APPENDIX I-3

MEMO BY RICHARD MITCHELL: IDENTIFICATION AND EVALUATION OF GROUND IMPROVEMENT TECHNOLOGIES TO MITIGATE LIQUEFACTION AT NISL

MEMORANDUM

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SUBJECT: Identification and Evaluation of Ground Improvement Technologies to Mitigate Liquefaction at Newby Island Sanitary Landfill

DATE: June 2, 2008

1.0 INTRODUCTION

This memorandum summarizes an evaluation of potentially applicable methods to mitigate lateral spreading that may occur if subsurface soils below the Newby Island Sanitary Landfill (NISL) liquefy during an earthquake. This evaluation was not intended to provide final liquefaction mitigation design. Rather, the objective was to: identify potentially applicable liquefaction mitigation alternatives; evaluate these alternatives with respect to NISL site-specific conditions; and provide recommendations for final mitigation design.

Liquefaction-induced cracking, lateral spreading, and sand boils were reported to have occurred south of NISL along Coyote Creek during the 1906 earthquake. In addition, the US Geological Survey has published maps for the San Francisco Bay Area that rate the NISL area as having "Very High" liquefaction susceptibility. Consistent with this information, the results of detailed site-specific liquefaction analyses completed by GeoLogic Associates (GLA) indicate a high potential for liquefaction of loose sand zones during the design earthquake for NISL.

Although site data show many of the potentially liquefiable zones are laterally discontinuous, several relatively continuous sandy zones have been identified that may represent a risk to landfill stability if they liquefy during an earthquake. These zones include a near-surface shallow zone and a relatively deeper intermediate zone. Because analyses indicate potentially excessive deformation if these zones liquefy, a mitigation program is warranted to ensure that the NISL containment system and ancillary facilities can withstand the design earthquake without jeopardizing the integrity of the foundation or structures that control leachate, surface drainage, erosion, or gas.

2.0 SITE CONDITIONS

The NISL is located within an irregularly shaped, 342 acre property that is enclosed by a perimeter levee which is largely bounded by water. For example, Coyote Creek abuts the NISL perimeter levee on the east, northeast, and northwest, and an unnamed slough abuts this levee on the south and southwest. The top of the levee varies from approximately elevation 14 feet mean sea level (MSL) along the south, to elevation 24 feet MSL in the north. Within the perimeter levee, elevations currently range from about -40 feet MSL in landfill cells areas that have been excavated but not filled and up to about 140 feet MSL in areas that contain municipal solid waste (MSW).

2.1 SITE DEVELOPMENT

Newby Island was reclaimed from tidal marshland by the construction of a perimeter levee system that was completed in the late 1800s. The island was used for agricultural production including orchards and pastureland until 1932 when the Newby Island Improvement Company began using the island as an unlined solid waste disposal facility. Between 1931 and 1956, the disposal and incineration of solid waste took place in select northern and eastern portions of the island. Incineration ceased in 1956. The NISL is currently permitted as a Class III solid waste management facility and accepts nonhazardous solid wastes, including residential, commercial, industrial, agricultural and inert wastes.

The pre-development site elevation was at or near mean sea level. Prior to implementation of California Code of Regulations (CCR) Title 23, Chapter 15 (Chapter 15), landfill cells were constructed on exposed subgrade that was excavated to about elevation -10 feet MSL. Following approval of Chapter 15 regulations, a low permeability liner consisting of compacted low permeability subgrade was placed above the floor of the excavation and a leachate collection system (LCS) was also constructed. In response to subsequent revisions to the CCR (i.e., Title 27) and implementation of Subtitle D to the Code of Federal Regulations (CFR), recent expansion areas in the south central portion of the landfill have increased the subgrade excavation to an elevation of about -40 feet MSL and incorporated a base liner system that consists of compacted subgrade overlain by a subdrain gravel layer, a low permeability soil barrier layer, an 80-mil high density polyethylene (HDPE) flexible membrane liner and a LCS.

2.2 GEOLOGIC CONDITIONS

The NISL is located at the southern end of the San Francisco Bay in the northwest-trending Santa Clara Valley structural trough. Over time, changes in sea level in the area resulted in the deposition of fluvial sands, silts and interbedded clays. The geologic structure of the San Francisco Bay region is controlled by the major northwest-trending San Andreas fault system located within the Santa Cruz Mountains west of the site and the Hayward and Calaveras faults east of the site. The NISL site is approximately 2.1 and 6.1 miles southwest of the Hayward and Calaveras faults, respectively, and about 15.5 miles northeast of the San Andreas fault. No known active or potentially active faults are present on the property.

Stratigraphic units present at the NISL and relevant to this evaluation include Pleistocene Older Bay Alluvium and Holocene Young Bay Mud. Samples of sediments obtained from a boring adjacent to the perimeter levee on the south side of the landfill were age dated using Carbon 14 (^{14}C) radiocarbon dating techniques. Average calibrated ages for Young Bay Mud samples collected from elevations between -8.75 feet MSL and -16.75 feet MSL ranged from 3,155 years before present (ybp) to 3,855 ybp and generally increase with depth.[1] There is a significant age gap between the oldest portion of the Young Bay Mud sampled at an elevation of -16.75 feet MSL (3,855 ybp) and the shallowest Older Bay Alluvium sampled at an elevation of -22.75 feet MSL (19,530 ybp).

Sand and silty sand horizons occur throughout the Older Bay Alluvium and the Young Bay Mud. Site data and the depositional history of the area indicate that the sand present in the Older Bay Alluvium represents discontinuous deposits associated with meandering stream courses. Similarly, site data and the depositional history of the area indicate most sands within the Young Bay Mud are likely related to tidal channels within the estuarine deposits and are for the most part discontinuous. This is consistent with the margins of the southern San Francisco Bay where historic and current depositional environments are not conducive to the formation of continuous sand blankets or tabular sand bodies. For example, the transition from Older Bay Alluvium to Young Bay Mud represents a mixed sedimentary environments marking the onset of sea level rise and localized accumulations of

[1] One notable exception to the expected depth related increases in age is age reported for the sand sample collected at an elevation of -13.75 feet MSL. Although this sand layer was identified in the middle of the Young Bay Mud, its age was measured to be 12,865 ybp. The fact that the two clay samples collected at a lower elevation were measured at 3,585 ybp and 3,855 ybp suggests that this sample represents reworked organic debris from older Pleistocene sediments. It is likely that this organic debris was transported into the area along with the surrounding sandy sediments in a high energy depositional environment.

sand. Additionally, it is likely that ancestral channels of Coyote Creek and the unnamed slough south of NISL migrated across the site throughout the late Pleistocene and Holocene time and have deposited overlapping and channeled sand deposits. These interpretations are supported by relatively extensive, site-specific subsurface data that do not indicate the presence site-wide continuous sand layers.

2.3 HYDROGEOLOGY

The site is located within the Santa Clara Valley Groundwater Basin at the boundary of the Niles Cone and Santa Clara Subbasins. This groundwater basin is composed of coalescing distal alluvial fans that flank the San Francisco Bay and is composed of clayey material (aquicludes) and isolated sandy aquifers. Groundwater at the NISL is locally influenced by both tidally-affected surface water (i.e. Coyote Creek and the unnamed slough) and on-site pumping for surface and groundwater control. This pumping has resulted in an inward-directed groundwater gradient toward a temporary sump on the southern side of the landfill, where groundwater occurs at about elevation -40 feet MSL. Outside the perimeter levee, groundwater occurs at or within several feet of the ground surface. Within the levees, borrow and subgrade excavations have often extended into and below the adjacent shallow aquifer system creating seeps within the exposed temporary slopes.

Liquids derived from the consolidation of underlying foundation soils, precipitation events, and/or from the overlying waste have resulted in a liquid mound within the older MSW cells in the northern portion of the landfill. This leachate mound currently rises to about elevation 40 feet MSL, although the facility has implemented a leachate extraction program to reduce leachate elevations to near sea level.

