



## TECHNICAL MEMORANDUM

DATE: June 3, 2014  
TO: Management Team, Matilija Dam Ecosystem Restoration Project  
FROM: Joel Monschke PE, Derek Booth PhD PE PG, and Yantao Cui PhD, Stillwater Sciences  
SUBJECT: Matilija Dam Removal, Sediment Transport, & Robles Diversion Mitigation Study  
WATERSHED AND IMPOUNDMENT-AREA SEDIMENT CHARACTERIZATION, Task 2.2

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### 1 INTRODUCTION

The purpose of this memo is to broadly characterize key locations and sources of sediment that may influence the selection of dam-removal scenarios, and that are anticipated to be the primary sources of sediment loads into the Ventura River without Matilija Dam in place. The discussion is divided into two sections, reflecting the scope of work for this subtask: the characterization of sediment presently stored behind the dam itself, and the ongoing, “natural” sediment load of the watershed that drains to Matilija Creek and the Ventura River. For the first component (reservoir sediment), the analyses and findings are based largely on previously published borehole data supplemented by topography and a field visit in March 2014. For the second component (watershed sediment yield), prior analogous studies of watershed sediment yields in various nearby watersheds in the western Transverse Ranges have been compiled and analyzed to characterize the likely rates, volumes, and episodicity of the watershed sediment load, formulated and presented to provide necessary input parameters for the sediment transport modeling of subsequent subtasks.

### 2 CHARACTERIZATION OF SEDIMENT BEHIND MATILIJA DAM

#### 2.1 Summary

In order to characterize and quantify the sediment stored behind the Matilija Dam, existing data and topography from 1947 and 2005 were reviewed and analyzed. Two different methods were used to characterize reservoir sediment: the first provides a general overview of the volumes of coarse- and fine-grained deposits behind the dam, while the second method more precisely subdivides the sediment into three size classes (gravel, sand, and silt/clay). Based on these analyses, there were approximately 6.9 million cubic yards of sediment stored behind the Matilija Dam as of 2005, comprising approximately 3.0 million cubic yards of silt and clay, 2.2 million cubic yards of sand, and 1.7 million cubic yards of gravel, cobble, and boulders. These volumes are consistent with the U.S. Bureau of Reclamation’s (BOR) estimate of 5.9 million cubic yards of stored sediment in 2000 (BOR, 2000). This difference in sediment volume is likely a consequence of additional sediment delivered into the reservoir between 2000 and 2005 (of which the likely majority would have been deposited during 2005 storm events). Using a straight-line

extrapolation from these data, we estimate that there is currently (2014) about 7.9M yd<sup>3</sup> of sediment stored behind the dam.

If further refinement of the sediment volume is ultimately needed, ground surveys could be conducted to field-check the LiDAR data and additional boreholes could be drilled to more accurately determine the pre-reservoir valley topography. In addition, a new aerial survey could be conducted that would accurately depict 2014 conditions. However, at this stage of the overall project the sediment volume calculations should be sufficiently accurate to determine the feasibility of conceptual restoration alternatives and to provide sediment modeling input data.

Following is a discussion of the steps taken to characterize the Matilija Reservoir sediments for this study.

## 2.2 Topographic Data

Total sediment volumes stored in Matilija Reservoir were calculated using AutoCAD Civil3D (CAD) by comparing two topographic data sets from 2005 and 1947. 2005 topography was based on the LiDAR-generated “upper\_matilija\_tin\_2005”. The LiDAR aerial survey was performed by Airborne1 in March 2005 (BOR, 2006; additional information on the LiDAR data included therein). The vertical datum for the LiDAR data is NAVD88 and the horizontal datum is NAD83 CA State Plane Zone 5. One-foot contour data were extracted from the GIS file and imported into CAD. The LiDAR data covering the area upstream of Matilija Dam, however, did not appear to be fully processed to determine a “bare earth” surface. In addition, data covering the area where reservoir water was present did not have accurate contours. Therefore, additional processing of the LiDAR data was completed to remove vegetation from the Matilija Reservoir “delta” area. Elevation data were also incorporated from borehole logs reported in the Geotechnical Report (USACE and BOR, 2004) to determine appropriate reservoir sediment levels wherever the impounded lake may have interfered with the LiDAR data collection.

1947 topography was based on the TIN surface titled “historic\_topography\_1947\_navd88”. This TIN was developed based on the CAD file provided by BOR with 5-foot contour intervals. The contours were based on a hard copy scan of pre-dam topography; although any such transcription is not likely to meet survey-quality standards, it is the best available pre-reservoir topography of the study area. The vertical and horizontal datums were re-projected from NGVD29 and NAD27 (in the original data file) to NAVD88 and NAD83, respectively.

