MEMORANDUM

Date:	January 29, 2015
To:	Bill Harrell, Russ Stein, Cassandra Enos Department of Water Resources
From:	Lenny Grimaldo, Meghan Heintz, and Jennifer Pierre
Subject:	**Sediment Accounting Analysis**

Problem Statement

Multiple agencies (e.g., BCDC, Federal and State agencies) and other stakeholders involved with the BDCP have expressed (in written and verbal form) concern regarding the potential for sediment loading into the BDCP Plan Area and downstream of the Plan Area to decrease as a result of BDCP project operations and restoration activities. Additionally, there is concern that reductions in sediment loading as well as the potential settling of sediments in newly restored areas may adversely affect fish species that prefer turbid environments, such as delta and longfin smelt. Current analysis indicates that there would be a net decrease of 8-9% of sediment entering the Plan Area, as a result of operations of the north Delta diversions on the Sacramento River. The current analysis for fish effects in the Plan Area assumes a negative effect on delta and longfin smelt due to increased water clarity. The issue of sediment loading into the bays downstream of the Plan Area has not yet been addressed.

This memorandum presents a brief summary of the technical issues of greatest concern to state and federal agencies, and offers a proposal to resolve these issues.

Technical Issues

Most sediment entering the Plan Area does so from the Sacramento River and the proposed north Delta diversions are likely to decrease the total loading, potentially resulting in decreased turbidity. As described above, a reduction in turbidity in the Delta in response to reduced supply could have negative effects for covered fish. Additionally, marsh habitats require sediment and organic matter accumulation to achieve and maintain elevation. Restoration of tidal marsh and sea level rise will generate additional accommodation space, or sediment demand, in the Delta. Reductions in sediment flux from the Delta to San Francisco Bay could also reduce sediment supply to tidal salt marshes and mudflats downstream of the Plan Area.

Until now, a dynamic, full suspended sediment model was not readily available for the Delta. As noted in the Public Draft BDCP, a robust, dynamic model is required to take into account the many interacting factors that may influence water clarity and sediment transport and to reduce uncertainty regarding the potential effects of BDCP. Recently, a robust hydrodynamic-sediment transport model for the Delta was developed and successfully applied by DWR (Dennis McEwan, DES) to evaluate how regional sediment and turbidity patterns could vary in the Cache Slough Complex under different Prospect Island project alternatives (i.e., size of breach, location of breach). Although this model would be an ideal tool for investigating potential Plan effects on sediment trends within and downstream of the Plan area, the model run time for each scenario takes several months. Given the urgency to finalize the Plan, ICF developed an alternative yet defensible method for estimating Plan effects to sediment loading within and downstream of the Plan area.

Approach

The Effects Analysis Plan currently includes an estimate of sediment load to the Plan Area due to operations, but does not calculate the sediment reduction to the Bay associated with the sediment loss to existing marshes and CM4 restoration. Changes to the Delta sediment budget associated with Plan implementation that may affect downstream sediment delivery for the Late Long Term will include: 1) the ongoing sediment needed to maintain marsh elevations as sea-level rises, 2) sediment lost to entrainment at the North Delta Diversion (NDD), and 3) sediment that can be reused from the settling basin at the NDD. Calculations related to the amount of sediment diverted at the NDD have only been calculated for the Late Long Term period and thus this analysis only provides an estimate of the change in sediment supply to the bay for the Late Long Term period.

Commented [RMS1]: Used several different terms: the bay, the Bay, San Francisco Bay, and downstream of the plan area. Maybe pick one term and be consistent.

Bay and Delta sediment budget should be separate. Sediment budget to the Bay would be sediment delivery to the Delta minus the sediment lost in the Delta to marshes and entrainment - Meghan

Commented [RMS2]: Isn't there a need for sediment to achieve marsh elevation equilibrium and then sediment needed to maintain that equillibrium?
No that's a one time reduction -Meghan

The sediment to the Plan Area that will be delivered downstream to the Bay can be approximated as follows:

$$Sed_{Bay} = Sed_{Plan} - Sed_{NDD} + Sed_{Reuse} - Sed_{Marsh}$$

Where:

Sed_{Plan} = Annual Cumulative Suspended Sediment Load Available to the Plan Area (tons)