3.0 EVALUATION OF MITIGATION METHODS

3.1 SUBSURFACE CONDITIONS

3.1.1 Representative Section

Most of the subsurface data for the site was obtained from the perimeter levee around the landfill. However, subsurface information inboard of the levee was obtained at several locations on the south side of the landfill prior to construction of new landfill cells and GLA constructed several detailed geologic cross sections through these areas. The information from GLA Section TS-1 was used to prepare the generalized subsurface profile shown in Figure 1. Type Section TS-1 is in an area of the site with the greatest number of CPTs perpendicular to the perimeter levee and is also in an area where the thickest shallow and intermediate sand zones have been identified. Figure 2 summarizes representative information from the CPTs located along the section.

As shown in these figures, the shallow zone sand layer is about 8 feet thick and occurs about 26 feet below the ground surface below the centerline of the levee (the midpoint of this layer occurs at about elevation -10 feet MSL). The intermediate zone sand layer is about 5 feet thick and occurs about 41 feet below the ground surface below the centerline of the levee (the midpoint of this layer occurs at about -25 feet MSL). The data shown in Figures 1 and 2 also illustrates the relatively discontinuous nature of the two horizons.

3.1.2 Percent Fines and Normalized Penetration Resistance of the

The percentage of silt and clay in the liquefiable horizon can have an appreciable influence on the effectiveness of the different mitigation measures. Therefore, the approximate percentage of fine-grained soil in the shallow and intermediate sand zones was evaluated by reviewing the CPT logs along GLA Type Section TS-1 and averaging the amount of fine-grained soil in each potentially liquefiable horizon (i.e., a horizon with a liquefaction safety factor of 1.3 or lower).[2] The results of this evaluation are shown in Figure 2 and are also summarized in Table 1. As indicated, the average fines content of the shallow zone is about 22 percent and the average fines content of the intermediate zone is 15 percent. The averaged normalized penetration resistances in the shallow and intermediate zones were also evaluated using the Moss et al. (2006) correlations. The results of this evaluation are summarized in Figure 2 and Table 1.

3.1.3 Available Area for Mitigation

The results of the GLA analyses indicate mitigation may be needed in existing fill areas and in areas of future construction. Site conditions and planned construction present several advantages and limitations to the final design of liquefaction alternatives, including:

- Existing Subtitle D cells and new landfill cells include excavation of the existing soils inboard of the perimeter dike to an average elevation of about -40 feet MSL. This excavation has or will remove the shallow and intermediate sands, and as a result, mitigation

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[2] It should be noted that laboratory testing completed by GLA on samples of soil from borings adjacent to CPT locations showed good correlation between the fines content measured in the laboratory and the fines content inferred from the CPT results.

inboard of levee as part of construction is not necessary in the existing and new Subtitle D construction areas.

- The shallow zone may have been partially excavated and the intermediate sands may remain inboard of the levee in the existing Subchapter 15 cells, although subsurface investigations indicate only limited sands are present in this area of the landfill. If mitigation is required, work inboard of the levee would likely be infeasible due to the existing waste fill and the underlying LCS.
- Both the shallow zone and intermediate sand zones may be present inboard of the levee in the pre-Subchapter 15 cells although the Young Bay Mud/Old Bay Alluvium contact occurs at a higher elevation on the north side of the landfill and the cells in this areas were excavated to -10 ft MSL prior to construction. In the event mitigation in this area is necessary, work inboard of the levee would likely be infeasible due to the existing waste fill.
- Wetlands and standing water are present on the outboard side of the levee around most of the site. As a result, mitigation outboard of the toe of the perimeter levee is judged infeasible.

These conditions indicate that mitigation will likely be limited to the area of the existing perimeter levee. As shown by Figure 1, this results in an approximately 55 to 60 foot wide zone available for ground improvement.

3.2 POTENTIALLY APPLICABLE MITIGATION METHODS

3.2.1 Drainage

The purpose of closely spaced vertical drains for liquefaction mitigation is to dissipate excess pore pressure in a liquefiable soil concurrently with its development during earthquake shaking. In this way, the strength reduction is limited and liquefaction is prevented. Sand, gravel and prefabricated vertical drains have been used. As a related benefit, the ground disturbance and vibrations induced by the installation process are believed to cause some improvement through densification. For example, ground settlements caused by the 1993 Kushiro-Oki and 1995 Hyogoken-Nambu earthquakes in Japan were estimated to have been reduced by 50 percent or more in areas containing sand drains, with part of this reduction resulting from the improvement caused during their installation.

The hydraulic conductivity of the native soil is the most important parameter controlling the effectiveness of drainage elements in dissipating excess pore pressure generation during earthquake shaking. Even small amounts of fines cause large reductions in hydraulic conductivity because the hydraulic conductivity of cohesionless soil varies approximately as the square of the 10 percent (or in some cases, the 5 percent) particle size. Because the shallow and intermediate sand zones contain appreciable fines, even closely spaced drains by themselves cannot be considered an effective means to prevent liquefaction at the site. However, drains may be useful when used in conjunction with other methods that depend on densification (e.g. dynamic compaction) owing to their ability to remove water during the densification process.

3.2.2 Grouting

Permeation grouting, using particulate (cement and soil-cement) grouts or chemical grouts has been used since the early 1800s as a means of soil improvement and stabilization. However, because of its relatively high cost, grouting is usually limited to zones of relatively small volume and to special problems that cannot be solved by other methods. Although permeation grouting has been typically used for seepage control or for ground strengthening to minimize settlement or ground movements, it has been used successfully to stabilize loose sands against liquefaction.

In all likelihood, displacement or compaction grouting, wherein a stiff grout mix is used to compress the surrounding soil and to fill larger voids, would be specified for liquefaction mitigation at NISL because the relatively high percentage of silt and clay would preclude use of permeation grouting. Available equipment can pump zero slump grout in excess of 100 feet. To be effective, compaction grouting could not be performed at depths less than 3 to 10 feet unless there is an overlying structure to provide confinement. Compaction grouting can be targeted at select zones or depths within a soil deposit and is using usually performed from the bottom-up, although sometimes it is performed from the top-down if additional confinement is necessary.

For compaction grouting, grout bulbs are generally inserted by pumping low slump grout through pipes that are typically spaced 3 to 10 feet apart. Typical post-treatment evaluation tests include CPT, SPT, pressuremeter tests, plate load tests, and compression and shear wave velocity tests.

Particulate and chemical grouting are not applicable for NISL because of the high percentage of silt and clay in the shallow and intermediate zone soils. The results of a small scale pilot study completed at NISL in 2007 indicated that compaction grouting may not effectively densify the shallow zone silty sand. As a result, compaction grouting is probably not a feasible mitigation measure at the site.

3.2.3 Deep Dynamic Compaction

Soil compaction by deep dynamic compaction (DDC) involves repeated dropping of heavy weights onto the ground surface (the method is also termed heavy tamping, dynamic consolidation, or pounding). When applied to partly saturated soils, the densification process is essentially the same as that for impact compaction in the laboratory. For the case of saturated cohesionless soils, liquefaction can be induced and the densification process is similar to that accompanying blasting and vibrocompaction. The effectiveness of DDC in liquefiable soils with higher fines contents can be enhanced by installation of closely spaced vertical drains (usually prefabricated "wick" drains). The effectiveness of the method in fine-grained saturated soils is uncertain as both successes and failures have been reported. DDC has been especially effective for compaction of waste and rubble fills. The pounders used for dynamic compaction may be concrete blocks, steel plates, or thick steel shells filled with concrete or sand and may range from one or two up to 30 tons in weight. Drop heights up to about 100 feet have been used. The effective depth of improvement using DDC varies with soil type, but is usually limited to about 30 to 35 feet.

