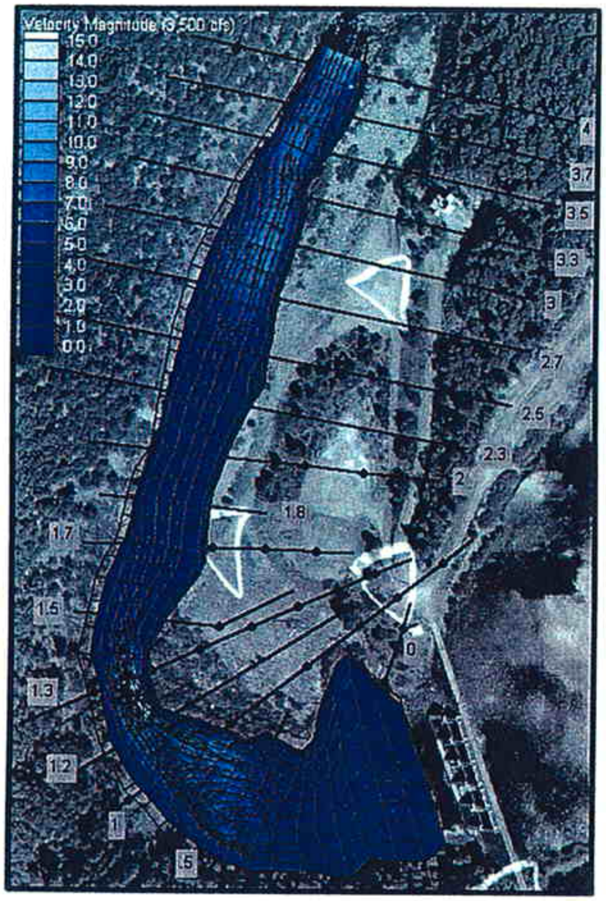
PCWA-L-106

INDIAN BAR SEDIMENT DISPOSAL SITE STUDY

Ralston Afterbay, California



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1. INTRODUCTION

Since its construction in the early 1960s, the Ralston Afterbay Reservoir has lost approximately 39 percent of its storage capacity due to sedimentation (Bechtel, 1997). To prevent further sediment buildup in the Afterbay, a Sediment Pass-Through (SPT) operation has been suggested. By changing the spillway and low-level outlet operations during floods, the SPT concept would reduce the amount of sediment deposited in the reservoir during floods. Coarser sediment (cobbles and gravel) deposited in the upstream end of the reservoir is too large to be mobilized by the SPT operation. In an effort to re-entrain this larger material and to provide a source of spawning gravels to the downstream channel, it may be dredged and relocated on Indian Bar (downstream from the Ralston Afterbay Dam) where it can be re-entrained by reservoir releases.

The Middle Fork of the American River between Ralston Afterbay dam and the North Fork of the American River confluence is a very steep, coarse grained, and canyon-bound river even though there are spatially localized alluvial segments along its course. In canyon-bound rivers, the hydraulic characteristics of both low and flood flows are controlled by localized contraction and expansion zones; these zones are the major controls on sediment transport and deposition within the system (O'Connor et al., 1986; Harvey et al, 1993; Mussetter and Harvey, 1994). Geomorphological characteristics of the proposed disposal site and its reported behavior in previous flood events (including the 100-year flood event in 1997) indicate that its hydrodynamics are typical of constrained canyon-bound rivers (Harvey et al., 1993; Harvey et al., 1995; Montgomery and Buffington, 1997). The Indian Bar Sediment Disposal Site lies within this canyon-bound system on the inside of a bend below the Ralston Afterbay Dam, where the potential for re-entrainment of disposed sediment is actually quite low. The purpose of this investigation was to develop a plan for disposal of the dredged material at the Indian Bar site in a manner that would facilitate its re-entrainment into the Middle Fork of the American River downstream from the site during SPT operations.

Mussetter Engineering, Inc. (MEI) was retained to develop and evaluate potential Indian Bar Sediment Disposal Site configurations. Tasks A.1 through A.6 of the Jones & Stokes Environmental and Engineering Services for Sediment Pass-Through and Ongoing Environmental Work at Ralston Afterbay Dam Scope of Services (Jones & Stokes, 2000) outline the range of this work, which includes:

- Collection and evaluation of existing data
- Development of a 2-D hydrodynamic model
- Preliminary modeling and verification
- Development and evaluation of sediment disposal site alternatives
- Final modeling and refinement of a preferred alternative
- Document preparation.
-

Completion of these tasks will allow MEI to evaluate the potential downstream environmental benefits of coarse sediment entrainment from the Indian Bar Sediment Disposal.

2. COLLECTION AND EVALUATION OF EXISTING DATA

A field reconnaissance of the site was conducted by Dr. Robert A. Mussetter and Dr. Michael D. Harvey in October 2000. Mapping of the site was provided to Mussetter Engineering, Inc. (MEI) in digital (AutoCAD) and hard copy formats. The 2.5-foot contour mapping by S&E Engineering Inc. was generated from aerial photography by Cartwright Aerial Surveys, Inc. (August 2000). Since the mapping was based on aerial photography, the portion of the riverbed that was underwater at the time of the photography was not mapped. S&E Engineering conducted a bathymetric survey to obtain in-channel topography in December 2000. The bathymetric data were provided to MEI in a 3-D coordinate file.

A gradation curve showing the size of the coarse material which may be relocated to the Indian Bar Sediment Disposal Site from the delta in the upstream reservoir was obtained from the Bechtel (1997) report (**Figure 1**). Sediment sampling location maps from the Bechtel report indicated that sample TP-5 would be representative of the larger material deposited in the upstream end of the reservoir. This sample had a D_{84} (size for which 84 percent of the sample is finer) of 112 mm and a median (D_{50}) size of 80 mm.

A one-dimensional (1-D) HEC-RAS hydraulic model was created by Bechtel Inc. to evaluate the hydraulics of the Indian Bar area under existing conditions (Bechtel, 1996). Output from this model including water-surface elevations, depth and velocity of flow at seven cross sections in the vicinity of Indian Bar was provided to MEI. **Figure 2** shows the locations of the original Bechtel cross sections.

3. TWO-DIMENSIONAL MODEL DEVELOPMENT

The MEI-J&S Team concluded that a 1-D model would be incapable of accurately representing the complex hydraulics of the reach of the Middle Fork of the American River downstream of Ralston Afterbay Reservoir. Previous comparison of the results of one-dimensional and two-dimensional models in canyon-bound rivers has indicated that for analysis of site-specific sediment entrainment, two-dimensional (2-D) modeling is required (Mussetter et al., 2001 in press). A 2-D hydrodynamic model of the reach along the Indian Bar Disposal Site was created from the available topography using the BOSS SMS software. SMS acts as a graphical interface for the U.S. Army Corps of Engineers RMA2 (Version 4.35) model, a finite element hydrodynamic numerical model that computes depth, velocity and direction of flow at nodes within a mesh that represents the site. The topographic mesh for the existing conditions Indian Bar model contains 673 elements and 2022 nodes. Using the Bechtel HEC-RAS model output at cross section 4 as the downstream water-surface boundary condition, the existing conditions Indian Bar 2-D model was run at several discharges within the range of previously identified SPT flows.

To satisfy environmental, operational, and SPT requirements, the Bechtel (1997) report identified an SPT trigger discharge of 3,500 cfs. Based on the number of days a specific discharge was exceeded in the 25-year hydrologic record from 1970 to 1995, Bechtel identified 8,000 cfs (exceeded 23 days in the 25-year period) as the high end of SPT discharges. The hydraulic analysis focused on the SPT reservoir outflows of 3,500, 5,000, and 8,000 cfs. Hydrologic analysis of the Middle Fork and North Fork of the Middle Fork of the American River gages below the Ralston Afterbay Dam indicated that these flows are 1.3-, 1.6-, and 2.2-year recurrence-interval events, respectively. Based on the same hydrologic analysis, a 5-year discharge from the Ralston Afterbay Dam would be about 17,700 cfs (10-year, 25-year, 50-year, and 100-year discharges would be 29,100, 50,700, 73,600, and 105,500 cfs respectively).

Output from the 2-D model was used to determine average and local flow velocities and water-surface elevations. The velocities and water-surface elevations served as input parameters for the incipient motion calculations (i.e., the discharge where sediment mobilization commences) and sediment entrainment analysis for the Indian Bar Sediment Disposal Site.

