Aramburu Island, Marin

Constructed Bay Beaches as Soft Engineering Alternatives to Shoreline Armoring at Three Southern Marin County Demonstration Sites: Greenwood and Brunini Beaches, Tiburon; Paradise Beach, Tiburon; and Seminary Drive, Marin County

Preliminary Design Report

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Introduction

Beaches are a natural part of the living shoreline of San Francisco Bay and support a diversity of benthic organisms. They are found where there is a supply of coarse-grained sediments (sand, gravel, or cobble) and a wave climate competent to mobilize, transport, and deposit these sediments allowing the formation of a beach (Goals Project 2015, SFEI and SPUR 2019, SFEI and Baye 2020). Bay beaches can adjust to the local wave climate, and the permeable nature of the sediments helps to absorb the uprush of wave swash, a process that protects the upper reaches of the beach and backshore and can help manage wave erosion issues. Beaches fronting stable backshore environments can serve as a reference for a design-with-nature approach as they provide useful information on beach structure (dimensions and material composition) and dynamics (sediment movement and morphological change from storm to storm).

Historically, San Francisco Bay had many natural beaches located around the bay margin (Appendix A). They were commonly found in Marin County in various settings ranging from flatter sandy beaches to rock beaches fronting higher energy cliff locations (SFEI and Baye 2020). As such, Marin County is an excellent location to evaluate the ability of enhanced bay beaches to inhibit shoreline erosion under a variety of conditions. Given the variety of shorelines, Marin County is also an excellent outdoor laboratory to assess the feasibility and cost-effectiveness to construct beaches in areas where it is not currently present or where there may be some remnant beach present that can be nourished.

This report develops conceptual preliminary plans with a feasibility analysis of those plans for three demonstration sites in southern Marin County, each with differing wave erosion issues and site settings. All three sites have some remnant beach, so beach nourishment with some construction is appropriate, but the concepts will be applicable at other locations with no existing beaches. These conceptual beach enhancement plans are an alternative to riprap or walls as a preferred way to manage shoreline erosion issues best. The design goals are to promote dynamically stable enhanced bay beaches that protect both upland shores and fringing backshore tidal marshes without impacting valuable public shoreline uses that armoring causes. Constructed bay beaches can also provide and sustain substantial co-benefits, including wildlife habitat (high tide roosts and feeding areas for shorebirds), recreation, coastal access, and scenic shorelines that riprap, boulder revetments, and seawalls negatively impact. These public shoreline uses are significant in San Francisco Bay, and there is a need to ensure that necessary erosion control measures are compatible with habitat and esthetic needs. These co-benefits collectively add up to what we believe to be a softer, environmentally superior approach to solving wave erosion problems compared to the traditional static hard structures like riprap and seawalls.

The three demonstration sites, shown in Figure 1 and described more fully in Section 3, are:

1. Greenwood and Brunini Beaches (shoreline at Blackie's Pasture Park), Tiburon – This is an eroding shoreline exposing rubble and asphalt fill to the bay. The park setting has considerable public use and high visibility for a public demonstration of a natural beach restoration project.
2. Paradise Beach Park, Tiburon Peninsula – This is a higher wave energy location for San Francisco Bay. It is located in a public park setting with an actively eroding shoreline and a failing hillside that needs protection with a retaining wall. The site contains sensitive eelgrass habitat located directly offshore of the Park. This beach is an excellent location to evaluate the integration of traditional engineering for shoreline stabilization with natural beach systems for a hybrid green-gray solution.

3. <u>Seminary Drive Roadside Erosion, Unincorporated Marin County –</u> This is a demonstration of a constructed beach to protect a retreating wave-cut salt marsh scarp adjacent to a levee and sensitive wetlands habitat. The design is based on coarse-grained sediment placement (cobble and gravel beach berm) and possibly using coarse wood debris (rootwads and logs). The design at this location would be useful for other agencies involved in protecting critical infrastructure (in this case, a County road) with limited space as an alternative to rock riprap.

Figure 1: Location of the three demonstration sites in Marin County, California.

Each site has characteristics that make them useful to investigate different commonly found issues around San Francisco Bay and beyond. For example, the three sites exhibit a range in wave and beach response from coarse-grained beach environments to stable sand-silt and vegetation bay beach environments. Each site can support demonstration projects that the public can see and experience. There are many challenges to address in these types of designs, which may not be solved at the site scale but will be brought forward and added to a regional conversation about priority setting.

Creating, enhancing, or constructing a beach will require a range of permits from local, state, and federal regulatory agencies and landowners. The Bay Conservation and Development Commission's policies that regulate fill in the Bay were updated in October 2019 to account for the need for a new approach given the threat of sea-level rise. Section 6 below discusses the permitting issues in more detail.

Note to reader: This report has multiple authors and reflects differences in both style and substance of the two design approaches and their broader experience of permitting and construction issues. The different designs are described in appendices authored by the respective designers and summarized by the project manager in the main report. Individual sections may reflect a view subject to some healthy differences and discussion, and in these cases, the primary author for each section will be identified upfront. This report is written to allow differing opinions to be expressed and the reader to evaluate and form their own opinion on the design approaches. Given the early state of beach design as a living shoreline design approach, this seems an appropriate way to further the discussion and science of estuarine beach restoration in San Francisco Bay at this time.

Design Approaches

There is a long history and a large body of engineering knowledge for open coast beaches (Jackson *et al*. 2010, Johannessen *et al.* 2014, Prosser 2018). However, there has been much less attention to estuarine beaches and their role in erosion control and sea-level rise adaptation (Nordstrom and Jackson 2012). Beaches have been constructed or nourished in San Francisco Bay, such as Crown Beach and Crissy Field for recreation and Aramburu Island for shoreline erosion protection. There are several more beach projects in development as the interest in softening the shoreline in anticipation of sea-level rise has increased. These are all demonstration projects, and the region is seeking ways to monitor and test design approaches so that the efforts can be scaled effectively.

During this study's design phase, it has become clear that different beach design approaches have pros and cons. The design difference could be summarized as “build a beach” versus “feed a beach” approaches to beach restoration. These contrasting approaches represent different ends of the broad spectrum of beach construction and nourishment methods. Both approaches are more natural alternatives to conventional coastal engineering stabilization methods that armor shorelines with riprap at the expense of habitat quality, recreational values, and esthetics.

Rather than force a single design approach, this report highlights the differences and the pros and cons of each approach. The more significant differences between approaches can then be the subject of higher-level review and discussion by regulatory agencies and stakeholders to inform bay beach's design throughout San Francisco Bay and beyond. Ultimately, selecting the appropriate design approach is not just a technical exercise but will respond to project, public, and regulatory goals for the Bay both today and under future conditions. As more projects are built and monitored, there will be an increasingly better understanding of which design approach works better under what conditions. Design with nature sounds simple but is complex, just like natural systems. Therefore, we should not expect that a single design approach is appropriate in all situations.

There are costs and practical difficulties to repeated permitting and funding to obtain and place sediments to maintain a beach. Coarser-grained sediments (gravels and larger) are not naturally present in the Bay beyond a limited supply of gravels (approx. 15 to 20 mm) that are a byproduct of sand mining in San Francisco Bay and also some coarse material from bluffs. Therefore, projects will have to locate and transport gravels and cobbles that meet the roundness specifications for mobility from other sources outside the Bay, such as river bars. The ecological impacts to the rivers and other source areas, together with the greenhouse gas (GHG) impacts and costs for transportation, will have to be considered. There is a commercial industry of landscape rocks and sands and gravels for construction from Washington State, but these costs are much higher. On a large scale, solving these factors will require a much more robust regional program for sediment management. There are also institutional barriers; many public flood control agencies, and private entities, have difficulties with longer-term maintenance programs as budgets and staff changeover. Traditional engineering solutions like riprap offer the promise of one-time design and construction, appealing in a world where funding is easier to get in a capital program tied to a specific project and much harder to obtain for a maintenance program. Since this study aims to increase the use of more natural approaches beyond parks and wetland areas, having a range of design approaches may help convince some agencies and private owners to implement what may appear to be a riskier approach that requires more maintenance. These human and institutional factors should not be discounted. There is a heightened awareness in San Francisco Bay of the need to reuse sediments, especially coarse-grained sediments, and projects such as Sedimatch seek to connect projects having excess sediment with those needing sediment for restoration (https://www.sfei.org/projects/sedimatch-web-tool). Cyclic beach nourishment differs from armoring in its ability to adapt to sea-level rise over time (Stive et al. 1991, Houston 2017, 2019). However, local or regional long-term sustainability may be constrained by sediment supplies and costs (Parkinson and Ogurcak 2018).

The two beach design approaches can be broadly described as follows:

Design Approach A - Dynamic Beach Nourishment

The "Dynamic Beach Nourishment" Design Approach is a geomorphological design approach based on nourishing the beach system with sediments of the appropriate size and allowing the wave to reorganize the beach material into a profile reflecting the wave conditions. The resultant beach profile will be dependent on the range of sediment sizes, their variation with depth, and the specific coastal setting. This approach is described in this report and the previous State Coastal Conservancy/Marin Community Foundation (SCC/MCF) grant by Dr. Peter Baye, Ph.D. coastal ecologist (SFEI and Baye 2020). The approach is based on observations of processes at the demonstration sites combined with knowledge and limited empirical measurements from local reference sites. This is essentially a beach restoration approach, modified for increased resilience to accelerated sea-level rise and associated climate change impacts on beach ecosystems, such as increased intensity or recurrence of droughts, extreme temperatures, floods, and storms. Estuarine beach restoration in this context is reliant on repeated shore (or profile) nourishment.

"Shore nourishment", shoreface nourishment, or profile nourishment, refers to recent trends of replenishing beaches and maintaining beach sediment volumes across the entire active beach profile. Shore nourishment is inherently dynamic: it is often based on sacrificial "feeder beaches" or nearshore sediment deposition designed to erode from where it is placed, and supply sediment to replenish the rest of the littoral cell's beaches (de Schipper et al. 2016, VanKoningsveld et al. 2008, Nordstrom 2008). Cyclic shore nourishment is increasingly used at different scales to strategically mitigate sea-level rise, flooding, and erosion (Stronkhorst et al. 2017, de Schipper et al. 2017, Houston 2017, 2019).

Shore (nearshore profile) nourishment is based on the placement of sacrificial, incremental deposits of mobile beach sediments across the intertidal zone where waves can transport and rework them into natural, dynamic self-constructed beach profiles. (Nordstrom 2000, 2008; Dallas *et al*. 2012) The Aramburu Island Habitat Enhancement Project's beach nourishment design, and Pier 94 San Francisco beach design (SFEI and Baye 2020) were based on this shore nourishment approach of self-constructed beaches artificially supplied with heterogeneous sediments for waves to sort and redeposit. Shore nourishment aims to maintain a volume of beach sediment within a littoral cell. This contrasts with classic beach nourishment or "design berm" construction, in which the high tide beach berm and beachface are graded to specified dimensions (Nordstrom 2000).

The zone of shore profile nourishment for estuarine beaches is necessarily narrower than that of open-coast high-energy beaches, where large waves can shoal and break over shallow subtidal bars at low tide. Estuarine beaches located above tidal mudflats have a narrower intertidal zone of active wave transport of beach sediment, with short-period wind-waves shoaling and breaking close to the beachface (Jackson *et al*. 2002). Wide tidal mudflats below estuarine beaches in San Francisco Bay are generally near Mean Sea Level. These mudflats damp wave energy until tide levels significantly rise above mid-intertidal levels that provide enough water depth for wave propagation to the beachface. Wave swash and backwash on the estuarine beachface are most competent to transport sand, shell, or gravel across and along shore during high tide stages. Estuarine beach sediment in this zone is highly available for reworking by wind waves, but shore nourishment in flats below may be unavailable for regular transport onshore, except in unusual wave conditions.

The local coastal setting is an essential determinant of estuarine restoration designs, including wetlands and beaches (SFEI and SPUR 2019, Goals Project 2015). Local San Francisco Bay beach types (beach sediment composition and grain size distribution, beach dimensions, forms, and dynamics) used as models for reference conditions can be inferred from either existing relict systems, or historical maps (U.S. Coast Survey T-sheets), or both (SFEI and Baye 2020). The classic restoration approach of emulating natural dynamic processes and variability of reference systems can be modified in living shoreline designs to enhance shoreline resilience to increased sea levels or increased storm wave energy[1]. Increasing resiliency to storm waves may involve increasing the variability of beach sediment size distribution to include larger volumes of coarser sediments like gravel.

Beach restoration aligned with living shoreline hybrid shoreline restoration/stabilization designs may incorporate modifications of local ecosystem features and processes, such as:

- periodic or episodic, incremental beach sediment replenishment (nourishment) to offset sediment deficits induced by losses, including sea-level rise;
- native vegetative stabilization elements (increased sediment trapping capacity, roughness for wave attenuation, or augmented substrate shear strength);
- addition or augmentation of longshore drift obstacles (drift-sills or groin-like features) in combination with sediment addition, compatible with local shoreline scale and types, to increase beach sediment retention and width by restricting local longshore drift;
- increasing variability of grain size to include coarser size-classes (coarse sand, gravel, shell hash); and,
- augmenting the local beach sediment supply, or enlarging beach size, to approach maximum size within the observed range of variability, to buffer episodes of extreme storm erosion, or drought-induced sediment deficits from stream or bluff erosion sources of beach sediment.

Because estuarine beach restoration designs aim to replicate whole ecosystems that balance multiple ecological and physical functions within and beyond their boundaries, they are not engineered to maximize specific functions, such as wind-wave erosion, over others. Their design is dependent on their fit within local coastal settings and local modern or historical reference systems, and so there is no all-purpose regional template or recipe for design (analogous with an engineered design template).

Beach ecosystem restoration approaches emphasize beach nourishment methods are compatible with “living shoreline” habitat objectives that incorporate local biotic and abiotic components of coastal ecosystems. The premise of beach nourishment for ecosystem restoration is to match beach sediments closely and integrate rates and volumes of replenished beach sediments with local transport processes to the greatest extent feasible. The ecosystem restoration approach relies in part on assessment of ecosystem processes, structures, composition, and dynamics of natural existing or historical reference systems (Goals Project 1999,

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[1] The definition of restoration is a complicated topic. There is historical restoration which involves rebuilding features that had existed prior to development. There is also restoration that uses reference sites to build natural features at locations where they did not exist to accomplish project goals. This is very commonly used in creek restoration projects for example, where fish passage and habitat features such as step pools and log jams, are built to provide ecological values in locations where they did not exist and these are all called restoration projects. It is subject to differing opinions where and how terms like “restoration” are defined and there may be value in a broader definition in a system where rising sea levels threaten large areas with erosion and flooding.

2015; SFEI and SPUR 2019), rather than engineer them to perform selected physical functions or meet a range of physical criteria. The ecosystem restoration components of beach restoration approaches must also anticipate and adapt to climate change stressors like accelerated sea-level rise, increases in extreme temperature events, droughts, and coastal storms. Beach ecosystem restoration goals are reflected in guidance on beach nourishment in National Parks (Dallas *et al*. 2012) and beach sediment replenishment projects that maintain and enhance existing natural coastal landforms and habitats within developed shores (Nordstrom 2000, 2008). This can be accomplished by restoring sediment supplies, nourishing beaches for shore protection, habitat, or recreation, or directly re-creating beach landforms, to restore them and enhance their resilience to erosion (Nordstrom 2008).

Background: Beach Nourishment for Multi-Purpose Coastal Management

Beach nourishment in San Francisco Bay has been proposed for purposes of ecosystem restoration, to provide habitat for endangered species, support special wildlife habitats, and buffer erosion of tidal marshes (Goals Project 1999, 2015). Natural coastal processes cannot always be relied on to re-establish coastal ecosystems or their erosion protection functions in developed shores that have been severely altered or where sediment supplies are severely depleted permanently (Nordstrom 2008). Beach ecosystem restoration approaches, including hybrid living shoreline designs, emphasize replenishment of compatible, matching beach sediments and reliance on natural geomorphic processes (including biogeomorphic interactions) to restore or enhance whole ecosystems that include erosion control or flood control benefits. Managing beach ecosystems from multi-objective ecosystem perspectives allows for staged (phased) ecosystem restoration measures (like incremental shore nourishment) that adapt to sea-level rise and other climate change factors without committing shorelines to fixed positions that may be incompatible with future adaptation needs.

Most beach nourishments in California have been carried out on the open coast, and there is limited experience in San Francisco Bay. Lessons have been learned on the open coast that could apply to the design of Bay beaches, for example:

- Use of beach sediment that closely matches native grain size distribution, with minimal fines, contaminants, and organic content (Dallas *et al*. 2012)
- Limit the total volume and rate of beach fill or replenishment (Dallas *et al.* 2012)
- If design profiles are engineered, they should correspond with natural berm crest elevation ranges rather than exceed them (Dallas et al. 2012)
- Indirect beach sediment placement (shore or nearshore nourishment) allows for sorting and transport of equilibrium profiles and natural landforms, where feasible (Dallas *et al*. 2012, Nordstrom 2008)
- Revegetate wetlands or beach/dune zones as appropriate for the setting and ecosystem (Dallas *et al.* 2012 Nordstrom 2008)
- Develop and implement appropriate monitoring programs that anticipate and sample physical and biological effects of beach nourishment. Pre-project environmental baselines should be monitored, followed by well-designed post-construction monitoring for biological impacts, including macroinvertebrates, wrack deposition and fate, wildlife, and vegetation (Peterson and Bishop 2015, Dallas *et al*. 2012).

Beach nourishment impacts in San Francisco Bay may be related to the conversion of one estuarine habitat type to another (e.g., conversion of marsh, mudflat, rocky shore, or submerged aquatic vegetation or macroalgal beds to beach), changes in their dynamic responses to natural processes, or indirect impacts of beach nourishment construction, or new public beach use on wildlife or food chains (trophic impacts). Beach nourishment projects should assess local coastal settings, existing habitats, vegetation, wildlife, and their natural range of dynamic variability to minimize impacts. This approach is adopted in the conceptual planning of beach design alternatives at each of the selected project sites in this report.

Long-Term Maintenance Requirements

Cyclic beach re-nourishment is normally included in the design of replenished or constructed maritime beaches in most countries (Stronkhorst *et al.* 2017, Van Konigsveld *et al.* 2008, Hanson *et al*. 2002, Leonard *et al.* 1990) and is a required component of beach nourishment design in much of Europe (Hanson *et al.* 2002). Incremental staged beach nourishment, with monitoring for adaptive management, is sometimes a recommended mitigation measure to reduce impacts of high-volume pulses of beach nourishment (Berry *et al.* 2013, Dallas *et al.* 2012, Peterson and Bishop 2005). For closed littoral cells of small, low-volume, low-energy pocket beaches in estuaries, re-nourishment cycles are likely to be needed at moderate to low intervals of low-volume re-nourishment, to compensate for erosion losses due to sea-level rise (Bruun’s Rule profile equilibrium adjustment) and losses due to trapping in mudflats. Eolian (wind driven) losses of sand are insignificant for Marin bay beaches, where shoreline orientations are primarily minimally exposed to frequent high onshore winds. No foredune accretion has been observed on any Marin bay beaches. Best professional judgment estimates (no local data available) for renourishment cycles are proposed at 7-15 years, to be determined by project monitoring and adaptive management plans. For drift-aligned bay beaches, re-nourishment cycles or groin/drift-sill rehabilitation may be required at somewhat greater frequencies, depending on grain size. Only one site (Seminary Drive) is proposed at a potential drift-dominated shoreline, and the very large (cobble) beach sediment is not prone to significant drift that may demand re-nourishment.

The “Dynamic Beach Nourishment” approach may have a smaller footprint and less upfront habitat impacts, and potentially more ecological benefits, but the erosion protection benefits may decrease over time. It is a dynamic adaptive management approach based on monitoring that may require more frequent nourishment. The approach relies on natural processes to distribute sediments to their proper location on the profile and may have less wave energy and flood reduction benefits than the GBDT approach. It may also require more maintenance over time with associated impacts. This approach is limited to the designer's observations and experience and is less reproducible and usable by other designers.

Design Approach B: The “Gravel Beach Design Template” (GBDT) Approach

The fundamental concept of the “Gravel Beach Design Template” or GBDT approach is to create a beach profile that forces waves to break offshore and dissipate that energy before it can cause erosion problems to the backshore environment. (Figure 2).

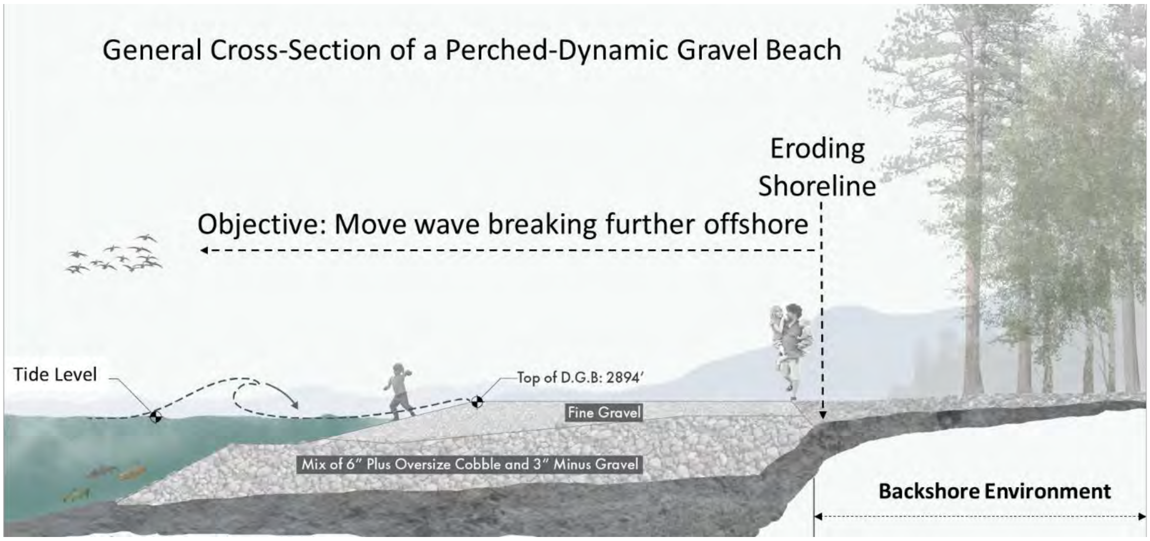


Figure 2: A general cross-section of a perched gravel beach. This depicts the fundamental design principle of moving wave breaking and swash processes offshore and away from the eroding shoreline (sensu Lorang 1991). The objective is to move the hydraulic forces

The GBDT template is an analytical-based engineered approach to gravel beach design that integrates engineering with coastal geomorphology by incorporating profile data from natural reference beaches. It is based on the standard engineering approach of beginning with a design wave and water level metrics (Figure 2). Once those primary design metrics are decided upon than breaker depths, wave dissipation distance and the size of gravel matched to the ability of the waves to move and transport (level of wave competence) the beach fabric can be determined (Figure 3). Once these design metrics are determined than they can be applied to survey data of the existing site profile to established structural dimensions of the proposed beach and nature of the fabric (size of gravel and layering) that will provide for full wave dissipation. Changes can easily be made by re-evaluating the primary design metrics to create an alternative design for smaller waves, lower tides and less sea level rise.

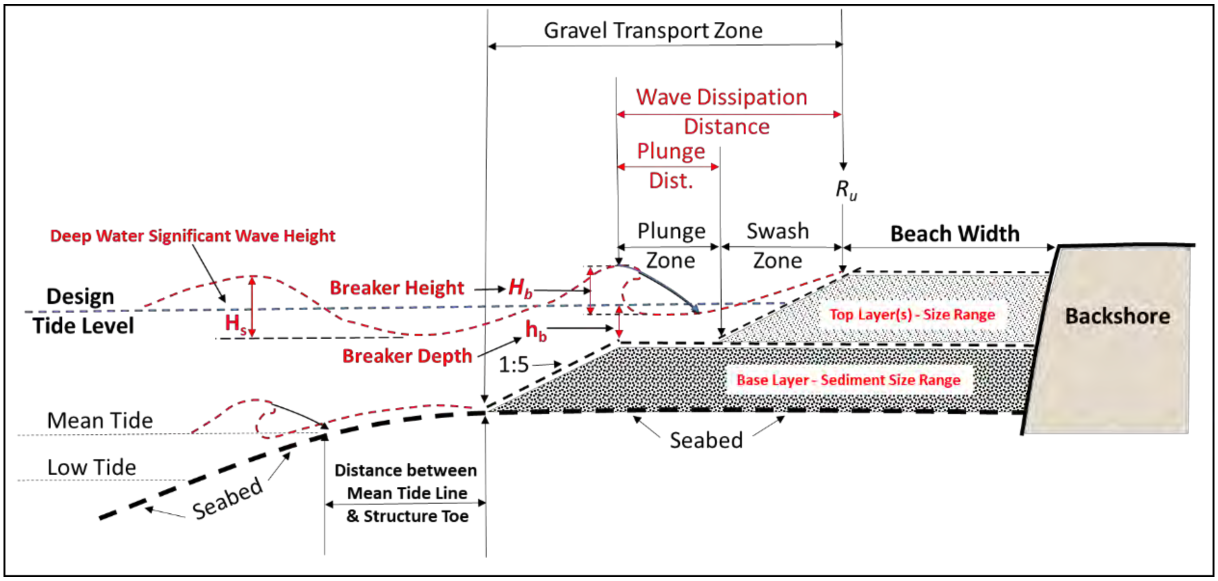


Figure 3: Schematic of the "*Gravel Beach Design Template*". Variables in red guide design and come from linear wave theory and other peer reviewed sediment transport equations that are appropriate for use with the design-with-nature approach. The design tide level and beach width are metrics dependent on stakeholder choice. The seabed elevation comes from survey data and control's location of breaker depth.

This approach was developed by Dr. Mark Lorang based on shallow water wave equations coupled with wave competence equations. These equations determine the size of beach material that waves cannot move and the size range that they can and under changing wave conditions and tide levels (Lorang 1984, Lorang 1991, Lorang and Komar 1991, Lorang et al., 1999, Lorang 2000, 2001, 2011 and Brayne 2020). Much of this work was started by assessing shoreline processes in Flathead Lake Montana as part of a Federal Energy Regulatory Commission relicensing of the dam that controls lake level regulation (Lorang et al. 1993 a,b & c). Those studies set the stage for the design-with-nature approach referred to here as the GBDT.