The shallow zone is soils are located about 26 feet below the ground surface and the intermediate zone soils are located about 41 feet below the ground surface at the center of the levee. As a result, the levee would require partial or complete removal prior to DDC and rebuilding on completion of the project for effective treatment of the intermediate layer. As a result, DDC is not applicable to areas of the site that have already been filled. However, DDC is a relatively inexpensive mitigation measure that may be applicable and could be considered for new cell construction areas where vibrations would not adversely affect adjacent containment structures. Subsurface conditions suggest that vertical drains would likely be required in association with DDC to enhance pore pressure dissipation and densification.

3.2.4 Blasting

Deep compaction by detonation of buried explosives (typically dynamite, TNT, or ammonite) can provide a rapid, low cost means for soil improvement in some cases. The general procedure consists of: installation of pipe by jetting, vibration, drilling, or other means to desired depth of charge placement; placement of the charge in the pipe; backfilling the hole; and detonation of the charges in accordance with a pre-established pattern. Loose, saturated, clean sands are generally well suited for densification by blasting. Success of the procedure depends on the ability of the shock wave generated by the blast to break down the initial structure and create a liquefaction condition for a sufficient period to enable particles to be rearranged in a denser packing order.

There appears to be no generally accepted theoretical design procedures for densification by blasting, although empirical guidelines provide a reasonable basis for initial designs that can then be validated by field test programs prior to production blasting. and the maximum depth to which blasting can be successfully used is not known. Since effective stresses and strength increase with depth, the required disruptive stress will increase and the effective radius of influence will decrease with depth. Previous experience has shown that blasting can densify clean sand to equivalent relative densities of 75 to 80 percent. In some cases, however, the results have been erratic and the method is not likely to be effective in the upper 5 to 10 feet below the ground surface. The presence of appreciable fine-grained soil in the shallow and intermediate zones, as well as high fines contents in the liquefiable sand zones, could limit the effectiveness of blast densification at NISL, although vertical drains could be used to enhance pore pressure dissipation. The vibrations associated with blasting would preclude this method next to existing fill areas and could also limit its use for new cells and the use of explosives below the water table could adversely affect groundwater quality. As a result, blast densification is not applicable for the site.

3.2.5 Vibrocompaction and Vibroreplacement

These methods for deep compaction of cohesionless soils generally include insertion of a cylindrical or torpedo shaped vibratory probe into the ground followed by compaction by vibration during withdrawal. A granular backfill is compacted beneath and around the vibrating probe as it is withdrawn. The probe is usually sunk to the desired depth using vibratory methods, often supplemented by water jets at the tip of the probe. Compaction piles of sand and gravel have also been used in soft cohesive soils and also occasionally to mitigate liquefaction. Ground treatment depths of 65 feet can be routinely achieved and depths in excess of 100 feet have been attained in some cases.

The gradation of the both the in-situ soil and the backfill, which may or may not be the same material, influence the level of improvement that may be obtained. Coarse sands give greater densification than fine sands because the coarse material is better able to transmit vibrations. In some instances, penetration resistance is so high following densification by vibrocompaction that relative densities greater than 100 percent are indicated according to conventional correlations. It should be noted that fine-grained soils can have a significant effect on the level of improvement that can be obtained by vibrocompaction. As a general rule of thumb, vibrocompaction is ineffective in soils containing more than 20 percent soil finer than the Number 200 sieve unless supplementary drainage is used in the form of closely spaced vertical drains installed prior to the vibratory treatment.

Vibrocompaction is not applicable at NISL due to the percentage of fine-grained soil present in the shallow and intermediate zones. Vibroreplacement with sand or stone columns is technically feasible at the site. However, stone columns are not recommended because they could create conduits between the upper and intermediate horizons. As a result, vibroreplacement and stone columns are not recommended.

3.2.6 Soil Mixing

Both cement deep soil mixing (CDSM) and jet grouting have assumed an important role in ground improvement and mitigation of liquefaction risk in recent years. These methods can be used in a wide range of soil types and gradations, with high fines content liquefiable soils being very well-suited for treatment. Each can be used to depths of up to 100 feet or more. Both methods require special equipment and each may produce significant discharge of spoils at the ground surface that must be dealt with in some manner. The design strength of properly constructed CDSM and jet grout elements is typically much greater than can be obtained by the other methods of soil improvement. However, both methods are relatively difficult to monitor during construction, although the uniformity of CDSM is usually better than can be obtained using jet grouting.

Complete treatment of a liquefiable soil layer by either method is impractical and would likely be prohibitively expensive. Accordingly, isolated columns, panels and walls can be installed to provide the necessary vertical compressive reinforcement and lateral shear resistance in the event of soil liquefaction. Jet grout columns can be installed over specified depth ranges as opposed to CDSM columns that ordinarily must extend full depth. Walls can be used to form cells that both provide enhanced structural resistance and containment for liquefied soil. The Trench Cutting Remixing Deep Wall Method (TRD) recently introduced into the U.S. involves a chain saw like process for wet cement mixing that produces continuous walls about 0.7 feet thick and up to 100 feet deep. Hardened column or wall compressive strengths of 150 to 200 pounds per square inch (psi) or more are feasible using the different methods of installation.

Jet grouting, CDSM, and TRD technologies are not appreciably limited by the fine-grained fraction of the shallow and intermediate horizons. The methods do not produce significant vibrations and can be implemented from the perimeter levee. Additionally, all methods can be implemented adjacent to previously filled areas of the site and in areas of new construction. As a result, all of these methods are generally applicable, although all may result in appreciable spoils disposal requirements.

3.2.7 Transverse Shear Walls

Transverse shear walls (TSWs) are similar to TRD technologies except that the shear walls are excavated and the excavation is backfilled with cement slurry. Transverse shear walls can be excavated using clamshell and backhoe equipment to construct panels up to 4 feet thick. The TSWs are oriented perpendicular to the axis of structure to be stabilized (or parallel to the direction of movement) and act to transfer load from the base of the structure to stronger materials located beneath the liquefiable zones. Hardened slurry strengths of 300 psi and large displacement friction angles of 45 degrees are feasible.

Similar to CDSM, TRD, and jet grouting techniques, TSWs do not produce significant vibrations, can be implemented from the perimeter levee, and are feasible to mitigate liquefaction at the site. Transverse shear walls may result in appreciable spoils disposal requirements.

3.2.8 Replacement and Reinforcement

Geosynthetic reinforcement typically consists of the placement of horizontal tensile strips, grids, or membranes buried in soil under embankments, gravel base courses, and footings. Reinforcement strips can be used to increase bearing capacity and to reduce deformations in the overlying earth structures. It should be noted that the use of geosynthetic reinforcement would do little to reduce or eliminate the possibility of liquefaction. Rather, the purpose of the reinforcement would be to increase the ability of the overlying structure (in this case the levee) to resist the affects of subsurface liquefaction. Design procedures for geogrid reinforcement and foundation support are readily available in the literature.

Replacement and reinforcement are not feasible in areas of the site where liner construction and waste fill placement have already occurred. The applicability and feasibility of replacement and/or reinforcement as part of new cell construction is difficult to determine without detailed analysis and advanced analytical studies. However, geometric and subsurface conditions suggest that these techniques are probably not feasible unless excavation and construction can encroach into the wetlands outboard of the existing levee or if the lateral occurrence of sand is more limited than indicated in Figure 1.

3.3 RECOMMENDATIONS

Based on the site conditions and the preceding evaluation of alternative mitigation measures, applicable and feasible liquefaction mitigation measures for the NISL include DDC, CDSM, TRD walls, TSWs, and jet grouting. DDC would only be applicable in areas of new construction and probably would require partial excavation of the perimeter levee and supplemental pore pressure relief with vertical drains. However, the low cost of DDC compared with the other alternatives suggests that this technique should be considered if the new cell is sufficiently distant that the vibrations associated with this method would not damage landfill containment or ancillary structures.