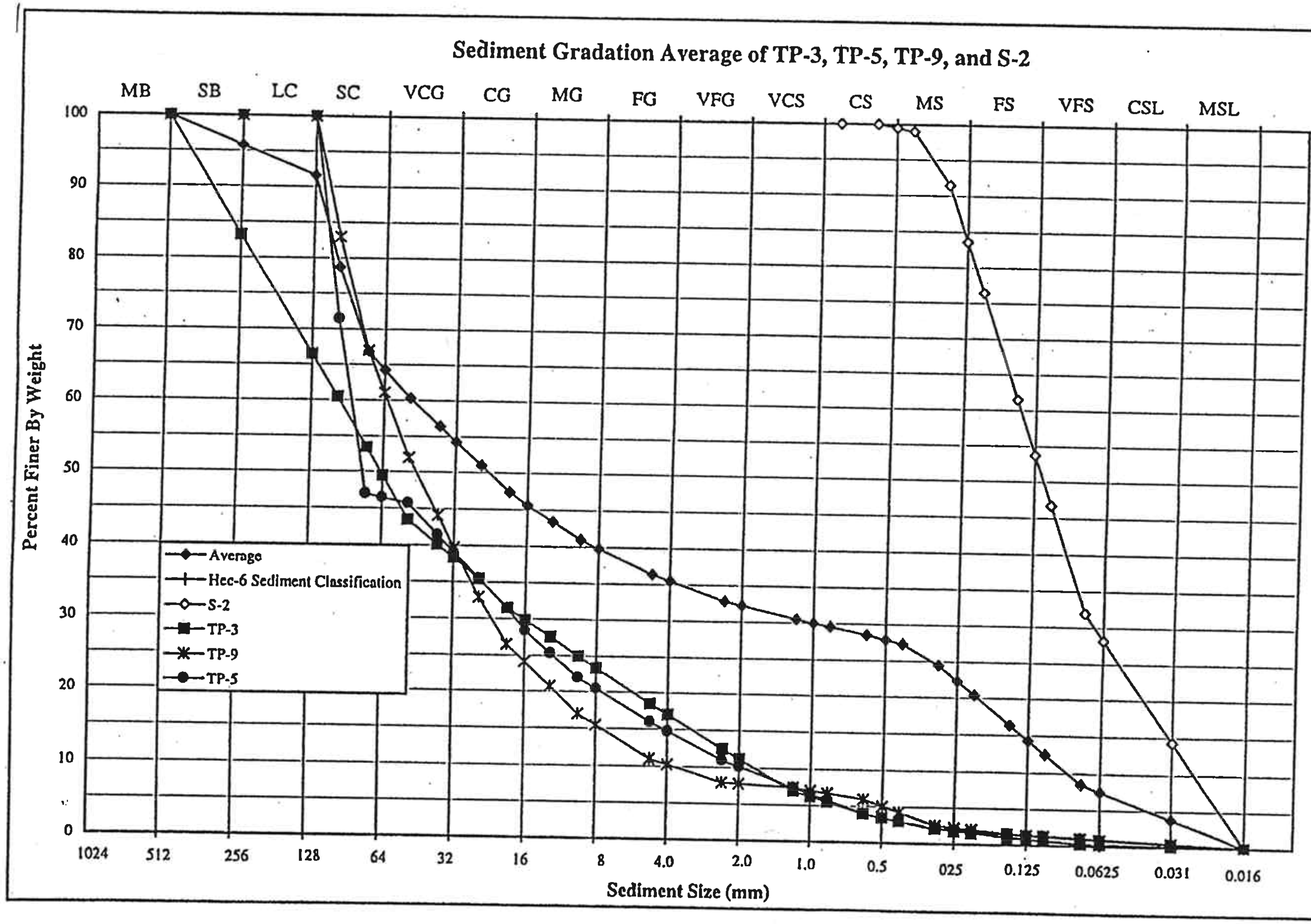

Figure 1. Sediment gradation curves for Ralston Afterbay deposits.

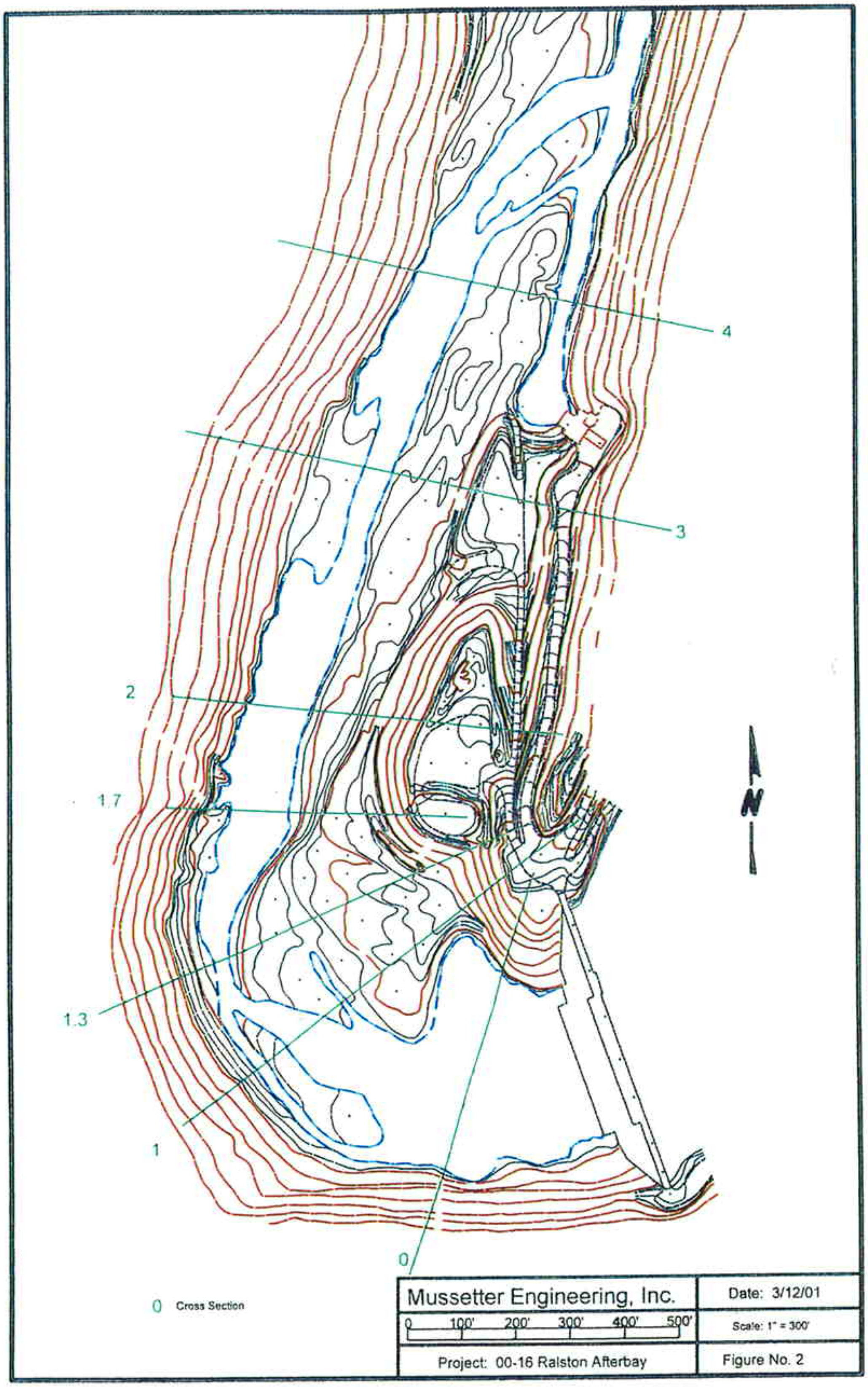

Figure 2. Map showing locations of Bechtel (1996) HEC-RAS cross sections.

4. MODELING AND VERIFICATION

To check the calibration of the existing conditions RMA2 model, the model results were compared to Bechtel's HEC-RAS output at Cross Sections 1, 1.3, 1.7, 2, 3, and 4. Table 1 summarizes the differences between the 2-D RMA2 and the 1-D HEC-RAS models. In general, the 2-D model predicts slightly higher water-surface elevations than the 1-D HEC-RAS model. The differences vary from –0.1 feet to 0.7 feet at 3,500 cfs, -0.4 to 0.5 feet at 5,000 cfs, and -0.6 to 0.6 feet at 8,000 cfs. At 3,500 cfs, the 2-D model yields a higher water surface at all cross sections except 1.7. At 5,000 cfs, the 2-D water surface is higher at all cross sections except 1.3 and 1.7. At 8,000 cfs, the 2-D model produces higher water surfaces for the downstream portion of the model (cross sections 2, 3, and 4) and lower water surfaces for the upstream end (Cross Sections 1, 1.3, and 1.7). The lack of cross sections in the 1-D model to adequately represent the pool and chute sequence between Cross Sections 1.3 and 1.7 may explain the overestimation of water-surface elevations in this area. Although data with which to directly calibrate either of the models were not available, the input values for channel roughness and eddy viscosity are within a physically reasonable range and the agreement between the 1-D and 2-D model results is also reasonable.

Table 1. Comparison of 2-D and 1-D outputs.

Cross Section	RMA2 Water Surface – HEC-RAS Water Surface at:		
	3,500 cfs	5,000 cfs	8,000 cfs
4	0.3	0.3	0.6
3	0.2	0.1	0.1
2	0.7	0.5	0.5
1.7	-0.1	-0.4	-0.6
1.3	0.5	-0.1	-0.3
1	0.7	0.2	-0.3

Figures 3 through 5 show velocity vectors and magnitudes from the existing condition RMA2 model at discharges of 3,500, 5,000, and 8,000 cfs, respectively. The upstream part of the project reach shows low velocities in the vicinity of Cross Section 0 (the Ralston Afterbay stilling basin). Higher velocities ranging from 6 to 18 feet per second characterize the chute from Cross Sections 0.5 to 1.5. A pool exists between Cross Section 1.5 to 2.5, and is shown by the lower velocities (0 to 6 feet per second) in this area. A small chute caused by a very coarse-grained bar that constricts the left side of the channel at Cross Sections 2.5 to 3.3 marks the beginning of another high velocity region in the downstream part of the study reach. Velocities ranging from 6 to 15 feet per second can be seen in the downstream cross sections.

5. SEDIMENT DISPOSAL SITE CONFIGURATION

A preliminary layout for the disposal site was developed (**Figure 6**) using the entire bar up to the edge of the hillside that bounds the right side of Indian Bar. Alternatives to this site configuration that were considered included disposing material farther out into the river, piling the material higher, and screening to reduce the size of the disposed material.

