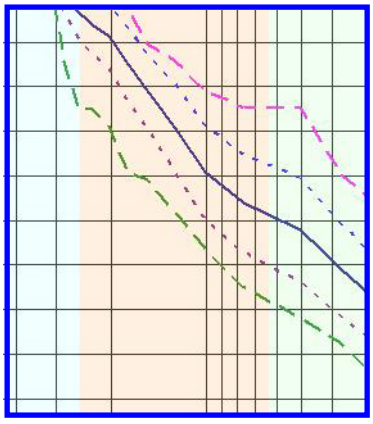
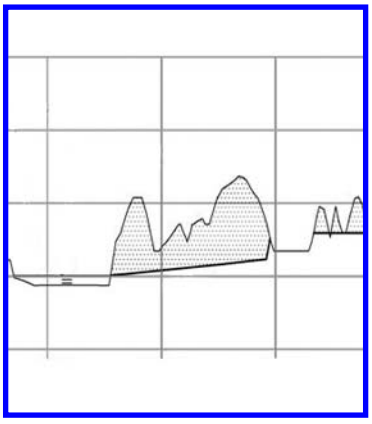
Merced River Corridor Restoration Plan
Phase IV: Dredger Tailings Reach

Technical Memorandum #4

Volume and Texture Analysis of the Merced River Dredger Tailings

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1 INTRODUCTION

1.1 Report Structure

The purpose of this technical memorandum is to document the volume and texture of the piles of dredger tailings that currently cover most of the floodplain within the Merced River Dredger Tailings Reach (DTR). The dredger tailing piles have significantly altered the floodplain morphology of the DTR, and a significant volume of these tailings will require excavation and disposal/re-use in order to achieve effective floodplain restoration along the reach. The volume and texture analysis discussed in this report was developed as the basis for estimating: 1) the total volume of tailings that must be removed to achieve floodplain restoration along the reach; 2) the volume of specific size classes of sediment that can be expected to become available for restoration uses; and 3) the potential cost of different restoration options.

This technical memorandum describes the methods and findings of the volume and texture analysis for the DTR and for the 318-acre Merced River Ranch (MRR). Components of the analysis which are described in detail include:

- Sampling methods;
- Stratigraphy of the tailing piles;
- Particle size distribution of the tailing pile material;
- Bulk densities of size classes that occur in the tailings; and
- Volume of tailings within the DTR and MRR and of size classes of particular relevance to channel and floodplain restoration.

This report is the fourth in a series of technical memoranda that will detail the existing and potential post-restoration physical and biological conditions of the DTR.

1.2 Project Setting

The Merced River is a tributary to the San Joaquin River in the southern portion of California's Central Valley (Figure 1). The river, which drains an

approximately 1,276-mi^2 watershed, originates in Yosemite National Park and flows southwest through the Sierra Nevada range before joining the San Joaquin River 87 mi south of the City of Sacramento. Elevations in the watershed range from 13,000 feet at its crest to 49 ft at the confluence with the San Joaquin River. This report focuses on the DTR of the Merced River, which extends from Crocker-Huffman Dam (river mile [RM] 52) to approximately 1.2 miles downstream of the Snelling Road Bridge (RM 45.2) (Figure 1). The channel in this reach is confined by piles of dredger tailings, which have replaced the natural floodplain soils and floodplain forest, and have increased floodplain elevations along the river. Within this reach, riparian vegetation is sparse, occurring primarily in narrow bands along the river channel and in fragmented patches in low-lying areas among the dredger tailings piles.

Historically, this reach was part of a highly dynamic, multiple channel system. Under pre-colonial conditions, as the river exited the Sierra Nevada foothills near Merced Falls, the river spread out across a broad alluvial valley floor that ranged up to 4.5 mi in width (Stillwater Sciences 2001). Within this reach, the historic river was a complex, multiple channel system, including the mainstem river channel and several sloughs. Under pre-colonial flow conditions, the dominant, or "mainstem," channel likely switched between the multiple channels, and channel avulsions during large flows may have been common.

The hydrology of the Merced River has been altered by water supply requirements and flood control operations, which together have reduced flood frequency, reduced peak flow magnitude, altered seasonal flow patterns, and reduced the temporal variability of flows, spring snowmelt flows, and summer baseflows. These changes in hydrologic conditions have altered the frequency, duration, and magnitude of floodplain inundation, reduced the frequency of sediment transport and bed scour, which in conjunction with channel incision, have increased the relative effectiveness of sediment transport in the remaining flood events (Stillwater Sciences 2001).

Since 1926, sediment supply from the upper 81% of the watershed has been intercepted at the original Exchequer Dam and then the New Exchequer Dam. This interception has eliminated the vast majority of the river's historical sediment supply, thus depriving the river of a basic component in maintaining its existing geomorphic equilibrium and causing a new equilibrium to be sought. Under pre-dam conditions, the bed was likely mobilized by small, relatively frequent floods that occurred about every 1–2 years. With the reduction in flood magnitude caused by flow regulation, the

bed is currently immobile at flows up to the 5-year recurrence interval flow (Q_3) (Stillwater Sciences 2001). As a result, the channel bed and formerly active bars are largely static, and riparian vegetation has encroached into the formerly active channel.

In addition to the effects of flow regulation and loss of sediment supply from the upper watershed, this reach has been extensively modified by gold dredging. In the early-to-mid twentieth century, gold dredges excavated the river channel, floodplain, and valley floor. The dredges had earthmoving capacities of 1.4–3.4 million cubic yards/year and excavated the channel and floodplain deposits to bedrock, usually a depth of 20–35 ft (Clark 1969). After recovering the gold, the dredgers redeposited the remaining tailings in long rows on the floodplain. These tailings consist of fine sand and gravel overlain by cobbles and boulders (Goldman 1964), a stratification pattern that resulted from the sluicing and discharge process. As a result of gold dredging, the channel has been depleted of coarse sediment and the adjacent floodplain has been raised and covered with dredger tailings piles.

The combined effects of gold dredging, flow regulation, elimination of coarse sediment supply, and land use development have converted this reach from a complex, multiple-channel system to a simplified, single-thread system with a narrow floodplain adjacent to the channel. The complex slough channels that once dominated the floodplain have been converted to agricultural irrigation and return-flow ditches. The dredger tailings on the floodplain constrain the river channel so that high flow events are prevented from spilling onto the floodplain. As such, although high flow events are now rare, even moderate flow events are capable of resulting in high shear stresses that are highly effective at transporting sediment. Over time, the occasional high flow events combined with the lack of coarse sediment supply have acted to transport the majority of finer sediments from the reach. One result of this high sediment transport capacity is the very coarse bed surface of the reach, which is composed of coarse gravel and cobble. The D_{50} (the median particle size) of the bed surface ranges from 28 to 134 mm, and the D_{84} (value for which 84% of the particles are finer) ranges from 68 to 270 mm (CDWR 1994, Vick 1995, Stillwater Sciences 2001 and 2004). Another result has been that the channel is now typified by long, deep pools that are scoured to bedrock or to a coarse cobble armor layer. These pools are partly controlled by bedrock outcrops and some of them are quite likely the result of dredger mining in the channel. The pools are separated by riffles that are also partly controlled by bedrock, but many of which are also maintained through frequent gravel augmentation of spawning riffles and water diversion wing-dams. The channel slope averages 0.0023 (Stillwater Sciences 2004).

The primary restoration issues in the DTR include flow reduction and alteration of seasonal flow patterns, lack of bed-mobilizing flows, lack of coarse sediment supply, conversion of the floodplain to tailings piles, and the high bed load transporting capacity aided by channel confinement. The lack of coarse sediment supply and bed-mobilizing flows in combination with high bed load transporting capacity during rare flood events prevent the accumulation and retention of gravels of suitable size for salmonid spawning habitat and result in encroachment of vegetation into the channel. The conversion of the floodplain to tailings and the confinement of the channel by the tailings piles prevent floodplain inundation during high flows and have eliminated the processes by which riparian vegetation is established and renewed, reducing riparian habitat.