The final design outcome from the GBDT can then be compared with a reference beach profile (Point Pinole in this report) to assess the functionality of the design. Dr. Lorang has published widely on this topic and was among the first practitioners to build beaches as a shoreline adaptation tool and to write a shore protection manual for gravel beaches as an alternative to riprap for the State of Oregon (Lorang 1994). That manual matched erosion severity to an appropriate gravel beach alternative and introduced the idea of a small sacrificial beach at the base of an eroding bluff and back of extensive sand beaches. The idea of the sacrificial beach was to provide protection from a single yet severe wave erosion event. That level of protection would then allow time to re-evaluate the approach or resupply the sacrificial gravel beach. These decisions require assessment of risk and the level of what the acceptable risk might be and the cost, both of which change with time.

While the GBDT model has not been applied to estuarine bay beaches in San Francisco Bay, it has been successfully used at Flathead Lake, Montana, for the past 30 years, where the wave heights are comparable to San Francisco Bay. These beach projects were undertaken with scrutiny and approval by the US Army Corps of Engineers, Various State Agencies, Local County agencies which hold public meetings and involvement with the Confederated Kootenai and Salish Tribes (Lorang 2017, 2016, 2014, 2006a, 2006b, 2004, 2003, 1994).

The analytical basis for the model makes it readily understandable and usable by other practitioners at other sites, which is a significant advantage of this approach. Moreover, it provides a quantitative template to assess different designs yielding what level of wave climate and sea-level rise the design will protect against and a way to assess reference beaches to determine if they are physically appropriate to the site.

The GBDT approach, combined with an evaluation of the site-specific setting and coastal processes, can be coupled with the nourished beach approach to develop a hybrid model that incorporates positive and appropriate aspects of each approach balanced against risk, habitat impacts, and cost.

Project Goals and Scope

The goal of this study is to prepare preliminary nature-based coarse beach designs for three sites in southern Marin county. The purpose of the designs is to inhibit shoreline erosion and provide both habitat and public access benefits. These designs will demonstrate the use of coarse-grained bay beaches as an alternative to hard engineering approaches such as rock riprap and seawalls.

This project's overarching objective is to provide designs for demonstration projects for environmentally superior and effective “soft” alternatives for erosion control. The designs focus on re-creating dynamic shoreline processes by first identifying the relative spatial severity of the problem, what is causing the problem, and then propose coarse-grained (gravel, cobble, and sand) beach solutions where static riprap would otherwise be the default solution. The Marin County Open Space District beach project (Aramburu Island) showed that after five years of monitoring (2011-2016), coarse-grained beaches could adjust to rising sea levels and storm wave energy. These beaches slow and buffer erosion like their natural analogs that still occur on a few Marin shorelines.

The specific goals of the project are:

1. Develop design plans for bay beach enhancement at three sites as an alternative to riprap or walls to manage shoreline erosion; including the selection of project sites and highlighting different shoreline types where natural beach design offers an alternative to riprap.
2. Provide County, State, and Federal regulatory and planning agencies opportunities to set regulatory guidance and requirements for design, evaluation, and policy-compliant approval of feasible “environmentally superior” alternatives for estuarine beach projects, balancing multiple public interest factors.
3. Demonstrate the feasibility of compatible multi-benefit engineered or artificially nourished beach projects, including recreational, esthetic, and ecological benefits compatible with local land uses and natural settings (SFEI and SPUR 2019, SFEI and Baye 2020).
4. Identify potential project site constraints associated with trade-offs among engineering, recreational, and ecological objectives for nourished or engineered estuarine beaches, and identify possible regionally applicable design solutions or mitigation measures for them.
5. Evaluate differing approaches to natural beach design and highlight each approach's pros and cons regarding cost-effectiveness, permitting issues, and habitat benefits.

Project Study Sites

The three sites were chosen to illustrate bay beach design variations to address erosion problems, enhance habitat, and improve public access based on the "living shorelines" concept. Living Shorelines projects utilize a suite of bank stabilization and habitat restoration techniques to reinforce the shoreline, minimize coastal erosion, and maintain coastal processes while protecting, restoring, enhancing, and creating natural habitats for fish and aquatic plants and wildlife. The term "Living Shorelines" was coined because these techniques provide living space for estuarine and coastal organisms, which is accomplished via the strategic placement of native vegetation, natural materials such as sand, gravel, and cobble, and reinforcing rock or shell for native shellfish settlement. The approach has been implemented primarily on the East and Gulf Coasts, where such techniques enhance habitat values and increase connectivity of wetlands and deeper intertidal and subtidal lands while providing a measure of shoreline protection.

The three sites represent a spectrum of eroding shoreline issues where the "living shorelines concept" can be tested with appropriately designed projects that demonstrate the value of a range of natural soft alternatives that follow the design-with-nature approach. Seminary Drive and Paradise Beach Park shores are wave-cut benches on rocky shores (boulder and cobble lag above bay tidal flats and subtidal shallows) with limited development of erosional pocket gravel and sand beaches. All have their supply of natural beach sediment artificially constrained by past shoreline armoring and filling. Both Greenwood Beach and Paradise Beach Park are public park shores with important public access and recreational uses and park infrastructure such as trails. The Seminary Drive roadside shore currently has limited public use itself but protects a county road embankment. If funding is secured to build one or more of these projects, this would include monitoring beach performance to improve beach design guidance.

Site 1: Greenwood and Brunini Beaches, Tiburon

The beaches lie within a cove between rocky headlands and rock-armored slopes, bordered by mixed sand and gravel beaches and the mouth of a flood control channel. Historically the site was a natural back-barrier salt marsh/lagoon and barrier beach subsequently filled for development. Portions of the shoreline at the west end of the beach are strewn with concrete and asphalt rubble eroded from the fill together with a steep and eroding bank (Figure 4). This small cove with exposure to brief episodes of intense storm wave energy is ideal for constructing a complete bay beach profile. The site is a well-loved park with public access and recreation priorities. This site's high profile and easy access will make it useful for public education and awareness-raising for the local and larger bay area community. The design concept is to reduce waves reaching the bank and eroding the fill. The Dynamic Beach Nourishment approach builds upon the early concept designs developed by the Boyer Wetland Lab at San Francisco State University (SFEI Baye 2020). The GBDT approach places larger sized sediments further down the tide elevations to dissipate and break wave energy before impacting the shoreline.

Figure 4: Eroded bank and boulder riprap at Greenwood beach. The coarse cobble-size material in the foreground is composed of asphalt and concrete rubble that waves erode from the lower layer seen in the steep bank. Once eroded from the bank, waves can move this material across the mudflat, providing evidence for the level of wave competence active at this site.

Site 2: Paradise Beach Park, Tiburon

Paradise Beach Park is an approximately 19-acre site located along the north side of the Tiburon Peninsula. During World War II, the park was part of the Tiburon Naval Net Depot, which manufactured anti-submarine nets for use in San Francisco Bay and other harbors on the West Coast. Following the war, many of the concrete anchor blocks used to secure the antisubmarine nets were re-purposed to construct retaining walls for shoreline protection at the Depot and what is now Paradise Beach Park. Over time, parts of the stacked block wall along the shoreline of Paradise Beach Park have moved due to settlement and slope erosion and many of the blocks are now uneven and, in some cases, blocks have actually become dislodged from the walls, and toppled onto the beach. In early 2017, failures occurred at two locations on the earthen slope behind the wall. In response, Marin County Parks (MCP), the owner of Paradise Beach Park, has retained several consultants to seek long-term stabilization of the shoreline slopes. The current consulting firm working on the shoreline stabilization is Anchor QEA.

The beach at Paradise Beach Park has experienced long-term erosion and now provides little high tide beach access for recreation. The narrowing of the beach and the collapse of an old bulkhead has triggered the adjacent backshore bluff's erosion. Waves can reach the bluff and erode the toe leading to slumping of the bluff. Failure of the bluff threatens the parking lot above and has previously been addressed with concrete blocks and riprap (Figure 5). Erosion here is also affected by ferry wakes and sediment starvation due to past armoring at this location and sites on the shoreline to the north and south. This popular park is used for bay access, beach play, public fishing, boat launching and more, so the new design must protect and support the recreational use while incorporating elements of resilient shore protection. The design concept is to create a series of mixed gravel and sand beaches along the wave-exposed shoreline by directly placing coarse sediment. Marin County Parks also plans reconstruction of an existing seawall as part of the master planning process for the entire park. Hence, the beach restoration plan needs to work with and help other efforts to stabilize the slumping bluff. Paradise Beach Park represents an excellent opportunity to integrate natural beaches with more traditional engineering.

Figure 5: Concrete blocks and riprap failing to protect the slumping bluff at Paradise Beach Park. Note the tree is lying at an angle due to the slumping of the slope. This photo was taken at high tide, and the beach is very narrow, providing no recreation value or protection to the bluff from breaking waves.

Site 3: Seminary Drive Shoreline Erosion, Unincorporated Marin County

This site is a demonstration of a more natural erosion buffer for a retreating wave-cut salt marsh scarp adjacent to a roadway embankment and sensitive off-shore wetlands habitat (Figure 6). The design at this location would be useful for other agencies involved in protecting critical infrastructure (a County road) with limited space as an alternative rock riprap.

Figure 6: Riprap used to protect the slumping bay cliff along Seminary Drive.

Background to Bay Beach Restoration as an Alternative to Shoreline Armoring

The conventional engineering approach to shoreline erosion in San Francisco Bay is hard armoring: placing riprap to resist erosion or construction of seawalls and bulkheads. Shoreline armoring deals with erosion in the short-term at the expense of long-term impacts to shoreline access, habitat quality, esthetics, and water quality to the degree that is increasingly unacceptable to communities, planners, and state, federal, and local regulatory agencies. People do not tend to recreate on riprap shorelines, and shorebirds that feed on tidal mudflats do not roost on steep riprap at high tide. The environmental impacts of shoreline armoring for erosion control in estuaries and open coasts are significant, and well-established in the scientific literature (Prosser *et al*. 2018, Nordstrom 2014). The Marin shoreline and many San Francisco Bay shorelines are armored with riprap resulting in a loss of intertidal and subtidal habitats, fracturing of habitat connectivity between the bay and terrestrial uplands, and major impacts to esthetics and public access and usage.

This project's major impetus is to evaluate alternative design approaches that utilize bay beach analogues as an alternative to hard shoreline protection structures such as riprap. This need for more compatible erosion control and public shoreline use is especially important as accelerated sea-level rise increases the potential conflict between them. In San Francisco Bay and Marin County, there are numerous areas of shoreline erosion and loss of tidal marsh habitat due to wind-wave energy. Beaches could play a significant role due to their ability to reduce wind-wave energy and shoreline erosion. In some locations, the riprap is being overtopped, leading to undermining and failure of the riprap as bay water levels increase. As sea levels rise, wind-wave energy will increase as well resulting in increased shoreline erosion and flooding. Traditional armoring approaches will predictably cause more significant conflicts between shoreline stabilization needs and public needs to conserve shoreline values. In contrast, bay beaches can adjust their profile in response to local wave and water level conditions, as well as long-term sea-level rise.

As total bay tide levels rise over time, the higher water levels could overtop beaches and flood the backshore. Unless these beaches have room to retreat and rebuild inland, they will lose some of their shoreline protection benefits. However, although natural systems have demonstrated the ability to dampen wave energy and evolve with rising water levels, the engineering design of these coarse beach systems to accomplish similar project goals is still in the early phases of testing and validation.

The need for pilot projects to demonstrate the environmental effectiveness of nature-based alternatives to riprap is immediate. Flood and erosion protection by ecosystem enhancement and restoration, including beaches, is likely to provide a more sustainable, cost-effective, and ecologically sound alternative to conventional coastal engineering (Temmerman *et al.* 2013, Toft *et al*. 2017, 2014). In the absence of other options to riprap and seawalls, private landowners and cities along the shoreline may propose a hodge-podge of standard short-term armoring. Regulatory agencies will likely push back on the cumulative impacts of incremental armoring of the bay shorelines during permit review and attempt to implement policies favoring more natural approaches.

Background to San Francisco Bay Beaches

Geographic Variability of Bay Beach Systems in the San Francisco Estuary

The natural regional patterns of variability in San Francisco Estuary beaches provide a framework for the conceptual design of constructed bay beaches in Marin. The regional variation in the Estuary's beaches was reviewed by SFEI and Baye (SFEI and Baye 2020). This section of the report summarizes that review, emphasizing implications for the three Marin beach project sites which are the subject of this report. For a more comprehensive overview of San Francisco Bay beaches, see Appendix A.

San Francisco Bay beaches historically occurred in a wide range of coastal settings before reclamation and filling of baylands for industrial, port, agricultural, and urban land uses. Sand beaches were widely distributed around Central Bay sand sources, such bluffs and streams eroding Colma Formation and paleodune sand deposits of the northern San Francisco Peninsula, and Merritt Sands around Oakland. Erosion of Holocene bay muds rich in fossil oyster shell deposits (Olympia oyster, *Ostrea lurida*) supplied shell hash to extensive marsh-fringing barrier beaches along the southern San Francisco Peninsula. Various small barrier, pocket, and fringing beaches of sand or mixed sand and gravel were distributed along cliffed shorelines of Marin County (Richardson Bay and San Rafael Bay, China Camp) and Richmond (SFEI and Baye 2020). Local supplies of beach sediment, and local headland controls of beach plan form and orientation appear to have influenced the uneven historical and modern distribution of beaches around San Francisco Bay. Shoreline stabilization (hard armoring of erosion-prone shores formerly supplying beach sediment) and flood control channel maintenance (removal of coarse stream channel bedload before it is transported and discharged to the Bay) are likely responsible for diminished supplies of beach sediments to the San Francisco Bay shoreline.

The beaches of Northern Richardson Bay and the adjacent northern Tiburon Peninsula shore are primarily mixed sand and gravel beaches, mostly with a prevalence of medium sand. Similar beaches are associated with rocky headlands and cliffs north to San Rafael Bay and China Camp State Park. A few remaining beaches have composite sand and gravel beach profiles, with differentiated gravel berms and relatively well-sorted sand beachfaces. Rocky shores, composed of wave-cut benches in shale or sandstone cliffs, are prevalent on the Tiburon Peninsula. Beaches there occupy coves or shallow embayments associated with gulches, seasonal stream canyons, or ancient slope failures. Rocky shores around pocket beaches include bedrock outcrops and lag deposits of boulders and cobbles, often embedded among interstitial finer sand or mud. Richardson Bay and Tiburon Peninsula beaches are also associated with fine-grained, low-energy tidal mudflats and submerged rocky or mud-veneered rock benches supporting macroalgal (seaweed) beds and submerged aquatic vegetation (eelgrass) in low-turbidity zones.

Cobble and cobble-gravel beaches are rare in the San Francisco Estuary. They mainly occur where cobbles erode out of sedimentary bluffs or weak bedrock cliffs, such as Richmond shores (Point Pinole, Point Molate, and Point San Pablo). Cobble beaches (depositional cobble berms, ridges) are only found on East and West Marin Island in Marin, while angular cobble lag rocky shores (relatively immobile intertidal platforms dominated by angular cobbles) are widespread. Pure gravel beaches (shale and sandstone gravels) are present in small Marin bay pocket beaches. Oyster shell hash beaches, typical of the southern San Francisco Peninsula bay shore, are not naturally present in Marin County. Few wide medium quartz sand beaches with narrow, low backshore foredunes (historically widespread in Central San Francisco Bay) occur in Marin County bay shores, except at Angel Island (Swimmer's Beach, Coast Guard Beach).

Many historical fringing and pocket beaches of cliffed shores represented in the first U.S. Coast Survey maps (T-sheets) of the 1850s are still present in the same approximate locations and forms. They provide useful reference sites for beach designs and assessment of baseline conditions. However, many of the marsh-fringing beaches have been filled, dredged, or otherwise and destroyed and replaced by artificial shorelines.

Local ecosystem functions (services) of Marin bay beaches have not been specifically studied. They may still be assessed by analogy with other regions, based on beach type, size, and associated biotic community types. Expected or qualitatively reported ecosystem services of Marin beaches are summarized below.

Wildlife habitat benefits include breeding or foraging habitat for birds such as Forster's terns (*Sterna forsteri*), black-necked stilts (*Himantopus mexicanus*), American avocets (*Recurvirostra americana*), black oystercatchers (*Haematopus bachmani*), and other shorebirds. Bay beaches can also provide unvegetated, high-tide roosts for shorebirds and high-tide refuge for marsh wildlife. Beaches provide spawning habitat for grunion (*Leuresthes tenuis*) and haul out spaces for harbor seals (*Phoca vitulina*; Goals Project 1999; Gillenwater and Baye 2018, SFEI and SPUR 2019). Beaches can also provide primary invertebrate production (trophic support) in wrack deposits. Estuarine beaches provide habitats for terrestrial and estuarine invertebrates, including rare species of tiger beetles, carrion-feeding and deadwood-feeding beetles, ground-nesting wasps, and solitary bees. The marginal terrestrial (supratidal) sand and shell substrate habitats of estuarine marsh-fringing beaches allow specialist insect species, including important pollinators like native solitary bees, to inhabit tidal marsh landscapes at locations remote from uplands (SFEI and Baye 2020). Estuarine beaches and related sandy washover flats support two overlapping or intergrading vegetation types: sandy high salt marsh and beach/foredune.

An ecologically important rare plant, California sea-blite (*Suaeda californica*), was historically associated with high salt marsh and estuarine sand beach localities of Central San Francisco Bay. It has also been found on some South Bay peninsula salt marshes where shell hash beaches occurred (USFWS 2013, Baye 2006). This endangered plant was extirpated in San Francisco Bay by the 1960s. Recent projects have re-established experimental research populations (San Francisco State University, Boyer Wetland Laboratory) in San Francisco, Marin, and Oakland.

Examples of other salt-tolerant native plants associated with San Francisco Estuary salt marshes and beaches include gumplant (*Grindelia stricta* var. *angustifolia*), pickleweed (*Sarcocornia pacifica*), saltgrass (*Distichlis spicata*), alkali-heath (*Frankenia salina*), jaumea (*Jaumea carnosa*), creeping wildrye (*Leymus triticoides* and *L. Xgouldii*; syn. *Elymus*), and California cordgrass (*Spartina foliosa*). All these species can tolerate periodic burial by sand and fine sediment. These plant species not only provide wildlife habitat, but also affect beach form by trapping sediments, stabilizing shorelines, and increasing resilience to erosion (Baye 2020; SFEI and Baye 2020).

Regional Regulation and Planning of Bay Beach Projects

Beach nourishment and beach creation (construction) projects in San Francisco Bay are subject to regulation under multiple federal and state agency jurisdictions. Each regulatory agency applies policies and regulatory procedures under different statutes, regulations, plans, and policies, with procedural interactions (interdependent, contingent approvals) among them. Regulatory interactions range from alignment (broad consistency or overlap) among policies and evaluation procedures to potential conflicts among policies based on project location, design, and differences in prioritizing public interest factors. Beach enhancement, creation or restoration generally raises issues of short-term habitat conversion: the sacrifice of one extant estuarine habitat type, such as rocky shore, tidal flat, tidal wetlands, or submerged aquatic vegetation, for estuarine beach. Beach nourishment can also cause habitat conversion yet enhance existing habitat conditions and other policy-prescribed high-value public "beneficial" uses, such as shore access, water-oriented or water-dependent recreation, erosion buffering, and flood management. Individual permit decisions among multiple federal and state regulatory or resource agencies require integrating cross-jurisdictional policies and regulatory practices in San Francisco Bay. These are reviewed and summarized below, with emphasis on potential applications to beach creation and nourishment projects.

Federal Regulation of Bay Beach Enhancement, Creation or Nourishment

The lead federal agency with jurisdiction over placement of sediment (dredged or earthen fill material) below the high tide line (approximately 8 ft NAVD in the Central Bay) is the **U.S. Army Corps of Engineers** (**USACE**; informally, Corps), which has permit authority under the **Clean Water Act (CWA) Section 404**. The Corps' jurisdiction extends to "all work or structures" (all activities, including but not limited to fill discharges) in the bay below Mean High Water, under the **Rivers and Harbors Act of 1899**. The implementing permit and public interest evaluation procedures of these two statutes are included in the Corps permit regulations (33 CFR 320-331) and **EPA's Section 404(b)(1) "Guidelines"** (regulations) at 40 CFR 230-233). Beach nourishment and creation activities are likely to fall within Section 404 CWA and Section 10 RHA jurisdiction. Only if beach fill is placed sacrificially above Mean High Water, for subsequent storm wave erosion and transport (reworking) would a Corps permit potentially be limited to Section 404 CWA jurisdiction.

Section **404 Clean Water Act jurisdiction in tidal waterbodies** like San Francisco Bay extends to the **High Tide Line (HTL).** The HTL is a regulatory boundary that is not defined as the astronomic tidal datum but an elevation practically equivalent to the highest recorded non-storm perigee spring tide within an 18-year tidal epoch (usually around or slightly below 8 ft NAVD in Central San Francisco Bay). The practical HTL boundary in artificially filled baylands or upland shorelines is simply the scarp, cliff, or break in slope where the upper tidal debris lines usually are deposited. Also, Section 404 jurisdiction includes wetlands that may extend above HTL, where seeps, springs, or streams contact the shoreline and support seasonally saturated soils and wetland vegetation. Therefore, all beach nourishment or construction activities involving placement of fill below the high tide line are regulated under Section 404 CWA.

The **Corps' permit process** includes: (a) individual (standard) permits, which require individual public notices, project descriptions, and comments; (b) letters of permission (seldom used short-cut authorizations for uncontroversial, minimal impact projects that fall within defined categories that have undergone public notice, specified for a given Corps district), and General Permits. General permits are limited to classes of activities that the Corps determines to have only minimal cumulative, indirect, or direct impacts, after mitigation. The most familiar and widely used are Nationwide Permits and Regional Permits that are applied to categories of activities with conditions, many of which including "Pre-Construction Notifications," which are essentially abbreviated permit review processes with no public notice components. Currently, no Nationwide Permits or Regional Permits expressly authorize beach nourishment or beach creation as a category of activity. Some Nationwide Permits expressly exclude beach nourishment, mostly because of public controversies over large-scale dredging and sand nourishment in other coastal regions of the U.S.

Individual Corps permits have multiple inherent restrictions and interagency consultation and approval requirements that generally apply to beach nourishment or enhancement and creation projects in San Francisco Bay, as well as some that may apply depending on location and the potential local effects on special-status habitats or species. Essential Corps permit requirements for any beach nourishment project include:

- Fill discharges, including beach fills, cannot be authorized if they may cause "significant degradation" of Waters of the United States (WOTUS), including wetlands and other "special aquatic sites."
- Wetlands and other "**Special Aquatic Sites**" that occur in likely beach nourishment project sites in San Francisco Bay have equal regulatory status as wetlands under **Section 404(b)(1) CWA.** Where they occur at beach nourishment sites, they require special evaluation. These include "vegetated shallows" (including eelgrass beds), "sanctuaries and refuges," and "mudflats." Wetlands and other special aquatic sites trigger a permit evaluation *presumption*, which requires rebuttal, that a "**least environmentally damaging practicable alternative" (LEDPA)** is available that does not require fill discharges in special aquatic sites.
- Generally "practicable," feasible beach nourishment requires aquatic (intertidal) sediment discharges since upland excavation to create new beach platforms is seldom feasible. 404(b)(1) alternatives analysis of beach nourishment, however, would need to address the feasibility (or infeasibility) of indirect, sacrificial backshore sediment placement (above High Tide Line, not requiring the aquatic discharge of sediment) to indirectly supply beach sediment during storm erosion events, analogous with dune or bluff erosion supply to beaches. Generally, for compliance with Section 404(b)(1) Guidelines, alternatives analyses for beach enhancement, creation or nourishment projects need to demonstrate that beach fill placement locations, types, volumes, and methods minimize impacts to the aquatic environment and compensate for unavoidable impacts (standard mitigation under CWA and National Environmental Policy Act, NEPA).
- Corps permits generally require **National Environmental Policy Act (NEPA)** compliance, which usually consists of an Environmental Assessment (EA), analogous with an Initial Study (IS) in the California Environmental Quality Act. The Corps prepares an integrated EA when it prepares overall public interest reviews and Section 404 evaluations, often requiring analysis submitted by the permit applicant or consultants. If a project may cause "significant" environmental impacts after mitigation, then an Environmental Impact Statement (EIS) must be prepared, with substantial public review and comment procedures and relatively long schedules and costs. Based on precedents for major beach enhancement, creation and nourishment in San Francisco Bay (Crown Beach), EISs are unlikely to be required for uncontroversial small-scale pocket beaches unless they fail to include adequate mitigation.
- Corps permits may trigger a requirement for some **interagency coordination** procedures under the **Endangered Species Act (ESA)** if they "may affect" a federally listed endangered or threatened species. The "may affect" threshold is low, and multiple federally listed species may occur in habitats in the vicinity of beach project sites, and so are regulatory risks for "may affect" thresholds.