The disposal site was designed to begin at an elevation 2 feet under the existing conditions 2,000 cfs water-surface elevation with the goal of mobilizing disposed material in the lower

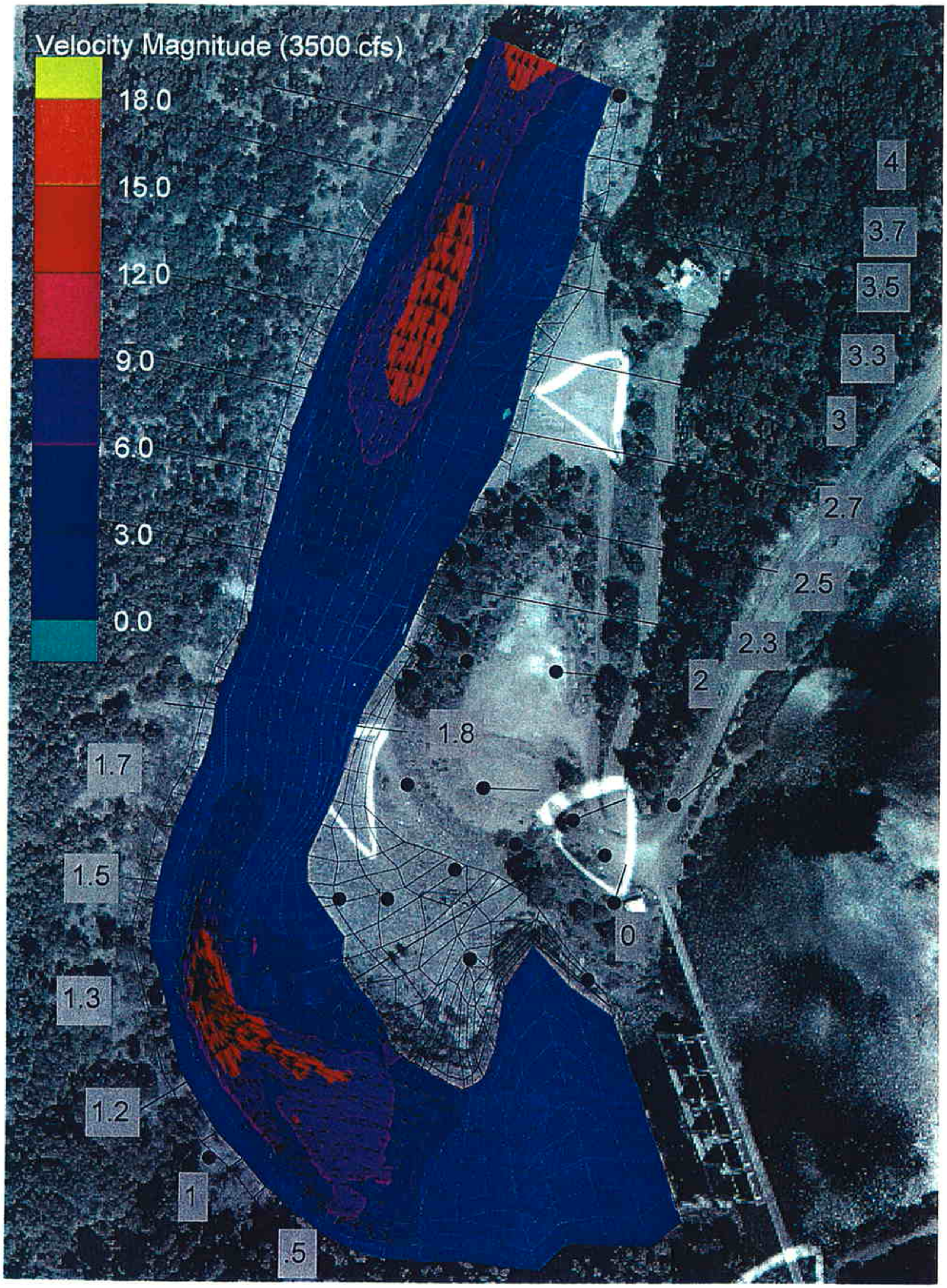

Figure 3. Map of Indian Bar Site existing conditions showing the velocity magnitudes and vectors at a discharge of 3,500 cfs.

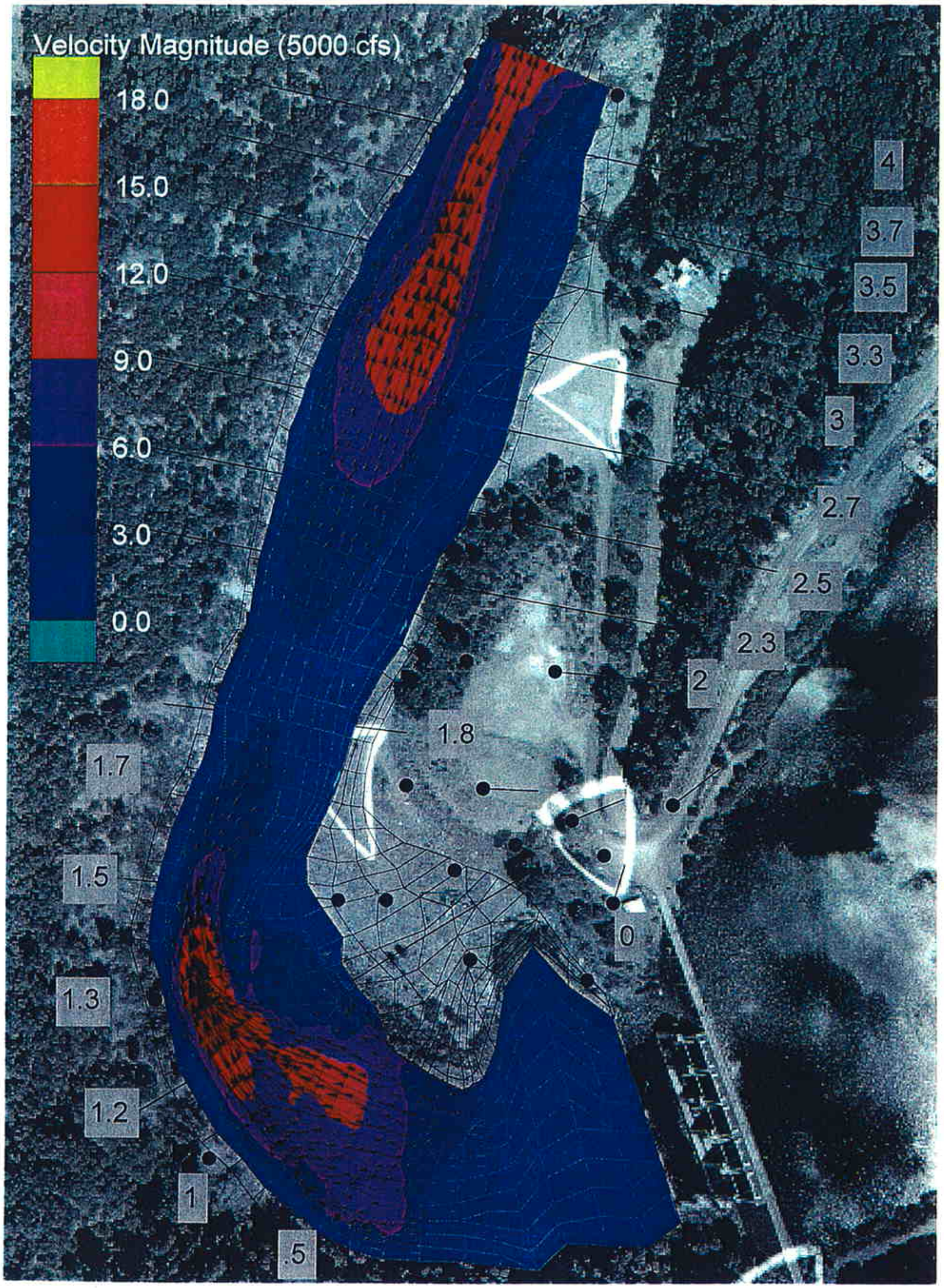

Figure 4. Map of Indian Bar Site existing conditions showing the velocity magnitudes and vectors at a discharge of 5,000 cfs.