1.3 Project Overview and Objectives

The dredger tailings volume and texture analysis reported in this technical memorandum was developed as a part of the Merced River Corridor Restoration Plan Phase IV: Dredger Tailings Reach project (California Bay-Delta Authority [CBDA] ERP-02-P12-D), which will evaluate strategies for channel and floodplain restoration in the MRR and 7-mile DTR.

The DTR has become a focus for restoration planning for several reasons. The DTR is now the primary spawning area in the Merced River for fall-run Chinook salmon (*Oncorhynchus tshawytscha),* an important management species, and, potentially, steelhead (*O. mykiss*), which is listed as threatened under the federal Endangered Species Act (Stillwater Sciences 2002). Salmonid species that historically migrated up the Merced River now concentrate spawning in the DTR directly downstream of Crocker-Huffman Dam, the current upstream limit of salmonid migration. In addition, past and current studies and restoration planning in the Merced River have provided a cursory understanding of the physical and ecological conditions of the river and factors limiting ecosystem health. These studies include the Anadromous Fish Restoration Program's Comprehensive Assessment and Management Program; U.S. Geological Survey and Central Valley Regional Water Quality Control Board water quality monitoring; Merced Irrigation District and the California Department of Fish and Game (CDFG) salmon population ecology studies; Stillwater Sciences' geomorphic and riparian vegetation evaluations; and CDFG and California Department of Water Resources (CDWR) restoration project-related monitoring.

Partly in response to these studies, the CBDA Ecosystem Restoration Program funded the development of the Merced River Corridor Restoration Plan (Stillwater Sciences 2002). The restoration planning process was designed to provide a technically sound, publicly supported, and implementable plan to improve geomorphic and ecological functions in the Merced River corridor from Crocker-Huffman Dam to the confluence with the San Joaquin River. The Restoration Plan identifies restoration objectives and provides recommendations for the Merced River based on current scientific understanding of the river with input from the Merced River Stakeholders (MRS), Technical Advisory Committee (TAC), and the broader public. Since the restoration objectives were discussed by a broad spectrum of interests represented by the MRS, TAC, and public, they address not only geomorphic and ecological restoration in the river but also the concerns of local citizens, landowners, and other stakeholders. In the DTR, which is affected by flow reduction and alteration of seasonal flow patterns, lack of bed-mobilizing flows, lack of coarse sediment supply, conversion of the floodplain to tailings piles, and channel confinement, the following reach-scale restoration objectives were recognized:

- Balance sediment supply and transport capacity to allow the accumulation and retention of spawning gravel and prevent riparian vegetation encroachment;
- Restore floodplain functions to improve the establishment of riparian vegetation and the quality of riparian habitat;
- Increase in-channel habitat complexity to improve aquatic habitat for native aquatic species; and
- Scale low-flow and bankfull channel geometry to current flow conditions.

The Merced River Corridor Restoration Plan Phase IV: Dredger Tailings Reach project begins to address the restoration objectives for the DTR developed in the Restoration Plan. The goals of the DTR project are to design pilot experiments in the channel and floodplain to test measures that will initiate the restoration of natural ecosystem function in the reach, to the extent feasible, and provide transferable scientific information that will reduce uncertainty in future restoration design. The DTR project is the precursor for conducting experimental pilot projects in floodplain and channel restoration, gravel infusion and augmentation, and floodplain re-vegetation. Removal of the tailings from the floodplain has the potential to yield multiple restoration opportunities and ecosystem benefits, but the detailed impact of such activities is largely unknown. The experiments designed as part of this project will increase the collective scientific understanding of the potential for dredger tailings removal and re-use (e.g., as material to fill the channel), and is intended to improve restoration

effectiveness and reduce project uncertainty when implementing similar projects in the future. Future projects will be implemented to increase coarse sediment storage in the Merced River channel, balance bed texture with sediment transport competence, remove dredger tailings to create diverse floodplain surfaces at functional elevations, and reconstruct a channel through a portion of the DTR.

A comprehensive understanding of the volume and texture of the dredger tailings in the DTR is required to address the reach-scale restoration objectives described in the Restoration Plan and meet the goals of the DTR project. For this reason, an analysis of the volume and texture of the dredger tailings was conducted for the DTR and MRR. The objectives of this analysis were to:

- determine the total volume of tailings that must be removed to achieve floodplain restoration along the entire reach;
- determine the volume of specific size classes of sediment that can be expected to become available for restoration uses; and
- estimate the costs associated with removing the tailings from the MRR.

The results of these dredger tailings volume and texture analyses are reported in this technical memorandum.

2 METHODS

Determining the volume and texture of the tailing piles in the DTR and MRR involved:

1. taking representative samples of tailing material throughout the reach;
2. evaluating tailing pile stratigraphy;
3. determining particle size distributions of the sampled material both in the field and laboratory;
4. measuring the bulk density of the particle sizes present in the tailing piles; and
5. calculating volume using the bulk density data, topographic data of the DTR floodplain surface, and potential post-restoration floodplain elevations.

Samples of the tailings were collected at 26 locations along the DTR (Figure 2). Twelve samples were taken from the MRR property and 14 samples were taken from other properties elsewhere in the reach. Sample locations were selected to provide an analysis representative of the entire reach. Sampling was more extensive on the MRR property which is owned by the California Department of Fish and Game and is likely to be the focus of the floodplain restoration in the near future. Sampling at regular intervals along the reach was not feasible due to property access constraints.

2.1 Representative Samples

Using an excavator, samples were taken from pits dug at each of the 26 sampling locations until either groundwater or the maximum feasible depth of the excavator was reached. The depth to which the excavator could dig was constrained by the narrow ridges of tailings on which the excavator sat and the uncohesive nature of the tailings, which tend to settle to an approximate 45 degree angle of repose. As the pits approached a diameter of approximately 9 m and an average depth of 6 m, the material around the pit perimeter became unstable, and the excavator began to run out of stable ground from which to continue digging. In general, samples were collected from pits that were an average of 5 m deep (see Section 3.1 for more detail).

Appendix A includes the depth of each sample pit where a representative sample was taken.

The field procedure used to obtain representative samples of the tailings for field and laboratory analysis was modified from the American Society for Testing and Materials (ASTM) C136-01 Standard Method for Sieve Analysis of Fine and Coarse Aggregates (2001). This test method covers the determination of the particle size distribution of fine and coarse aggregates by sieving. ASTM C136-01 incorporates the following ASTM standard methods by reference: C117 Test Method for Materials Finer than 75 mm (No. 200) Sieve in Mineral Aggregates by Washing; C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials; C702 Practice for Reducing Field Samples of Aggregate to Testing Size; and D75 Practice for Sampling Aggregates.

Section 6.4 of ASTM C136-01 calls for a minimum mass of 500 kg for a test sample when testing materials with diameters as large as 150 mm. However, according to Section 6.6 in ASTM C136-01, "the intent of this method will be satisfied for samples of aggregate larger than 50 mm nominal maximum size if a smaller weight of sample is used, provided that the criterion for acceptance or rejection of the material is based on the average of results of several samples." If the results are reproducible in smaller samples the methodology is still valid. The field testing was modified so that the total sample mass was reduced by half, or to an approximate target sample mass of 250 kg per sample, with the knowledge that the average result across the 26 samples should suffice to provide a representative overall indication of sediment texture within the tailings.