Sed_{NDD} = Annual Sediment Load Captured from NDD (tons)

Sed_{Reuse} = Annual Sediment that can be Reused after Settling in the NDD Settling Basin (tons)

Sed_{Marsh} = Annual Sediment Load Sunk into Marshes to Maintain Elevation as Sea Level Rises (tons)

Sed_{Bay} = Annual Sediment Load to the Bay (tons)

Annual Sediment Load Available to the Plan Area

The cumulative suspended sediment load available to the Plan Area was approximated for two scenarios: ESO_LLT (Evaluated Starting Operations, Late Long Term) and EBC2_LLT (Existing Biological Conditions, Late Long Term). This estimate was calculated from the CALSIM and DSM2 simulations and U.S. Geological Survey (USGS) sediment data (Figure 1). For further discussion of this methodology see Attachment 5C.D Water Clarity -Suspended Sediment Concentration and Turbidity of the 2013 Public Draft of the Bay Delta Conservation Plan.

Broadly, this analysis addresses changing water export locations, climate change and sea level rise, and changing salinity conditions. The annual cumulative sediment load available to the Plan Area for this calculation would be the sum of the cumulative suspended sediment load for EBC2_LLT or approximately 27,600,000 tons.

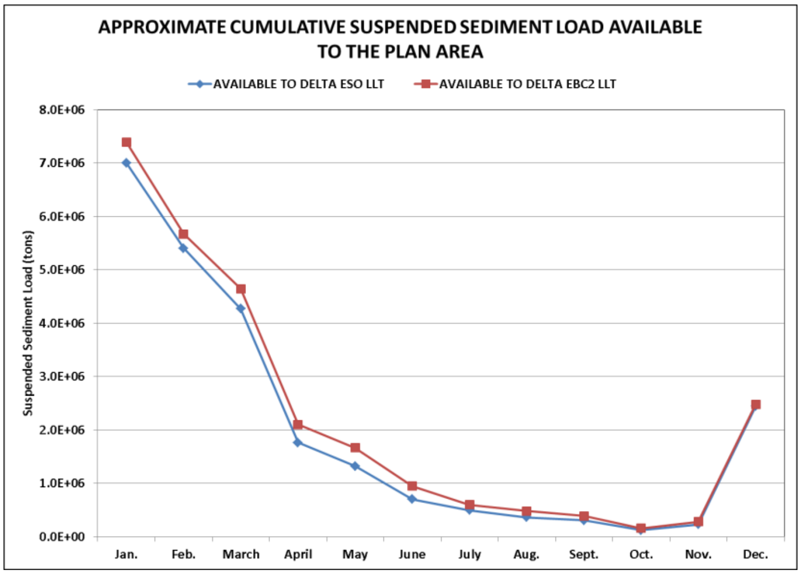

Figure 1: Comparison of Cumulative Suspended Sediment Load Available to the Plan Area in the EBC2_LLT and ESO_LLT Scenarios (RMA, 2013)

Annual Sediment Load Captured from NDD

As discussed above, the cumulative suspended sediment load available to the Plan Area was approximated for two scenarios: ESO_LLT (Evaluated Starting Operations, Late Long Term) and EBC2_LLT (Existing Biological Conditions, Late Long Term). The difference in cumulative suspended sediment load between these two scenarios is the amount of sediment that would be entrained in the North Delta Diversion or approximately 2,650,000 tons.

Annual Sediment that can be Reused after Settling in the NDD Settling Basin

Materials that can be reused after they have been settled from the water entrained at the NDD are assumed to be approximately 7-9% of the entrained sediment. Conservatively, this amount would be at 7%, 185,500 tons.

Annual Sediment Load Sunk into Marshes to Maintain Elevation as Sea Level Rises

This method proposes to calculate annual volume of sediment needed to maintain marsh elevation as sea level rises by modeling the vertical accretion of mineral and organic sediment across the area of marshes with and without CM4 restoration. Vertical accretion is approximating as the amount of suspended sediment that settles during each period of tidal inundation summed over the period of interest.