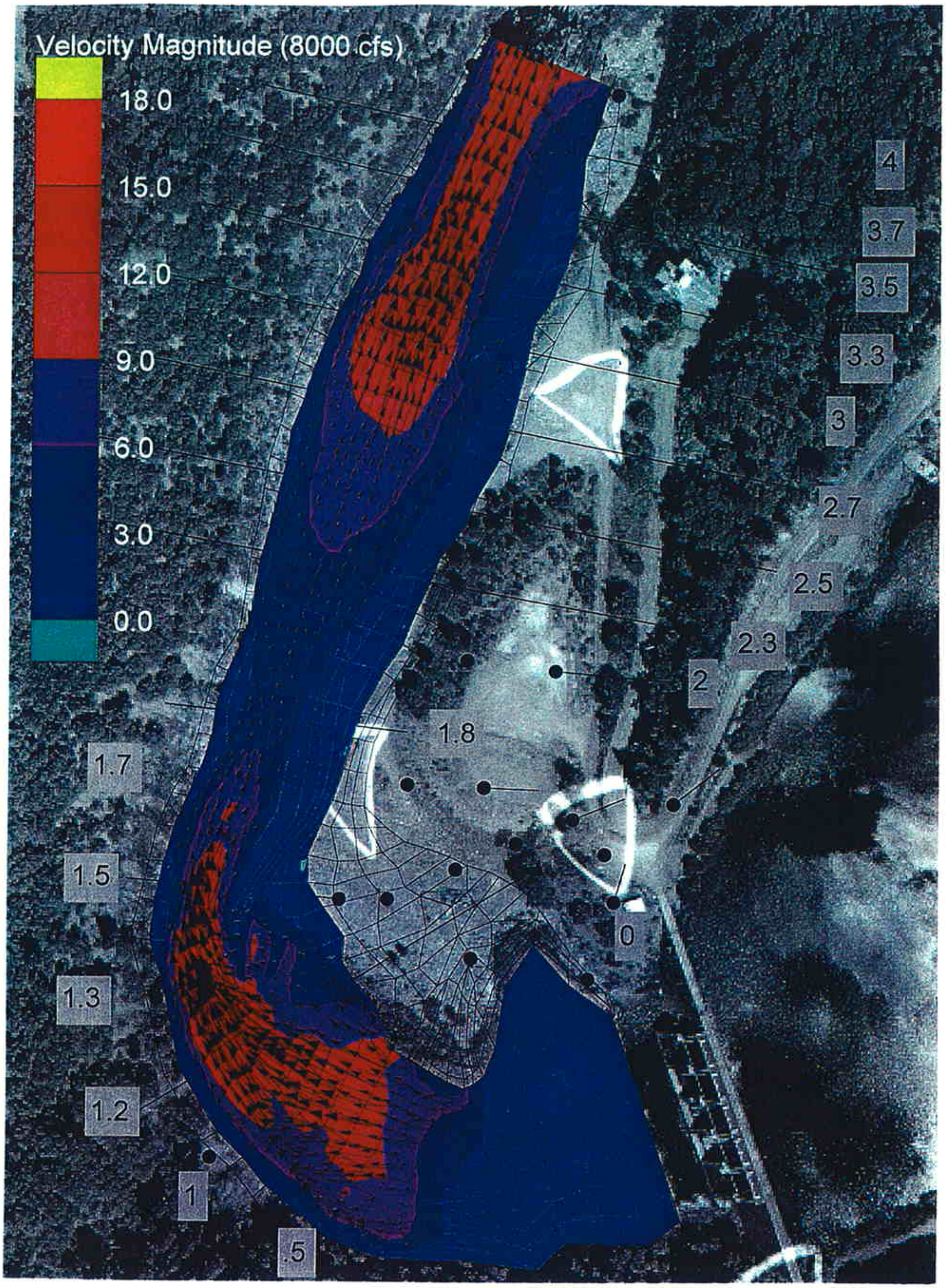

Figure 5. Map of Indian Bar Site existing conditions showing the velocity magnitudes and vectors at a discharge of 8,000 cfs.

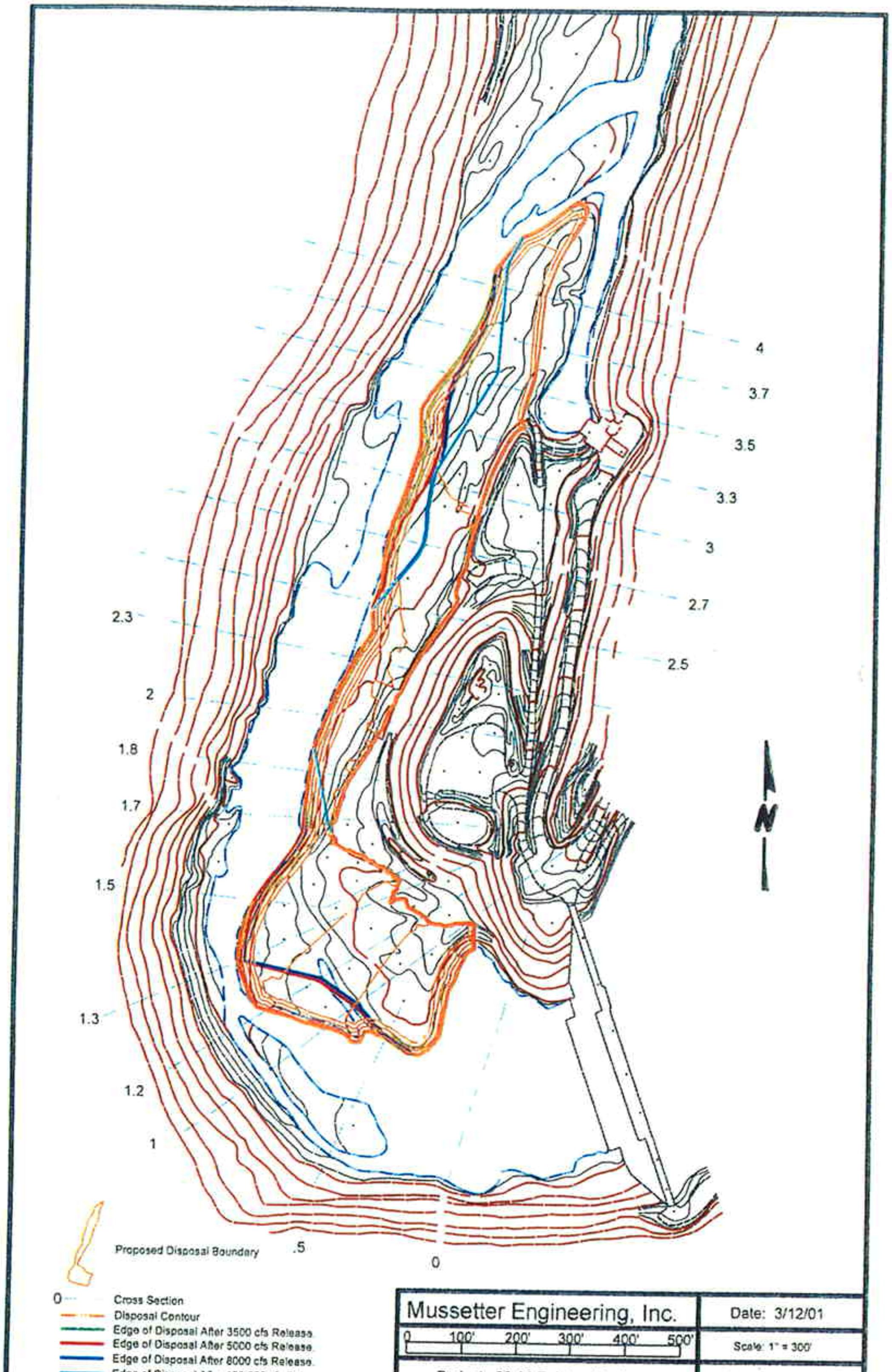

Figure 6. Map of Indian Bar Site showing the outline of the proposed disposal site and boundaries of entrained material at 3,500, 5,000, 8,000, and 105,500 cfs.

range of the identified SPT flows. The streamside embankment was set at an angle of 30° (estimated angle of repose) up to an elevation that would allow for storage of 75,000 cubic yards of material. **Figure 7** is a 3-dimensional rendering of the proposed disposal site configuration that has a volume of approximately 75,710 cubic yards.

6. FINAL MODELING

To evaluate the potential for entraining material from the Indian Bar Sediment Disposal Site, the RMA2 model was modified to represent the disposal site geometry. The dimensionless shear stress distribution along the reach was calculated using results from the modified RMA2 model. The results were then compared with the critical shear stress for the range of particle sizes that are likely to be present in the disposal site.

6.1. Critical Shear Stress

The critical shear stress represents the shear stress at which the particles are just at the verge of motion. Because large particles are more easily mobilized than small interlocked particles; once the critical shear stress for the median particle size is exceeded, the bed is mobilized and all sizes up to five times the median size are capable of being transported by the flow (Parker et al., 1982; Andrews, 1984). The critical shear stress for a given particle size can be estimated using the Shields (1936) relation:

$$\tau_c = \tau_{*c}(\gamma_s - \gamma) D_{50} \qquad (6.1)$$

where τ_c is the critical shear stress, τ_{*c} is the dimensionless critical shear stress, γ_s is the unit weight of sediment (~165 lb/ft^3), γ is the unit weight of water (62.4 lb/ft^3), and D_{50} is the median particle size. Values for τ_{*c} for the median particle size of the surface bed material range from 0.03 (Meyer-Peter, Muller, 1948; Neill, 1968) to 0.06 (Shields, 1936). Detailed evaluation of Meyer-Peter, Muller's data and more recent studies (Parker et al., 1982; Andrews, 1984) indicate that a value of 0.03 is more reasonable for true incipient motion in gravel and cobble bed streams. Neill (1968) concluded that a dimensionless shear value of 0.03 corresponds to true incipient motion of the bed material matrix while 0.047 corresponds to a low but measurable transport rate. Based on these observations, a τ_{*c} of 0.04 was considered a conservative shear stress value to define the point of incipient entrainment.

6.2. Grain Shear Stress

The bed shear stress due to grain resistance (τ') is used in the incipient motion and bed material transport analysis because it is a better descriptor of near-bed hydraulic energy in gravel-cobble bed streams than the more commonly used total shear stress. Grain shear stress eliminates the effects of flow resistance due to irregularities in the channel boundary, nonlinearity of the channel, variations in channel width, and other factors that contribute to the total flow depth, but not the energy available to move individual particles on the channel bed (Einstein, 1950; Mussetter, 1989). The grain shear stress (τ') is computed from the following relation:

$$\tau' = \gamma Y' S \qquad (6.2)$$

where Y' is the portion of the total hydraulic depth associated with grain resistance (Einstein, 1950) and S is the energy slope at the cross section. The value of Y' is computed by iteration of the semilogarithmic velocity profile equation:

Figure 7. Three-dimensional rendering of sediment disposal site on Indian Bar.

$$\frac{V}{V_*'} = 5.75 + 6.25\log(\frac{Y'}{K_s}) \tag{6.3}$$

where V is the mean velocity at the cross section, K_s is the characteristic roughness height of the bed (assumed to be 3.5 D_{84}, Hey 1979), and V_*' is the shear velocity due to grain resistance given by:

$$V_*' = \sqrt{gY'S} \tag{6.4}$$

6.3. Dimensionless Grain Shear Stress

The dimensionless grain shear stress is defined by the ratio of the grain shear to critical shear:

$$\tau_*' = \frac{\tau'}{\tau_c} = \frac{\gamma Y'S}{\tau_{*c}(\gamma_s - \gamma)D_{50}} \tag{6.5}$$

When $\tau_*' < 1$, the shear stress is insufficient to mobilize the bed material, and when $\tau_*' > 1$, bed mobilization is indicated. At dimensionless shear stresses in the range between 1.0 and approximately 1.5, bed material transport rates are low, but measurable (Neill, 1969) and bed adjustment will occur relatively slowly. At higher shear, transport can be significant and bed adjustment rapid.