At each sampling location, one excavator-bucket (approximately 2 m^3) of material was removed every 1.5 m below ground surface as the sample pit was dug. This bucket-load of sample was then placed on the ground surface and set aside for the sample (Figure 3). For example, a pit dug to a depth of 6 m yielded four excavator bucket loads of tailings set aside for the representative sample.

The methodology outlined in ASTM C136-01 Section 6.6 dictates that only a portion of the overall excavated material needs to be analyzed to obtain a representative sample. Therefore, equal volumes from each of the four excavation buckets were mixed together to achieve the target sample mass of 250 kg.

Although there is a 0.2 m layer of coarser materials (large cobbles and boulders) at the surface of the pits, this amount of material was considered

minimal relative to the total amount of material sampled for each pit. In combination with the overall lack of material stratification within the excavated depth (see photographs in Appendix A), it was unnecessary to differentiate sample analysis by depth. Therefore, the analyses completed at each pit location can be considered representative for the entire excavated depth.

In addition to the sub-samples taken to produce the representative sample, twelve 5-gallon buckets of material were taken from the bottom of each pit on the MRR in coordination with the mercury analysis effort being conducted for the Merced Phase IV project. The mercury analysis will be reported in a future technical memorandum.

2.2 Stratigraphy

Stratigraphy was determined by observing the side wall of the sample pits as the excavator dug. Careful visual observations were necessary to record the nature of the material as the excavator arm removed each bucket-load of material because of the tailings' tendency to cave in on the sampling pit. The photos of sample pits illustrate the lack of stratigraphy in the tailings piles (Appendix A). Results of the stratigraphy analysis are discussed in Section 3.1.

2.3 Particle Size Determination

The following procedure, from ASTM C136-01, was used to determine the particle size distribution of the 76.2 mm to 304.8 mm size fractions of the composite samples:

1. Sieve the sample to separate 76.2 mm diameter and smaller size fractions from larger rock. Place <76.2 mm fraction in buckets and weigh.
2. Separate the 76.2 mm diameter and greater material by diameter (i.e., 76.2 to 101.6 mm, 101.6 to 127.0 mm, 127.0 to 152.4 mm, etc. up to 304.8 mm diameter), place into buckets, and weigh (Figure 4).
3. Determine the total mass of the sample by summing the mass of all size fractions (<76.2 mm through 304.8 mm diameter).
4. Empty the <76.2 mm fraction onto a plywood sheet, mix thoroughly and split to obtain one 5-gallon bucket representative of the <76.2 mm fraction to be sent to the laboratory (see Section 2.4). This value represented, on average, approximately one-third of the volume of <76.2 mm material present in the samples. The mass of the sample was

usually in excess of 30 kg, comparing favorably with the ASTM C136-01 target sample mass of 35 kg for materials up to 76.2 mm in diameter.

5. Record the depth and width of the sample pit, stratification if present, depth to groundwater, and take a GPS point.

Separated sample material less than 76.2 mm was sent for laboratory analysis for particle size distribution using the methodology outlined in ASTM C136-01 (2001). This method uses a series of sieves to separate fine aggregates into the following size fractions: 76.2 mm, 50.8 mm, 38.1 mm, 25.4 mm, 19.1 mm, 9.5 mm, 4.8 mm, and <2.0 mm. These fractions represent the standard size classes (when converted to English units) used in excavation industry practice, reflecting the potential use of the dredge tailings in industrial applications. Results of this analysis are presented as percent finer by mass in Appendix B. For potential restoration applications, data was re-worked into Wentworth-scale sizes spanning medium gravel (8 to 16 mm) to fine cobble (64 to 128 mm) classes and is reported in section 3.4.3.

To determine the particle size distribution of the entire field sample (i.e., combination of the <76.2 mm and >76.2 mm size classes), the mass of each size class <76.2 mm was calculated based on the total mass of <76.2 mm material obtained at each sample pit, rather than using the reduced sample mass sent for laboratory analysis. The total fraction of <76.2 mm material was calculated by multiplying the laboratory percent passing data with the total mass of the <76.2 mm fraction as measured in the field. The >76.2 masses were determined in the field as described above. The results of this combined analysis are discussed in Section 3.2 and presented in Appendix A.

2.4 Bulk Density

Bulk density values were determined for each of the 17 sieve size classes represented in the tailing piles in order to calculate the volume of material in each of the size classes. Bulk density values for well-sorted material (i.e., all material is of similar diameter and shape) are lower than values for poorly-sorted materials (i.e., material with a range of diameters and/or shapes) because they have a greater amount of pore space per equivalent volume than poorly-sorted or mixed materials (Das 1994).

The estimate of bulk density for classes of material <2 mm, 1,602 kg/m^3, was obtained from published values (SI Metric 2004). Bulk densities for individual classes larger than 2 mm were estimated at 1,682 kg/m^3, from

published values (SI Metric 2004), and were checked by field testing. Field bulk density was determined by obtaining the total mass of three full 5-gallon buckets of each size class and dividing by the total volume of material. This field bulk density procedure could only be used to accurately determine densities for smaller classes of material because in the larger classes, 5-gallon buckets do not allow the material to be totally clast-supported (i.e., the material is leaning on the bucket instead of retaining its in-situ position). The values determined for the smaller classes in the field corresponded well with the published value of 1,682 kg/m^3, so this value was used for all size classes.

It is important to note that bulk density values of excavated material are slightly different than the values of in-place material due to settling and compaction over time. An in-place bulk density value of the tailings material (as opposed to the bulk density of each separate size class as described above) was estimated at 2,203 kg/m^3 based upon visual assessment and engineering judgment, and from bulk density values of similar type material provided in EPRI (1990).

Results of the bulk density analysis are discussed in Section 3.3.

2.5 Volume of Tailings

2.5.1 Volume of Tailings along the DTR and on the MRR

Tailing volumes were estimated using the grid method in the Autodesk Land Desktop 3 (LDD) software. Volumes calculated in LDD using the grid method are calculated by performing the following steps:

- Creation of two (existing and proposed) Triangulated Irregular Networks (TIN). A TIN is defined as a surface representation derived from irregularly spaced sample points and breakline features. The TIN data set includes topological relationships between points and their neighboring triangles. Each sample point has an x, y coordinate and a surface, or z-value. These points are connected by edges to form a set of non-overlapping triangles used to represent the surface. The result is a three-dimensional mesh of triangles. Commonly, two surfaces are created for the purposes of earthwork volume calculations, one surface for existing ground (EG), and a second surface for finished ground (FG, the proposed ground surface).

- In the grid method, the map of interest is divided into evenly spaced rectangles by parallel and perpendicular lines. Each rectangle is known

as a grid square. For estimating purposes, each grid square is assigned an existing and a proposed elevation. The difference of the two elevations multiplied by the area of the grid square is the cut or fill volume associated with that grid square. Total project volume (cut or fill) is calculated by summing the individual grid square volumes. The elevation to be assigned to a grid square is determined by interpolating between the TIN formed from all known elevations on the site.

Based on a site grid square distance sensitivity analysis, it was determined that a grid square distance of 4.57 m (15 ft) was acceptable for this analysis. Volumes calculated by LDD are raw, unadjusted volumes. The volumes do not account for any shrinkage or subsidence that may occur on a given site.