Jet grouting, CDSM, TSWs, and TRD walls may be implemented in areas of new construction and in areas that have been previously filled. As indicated in Table 1, the treated strength of jet grout columns, CDSM columns, and TRD walls are on the order of 150 to 200 psi. The hardened slurry strength of TSWs is reported to be on the order of 300 psi, with large displacement friction angles of about 45 degrees. Stability analyses completed by GLA that were based on a remediated zone strength of 100 psi, a replacement ratio of 12.5 percent, and a treatment zone width of about 44 to 55 feet indicated that deformations estimated for failure surfaces that passed through the shallow and intermediate sand horizon were within acceptable limits under the design earthquake for the site. These results indicate that liquefaction mitigation is technically feasible and should be effective because the strength assumed by GLA is lower than the strengths reported for the recommended alternatives, a replacement ratio of 12.5 percent is relatively low, the cross section used for analysis represents the greatest thicknesses of liquefiable horizons, and the treatment zone assumed by GLA is within the limits of the area available for treatment.

It is anticipated that liquefaction mitigation will be performed incrementally at the site. Because site-specific data and the geologic history of the area indicate that the liquefiable sand horizons are laterally discontinuous, the degree of mitigation required for different areas around the perimeter of the landfill is likely to vary. As a result, additional subsurface investigation using closely-spaced CPT techniques is recommended prior to initiating final mitigation design. A pilot program is also recommended prior to initiating production mitigation.

Table 1

SUMMARY OF POTENTIALLY APPLICABLE SOIL IMPROVEMENT METHODS
SHALLOW AND INTERMEDIATE LIQUEFIABLE ZONES
Newby Island Sanitary Landfill, Santa Clara County, California

REPRESENTATIVE SHALLOW ZONE PROPERTIES		REPRESENTATIVE INTERMEDIATE ZONE PROPERTIES	
Thickness ~8 feet		Thickness ~5 feet	
Depth	~26 feet below ground surface (centerline of dike)	Depth	~41 feet below ground surface (centerline of dike)
Dike Thickness	~14 feet (maximum)	Dike Thickness	~14 feet (maximum)
Percent Fines	22 ± 8 percent (potentially liquefiable horizons)	Percent Fines	15 ± 7 percent (potentially liquefiable horizons)
$(N_1)_{60}$	8.4 ± 1.9 (potentially liquefiable horizons)	$(N_1)_{60}$	14.1 ± 3.6 (potentially liquefiable horizons)
$(N_1)_{60cs}$	10.4 ± 2.5 (potentially liquefiable horizons)	$(N_1)_{60cs}$	17.0 ± 4.4 (potentially liquefiable horizons)

METHOD	MOST SUITABLE SOIL CONDITIONS	MAXIMUM EFFECTIVE TREATMENT DEPTH	TYPICAL PROPERTIES OF TREATED MATERIAL	ADVANTAGES & LIMITATIONS	APPLICABILITY FOR NISL EXPANSION
Vertical Drains	Sands, silty sands	±100 ft	Reduce pore pressure buildup, intercept pore pressure plume	Full area treatment not required; inexpensive; limited performance record; questionable effectiveness, possible cross contamination concern	Not by itself, although could be combined with DDC or VC
Particulate Grouting	Medium to coarse sand and gravel	Unlimited	Impervious, high strength with cement grout	Low cost grouts, high strength; limited to coarse-grained soils, hard to evaluate	Method not applicable ~ fines content too high
Chemical Grouting	Medium silts and coarser	Unlimited	Impervious, low strength compared with cement grout	Low viscosity, controllable gel time, good water shut-off; high cost, hard to evaluate	Method not applicable ~ fines content too high
Displacement (Compaction) Grouting	Compressible fine grained and liquefiable soils; foundation soils with large voids or cavities	Unlimited	D_r = 80+% $(N_1)_{60} = 25$ q_{c1} = 10-15 MPa (Soil type dependent)	Good for correction of differential settlements, filling large voids; has been used to mitigate liquefaction; can control treatment zones	Method probably not applicable based on site pilot study results
Deep Dynamic Compaction (DDC)	Saturated sands and silty sands; partly saturated materials	~35 ft	D_r = 80% $(N_1)_{60} = 25$ q_{c1} = 10-15 MPa	Simple, rapid, suitable for soils with some fines; usable above and below water; vibrations, high mobilization cost, adjacent settlement, good for large areas	Could be effective for shallow zone in combination with vertical drains. Fines may limit effectiveness, existing dike could be partially excavated

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METHOD	MOST SUITABLE SOIL CONDITIONS	MAXIMUM EFFECTIVE TREATMENT DEPTH	TYPICAL PROPERTIES OF TREATED MATERIAL	ADVANTAGES & LIMITATIONS	APPLICABILITY FOR NISL EXPANSION
Blasting/Explosive Compaction (EC)	Loose, saturated sands and silty sands;	>100 ft	$D_r = 75\%$ $(N_1)_{60} = 20\text{-}25$ $q_{c1} = 10\text{-}12$ MPa	Rapid, inexpensive, can treat any size area; can target specific zones; can accommodate variable properties; no improvement near ground surface; safety, psychological barriers	Not applicable for shallow zone; questionable for intermediate zone
Vibrocompaction	Cohesionless soils with less than 20% fines	100 ft	$D_r = 80+\%$ $(N_1)_{60} = 25$ $q_{c1} = 10\text{-}15$ MPa	Useful in saturated and partly saturated cohesionless soils, best in clean sand, backfill required in most cases, uniformity	Method not applicable ~ fines content too high
Vibroreplacement Stone and Sand Columns	Silty and clayey sands, silts, clayey silts	100 ft	$(N_1)_{60} = 20$ $q_{c1} = 10\text{-}12$ MPa	Provides drainage and reinforcement, uniformity with depth in some soils, fines can compromise column integrity, difficult QA/QC; possible cross contamination concern	Method not applicable ~ questionable QC; may not be able to rely on strength of column; possible cross-contamination concerns
Sand and Gravel Compaction Piles	Most soil types	60-70 ft	$(N_1)_{60} = 20\text{-}25$ $q_{c1} = 10\text{-}15$ MPa (Soil type dependent)	Proven effectiveness, provides drainage and reinforcement, uniform compaction, easy to check results; slow, possible cross contamination concern, expensive	Method not applicable ~ questionable QC; may not be able to rely on strength of column; possible cross-contamination concerns
Cement Deep Soil Mixing (Columns, Panels and Walls)	Most soil types	100 ft	Depends on size, strength and configuration of CDSM elements; 150 - 200 psi compressive strength typical	Can contain liquefiable soil within high strength grid walls, brittle elements, positive ground reinforcement, may be difficult to QA/QC	Potentially Applicable