Substitution of a slope solution of the Manning's equation:

$$S = \frac{V^2 n^2 (0.4504)}{Y^{4/3}} \tag{6.6}$$

into Equation 6.5, and simplification yields:

$$\tau_*' = \frac{0.274 V^2 n^2}{\tau_{*c} D_{50} Y'^{1/3}} \tag{6.7}$$

The SMS data calculator module was used to solve Equation 6.7 with values of D_{50} = 143 mm, n = 0.035, and τ_{*c} = 0.04. The channel D_{84} of 200 mm was based on field observation and visual estimation. Using a similar gradation to that of the placement material, this yields a D_{50} of 143 mm.

The resulting dimensionless shear stress distributions for the range of SPT discharges of 3,500, 5,000, and 8,000 cfs are shown in **Figures 8, 9, and 10**, respectively. Velocity vectors are superimposed on the dimensionless grain shear contours in these plots. Note that areas of high velocity (Cross Sections 0.5 to 1.5 and 2.7 to 4) also have high dimensionless grain shear. These are areas where mobilization of the disposal material can be expected. Conversely, areas of low velocity (Cross Sections 0, and 1.7 to 2.5) have low dimensionless grain shear. Velocities and dimensionless grain shear values along the edge of the proposed placement followed the same trends.

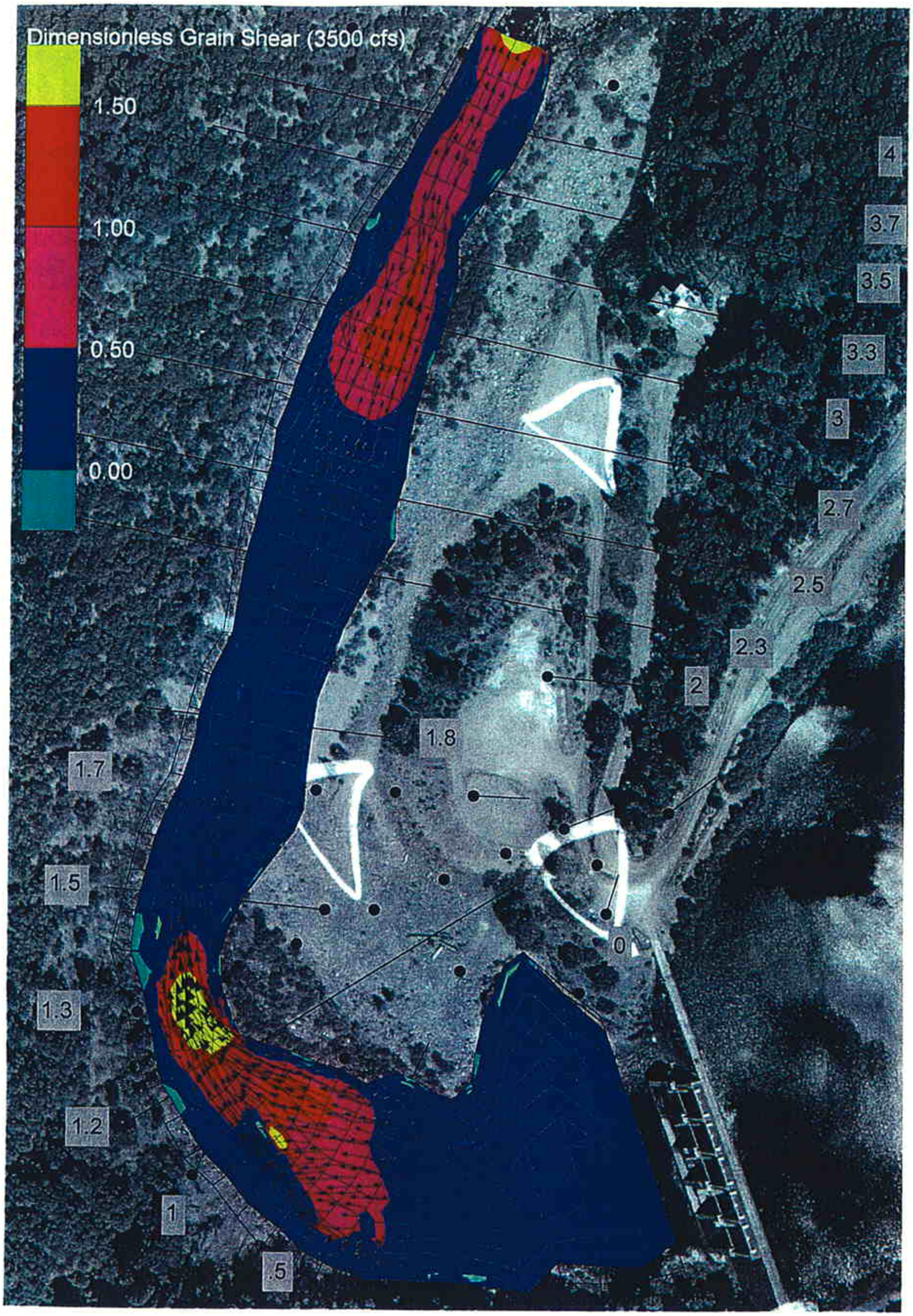

Figure 8. Map of Indian Bar Site showing the distribution of dimensionless shear stress and velocity vectors at a discharge of 3,500 cfs.

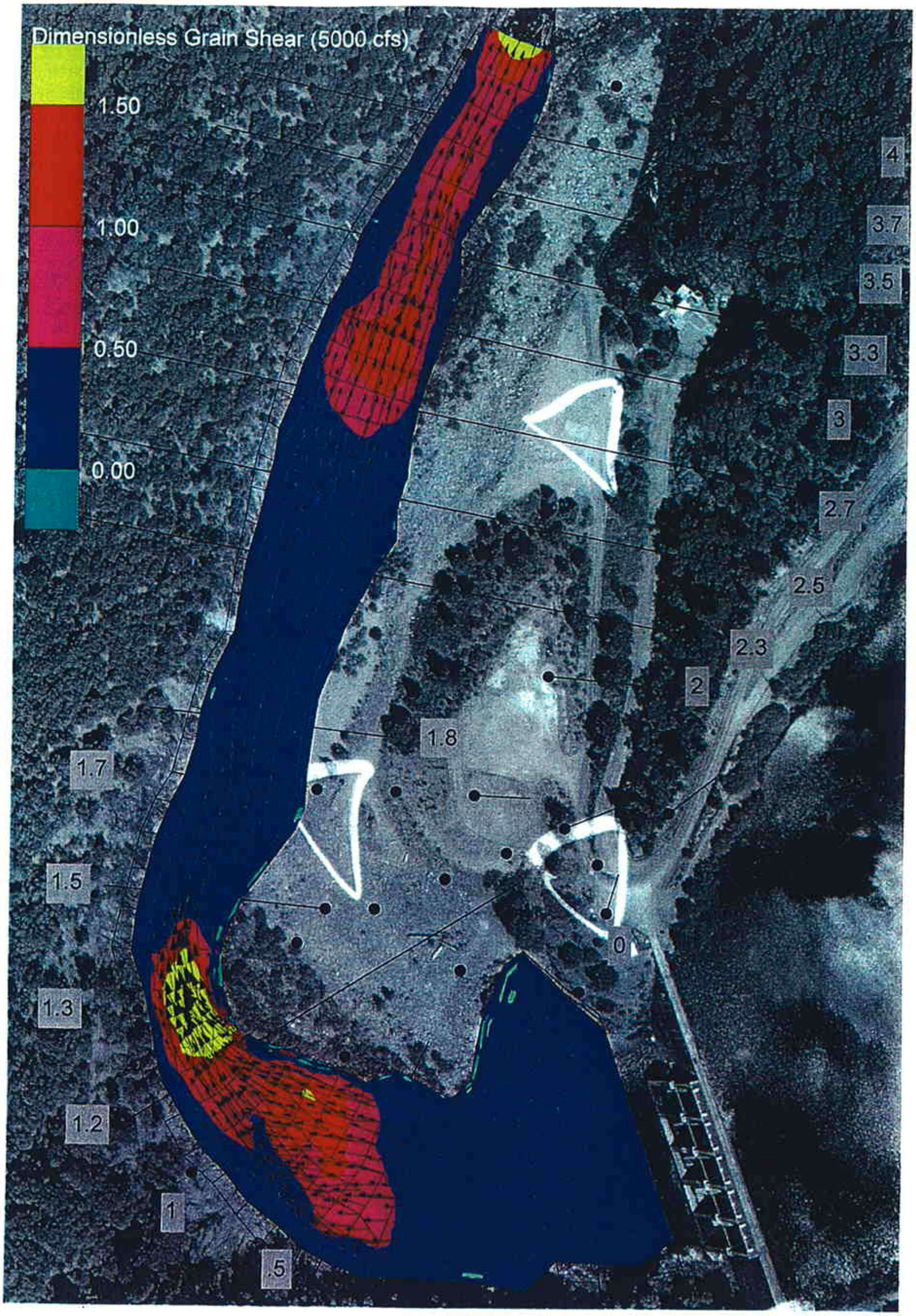

Figure 9. Map of Indian Bar Site showing the distribution of dimensionless shear stress and velocity vectors at a discharge of 5,000 cfs.