- Most ESA interagency coordination compliance for listed plants and wildlife at beach nourishment sites would likely be covered by a relatively abbreviated informal (rather than formal) consultation process between the Corps and U.S. Fish and Wildlife Service (for listed plants, wildlife, or non-anadromous, non-marine fish) or National Marine Fisheries Service (for listed fish and marine mammals), concluding with a letter of determination from the Service that the project is “unlikely to adversely affect” listed species. The applicant is responsible for providing the Corps with sufficient biological assessment information to provide the Service to support this determination. Similarly, for listed anadromous or marine fish species protected by National Marine Fisheries Service, the Corps would potentially conduct informal consultations, with proposed enforceable permit conditions to avoid potential “take” of listed fish species (e.g., seasonal or tidal timing restrictions for fill discharges). Otherwise, a formal consultation with a Biological Opinion (and Incidental Take Statement, an authorization) would be required if acceptable take cannot be avoided.
- The informal consultation process with USFWS is officially conducted by the Corps, with support from the permit applicant and consultants. As a practical matter, the Corps permit manager often acts as an intermediary, with the option of designating the applicant’s endangered species biological consultant as a non-federal representative of the Corps, under Corps supervision and control. The burden to provide sufficient site-specific biological assessment information to support informal consultation is the applicant’s. The Service and Corps have flexibility in negotiating the scope and contents of a biological assessment, but assessments that develop alternatives or mitigation measures to avoid or minimize “take” of listed species is generally more effective than merely compiling background database, map, or survey information about the past distribution or abundance of “may affect” species.
- Listed species that occur in Central San Francisco Bay that may potentially occur within “may affect” vicinity of beach construction or nourishment sites include California Least Terns, Western Snowy Plovers, Chinook salmon, Central Coast steelhead, and green sturgeon. Beach sites that occur near tidal marshes (especially over 1 acre in size) may need to address indirect impacts to California Ridgway’s rail and salt marsh harvest mouse. Tern and plover occurrences are usually associated with pre-existing established wide sand beaches with low visitor pressure. Salt marsh-dependent listed wildlife are seldom likely to occur unless marsh-fringing barrier beaches are restored or enhanced. Listed plants rarely occur in beach nourishment sites unless they are actively introduced as research or restoration actions.
- **State Certifications required for Corps permits**. Corps permits generally require a **Section 401 Clean Water Act certification**, an authorization by the state water quality agency – San Francisco Bay Regional Water Quality Control Board (Region 2). In addition, the Corps permit must have a coastal zone consistency determination from a local Coastal Zone Management agency, which is the **Bay Conservation and Development Commission** (BCDC). These state agencies are discussed below.
- The Corps permit process, including Section 404 CWA compliance, has no specific policies or prohibitions regarding beach nourishment; general regulatory (public interest, environmental) requirements apply to all jurisdictional aquatic fill discharges. The Section 404(b)(1) guidelines do expressly consider fill discharges for purposes of habitat conversion or enhancement as potentially consistent with the Guidelines, providing they minimize impacts and provide appropriate habitat conversion. The applicant bears the burden of demonstrating to the Corps that habitat conversion and fill discharge volumes, types, and locations are not contrary to the public interest and meet all applicable regulatory criteria.

State of California Regulation of Bay Beach Enhancement, Creation or Nourishment

The lead State regulatory agencies with independent jurisdiction over beach enhancement, creation or nourishment in San Francisco Bay are the San Francisco Bay Regional Water Quality Control Board (RWQCB Region 2, RWQCB-SFB) and the San Francisco Bay Conservation and Development Commission (BCDC). In addition, the California Department of Fish and Wildlife may, in exceptional cases, have limited jurisdiction over beach nourishment through the California Endangered Species Act or agency ownership of shorelines. The State Lands Commission also may have jurisdiction over beach nourishment as they own tidelands and submerged lands in many areas of the bay. Other State agencies, including local city or county governments, may have lead CEQA (California Environmental Quality Act) responsibility over beach creation or nourishment projects.

San Francisco Bay Regional Water Quality Control Board (RWQCB)

The RWQCB has broad jurisdiction over all waters of the State of California, (including surface waters, tidal waters, and groundwater) through the Porter-Cologne Act. The State Water Resources Control Board delegates its Porter-Cologne authority to its Regional Water Quality Control Boards. RWQCB typically exerts this authority to regulate fill discharges in San Francisco Bay by placing mandatory conditions on its CWA Section 401 Water Quality Certification of USACE permits, and by providing independent discretion over approval of environmental assessments, alternatives analyses or mitigation plans that are required to support Section 401 certification decisions. In effect, the RWQCB has “veto” power over Corps individual (standard) permits, as well as autonomous authority to impose enforceable special permit conditions, including monitoring and reporting plans, and performance criteria.

The discretion of the RWQCB over regulation of fill discharges in San Francisco Bay is guided by its Basin Plan, which is a regional master plan (updated periodically) for maintaining public beneficial uses of state waters. RWQCB discretion to authorize, condition approval, or deny approval of discharges in San Francisco Bay is based on the specific “beneficial uses” designated for state waters. Specific beneficial uses in the Basin Plan that may be affected positively or negatively (or both) by beach creation or nourishment include:

- Areas of special biological significance, including refuges, ecological reserves, or other designated environmentally protected areas (i.e., Clean Water Act Section 404 “Sanctuaries and Refuges” special aquatic sites)
- Estuarine habitat, generally fish, wildlife, shellfish, vegetation of tidal areas within the bay
- Wildlife habitat (general aquatic and wetland)
- Preservation of rare and endangered species
- Water contact recreation
- Non-contact water recreation (including beachcombing)
- Shellfish harvesting (support of shellfish production for collection)
- Fish spawning
- Surface waters and wetlands, including mudflats.

In addition, recent policy updates and staff guidance within Region 2 RWQCB incorporate non-regulatory sea-level rise adaptation principles for San Francisco Bay when interpreting and applying the Basin Plan, such as the RWQCB-funded San Francisco Bay Shoreline Adaptation Atlas (San Francisco Estuary Institute and SPUR 2019) and the Bay Ecosystem Habitat Goals Update (BEHGU) (Goals Project 2015). These scientific and technical guidance documents provide important project-specific and site-specific assessments of compatibility between potential beach construction or nourishment projects and "beneficial uses" interpreted by RWQCB staff.

San Francisco Bay Conservation and Development Commission (BCDC)

BCDC The San Francisco Bay Conservation and Development Commission (BCDC) is the state agency that has regional permit authority under the **McAteer-Petris Act** over all fill discharges and dredging in San Francisco Bay within its bay (tidal) jurisdiction, including beach creation and nourishment. BCDC's **bay jurisdiction** extends up to the mean high tide line (MHW) in shoreline areas *without* tidal marsh, and up to *5 ft above mean sea level (MSL)* in shoreline areas with tidal marsh present. BCDC is also the lead state agency within San Francisco Bay for providing consistency determinations under the federal **Coastal Zone Management Act** (CZMA), a regulatory requirement for all Corps permits in the Coastal Zone to be consistent with the Bay Plan and its amendments.

Within its **bay jurisdiction**, BCDC has broad permit authority over all activities that affect the environment, recreation, public access, and other public interest factors. Under its "**shoreline band**" jurisdiction (100 ft landward of highest tide shorelines), BCDC has more limited direct permit authority over activities affecting shore access, but its authority to implement the provisions of the **Bay Plan** (the master regulatory plan for San Francisco Bay) has the force of state and federal law (through the CZMA).

BCDC has direct jurisdiction over all aspects of beach nourishment involving sediment (fill) discharges in San Francisco Bay. Section 66605 of the McAteer Petris Act states in part that "the water area authorized to be filled should be the minimum necessary to achieve the purpose of the fill". BCDC regulates activities under "major permits", "administrative permits" and (abbreviated) "regionwide permits". There are no regionwide permits covering beach creation or nourishment activities. BCDC has discretion over regulation of beach creation and nourishment activities as administrative or major permits, depending on its evaluation of the size, environmental impact, and complexity of Bay Plan consistency factors.

BCDC has discretion to interpret what constitutes a "minor amount" of fill in local project settings, and it has discretion to allow more than a "minor amount" of fill, depending on project goals and Bay Plan consistency. For example, BCDC authorized the **Aramburu Island Enhancement Project** (BCDC permit M2010.032) with an interpretation of "minor fill" discharge of approximately 7,650 yd^3 of sand, gravel, rock and oyster shell hash over approximately a 2.17 acre area of the Bay to create a beach on an eroding artificial fill island in Richardson Bay. In contrast, BCDC authorized "major" bay fill for beach nourishment at **Crown Beach** on Alameda Island. This project used 200,000 yd^3 of sand to construct the beach, and approximately 80,000 yd^3 of sand every 20 years to maintain it. In the late 20th century, BCDC also indirectly (not explicitly) authorized beach nourishment by permitting shallow subtidal disposal of dredged Merritt sand from the Port of Oakland near the Bay Bridge Toll Plaza; tidal currents and waves reworked it, as anticipated, to form what is now Radio Beach (James McGrath, BCDC commissioner and retired Port of Oakland Environmental Manager, personal communication to P. Baye 2010).

Unlike Corps permits, which have only general environmental regulatory criteria that apply to all fill types and special aquatic sites (special-status habitat types under Section 404(b)(1) CWA regulations, like wetlands, mudflats, vegetated shallows, etc.), BCDC's permit policies and practices are directly guided by specific policies and maps of the Bay Plan, its amendments, and policies, and published internal guidelines (Staff Reports).

The Bay Plan explicitly refers to bay beach creation and nourishment ("enhancement"), and their public uses and benefits, both in general, and in specific geographic subregions (identified in Bay Plan shoreline maps). In addition, BCDC amendements of the Bay Plan incorporate by reference other regional plan principles and recommendions, such as the Baylands Wetland Ecosystem Habitat Goals Project (Goals Project 2015). Staff reports include climate change and sea-level rise adaptation guidance that cite and adopt principles and recommendations of the 2015 Science Update of the Bay Ecosystem Habitat Goals Update (Goals Project 2015).

Beaches and beach creation are expressly included in Bay Plan policies, since the original Bay Plan was published. The **Bay Plan's "Major Conclusions and Policies**" regarding "**Justifiable Filling**" stated:

> Some Bay filling may be justified for purposes providing substantial public benefits if these same benefits could not be achieved equally well without filling. Substantial public benefits are provided by: c. Developing new recreational opportunities— shoreline parks, marinas, fishing piers, *beaches*…(emphasis added).

The Bay Plan's recommendations for constructing and enhancing beaches were primarily aimed at public shore access and recreation, and were included under "major Plan proposals" for recreational facilities including beaches that provide shore access and recreation opportunities for congested urban populations. Other beach purposes, such as wildlife habitat, erosion and flood control, and sea-level rise adaptation, were not identified expressly in the Bay Plan, but only indirectly by reference (in amendments) to the Goals Project (1999) and Goals Project (2015).

The Bay Plan included advisory (not regulatory policy) maps that show how to apply Bay Plan policies and priorities. Bay Plan maps identify "shoreline parks and beaches" as zones where beach enhancement or creation would be suitable. For example, Map 4 (South Marin) shows "shoreline parks, beaches" delineated at China Camp State Park, Keil Cove-Bluff Point, **Paradise Beach Park**, Romberg Tiburon Center, and **Blackie's Pasture to Tiburon Linear Park**. The Bay Plan sets a "Regional Restoration Goal for Central Bay" that prescribes restoration of beaches and protection of shallow subtidal areas: "Protect and restore tidal marsh, seasonal wetlands, *beaches*, dunes and Islands…Shallow subtidal areas (including eelgrass beds) should be conserved and enhanced. See the Baylands Ecosystem Habitat Goals report for more information."

Some BCDC habitat fill policies may affect evaluation of Bay beach nourishment projects where tidal flats or tidal marshes occur. These echo general CEQA mitigation principles and bay fill minimization principles:

> Tidal Marshes and Tidal Flats Policy 2: Any proposed fill, diking, or dredging project should be thoroughly evaluated to determine the effect of the project on tidal marshes and tidal flats, and designed to minimize, and if feasible, avoid any harmful effects.
>
> Tidal Marshes and Tidal Flats Policy 3: Projects should be sited and designed to avoid, or if avoidance is infeasible, minimize adverse impacts on any transition zone present between tidal and upland habitats.

The BCDC Staff Report (2019) "Bay Fill for Habitat Restoration, Enhancement, and Creation in a Changing Bay", discussed trade-offs and habitat conversion concerns regarding bay fills (including beach nourishment) for sea-level rise adaptation. BCDC Staff Report noted (p. 51) "Mudflat communities are most likely to be affected by fill placement directly on mudflats to raise elevation, or that convert mudflats to beaches, marshes, or other habitat", but it also acknowledged that "no action" can also jeopardize mudflats, and some habitat conversions may be beneficial or at least acceptable in impacts, depending on location and scale:

> …some existing type conversion projects have resulted in positive local effects. Because these projects were expected to create, restore, and enhance habitat and provide net benefits to Bay

ecosystems, they may be self-mitigating. However, it is difficult to know how these relative benefits and impacts might play out at a larger scale.

BCDC often has the most detailed permit application and review requirements of all state and federal agencies regulating San Francisco Bay shoreline projects. Staff recommendations and interpretations may or may not align with those of other resource agencies, such as CDFW, USFWS, and RWQCB, since the Bay Plan, and BCDC permit precedents, may differ from regulatory policies of other agencies that have narrower resource management policies for fish, wildlife, or water quality and beneficial uses of waters of the State. BCDC's Bay Plan places high priority on shore public access and recreation, and it is the only resource agency with explicit recommendations for "justifiable filling" of the Bay to establish or enhance beaches.

Integrating Federal and State Permits for San Francisco Bay Beaches

Two state agencies, BCDC and RWQCB, have the most geographically explicit and substantive, detailed evaluation procedures for San Francisco Bay beach projects. They have specific evaluation policies for public access and recreation priorities (BCDC), wildlife, fish, and estuarine habitat conservation (including habitat conversions), as well as regional sea-level rise adaptation guidance that is non-regulatory (interpretive) and complex. In contrast, USACE has only general federal evaluation procedures that apply nationally, but which act partly as a clearinghouse for state agency regulatory authority over beach nourishment/construction, since USACE permits require state agency certification or consistency determinations from RWQCB and BCDC. All state and federal agency permit evaluation procedures require weighing short-term as well as long-term cumulative impacts and benefits, not just short-term impacts and mitigation.

All these San Francisco Bay regulatory agencies have established a slim history of permit precedents for beach nourishment and creation in San Francisco Bay, ranging from "minor" (under 7000 cy bay discharge) to "major" (over 200,000 cy plus renourishment cycles of 80,000 cy) projects, as well as minor projects treated as administrative permit modifications of previously authorized shoreline enhancement projects (Pier 94 Port of San Francisco, < 2000 cy). Each of the precedent bay beach projects was located each in relatively degraded or artificial urban shore settings, with no high-sensitivity or high-value natural refuges, sanctuaries, ecological reserves or special-status habitats adversely impacted. Additional complexity in impact assessment, mitigation, and alternatives analysis may be required for permit evaluation where beach project sites potentially have marginal impacts on tidal wetlands, mudflats, rocky shores (including intertidal to shallow subtidal native oyster habitat, fish spawning habitat), and submerged aquatic vegetation beds or estuarine macrophyte beds (subtidal habitats).

Balanced beach project permit decisions (under CEQA, NEPA, and 404(b)(1) alternatives analysis and its factual determinations) would also weigh short-term impacts, short-term mitigation, and long-term benefits that address long-term climate change, sea-level rise, and shoreline evolution. Accordingly, bay beach permit applications and supporting documents would have more predictable pathways through the multi-agency permit process if they comprehensively anticipate and address public interest factors, impacts, and regional plans in project descriptions, designs, and supporting environmental analyses. Specifically, San Francisco Bay beach project descriptions should explicitly analyze and explain:

- Site-specific "no action" site evolution in short-term and long-term in the absence of beach nourishment or construction, considering habitat type or quality change trends; wildlife, fish, and plant population trends; shoreline retreat rates; and trends or rates affected by climate change/sea-level rise. "No action" alternative assessment also should consider likely actions taken other than the proposed project, such as shore erosion, structural collapse or emergency stabilization and armoring (NEPA and 404(b)(1), USACE). This dynamic "no action" alternative provides the federal baseline for long-term alternatives analysis, rather than static “snapshot” existing conditions. The “no action” alternative can also be used as the baseline for CEQA if it is justified.

- Public shore access and recreation benefits relative to existing conditions, in long-term and short-term (BCDC). Geographic distribution of public shore access and recreation is heavily weighted in the Bay Plan. In some locations, nature based beach designs may not be conducize to public access and recreational uses like sunbathing, swimming etc.
- Mitigation measures that reduce impacts of beach sediment placement and construction in the short-term and long-term, including rate-dependent impacts and timing (spreading out impacts of sediment addition over time, minimizing deviation between beach sediment loading and transport rates);
- Anticipated beach nourishment impacts identified in other regions with longer histories and more rigorous environmental impact assessment of beach nourishment, noting physical and biological geographic distinctions of San Francisco Bay.
- Apply alternatives analysis approach to beach project design at the earliest stages of project formulation, including alternative site selection, impact minimization and avoidance, and maximization of public benefits consistent with the Bay Plan (BCDC) and Basin Plan (RWQCB).

Uncertainties in Current Permitting Environment

Most uncertainties about permitting beach nourishment projects in the Bay are project-specific and site-specific. There are no policies prohibiting beach nourishment or imposing undue burdens on projects proposing beach fill discharges that do not apply to other fill discharges for other purposes. Indeed, some policies and regional guidance, such as the BCDC Bay Plan and the San Francisco Bay Habitat Ecosystem Goals Project (Goals Project 1999, 2015) and the San Francisco Bay Subtidal Habitat Goals Project (2010) endorse beach nourishment as restoration, climate change adaptation measures, multi-habitat and multi-objective projects, and recreational amenities. Agency staff permit managers, however, may rely on precedents of similar past projects with similar sites and purposes and impacts to inform individual permit evaluations and conditions of authorization. Since beach nourishment has been uncommon in San Francisco Bay, few staff have experience or comparable precedents to rely on for facilitating permit review and environmental evaluation. Beach nourishment impact assessments from ocean coasts and other regions may indirectly place a burden on estuarine beach restoration projects here to demonstrate compliance with mitigation and “least environmentally damaging alternative” criteria. Well-designed pilot projects that fully integrate regulatory requirements and policies, distributed in different sub-regions of the Bay, may establish working and precedents for future beach restoration and nourishment permits.

Repeated placement of bay fill even for beach nourishment may involve significant additional permitting costs to both justify and mitigate for any habitat impacts. In addition, finding and placing sediments can be expensive as well as raising funds to accomplish the work. The agencies typically place the burden on any applicant seeking to place bay fill, so the upfront establishment of an approved maintenance and replenishment program in the original permit may be useful.

There is a new coordinated permitting group which is put together to permit projects of this type and to resolve issues between competing objectives. The purpose of the Bay Restoration Regulatory Integration Team (BRRIT) is to improve the permitting process for multi-benefit habitat restoration projects and associated flood management and public access infrastructure in the San Francisco Bay. The BRRIT consists of staff dedicated to this purpose from the six state and federal regulatory agencies with jurisdiction over habitat restoration projects in the Bay.

Balancing Habitat Impacts with Robust Shoreline Protection

One of the significant design and permitting considerations for the GBDT design approach is balancing upfront impacts from a more robust design that implements a fuller build-out built for higher sea-levels constructed upfront and may include more initial habitat impacts. This contrasts with a Dynamic Beach Nourishment approach that emphasizes regular nourishment of sediment with smaller upfront impacts to habitat but more regular additions of sediment (with impacts) over time. It has also historically been more difficult to obtain grant funding for project maintenance than it is to obtain grant funding for new projects, thereby making it more difficult to successfully maintain or re-nourish a project after construction.

Site Specific Preliminary Design: Greenwood and Brunini Beaches

This section describes the site-specific preliminary designs at Greenwood and Brunini Beach. As noted, there are two design approaches. Each design is presented below starting with the dynamic beach nourishment approach by Dr. Peter Baye (approach A) and followed by the GBDT approach by Dr. Mark Lorang (approach B).

Greenwood Beach Site Background

Project Location and Background

The Greenwood Beach Project site (Figure 7) lays within the Town of Tiburon property and currently functions as a public park very popular with local residents. The project site encompasses Greenwood Beach and Brunini Beach, and Brunini Marsh, and comprise the bay shore south of “Blackie’s Pasture”, the local traditional name of a reclaimed, filled diked bayland managed as a public bayside park by the Town of Tiburon and named after a horse that lived in this area for many years. The shoreline has evolved from early historical beaches between the Greenwood headlands and the Tiburon Peninsula at the head of northern Richardson Bay. The beach and salt marsh complex are directly related to the mouth of a flood control channel and intertidal delta extending over wide fine-grained tidal mud and sand flats. The main Greenwood beach has eroded and exposed underlying asphalt and concrete rubble from former bay fill. The beach and marsh are subject to long-term erosion driven in part by sea-level rise and reduced sediment supply to the shore.

Figure 7: Greenwood and Brunini Beaches ecological features. The beaches form the modern estuarine shoreline of a reclaimed, filled historical salt marsh at the northeast end of Richardson Bay, San Francisco Bay. The reclaimed marsh was previously (prior to 1966) used as a privately-owned horse pasture (Fletcher 2019). A pedestrian bridge near the shoreline at the channel mouth connects access to the west and east side of the park. The City of Tiburon public land use of this open space is a recreational park. The park trail is connected to Tiburon Linear Park pedestrian/bicycle trail along the bay shore (from Baye 2016)

In the absence of established, standard place-names for the shoreline features in the vicinity of Blackie’s Pasture, this report provisionally designates local beach and marsh place-names for purposes of this report. These names are adapted from the closest adjacent trails and roadways identified in the Town of Tiburon Bay Trail Gap Study (June 2012), as shown below. The predominantly sandy beach at the southwest end of the park, nearest the end of Greenwood Beach Road is “Greenwood Beach”. The small eastern pocket sand beach adjacent to the northeast end of Brunini Way is “Brunini Beach”, and the small salt marsh patch at the end of Brunini Way is “Brunini Marsh”. Greenwood Beach is distinguished from the headland fringing beaches along private residential lots at the western end of Greenwood Beach Road.

Greenwood and Brunini Beaches form the modern estuarine shoreline of a reclaimed, filled historical salt marsh at the northeast end of Richardson Bay, San Francisco Bay. The reclaimed marsh was previously (prior to 1966) used as a privately-owned horse pasture (Fletcher 2019). The beach occupies the head of a very shallow intertidal sub-embayment defined by the rocky Greenwood Beach Road headland (cliffed hillslope) to the west, and the Tiburon Linear Park shoreline of the Tiburon Peninsula. A wide tidal flat (section 2.2 below) extend south of the beach to the Mean Lower Low Water line. The terrestrial lowlands of the Pasture open space are artificial 20th century diked bayland fill approximately 10-12 ft in elevation, with nearly level to very gently sloping topography. A pedestrian bridge near the shoreline at the channel mouth connects access to the west and east side of the park. The City of Tiburon public land use of this open space is a recreational park. The park trail is connected to Tiburon Linear Park pedestrian/bicycle trail along the bay shore.

Greenwood and Brunini beaches differ from the neighboring headland beaches in some important aspects. They are associated with an artificially channelized flood control ditch delivering fluvial sediment to an intertidal delta and salt marsh bordering tidal flats up to 470 ft wide. Their bay-head position restricts potential net longshore drift. The beaches are both composed of mixed sand and gravel, with predominant medium sand near the beachface and backshore beach surface layers.

The western Greenwood Beach is the larger of the two beaches bordering the flood control channel mouth. It was approximately 0.2 acres in 2019, extending from a rock-armored shoreline at the west end to the flood control channel. The beach was recently (2019) about 230 ft in length, varying among years depending on beach accretion and the relative extent of beach and salt marsh (see dynamics, below). The majority of the beach consists of an intertidal sloping beachface dominated at the surface by poorly sorted medium to fine sand mixed with gravel and coarse sand, often with a patterned veneer of fine shell hash. The beachface narrows to the west, ranging between about 14-30 ft wide. At the narrowest west end, the beachface thins to a sandy veneer over exposed lag surface of artificial rocky fill (concrete, asphalt, and angular quarried rock). At the east end of West Beach, near the channel, the beachface grades into an erosional remnant of wave-scoured intertidal salt marsh rootmats (peaty marsh soil outcrops) overlying coarser delta bar deposits.

The backshore (dry high tide) of Greenwood Beach is narrow, and varies in size among years. In 2019, it widened from about 1-5 ft wide at the west end, to a maximum of about 12-17 ft wide at the east end (measured from Google Earth imagery June 2019). The backshore beach grades into high saltgrass-pickleweed salt marsh patches, where sandy swash bars are deposited and become vegetatively stabilized as low-relief sandy marsh berms. These are remnants of a former large deltaic salt marsh on the west side of the channel mouth, which has been converted to beach by wave erosion and deposition. The back of Greenwood Beach is a low (3-5 ft) erosional bluff in artificial fill at the west end, declining to a sloping lowland near the channel mouth. Asphalt and concrete rubble outcrop in the eroded bluff toe of the Greenwood Beach in winter. A small gravel storm berm is occasionally exposed at the toe of the low bluff in artificial fill at the backshore. The calm-weather (spring-summer) backshore beach elevation range appears to be similar to the Sanctuary Beach, about 8 ft NAVD 88.

Greenwood Beach is more heavily used by the public for walking and dog exercise and water play area. Other uses are walking and bird watching. There is no formal trail to the West Beach. A social trail (trampled path) extends from the paved Bay Trail and bridge to the gently sloping east end of West Beach. No other infrastructure is known to exist at Greenwood Beach. The eastern Brunini Beach is a very small pocket beach (about 0.05-0.07 acres in 2018-2019) located in a gap between salt marsh and the armored fill bluff. It has recently (2019) been about 65 ft in length, varying among years with erosion or encroachment of the adjacent salt marsh. The backshore beach is variously vegetated with high salt marsh and beach vegetation (saltgrass, sea-rocket) and partially buried with wrack-lines (storm-drifted tule litter from Suisun/Delta marshes or local eelgrass and salt marsh litter). The beachface is relatively steep and narrow, only about 20 ft wide, terminating on the sandy mud low tide terrace. The beachface has become encroached by spread of low California cordgrass marsh near the toe of the beachface, offset at times by storm erosion. The invasive spartina removal began around 2005 which remobilized the sand in the marsh fronting area. The boundary between salt marsh and beach is uneven and unstable. The long-term trend of the beach and marsh is uncertain, but marsh recovery after removal of hybrid non-native cordgrass may result in conversion of beach to marsh from the lower end of the profile upward.

Brunini Beach is a small pocket of unvegetated sand, shell hash, and minor gravel at the east end of the salt marsh east of the channel, bounded by the boulder-armored shoreline at the east end. A sandy terrace occurs behind the crest of the East Beach, representing vegetative stabilization of former prograded beach zones. The beach terrace is overwashed by winter storm high tides and waves depositing wrack.

Brunini Beach is less heavily used by the public for walking and dog exercise and water play area, but a small social trail from the bay trail appears to be used primarily for dog exercise and water play. Other uses are walking and bird watching. The paved Bay Trail (Brunini Way/Tiburon Linear Park trail connection) lies adjacent to the east end of Brunini Beach. No other infrastructure is known to exist at the East Beach.

Below the intertidal beach profile is a wide low tide terrace and intertidal fluvial delta. The upper intertidal portion of the flood control channel delta is a broadly and irregular fan-shaped, asymmetric mid-high pickleweed-dominated salt marsh, fringed with low cordgrass marsh. The upper salt marsh is formed in part by wave-deposited stratified fine sand, organic detritus (including marsh peat and vegetation particles, eelgrass and algal litter).

