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Subject: Report of Geotechnical Findings, Living Shoreline Project, Humboldt Bay

Dear Jeremy Svelha:

Introduction

This report presents the results of SHN's evaluation of geotechnical conditions along a 1.25-mile-long segment of the Humboldt Bay shoreline as part of the County of Humboldt's Living Shoreline project. The Living Shoreline project intends to restore the pre-existing estuarine marsh plain along a key stretch of the bay shore adjacent to U.S. Highway 101, between the Brainard and Bracut industrial areas, as a means of providing adaptive mitigation for sea level rise. The project seeks to utilize the natural flood and wave reduction properties of salt marshes along the bay margin to restore habitat and to protect the existing highway corridor. The information herein builds upon the information provided in 50% design documents and is intended to inform the planning and design teams relative to geotechnical conditions in the bay environment at the project site.

Our work scope is focused on addressing the primary geotechnical issues facing the project, which we take to be related to the import of fill soils and their placement over soft, saturated bay muds in a portion of Humboldt Bay where the pre-existing salt marsh plain was lost to erosion and shoreline reclamation from wind waves. As several feet of fill soil will need to be placed to develop the restored marsh plain, estimation of the amount and rate of settlement potential is a primary focus of this report. The source of fill material is not known and may range from wet bay muds (dredge spoils) to heterogeneous upland soils. Therefore, in this report, we evaluate the implications and construction considerations of a variety of potential fill materials and methods of emplacement.

The information in this report is based on available existing data. Due to the difficulty in collecting samples in wet bay muds, it is not feasible to obtain project-specific soil samples and representative laboratory test results. Rather, we have utilized the extensive geotechnical sampling, testing, and reporting associated with the adjacent California Department of Transportation (Caltrans) Indianola undercrossing project along U.S. Highway 101 across about 4,100 feet of the project area. Specifically, much of the geologic and geotechnical data for the project is derived from the Caltrans geotechnical design report memorandum (2022).

Relevant site-specific data is also available in geotechnical reporting for the Humboldt Bay Trail through the project area (CAI, 2019). That work included subsurface investigation (machine borings) on the trail alignment along the shoreline edge of the project area and subsequent laboratory testing (moisture content, dry density, percent passing the #200 sieve).

These reports, and our own previous observations, provide a consistent picture of the bay margin setting through the project area. The area is underlain by a thick (60- to 100-foot-thick) sequence of Holocene age bay mud deposits that are very soft fine-grained soils (including fat clays), organic rich, and interbedded by occasional thin sandy layers.

Information related to analogous restoration projects in similar estuarine environments was gathered through literature review and interviews with pertinent scientists and engineers.

Our understanding of the project is based on the Natural Shoreline Infrastructure in Humboldt Bay for Intertidal Coastal Marsh Restoration and Transportation Corridor Protection project documents; specifically, the 50% Design Plans (dated March 7, 2022) and 50% Design Report (dated September 2, 2022).

We understand the project may be implemented in phases or cells as shown on the 50% Design Plan and completed sequentially from northeast to southwest (see the Staging and Phasing Plan, Sheet G-007 in the 50% Design Plans). The northeastern area, "Phase 1" is adjacent to the Bracut Industrial Park, and we understand this area to be viewed as a "pilot" phase for the subsequent phases of construction. As such, some information in this report is focused on the initial Phase 1 area.

Project Description

Preliminary Design

As described in the 50% Design Report, the goals and objectives of the Living Shoreline project focus on the creation, diversity, and resiliency of native intertidal coastal marsh habitat; using the natural flood hazard reduction properties of salt marshes to protect critical transportation infrastructure; and creating opportunities for innovation and learning to enhance our understanding of nature-based sea level rise adaptation while providing beneficial reuse of local sediment sources. From a lengthy analysis of design alternatives to meet these project goals and objectives, the "apparent best alternative" identified in the 50% Design Report consists of three primary components:

1. **Salt marsh plain** with tidal channel network**;**
2. **Coarse sediment shingle** beach along the outer edge of the marsh plain, with log groins, and**;**
3. **Transition (high marsh ecotone) zone** between the back edge of the marsh plain and the existing trail corridor.

Salt marsh—Based on analyses of wind wave potential and tidal current, as well as conditions in analogous settings elsewhere in Humboldt Bay, a total marsh width of 150 feet was established, of which

115 feet would be the salt marsh plain at an elevation of approximately 7.1 feet (North American vertical datum, 1988 [NAVD88]). The remaining 35 feet would encompass the transition zone. Existing marsh remnants would be retained and incorporated into the proposed marsh plain. The 7.1-foot elevation of the proposed marsh plain is consistent with mean higher-high water (MHHW) and analogous surfaces elsewhere in Arcata Bay.