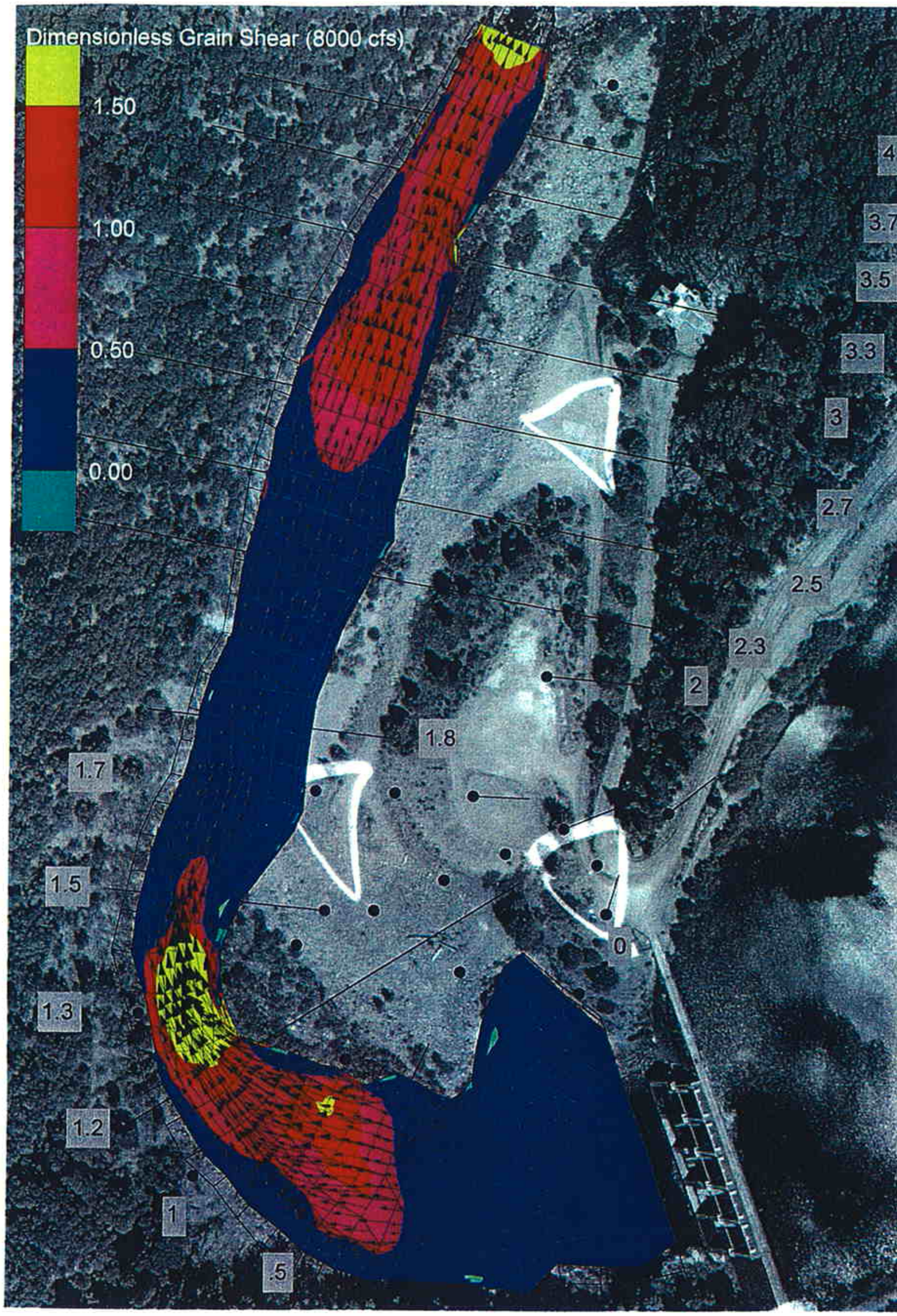

Figure 10. Map of Indian Bar Site showing the distribution of dimensionless shear stress and velocity vectors at a discharge of 8,000 cfs.

To determine the extent of possible disposal material mobilization at the SPT flows, Equations 6.3 and 6.4 were iteratively solved with local bar velocities and dimensionless grain shear stresses that were developed along the disposal site at each of the 17 cross sections shown in Figure 6. For a given discharge, dimensionless grain shear was calculated along the Indian Bar portion of each cross section. The values of dimensionless grain shear were computed and evaluated 0.25, 0.50, and 0.75 times the distance between the toe of the proposed sediment disposal site and the water's edge under existing conditions. If the computed critical dimensionless grain shear was greater than 0.04 (see the Critical Shear Stress discussion, page 4), disposal material was considered entrainable at that location. The critical dimensionless grain shear value of 0.04 is conservative in comparison to the 0.03 value Parker et al., (1982) determined for incipient motion in gravel- and cobble-bed streams. The river should react to critical dimensionless grain shear values greater than 0.04 by widening (entraining disposal material) until the value decreases to less than 0.04.

To estimate the degree of possible entrainment at discharges higher than the SPT range of flows, two HEC-2 models (one of the existing Indian Bar site, one of the site including the proposed Indian Bar Sediment Disposal) were created. The 100-year discharge of 105,500 cfs was simulated with these HEC-2 models and a similar evaluation of critical dimensionless grain shear was used to determine the extents of entrainment. A log-linear relationship between river discharge (cfs) and coarse sediment entrainment (cubic yards) was developed, and used to determine the expected volumes of entrainment at 5-, 10-, 25-, and 50-year discharge events.

In this manner the edge of the placement after 3,500, 5,000, 8,000, and 105,500 cfs discharges was determined. The expectable extents of entrainable disposal material resulting from the range of SPT discharges, and the 100-year discharge is represented by the green, red, blue, and light-blue lines in Figure 6. **Figures 11 through 14** are 3-dimensional renderings of the proposed disposal site after entrainment of material resulting from 3,500, 5,000, 8,000, and 105,500 cfs discharges. Cross-sectional views of Cross Sections 1.2 and 3 are shown in **Figures 15 and 16**. The computed water-surface elevations at the three SPT flows and the 100-year discharge under existing and proposed conditions are also shown in these figures. The disposal site causes a backwater condition at these cross sections; note the higher water-surface elevations under the proposed condition. The lateral erosion of the disposed material under these discharges is represented by green (3,500 cfs), red (5,000 cfs), blue (8,000 cfs), and light blue (105,500 cfs) lines. While the 100-year discharge is expected to remove the entire upstream portion of the Indian Bar Sediment Disposal (Cross Sections 0.5 to 1.7), the 105,500 cfs flow is expected to remove only slightly more of the Disposal at Cross Section 3 than the 8,000 cfs flow would.

It should be noted that the RMA2 results indicate an increase in the water-surface elevation at the base of the dam of 0.1 feet at 3,500 cfs, 0.2 feet at 5,000 cfs, and 0.30 feet at 8,000 cfs over the existing conditions model. This result indicates that the disposal site geometry does create a slight backwater and will raise the tailwater elevation slightly in the pool below the dam. The high flow HEC-2 results indicate a 5-foot increase in water- surface elevation at the base of the dam at 105,500 cfs over the existing conditions model. As the coarse material that makes up this part of the disposal site is entrained (it should be entirely entrained), the effect of the disposal site on increasing the water-surface elevation will diminish.

Assuming a sufficient reservoir release to maintain reasonable coarse sediment concentrations, and assuming that the streamside embankment of the sediment disposal site will not become armored; 8,530 cubic yards of the 75,710 cubic yards disposal could be removed under a 3,500 cfs release (11 percent), 12,020 cubic yards under a 5,000 cfs release (16 percent), and 16,580 cubic yards under a 8,000 cfs release (22 percent). A 5-year event (17,700 cfs) could entrain