The intertidal flats below the beachface and salt marsh are not soft, unconsolidated mud, but firm, muddy sand (bearing weight of an adult) close inshore. The delta shoals (low-gradient convex lobes) and bars are also composed of firm muddy sand and gravel. A smaller peripheral freshwater drainage ditch discharges perennially (seep outflows) west of Pasture parkland; it exhibits a minor delta.

The mid-intertidal flats are often sandy at the surface and rippled during periods of high onshore winds, indicating potential shoreward transport of sand from the flats at times. During calm periods, the intertidal flats often exhibit a veneer of fine bay mud. An erosional artificial rubble lag surface of asphalt, concrete, and rock fragments outcrop at the west and east ends of the muddy sand low tide terrace. Eroded former salt marsh rootmats (peaty marsh muds) outcrop in the low tide terrace and lower beachface around the channel mouth.

Annual and inter-annual dynamics of the beach profiles have not been analyzed with repeated seasonal surveys. Qualitative annual changes observed during the last two decades (P. Baye pers. obs.) include flattening and widening of dissipative intertidal beachface slopes during the winter storm season, with corresponding narrowing and lowering (or elimination of) the backshore sand berm. A narrow gravel storm berm often deposits (or becomes re-exposed) at the toe of the low Greenwood Beach bluff during winter sand beach erosional phases. The backshore beach (high tide dry beach) variably widens in spring-summer, but can remain narrow some years. Indicators of persistent erosional trends include perennial exposure of basal rubble layers in the low bluff.

The flood control channel provides a watershed sediment source to the shoreline that is sufficient to deposit substantial intertidal delta (0.75 ac). The delta is evident in all historical aerial images since the 1980s, and remained a conspicuous intertidal feature from on-site views during the last two decades. The delta includes multiple shifting distributary channels and variable bars and shoals composed of relatively firm muddy sand and coarser gravel (and minor amounts of small cobble) extending over the soft muddy low tide terrace (Figure 8). The sand and gravel deposits in bars and shoals are evident following high precipitation and runoff in winter (Figure 8), but they are often buried by finer estuarine sediment at the surface during the dry season. The drainage channel conveys storm runoff from the local watershed to the Bay, but is open to daily tidal flows (Figure 8), but it has no significant freshwater discharge (or brackish tidal marsh gradients) during the dry season.

The flood control channel has likely been a past significant local source of silt and sand for the relatively wider mudflats, the associated deltaic salt marsh patches flanking the mouth of the ditch, and Greenwood Beach. Adjacent to the mouth of the flood control channel are two asymmetric patches fringing tidal salt marsh (Figure 8), apparently formed on past lobes of the channel mouth delta: a smaller remnant west-side high salt marsh lobe currently reduced to approximately 0.23 acres (bayward of the low bluff), and a larger east-side salt marsh (low cordgrass marsh and high pickleweed-dominated marsh) about 0.31 acres.

The low bluffs west and east of the beaches are heavily armored by old boulder, concrete slab and rubble riprap, including asphalt rubble, placed prior to regulation of non-navigable bay waters (Figure 8). These armored shorelines resist erosion and appear to contribute no significant sand to Greenwood and Brunini beaches. Rock armoring continues along the entire Tiburon Linear Park shoreline. The low, non-armored fill bluff behind the beaches also contain significant amounts of buried rubble, and little sand-sized sediment. Prior to armoring, bluff and cliff erosion of sandstone-derived soils (including gulches and slope failures) east and south of the beaches may have contributed sand and gravel to the local littoral cell. Therefore, the intertidal delta of the flood channel mouth is likely a relatively important modern local source of sand and gravel sized sediment to the local littoral cell and is incorporated in the proposed project design.

Site Conditions and Existing Infrastructure

As noted above, Greenwood Beach is most heavily used by the public for walking and dog exercise and water play area. Other uses include bird watching. Since there are no designed trails to the beach, people often thread their way down to the beach via a variety of locations and often have to navigate down the existing eroded slope. There is a natural area (Brunini Marsh) that contains remnant salt marsh habitat and experimental populations of endangered California sea-blite (*Suaeda californica*) established for research by San Francisco State University, Estuary and Ocean Science Center, Boyer Wetland Laboratory.

Figure 8: Greenwood Beach features. A) overview of shoreline features. June 2019 Google Earth image.. b– west beachface, winter erosion phase, February 2019. C) zonation of high tide (backshore) dry beach, wetted intertidal beachface, and rocky lag low tide terrace (exposed) above mid-intertidal mudflats (submerged), west beach, August 2018. E-F) -gravel storm berm at toe of low bluff above erosional winter beachface, February 2019 and Nov 2016 (from Baye 2016).

Tide and Wave Climate

The Sausalito Station tide gauge (# 9414806) is the NOAA tide station closest to the site. This tide station is located at the entrance to Richardson Bay. Tidal datums are shown in Table 1.

Table 1: Tidal datums, Sausalito

Tidal Datum for NOS 941-4806 [1]		Elevation (ft NAVD88)
Highest Observed Water Level [2]	(HOWL)	8.48
Mean Higher High Water	(MHHW)	5.86
Mean High Water	(MHW)	5.26
Mean Tide Level	(MTL)	3.29
Mean Low Water	(MLW)	1.31
Mean Lower Low Water	(MLLW)	0.17
Lowest Observed Water Level [3]	(LOWL)	-2.54

1) National Ocean Service. 2004. Tidal Benchmark, Sausalito, CA. Feb 5. Period of record 11/77 - 10/79
2) HOWL observed 1/9/78
3) LOWL observed 5/5/77

Much of the highest wave energy and associated erosion occurs during winter storm periods corresponding to high tides (i.e. spring tides) when the waves are able to break at the shoreline and directly erode the Island shore. It is believed that significant erosion may take place during these storm and tide conditions. Under typical storm conditions, the expected breaking wave height along Richardson Bay shorelines would be on the order of 1 – 2 ft. This range is significantly below typical ocean swell wave heights of the adjacent Marin outer coast. However, while the heights of the local wind-waves are not large, these waves are typically high frequency (wave periods on the order of 1 – 3 seconds) and are therefore steep (i.e. the ratio of wave height to wavelength). These types of steep wind-waves can be very erosive at a shoreline (Allan and Kirk 2000) even though their wave height is not great. The rise and fall of tides are another factor contributing to the erosion of the shore, since the elevation of the tide determines where the waves are able to reach on the beach profile. As described below, higher wave heights on the order of 3 feet may be possible during extreme winter storms from the south. These values are calculated using the significant wave height estimation methods contained in the USACE Coastal Engineering Manuals (USACE CEM 2004 and USACE SPN 1984) but this significant wave height is likely limited to extreme storm events.

The 100-year wave heights developed as part of the FEMA San Francisco Bay flood insurance mapping by bay wide hydrodynamic modeling and analysis of decades of Bay wave data are in the 1 to 1.9 ft range which is relatively low for a 100-year (0.1 AEP) wave event (Figure 9). The wide tidal flats (400 plus ft) at Greenwood Beach limit wave energy to the higher storm events. The available wave energy is sufficient to significantly erode the shoreline as shown below especially on high tide storm events.

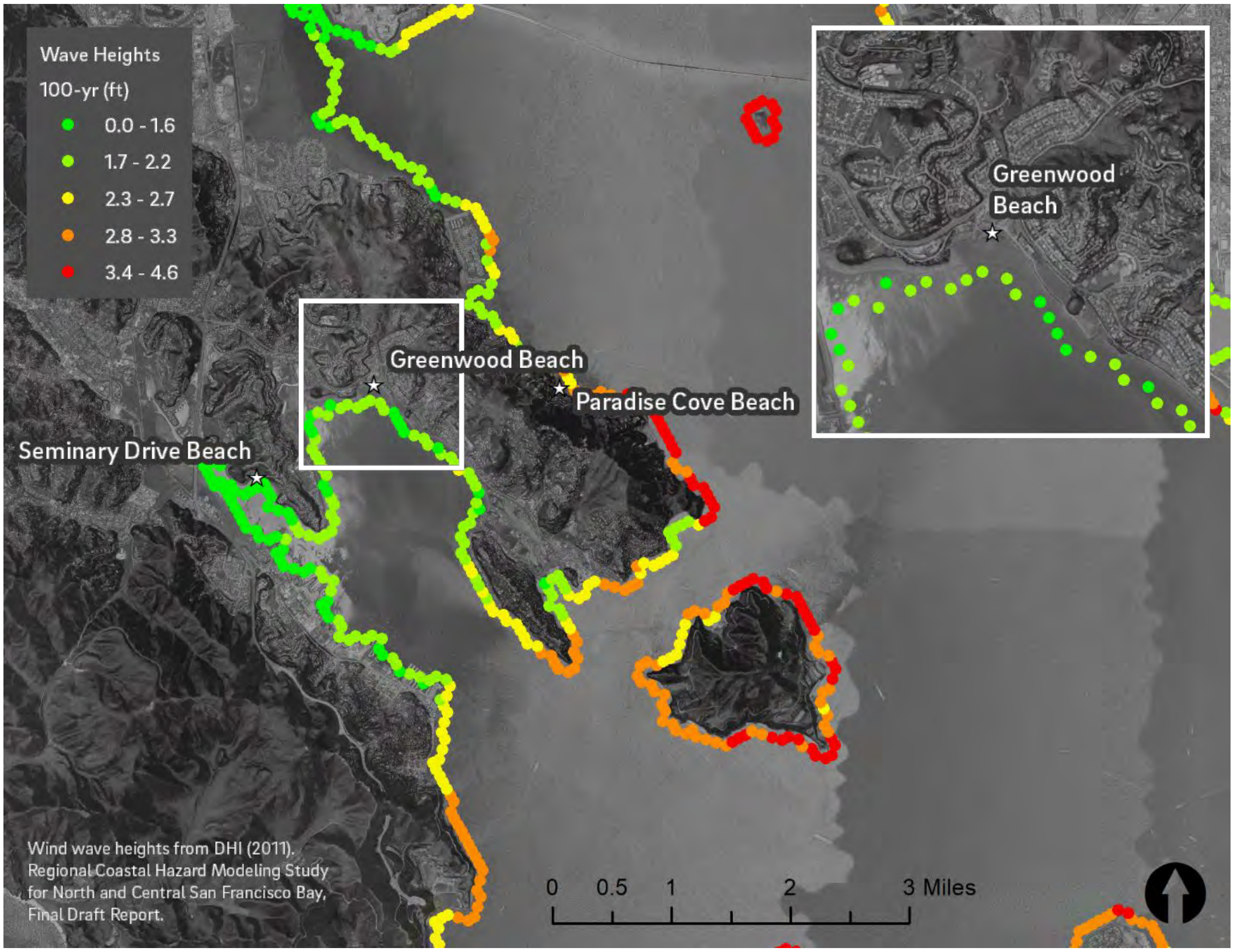


Figure 9. 100-year wave heights at Greenwood Beach, based on data from DHI (2011).

Sediment Supply

Greenwood and Brunini beach planforms are consistent with a predominantly swash-aligned pocket or bay-head beach that traps beach sand in a confined littoral cell (SFEI and Baye 2020). Although wind-wave approach to the shore is variable, predominant wave direction appears to be perpendicular to the beach (wave crests nearly parallel to the shore most of the time). There is no indication of significant net longshore drift, such as long-term asymmetric beach erosion or accretion along the shoreline. Short-term longshore drift of beach sand, however, can occur even in pocket beaches with little or no net longshore drift. Short-term longshore drift rates may be significant during infrequent periods of high wind-waves with strongly oblique wave approach. The risk of significant short-term longshore drift may increase during non-equilibrium beach profile conditions when additional sand and gravel added to the shoreline during beach nourishment episodes. Some modification of shoreline structure to restrict longshore drift may therefore be needed in this project.

Opportunities

Opportunities include the following:

- Existing beach at the site that provides the basis for restoration designs that utilize nourishment approaches as well as other design approaches that build beach types not present historically.
- Site access for construction is excellent resulting in reduced implementation and monitoring costs.
- The site is in an easily accessible public Park which greatly facilitates public and stakeholder views of the built project, which is important since as a demonstration project the ability to easily bring people to view the built beach is very important.

Constraints

There are constraints to the project site which include the following.

- There are existing stormwater outflow channels in the site, notably, a main channel in the center of the project area. The project design needs to protect this channel from blockage and potential backwater flooding.
- There is an existing ecological area in Brunini Marsh that contains tidal salt marsh plants as well some experimental plantings of a rare and endangered plant by the Boyer Lab at SFSU. There are existing subtidal and intertidal habitats primarily consisting of mudflats offshore. In order to assess impacts from the proposed designs on these habitats, the existing mapped layers from the subtidal goals project were used for mapping of impacts following adjustment of these mapped layers by SFEI staff to better match observed aerial photo data. As described in more detail below, the two proposed designs were mapped onto these layers for comparison purposes.
- Both designs involve placement of fill in the bay for restoration purposes. As such, the various designs will have to meet a number of regulatory permitting requirements. Other sections of this report describe these requirements in greater detail.

Integration with Existing Park Uses

Our understanding through conversations and site visits is that the shoreline is currently primarily used for passive recreation activities especially walking and dog walking. The proposed design plans will need to integrate well with the existing Park uses. This will be accomplished in coordination with the Tiburon Parks Commission (POST). The project presented at one POST meeting in 2019 and two meetings with POST in 2020 and to the Town council in 2021. At these meetings, public comment was invited. There were concerns raised by some neighbors about the project creating an attractive nuisance and exacerbating existing traffic and parking issues. These concerns will be further addressed during the next phase of the project in CEQA and public outreach. Both proposed designs should integrate well with these types of passive recreational uses. The restoration project does not plan any more active uses that may attract significant additional Park users. Increased public usage is not a design goal for this project because that might also conflict with wildlife goals.

Approach A: Greenwood Beach Dynamic Beach Nourishment by Dr. Peter Baye

This section presents the conceptual design developed by Peter Baye, PhD coastal ecologist for the Greenwood and Brunini beach site emphasizing a dynamic adaptive management approach that feeds the existing system with sediments of the proper size and with minor sediment retaining structures. Appendix D contains the conceptual design memo prepared by Peter Baye for the New Life for Eroding Shorelines Project (SFEI and Baye 2020) in its entirety to provide additional context for the section. Note that this design is only to the concept level with very approximate estimates for volumes. As compared with the GBDT design which was developed in scaled CAD drawings, this design is more approximate at this time but there is more than sufficient detail provided to understand the design approach, rough quantities and the design approach differences with the GBDT approach. This design will be brought into scaled plans for construction if carried forward under the next phases of project design.

Project Design Overview

The beach restoration approach presented here is to combine incremental (repeated) shore nourishment with related wetland and terrestrial elements. These include regraded sloping bluffs stabilized with native sand-trapping beach and bluff vegetation, and low-relief drift-sills (perpendicular to the shore) composed of cobble salt marsh, intergrading with existing salt marsh. Cobble salt marsh designs for drift-sills are based on natural local San Francisco Estuary reference systems from Richardson Bay and Point Pinole. Vegetated cobble salt marsh drift-sills are designed to provide groin-like living shoreline functions capable of accreting and maintaining sand-trapping high salt marsh vegetation. Their primary purpose, like that of beach groins, is to restrict longshore drift of sand and increase retention of mixed sand and gravel placed in the upper intertidal zone, and minimize sand drift that may temporarily choke tidal circulation in the flood control channel mouth during low flows and weak neap tides.

The shore profile nourishment proposed relies on natural wave transport processes reworking artificially placed beach sediment, rather than engineered construction of a beach berm, to form a natural beach profile. Sacrificial sand placement of mobile sand deposits in the upper intertidal zone (sand or rocky rubble lag) would likely occur using ground-based equipment at accessible locations. Sand and gravel mixtures used for nourishment would approximately match the heterogeneous beach sediment present, but additional coarse gravel would be supplemented to facilitate evolution of a storm gravel berm at the back of the beach profile, near the toe of the bluff. The proposed profile nourishment method is phased over years, depending on the availability of suitable sand-gravel supplies, and the post-erosion recovery rate and size of the beach after initial nourishment. Beach re-nourishment would be phased incrementally over years, with deposition of relatively small beach sand volumes to minimize impacts of each cycle on beach infauna and vegetation. Beach nourishment design also incorporates existing salt marsh, which itself is sediment-nourished by local beach drift.

Erosional bluffs are proposed for set-backs to gentler slopes, and revegetation with native plant species assemblages including a spreading native salt-tolerant sandy marsh shrub (California sea-blite) that is expected to facilitate sand trapping and deposition, and help vegetatively re-stabilize the bluff slope after erosion episodes. Proposed beach and high salt marsh vegetation is adapted to recolonizing eroded shorelines and binding substrate (increasing erosion resistance). The vegetative stabilization design is aimed at demonstrating the compatible use of an endangered salt marsh and beach plant, California sea-blite, as a practical tool for enhanced shoreline resilience to erosion and sea-level rise, in a recreational shoreline park.

Greenwood Beach Profile Nourishment

The proposed Greenwood Beach restoration design is based on periodic low-volume profile nourishment with mixed sand and gravel, within an augmented framework low-relief, vegetated cobble salt marsh drift-sills (explained below), backed by an augmented gravel storm berm, upgraded to a cobble-gravel berm. The beach nourishment is integrated with the existing salt marsh platform of the tidal flood control channel delta.

Cobble salt marsh drift-sills are living shoreline versions of beach groins for San Francisco Bay shorelines where beaches and salt marshes co-occur. They are semi-permeable, low-relief vegetated erosion-resistant cobble salt marsh with crests slightly above beach grade, acting as partial barriers to longshore drift. Their conceptual design and dynamics are described below. Some of the drift-sills merge with, expand, and protect existing high salt marsh. Some drift-sills merge with groins composed of small boulders and large woody debris and logs, where rubble and rocky fill exists. At the back of the beach profile, near the toe of the bluff, a small existing gravel storm berm would be enlarged by localized deposition of coarse gravel in a narrow backshore zone about 4-6 ft wide. The gravel would be reworked by storm waves only, redeposited as a defined berm on the erosional, lower storm beach profile. The gravel storm berm would typically be buried by sand during phases of beach accretion in spring and summer, and re-exposed and activated during storm conditions, when it would intercept storm wave runup.

The backshore (above normal tide) zone of Greenwood Beach would be modified to increase wave energy dissipation by re-grading the near-vertical barren, reflective wave-cut low cliffs to a ramp-like bluff profile supporting perennial salt-tolerant creeping substrate-stabilizing native shoreline vegetation. The set-back bluff crest, gentler slopes, and vegetative stabilization (increased soil strength to resist erosion, canopy roughness to dissipate wave energy) would increase dynamic resilience of the bluff during shoreline retreat, erosion episodes, and post-storm recovery and recolonization phases. The ramp-like lower bluff slope at the shoreline would be vegetated with the native salt marsh/estuarine beach species such as gumplant, pickleweed, saltgrass, alkali-heath, jaumea, creeping wildrye, and California sea-blite, which is expected to spread up the bluff as it does in many natural shoreline settings.

Sand Beach Nourishment

Sand beach nourishment would occur as profile nourishment: placement of sacrificial shallow deposit of unconsolidated sand across the active intertidal beachface, with relatively greater volume at the west (presumed net updrift) end of Greenwood beach, along the east side of the drift-sill. The western intertidal delta lobes (shoals of stratified sand, gravel and mud) themselves may be also be considered as potential locations of indirect sediment nourishment for both salt marsh and beaches. Past patterns of deltaic salt marsh and beach accretion suggest that aggraded delta shoals have supplied sand to the adjacent beaches and marshes. Hydraulic placement of heterogeneous sediment slurry over the natural storm-deposited delta shoals could supply a similar mix of silt, sand, and gravel to augment the local sediment supply, and increase wave energy dissipation over accreted intertidal flats.

Beach nourishment would likely be performed by mechanical placement by ground-based equipment accessing the shoreline from road-accessible uplands. Sand would likely be transported onshore or embedded in the low tide terrace. Silts would be resuspended, dispersed, and some would likely become incorporated in local mudflats or marshes. Flood control channel maintenance (removal of muddy sand or gravel bars) may be a source of sediment for hydraulic placement. A modified approach to mechanical placement of sand on the beach may include (a) hydraulic discharge of slurried sand or sand/gravel mixtures over the upper delta and beachface at low tide, forming sand splays (fans like small deltas), or (b) hydraulically redistributing mechanically placed sand mounds into washed sediment fans with a high-pressure firehose, using bay water pumped at mid-tide. Hydraulic placement of sediment to the delta (indirect beach nourishment) could be dispersive placement of mechanically placed sediment into the mouth of the flood control channel during periods of very high storm outflow, in small, incremental batches. This may be considered a component of dual beach profile nourishment of Greenwood Beach and salt marsh nourishment of Brunini Marsh.

Beach Replenishment Methods, Materials, Rates, and Patterns

The beach replenishment component would approximately match sediment size range to the existing beach berm and beachface, dominated by medium sand, with a minor component of small gravel. Sediment quantities and sizes will be further refined during the next preliminary design phases of the project.

The sediment texture of Greenwood Beach has not been quantitatively analyzed, but its heterogeneous mixture of medium to coarse sand and gravel, with prevalence of medium sand near the beach surface during calm-weather conditions, is consistent with the textural analysis of Sanctuary Beaches used as reference for Aramburu Island shoreline enhancement (Wetlands and Water Resources et al. 2010). The heterogeneity of the existing mixed sand and gravel beach, and the demonstrated self-construction and sorting by waves at Aramburu Island beaches, provides indicators for the feasibility of profile nourishment (Nordstrom 2000): sacrificial placement of beach sediments in the zone of wave transport (in this case of a low energy beach above a tidal flat, the swash zone of the beachface) for subsequent reworking (redistribution by erosion and deposition. This approach presumes seasonal erosion and re-deposition of a berm and beachface, alternating with a dissipative, flatter winter storm erosion profile, rather than design of an equilibrium profile or constructed beach berm. The objective of profile nourishment design, therefore, would be a range of beach sediment volumes (Stive *et al*. 1991, Kana 1993) rather than a fixed beach form or profile target.

The volume of beach sediment placed in any interval could be opportunistic, following construction of sediment retention structures (groins, drift-sills) to make the shoreline receptive to multiple episodes of beach nourishment. Incremental “construction” (nourishment) of the beach would occur after authorization for fill (sediment) discharge are obtained for an appropriate multi-year permit (potentially including a regional permit for small-scale, low-impact, low-volume local beach nourishment in Richardson Bay), as suitable sand and gravel supplies become available. Incremental, small volume episodes of beach profile nourishment (in units of 1-2 truckloads per year; ca. 15-30 yd^3/yr maximum) would minimize the magnitude and duration of disequilibrium beach conditions, or minor beach nuisances or hazards such as soft “sinking” sand or muddy sand.

The rate of beach sediment delivery could be adjusted based on beach morphodynamic and profile response to added sand during the spring-summer accretion season. It could also be adjusted based on beach response to unpredictable extreme storm erosion events. Average dry (high tide, backshore) recent (2011-2018) summer beach widths in northern Richardson Bay and the north shore of the Tiburon Peninsula are approximately 10 ft, near the year-round average of 18.8 ft (J. Beagle, San Francisco Estuary Institute, 2020). A maximum beach sediment volume per year or decade would be established by engineering estimates for a maximum beach profile width (on the order of 40 ft wide backshore, 60 ft beachface), to avoid potential excessive short-term sediment loads. A reasonable range of beach nourishment frequencies would be 2-6 year intervals, but may be considered for annual or decadal intervals based on shoreline response, ecological performance or impacts, or public park preferences.

Placement of sand and gravel may need a permanent ramp (dual purpose of public shore access and truck access) at the west end of Greenwood Beach, where rubble fill cliffs exist. Sacrificial placement of unstable sand and gravel updrift (west) of the active swash zone of the beachface in fall-winter would likely result in rapid natural wave reworking of the mobile sediment.

This approach to beach reconstruction through incremental, opportunistic profile nourishment implies that project construction is aimed primarily at grading of scarp/cliff profiles, ramps, and groins and drift-sills, prior to subsequent, phased beach sediment placement.

Gravel Storm Berm Augmentation

A small gravel storm berm exists at the toe of the existing bluff at the central reach of the West Beach. The west end of the beach lacks a gravel berm, and exposes asphalt and concrete rubble during winter storm erosion profile phases; the east end is sandy high salt marsh terrace. The gravel storm berm should be augmented as a minor, but geomorphologically important subordinate component of the beach profile, and extended along the entire scarp toe. The augmented gravel berm would increase wave attenuation at the bluff toe during storm wave conditions at high tide. The conceptual design for the augmented small gravel storm berm is a composite beach profile comprising a cobble and gravel berm exposed during storm conditions, and a predominantly sand beachface that normally buries it during calm-weather full beach profiles. This design is analogous, at a small estuarine beach scale, with cobble berm/sand beach restoration designs applied to Oregon’s Cape Lookout State Park (Komar and Allan 2010) and beach restoration and managed retreat design for Surfer’s Point, Ventura, California (Judge *et al*. 2017) It would be constructed during erosional beach profile phases by directly placing a wedge of cobble and gravel along the base of the bluff, prior to scarp ramp grading. The size of cobble and gravel would likely range between that of the existing berm (usually buried below sand), and the small naturally deposited gravel storm berm across northern Richardson Bay at Aramburu Island, which was formed by wave action and sorting of artificially placed gravels on a veneer of cobbles.

The target size of the gravel storm berm would be based on the naturally deposited storm gravel berm (not the as-built condition) at Aramburu Island, central shoreline. This storm wave-built feature is a minor ridge or crest on top of the whole beach profile at Aramburu Island; its volume and dimensions are not comparable with the original whole-profile beach nourishment rate at Aramburu Island, which was on the order of 2-3 yd^3/lft. The volume of cobble and gravel for the bluff-toe cobble storm berm at West Beach may be roughly estimated by the dimensions of the smaller naturally deposited Aramburu gravel berms of the south and south-central shoreline. This local reference system suggests that the volume of cobble and gravel needed for a small but augmented cobble and gravel storm berm would be on the order of 2-4 ft^3/lft of shoreline, or a total gravel volume on the order of 400-500 ft^3 (about 15 yd^3 per truckload) for the West Beach.