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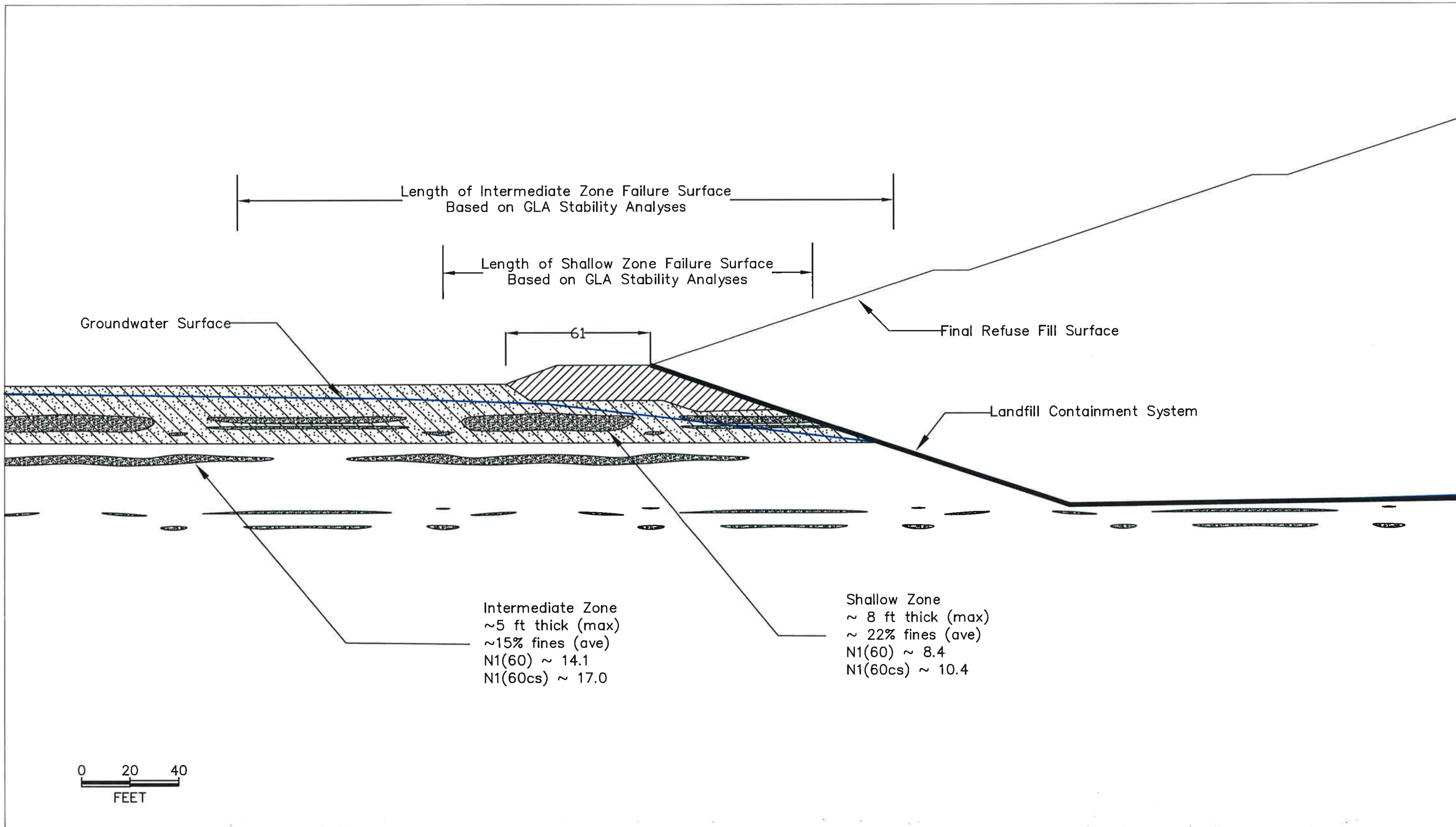
Dike Thickness	~14 feet (maximum)
Percent Fines	22 ± 8 percent (potentially liquefiable horizons)
$(N_1)_{60}$	8.4 ± 1.9 (potentially liquefiable horizons)
$(N_1)_{60cs}$	10.4 ± 2.5 (potentially liquefiable horizons)

REPRESENTATIVE INTERMEDIATE ZONE PROPERTIES

Thickness ~5 feet	
Depth	~41 feet below ground surface (centerline of dike)
Dike Thickness	~14 feet (maximum)
Percent Fines	15 ± 7 percent (potentially liquefiable horizons)
$(N_1)_{60}$	14.1 ± 3.6 (potentially liquefiable horizons)
$(N_1)_{60cs}$	17.0 ± 4.4 (potentially liquefiable horizons)

METHOD	MOST SUITABLE SOIL CONDITIONS	MAXIMUM EFFECTIVE TREATMENT DEPTH	TYPICAL PROPERTIES OF TREATED MATERIAL	ADVANTAGES & LIMITATIONS	APPLICABILITY FOR NISL EXPANSION
Jet Grouting (Columns, panels and walls)	Most soil types, may be difficult in highly plastic clays	Unlimited	Depends on size, strength and configuration of jetted elements; 150 compressive strength- 200 psi typical	Controlled treatment zone, useful in soils with fines, high strength columns, difficult to QA/QC	Potentially Applicable
Transverse Walls Cement-Bentonite and Soil-Cement Bentonite Barriers	Any soil	60 ft	300 psi hardened slurry strength; 45° large displacement friction angle	Contains liquefiable soil within high strength transverse walls, positive ground reinforcement, recent precedent	Potentially Applicable
Remove and Replace (with or without reinforcement)	All soils	±20 ft	High density fills; self-supporting earth structures, increased bearing capacity	Can design to desired improvement level, easy to QA/QC, may require dewatering, may require shoring, may impact stability of adjacent ground, site-specific constraints and limitations, may require advanced analytical techniques	Applicability difficult to determine without detailed analysis. Probably not applicable by itself unless construction can occur outboard of existing dike.



GENERALIZED LIQUEFACTION MITIGATION
CROSS SECTION (TS–1)