Conceptual floodplain surface elevations were inserted manually into the software, based on preliminary discussions regarding the likely floodplain grading requirements. The proposed floodplain surface utilized in the DTR volume analysis includes a floodplain beginning at the bankfull channel elevation (i.e., the elevation inundated by flows with a 1.5-year recurrence interval), excavated back at a one percent slope until a 107 m (350 ft) length is reached from each bank, or until such time that infrastructure constraints or lack of tailings curtail the grading. The maximum corridor width of 107 m from each bank corresponds to the mean width for which detailed photogrammetric mapping exists. For the MRR, the one percent slope is also extended back from the bankfull channel elevation, and ends when an elevation of 88 m (288 ft, NGVD29) is reached, then extends flat from that point to the edge of the MRR property. This elevation is approximately 0.61 m (2 ft) higher than the anticipated groundwater elevation, and was selected to provide an adequate depth to groundwater for proposed revegetation. Figure 5 illustrates the extent and EG and FG elevations used in the MRR and DTR volume calculations.

2.5.2 Volume of Size Classes in the Tailing Piles

Volumes of the 17 size classes found at the sample sites were determined based upon the total amount of material sampled at each pit and the individual particle size class bulk densities. The mass of each size class was divided by the bulk density of each size class.

An in-situ bulk density value of 2,203 kg/m^3 for the on-site material was estimated as discussed in Section 2.4, and represents the value for mixed heterogeneous material of all size classes as opposed to the bulk density data for individual particle size classes. The volume of the total amount of material sampled at each pit was determined by dividing the total mass of the sampled material by the 2,203 kg/m^3 bulk density value. Total sample

volume and volume by particle size class are presented for each sample pit in Appendix A.

The volume data at each of the 26 sample pits was used to develop volume ratios of individual size class volume to total in-place volume of the material sampled at each pit. The volume of the individual size class was divided by the total volume sampled at each pit. These ratios were developed in order to calculate the total volume of each of the 17 size classes that are found within the MRR and riparian corridor of the DTR.

2.5.3 Volume of Size Classes with Importance to Restoration

The volumes of four size classes of material that may be of particular importance to potential floodplain and channel restoration efforts were calculated. These size classes include spawning gravel sizes for Chinook salmon (13 to 102 mm) (Platts et al. 1979, Bell 1986, Bjornn and Reiser 1991), steelhead (6.4 to 130 mm) (Barnhart 1991), and material that may potentially be used to reconstruct the channel. These class sizes are: medium gravels (8 to16 mm), coarse gravels (16 to 32 mm), very coarse gravels (32 to 64 mm), and fine cobbles (64 to 128 mm). The volumes of these four size classes were calculated by determining the percentage of the size class as a part of the average total volume that was sampled in the 26 pits. This was done using the particle size distribution data discussed in Sections 2.3 and 2.4.

3 RESULTS AND DISCUSSION

3.1 Stratigraphy, Lithology and Elevation

Minimal stratigraphic differentiation was observed within each sample pit and between the sample pits. In general, a well mixed, heterogeneous distribution of all size classes of tailings material was present at all sampling locations (Figure 6, upper photograph). As described previously, a shallow (0.2 m) surface layer of coarse materials (larger cobbles and boulders) was present at the surface over all the tailings as a result of the finer size materials settling out. A layer of sand was encountered at varying depths in some sample locations and, where present, extended beyond the bottom of the pit (Figure 6, lower photograph). No sand lenses or inclusions were found within any of the pits, and the description of minimal stratigraphy refers only to the dredger tailing material that is present above the layers of sand. Appendix A includes excavation depths and stratification notes for each of the 26 sample pits.

The dredger tailings material is predominantly rounded to sub-rounded, with minor sub-angular and rare angular clasts. The clasts comprise predominantly metamorphic rocks from the Foothills metamorphic belt, with lesser amounts of granitic clasts from the main Sierran batholith. Exposures in the test pit walls indicate that these tailings are non-stratified, with a heterogeneous mix of clast-supported cobbles and boulders in a matrix of gravel, sand, and silt.

Elevation data including top of sample pit (ground surface), depth of pit, presence and depth of groundwater, and stratigraphy are presented in Figure 7 and in Table 3-1. The shallowest pit was 3.0 m deep (reached groundwater at that depth) and the deepest pit was 7.9 m (sand was reached at a depth of 5.8 m and the excavator continued digging through the sand to a depth of 7.9 m). Groundwater was encountered in 12 of the 26 pits, and the depth to groundwater varied from 3.0 to 5.5 m below ground surface (Appendix A).

Table 3-1. Elevation Data for the Sample Pits.

Site No.[1]	Elevation Data (m)[2]			
	Ground Surface	Groundwater[3]	Sand[3]	Bottom of Pit
1	91.4	87.8	87.8	87.8
2	92.7	--	--	86.6
3	89.6	86.0	86.0	86.0
4	89.0	--	--	85.0
5	93.3	--	87.5	85.3
6	92.0	87.4	--	87.4
7	91.0	--	--	83.4
8	89.5	--	85.9	85.0
9	89.0	85.3	--	85.3
10	89.6	84.7	85.3	84.7
11	91.2	--	--	85.4
12	91.9	--	--	86.4
13	93.4	--	--	87.9
14	86.6	82.3	--	82.3
15	88.9	--	--	84.3
16	86.6	83.5	--	83.5
17	88.1	--	83.5	82.6
18	No data[4]	--	--	4.6 bgs[5]
19	No data[4]	4.3 bgs[5]	--	4.3 bgs[5]
20	74.4	68.9	--	68.9
21	No data[4]	--	--	5.8 bgs[5]
22	87.2	82.9	83.8	82.9
23	No data[4]	--	2.7 bgs[5]	4.0 bgs[5]
24	89.9	--	86.8	84.4
25	85.5	81.3	--	81.3
26	82.8	79.1	--	79.1

[1] See Figure 1 for the location of sampling sites.
[2] Source: NGVD29
[3] Cells left empty (--) indicate that groundwater and/or sand was never reached.
[4] No elevation data is available for Sites 18, 19, 21, and 23 because they were sampled outside the extent of floodplain topography data (Stillwater Sciences 2004).
[5] bgs = below ground surface

3.2 Particle Size Distribution

Particle size distributions for material greater than 76.2 mm were calculated in the field at each sampling site (see Section 2.3) and are included in Appendix A. Particle size distributions for material 76.2 mm and finer at each sampling site were calculated in the laboratory (see Section 2.4) and are included in Appendix B.

To develop a composite picture of the texture of tailings throughout the DTR, particle size data from both the field and laboratory efforts for all 26 sampling sites were combined. The mean, minimum, maximum, and standard deviations of the combined percent finer, or percent passing, data are presented in Table 3-2 and Figure 8. Field and laboratory particle size data indicates that 17 sediment size classes make up the tailings material. Table 3-2 lists the particle size classes sampled in the tailings as well as percent finer data for each size class.

Table 3-2. Particle Sizes and Percent Finer of all Size Classes Found in the Tailings Piles.

	Particle Size (inches)	Particle Size (mm)	Percentage Finer				
			Maximum	Mean + 1 std. dev.	Mean	Mean – 1 std. dev.	Minimum
Sand	<0.08	<2.0	14.9	6.9	3.7	0.6	0.0
Gravel	0.08–0.19	4.8	17.9	8.1	4.4	0.8	1.2
	0.19–0.38	9.5	21.9	12.8	8.1	3.5	3.3
	0.38–0.85	19.1	38.3	28.8	21.0	13.1	10.4
	0.75–1.00	25.4	50.2	37.5	28.4	19.3	15.2
	1.00–1.50	37.5	60.2	49.3	38.9	28.5	22.4
	1.50–2.00	50.8	75.2	59.5	48.0	36.4	28.4
Cobbles	2–3	76.2	75.2	64.9	54.0	43.0	35.2
	3–4	101.6	79.3	71.5	60.9	50.3	43.9
	4–5	127.0	85.9	80.9	71.0	61.1	52.1
	5–6	152.4	89.5	87.1	78.7	70.4	59.0
	6–7	177.8	97.0	93.4	85.2	76.9	60.9
	7–8	203.2	100.0	98.4	91.3	84.2	71.5
	8–9	228.6	100.0	100.0	93.8	87.3	75.0
	9–10	254.0	100.0	100.0	96.7	90.5	75.0
Boulders	10–11	279.4	100.0	100.0	99.4	96.5	85.0
	11–12	304.8	100.0	100.0	100.0	100.0	100.0

Particle size distribution data were ultimately used in the development of volume ratios and in volume calculations. Section 3.4 describes how the particle sizes are distributed compared to one another and to the entire volume of the tailings in the DTR and MRR.