The tidal channel network is intended to allow flow across the marsh plain to maximize the supply of fine sediment and to allow for vertical accretion on the marsh plain to accommodate sea level rise. The location and complexity of the channels is based on analogous marsh plains elsewhere on the bay (Jacoby Creek marsh, for example). The tidal channels would presumably be excavated following the placement of the marsh fill (and the completion of settlement).

The elevation of the current mudflat surface is approximately 3.5 feet; therefore, several feet of fill will need to be imported to raise the marsh plain surface to the desired elevation of 7.1 feet. The source of the fill materials is not known, but the 50% Design Report defines the desired soil to be "lightly compacted silts, clays, and fine sands (similar to existing salt marsh sediment)." The material will need to comply with the Regional Water Quality Control Board's Incremental Sampling Method (ISM).

Coarse sediment beach—The coarse sediment beach along the exposed outer edge of the restored salt marsh plain is intended to provide a self-maintaining buffer against erosion related to wind-wave energy. As described in the 50% Design Report, "the coarse beach is not intended to permanently stabilize the shoreline in a fixed position, but rather provide a sloping beach face to dissipate wave energy and a local sediment source to facilitate natural evolution of the beach profile in response to future water levels and wave events." The coarse sediment beach is intended to facilitate the establishment of protective vegetation on the marsh plain. Some landward migration of coarse sediment is anticipated in large wave events, which will result in formation of over wash berms along the edge of the marsh plain.

The preferred texture of the coarse sediment beach was defined based on evaluation of analogous sites in Humboldt Bay and the San Francisco Bay estuary. The preliminary design includes a coarse sand and gravel beach that would be constructed as part of the placement of fill materials. Some design concepts include passive filling or placement of hydraulic spoils as marsh plain fill, which would require development of a cobble containment berm. A coarse sediment beach would still be constructed along the outboard edge of a cobble berm to provide a dynamic buffer against erosion and wave run-up.

The slope of the coarse sediment beach would be on the order of 10:1 to 15:1 (horizontal:vertical). The design allows for the constructed beach slope to be steeper (3:1 to 5:1) than the anticipated beach slope once it reaches equilibrium.

Log Groins—Log groins would be developed at tidal channel inlets to reduce erosion potential and to reduce downdrift loss of the coarse sediment beach material.

Transition Zone—The transition from the marsh plain surface at elevation 7.1 to the rail prism at elevation 11.5 will be a gradual slope intended to accommodate vegetation and attenuate wave energy during extreme storm events. The primary criteria for the type of soil utilized in the transition zone is its ability to support the desired vegetation. The transition zone is intended to be 35 to 40 feet wide.

Phase 1 Area

The preliminary design for the Phase 1 area is shown on Site Plan 4 (Sheet C-104) of the 50% Design Plans. The existing mudflat surface has an elevation of 3 to 3.5 feet. The area extends from the Bracut Industrial Park on the northeast end to a remnant of a 600+-foot-long, west-trending earthen groin that extends into the bay from the rail corridor.

A narrow (100-foot-wide) strip of remnant salt marsh occurs along the shoreline adjacent to Bracut. The remaining shoreline occurs along the rail corridor, which is armored by riprap (and a sand/gravel beach). The outer edge of the proposed marsh plain projects to the southeast from a peninsula formed by a strip of remnant salt marsh connected to Bracut.

The 50% Design Plans show the Phase 1 area with a log groin protecting the mouth of a tidal inlet that leads to shore-parallel tidal channels.

Preliminary Construction Alternatives

We understand the project has been designed to allow construction within a single phase, should all the necessary fill material be available, or over multiple phases/years, as suitable fill soils become available. The project is intended to be constructed from northeast (Bracut) to southwest (Brainard). The 50% Design Plans show nine construction areas (phases) that represent successive work areas to be completed as adequate quantities of fill soils and/or funding become available.

As the construction will initiate from the northeast end of the project area, the Bracut area would ideally serve as the staging area for soil and equipment storage for the initial construction phases.

The source of suitable fill soils for the project is not known at this time. We understand that preliminary consideration has been given to a variety of materials and sources, but the primary controlling factors are the need for fine-grained sediment capable of meeting the project objectives and the desire to facilitate beneficial re-use of the abundant dredge spoils that are generated in Humboldt Bay maintenance operations. This would suggest the most likely sediment source will be dredged bay muds (predominantly silts), either wet or moisture conditioned (dried).