Cobble Salt Marsh Drift-Sills and Groins

Greenwood and Brunini beach planforms are consistent with a predominantly swash-aligned pocket or bay-head beach that traps beach sand in a confined littoral cell. Although wind-wave approach to the shore is variable, predominant wave direction appears to be perpendicular to the beach (wave crests nearly parallel to the shore most of the time). There is no indication of significant net longshore drift, such as long-term asymmetric beach erosion or accretion along the shoreline. Short-term longshore drift of beach sand, however, can occur even in pocket beaches with little or no net longshore drift. Short-term longshore drift rates may be significant during infrequent periods of high wind-waves with strongly oblique wave approach. The risk of significant short-term longshore drift may increase during non-equilibrium beach profile conditions when additional sand and gravel added to the shoreline during beach nourishment episodes. Some modification of shoreline structure to restrict longshore drift may therefore be needed in this project.

To increase predictability and retention of nourished sand and gravel within local beach compartments (littoral sub-cells) nature-based living shoreline obstacles to longshore drift functionally similar to groins, incorporated into the shoreline design. A modified version of drift-sills is proposed here for ecological compatibility with estuarine shoreline settings where beaches intergrade with or contact salt marsh habitats. The “cobble salt marsh drift-sill” is based on natural but uncommon occurrences of erosion-resistant cobble lag armored surfaces in salt marsh vegetation, as well as salt marsh accretion over or within cobble beach shores. The basic concept of this vegetated drift-sill is to create a local small-scale cobble salt marsh headland to provide inconspicuous groin functions, using a fortified, cobble-armored, salt marsh capable of accretion and erosion-resistance to storm wind-waves.

Backshore Bluff Slope

The existing bluffs at Greenwood Beach include a low, mostly bare wave-cut cliff (scarp) in artificial bay fill (Figure 10 and Figure 11). The cliff is nearly vertical after storm wave erosion events, which expose asphalt and rubble fill at the toe. The bluff height depends on the variable sand-gravel backshore beach elevation and its erosion/accretion cycles, but it ranges up to nearly 5 ft. The near-vertical cliff face is mostly unvegetated because of recurrent wave erosion, but weedy herbaceous vegetation occurs sparsely. The bluff gradient flattens and lowers to the east, grading into a gentle slope with no scarp near the channel. The upper cliff is mostly consolidated subsoil fill. The substrate and extremely steep slope of the unstable bluff reflect storm waves, are not conducive to establishment of gentler slopes and roughness of perennial vegetation that could dissipate wave energy and increase bank stability, interacting with the replenished backshore beach profile.

The bluff at the East Beach is an inactive, relict scarp forming a predominantly vegetated steep slope, dominated by non-native weeds with low capacity for soil binding, erosion resistance, or slope stabilization. The substrate is also a mix of infertile, compacted subsoil and rubble fill.

The proposed treatment of the bluff is aimed at providing a gentler slope with substrate supporting perennial vegetation that is capable of dissipating wave energy and reducing wave runup by friction from a rough shoot canopy, and increasing bank strength with root systems, stabilized by native estuarine beach, high salt marsh, and bluff toe vegetation including saltgrass and California sea-blite. Reference system model for the design is provided by a low bluff (relict wave-cut scarp and slumps, naturally stabilized vegetatively) at Fairbanks Point, Morro Bay (Central Coast); natural San Francisco Bay analogs from Oakland, Alameda and San Francisco have been eliminated by urban expansion since the 19th century.

This may be performed by measures modified from the approach used at Aramburu Island shoreline enhancement (Wetlands and Water Resources 2010):

- Remove asphalt and other deleterious materials from the existing shoreline and dispose of at an appropriate facility. There is a lot of asphalt for example along the shoreline that should be removed from the shoreline. It is anticipated that some of the concrete can be reused along the shoreline but that some of the flatter slabs of concrete may need to be removed, broken up and recycled or potentially the more roundish concrete pieces may be able to be reused along the shoreline.
- Set back the bluff crest by grading the bluff scarp to a less steep more ramp-like profile (proposed as 3:1-5:1 H:V).

- Construct a storm cobble berm as an erosion resistant backstop in the event of shoreline erosion.
- Backfill the graded ramp-like slope profile to provide a root zone, minimum 1 ft deep, composed of suitable substrate (sandy clay loam to sandy silt loam) to support transition zone (beach-terrestrial grassland) vegetation.
- Actively revegetate the slope with selected native plant assemblages including salt-tolerant native clonal perennial grasses and subshrubs (bank stabilization, sediment trapping, and wave dissipation functions), including California sea-blite, saltgrass, and creeping wildrye (see Vegetation, below).

Spoils (graded fill) from the ramp and set-back bluff crest grading could be spread as a topsoil layer in the zone between the set-back crest and the optional bioswale (see below). The topsoil should slope very gently landward to minimize gully and rill erosion at the ramp/bluff crest. This soil cap could be stabilized by plugs of perennial, slow-growing, trampling-tolerant, turf sod-forming native creeping wildrye (*Leymus triticoides*) and saltgrass (*Distichlis spicata*; see Vegetation, below), with a transitional fast-growing erosion-control seed mix of non-native annual ryegrass (*Festuca perenne*, syn. *Lolium perenne*), which is already abundantly established at the rough pasture/turfgrass of the park. The perennial creeping native components of the enhanced grassland would help regenerate soil-stabilizing vegetative cover and sod at the top of the bluff following future episodes of storm wave erosion. This process would operate in concert with vegetative recolonization by upslope-creeping high salt marsh vegetation at the bluff toe following erosion events.

Constructability of the Greenwood and Brunini Beach project appears more favorable than at Aramburu which as an island required marine transport which is much more costly. Site access is excellent, and there are large areas that could be used by the contractor for equipment and material storage within minimal impacts to park uses. There will be some impacts to public usage but overall, these are expected to be minimal. Construction feasibility and design will have to be reviewed and approved by the Town of Tiburon during future design and permitting phases of the project.

Brunini Beach and Marsh

The small existing pocket Brunini Beach would also be nourished by mixed sand and gravel deposited in the beachface for reworking by waves. No storm gravel berm is proposed for the Brunini Beach, which is partially sheltered by the (currently) expanding salt marsh. The relict wave-cut scarp behind Brunini Beach has not been actively eroding in recent years, and is vegetated with weedy species that provide little bank stabilization. California sea-blite plantings at the toe of the Brunini Beach bluff, set behind a more protected, prograded, nourished sand beach profile, are expected to provide increased bank stabilization over time. California sea-blite stands with enhanced wave-damping canopies (clambering vegetation supported by coarse driftwood or similar wood trellis support), backed by enlarged stands of coarse clonal perennial native grasses (creeping wildrye, *Leymus ×gouldii* and *L. triticoides*). Creeping wildrye is already established as large patches at the back of the Brunini marsh/beach terrace, and could be spread by transplanting and burying sod clumps in early winter. Expanded colonies of creeping wildrye at the back of the terrace, and California sea-blite and the beach and salt marsh, would together provide a broad gradient of vegetative roughness to trap overwash-deposited sand, and attenuate wave energy.

The deltaic salt marsh platform and sea-blite colonies of Brunini Beach and salt marsh would indirectly be nourished with sand drifting from the beach during storms, providing sediment for vertical accretion of sandy high salt marsh berms – an alternate state of low-gradient, low-energy estuarine beaches. Both beach and salt marsh accretion would be expected to increase after each episode of sand re-nourishment at Brunini Beach.

An additional small pocket beach, similar in size to the existing pocket East Beach, would be established over existing rubble and boulder upper intertidal shoreline. It would be enclosed by a composite groin and cobble salt marsh drift-sill, partially constructed by restructuring existing rubble to form a low boulder groin, and extending it bayward to near Mean Sea Level with a vegetated cobble salt marsh drift-sill.

The beach-salt marsh complex design is intrinsically dynamic and phased over time to balance beach and salt marsh sediment budgets with deficits caused by sea-level rise and infrequent extreme erosion events.

Longshore Drift and Beach Groins

Engineered beach groins are shore-perpendicular hard structures (rock, wood) designed to obstruct or slow longshore drift of beach sand or gravel, and retain sufficient volumes of it it within a designated shoreline cell to maintain a necessary or desired profile of a nourished beach (Dean 2000) or modified semi-natural beach (Nordstrom 2000). Groins generally extend across the full beach profile, but may allow for bypassing (drift beyond the groin tip) when the groin-altered beach profile is sufficiently filled with sand or gravel. They are also used to restrict migration of channels or inlets, like larger jetties which are designed to maintain permanently open navigable tidal inlets. Alternative variations of groins may be partially permeable to drifting beach sediment. Poorly designed groins and beach sediment management can result in objectionable, harmful down-drift sediment deficits and erosion. Well-designed groins, combined with sound beach nourishment, can avoid typical adverse downdrift erosion impacts of groins on the southern California coast (Griggs *et al.* 2020).

Constructed small-scale groin-equivalent features designed to be relatively low (near beach crest elevation) and short (near beachface width) serve as partial longshore drift obstacles on low-energy Puget Sound beaches gravel and sand within rocky shore settings. They have been termed “drift-sills” to distinguish them from typical groin designs (Johannesen *et al*. 2014). Drift-sills are equivalent to “micro-groins” designed in San Francisco Bay at Aramburu Island’s constructed estuarine beaches (Wetlands and Water Resources *et al*. 2010).

Approach B: Greenwood Beach Gravel Beach Design by Dr. Mark Lorang

Problem: The main problem at Greenwood beach is bank erosion and limited bay beach access (Figure 10).

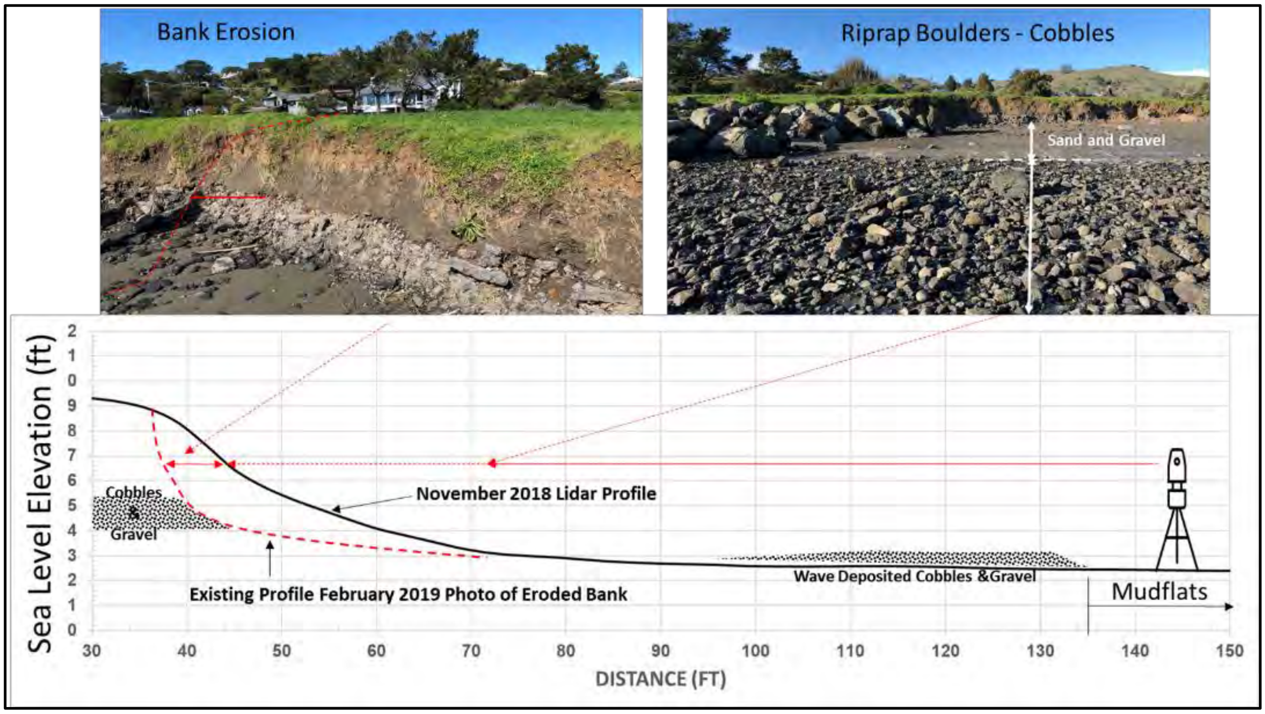


Figure 10: Bank erosion problem at Greenwood Beach. The plotted profile (bottom panel) is for the location of the red dotted line in the left photo and the white line in the right photo. The bank is composed mainly of sand with a lower layer of rubble cobble sizes asphalt and concrete material (left photo). Waves erode the bank and redistribute the gravel and cobble rubble forming the edge of the mudflat.

Solution: The proposed gravel beach solution for bank erosion and limited bay beach access for Greenwood Beach would be to use the GBDT and design a perched gravel beach (Figure 11). This solution would stop the bank erosion and provide ancillary habitat benefits using an array of sediments sizes that currently exist at this. The cuspate horns or headlands that bound the beach will need to be composed of cobbles on the coarse end of the spectrum. This approach is the best we can do for now in terms of minimizing longshore drift of the cobble material composing these headlands.

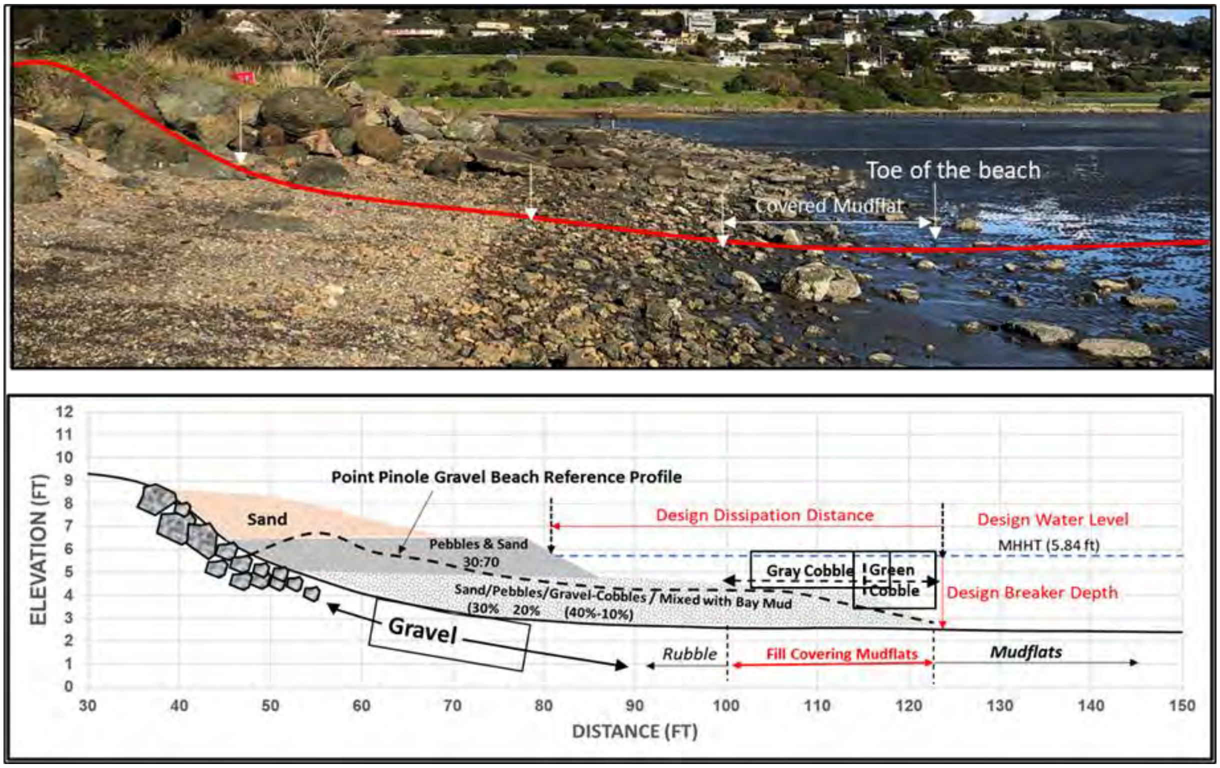


Figure 11: Riprap bank at Greenwood Beach. The plotted profile (bottom panel) is for the location of the solid red line in the photo above. The lower panel shows a completed cross-section for a proposed gravel beach composed of 3 layers that can fully dissipate the design wave conditions when exposed to MHHT water levels. The boulder riprap should be removed. The reference profile from Point Pinole is plotted as well and seems to match with the gravel beach design. This design would stop all wave erosion and provide easy access to a recreational beach for all tides. The sand and pebble layers could be habitat restoration platforms.

The first iteration of the design (Figure 12) encroached too heavily into the existing salt marsh area hence the decision was made that all the material needed to be removed from the inlet so that placement does not encroach into this conservation habitat area. Furthermore, additional sand could be brought into the conserved marsh area in the future if it continues to erode as sea-level rises by depositing the sand in the east side of the marsh in the area marked sand nourishment area to allow wave action to redistribute it (Figure 12). The team also thought the embayment just east of the stream mouth should be a bit more developed on the east side and use more sand than cobble on the upper layers while still designing for the increasing storm intensity and sea-level rise expected to happen because of climate change.

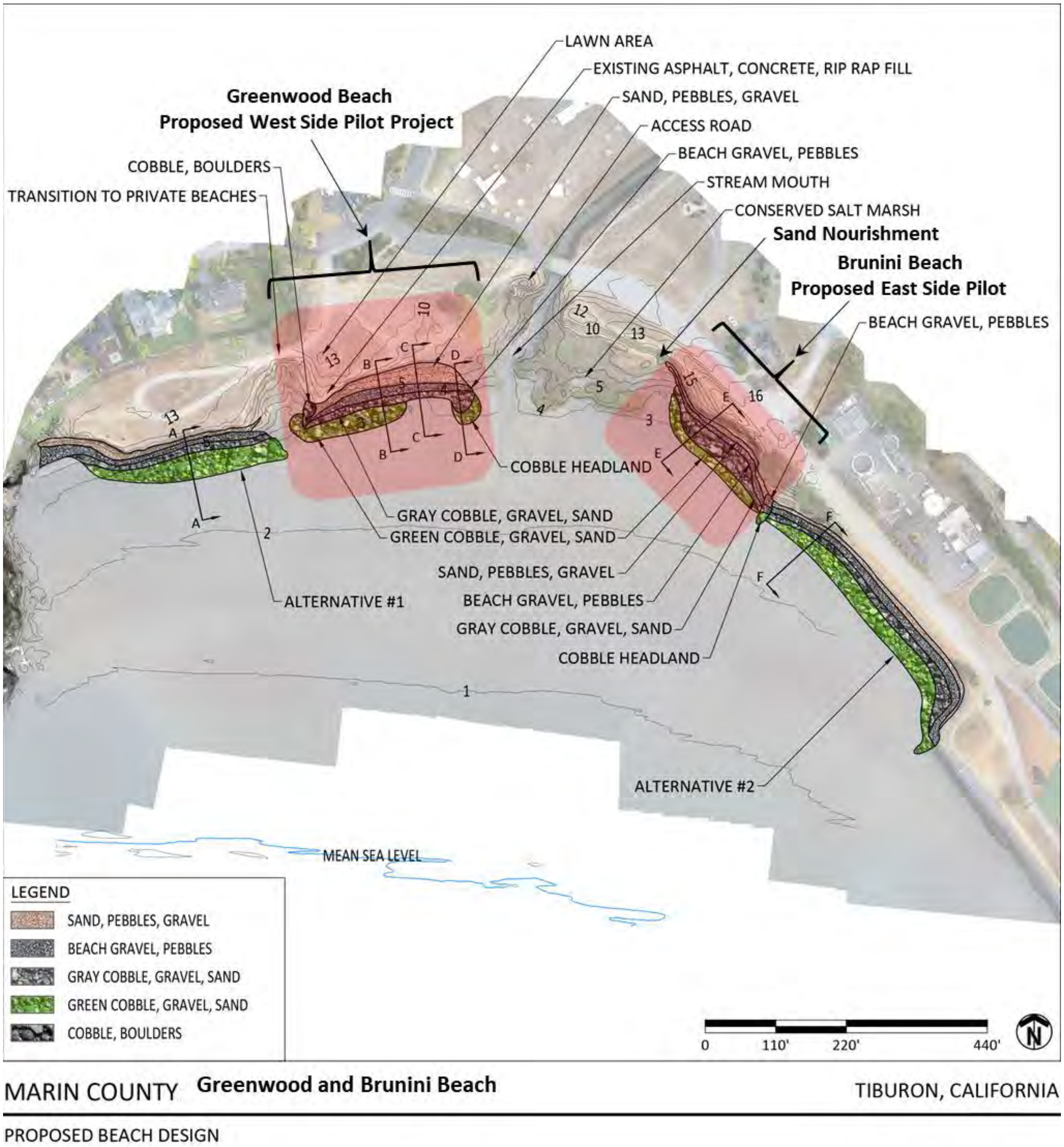


Figure 12: Plan view extent for the preliminary design, taking into consideration of the *GBDT* results, site morphology and potential longshore sediment transport process but not encroaching into the conserved salt marsh area. And the project design was extended to the west (Alternative 1) and to the east (Alternative 2) to provide additional recreational opportunities. The proposed pilot projects are labeled with red shading. Data from the pilot project would help further design each alternative expansion at Greenwood beach park.

Based on input, the cobble headlands were redesigned to be more pronounced on the east side as well as extend the design further to the west (Alternative 1) and further along the east side fronting the riprap (Alternative 2) to greatly extend the recreational beach opportunities in both areas (Figure 13 and Figure 14). If alternatives 1 and 2 were undertaken the existing riprap could be removed and perhaps used to outer-reef restoration areas help reduce loss of the leading edge of tidal marsh elsewhere in the bay.

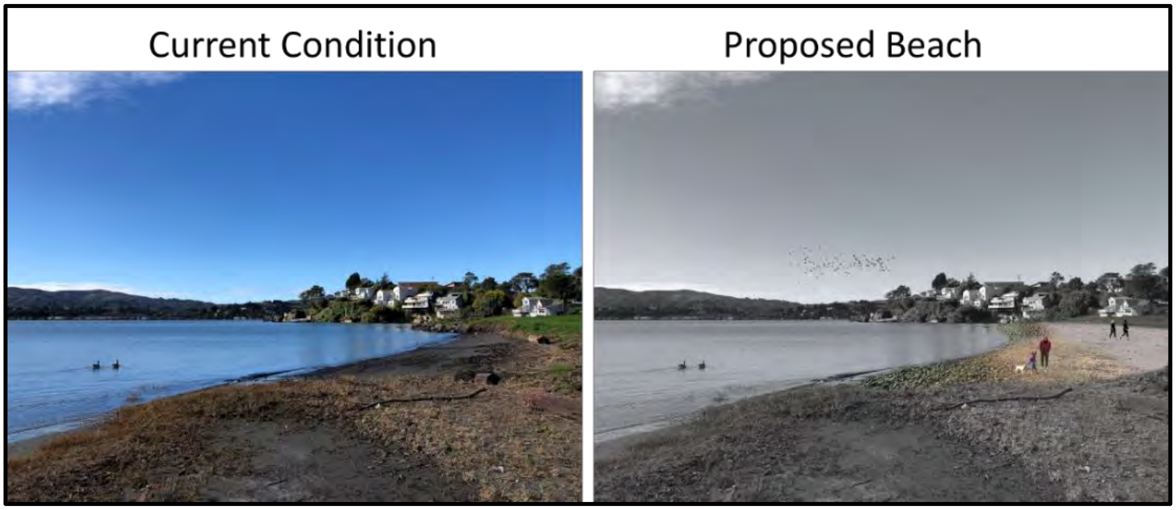


Figure 13: Images looking west from the stream mouth showing the sand beach embayment +5ft MHHT in February 2020. The landscape rendition to the right depicts what the final design would look like from the same location.

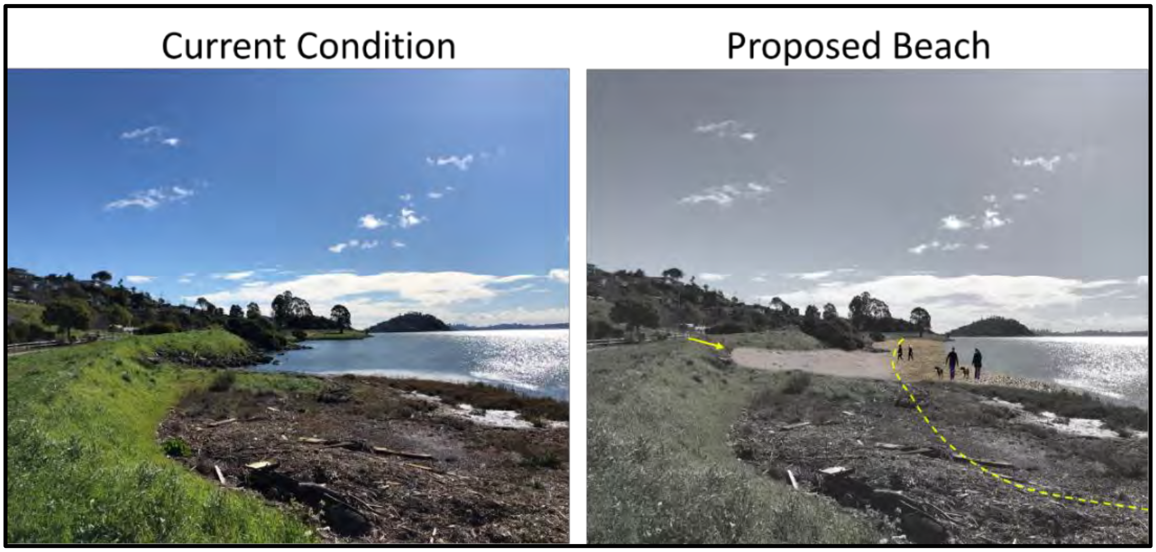


Figure 14: Images looking south from the eastern edge of the conserved salt marsh during a +5 ft MHHT in February 2020. The landscape rendition to the right depicts what the final design would look like from the same location. The yellow dotted line shows where the same tide level would reach given 1 ft of sea-level rise. The yellow arrow shows the sand nourishment location.