3.3 Bulk Density

As indicated in Section 2.4, bulk density for the sub-2 mm particle size classes was estimated at 1,602 kg/m^3 from published values (SI Metric 2004). Bulk density for individual size classes of sediments up to 304.8 mm was estimated at 1,682 kg/m^3, based also on published values. The in-situ bulk

density value of the tailings material was estimated at 2,203 kg/m^3 based upon visual assessment and engineering judgment, and from bulk density values of similar type material provided in EPRI (1990). This represents a value for mixed heterogeneous material of all size classes rather than for individual particle size classes.

3.4 Volume Calculations

Stratigraphy, bulk density, mass, particle size distribution, and topographic data were used to calculate: 1) the total volume of tailings present on the MRR and along the riparian corridor of the DTR; 2) the volumes of all sediment size classes found in the tailings; and 3) the volumes of sediment size classes that are of particular relevance to restoration efforts (e.g., size classes suitable for spawning gravel augmentation).

3.4.1 Volume of Tailings along the DTR and on the MRR

Volumes of tailings that would need to be removed to facilitate floodplain restoration and/or become available for restoration uses were calculated for both the riparian corridor of the DTR (i.e., a 107 m [350 ft] width on both banks of the river) and for the MRR property (see Section 2.5.1 for detail on methods). The MRR is 318 acres (1,286,890 m^2) and covered, almost entirely, in dredger tailing piles. A 350-ft corridor on each side of the river along the entire DTR (7.2 mi) is equivalent to 305 acres (1,236,131 m^2). Figure 5 illustrates the differences in area included in the two volume calculations. The results are presented in Table 3-3.

Table 3-3. Volume of Tailings along the DTR and on the MRR.

Location	Volume (yd^3)	Volume (m^3)
Riparian Corridor of the DTR	3,220,000	2,462,000
Merced River Ranch	3,215,000	2,458,000

3.4.2 Volume of Size Classes in the Tailing Piles

Using the methods described in Section 2.5.2, the volumes of each size class found in the tailing piles were calculated. Total sample volume and volume by particle size class, which were the basis of the calculation, are presented for each sample pit in Appendix A. The proportional volume of each sediment size class obtained from the overall sample volume is assumed to reflect the proportion of that size class within the entire volume of dredger tailings. This result is presented in Table 3.4 and forms the basis for

estimating the volume of each size class within the MRR and riparian corridor of the DTR. Size classes with a volume ratio of 0.1 or larger represent the greatest percentage of tailing volume. The size classes with the greatest volumes are 9.5 to 19.1 mm (medium to coarse gravel), 25.4 to 38.1 mm (coarse to very coarse gravel), 38.1 to 50.8 mm (very coarse gravel), and 101.6 to 127.0 mm (fine cobble), and 127.0 to 152.4 mm (large cobble).

Table 3-4. Volume of Tailings by Size Class.

Particle Size (mm)	Average Volume Proportion	Volume Within MRR		Volume Within DTR	
		(yd^3)	(m^3)	(yd^3)	(m^3)
<2.0	0.052	167,000	128,000	168,000	128,000
2.0 – 4.8	0.009	29,000	22,000	30,000	23,000
4.8 – 9.5	0.048	156,000	119,000	156,000	119,000
9.5 – 19.1	0.169	543,000	415,000	543,000	415,000
19.1 – 25.4	0.097	313,000	239,000	314,000	240,000
25.4 – 38.1	0.138	444,000	339,000	444,000	339,000
38.1 – 50.8	0.119	383,000	293,000	384,000	294,000
50.8 – 76.2	0.079	254,000	194,000	254,000	194,000
76.2 – 101.6	0.090	290,000	222,000	291,000	222,000
101.6 – 127.0	0.132	426,000	326,000	426,000	326,000
127.0 – 152.4	0.101	326,000	249,000	326,000	249,000
152.4 – 177.8	0.084	270,000	206,000	270,000	206,000
177.8 – 203.2	0.081	260,000	199,000	261,000	200,000
203.2 – 228.6	0.032	104,000	80,000	104,000	80,000
228.6 – 254.0	0.037	120,000	92,000	121,000	93,000
254.0 – 279.4	0.036	117,000	89,000	117,000	89,000
279.4 – 304.8	0.008	25,000	19,000	25,000	19,000

When the average volume proportion values from Table 3-4 are added together, the result is larger than 1 (100%). This is because the mass of the sorted materials (individual size classes) is the same as the mass of the excavated material, but the volume is greater due to lower density of the material in narrow gradation ranges.

3.4.3 Volume of Size Classes with Importance to Restoration

The size class volume data described above were manipulated to evaluate the volumes of four size classes of material that may be of particular importance to potential floodplain and channel restoration efforts. These class sizes are: medium gravels (8 to16 mm), coarse gravels (16 to 32 mm), very coarse gravels (32 to 64 mm), and fine cobbles (64 to 128 mm).

An estimated mass was calculated for each size class and a bulk density value of 1,682 kg/m^3 was used. From the mass and bulk density values,

volumes of each size class were calculated based on the average total volume sampled in a pit (252 kg). Volume proportions were estimated for three of the four size classes by interpolating the volume proportions from Table 3-4 in which the restoration size classes coincided. Table 3-5 lists the interpolated volume proportions and the estimated volumes of these particular size classes estimated within the MRR and along the riparian corridor of the DTR.

Table 3-5. Volume of Tailings with Importance to Restoration.

Particle Size (mm)	Size Class Description	Average Proportion Applied	Volume Within MRR		Volume Within DTR	
			(yd^3)	(m^3)	(yd^3)	(m^3)
8–16	Medium gravel	0.138	445,000	340,000	446,000	341,000
16–32	Coarse gravel	0.218	701,000	536,000	702,000	537,000
32–64	Very coarse gravel	0.223	718,000	549,000	719,000	550,000
64–128	Fine cobble	0.260	837,000	640,000	838,000	641,000

3.4.4 Assumptions and Primary Error Sources in Volume Estimates

The volume calculations presented herein are subject to several assumptions and potential error sources that have bearing on the confidence that can be assigned to the resultant estimates. These assumptions and error sources include:

- Measurement error inherent to the sampling design and excavation technique, including bias introduced by accessibility requirements for the excavator;
- Measurement error associated with field processing of samples;
- Instrument error associated with the field scale (calibrated to +/- 1.36 kg);
- Potential bias introduced in sampling primarily towards the upper end of the DTR reach due to restrictions on property access. As the contemporary floodplain stratigraphy is primarily a reflection of the sediment processing methods used on the dredger barges, the potential for bias will more likely be realized if several different dredger types were used within the reach. Conversely, if the reach was mined primarily using one barge type, the likelihood is greater that the floodplain stratigraphy is relatively consistent along the entire reach;
- Errors introduced as function of the differences between published values of sediment density used in analysis with the actual field measurements;
- Error introduced with the assumed in-place density. Density values for sediment containing material in excess of 76.2 mm are not well-established in the literature or in industry, and field measurement of the

larger size classes is prone to error unless resources permit analysis such as the ASTM D5030-04 "Standard Test Method for Density of Soil and Rock in Place by the Water Replacement Method in a Test Pit", in which water is used to fill a lined test pit to determine its volume; and
- Excavation volume estimate error introduced with the assumption of a 1.1 ratio bulking factor (although the value is considered reasonable for this type of material).