Figure
1

OUTBOARD SITE OF DIKE
SOUTHWEST

GLA SECTION TS-1

INBOARD SIDE OF DIKE
NORTHEAST

CPT-6 Depth (ft)	Elevation (ft)	CPT-6				CPT-51				CPT-66				CPT-54				CPT-68				CPT-67				CPT-42			
		SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs
21.65	-6.15	0.53	25.15%	6.92	12.06	#N/A	62%	2.34	#N/A	#N/A	100%	2.62	#N/A	#N/A	96%	3.25	#N/A	#N/A	90%	1.29	#N/A	#N/A	60%	2.46	#N/A	#N/A	54%	2.95	#N/A
21.82	-6.32	0.60	16.00%	8.76	14.08	#N/A	60%	2.33	#N/A	#N/A	97%	2.54	#N/A	#N/A	98%	3.06	#N/A	#N/A	98%	1.29	#N/A	#N/A	58%	2.41	#N/A	#N/A	54%	2.94	#N/A
21.98	-6.48	0.62	16.11%	8.62	13.83	#N/A	61%	2.37	#N/A	#N/A	97%	2.18	#N/A	#N/A	54%	4.24	#N/A	#N/A	87%	1.39	#N/A	#N/A	57%	2.49	#N/A	#N/A	54%	3.13	#N/A
22.15	-6.65	0.55	22.87%	7.95	13.65	#N/A	60%	2.37	#N/A	#N/A	79%	1.92	#N/A	#N/A	52%	4.19	#N/A	#N/A	84%	1.44	#N/A	#N/A	57%	2.60	#N/A	#N/A	52%	3.16	#N/A
22.31	-6.81	0.52	33.31%	6.96	9.99	#N/A	56%	2.37	#N/A	#N/A	78%	2.00	#N/A	#N/A	56%	4.21	#N/A	#N/A	76%	1.51	#N/A	#N/A	57%	2.56	#N/A	#N/A	55%	3.05	#N/A
22.47	-6.97	#N/A	46.63%	5.78	#N/A	#N/A	56%	2.40	#N/A	#N/A	67%	2.29	#N/A	#N/A	73%	3.57	#N/A	#N/A	71%	1.57	#N/A	#N/A	59%	2.62	#N/A	#N/A	55%	2.92	#N/A
22.64	-7.14	#N/A	48.67%	5.41	#N/A	#N/A	54%	2.65	#N/A	#N/A	41%	3.08	#N/A	#N/A	85%	3.18	#N/A	#N/A	62%	1.70	#N/A	#N/A	44%	2.55	#N/A	#N/A	54%	3.00	#N/A
22.80	-7.30	0.52	32.00%	6.76	14.26	#N/A	60%	2.77	#N/A	#N/A	36%	4.01	#N/A	#N/A	88%	3.00	#N/A	#N/A	48%	3.46	#N/A	#N/A	40%	2.99	#N/A	#N/A	55%	3.09	#N/A
22.97	-7.47	#N/A	37.06%	5.86	#N/A	0.36	29%	5.11	5.89	0.34	29%	5.24	6.03	#N/A	86%	3.01	#N/A	0.37	26%	6.68	7.83	#N/A	42%	3.81	#N/A	#N/A	56%	3.00	#N/A
23.13	-7.63	#N/A	48.54%	5.39	#N/A	0.39	23%	6.47	6.92	0.36	25%	6.20	6.85	#N/A	86%	3.08	#N/A	0.39	15%	8.74	9.06	0.38	23%	8.04	9.20	#N/A	56%	3.03	#N/A
23.29	-7.79	#N/A	40.80%	6.26	#N/A	0.40	19%	7.24	7.46	0.36	26%	6.09	6.87	#N/A	88%	3.14	#N/A	0.41	19%	9.37	10.33	0.44	19%	10.50	11.80	#N/A	49%	3.16	#N/A
23.46	-7.96	0.53	24.70%	7.42	11.82	0.41	22%	7.48	8.13	0.37	30%	5.89	7.40	#N/A	93%	3.10	#N/A	0.42	20%	8.81	9.91	0.45	18%	10.41	11.56	#N/A	60%	3.21	#N/A
23.62	-8.12	0.56	16.64%	8.19	11.84	0.43	27%	6.77	8.19	0.37	32%	6.04	7.94	#N/A	97%	2.98	#N/A	0.41	22%	8.49	9.71	0.44	19%	9.77	10.93	0.37	29%	6.79	8.69
23.79	-8.29	0.51	23.37%	7.75	12.16	0.45	32%	6.68	9.30	0.36	21%	6.39	6.53	#N/A	94%	3.06	#N/A	0.39	19%	8.06	8.65	0.44	22%	9.51	11.40	0.41	16%	10.67	11.68
23.95	-8.45	0.50	33.66%	6.94	10.02	0.42	24%	7.85	8.99	0.36	24%	6.69	7.33	#N/A	93%	3.30	#N/A	0.38	24%	7.77	9.22	0.42	22%	8.76	10.29	0.43	15%	11.16	12.13
24.11	-8.61	#N/A	38.23%	6.77	#N/A	0.41	17%	7.61	7.61	0.36	25%	6.37	7.10	#N/A	90%	3.40	#N/A	0.37	32%	6.11	8.33	0.39	21%	8.56	9.73	0.43	16%	10.01	10.99
24.28	-8.78	0.46	28.41%	7.70	9.86	0.42	24%	7.66	8.83	0.36	24%	6.50	7.07	#N/A	92%	3.29	#N/A	0.37	29%	6.18	7.81	0.37	21%	7.47	8.25	0.42	19%	9.55	10.85
24.44	-8.94	0.45	30.24%	7.50	10.03	0.44	27%	7.57	9.42	0.36	23%	7.07	7.72	#N/A	86%	3.01	#N/A	0.37	26%	6.98	8.33	0.36	26%	6.87	8.36	0.41	23%	8.90	10.95
24.61	-9.11	0.44	28.74%	7.28	9.24	0.43	25%	7.65	9.01	0.38	34%	6.02	8.48	#N/A	85%	2.95	#N/A	0.37	26%	6.93	8.40	0.36	33%	6.15	8.66	0.40	31%	7.17	10.27
24.77	-9.27	0.43	19.07%	8.90	9.52	0.39	15%	8.15	8.15	#N/A	38%	6.23	#N/A	#N/A	81%	3.06	#N/A	0.38	25%	7.25	8.70	0.37	32%	5.70	7.59	#N/A	42%	4.63	#N/A
24.93	-9.43	0.44	16.96%	9.63	10.09	0.38	15%	7.64	7.64	0.39	31%	6.70	8.96	#N/A	81%	3.05	#N/A	0.38	22%	7.63	8.67	0.38	33%	6.94	10.17	0.36	32%	5.83	7.86
25.10	-9.60	0.47	23.64%	8.99	10.61	0.38	25%	6.80	7.65	0.37	25%	7.18	8.33	#N/A	83%	2.97	#N/A	0.38	18%	8.21	8.80	0.39	32%	6.75	9.56	0.37	33%	6.75	10.12
25.26	-9.76	0.49	29.38%	8.52	11.54	0.41	29%	6.19	7.67	0.37	22%	7.25	7.77	#N/A	82%	2.84	#N/A	0.39	17%	8.88	9.41	0.38	24%	7.56	8.95	0.38	30%	6.72	9.13
25.43	-9.93	0.49	18.48%	9.57	10.30	0.42	30%	6.42	8.40	0.37	23%	7.55	8.50	#N/A	83%	2.77	#N/A	0.41	12%	10.92	11.31	0.37	17%	8.82	9.37	0.38	23%	8.23	9.89