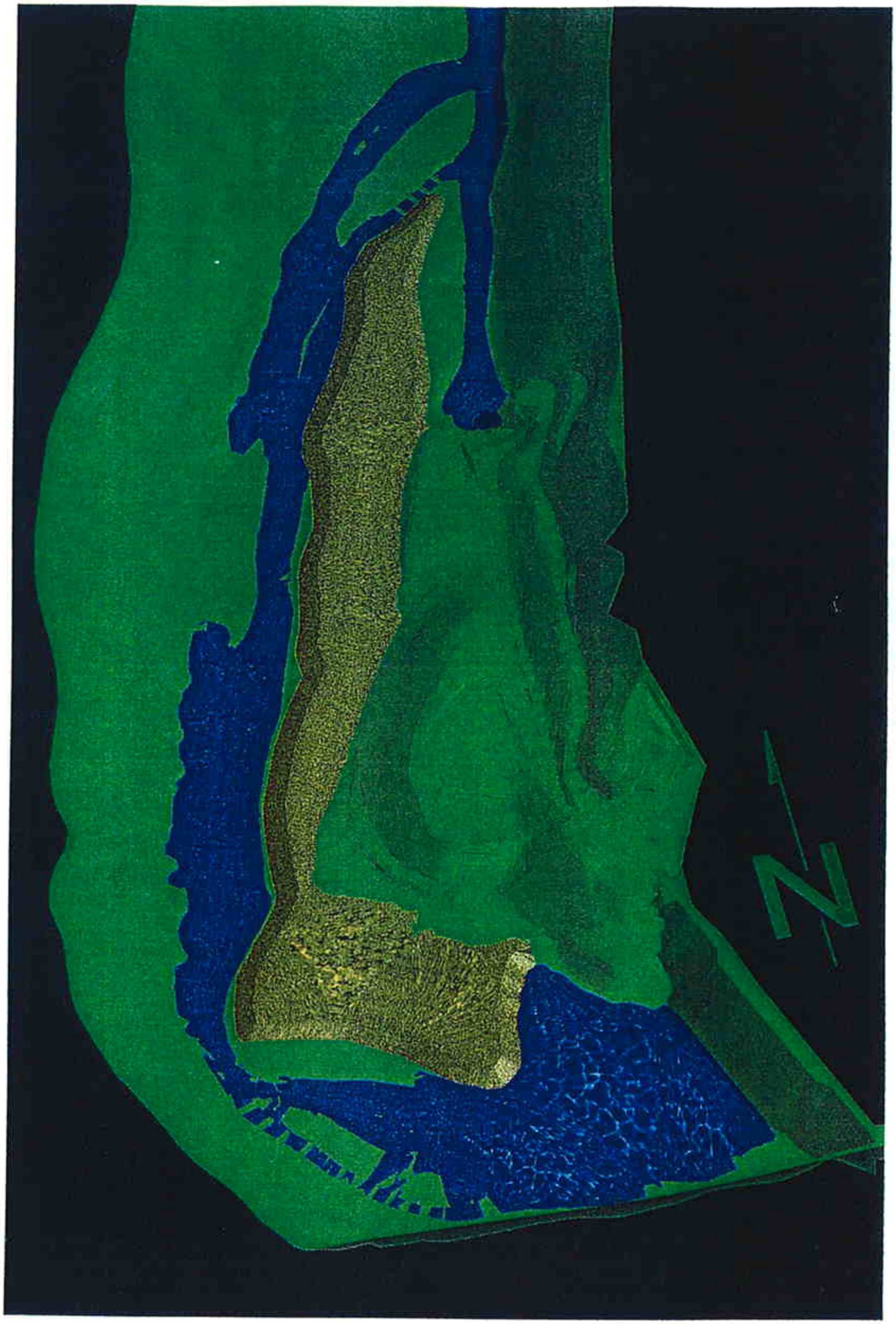

Figure 11. Three-dimensional rendering of Indian Bar sediment disposal site following entrainment by a 3,500 cfs release.

Figure 12. Three-dimensional rendering of Indian Bar sediment disposal site following entrainment by a 5,000 cfs release.

Figure 13. Three-dimensional rendering of Indian Bar sediment disposal site following entrainment by a 8,000 cfs release.

Figure 14. Three-dimensional rendering of Indian Bar sediment disposal site following entrainment by a 105,500 cfs release.

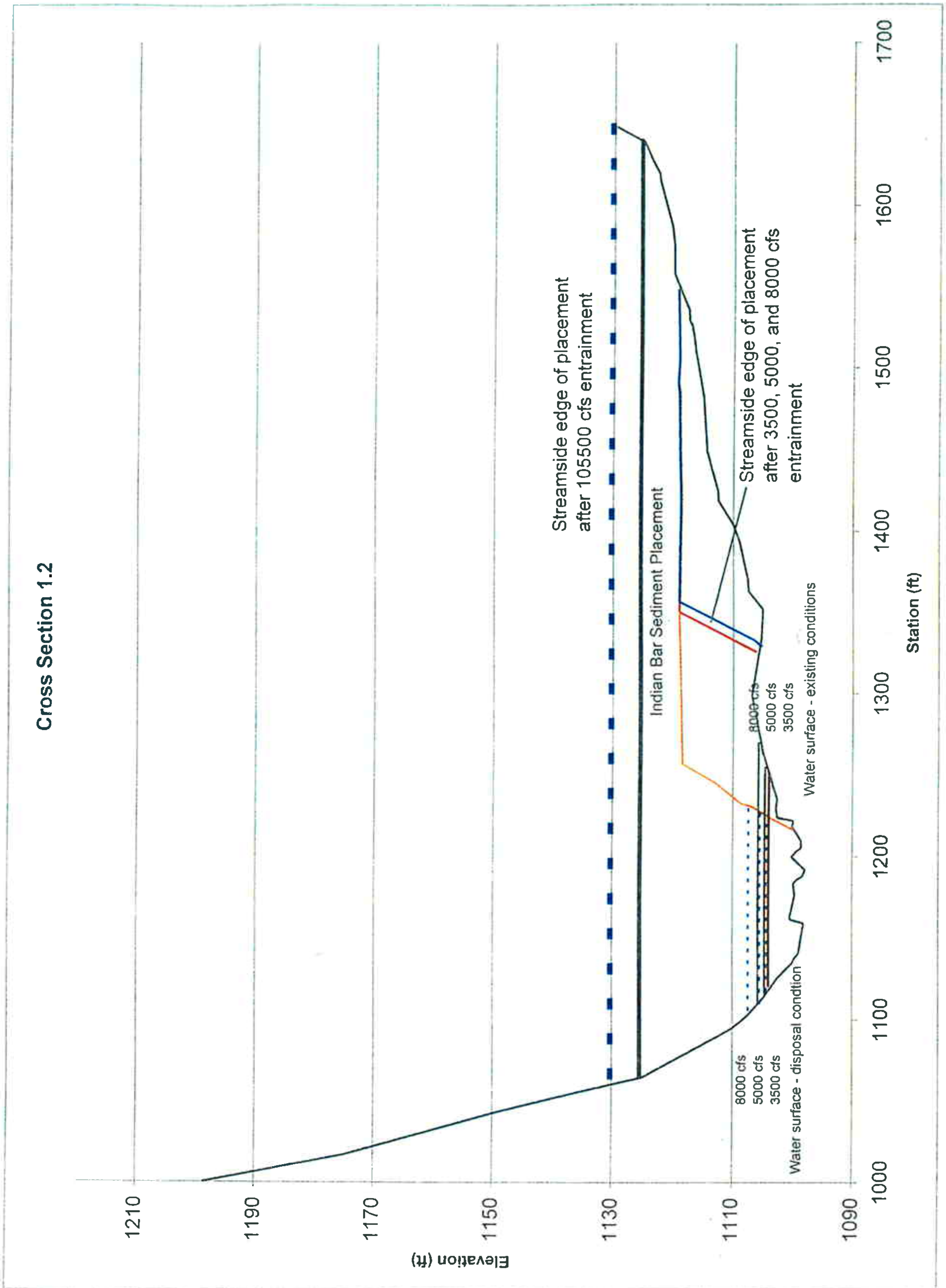

Figure 15. Cross Section 1.2 showing the Indian Bar Placement, water surfaces at 3,500, 5,000, 8,000, and 105,500 cfs, and retreat of the Placement due to those flows.

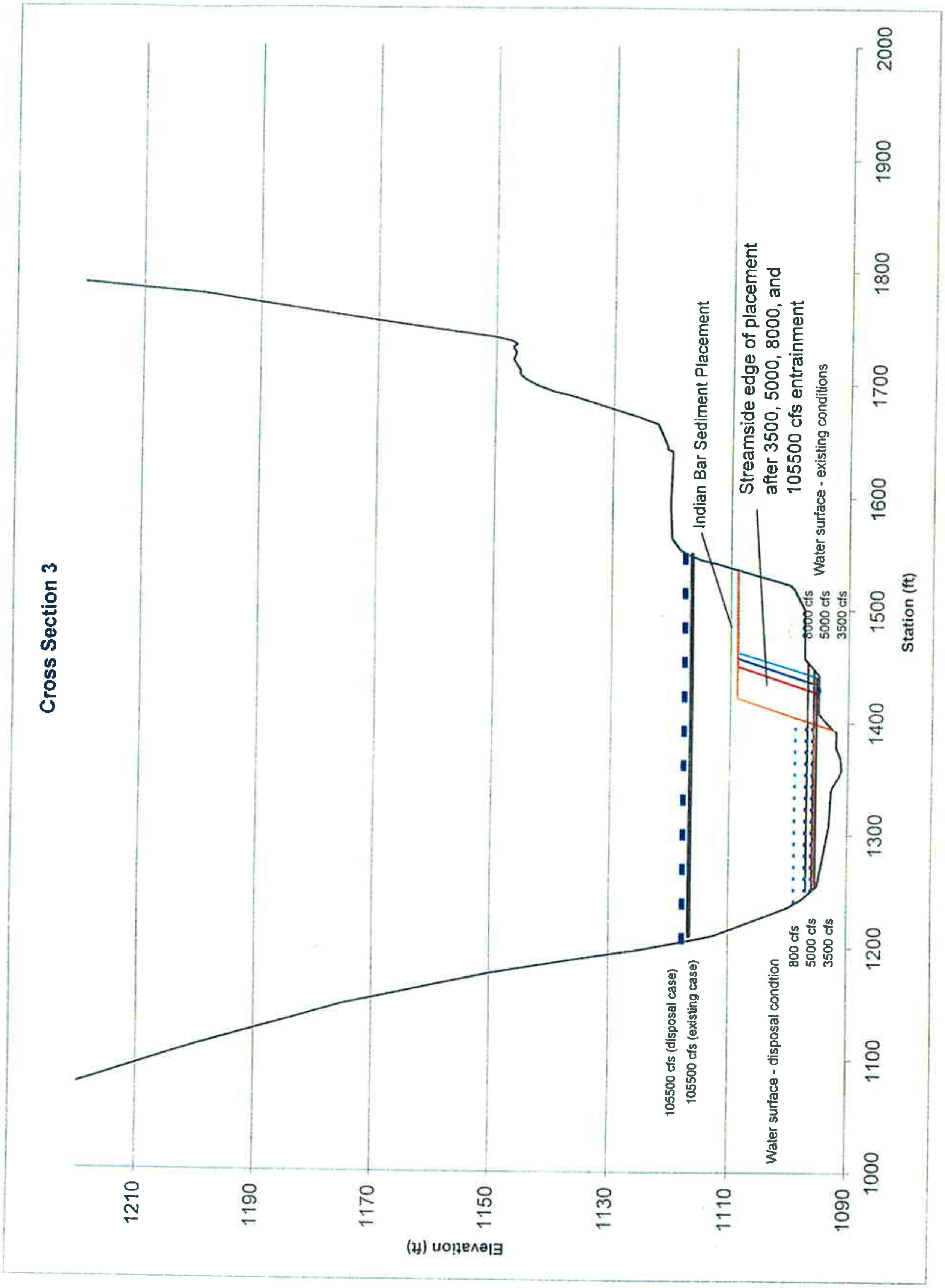

Figure 16. Cross Section 3 showing the Indian Bar Placement, water surfaces at 3,500, 5,000, 8,000, and 105,500 cfs, and retreat of the Placement due to those flows.