Final excavation and cost values should, therefore, be considered as preliminary estimates for planning purposes.

3.5 Estimated Costs to Remove Tailings

It is estimated that five bulldozers and five processing plants would be necessary to complete the processing and excavation of tailings from the MRR and DTR in 5.5 years. The amount of equipment and number of processing plants were selected to minimize the excavation and processing phase to a practical length. Processing costs could be reduced if fewer processing plants are utilized. Costs for excavation and hauling of the tailings were estimated using 2003 RS Means Building Construction Cost Data, a widely used guidebook for construction cost estimating (RS Means 2003). Processing costs were estimated using a combination of the 2003 RS Means and vendor quotations.

It is assumed that excavation equipment will include a 460-horsepower bulldozer with a haul of 300 ft, at a price of approximately $\$3.96/yd^3$.

It is assumed that processing will be completed using self-contained screening plants. Costs associated with processing and screening include crushing, additional conveyance systems, periodic screen replacement, on-site generators, and fuel. It is assumed at this time that two processing plants will be dedicated to processing aggregate solely from the DTR, and two plants dedicated to aggregate solely from the MRR. The fifth plant would be shared between areas. The unit price for processing is estimated to be $\$0.81/yd^3$ of bulked material.

Excavated material is assumed to be loaded using a 5 yd^3 front-end loader into a 20 yd^3 capacity dump truck with a maximum 20-mile round trip haul route. The unit price for hauling is estimated to be $\$13.83/yd^3$.

Excavation increases the volume of material by changing the compaction and sorting of the material. It is therefore necessary to use a bulking factor

to determine the volume of material that will be created by the excavation itself. The bulking factor is defined as:

Bulking Factor = Volume after Excavation/Volume before Excavation

The bulking factor for gravel is 1.05 (Wilkinson 1997). This would imply a material with less than 30 percent fines and sand. A mixture of sand and gravel has a factor of 1.15. Given the material present in the DTR and based on engineering experience, a bulking factor of 1.10 (or 10% volume expansion) was used for this cost analysis.

Table 3-6 lists the calculated volumes and associated costs for excavation, processing, and hauling tailings material from the MRR and DTR.

Table 3-6. Estimated Costs to Excavate, Process, and Haul Tailings from the DTR and MRR.

Reach	Excavation Volume (yd^3)	Bulked Volume (yd^3)	Excavation Cost ($)	Hauling Cost ($)	Processing Cost ($)	Total ($)
Riparian Corridor of the DTR	3,220,000	3,550,000	$12,770,000	$49,100,000	$2,862,500	$64,800,000
Merced River Ranch	3,215,000	3,540,000	$12,750,000	$48,960,000	$2,862,500	$64,600,000

4 ACKNOWLEDGEMENTS

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6 FIGURES

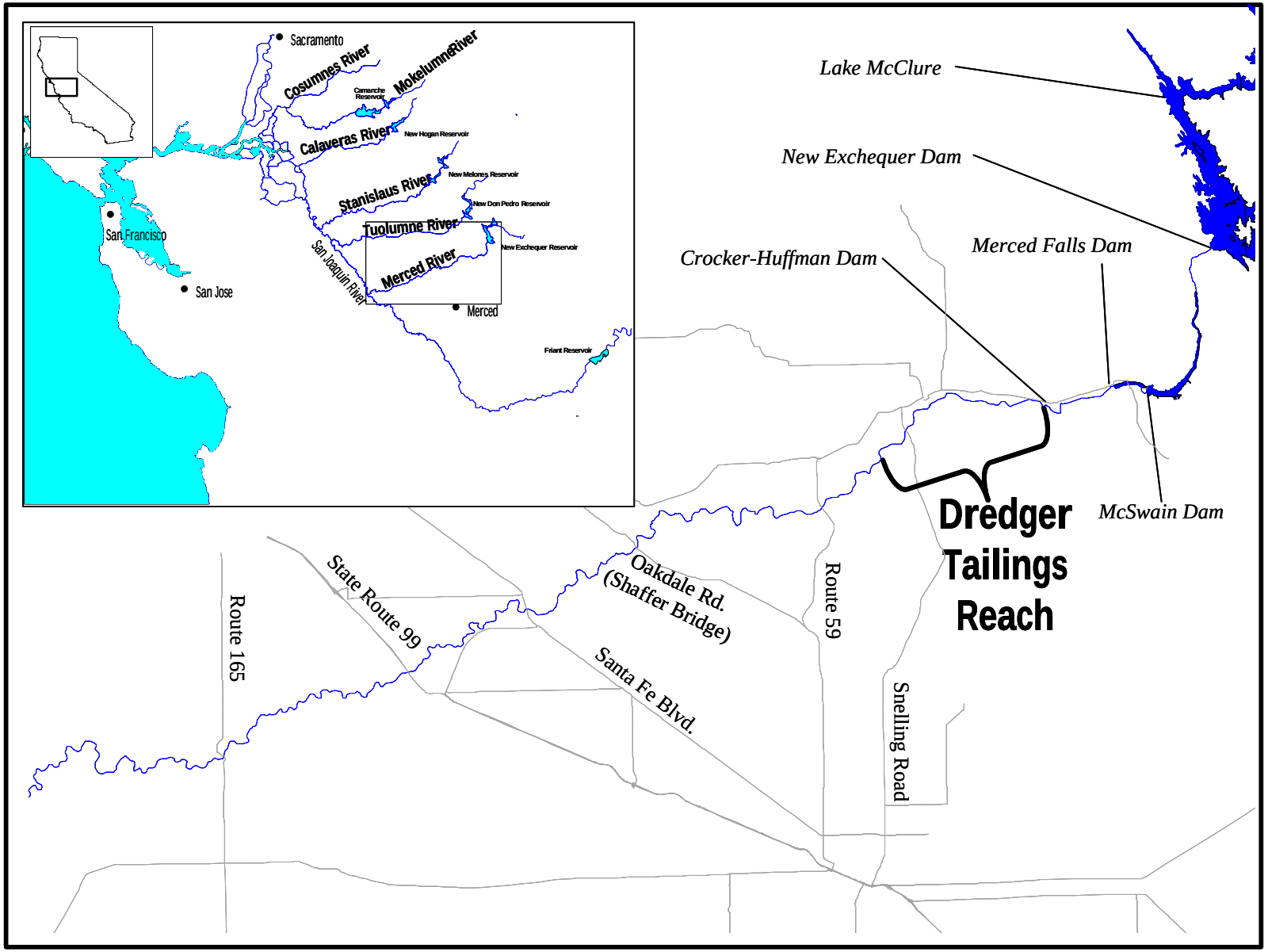

FIGURE 1
Vicinity of the Merced River and the Dredger Tailings Reach.