25.59	-10.09	0.50	10.65%	13.13	13.22	0.42	26%	7.23	8.57	0.37	27%	6.85	8.20	#N/A	83%	2.75	#N/A	0.40	8%	11.82	12.25	0.38	25%	7.72	9.55	0.38	17%	9.38	10.30
25.75	-10.25	0.53	8.76%	13.74	13.79	0.42	22%	8.08	9.10	0.39	25%	7.08	8.14	#N/A	82%	2.87	#N/A	0.38	9%	9.70	10.04	0.36	31%	6.57	8.87	0.38	14%	9.59	10.17
25.92	-10.42	0.52	10.00%	13.23	13.28	0.42	18%	8.56	8.90	0.40	11%	11.21	11.21	#N/A	90%	2.68	#N/A	0.36	21%	7.64	8.44	0.35	34%	5.47	7.51	0.37	16%	8.72	9.33
26.08	-10.58	0.49	11.41%	12.20	12.29	0.41	17%	8.65	8.86	0.41	7%	11.72	11.72	#N/A	92%	2.57	#N/A	0.37	30%	6.63	8.73	#N/A	44%	4.86	#N/A	0.37	29%	7.52	10.18
26.25	-10.75	0.46	12.71%	10.79	10.88	0.41	22%	7.81	8.61	0.40	10%	10.71	10.71	#N/A	86%	2.55	#N/A	#N/A	37%	5.72	#N/A	#N/A	35%	5.62	#N/A	0.37	35%	5.66	8.84
26.41	-10.91	0.44	14.14%	9.61	9.66	0.41	22%	7.81	8.61	0.39	13%	9.47	9.47	#N/A	89%	2.47	#N/A	#N/A	36%	5.65	#N/A	#N/A	39%	5.26	#N/A	#N/A	41%	5.18	#N/A
26.57	-11.07	0.43	21.33%	8.87	9.95	0.44	22%	7.80	8.61	0.40	23%	8.22	9.50	#N/A	91%	2.44	#N/A	0.45	34%	6.07	11.63	#N/A	48%	4.03	#N/A	#N/A	41%	4.81	#N/A
26.74	-11.24	0.46	31.91%	7.41	10.44	0.45	10%	11.74	11.74	0.41	31%	7.28	10.12	#N/A	89%	2.60	#N/A	0.42	33%	4.66	7.82	#N/A	71%	3.18	#N/A	#N/A	54%	3.68	#N/A
26.90	-11.40	#N/A	42.13%	7.05	#N/A	0.45	7%	12.07	12.07	#N/A	41%	5.95	#N/A	#N/A	93%	2.61	#N/A	#N/A	51%	3.72	#N/A	#N/A	57%	4.10	#N/A	#N/A	72%	3.02	#N/A
27.07	-11.57	0.59	32.49%	8.45	12.41	0.42	7%	10.87	10.87	#N/A	36%	6.53	#N/A	#N/A	100%	2.54	#N/A	#N/A	50%	4.02	#N/A	0.47	17%	9.46	14.42	#N/A	42%	4.76	#N/A
27.23	-11.73	0.62	26.69%	9.66	15.64	0.40	10%	9.55	9.55	#N/A	40%	6.21	#N/A	#N/A	88%	2.86	#N/A	#N/A	38%	5.01	#N/A	0.54	11%	11.19	16.59	#N/A	36%	6.54	#N/A
27.40	-11.90	0.70	20.65%	10.81	15.93	0.43	26%	6.96	8.40	0.66	27%	7.46	11.14	#N/A	96%	3.01	#N/A	0.58	32%	5.55	9.93	0.51	9%	10.79	15.99	0.58	34%	7.67	16.24
27.56	-12.06	0.68	15.15%	12.34	17.16	#N/A	39%	5.41	#N/A	0.69	13%	11.30	14.39	#N/A	100%	3.12	#N/A	0.66	16%	8.41	12.51	0.48	15%	8.72	12.93	0.60	22%	9.41	16.43
27.72	-12.22	0.65	11.59%	12.19	16.32	0.47	31%	6.53	8.84	0.70	10%	11.24	14.15	#N/A	97%	3.14	#N/A	0.69	10%	11.04	16.41	0.46	17%	8.50	12.73	0.57	18%	9.57	15.96
27.89	-12.39	0.60	12.21%	11.85	15.92	0.45	26%	8.14	10.01	0.67	12%	10.31	12.97	#N/A	90%	3.22	#N/A	0.68	11%	9.53	14.18	0.47	24%	7.61	12.31	0.53	21%	8.71	14.96
28.05	-12.55	0.55	11.86%	10.88	14.55	0.48	25%	8.58	10.38	0.66	15%	9.45	11.94	#N/A	82%	3.48	#N/A	0.62	14%	8.36	12.43	0.41	30%	6.62	11.78	0.44	24%	7.37	12.78
28.22	-12.72	0.51	12.94%	9.23	12.34	0.50	23%	9.47	11.21	0.68	19%	9.08	12.11	#N/A	87%	3.49	#N/A	0.60	18%	7.30	10.85	#N/A	43%	4.63	#N/A	#N/A	44%	5.02	#N/A
28.38	-12.88	0.46	18.95%	8.68	12.14	0.51	17%	11.47	12.35	0.69	19%	9.59	12.97	#N/A	88%	3.43	#N/A	0.56	29%	6.29	10.87	#N/A	62%	3.32	#N/A	#N/A	63%	3.46	#N/A
28.54	-13.04	0.44	30.96%	7.25	9.86	0.50	11%	12.60	12.64	0.67	17%	9.33	12.13	#N/A	82%	3.55	#N/A	#N/A	44%	4.45	#N/A	#N/A	65%	2.95	#N/A	#N/A	67%	3.19	#N/A
28.71	-13.21	#N/A	40.91%	5.71	#N/A	0.47	6%	12.62	12.62	0.64	20%	8.70	11.62	#N/A	85%	3.42	#N/A	#N/A	55%	3.69	#N/A	#N/A	67%	2.71	#N/A	#N/A	59%	3.09	#N/A
28.87	-13.37	#N/A	48.31%	5.40	#N/A	0.43	6%	11.71	11.71	0.61	31%	7.10	11.32	#N/A	80%	3.56	#N/A	#N/A	62%	2.99	#N/A	#N/A	81%	2.40	#N/A	#N/A	69%	2.83	#N/A
29.04	-13.54	#N/A	62.59%	4.08	#N/A	0.40	8%	10.35	10.35	#N/A	50%	4.99	#N/A	#N/A	67%	3.69	#N/A	#N/A	79%	2.49	#N/A	#N/A	56%	3.04	#N/A	#N/A	60%	3.25	#N/A
29.20	-13.70	#N/A	91.51%	2.91	#N/A	0.38	10%	8.97	8.97	#N/A	66%	4.07	#N/A	#N/A	55%	3.65	#N/A	#N/A	50%	2.79	#N/A	#N/A	40%	4.07	#N/A	#N/A	50%	3.50	#N/A
29.36	-13.86	#N/A	78.77%	2.64	#N/A	0.38	13%	7.83	7.83	#N/A	54%	4.07	#N/A	#N/A	56%	3.40	#N/A	0.41	34%	2.91	5.24	#N/A	45%	3.28	#N/A	#N/A	62%	3.03	#N/A
29.53	-14.03	#N/A	85.96%	2.34	#N/A	0.38	27%	6.21	7.62	#N/A	66%	3.02	#N/A	#N/A	57%	3.32	#N/A	#N/A	57%	2.44	#N/A	#N/A	66%	2.61	#N/A	#N/A	67%	2.72	#N/A