The marsh area with and without CM4 restoration across the period of interest was calculated by ESA using the Marsh98 model for the following scenarios, Existing Conditions, No Project Early Long-Term, No Project Late Long-Term, With Project Near Term, With Project Early Long-Term, and With Project Late Long-Term. The methodology and assumptions for this calculation are discussed in detail in Appendix 3.B: BDCP Tidal Habitat Evolution Assessment. Assessment of changing tidal area for each delta region throughout each of the six scenarios accounts for incremental accretion over the period of interest for 10 m x 10 m areas and their associated elevations calculated from corrected LiDAR data and accelerated, nonlinear sea level rise assumptions.

Commented [HM3]: Broadly the model we have recreates ESA's vertical accretion model (with some differences ie they used a singular ssc for an entire year) and the next step they took to calculate acreages was to discretize the area into 10x10m areas and run the vertical accretion model for each of those area. We also can do this but we would need to add one more layer of iteration to our model. This would be relatively simple to do. We also have the LiDAR elevation files for GIS. I extracted the elevations at this level for one of the tidal areas but stopped before doing the rest because it wasn't necessary for the analysis of these footprints. BUT if in the future we want to look at new hypothetical footprints we have the capability to put this together relatively quickly.

The vertical accretion model prepared by ICF estimates sediment deposition for each tidal inundation period over the period of interest (Existing Conditions or Near Term to Late Long-Term, 50 years). The amount of mineral sediment deposited at each period is a function of the length of time inundated, the depth of inundation over that period, the suspended sediment concentration, and the assumed sediment density and settling velocity; additionally there is an assumed 2 mm/year accretion rate of organic sediment consistent with historical records. Values for sediment density[1] and settling velocity[2] are based on estimated values from the Sacramento River (Bliss, 2004) (Ganju, 2005).

Commented [HM4]: I calculated a high, mid, and low estimate based on the settling velocity range but the sediment density estimates also very pretty significantly depending on which paper you're reading. We could pretty easily also run the model with a couple different density estimates to get another range. These are the two assumptions the model is most sensitive to.

The depth of inundation and the time inundated is calculated by comparing the water depth over the tidal period to the elevation of the marsh area at the timestep. The California Coast experiences mixed, semi-diurnal tides, meaning there are two unequal high tides and two unequal low tides during each day. For each region, an approximation of this cycle was calculated using a sine curve from the mean higher high water (MHHW), mean high water (MHW), mean low water (MLW), and mean lower low water (MLLW). The model compares depth of water at each hour of this cycle to the marsh elevation and determines the length of time inundation in hours and the depth in meters. The vertical accretion is a function ratio of the settling time by the period of inundation, the suspended sediment concentration (SSC), the depth of inundation and the density of the sediment (EQN 1).

Commented [RMS5]: Higher?

Commented [RMS6]: Lower?

The suspended sediment concentration fed into this model is the historical record from 2013 recorded at the USGS station below Freeport. The record from this year was used to account for the natural variation throughout the winter and summer months. SSC dramatically increases following winter storms and declines an order of magnitude during the drier summer months. The year 2013 was selected rather than the average of the historical record to retain the spikes in SSC concentration following storms and because as a dry year this provides a relatively conservative estimate of the concentration of sediment in the water column.

$$\frac{\left(\frac{Settling\ Time\ (hr)}{Inudation\ Time\ (hr)}\right)\left(SSC\frac{g}{m^3}\right)(Depth\ (m))}{Density\ \frac{m^3}{g}} = Depth\ Accreted(m) \qquad \text{(EQN 1)}$$

Commented [HM7]: This methodology is based on the concepts in this following paper But they don't explicitly write out this equation Suspended Sediment Fluxes in a Tidal Wetland: Measurement, Controlling Factors, and Error Analysis http://water.usgs.gov/fluxes/publications/ganju_et_al_bi.pdf

For each tidal period or time step, the depth accreted is added to the marsh elevation. At the next tidal period, the length of time inundated in hours and inundation depth are calculated with respect to the new marsh elevation. As the elevation increases, the length of time inundated in hours and inundation depth decrease and the amount of sediment accreted each time step declines as the marsh comes to equilibrium. This

[1]Sediment Density is assumed to be 2650 kg/m^3

[2] Settling velocities in the Sacramento River were estimated to be between 0.01 and 0.10 mm/s

sequence occurs 350 times per year[3] and at the end of each year the final marsh elevation is set as the initial elevation and the process repeats until the full period of interest has been iterated through. Accelerated sea level rise is incorporated into this process by adjusting the water depths of the tidal period according to the sea level rise curve estimated in the Bay Delta Conservation Plan (Figure 2, Table 1).