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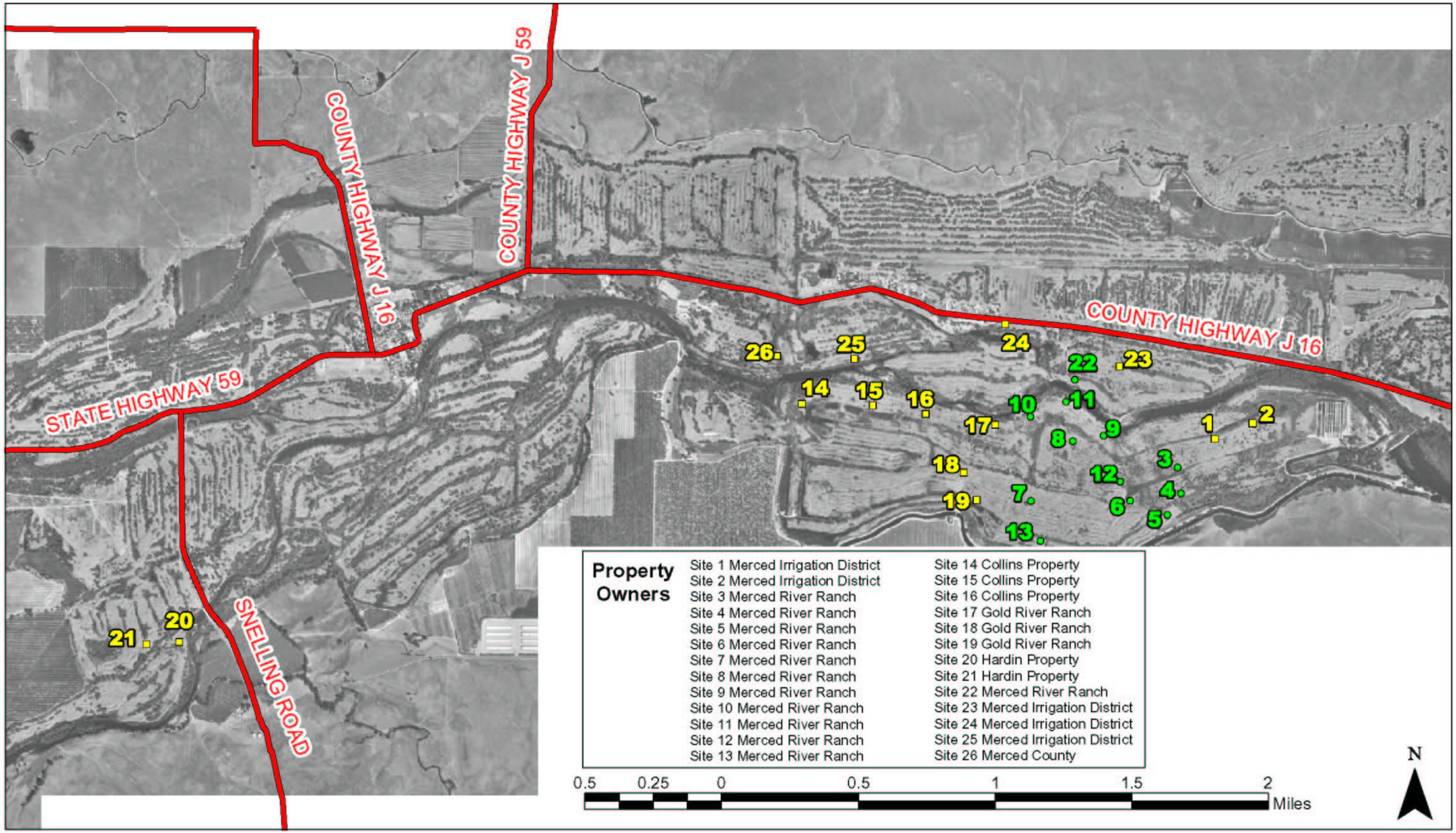

FIGURE 2
Locations of sampling sites within the Merced River Ranch property (green) and Dredger Tailings Reach (yellow).

FIGURE 3
Photographs of excavator with bucket load of tailings sample (top) and a sample that has been placed on the ground for subsampling (bottom).

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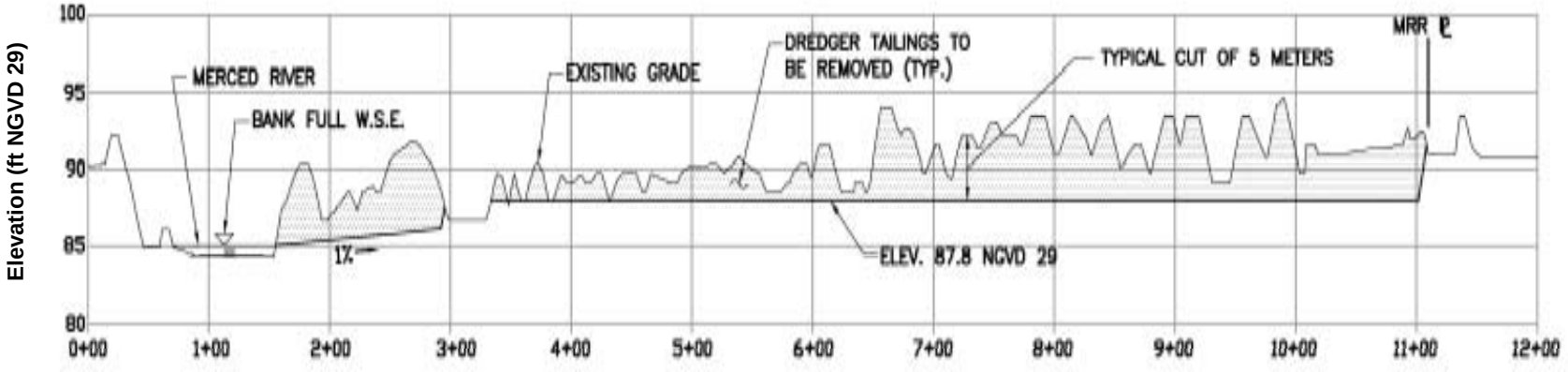
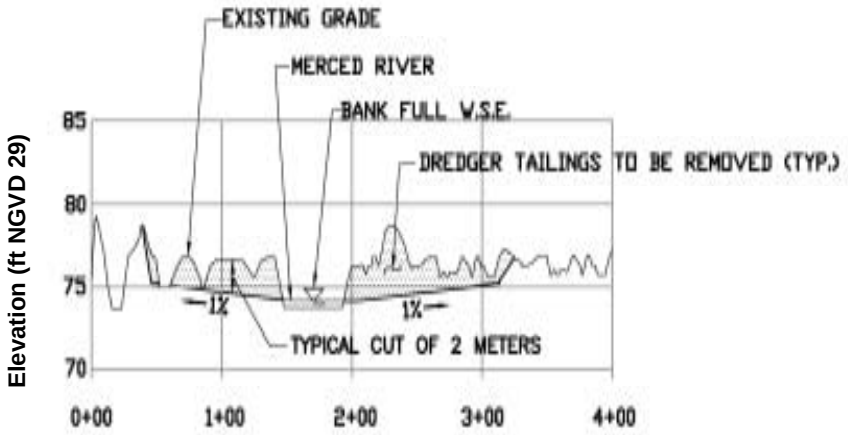
FIGURE 4
Photograph of crew separating and weighing material 76.2 mm and greater from a composite sample.



Typical Cross-section
Merced River Ranch Property



Typical Cross-section
Dredger Tailings Reach

FIGURE 5
Typical cross-sections of potential post-restoration floodplain excavation elevations used to calculate the volume of tailings on the Merced River Ranch (top) and along the riparian corridor of the Dredger Tailings Reach (bottom).

FIGURE 6
Photographs of the heterogeneous mixed rock seen throughout the tailings piles (top) and the layer of sand reached at 10 feet below ground surface at Site 24 (bottom).