Alternative 1 plus the material fill on the center section (referred to as the Pilot Project containing transects B, C & D) greatly increases the recreational opportunities for the east side of Greenwood beach and Alternative 2 more than doubles the total length of recreational beach compared to current conditions (Figure 12Figure 14). Moreover, it solves the erosion problem and removes the hazardous vertical bank and riprap that currently prevent public access to the tidal beach and (Figure 14).

The gravel beach designs for Greenwood beach are divided into three sections, the middle section or the Greenwood Beach Pilot Project and Alternative 1 to the west and Alternative 2 which is to the east across the stream. The middle section is separated on the east by Brunini stream and a smaller flowing groundwater seep that has its own mini canyon at the transition to the private properties. This middle section was designed as a pilot project that could be build first and adequately monitored to provide information to help improve the *GBDT* and hence the designs for Alternatives 1 & 2. Transect A represents Alternative 1, transects B, C and D represent the proposed pilot project and transects E and F represent Alternative 2 (Figure 12).

The cross-sectional areas for the treatment layers on each of these sections reflects the actual topography at these locations, hence the layer thickness changes from transect to transect to reflect the existing topography and final desired shape. These differences also reflect the volume of material proposed to use to build the beach and determines the amount of existing aquatic habitat that will be buried by the placed gravel-cobbles and sand. This placed material will impact the habitat it covers but at the same time it will provide new substrate that will support active recolonization of aquatic and terrestrial organisms. Indeed, the upper sand foreshore material is new area and substrate that could support native plantings and restoration efforts in areas that are currently eroding away or covered by boulder riprap.

Final Design: Transect Interpretations

The following discussion describes, for each section, the relationships between existing conditions and proposed treatment layers as a function of design tide levels, and breaking wave heights and depths that control wave energy dissipation relative to the reference beach at Point Pinole and the expected 1-ft sea-level rise. These AutoCAD plots are all drawn to scale with the distance scale set to zero where mean sea level (msl) crosses the survey transect line. This allows a quick assessment of the relative amount of total wave energy each profile will be exposed to, the closer to the mean sea level contour the more energy. The vertical axis is set to zero for mean sea level (msl) with positive numbers indicating elevations above msl and negative elevations below msl.

On all the plots the top panel compares a plot of the survey transect that shows the topography at the location of both the backshore and the tidally influenced area. Both the design water level MHHT (+5.84 ft) and a 1-ft sea-level rise (+6.84 ft) are plotted as blue and red dotted lines, respectively. And the Pinole Point reference profile plus that same profile plotted with a 1 ft vertical rise added are plotted as a solid purple line and dotted purple line, respectively. The break point for the design breaking wave depth is plotted as a breaking wave, red dotted, for the sea-level rise break point and blue dotted for the current MHHT design water level. This allows quick relative comparison of how wave energy will be increasing as sea level increases for that transect. If only a red breaker wave is plotted that means the current break point during MHHT occurs further offshore than what can be plotted without changing scale between graphs.

The bottom panels show the suggested fill for each treatment layer to fully dissipate all storm wave energy relative to the *GBDT* metrics and using Point Pinole as a reference profile guide. The top layer changes depending on the variability of the backshore elevations relative to the MHHT elevation representing 1 ft of sea-level rise as well as using the elevated reference profile as a guide. The size of material is simply plotted as one of three possibilities from cobble, to gravel to sand. The specific range of material sizes for each layer can then be finalized after the thickness, extent and elevations of the final design are agreed upon by all the stakeholders.

Plotting the data and design constraints from the *GBDT* and chosen design water and wave conditions provides a consistent yet objective way to initialize the design and therefore these plots provide a quantitative way to assess further potential design changes. Using the *GBDT* to design beach cross-sections, that will fully dissipate all expected wave energy for all expected extreme but rare storm events occurring during MMHT tides and future expected sea-level rise is a classic traditional engineering approach. This gives the stakeholders confidence that this design will withstand what nature is expected to deliver while protecting the backshore from erosion and while doing so with a soft dynamic natural gravel beach, one that also greatly improves recreational opportunities and habitat restoration opportunities within the constraints of immediate impacts to the mudflats and those import intertidal habitats. This level of gravel beach design will not require much if any future maintenance for at least two to three decades into the future.

However complete wave dissipation is perhaps not the design parameter that you want to build to. It may be appropriate to allow for wave action, including overtopping. These cross-sectional profile designs can all be reduced in scale. The beauty is that they are all a product of an objective and repeatable methodology that are backed up by the complete suite of wave, tide and material size wave-competence analysis contained within linear wave theory and the *GBDT*. Hence, what the profiles below allow, coupled with the *GBDT*, is to assess within a visual framework easily and quickly what a reduction means in terms of backing off from design water levels, design wave energy and expected sea-level rise relative to the risk stakeholders are willing to accept regarding continued shoreline erosion due to rare yet severe events.

The *GBDT* allows for modification to reduce volumes and sizes of placed sediments and design for the common everyday storm event and much lower tide levels and much less expected sea-level rise. Doing so within the *GBDT* framework then also allows a quantitative assessment of long-term expected maintenance volumes for the proposed design. One could build a small beach and only use a little bit of sand and it could last for years if big storms don’t impact the site during high tides, but it could also wash away the following week. So perhaps the preferred design approach would be constantly nourishing the beach with material that the waves can easily rework. That is a reasonably good approach, especially if one also measures the wave and tidal conditions that washed the material away and the volume of material that was moved and where it went. If you do that, then you learn something that could help better determine how much material the next nourishment supply may require and perhaps save some money. Unfortunately, that is rarely done, given that we do not have wave power vs volume flux equations (i.e. equation 41).

Pilot Project

The main proposed Greenwood beach Pilot Project is the center of the site although it could be expanded to include the part of alternative 1 with red shading (Figure 12). The goal for this site is to create a beach as close as possible in size and plan form to the reference gravel-cobble pocket beach at Point Pinole. This design will immediately stop the erosion at the site as well as provide improved recreational beach access and thereby remove the hazardous conditions that are currently posed by the eroding vertical back and large boulder riprap. The beach design has a sand embayment foreshore beach bounded by two cobble-gravel horns with each of these features represented by transects B, C and D (Figure 12, Figure 15, Figure 16). Transect B is the same location that has been used in all the previous profile plots (Figure 15).

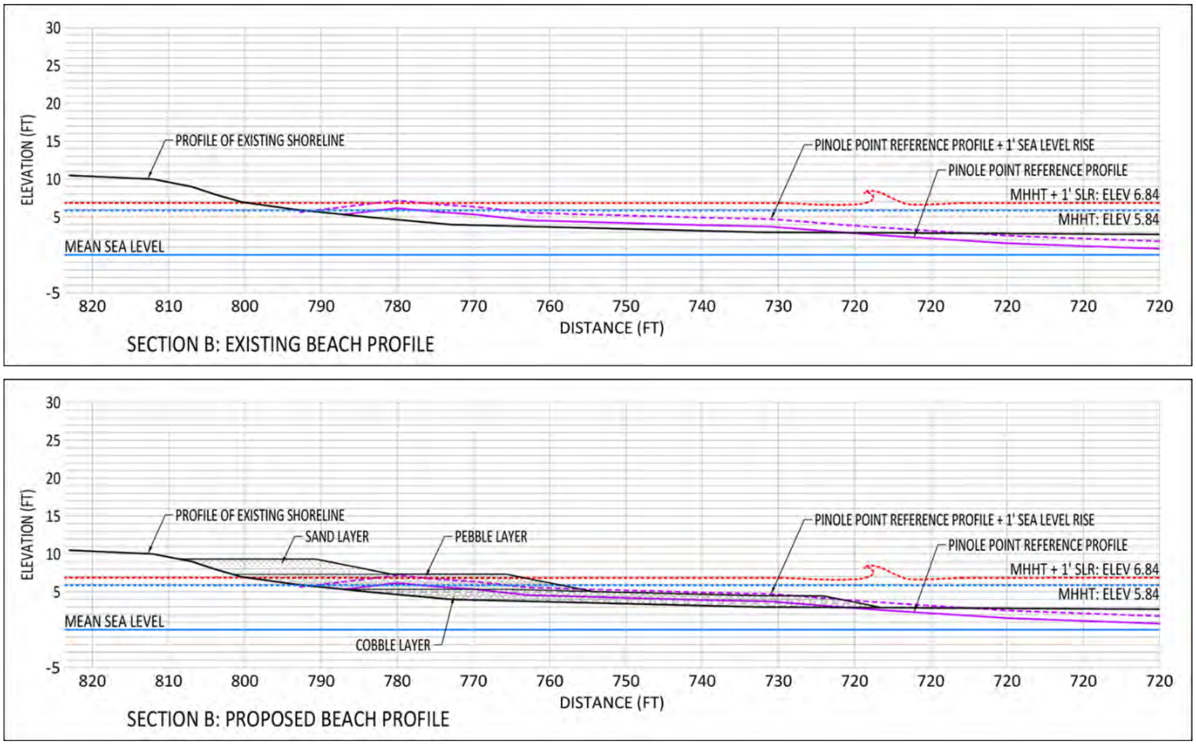


Figure 15: Plot of transect B for the proposed middle section of the Greenwood beach site (see Figure 12 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower panel.

The MHHT level intersects the reference profile at the top of the beach crest for each plotted Point Pinole reference profile. Extending the 1-ft sea level water level back towards the existing backshore indicates that this area would need sand fill to grade (Figure 15). One could simply not fill this area and allow storm waves to over top. That process would over time fill the area while material from the middle pebble-layer would roll-over into that space. This would be like the process-based dynamics at the Aramburu Island site.

This final design includes sand to this layer to bring the beach up to grade with the backshore slope to enhance ease of use by beach goers and to provide a supply of sand during high tide storms that wave action could then deposit towards the conserved salt-marsh area further to the east. Longshore transport in this area is often west to east and if the salt-marsh is to keep up with sea-level rise it will need a supply of material. This sand layer would be brought to grade across the whole pilot project (Figure 16, Figure 17) with a bit extra added on the eastern boundary with the salt marsh (Figure 17).

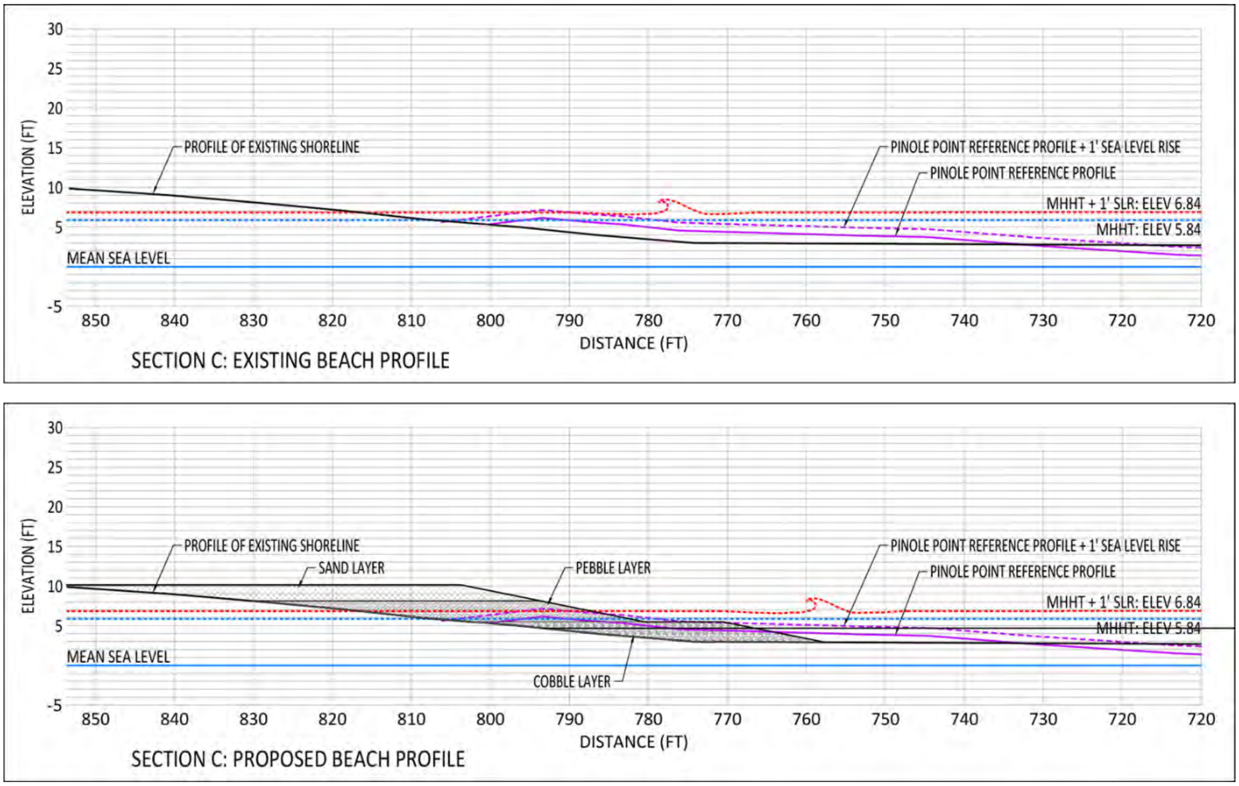


Figure 16: Plot of transect C for the proposed middle section of Greenwood beach site (see Figure 12 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower panel.

This extra sand on profile D next to the salt-marsh would be the nearest supply of sand for the salt marsh while sand from profile B and C further the west would take longer to reach the salt marsh and supply a smaller volume. However, it is not actually possible at this time to quantify the actual volumetric rate because we are lacking appropriate values for the *K* coefficient in equation and therefore the best we can do at this design stage is make an educated guess and use a volume that can be soothed into the topography.

The location the current break point for the design wave height occurs off scale to the right in each of these profiles. During storms of that magnitude occurring during MHHT tide levels and above waves will create a large broad surf-zone composed of spilling breakers that would not form plunging breakers that spill and swash onto the beach until they reach the nick point of the cobble layer located 725, 770 and 765 ft from the msl location (Figure 15Figure 16, andFigure 17 respectively).

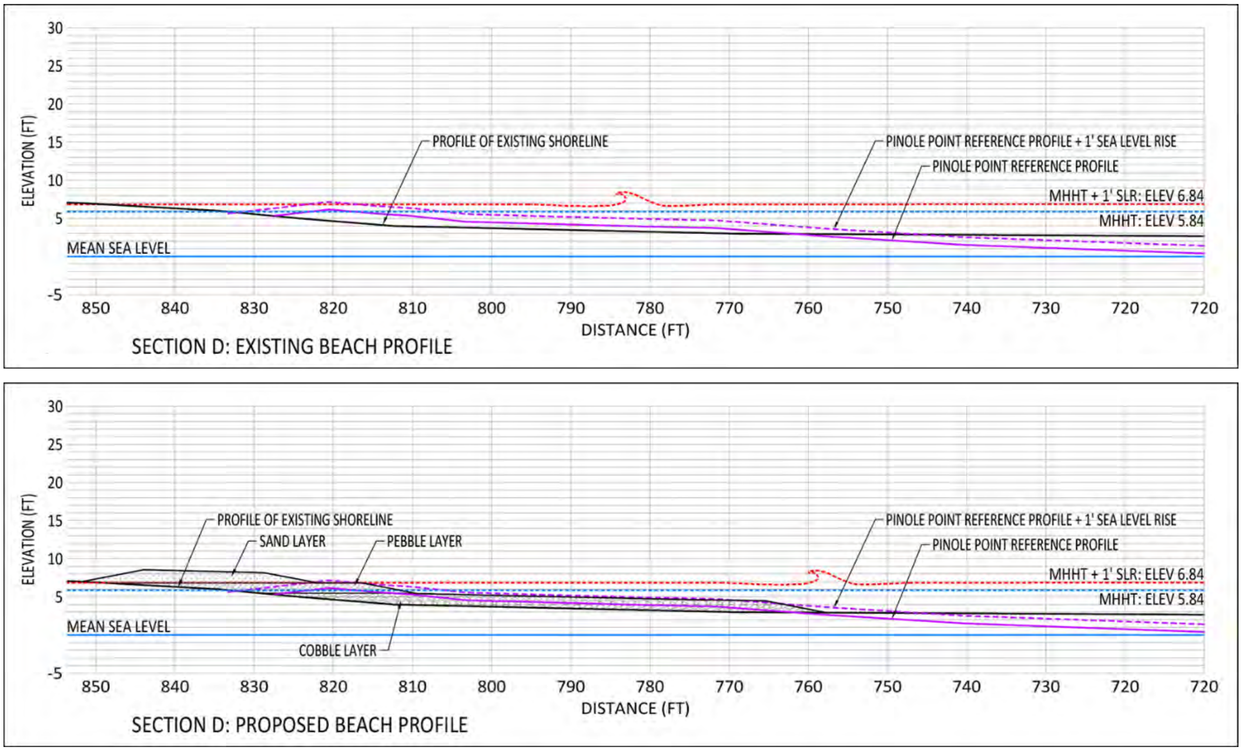


Figure 17: Plot of transect D for the proposed middle section of Greenwood beach site (see Figure 12 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower panel.

Section C has the shortest plunge zone of 11 ft but that is the minimum required to dissipate the waves and allow for swash to reach the beachface of the pebble layer and for sections B and D the plunge zone is approximately 30 ft wide (Figure 15, Figure 16, Figure 17). Waves would likely reform into a surf-bore or spilling breaker as they move across this cobble shelf until they break and swash up the beachface of the pebble layer. Waves would only reach the upper fore-shore sand layer during extreme tide and storm wave conditions which can occur but are exceedingly rare events). The occurrence of waves reaching the sand foreshore will increase as sea-level rise occurs and as storms increase in intensity (higher waves) duration (longer events) and re-occurrence intervals (more often) with the onset of rapid climate changes.

The cobble horns (sections B and D) of the proposed pilot project have cobble layers that are extended offshore according to estimates of the *GBDT* and the desires of some design team members to make them larger, and thereby, give the planform more 3D shape. This layer also extends offshore as far as the green algae cover can be seen growing on rubble material on imagery. This indicates a seaward limit to wave-competence action at the site beyond which it cannot move cobbles across the nearly horizontal mud-flat. Therefore, extending the cobble layer further out, while it covers more tidal mud flat and thereby impacts more existing habitat it will result in producing more “green cobble” habitat for the future and hence enhance the nearshore ecology of this area over the current conditions. The permitting implications for converting existing mud flats to cobble lag surface are unknown and will need to be explored during the final design and permitting phases of the project. It is unclear if the agencies will view the cobble as an ecological enhancement or an impact.

East Side: Alternative 1

The area to the west of the pilot project section is similar in that it has a large boulder riprap fronting much of the grassy area separating the private homes from the bay. The same design procedures were taken here as for the pilot project resulting in an expansion of potential recreational beach opportunities subject to review and approval of the permitting agencies and the Town (Figure 12). A cobble headland is proposed for the eastern edge that pinches out on the western boundary to not impact the private docks and structures further to the east (Figure 12). The green cobble layer base extends slightly further into the bay because the tidal mud flat is also slightly deeper as shown by the + 2ft contour is much closer to the toe of the beach (Figure 12). Section A represents the cross-sectional view for Alternative 1. Breaking waves for both MHHT and MHHT plus 1 ft of sea-level rise appear on this profile indicative of the slightly higher exposure of wave energy for this western portion of Greenwood beach (Figure 18).

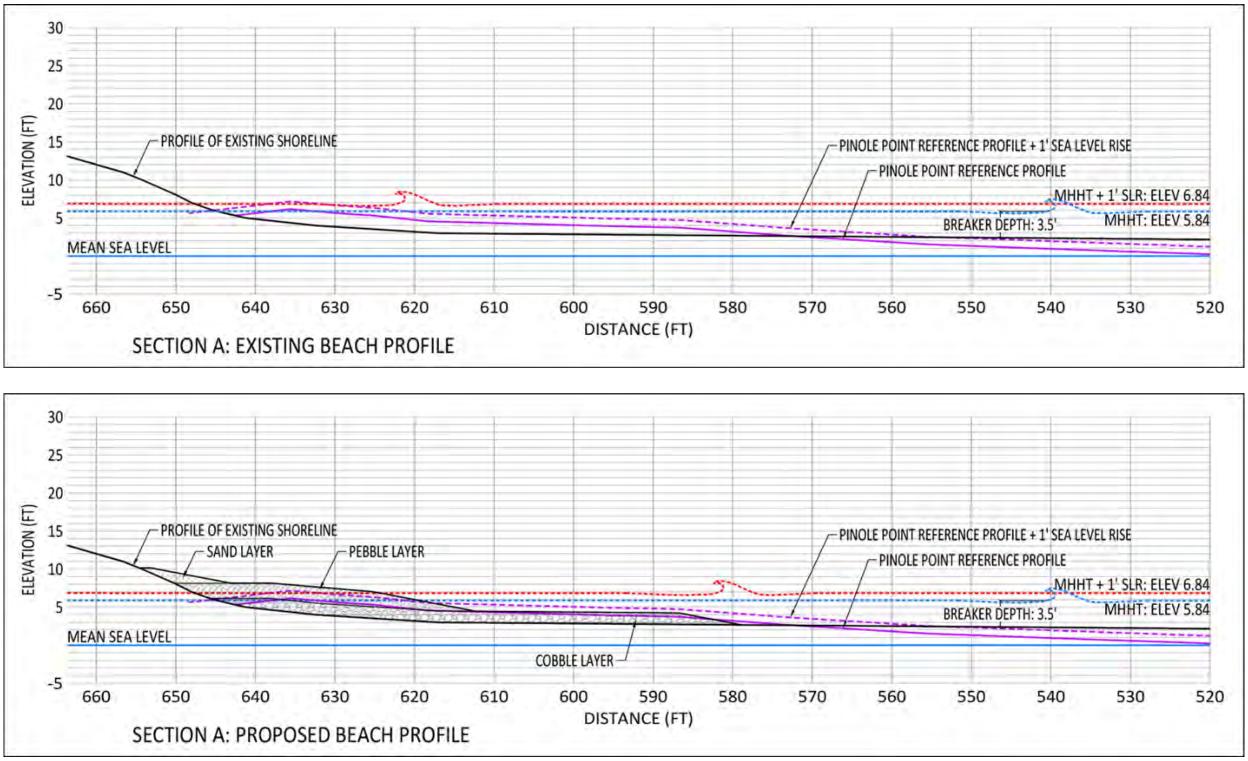


Figure 18: Plot of transect A for the proposed Alternative 1 section of Greenwood beach site (see Figure 12 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower panel.

The sand layer was not brought to grade for this area because in part because it is much higher than the middle section (Figure 18). Wave breaking during storms will be like the middle section with wave swash rarely reaching the fore-shore sand beach until sea-level rise brings that energy closer. The inlet between Alternative 1 and the pilot project is left untreated. This area could potentially be encouraged to evolve in a similar manner as the conserved salt-mash area thereby creating some ecological enhancement. The green cobble headland is extended further out to protect the inlet from Southwest waves by forcing those waves and those approaching more from the south to refract and dissipate energy before entering the inlet (Figure 12). The inlet area would therefore be a prime restoration enhancement opportunity.

West Side: Alternative 2

The area to the east of the pilot project and past Brunini marsh section has large boulder riprap covered and with fine material and vegetative overgrowth (Figure 15). The same design procedures were taken here as for the pilot project resulting in an extensive expansion of recreational beach opportunities (Figure 15). A cobble headland is proposed for the center to segregate the two sides of a current cuspate shaped beach that extends along Brunini Way ending at the sharp 90-degree shoreline switch (Figure 12). The green cobble layer base extends slightly further into the bay because the tidal mud flat is also slightly deeper as shown by the + 2ft contour is much closer to the toe of the beach (Figure 12).

Sections E and F represents the cross-sectional views for Alternative 2. Breaking waves for both MHHT and MHHT plus 1 ft of sea-level rise appear on profile F indicative of the slightly higher exposure of wave energy for this portion of Greenwood beach (Figure 19 and Figure 20). The sand layer was not brought to grade for this area because the elevation of the road is much higher (Figure 19 and Figure 20). Wave breaking during storms will be like the middle section with wave swash rarely reaching the fore-shore sand beach until sea-level rise brings that energy closer. The alternative 2 area shown with red shading in Figure 12 could be added to the pilot phase. It is represented by transect line E shown below in Figure 19.

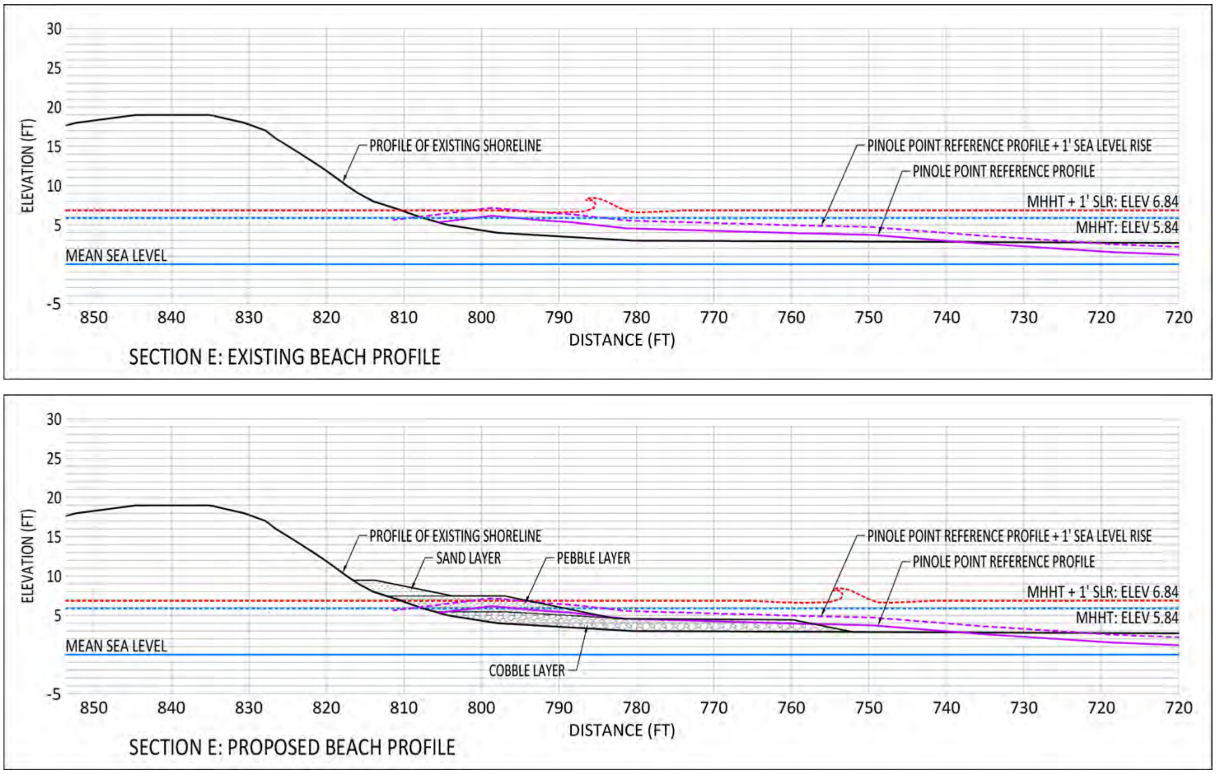


Figure 19: Plot of transect E for the proposed Alternative 2 section of Greenwood beach site (see Figure 12 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave

position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower panel.

