediment load). For Scott Dam, the annual sediment load was estimated by taking the approximate annual sediment deposited per year, estimated to be 226,000 cy (the average of the two estimates calculated using the McBain volume estimates) and adjusting by assuming a 94% trap efficiency. A 94% trap efficiency is a reasonable estimate based on Porterfield and Dunnam (1964) but possibly too high since the amount of fine sediment passing by the dam is unknown. Using these two assumptions, the estimated annual sediment load is 240,000 cy per year. Dividing the average of the reservoir sediment volume estimates (21.2 million cy) by the estimated annual sediment load results in an estimated V* value of 88 for Scott Dam.
- E* is equal to V* multiplied by the fraction of reservoir sediment that is eroded during the first year following dam removal. Dotted lines are shown representing removal fractions of 10% and 60% and a black dot representing Scott Dam is shown at the average value of 35%: E*= V* x 0.35 = 88 x 0.35 = 31.

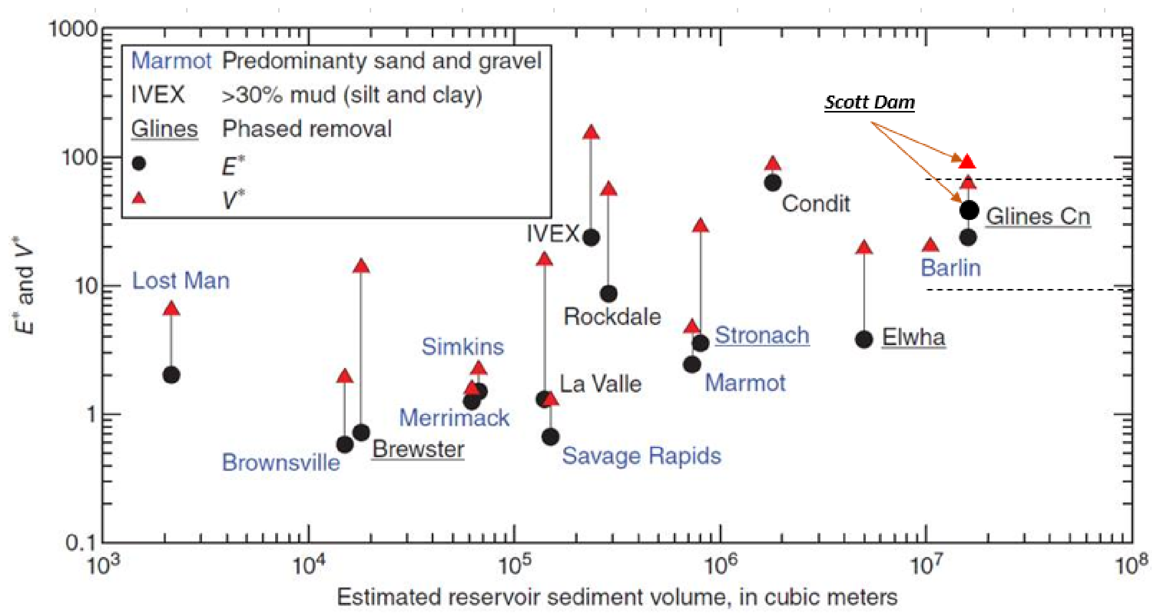

Figure 3. Modified from Major et al. (2017). Scatterplot of V* and E* (defined above) as a function of sediment volume stored in the reservoir.

Important observations from Figure 3 relevant to Scott Dam and Lake Pillsbury include:

- The higher estimate of sediment volume trapped behind Scott Dam (22 million cy or 16.8 million cubic meters) is higher than the estimated sediment volume for any dam removal in the Major et al. dataset, slightly higher than for the Glines Canyon Dam.
- For some past dam removals, e.g., the Condit Dam, E* and V* are relatively similar, meaning that a substantial percentage of the stored sediment is mobilized in the first year. However, for the two phased removals of dams with >30% silt and clay in the impoundment, E* is just 7% (Brewster) and 33% (Glines Canyon) of V*, meaning that much of the trapped sediment is not mobilized, at least in the first year.
- The two dashed black lines representing 10% and 60% removal of impounded sediment in the first year represent a range of 2.05 to 13.2 million cy of sediment transport in the first year when also considering the range of trapped sediment estimates from McBain.
- While there is substantial uncertainty regarding the fraction of the sediments that will be mobilized following dam removal, the high V* value means that there is a large amount of sediment stored behind the dam relative to the annual sediment load. This means that there is substantial potential for downstream impacts in the short-term and medium-term (e.g., turbidity increases, aggradation of the channel, etc.) Sediment transport modeling will be critical to understand the extent and implications of these downstream effects and the ability of a phased removal approach to mitigate these impacts.

EVALUATION OF POST-REMOVAL SEDIMENT STABILITY

The McBain (2019) presentation discusses work by EnviroAnalytics Group (EAG) (2018) which include natural channel development and sediment management. The McBain analysis concludes that the EAG sediment management approaches are infeasible because of:

- The large amounts of stored sediment in the reservoir and deep sediment depths.
- Lessons from past dam removals which show that sediment is readily mobilized following dam removal.