The 1947 topography lacked accurate contours covering the stream reach immediately upstream of the dam for approximately 500 feet. The topography in this area was reconstructed using elevations at three locations: 1) the elevation at the dam, based on the 2005 LiDAR topography from the downstream channel; 2) the elevation approximately 330 feet upstream from the dam, based on the Borehole 15 “bottom of hole” elevation; and 3) the elevation approximately 500 feet upstream from the dam, tied into the existing 1006-foot elevation contour from the 1947 topography. The slopes were assumed to be constant between these three known locations and a channel width of 40 feet was used, based on upstream channel widths taken from the 1947 topography. The channel was generally reconstructed along the center of the valley. These reconstructed new contour lines, at 10-foot intervals, are shown on Figure 1.

Following these changes, a series of cross sections along the length of the reservoir were drawn in CAD to compare the 1947 and 2005 topography. From these sections, an appropriate boundary for the 1947 topography was determined that best tied in with the 2005 topography along the lateral extents of the reservoir. A cut/fill analysis was then performed in CAD to determine the elevation differences between

the 1947 and 2005 surfaces, thus defining the volume of the sediment wedge behind the Matilija Dam. The results of this analysis are also displayed on Figure 1 (page 8, below).

### 2.3 Sensitivity Analysis

The sediment volume calculations are not highly sensitive to the horizontal alignment between the 1947 and 2005 surfaces (i.e., as long as they are aligned within +/- 15 feet, calculated sediment volumes do not change by more than one percent). In addition, the minor reconstruction of topography immediately upstream of the dam led to an increase of only 20,000 cubic yards of stored sediment (0.3%). In contrast, the calculated sediment volumes were quite sensitive to vertical changes across large portions of the study area. Removing obvious vegetation from the LiDAR data and correcting for the reservoir sediment levels decreased the predicted sediment volumes by approximately 200,000 cubic yards (about 3%). Even more extreme, changing the vertical datum of the 1947 topography from NGVD29 to NAVD88 decreased the predicted sediment volume by approximately 500,000 cubic yards (about 7%). Further refinement of the sediment volume, if necessary, would require field-checking of the LiDAR data, additional boreholes, and/or a new aerial survey.

### 2.4 Borehole Analysis

Data from the borehole logs in the Geotechnical Report (USACE and BOR, 2004) were used to determine the elevation of the top of the sediment within the Matilija Reservoir and to double-check the elevation of the 1947 and 2005 topography. First, the borehole locations from USACE and BOR (2004) were digitized into CAD. Next, the elevations at the top and bottom of each borehole were compared to both the 2005 LiDAR and 1947 topography. Overall, there was very strong consistency between the borehole data and CAD surfaces: within +/- 1.5 feet at most borehole locations and no more than +/- 4 feet at a few outliers.

In addition to checking the surface elevations, the borehole logs were also used to characterize the grain-size distribution of the reservoir sediments themselves. First, a longitudinal profile was created in CAD that spanned the length of the Matilija Creek channel covered by the LiDAR data, drawn down the center of the valley and intersecting nearby borehole locations where feasible, but in all cases seeking to minimize the horizontal distance over which the borehole data would need to be projected onto the profile. The 1947 and 2005 ground surfaces were projected onto the profile in CAD (Figure 2; alignment shown on Figure 1).

The textural data from the boreholes were subdivided into two categories based on the narrative descriptions on the logs: 1) fine-grained sediments consisting of clay, silt, and sand; and 2) coarse-grained sediments consisting of gravel, cobble and boulders. The coarse-grained sediment deposits also included a fine-grained component, with sand and some silt filling the voids between larger particles. These data were projected onto the longitudinal profile (Figure 3), based on the location of the boreholes. The textural categories were manually digitized based on the elevations from the borehole logs. After all data were added to the profile, inferred contacts between predominantly fine and predominantly coarse sediment deposits were interpolated in the areas between boreholes.

In the northern portion of the “reservoir” area, three boreholes (04-01, 06-01, and 07-01) all terminated at less than 40’ depth (and thus spanned only about one-half of the total thickness of the accumulated sediments at the boring locations) because of methane gas. Based on the position in the sediment pile relative to the dam and the characteristics of the overlying and adjacent sediment, the underlying material is almost certainly dominated by clay, silt, and/or sandy silt, and it is so included in the calculated

volumes of “fine” sediment, recognizing that it must also include with sufficient organic material to generate appreciable methane. This material may pose an additional hazard for certain dam-removal alternatives, particularly those that involve mechanical excavation of reservoir sediment in this area.

**2.5 Determining Sediment Gradation and Volumes**

Two different approaches were used to calculate sediment volumes and size gradations in the Matilija Reservoir. The first approach utilized the sediment profile shown on Figure 3, which broadly distinguishes between coarse and fine deposits. The second approach utilized the reservoir sediment gradation table (Table 5.6, BOR, 2006) to more precisely define the sediment volumes within each of the three size classes (“gravel,” “sand,” and “silt/clay”) that may be required for future sediment modeling input data. The methodologies used for each approach are described below.