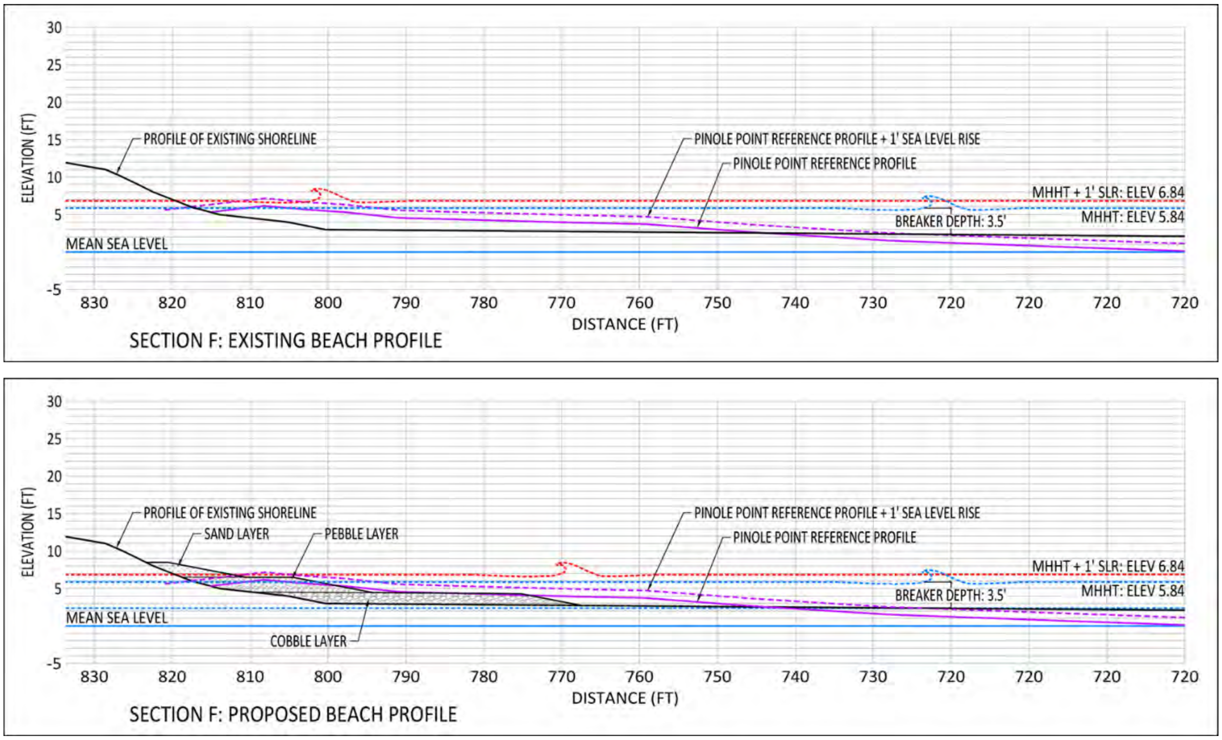
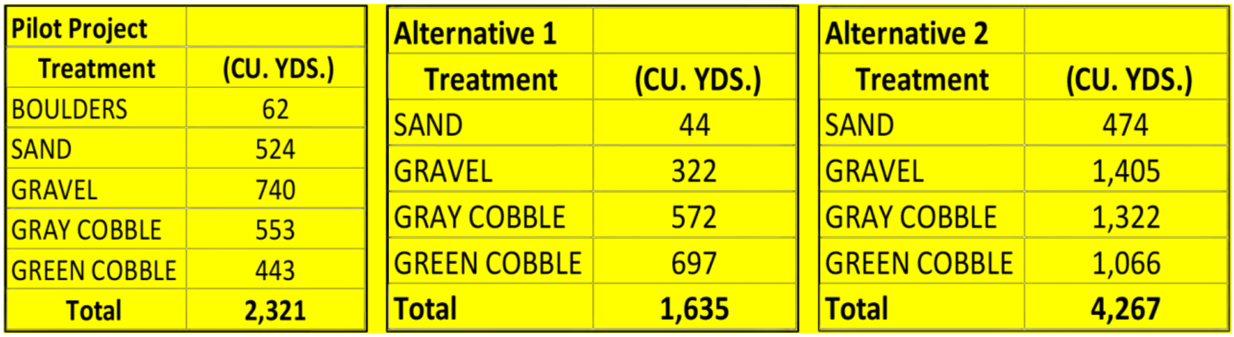


Figure 20: Plot of transect F for the proposed Alternative 2 section of Greenwood beach site (see Figure 12 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower panel.

For Greenwood beach 3 conceptual designs have been put forward and for each design the total volume of gravel material per treatment type are listed (Table 2).

Table 2: Gravel volumes per treatment for each of the Greenwood beach conceptual designs



Pilot Project	
Treatment	(CU. YDS.)
BOULDERS	62
SAND	524
GRAVEL	740
GRAY COBBLE	553
GREEN COBBLE	443
Total	2,321

Alternative 1	
Treatment	(CU. YDS.)
SAND	44
GRAVEL	322
GRAY COBBLE	572
GREEN COBBLE	697
Total	1,635

Alternative 2	
Treatment	(CU. YDS.)
SAND	474
GRAVEL	1,405
GRAY COBBLE	1,322
GREEN COBBLE	1,066
Total	4,267

Summary of Potential Habitat Impacts

Habitat data were obtained by the San Francisco Estuary Institute based on the sub-tidal goals mapping layers from 2010, the Bay Area Aquatic Resources Inventory, and the SF Bay Shoreline Adaptation Atlas and adjusted by SFEI staff to better reflect site specific conditions based on a review of aerial photos over time. Habitat data relevant to Greenwood Beach included mudflats (based on elevation), beaches, and tidal wetlands (Figure 21). Aerial extents for the beach treatments for each design were derived from CAD files or hand drawings and converted to GIS data. For each beach design, the estimated total habitat covered by all beach treatment was determined (Table 3). These estimates provide a good measure of what habitats will be initially impacted by each beach design but are not intended for permitting purposes and may need to be remapped and reconfirmed during future design and permitting stages of the project.

Figure 21 below shows the existing habitats polygons at the Greenwood Site.

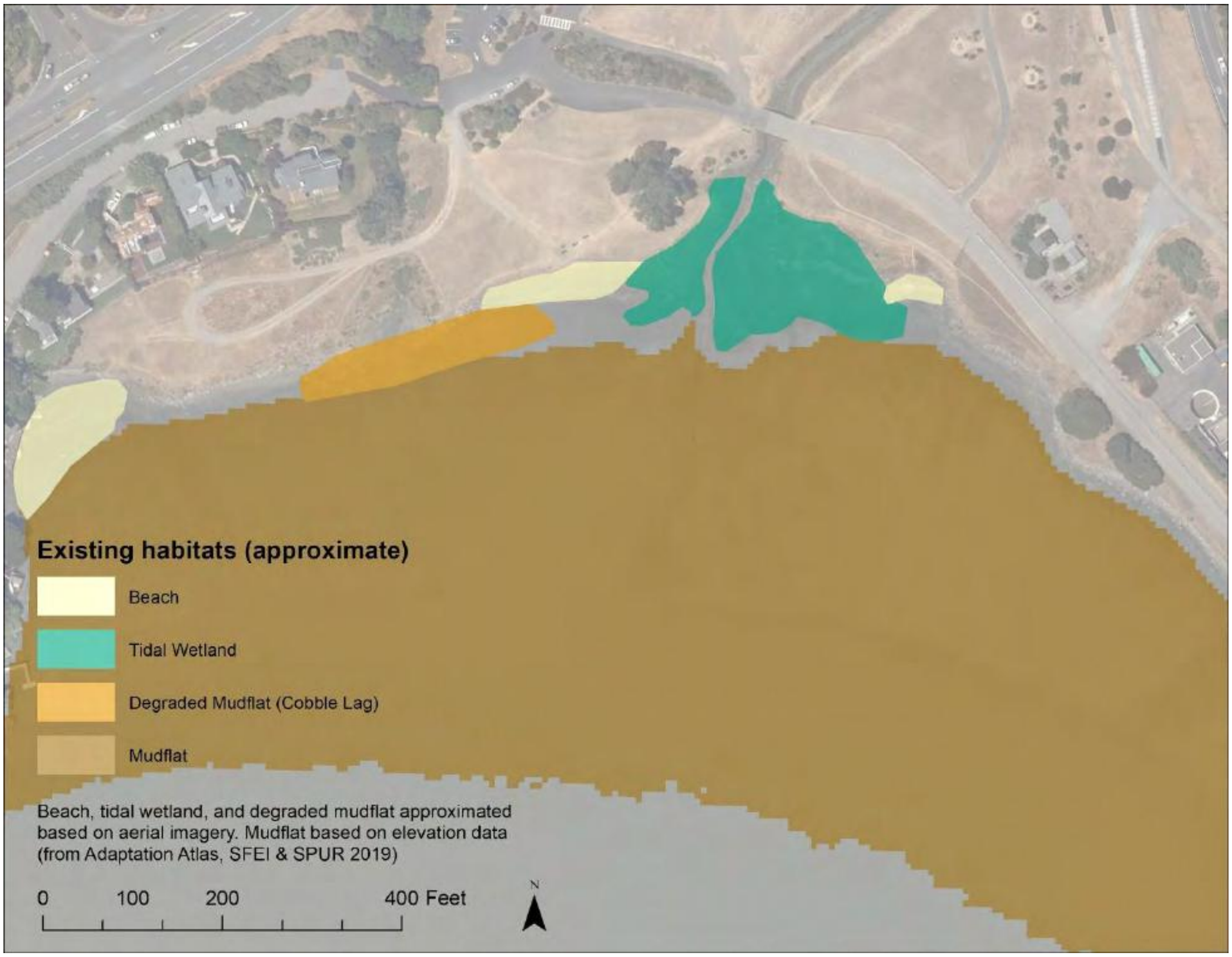


Figure 21: Existing habitat types at Greenwood Beach, approximated from aerial imagery and elevation data

For Approach A, the Dynamic Beach Nourishment approach, the designs were provided as sketches that were dimensioned but are not scaled drawings. As such they are not as accurately developed as the Approach B designs which were developed in AutoCad and then exported to GIS for the impacts analysis and are thus to scale. To assess impacts for this approach, SFEI staff fitted the sketches onto the landscape as polygons shown below in Figure 22. As such, these are approximate and only intended to provide an approximate assessment of the potential habitat impacts from both approaches.

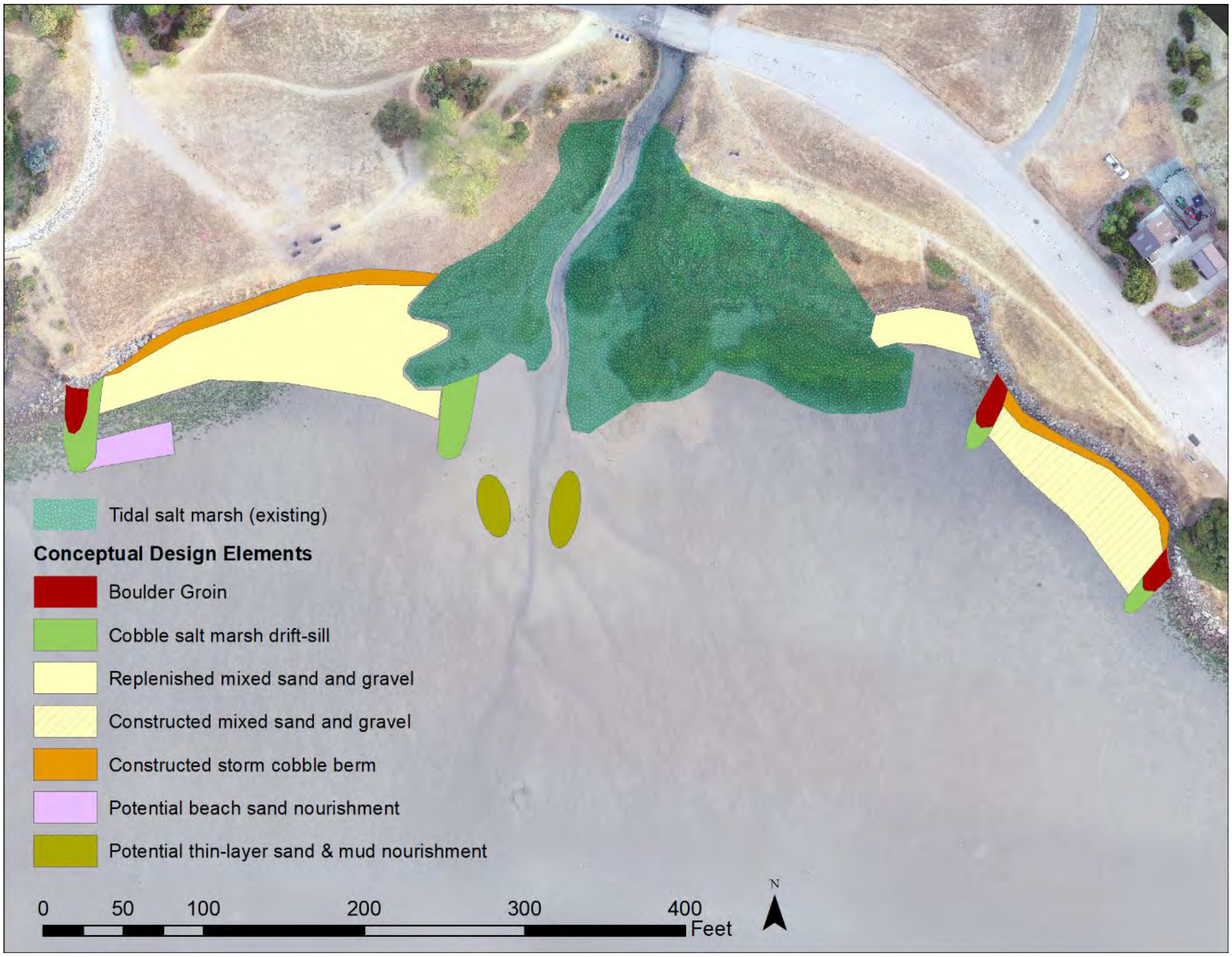


Figure 22: Proposed design approach A impact areas

Table 3. Summary of habitat impacts at Greenwood Beach (approximate)

	Square feet impacted				
Habitat Type	GBDT Alt 1	GBDT Alt 2	GBDT Pilot	Dynamic Beach Nourishment	Total habitat area, as shown in Figure 63
Beach	1,600	0	5,300	6,300	17,400
Mudflat	4,600	13,000	4,000	3,500	630,000*
Degraded mudflat	3,900	0	7,900	3,900	13,600
Tidal wetland	0	0	1,200	0	32,600

*Approximate area of extent shown in Figure 21– mudflat extends beyond these bounds.

Approach B: Preliminary Project Construction Cost Estimate – GBDT Design

The level of preliminary costs is only plus/minus 30% to 50% depending on the construction item. For this report, the final design, permitting, implementation and monitoring costs have been estimated only for the GBDT approach for two reasons; (1) because the design has the higher upfront cost although likely a lower maintenance cost and (2) this design was developed from scaled plans that allow for quantification of volumes. The scope of this report did not allow for scaling of concept sketches for the other design approach but whichever design approach is brought forward for the final design phases of the project will be further developed and costed out in greater details.

Constructability

Access and Staging Areas

Construction access is excellent for the project with easy proximity to major roadways and a parking area. There are areas immediately adjacent to the west side shoreline that can be used as a staging area for offloading of sediments and staging for work areas.

Protection of Existing Biological Resources

We anticipate that construction silt fences will be placed to protect sensitive areas from direct disturbance from sediment placement. Prior to construction, individual locations of listed plant species within the work area will be identified and marked and surrounded by exclusion fencing where required by the project biologist. The need for more expensive offshore turbidity curtains during sediment placement will be identified.

A preliminary level cost estimate has been prepared to develop costs to allow for assessment of future costs (Table 4). The range of future cost is always unpredictable and is subject to larger economic forces that govern fuel costs or how busy contractors are with other projects. We estimate the variability to be as much as plus/minus 30 to 50 percent on some costs. At this feasibility stage of project development, the costs are approximate and subject to significant revision upon future analysis during future design phases.

Costs have been divided into the following categories:

- *Construction and Site Operations* – including site preparation, material and equipment staging and implementation of site environmental protection measures. These costs also include. Silt fencing will be installed around identified special status plants and to inhibit inflow of sediments into mosquito ditches.
- *Engineering Design and Permitting* Costs - This section includes cost for the next stages of final design and permitting assuming a mitigated negative declaration for the project. These assumptions will be checked during subsequent design phases.
- *Monitoring and Reporting* – A first cut estimate for costs associated with monitoring and reporting for five years following project construction have been developed and contained in the cost table. Note that these are the estimated cost for monitoring and reported related to permits and do not include the additional costs for research monitoring to improve the model development.

The results of the cost estimate are summarized below. Note that we have provided three results; the estimate total cost (design, permitting, construction and monitoring) with the 50% contingency, the total costs without the contingency and the costs for just the proposed pilot studies without the cleanup costs associated with concrete rubble piles, which although included as part of the overall project, are not integral to the pilot study evaluations but rather are part of the larger marsh restoration. Appendix B contains a detailed summary backup for these costs. Note that these costs will be further refined in future phases of the project. All cost rounded to the up to the nearest $10,000.

Table 4: Summary of Greenwood Beach preliminary cost estimate for GBDT (detailed cost estimate in Appendix B)

Cost Item	Pilot Project (no contingency to 30%)	Pilot + Alt 1 Project (no contingency to 30%)	Pilot + Alt 1 + Alt 2 Project (no contingency to 30%)
Construction costs	$565,000 to $730,000	$922,000 to $1,200,000	$1,700,000 to $2,200,000
Engineering final design, plans and specifications and permitting	$470,000	$470,000	$470,000
10 year monitoring and reporting (assumes 5 events in 10 years)	$266,000	$280,000	$300,000
TOTALS:	$ 1,235,000 to $1,465,000	$1,595,000 to $1,930,000	$2,356,000 to $2,900,000

Site Specific Preliminary Design: Paradise Beach Park

This section describes the site-specific preliminary designs at Paradise Beach Park. As noted, there are two design approaches. Each design is presented below starting with the dynamic beach nourishment approach by Dr. Peter Baye (approach A), and followed by the GBDT approach by Dr. Mark Lorang (approach B).

Paradise Beach Park Site Background

The section presents both design approaches for the Paradise Beach Park project site. This site is owned by Marin County Parks and operated as a public park. The shoreline and adjacent hillside are experiencing significant undercutting and slope stability issues. This site has the highest wave energy of all three project sites and represents an actively eroding shoreline impacted by waves and high tides. As such, it also presents the best opportunity to demonstrate an integrated green and gray solution that can provide better shoreline erosion reduction utilizing the benefits of natural shorelines with more traditional engineering approaches.

The site is located on the east side of the Tiburon Peninsula (Figure 23).

Figure 23: Tiburon north shore reference beaches named in text. Names are provisional, for reference in this memorandum, based on local mainland place-names and road names.

The site characteristics are show in the figures below.

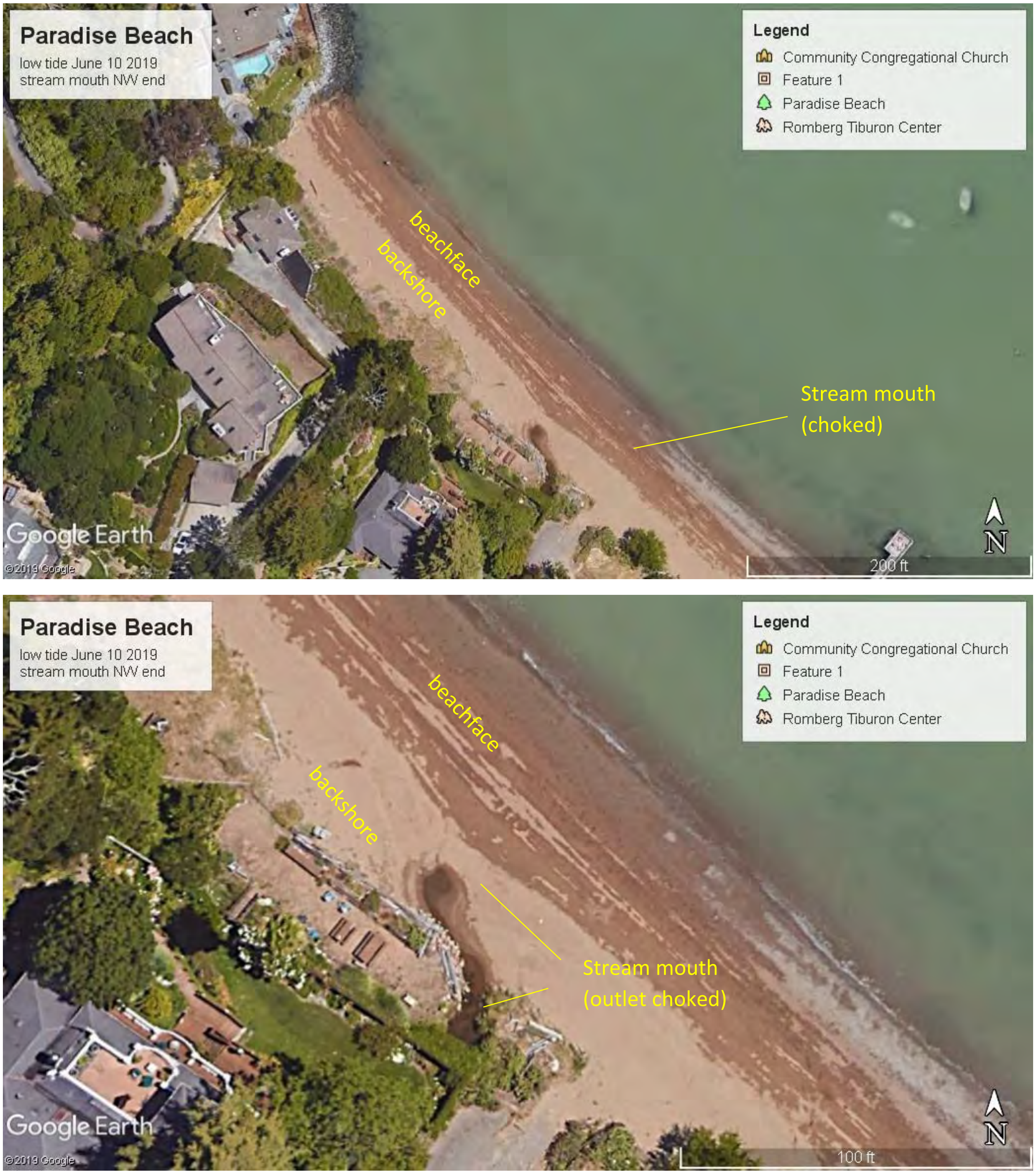


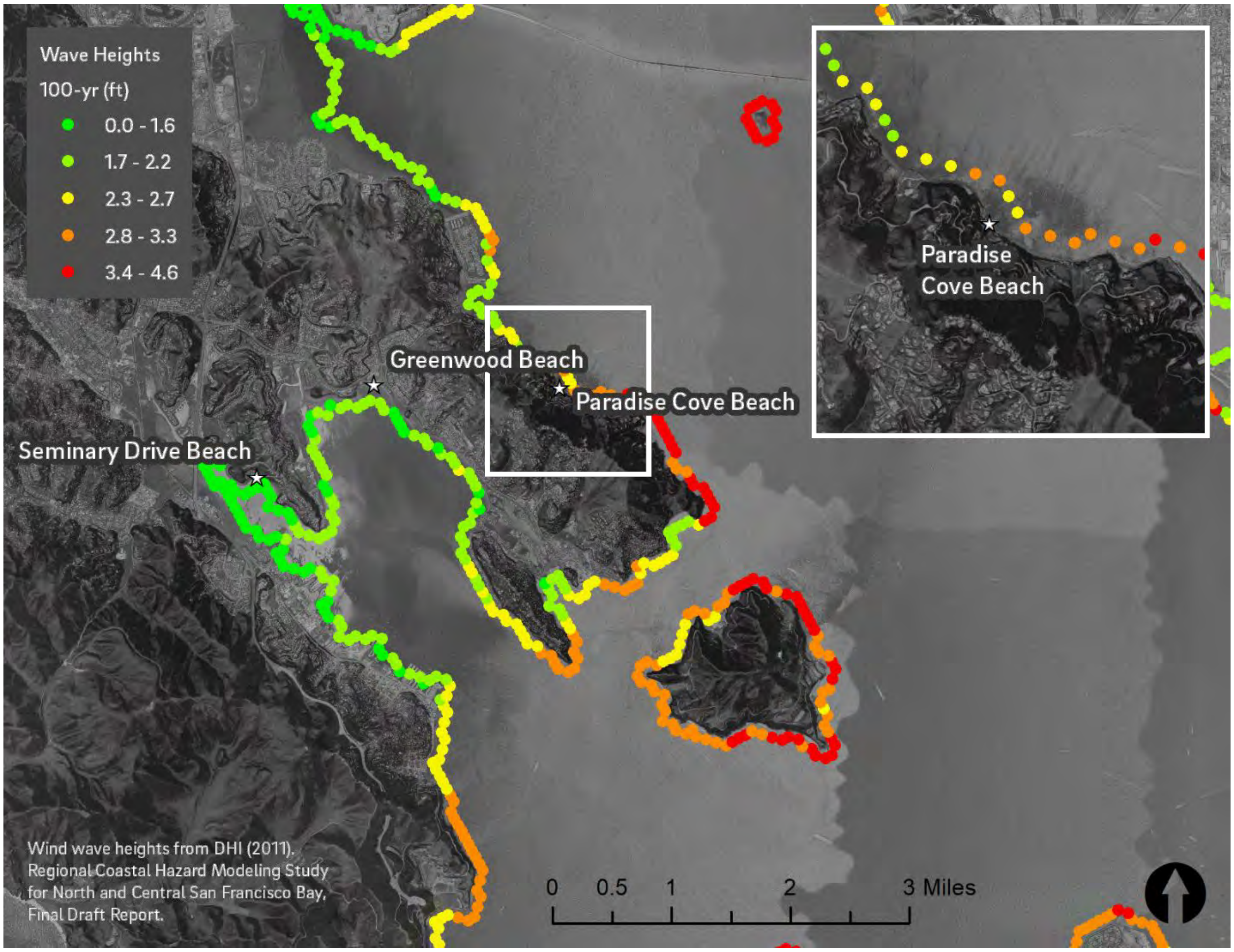
Figure 24: West Paradise Beach (June 2019) generally supports a wide linear dry sand backshore (circa 30-40 ft) and beachface (circa 40-45 ft wide), associated with a seasonal stream mouth, which is a potential long-term sediment source for beach sand and gravel (from Baye 2020).