Saturated dredge spoils could be delivered to the site via pipes, which would require long reaches across the bay, or barges, which could access the site only during high tides. Trucking saturated dredge spoils would be problematic unless it could be contained during transport. Construction using saturated dredge spoils would require development of a gravel/cobble containment berm along the outer edge of the proposed marsh plain, as the material would be placed as a slurry that will flow into place. Heavy equipment will not likely be able to access the work area to redistribute saturated muds.

Consideration has been given to passive infill approaches, where a containment berm with a breach cut would be developed that allows tidal inflow and slow accretion of sediment. This would require construction of the gravel/cobble berm as a long peninsula or low-crested breakwater across the outboard edge of the proposed marsh plain.

Moisture conditioned (dried) fill soils could be trucked to the site and stockpiled (at Bracut, for example) if necessary. Application of moisture conditioned material would presumably be achieved with standard heavy equipment; the material would essentially be graded into place. The use of moisture-conditioned fills would facilitate over-building the marsh plain to provide surcharge loading to induce settlement, after which the finished marsh surface could be cut to the desired geometry.

Review of Analogous Restoration Projects

In order to develop an understanding of lessons learned from analogous restoration projects, we reviewed a series of previous efforts in Humboldt Bay and interviewed the Ducks Unlimited project engineer experienced with a similar effort in South San Francisco Bay.

SHN staff have previously worked on a variety of restoration projects in Humboldt Bay, including the White Slough Wetland Restoration Project. We have reviewed available documents and discussed with the relevant staff the observations and lessons learned from those efforts.

There are two significant projects currently ongoing along the Humboldt Bay shoreline in the project area that inform our interpretation of geotechnical conditions. Caltrans is currently building the Indianola undercrossing adjacent to the project area; the Indianola Cutoff is adjacent to the Phase 4 cell (per 50% Design Plans), and the construction encompasses all or most of the area adjacent to Phases 3, 4, and 5. SHN staff are engaged in materials testing of concrete in deep displacement columns that are being used as ground improvement beneath the site. Significant work has been completed in the past few years along the Bay Trail corridor following the abandoned rail alignment that abuts the back edge of the project area; the transition zone will be integrated into the bay-ward edge of the Bay Trail corridor. We have reviewed geotechnical reporting for the project. A bridge was constructed this year at the southwestern end of the project area ("Phase 9") to facilitate the trail reaching Brainard.

City of Mountain View South Bay Salt Pond Project

On August 23, 2024, SHN and GHD staff interviewed Steve Carroll, PE, with Ducks Unlimited, who has worked on a similar marsh ecotone slope restoration project in the City of Mountain View, as part of the South Bay Salt Pond Project in the southern part of San Francisco Bay. We reviewed photographs of the construction. Key takeaways from our conversation included:

- The construction was completed using dry soil trucked to the site in dump trucks. Fill was placed in thick lifts and spread across the site, from the shoreline outward, with standard heavy grading equipment. The initial lift was described as 4- to 5-feet-thick or more to allow bridging over the soft existing mud flats. Additional thick lifts were placed without mechanical compaction.
- The area was overbuilt with a surcharge that was allowed to settle for several months.

- The texture of the imported soil was relatively broad, and mostly consisted of granular upland soils derived from local development sources. It was noted that some fines and organic silts were necessary to achieve project objectives.
- 30% to 40% consolidation was noted (including both consolidation of the loose fill soils and settlement of the underlying soft bay muds).
- Following the settlement period, the marsh plain was cut to grade. In the Mountain View example, this consisted of tapering the outer edge of the plain, which was accomplished with long reach excavators.
- The challenges of establishing vegetation on the finished grade were noted, as the ground was generally overly firm. To facilitate planting, the surface was "de-compacted" (ripped) to loosen shallow soils. This was noted as challenging in terms of construction sequencing, as once an area is "de-compacted," it becomes inaccessible to machinery.
- Placement of the fill section resulted in a consistent bearing failure within the bay muds at the leading (outboard) edge of the fill prism. This bearing failure was accompanied by a persistent broad "mud wave" within the mud flat directly outboard of the edge of fill. The mud wave was a few feet in height and extended a few tens of feet onto the adjacent mud flats. The mud wave was left in place and has reportedly reduced erosion (it attenuates the small wind waves at the site).