**2.5.1 Approach 1 - Determine volume of fine versus coarse sediment deposits**

The percentages of “fine” and “coarse” sediment, broadly distinguished, were determined using data from the Matilija Reservoir sediment profile (Figure 3). The two-dimensional fractions of fine sediments (i.e., silt, clay, and some associated sand) versus coarse sediments (i.e., gravel and coarser, plus an indeterminate amount of associated sand-sized sediment) were calculated in CAD, with a result of 34% coarse sediment and 66% fine sediment. These percentages were then applied to the total sediment volume of 6.8 million cubic yards, assuming that lateral variability of the grain-size distribution followed that of the centerline profile. This results in an estimate of approximately 2.3 million cubic yards of “coarse” sediment deposits and 4.5 million cubic yards of “fine” sediment deposits. There is no basis to presume uniform lateral variability, and it is likely that the marginal deposits are somewhat finer than those of the centerline reflecting greater dispersion of finer particles. Thus, the estimate of 4.5 million yards of fine sediment deposits is likely conservative (i.e., low) relative to the actual fine sediment volumes in the reservoir as of 2005, with a likely increase of 10-15% over the following nine years (see below).

**2.5.2 Approach 2 - Determine volume of gravel, sand, and silt/clay size classes**

To provide input data for the sediment modeling phase of the project, a second analysis was performed that divided reservoir sediments into three numerically defined size classes: 1) gravel [ $>2$  mm]; 2) sand [ $0.0625-2$  mm]; and 3) silt/clay [ $<0.0625$  mm]. The data source for this approach was Table 5.6 from BOR (2006), which was assembled using borehole data from USACE and BOR (2004). Based on this table, the percentages of each sediment gradation size class within the three reservoir sub-areas were determined (Table 1; see Figure 1 for longitudinal location of each sub-area). The data from Table 1 are also shown on the bottom of the sediment profile on Figure 3 to display the spatial context of sediment gradations.

**Table 1.** Sediment gradation percentages (determined from BOR 2006, Table 5.6).

<b>Sediment Deposit Sub-Area:</b>	<b>% Gravel (&gt;2 mm)</b>	<b>% Sand (0.0625–2 mm)</b>	<b>% Silt/Clay (&lt;0.0625 mm)</b>
<b>Reservoir</b>	0%	17%	83%
<b>Delta</b>	13%	54%	33%
<b>Upstream Channel</b>	78%	16%	6%

CAD was used to determine the overall sediment volume change of the deposits behind the dam; within each of the three sub-areas, we assumed the same distribution of sediment amongst the three sub-areas as reported in BOR (2006, Table 5.6) and their sediment-size percentages listed in Table 1. These results are tabulated in Table 2.

Table 2. Sediment gradation volumes.

Sediment Deposit Sub-Area	Total Volume Sediment (as of 2005)	Volume Gravel (>2 mm)	Volume Sand (0.0625 - 2 mm)	Volume Silt/Clay (<0.0625 mm)
	(all values in cubic yards)			
Reservoir	2,420,000*	0	410,000	2,010,000*
Delta	3,230,000	420,000	1,740,000	1,070,000
Upstream Channel	1,150,000	900,000	180,000	70,000
<b>Total Volume</b>	<b>6,800,000*</b>	<b>1,320,000</b>	<b>2,330,000</b>	<b>3,150,000*</b>
<b>Total Percent</b>	<b>100%</b>	<b>19%</b>	<b>35%</b>	<b>46%</b>

\*Inferred deposition of silt/clay in the Reservoir sub-area during the period 2002–2005 but not “seen” by the LiDAR or 2001 boreholes should raise these amounts by ~160,000 yd<sup>3</sup> (see below).

In summary, calculations indicate that sediments stored behind the Matilija Dam as of 2005 included 3.3 million cubic yards of silt and clay, 2.3 million cubic yards of sand, and 1.3 million cubic yards of gravel, cobbles, and boulders.

### 2.5.3 Reservoir Sub-Area Sediment Deposition between 2001 and 2005, and post-2005

The 2005 sediment volume within the Reservoir sub-area is likely higher than the volume determined through the analysis described above. This is due to the fact that borehole data from 2001 was used to supplement LiDAR data where reservoir water prevented LiDAR data collection. Thus, the volume calculations for the Reservoir sub-area (only) do not include deposition from 2005 storm events (or from any subsequent deposition), presumed to be overwhelmingly silt/clay. The following general analysis was used to estimate sediment deposition in the Reservoir sub-area between 2002 and 2005 to be consistent with the date of LiDAR data collection.

The Reservoir sub-area covers approximately 1.3 million square feet, so every foot of sediment deposition produces a volume increase of approximately 50,000 cubic yards. From Figure 5.11 in the 2006 BOR Report, sediment depths near the dam increased approximately 0.8 feet per year between 1986 and 1999, a period that had numerous high peak discharges. Applying this rate for the period of 2002 to 2005 (which also assumes constant trap efficiency) would produce an additional 3.2 feet of sediment depth and 160,000 cubic yards of additional fine sediment deposition in the Reservoir sub-area, increasing the total sediment volume by 2.4%.