McBain (2019) concluded that the quantity of fine-grained sediment in a high-energy environment cannot be held back by sediment stabilization techniques. It is true that past dam removals have demonstrated that under some conditions, trapped reservoir sediments can be readily mobilized downstream and that stabilizing the trapped sediments in place using rocks, logs, weir, etc. is unlikely to be effective. Furthermore, the uncertainty regarding how the channel will move following dam removal would make design of the stabilization techniques difficult. However, the sediments stored in Lake Pillsbury are likely cohesive and consolidated based on the hard sediment that made it impossible to reach vibracore target depths as well as the high clay and silt content of the sediment core samples (Geosyntec, 2020). These characteristics are likely to make the sediments more resistant to mobilization. The channel profiles in McBain (2019) do not show evidence of sediment deposits near the angle of repose–only the Rice Fork shows a steep foreset slope, but its slope is approximately 2.3 degrees compared to typical angle of repose values for fine sediment of approximately 18-32 degrees depending on degree of consolidation. There is significant uncertainty regarding how much of the trapped sediment will be mobilized, and past dam removals show that a reasonable range of uncertainty is that 10-60% of the trapped sediment will be eroded in the first year after dam removal. Furthermore, mobilization is typically slower for staged removals. Thus, while there will be downcutting as a result of the lowered water surface elevation following dam removal, it is not clear that there will be rapid slope changes immediately following dam removal.

IMPLICATIONS OF THE DRAFT SEDIMENT INVESTIGATION REPORT

As part of the sediment investigation (Geosyntec, 2020), nine sediment core samples from Lake Pillsbury were analyzed for grain size. The samples were predominantly silt and clay, with six of nine samples having over 90% silt and clay and two other samples (PS-03 and PS-08) having over 78% silt and clay. Only one Lake Pillsbury sample, PS-07, was predominantly sand and gravel. This sample was collected in the upstream end of the mainstem Eel River reach, where coarser material is expected and consistent with reservoir sedimentation literature. A hard surface was encountered in sampling PS-03, PS-07 and PS-08, which likely indicates consolidation of previously deposited sediments. All samples except PS-07 were between 61% and 72% silt and between 13% and 31% clay and are classified as silt loam or silty clay loam according to the United States Department of Agriculture (USDA) soil taxonomy; PS-07 is classified as loamy sand (Soil Science Division Staff, 2017). Overall, the reservoir sediments are cohesive, which has been associated with slower and less complete erosion of trapped sediments (Major et al., 2017). As a result, given the relative lack of contamination and uncertainty regarding erosion of the deposit, strong consideration should be given to less costly sediment management options if supported by sediment transport modeling of both the mobilization of trapped sediments and impacts on the downstream river.

RECOMMENDATIONS FOR FURTHER ANALYSIS

There are several interim analyses that could be conducted prior to development of a full sediment transport model that could inform the magnitude of sediment that would be expected to mobilize following dam removal. Such analyses include:

- The potential for specified river flow events (e.g. the 2, 10, and 100-year flood events) to erode and transport the cohesive reservoir sediments could be evaluated for a range of assumed properties of the silt and clay sediments, such as critical shear stress and erosion rate.
- The critical shear stress and erodibility of the reservoir sediments could be measured using a technique such as Sedflume (McNeil et al., 1996). Such an analysis would support the sediment transport modeling as well as inform the design of slope stabilization strategies.

While analyses like those described would be informative interim steps, sediment transport modeling of the erosion of reservoir sediments under a range of flow conditions as well as the downstream impacts will be critical for understanding the impacts of dam removal on both the former impoundment and the river downstream of Lake Pillsbury. However, because of the highly site-specific nature of the dam, the range of reservoir responses to dam removal (Figure 3), and the uncertainty regarding the magnitude of river discharges that will occur following dam removal, some uncertainty regarding the magnitude of sediment that will be mobilized will remain.

SUMMARY

Updated sediment volume calculations provided by McBain (2020) appear reasonable and provide an accurate estimate of the volume of sediment stored behind Scott Dam. The Conceptual Approach for Scott Dam Decommissioning and Lake Pillsbury Sediment Management presentation given by McBain and Princeton Hydro (2019) includes a good discussion of the dam removal literature. However, overall, the McBain work underestimates the uncertainty associated with the erosion of impounded sediment that will occur in the first year following dam removal and likely overestimates the speed and magnitude of the erosion. The sediment investigation (Geosyntec, 2020) showed that the Lake Pillsbury sediments are primarily silt and clay, which is associated with slower and less complete mobilization of trapped sediments. Given the relative lack of contamination and uncertainty regarding erosion of the deposit, strong consideration should be given to less costly sediment management options if supported by further analysis, including sediment transport modeling of the downstream impacts.

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