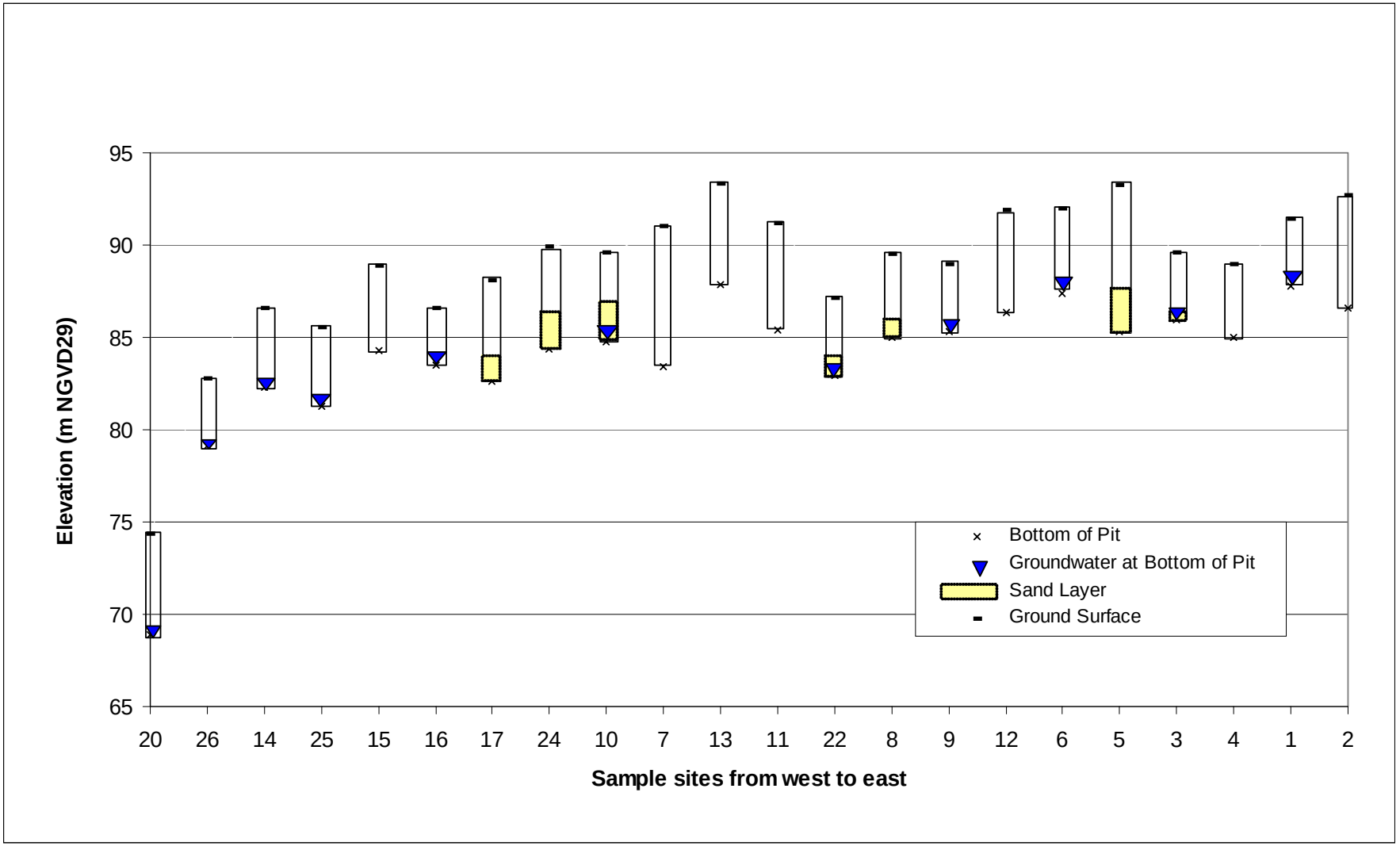


FIGURE 7
Elevation and stratigraphy of sample sites. Refer to Figure 2 for sample locations. Sites 18, 19, 21, and 28 have no elevation data as they were outside the boundary of the floodplain topography data.

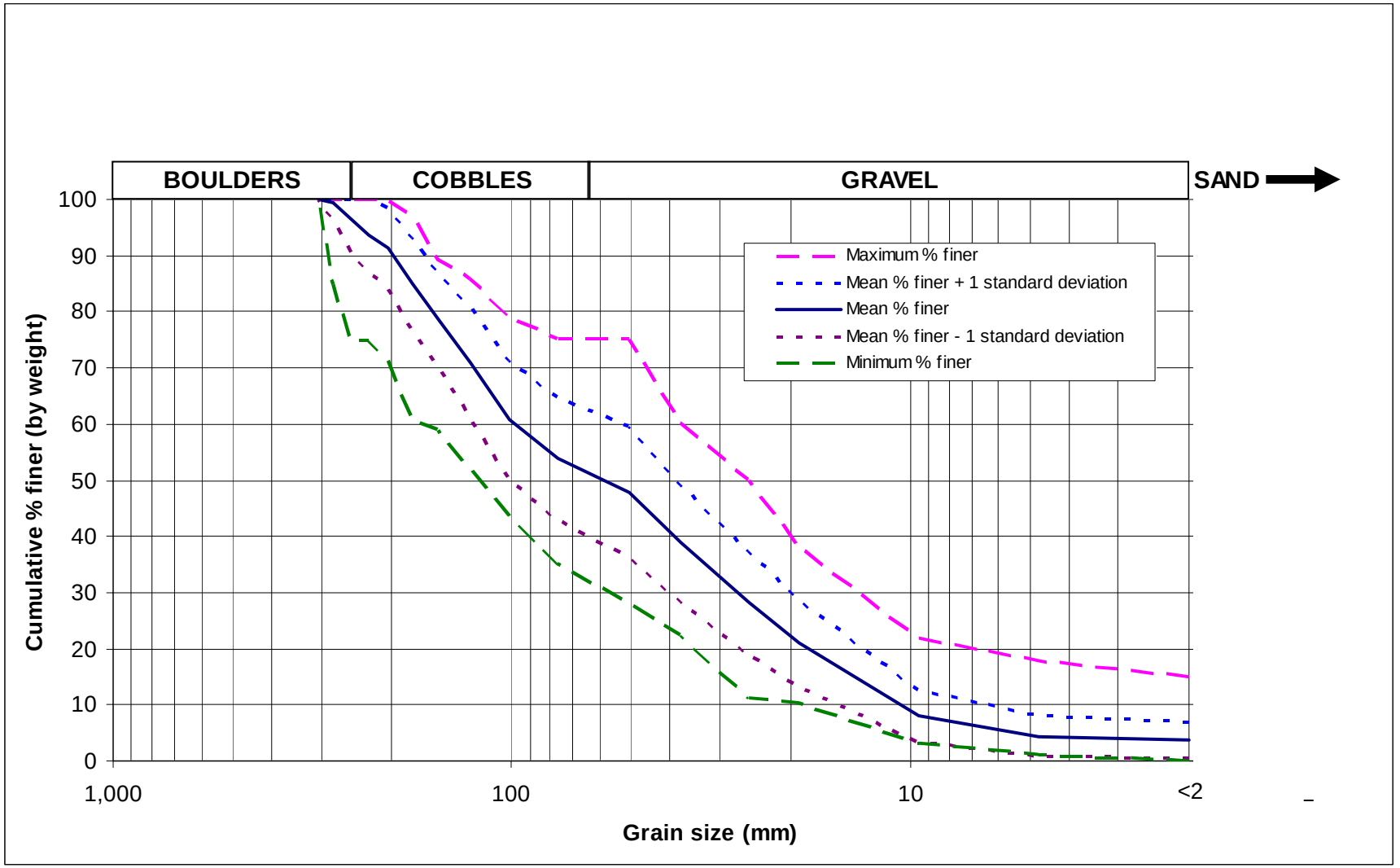


FIGURE 8
Particle size distribution for all 26 sampling sites combined. Particles less than 2 mm in diameter are not differentiated.

Appendix A
SAMPLING SITE FIELD NOTES, PARTICLE SIZE DISTRIBUTIONS, AND PHOTOGRAPHS

Appendix B
LABORATORY PARTICLE SIZE DISTRIBUTION REPORTS