There are no data available to directly calculate the volume of sediment presently (2014) behind Matilija Dam, but the variety and general consistency of prior measurements provide a remarkably consistent estimate. Using the estimates (both inferred and surveyed) from BOR (2006, Table 5.4), our calculation of 2005 volumes using topography differences (and post-2001 subaqueous sedimentation), and a straight-line extrapolation that appears warranted given the general regularity of the data (Figure 4), we estimate that approximately **7.9M yd<sup>3</sup> of sediment** is currently impounded behind Matilija Dam.

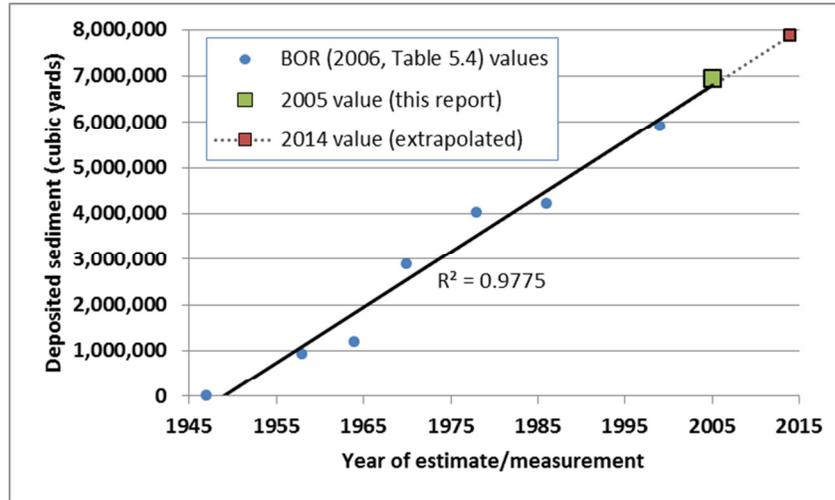


Figure 4. Historically inferred, measured, and extrapolated sediment volumes behind Matilija Dam (data sources as noted).

## 2.6 Bulk Density Calculation

According to BOR (2006), the Matilija Reservoir sediments have a computed average bulk density of 71 lb/ft<sup>3</sup> and a measured average bulk density of 73 lb/ft<sup>3</sup> (approximately 0.99 ton/yd<sup>3</sup>). Although not explicitly stated in BOR (2006), these bulk density values appear to apply to the “reservoir sub-area” and not the bulk density for all of the stored sediment behind the dam. BOR (2006) also stated that the bulk density of sand and gravel within the reservoir is 97 lb/ft<sup>3</sup> (1.3 tons/yd<sup>3</sup>), a value that is likely applicable to the upstream channel sub-area.

The bulk density values presented by BOR (2006) lie within the range of average reservoir sediment bulk densities from recent publications, including 60 lb/ft<sup>3</sup> (0.81 ton/yd<sup>3</sup>) (Miner and Kondolf, 2007) and 106 lb/ft<sup>3</sup> (1.43 ton/yd<sup>3</sup>) (Lavé and Burbank, 2004). In addition, these bulk densities also lie within the range of densities of reservoir-deposited sediments listed in ASCE Sediment Engineering Manual 54 for clay/silt mixtures, which range from 40 to 84 lb/ft<sup>3</sup> (0.53 to 1.14 ton/yd<sup>3</sup>); sand, ranging from 84 to 99 lb/ft<sup>3</sup> (1.14 to 1.34 ton/yd<sup>3</sup>); and poorly sorted sand and gravel, ranging from 94 to 129 lb/ft<sup>3</sup> (1.28 to 1.74 ton/yd<sup>3</sup>). Table 3 summarizes the estimated bulk densities in each of the three sub-areas, showing different density units for comparison with other studies. These values are primarily taken from BOR (2006), with densities inferred for the delta sub-area. If more precise bulk densities are subsequently required, additional field data collection and laboratory testing will be needed.

Table 3. Sediment bulk density by sub-area.

Sediment Deposit Sub-Area	Bulk Density (lbs/ft <sup>3</sup> )	Bulk Density (tons/yd <sup>3</sup> )	Bulk Density (tonnes/m <sup>3</sup> )
Reservoir	73	1.0	1.2
Delta	86	1.2	1.4
Upstream Channel	97	1.3	1.6

## **2.7 Upstream Sediment Wedge**

The longitudinal profile shown on Figure 2 suggests that additional sediment has been deposited between Stations 40+00 and 70+00, upstream from the historic extent of the reservoir. This region is not included in the sediment volume calculations presented above, but that sediment has likely been deposited in this reach as a result of downstream aggradation, which has lowered the gradient and reduced the creek's sediment transport capacity. Based on field observation of the surface deposits, the sediments within this area are likely coarse-grained throughout, with a total volume of 100,000 to 150,000 cubic yards based on simple geometric calculations. These sediments will have minimal implications for the preliminary period of sediment release but will likely lead to a modest increase in medium- to long-term coarse-grained sediment transport in Matilija Creek. As the main reservoir sediments are eroded and the downstream channel gradient is steepened, these upstream accreted sediments are likely to mobilize as well.