Consolidation/Settlement Potential

In order to assess or estimate the potential settlement of surcharge fill placed on bay muds to raise the elevation to develop the salt marsh plain at approximately 7.1 feet (NAVD88), we used consolidation test data derived from the Caltrans geotechnical design report memorandum (2022). The closest subsurface data from the Caltrans study was from their cone penetration test CPT-18-017 and boring RC-18-003 at the northeastern portion of their 4,100-foot-long geotechnical transect and the southwestern edge of our project location. Based on the logs of borings and CPTs, there are thick layers of bay mud (soft, highly plastic silts and clays) with intermittent thin layers of silty sand sandwiched in between to over 100 feet in depth. This condition was encountered in shallow borings along the Humboldt Bay Trail as well (CAI, 2019). Assuming similar subsurface conditions and approximately 100 feet of bay mud in the area where the proposed salt marsh elevations will be raised, we utilized consolidation data from the Caltrans study to estimate potential settlement.

Based on our review of the consolidation laboratory test results from the Caltrans study, we determined that an average consolidation coefficient C_c of 0.56 is appropriate for use in our settlement analyses. In assessing potential settlement from surcharging the salt marsh area, we used an average density of 100 pounds per cubic foot (pcf) for the material being placed. Utilizing the average consolidation coefficient of 0.56 and an assumed average density of 100 pcf, we estimate settlement of approximately 30% due to consolidation of the underlying bay mud. Therefore, to raise the existing elevation from 3 to 3.5 feet to approximately 7.1 feet and account for the settlement of the underlying muds, the salt marsh would need to be surcharged with approximately 5 feet of surcharge fill soils (see following discussion).

An analysis of the settlement potential for the barrier berm (including the "portion to remain and optional barrier berm" on the Salt Marsh – Typical Section on Sheet C-301 of the May 2, 2022 plans project plans) was also performed. Assuming an average density of 140 pcf for the cobbles, gravels, sand, and soil that the barrier is anticipated to be composed of, and approximate 5-foot thickness, we estimate about 1.2 feet of settlement. The coarse gravel/sand beach is anticipated to settle with the barrier berm on the inboard (landward) edge, where it will have similar thickness, with reduced settlement potential (becoming negligible settlement potential) toward the outboard edge.

The settlement analysis is sensitive to the presence of sand layers in the section that will aid in drainage of the bay mud during consolidation, so it is likely that actual settlement values may be affected by varying stratigraphy across the project area.

Some consolidation would be anticipated within the fill prism itself, especially if placed in one or two large dry unconsolidated lifts. Under its own weight, the fill prism may consolidate up to 10% (depending on the unit weight of the material used), but we expect additional consolidation under the weight of heavy grading equipment should it be utilized. If grading equipment is operating on the surface of the fill prism as it is being placed, additional, accelerated settlement and consolidation is expected. If material is being hauled onto the surcharge fill surface from a launch point at Bracut, well-travelled haul routes would experience additional consolidation relative to other areas. If this is the case, the rate and magnitude of settlement would be expected to vary depending on the level of traffic.

Placement of the fill prism and operation of heavy equipment on the surcharge fill surface will result in settlement, as discussed above, and a likely bearing failure and accompanying "mud wave" (bulge) at the outboard edge of the fill prism. Consolidation associated with heavy equipment loading may occur in a relatively short time frame, so the potential for grade changes across the mud flat outboard of the fill prism (or on both sides of a cobble containment berm) during construction can be expected.

In order to account for variations in settlement rates (due to variable mud flat stratigraphy), consolidation rates (if heavy equipment is utilized and the surcharge fill surface is subject to variable traffic patterns) and the potential bearing failure-related grade changes, we recommend building the finished surcharge grade at a consistent elevation of at least 9.0 feet. Variations in elevation following a suitable surcharge settlement period can be alleviated during final grading.

It is difficult to estimate the time to complete the anticipated settlement due to the existence of the silty sand layers sandwiched between the bay mud layers. Each layer of bay mud would be double drained (from the top and bottom of the layer) which will speed up the time for settlement. Depending on the thickness of each bay mud layer sandwiched between the silty sand layers, the time for primary consolidation of the bay muds will vary. However, we would anticipate that most of the settlement would occur in roughly 12 months.

Settlement markers can be installed and surveyed periodically. Settlement monitoring will allow measurement of the consolidation settlement to evaluate when an acceptable level has occurred, or when the settlement rate decreases to a point indicating completion of primary settlement.

Following an appropriate primary settlement period (12 months, for example), if the desired elevation of 7.1 feet is not achieved, final grade changes can be made. We expect that the final grade will need to be ripped to de-compact the surface and facilitate re-vegetation.

Discussion

Based on the geotechnical conditions at the site relative to the project goals and objectives, we offer the following discussion points.

Use of wet dredge spoils—Relative to soil textural criteria, beneficial re-use of dredge spoils as a primary sediment source is a favorable option. Using the dredge spoils when wet, however, would present many challenges. The project area is remote relative to areas in the bay where dredging occurs, so transport of the spoils (via pipe, barge, or truck) would pose substantial challenges.