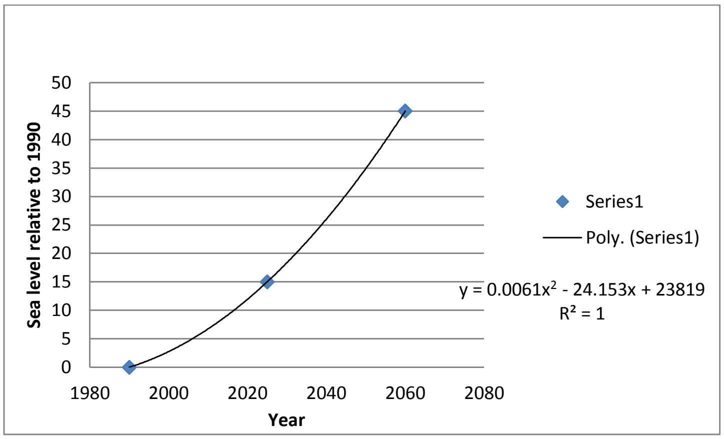

Figure 2. Calculated SLR curve for the Plan

Year	SLR cm	Rate of SLR cm/yr
1990	0	0.125
2025	15	0.552
2060	45	0.979

Table 1. Plan sea level and associated rate for existing conditions, ELT and LLT.

The annual sediment volume needed to maintain marsh elevation is calculated from the difference in marsh elevation at the beginning and end of the year multiplied by the acreage of the marsh area and divided by the assumed sediment density value. Because the elevation of the marsh varies throughout, the model repeats the calculations for the minimum and maximum elevations for each marsh region and averages the annual sediment volume from both simulations. The model was run using the hypothetical acreages with and without CM4 restoration and thus produces an estimate annual sediment volume with and without restoration.

One of the most sensitive parameters of this model is the assumed settling velocity of Sacramento River watershed sediment. A range of settling velocities in the Sacramento River was estimated by Neil K. Ganju and associates at the USGS to be between 0.01 and 0.10 mm/s. For the purposes of this model, a high, medium, and low estimate was produced using the average of this range and the 25th and 75th quartile values of this range.

Major assumptions of this model include:

[3] A full tidal period is 25 hours and thus there are 350 tidal periods in one year

- Suspended sediment concentration is uniform throughout that water column and throughout the marsh areas;
- Settling velocities are uniform throughout the marsh areas;
- Marsh bed elevations are evenly distributed between the maximum and minimum elevations.

Similar to the Marsh98 model, this model does not taken into account the influence of waves, which become more important as site size increases and availability of sediment diminishes. Furthermore, it does not distinguish between vegetation colonization for marsh areas with higher or lower salinity. Observations of accretion rates in delta marshes have shown that the type of vegetation (typical fresh or brackish marshes) affects the rate of sediment deposition (Kiwan, 2013).

Commented [RMS8]: Citation?

Results of the model are shown below in tables 2 and 3 with and without CM4 restoration.

	Annual Sediment Mass (tons)		
ROA	High	Mid	Low
Cache Slough	92,923	78,251	57,138
North Delta	26,580	24,195	17,565
Western Delta	114,112	100,009	74,219
Suisun High Marsh	3,248	2,897	2,310
Suisun Mid Marsh	35,677	31,686	24,421
Suisun Low Marsh	95,345	80,720	60,196
Suisun Bay High Marsh	180	161	129
Suisun Bay Mid Marsh	2,277	2,039	1,573
Suisun Bay Low Marsh	21,825	18,861	14,074
South Delta	50,751	45,835	36,487
Sum	442,919	384,653	288,112

Commented [RMS9]: Maybe say Without Tidal Natural Community Restoration (CM4).

Commented [RMS10]: The high, medium, and low columns are for settling velocities, right? Should be labeled to make that more clear.