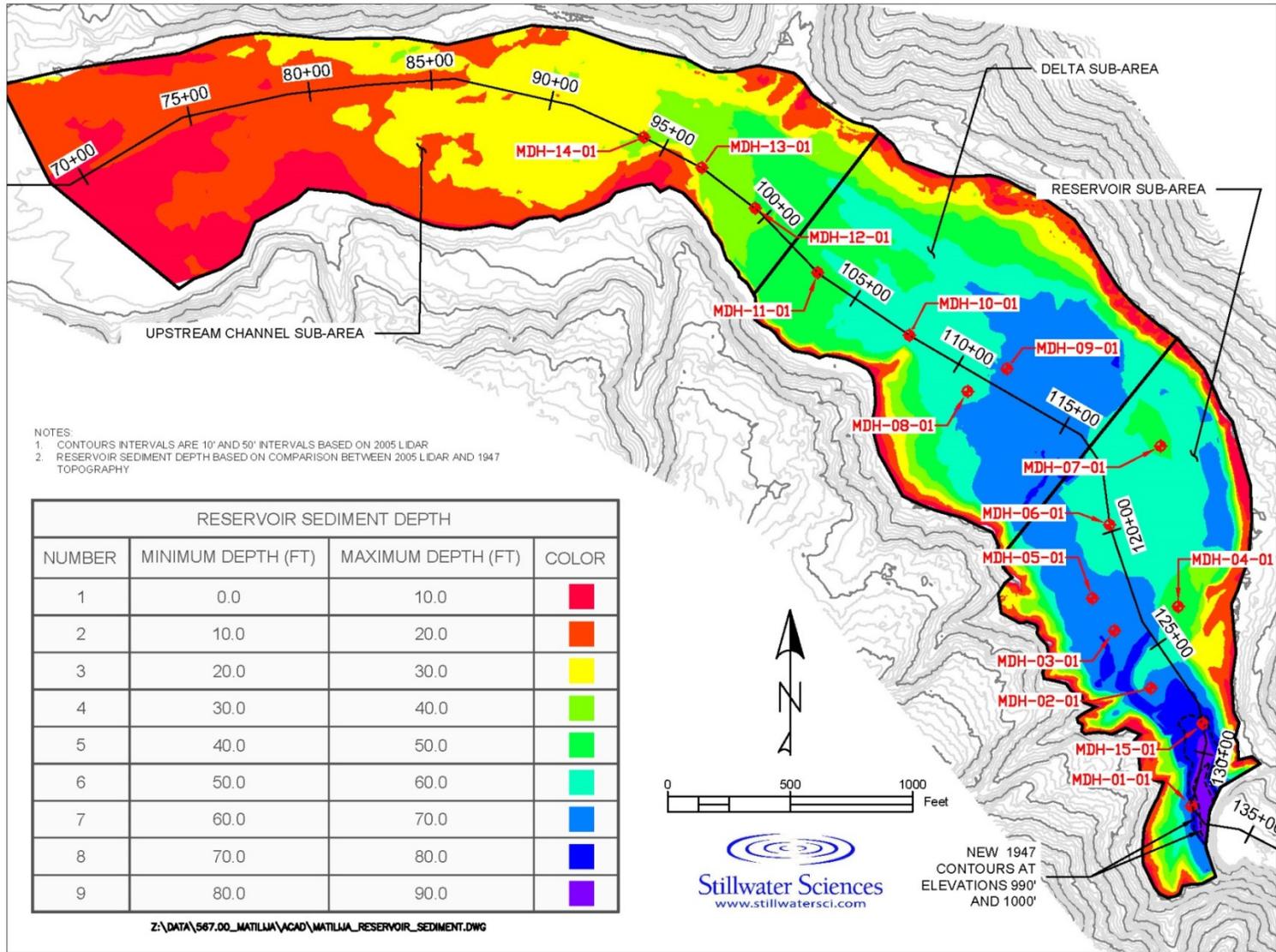


Figure 1. Plan view of Matilija Reservoir sediment deposits and borehole locations.