SHALLOW ZONE - MOSS ET AL., 2006			
~8 ft Thick			
~26 ft Below Ground Surface (Center of Dike)			
	FINES	$N1_{60}$	$N1_{60(cs)}$
AVE	22%	8.35	10.42
ST DEV	8%	1.90	2.45
MAX	35%	13.74	17.16
MIN	6%	2.91	5.24

CPT-6 Depth (ft)	Elevation (ft)	CPT-6				CPT-51				CPT-66				CPT-54				CPT-68				CPT-67				CPT-42			
		SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs	SF	%Fines	N160	N160cs
38.39	-22.89	#N/A	46.43%	6.33	#N/A	#N/A	43%	7.78	#N/A	#N/A	41%	5.76	#N/A	0.93	18%	15.00	18.17	#N/A	36%	9.12	#N/A	#N/A	49%	7.36	#N/A	#N/A	47%	7.45	#N/A
38.55	-23.05	#N/A	57.89%	5.58	#N/A	#N/A	43%	8.47	#N/A	#N/A	43%	6.10	#N/A	1.12	14%	21.78	25.42	1.01	31%	10.92	24.73	#N/A	50%	6.95	#N/A	#N/A	47%	7.22	#N/A
38.71	-23.21	#N/A	64.29%	5.08	#N/A	#N/A	44%	8.82	#N/A	#N/A	41%	6.56	#N/A	1.28	18%	19.14	23.45	#N/A	38%	11.09	#N/A	#N/A	48%	7.27	#N/A	#N/A	45%	7.31	#N/A
38.88	-23.38	#N/A	69.11%	4.76	#N/A	#N/A	46%	8.98	#N/A	#N/A	46%	6.63	#N/A	1.16	17%	18.78	22.85	#N/A	49%	9.01	#N/A	#N/A	49%	7.43	#N/A	#N/A	46%	6.90	#N/A
39.04	-23.54	#N/A	62.62%	4.47	#N/A	#N/A	46%	8.39	#N/A	#N/A	48%	6.67	#N/A	1.01	14%	19.09	22.06	#N/A	52%	7.59	#N/A	#N/A	47%	7.25	#N/A	#N/A	49%	6.24	#N/A
39.21	-23.71	0.56	29.57%	6.64	8.75	#N/A	45%	7.78	#N/A	#N/A	50%	6.71	#N/A	0.86	6%	17.23	18.73	#N/A	53%	6.18	#N/A	#N/A	51%	7.29	#N/A	#N/A	50%	5.91	#N/A
39.37	-23.87	0.58	25.90%	7.89	10.03	#N/A	42%	7.68	#N/A	#N/A	50%	6.70	#N/A	0.79	8%	16.62	18.06	#N/A	55%	5.65	#N/A	#N/A	49%	7.43	#N/A	#N/A	49%	5.61	#N/A
39.53	-24.03	0.60	27.42%	7.98	10.65	#N/A	37%	9.36	#N/A	#N/A	54%	6.64	#N/A	0.75	9%	15.18	16.50	#N/A	50%	6.18	#N/A	#N/A	51%	7.13	#N/A	#N/A	51%	5.40	#N/A
39.70	-24.20	0.61	31.24%	7.62	10.91	#N/A	40%	9.70	#N/A	#N/A	55%	6.42	#N/A	0.75	9%	14.08	15.31	#N/A	44%	7.99	#N/A	#N/A	51%	7.02	#N/A	#N/A	51%	5.31	#N/A
39.86	-24.36	0.61	31.25%	7.97	11.43	1.18	22%	14.97	19.83	#N/A	58%	6.36	#N/A	0.75	9%	14.92	16.21	0.91	31%	9.61	16.59	#N/A	49%	7.21	#N/A	#N/A	53%	5.12	#N/A
40.03	-24.53	0.61	30.46%	8.10	11.34	1.27	9%	24.28	27.98	#N/A	53%	6.35	#N/A	0.75	9%	15.15	16.47	1.01	26%	12.18	19.49	#N/A	50%	7.15	#N/A	#N/A	58%	4.94	#N/A
40.19	-24.69	0.60	26.60%	8.57	11.04	1.43	9%	22.43	25.77	#N/A	52%	6.77	#N/A	0.74	9%	14.41	15.69	1.07	20%	14.57	21.08	#N/A	48%	6.83	#N/A	#N/A	60%	4.64	#N/A
40.35	-24.85	0.57	19.73%	9.05	10.25	1.27	10%	21.37	24.56	#N/A	57%	7.06	#N/A	0.73	10%	13.98	15.31	1.07	14%	16.18	21.76	#N/A	51%	6.34	#N/A	#N/A	62%	4:35	#N/A
40.52	-25.02	0.56	14.16%	9.06	9.60	1.17	10%	20.06	23.08	#N/A	43%	8.74	#N/A	0.73	11%	14.01	15.52	1.05	10%	17.29	22.34	#N/A	45%	7.27	#N/A	#N/A	61%	4.18	#N/A
40.68	-25.18	0.56	14.17%	9.41	9.98	1.09	9%	19.02	21.69	#N/A	37%	8.93	#N/A	0.74	11%	14.34	15.88	1.02	10%	16.92	21.96	#N/A	37%	9.37	#N/A	#N/A	61%	4.16	#N/A
40.85	-25.35	0.57	13.76%	9.48	10.06	1.03	8%	18.69	21.17	#N/A	46%	9.26	#N/A	0.74	8%	14.33	15.58	0.94	8%	15.56	19.90	1.13	26%	12.87	21.49	#N/A	64%	4.70	#N/A
41.01	-25.51	0.59	12.49%	9.67	10.26	0.96	5%	17.66	19.82	1.32	18%	19.79	25.01	0.76	8%	15.69	17.05	0.91	9%	14.76	18.92	1.44	24%	15.91	26.09	#N/A	49%	6.25	#N/A
41.17	-25.67	0.60	11.70%	10.38	11.00	0.93	6%	17.20	19.31	1.48	14%	23.34	28.04	0.76	8%	15.59	16.94	0.87	17%	14.23	19.66	1.70	24%	17.27	28.28	#N/A	61%	5.67	#N/A
41.34	-25.84	0.61	11.41%	10.77	11.42	0.88	5%	16.51	18.54	1.19	6%	20.64	23.01	0.74	10%	13.98	15.30	0.84	31%	8.95	15.33	1.80	24%	17.83	28.96	#N/A	61%	5.62	#N/A
41.50	-26.00	0.62	12.06%	10.46	11.09	0.85	6%	15.02	16.86	0.87	6%	17.45	19.45	0.71	11%	13.30	14.57	#N/A	45%	7.02	#N/A	1.87	22%	19.07	29.80	#N/A	64%	5.54	#N/A
41.67	-26.17	0.62	13.38%	10.63	11.44	0.83	7%	14.81	16.62	0.72	11%	12.91	14.39	0.74	12%	13.47	14.94	#N/A	50%	7.06	#N/A	2.01	18%	21.04	31.52	#N/A	63%	5.57	#N/A
41.83	-26.33	0.61	12.93%	10.09	10.72	0.80	8%	14.63	16.43	0.67	17%	11.04	13.16	0.79	11%	15.22	16.91	#N/A	52%	7.05	#N/A	1.97	15%	22.88	32.92	#N/A	62%	5.45	#N/A
41.99	-26.49	0.62	11.15%	10.29	10.91	0.78	8%	13.87	15.57	0.75	26%	9.41	13.24	0.86	10%	16.21	17.99	#N/A	53%	6.83	#N/A	1.68	8%	21.77	29.52	#N/A	62%	5.40	#N/A
42.16	-26.66	0.63	19.51%	10.84	12.78	0.76	10%	13.86	15.61	#N/A	39%	8.97	#N/A	0.93	13%	16.88	19.33	#N/A	53%	6.71	#N/A	1.39	10%	20.70	28.36	#N/A	59%	5.57	#N/A
42.32	-26.82	0.66	29.08%	7.70	10.58	0.73	10%	13.55	15.22	0.82	21%	12.29	15.85	1.02	16%	17.15	20.42	#N/A	49%	6.46	#N/A	1.18	21%	15.69	23.95	#N/A	57%	5.74	#N/A
42.49	-26.99	#N/A	51.28%	5.93	#N/A	0.71	9%	12.76	14.32	0.80	15%	14.93	17.54	1.12	19%	17.52	21.79	#N/A	48%	6.64	#N/A	#N/A	36%	10.44	#N/A	#N/A	55%	5.71	#N/A
42.65	-27.15	#N/A	58.42%	6.11	#N/A	0.70	7%	13.27	14.90	0.80	14%	14.58	17.03	1.12	19%	18.54	23.02	#N/A	48%	7.49	#N/A	#N/A	48%	8.02	#N/A	#N/A	56%	5.52	#N/A
42.81	-27.31	#N/A	65.23%	5.69	#N/A	0.71	8%	13.09	14.69	0.81	16%	13.89	16.44	1.07	22%	16.82	21.96	#N/A	52%	7.34	#N/A	#N/A	52%	7.71	#N/A	#N/A	55%	5.53	#N/A
42.98	-27.48	#N/A	70.29%	5.50	#N/A	0.74	10%	12.90	14.53	0.85	14%	14.70	17.22	0.98	28%	14.28	20.66	#N/A	59%	7.01	#N/A	#N/A	51%	7.89	#N/A	#N/A	53%	5.83	#N/A
43.14	-27.64	#N/A	69.71%	5.64	#N/A	0.77	12%	13.47	15.51	0.95	14%	16.41	19.37	#N/A	44%	9.37	#N/A	#N/A	62%	7.02	#N/A	#N/A	56%	7.70	#N/A	#N/A	51%	6.42	#N/A
43.31	-27.81	#N/A	71.78%	5.79	#N/A	0.79	10%	13.61	15.40	1.00	17%	17.16	20.97	#N/A	53%	7.28	#N/A	#N/A	59%	6.46	#N/A	#N/A	58%	7.41	#N/A	#N/A	50%	6.97	#N/A
43.47	-27.97	#N/A	73.50%	5.68	#N/A	0.85	17%	13.95	17.03	1.01	22%	14.61	19.12	#N/A	57%	6.34	#N/A	#N/A	59%	6.05	#N/A	#N/A	60%	7.02	#N/A	#N/A	52%	6.99	#N/A
43.64	-28.14	#N/A	75.11%	5.65	#N/A	0.91	23%	13.85	18.78	1.07	30%	12.94	20.06	#N/A	62%	5.93	#N/A	#N/A	61%	5.67	#N/A	#N/A	60%	6.71	#N/A	#N/A	53%	6.95	#N/A

INTERMEDIATE ZONE - MOSS ET AL., 2006			
~5 ft Thick			
~41 ft Below Ground Surface (Center of Dike)			
	FINES	$N1_{60}$	$N1_{60(cs)}$
AVE	15%	14.10	17.03
ST DEV	7%	3.55	4.35
MAX	31%	24.28	27.98
MIN	5%	6.64	8.75

Figure 2
EVALUATION OF FINES CONTENT
ALONG TYPE SECTION TS-1