	Annual Sediment Mass (tons)		
ROA	High	Mid	Low
Cache Slough	261,708	220,387	160,923

North Delta	18,074	16,453	11,944
Western Delta	163,717	143,483	106,482
Suisun High Marsh	4,241	3,782	3,016
Suisun Mid Marsh	36,473	32,392	24,965
Suisun Low Marsh	151,244	128,044	95,489
Suisun Bay High Marsh	180	161	129
Suisun Bay Mid Marsh	5,123	4,588	3,539
Suisun Bay Low Marsh	15,797	13,652	10,187
South Delta	154,401	139,444	111,007
Sum	810,959	702,386	527,681

Results

The results of this analysis apply equation 1 using values of the parameters discussed above for LLT. Table 4 shows the estimates sediment supply available to the Bay from with and without the North Delta Diversion (NDD) and with and without CM4 restoration for the high, mid and low estimates of marsh sediment requirements.

From these estimates, changes in sediment available to the Bay are shown with the NDD and CM4 restoration (BDCP implementation) in comparison to no NDD and no CM4 restoration (no implementation of BDCP) (Table 5). Sediment load to the Bay is expected to decrease approximately 10.4-9.9% or 2,832,540 to 2,704,069 tons with BDCP implementation.

Changes in sediment available to the Bay with the NDD and with and without CM4 restoration are shown in Table 5. With NDD, sediment load to the Bay is anticipated to decrease 1.0-1.5% or 368,040 to 239,569 tons with CM4 restoration.

Commented [RMS11]: The results presented in Tables 2 and 3? Or in Table 4?

Table 4: Sediment Supply to the Bay (with the North Delta Diversion (NDD) and without NDD and with CM4 (marsh restoration) and without CM4)

	With CM4			**Without CM4**		
	High	**Mid**	**Low**	**High**	**Mid**	**Low**
With NDD (tons)	24,324,541	24,433,114	24,607,819	24,692,581	24,750,847	24,847,388

Without NDD (tons)	26,789,041	26,897,614	27,072,319	27,157,081	27,215,347	27,311,888

Table 5: Change in Sediment Supply to the Bay with NDD and CM4 versus without NDD and without CM4

High	**Mid**	**Low**	
(2,832,540)	(2,782,233)	(2,704,069)	tons
-10.4%	-10.2%	-9.9%	%

Table 6: Change in Sediment Supply with NDD and CM4 Restoration versus with NDD and with no restoration

High	**Mid**	**Low**	
(368,040)	(317,733)	(239,569)	tons
-1.5%	-1.3%	-1.0%	%

Commented [RMS12]: Maybe consider making this number negative, it is a decrease in sediment delivery right?

Good point-meghan

Commented [RMS13]: Seems like these results suggest that there isn't much difference between with and without restoration? Am I reading the correctly? Does this mean that it's the NDD that is really driving the approximate 9% decrease in sediment delivery? That's a little surprising.

Commented [RMS14]: It seems a little strange to separate the tunnels from restoration as tunnels+restoration=BDCP but if you need to do this, perhaps change "with/without BDCP" to "with/without NDD" as that is how it's referenced above.

References

Deverel, Steven J., et al. "Impounded Marshes on Subsided Islands: Simulated Vertical Accretion, Processes, and Effects, Sacramento-San Joaquin Delta, CA USA." San Francisco Estuary and Watershed Science 12.2 (2014).

Drexler, J.Z., de Fontaine, C.S., and Thomas A. Brown. 2009. Peat accretion histories during the past 6,000 years in marshes of the Sacramento-San Joaquin Delta of California, USA. Estuaries and Coasts 32: 871-892.

Ganju, Neil K., Schoellhamer H. David, Bergamasch, Brian A. "Suspended Sediment Fluxes in a Tidal Wetland: Measurement, Controlling Factors and Error Analysis". Estuaries Vol. 28, No. 6, p 812-822 December 2005.

Kirwan, Matthew. "Tidal Wetland Stability in the face of human impacts and sea-level rise." Nature. Volume 504, December 5, 2013, pg 53-60.

McKee, Lester J., Neil K. Ganju, and David H. Schoellhamer. "Estimates of suspended sediment entering San Francisco Bay from the Sacramento and San Joaquin Delta, San Francisco Bay, California." Journal of Hydrology 323.1 (2006): 335-352.Schile, Lisa M., et al. "Modeling tidal marsh distribution with sea-level rise: Evaluating the role of vegetation, sediment, and upland habitat in marsh resiliency." PloS one 9.2 (2014): e88760.