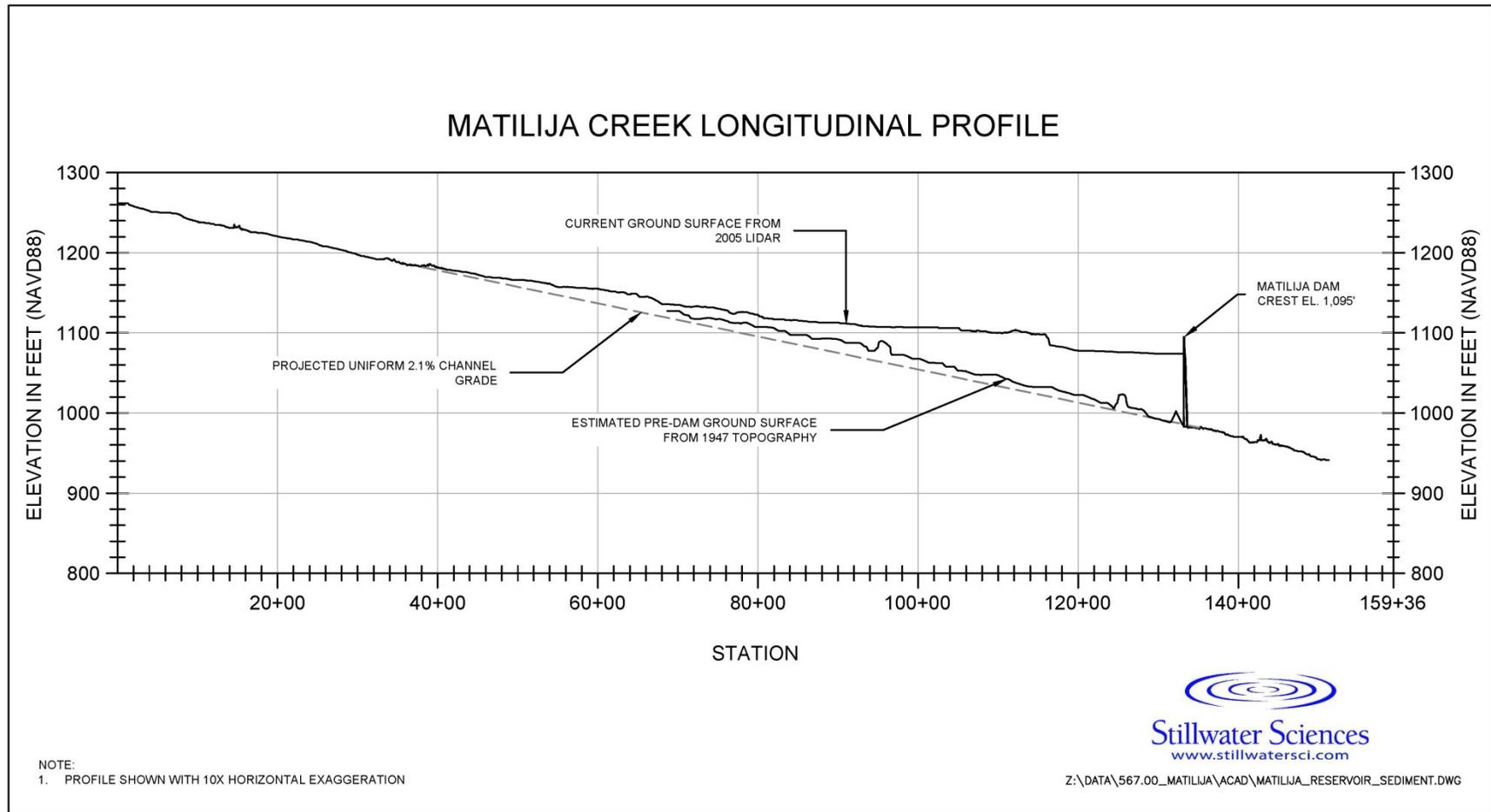


Figure 2. Matilija Creek longitudinal profile.