25,560 cubic yards (34 percent); a 10-year event (29,100 cfs) could entrain 30,890 cubic yards (41 percent); a 25-year event (50,700 cfs) could entrain 36,840 cubic yards (49 percent); a 50-year event (73,600 cfs) could entrain 40,830 cubic yards (54 percent); a 100-year event (105,500 cfs) could entrain 44,800 cubic yards (59 percent).

6.4. Hydrology of Historic Reservoir Releases

The hydrology downstream from the Ralston Afterbay Dam was investigated to determine the historic duration of the range of SPT magnitude releases. The Middle Fork of the American River Near Foresthill California (Gage #11433300) and the North Fork of the Middle Fork of the American River Near Foresthill California (Gage #11433260) gages have an overlapping mean daily flow record from October 1, 1965, to May 29, 1972. A relationship was developed between these two gages and the North Fork of the Middle Fork of the American River gage record was extended to the end of the Middle Fork record (September 30, 2000). The North Fork flows were subtracted from the Middle Fork flows to back-calculate the discharge at Indian Bar. During this period of record there were over 80 events where the Indian Bar discharge was greater than 3,500 cfs. Assuming that discharge events similar to these historic events will be expected to entrain the proposed Indian Bar Sediment Disposal Site, the ten most recent years of record (September 1990 to September 2000) were investigated with respect to sediment mobilization potential of the Disposal Site. Daily mobilization rates were determined for the runoff events in this ten-year period, keeping bed-load concentrations below a maximum value of 300 parts per million (ppm). The threshold 300 ppm bed-load concentration was based on values for similar coarse bed rivers and streams in Idaho (Mussetter Engineering, 1997). Runoff events with discharges over 3,500 cfs were considered, and the mobilization in cubic yards of disposal site material, per event, was calculated. If at least two weeks passed between runoff events, it was assumed that grading operations would have been undertaken to fill in the areas where coarse sediment was previously entrained and removed from the site. Over the past ten years of record, the river (and appropriate re-grading) could have entrained the entire 75,000 cubic yard sediment disposal site twice. The mobilization of sediment at the proposed disposal site in the past ten years of runoff is summarized in Table 2.

6.5. Alternative Configurations

Moving the edge of the sediment disposal site farther into the river appears to be environmentally undesirable and was not modeled. Increasing the height of the placement will allow for increased disposal material storage and entrainment of more material. Volume computations of a range of placement configurations indicated that raising the top surface of the placement a foot would add a potential 600 cubic yards of entrainable material at 3,500 cfs (800 and 1100 cubic yards at 5,000 and 8,000 cfs, respectively). For the range of SPT discharges, an increase in the top of the disposal site elevation of one foot would yield an approximately 7 percent increase in entrainable material.

Screening the sediment disposal material to a D_{84} of 56 mm and D_{50} of 40 mm (half the size of Bechtel's TP-5 sample, D_{84} = 112 mm, D_{50} = 80 mm) will increase the volume of potentially entrainable material on the order of 10 to 15 percent under the range of SPT release discharges. The expense of sorting the disposal material would likely outweigh the marginal benefit of slightly more entrainable material.

Table 2. Cumulative Sediment Mobilization (1990-2000).			
Runoff Dates	Discharge (cfs)	Cubic Yards Removed	Cumulative Mobilization (cubic yards)
3/4/1991	5,168	4,929	
1/21 - 1/22/1993	4,550 - 6,006	5,663	10,592
3/24 - 3/25/1993	3,622 - 3,747	3,592	14,184
1/10 - 1/15/1995	4,543 - 10,366	9,378	23,562
3/9 - 3/23/1995	3,522 - 9,462	8,967	32,529
4/8/1995	3,827	3,667	36,196
4/30 - 5/3/1995	3,866 - 9,462	8,697	44,893
2/4 - 2/21/1996	3,992 - 10,426	9,425	54,318
5/16 - 5/19/1996	4,648 - 14,739	13,357	67,675
12/5 - 12/13/1996	4,027 - 12,768	11,407	79,082
12/27 - 1/6/1997	3,588 - 32,352	30,063	109,145
1/22 - 1/29/1997	3,529 - 9,825	8,966	118,111
1/15/1998	3,714	3,560	121,671
2/3/1998	3,827	3,667	125,338
3/24 - 3/25/1998	4,084 - 6599	6,219	131,557
1/20 - 1/23/1999	3,602 - 4,967	4,757	136,314
2/7 - 2/17/1999	3,602 - 7,925	7,592	143,906
1/25/2000	3,569	3,423	147,329
2/14 - 2/15/2000	3,813 - 7,863	7,524	154,853

7. CONCLUSIONS

The modeled Indian Bar Sediment Disposal Site was determined to have the capacity to mobilize coarse sediment within the range of the designated SPT flows. The proposed configuration, which would store 75,710 cubic yards of coarse material, could facilitate disposal of 8,530 cubic yards (11 percent) at 3,500 cfs, 12,020 cubic yards (16 percent) at 5,000 cfs, or 16,580 cubic yards (22 percent) of its total volume at 8,000 cfs. The main areas of the placement that are entrainable under the range of SPT discharges are between Cross Sections 0.5 and 1.5, and between Cross Sections 2.5 and 4. Placement material may be re-graded to fill in the localized areas of entrainment after SPT releases. Coarse sediments entrained from the proposed Indian Bar Sediment Disposal Site are expected to move downstream and settle in previously identified depositional areas. The potential depositional areas (summarized in Table 3) are river reaches where sediment transport is controlled by local constrictions including tributary alluvial fans, landslide debris and bedrock constrictions. The locations of the depositional areas including Louisiana Bar, Mammoth Bar, Cherokee Bar, Canyon, Otter, and Volcano Creeks are referenced by river mile (RM), where RM 50.37 is the confluence with the North Fork of the American River. Although the tunnel at Horseshoe Bar was initially considered to be a potential sediment deposition site, field observations indicate that the existing sediment load in the Middle Fork of the American River upstream of the tunnel is passed through the tunnel. Providing that the bed material concentrations are within the range of normal concentrations (less than 300 ppm) there is no reason to believe that the disposed entrained sediments will not pass through the tunnel and be dispersed downstream.

Discharges greater than the SPT range of flows (>8,000 cfs) will help to mobilize the edge of the disposed material placement farther up the bar, but cannot be expected to entrain the entire placement. A large volume of disposed material (about 75,000 cubic yards) was placed on

Indian Bar by PCWA in March 1986. This site was observed under subsequent discharges of 50,000 and 100,000 cfs (24- and 91-year events respectively). While the area between the pile and the river was stripped away, the disposal pile did not experience any noticeable erosion (Placer County Water Agency, 1999). High flow analysis of the proposed Indian Bar Sediment Disposal Site indicated that 34 to 59 percent of the proposed placement could be mobilized at 5- to 100-year discharges.

Table 3. Potential Entrained Sediment Deposition Sites Downstream of Indian Bar.

Location	River Mile	Comments
Louisiana Bar	50.4	Pool and Riffle upstream of bedrock control. Road Accessible
Mammoth Bar	52.4	Pool and riffle upstream of bedrock constriction at Murderer's Gulch. Road Accessible
Cherokee Bar	59.0	Head of alluvial reach extending from Greenwood Bridge to Mammoth Bar. Pools and riffles. Road Accessible
Canyon Creek	61.44	Pool formed by alluvial fan constriction and backwater from Ruck-A-Chucky landslide. Not road accessible, but can be reached by track in about 20 minutes.
Other Sites: Otter Creek, Volcano Creek	64.65, 71.4	Pools and riffles upstream of alluvial fan induced contractions. Neither site is readily accessible, but they are closer to Ralston Afterbay Dam.

8. RECOMMENDATIONS

Observation of the 1986 PCWA placement indicated a lack of noticeable erosion, even under high flows. The success of the proposed Indian Bar Sediment Disposal Site is therefore dependant on its location, construction, and maintenance. The proposed Indian Bar Sediment Disposal Site was sized to store 75,000 cubic yards of coarse material and placed close to the river's edge in a manner that will maximize its ability to entrain the coarse sediment back into the river without encroaching excessively into the river. The coarse material should be dumped on the bar and then graded to the riverside edge of the disposal site. Compaction should be kept to a minimum and end dumping should be avoided. End dumped sediment tends to armor because of inverse sorting where the largest pieces pile are concentrated at the bottom of the slope leaving the finer material at the top of the slope. Following an SPT release (or high flow event), field observations should be made to verify entrainment zones within the disposal site. Re-grading should be scheduled after releases to fill in the observed entrainment zones. By re-grading the coarse material from areas of low entrainment to high entrainment zones, the river will be able to mobilize the disposal site material under a series of low flows without relying on (less frequent) high flows.

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