A cobble containment berm, or other containment system, would be required on all sides of each work area prior to the application of the spoils. The material would be applied as a slurry and equipment would be unable to access the area until a sufficient volume of material had been applied and allowed to dewater. Application of a surcharge would require the containment berms be over-built (exceeding elevation 7 feet). Some or all of the containment berms would need to be removed following completion of each work phase, and the coarse sediment beach developed after removal of the outboard berm. The use of wet dredge spoils appears marginally feasible due to the difficulties in transport, application, moisture conditioning, and grading.

Use of dried dredge spoils—By drying and moisture conditioning the dredge spoils, they would still meet project soil texture objectives, but they would be more easily transported, applied, and graded. The material could be trucked to the site and dumped in stockpiles or directly applied to the work area. These fill soils could be spread with conventional grading equipment, easily facilitating the development of a surcharge over-build to accelerate consolidation and settlement. A cobble berm (possible temporary) is likely necessary to mitigate short-term wave erosion. The coarse sediment shingle beach could be developed with excavators depositing material from the edge of the fill surface once the desired marsh plain width is achieved and after stabilization of the exposed outer edge of the marsh plain (via the cobble berm). After the settlement period, the surface could be graded to the final desired configuration (elevation 7.1-foot marsh plain with tidal inlets, log groins, and tidal channels).

Drying dredge spoils to an appropriate moisture condition requires a significant amount of time and space. The material is ideally laid in thin wind rows and frequently turned to facilitate drying. Even under ideal conditions, drying times can be considerable. Achieving project goals with this approach would require careful planning and a phased approach over several years. The timeline of the project may be limited by the frequency of dredging in the bay (which is currently sporadic).

Use of imported "upland" soil—It would be difficult to achieve project objectives relative to preferred soil texture using entirely imported "upland" soils due to the unique qualities of estuarine marsh sediments. Estuarine marsh sediments are silt-rich soils not found in other (upland) environments. It may be feasible to utilize upland soils, which would presumably be more readily available, in limited parts of the fill section (in the basal part of the section, for example) or blended with more favorable material. Dried dredge spoils could then be spread over the top to facilitate planting. Should the upland soils represent a portion of the soils column, it is likely that they would be exposed in the sidewalls of tidal channels when they are excavated; these soils may be more erosive, for example, than fine-grained marsh soils. Segregated soil types may be difficult to achieve if the material is placed en masse in one thick lift.

Construction Considerations

Based on the site conditions and project objectives, it appears the most favorable approach is to use moisture-conditioned dredge spoils, as much as possible, and to utilize the general approach described above for the City of Mountain View example. That is, truck fill soils to the site and spread it out in a thick lift or lifts to bridge the soft bay muds. Over-build the fill prism to develop a surcharge and allow an adequate consolidation/settlement period. Develop a cobble berm, as appropriate, to protect the outer edge of the marsh plain fill. After the settlement period cut the marsh plain to shape and appropriate elevation. Material removed in the final grading can be stockpiled for future phases. Development of the coarse shingle beach may occur over the cobble berm, or all or part of the cobble berm can be removed over time.

Anticipate the "mud wave", which will occur at a minimum, along the outboard edge of the fill prism (or along both sides of a cobble containment berm). If dried fill soils are imported to the site and hauled onto the progressively expanding marsh plain as it is being constructed, a succession of mud waves is likely to follow the leading edge of the fill prism. This will result in grade changes in the mud flat outboard of the fill as construction occurs. It appears feasible that some bay mud may be "harvested" from the mud wave and stored for use as a mud cap on the marsh plain surface.

Closure

This geotechnical report of findings is based on existing data and does not include the collection of site-specific data. We extrapolate the abundant existing geotechnical information from adjacent studies along the bay shoreline and adjacent highway corridor and assume its continuity across the project area, which is reasonable in the bay margin setting.

This is a unique project, with few analogues, and we understand the initial phase will likely be completed as a pilot study to evaluate design and construction constraints and opportunities. We encourage this approach. We look forward to the opportunity to assist in the continued development of the Living Shoreline.

Please call me at 707-441-8855 if you have any questions.

Sincerely,

SHN

Gary D. Simpson, CEG
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Sr. Geotechnical Engineer

GDS:ame

References

California Department of Transportation (Caltrans). (June 9, 2022). "Geotechnical Design Report for the Indianola Cutoff Undercrossing (Eureka-Arcata Route 101 Improvement Project)" memorandum. NR:Caltrans.

Crawford and Associates, Inc. (CAI). (2019). *Geotechnical Report for the Humboldt Bay Trail South, Eureka, California*. Sacramento, CA:CAI.