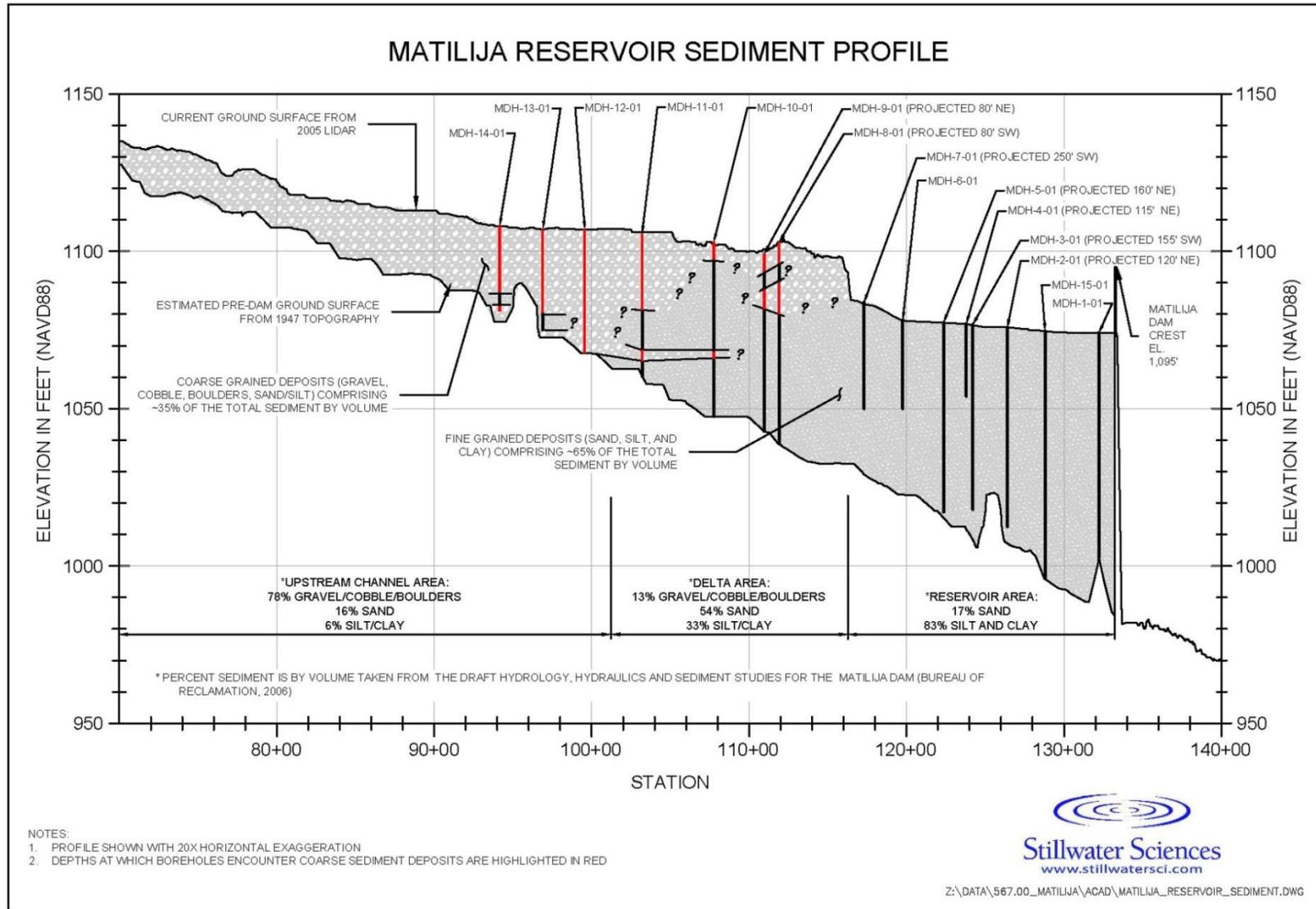


Figure 3. Matilija Reservoir sediment deposit profile.

### 3 CHARACTERIZATION OF WATERSHED-DERIVED SEDIMENT

In addition to the sediment already stored behind Matilija Dam, the overall watershed is a highly productive source of sediment during storm events. The magnitude of watershed sediment yield was discussed extensively in BOR (2006, particularly Section 5.5 of that report). For the present effort, no attempt is made to duplicate or review that discussion, but rather to augment those data with additional studies conducted since that time with likely relevance to sediment delivery from the watersheds of Matilija Creek and the Ventura River.

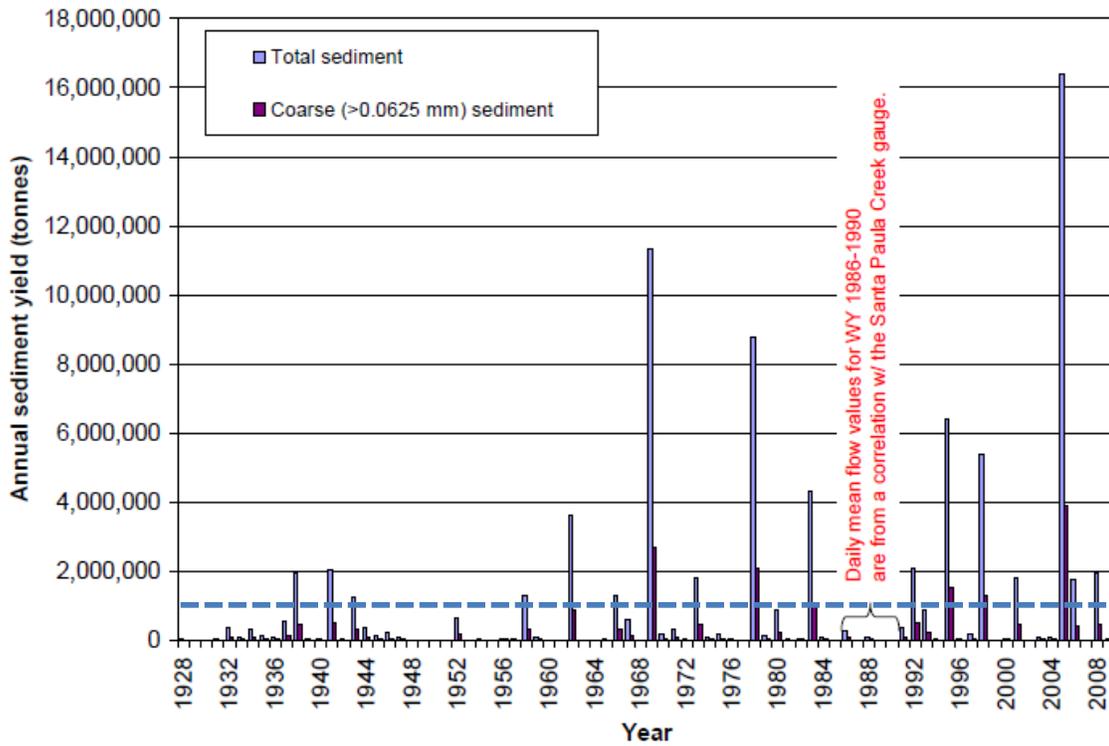
Table 5.14 of BOR (2006) reports the following estimates of watershed sediment yield:

Watershed	Sediment Yield per mi <sup>2</sup> (acre-ft/mi <sup>2</sup> /yr)
Ventura Watershed without Casitas Dam and Matilija Dam	2.10
Ventura Watershed with Casitas Dam and Matilija Dam in place (current conditions)	1.36
Ventura Watershed with Casitas Dam in place	1.64
Matilija Creek Watershed	1.92

By way of comparison, sediment yield in the adjacent Sespe Creek watershed (Booth et al., 2014) was calculated from both measured suspended sediment in Sespe Creek (at USGS gage 11113000 from 1966 through 1978), and by analogy to debris basin records and geologically determined rates of uplift and erosion (Lavé and Burbank, 2004; Warrick and Mertes, 2009). They found yields to be about 2,600 tonnes/km<sup>2</sup>/year (using the units of that study), or about 1 mm/yr of landscape lowering (equivalent to the first entry on the table above of 2.10 acre-ft/mi<sup>2</sup>/yr, which is attributed to Brownlie and Taylor 1981). Given the preponderance of steep, relatively highly-erosive lithologies in the watershed of Matilija Creek relative to those in Sespe Creek, this value is likely a lower bound on the long-term average rate of watershed sediment production, but the overall correspondence of these disparate values given typically broad uncertainties in their calculation (Reid and Dunne 1996) suggest that seeking greater precision in any such estimate is unlikely to be fruitful.

By analogy to the annual reconstruction of Sespe Creek sediment loads (Stillwater Sciences 2010, Figure 3.2; reproduced below as Figure 4), the annual average load is exceeded (by up to 16-fold) in a single storm or set of storms that exceed about a 5-year recurrence interval (i.e., 17 of 81 years).

Conversion of these measures of mass (as originally reported in the cited literature) into a volume of water-transported sediment (as is commonly measured in spatial analyses of reservoir deposits) requires a density conversion, as discussed in the previous section. For purposes of the following discussion a mid-range value of 1.4 tonnes/m<sup>3</sup> (Table 3) is assumed.



**Figure 4.** Calculated total sediment yield (i.e., suspended load + bedload) and coarse-only (>0.0625 mm) sediment load for Sespe Creek at Fillmore (USGS gage 11113000). Dashed blue line is the average annual sediment yield calculated from these data (990,000 tonnes/year). The year of greatest sediment yield (2005) had an annual load more than 16 times the average; other major sediment-yielding years produce two to more than ten times the long-term average value. From Stillwater Sciences (2010, their Figure 3.2).

Assuming an annual average sediment from the watershed draining to Matilija Dam of 3,000 tonnes/km<sup>2</sup>/year (an extrapolated estimate based on Sespe Creek findings, and equivalent to single-digit precision of BOR’s [2006] estimate of yield to the dam), the average annual sediment yield from the upstream watershed is about 400,000 tonnes per “average” year (about 400,000 yd<sup>3</sup>), and thus potentially more than 5M yd<sup>3</sup> of transported sediment during a truly exceptional year. Even with the dam in place, the fraction of silt and clay in the sediment load (see BOR 2006, Table 5.6) coupled with the current trapping efficiency of the dam (about 45% for fines; BOR 2006, Table 5.4) suggest that at least 100,000 yd<sup>3</sup> per year of fine sediment are moving down the Ventura River past Robles Diversion. This represents about one-third of the total annual load of fines presently estimated to be delivered to the Pacific Ocean (BOR 2006, Table 5.15) from this relatively steep and erodible fraction of the total watershed (i.e., 54 of 226 mi<sup>2</sup>, or about 24%).

In summary, watershed sediment yields during major sediment-transporting events are of the same magnitude as the volume of sediment presently stored behind Matilija Dam. Predicted transport volumes out of the reservoir area following dam removal during major events are likely to be augmented by a similar amount of “new” sediment from the contributing watershed, both

from Matilija Creek and the North Fork Matilija Creek, together with the even larger watershed entering the Ventura River downstream of Robles Diversion. Estimates of watershed sediment yield also suggest that sediment management at the Robles Diversion, however problematic during the period of reservoir sediment releases following dam removal, will pose an ongoing challenge of nearly equivalent magnitude in the post-dam era during all subsequent high-flow years, even after the reservoir sediment has been fully evacuated.

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