Site Topographic and Bathymetry Surveys

A detailed site topographic and bathymetric survey was conducted in 2017 by Foth for all three sites and is used as the basemap for each project design.

Waves

The 100-year wave heights developed as part of the FEMA San Francisco Bay flood insurance mapping by bay wide hydrodynamic modeling and analysis of decades of Bay wave data are in the 2 to 3 ft range which is the highest wave energy of the three project sites (Figure 25), plus there are ferry boat waves that also work to impacts the shoreline. The wave energy is sufficient to significantly undermine the adjacent hillside and erode the shoreline as described below.



Wind wave heights from DHI (2011). Regional Coastal Hazard Modeling Study for North and Central San Francisco Bay, Final Draft Report.

Figure 25. 100-year wave heights at Paradise Cove Beach, based on data from DHI (2011).

Opportunities

Opportunities include the following:

- Existing beach at the site that provides the basis for restoration designs that utilize nourishment approaches as well as other design approaches that build beach types not present historically.
- Site access for construction is good resulting in reduced implementation and monitoring costs.

- The site is in an easily accessible public Park which greatly facilitates public and stakeholder views of the built project which is important since as a demonstration project the ability to easily bring people to view the built beach is very important.

Constraints

There are significant constraints to the project site which include the following:

- The hillslope adjacent to the shoreline is failing. The failure is likely from both gravity hillslope processes but is also being undercut and exacerbated from wave erosion that can be addressed from a combination of both traditional engineering solutions (such as the proposed retaining wall proposed by Anchor QEA under contact to Marin County Parks) as well as the natural beach proposed within as a living shoreline approach to dissipating wind-wave energy prior to continued undercutting of the shoreline slope.
- Regulatory Considerations - Both designs involve placement of fill in the bay for restoration purposes. As such, the various designs will have to meet a number of regulatory permitting requirements. Other sections of this report describes these requirements in greater detail.
- Integration with Existing Park Uses - The proposed design plans will need to integrate well with the existing Park uses. One goal of Marin Parks is to provide public access to the beach at lower tides. However, this goal may be difficult to achieve and does set-up the potential for safety issues if people access the beach at low tide and then are unable to return as the tides rise.
- Biological Resources and Impacts – The site contains areas of eel grass habitat located just offshore of the existing beach as shown below. We are unaware if this habitat has been mapped in recent years but a fuller remapping would be needed during the permitting phase of the project to assess direct impacts.

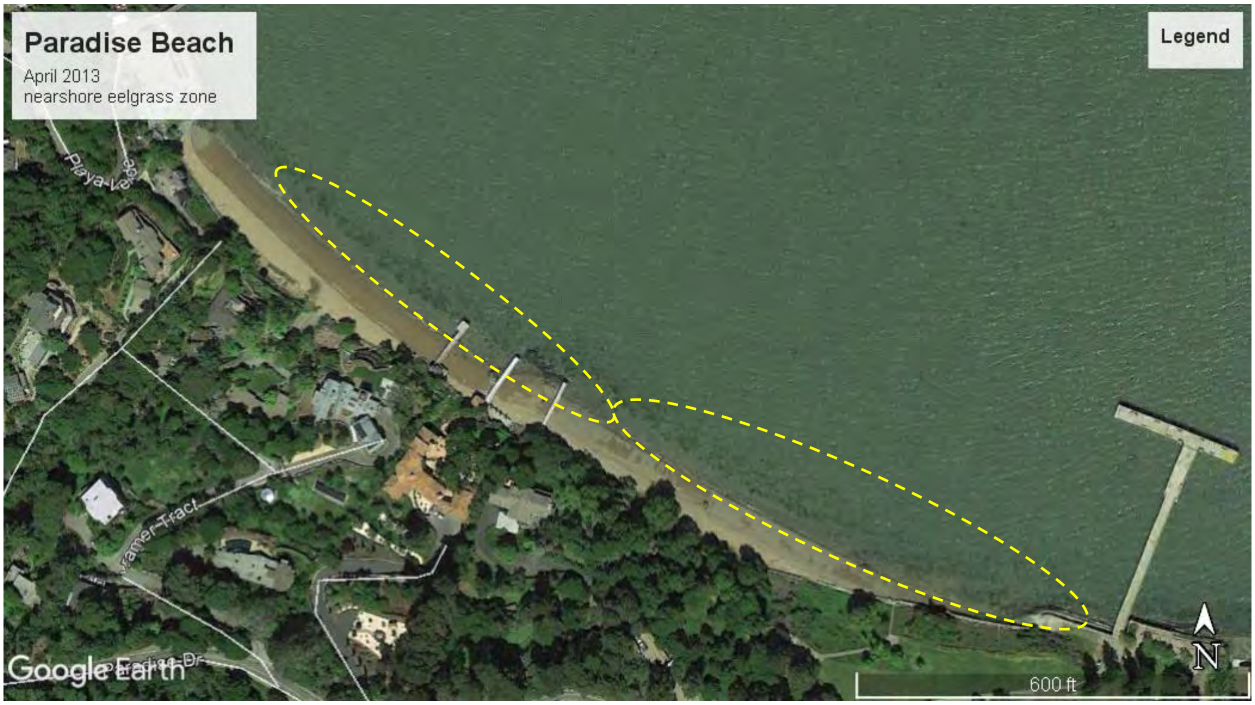


Figure 26: Eelgrass and macroalgae colonies April 2013 (circled) are visible along the inner low tide terrace (rocky muddy lower intertidal zone below the beachface step) during periods of low turbidity at mid/low tide stages at West and East Paradise Beach. April 2013. Google Earth images.

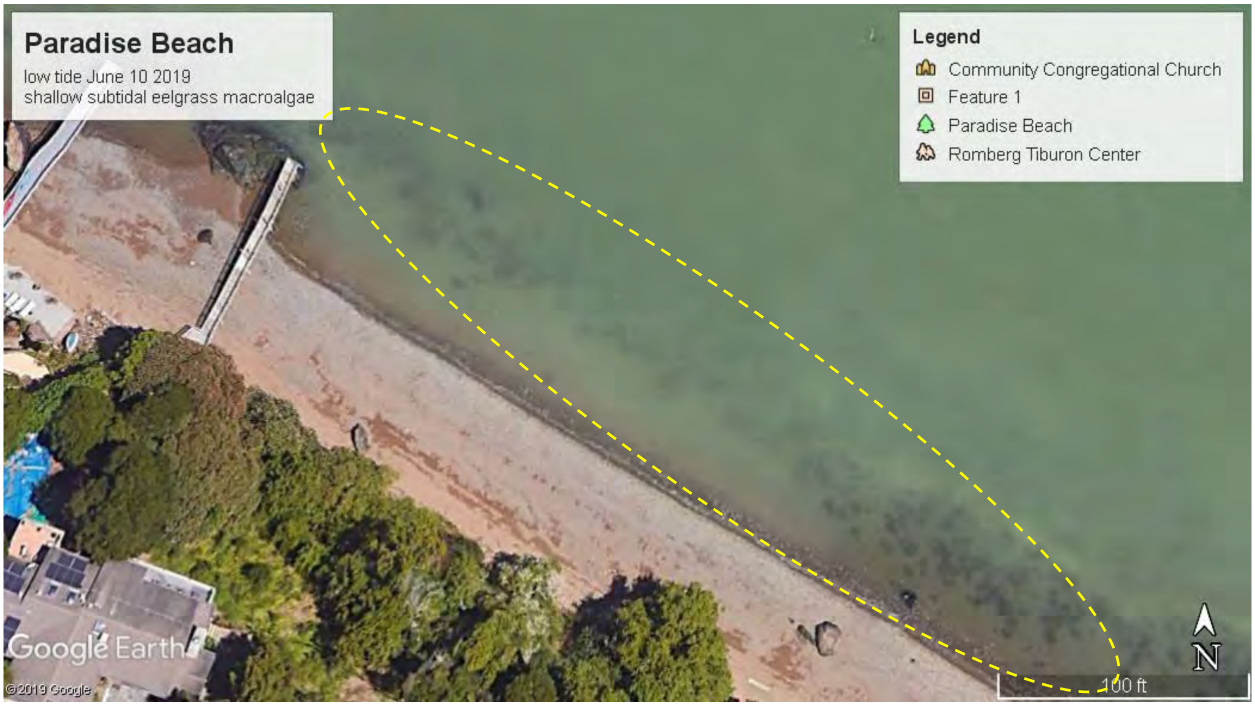


Figure 27: June 2019 distribution of shallow-submerged lower intertidal/subtidal macroalgae and eelgrass at Paradise Beach Park is visible during mid/low tide stages and low turbidity periods.

Figure 28: Rocky lower intertidal/shallow subtidal habitat

supporting native Olympia oyster (*Ostrea lurida*), macroalgae (*Ulva, Fucus* spp.) and eelgrass (*Zostera marina*) among small boulders and interstitial fine sediment, Point Chauncey (SFSU EOS Center) southeast of Paradise Beach Park. June 26, 2019.

Figure 29: Herring eggs (*Clupea pallasii*,) attached to subtidal macroalgae and eelgrass leaves, Tiburon Peninsula shoreline. February 2019 (from Baye 2020).

Approach A: Paradise Beach Park Dynamic Beach Nourishment by Dr. Peter Baye

This section is authored primarily by Peter Baye, PhD coastal ecologist and follows his dynamic adaptive management nourishment-based approach that works with the existing natural coastal processes in the area by providing the system with sediment of the proper size and location with sediment retention structures to reduce loss of sediments due to longshore drift.

Site and Environmental Setting

The Paradise Beach Park site conditions of the recent past and present, and their setting within the North Tiburon rocky shore, are reviewed as context for beach restoration objectives and design, and as background for assessment of ecological objectives and constraints. The North Tiburon rocky shore includes multiple pocket sand and gravel beaches, similar to Paradise Beach, in private ownership. These neighboring pocket beaches provide potential local, comparable reference systems for beach restoration design and assessment (e.g., dimensions, slopes, grain size distribution, and annual or seasonal variability).

Coastal setting: North Tiburon Shore (Point Chauncey to Paradise Cay)

The rocky coastline of the northern Tiburon shore consists of a series of rocky headlands, rocky intertidal and shallow subtidal shore platforms, and pocket mixed sand-gravel beaches in shallow embayments, with patchy outcrops of bedrock or rocky lag deposits of eroded bluffs and landslides. The nearshore zone below the step is a rocky shelf (wave-cut platform) with immobile bounders, cobbles, and veneer of fine sediment, but no intertidal mudflats or sandflats. The entire rocky-muddy shallow subtidal zone from Paradise Cay to Point Chauncey supports a narrow, annually variable, dense zone of eelgrass (Zostera marina; seagrass), marine macroalgae, and eelgrass spawning habitat, native oyster (Ostrea lurida) habitat, as at East Paradise Beach. The sensitive shallow subtidal habitats have naturally co-existed in zonation with active swash zones of sand-gravel pocket beachfaces. These are high priority habitat conservation targets for subtidal and intertidal goals (Goals Project 1999, 2015; NOAA 2007), routinely applied in policy by Bay regulatory and resource agencies.

Prior to recent erosion, Paradise Beach was similar to a series of embayed sand-gravel beaches occurring along the north shore (Paradise Drive) of the Tiburon Peninsula between SFSU EOS and Paradise Cay. The structure of the Paradise pocket beaches generally included a variable linear backshore sand berm (dry, pale tan sand in aerial photographs) about 10-30 ft wide, a sand-gravel beachface about 40-60 ft wide, with a sharply defined, linear step. Pocket beaches vary from thin mixed sand and gravel veneers (beachfaces with no berm profile), to well-developed perennial berms with wide backshores 20-30 ft wide. Relatively wide backshore sand and gravel berms occur at West Paradise Beach, El Campo (west side), Point Chauncey, and Seafirth.

Paradise Cove Beach

East Paradise Beach (Marin County Parks) as recently as 2009 supported a seasonally variable mixed sand and gravel pocket beach with distinct pre- and post-storm profiles. The beach is backed by low bluffs (artificial fill and natural hillslope/bedrock outcrops), and a concrete block revetment at the east end. The sand and gravel beachface extending from the north half of the WWII-era concrete block revetment (approximately 390 ft long). The County beach extends to the bedrock headland at the north end of the County Park boundary. The total shoreline length of East Paradise beach (boat ramp to headland/N park boundary) is approximately 560 ft. The upper foreshore (beachface) below the small rocky headland at the west end of the beach is continuous with the beachface of privately-owned West Paradise Beach, which extends about 910 ft farther northwest to the armored headland at El Campo. The mixed sand beach at East Paradise Beach is old: remnants of old vegetated beach berm tops, with incipient soil development, are still present above low scarps at the back of the west end.

The shore platform (visible in low tide aerial photos) below the mixed sand-gravel beachface of East Paradise Beach extends at least 50-70 ft bayward of the beach step. It is apparently dominated by a rocky (angular boulder and large cobble) wave-eroded lag surface, partly mantled by the mixed sand-gravel beach. The lower intertidal and shallow subtidal rocky nearshore shelf below the beachface has a variable veneer of finer sediment (sand, mud). This nearshore shelf has supported variable eelgrass populations (Zostera marina) at least since the 1980s and probably long before (Zimmerman et al. 1995; Wylie-Echeveria and Rutten 1987), as well as marine macroalgae, herring spawning habitat (Incardona et al. 2011), and native Olympia oysters (Ostrea lurida). The eelgrass and macroalgae colonies track the shallow subtidal shore platform from Paradise Beach to Paradise Cay, and are sometimes highly abundant and conspicuous in aerial photos during periods of low turbidity.

West Paradise Beach still has a persistent backshore sand berm (berm top/dry sand beach up to about 30 ft wide), with a mixed sand and gravel beachface about 40-50 ft wide (wetted beachface to step). West Paradise Beach has a small seasonal stream mouth discharging to the back of the berm (a potential long-term source of beach sand), and several bedrock outcrops in the lower foreshore and inner subtidal shelf (up to about 75-100 ft bayward of the bluff), forming a subdued tombolo or beach protuberance. The stream mouth is a potential past or present long-term sediment source of beach sand and gravel for the local sediment supply.

East Paradise Beach erosion trends and patterns

In recent decades, the County Park-owned East Paradise Beach segment exhibited cyclic, seasonal beach profiles with winter erosion (profile flattening) and calm-weather accretion (spring-summer), with episodes of significant winter storm erosion. Post-storm recovery of the beach profile has apparently declined in the County-owned East Paradise Beach segment (littoral sub-cell), while the mixed sand-gravel beach berm has persisted in the privately-owned West Paradise Beach segment.

Past cyclic storm/post storm recovery of the mixed sand and gravel beach at the east end (concrete block revetment) has shifted to perennial shoreface erosion of the artificial bluff fill, undercutting of the revetment and wave erosion of bluffs behind it, and exposing the underlying and rocky shore platform. In the last several years, the mixed sand and gravel beach has apparently shortened and narrowed, persisting only as a narrow dry upper beachface (bayward slope about 10 ft wide or less in 2018-2019) west of the concrete block revetment.

Long-term net beach erosion the east (County) end of Paradise Beach is apparently associated with significant backshore bluff erosion in 2018-2019. Bluff toe erosion behind the concrete blocks has apparently undermined and destabilized the bluff slope when it is saturated in winter. Slope failures and exposed gullied subsoil were evident above the concrete block revetment in 2018-2019. Slope instability is likely influenced by cumulative saturation of subsoil by irrigation, drainage, and rainfall runoff.

The erosion of intertidal sand-gravel beach between the old concrete boat ramp (east end of beach) to the persistent sand-gravel beach segment establishes a gap in public shoreline access for over half the tidal cycle (low tide access only on boulder lag). The erosion gap disconnects the remaining sand beach (west end) access from the main public shore access at the boat ramp at the east end all year. This change in perennial continuity of high tide beach restricts public recreation use of the beach park.

Paradise Beach Park Restoration Concept Sketches

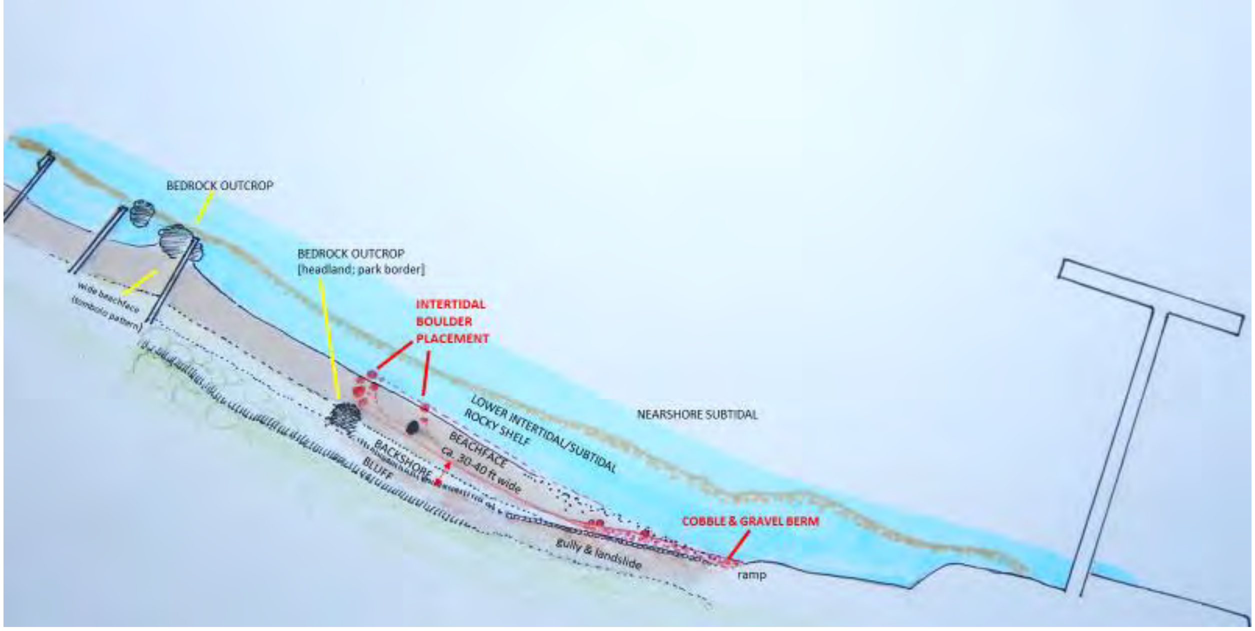


Figure 30: Conceptual plan view sketch of Alternative 2.

Figure 31: Approximate plan view layout of Alternative 2 conceptual design over Google Earth low tide image of Paradise Beach (June 2019), with scale.

Figure 32: Cross-section conceptual sketch view of cobble-gravel berm between boat ramp and concrete block revetment. No coarse beach sediment is directly placed below the existing beachface.

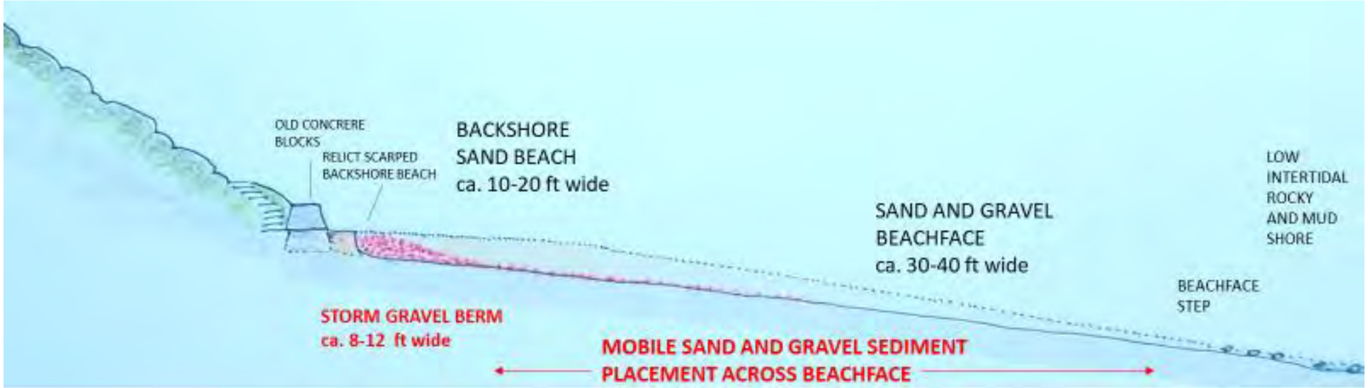


Figure 33: Cross-section conceptual sketch view of sand-gravel nourished beach, with storm gravel berm (exposed during storm erosion events, partly buried by sand backshore post-storm recovery beach profile), between and concrete block revetment and bedrock outcrop headland at Park boundary. No cobble is included in this reach; no sand or gravel is directly placed below the existing beachface.

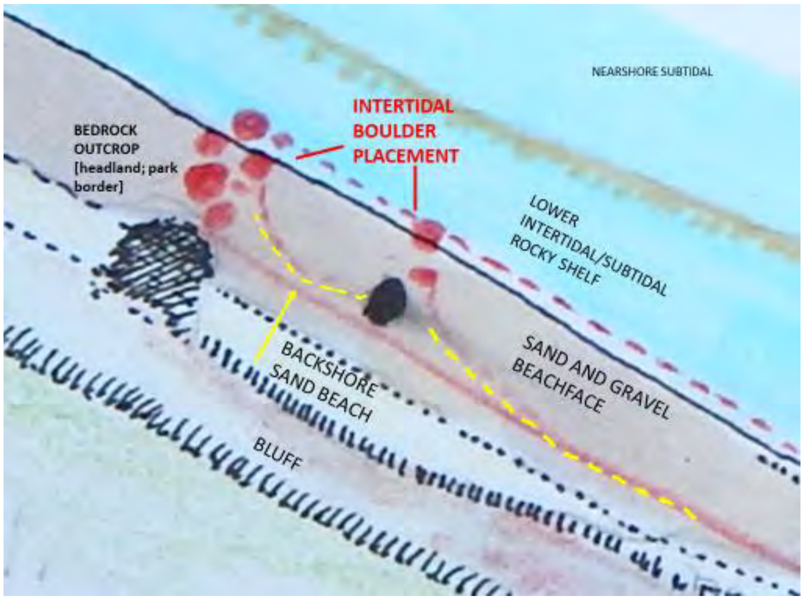


Figure 34: Plan view sketch detail of clustered boulder placement bayward of rocky headland at park boundary, and around natural foreshore bedrock outcrop, to induce local tombolo-like pattern of backshore beach cuspate planform (salient), with "drift sill" or permeable groin-like effects on longshore transport of mobile sand and gravel. Potential modification may include placement of cobble among boulders.

Figure 35: The gap between the sand-gravel beach and the old concrete boat ramp in Sept 2004 and May 2009 was small (less than 150 ft) at mid-tide. In 2019, it was close to 280 ft wide because of beach erosion.

Figure 36: Aramburu Island south shore cobble beach (lag), June 26 2019.

Figure 37: Emergent bedrock outcrops in the lower foreshore/inner nearshore between piers at West Paradise Beach provide a local reference model for the minor tombolo design of boulder clusters. Note beach salient in lee of emergent rock outcrops.

Figure 38: Serpentinite boulders (past artificial fill) in bluff slope above Paradise beach may be re-purposed

Approach B: Paradise Beach Park Gravel Beach Design by Dr. Mark Lorang

Project Design Overview

Paradise Cove is a popular public park located on the Tiburon Peninsula and exposed to waves created by winds that blow across San Pablo Bay (Figure 24). The beach at Paradise Cove has suffered long-term erosion and now provides little high tide beach access for recreation. The wave erosion to the toe of the backshore bluff is also triggering slumping of that slope. This problem has been addressed in the past by using concrete blocks and boulder riprap (Figure 39). Erosion is also affected by ferry wakes and sediment starvation due to past armoring.

Figure 39: Concrete blocks and riprap failing to protect the slumping bluff. This photo was taken at mean tide and you can see that the beach is not accessible for recreation and does not provide any protection to the bank from breaking waves at tidal levels above mean tide. The result is wave attack to the toe of the backshore bluff occurs through much of the tidal cycle whereas Seminary and Greenwood beach in Richardson Bay only see wave action at tidal levels above +2 ft and +3 ft, respectively.

This park is used for bay access, picnics, beach play at low tide, public fishing, boat launching and more, so the new design must protect and support those recreational uses while incorporating elements of resilient shore protection. Reconstruction of an existing seawall in the park is currently planned by Marin County Parks along with a master planning process for the entire park. Hence our plan for beach restoration needs to work with and help the efforts to stabilize the slumping bay cliff. We merged the bluff stabilization plans with the smaller beach plan show here. Those scaled AutoCAD drawings are presented at the end of this section of the report.

Opportunities and Constraints

Access to Paradise Beach Park and the beach has great opportunities and some constraints. Trucks hauling material will need to exit Highway 101 on to Tiburon Blvd and follow that past Greenwood Park which is easy and not an issue and then the trucks need to follow Trestle Glen Blvd to Paradise drive which is a narrow winding drive until they reach the park. Paradise drive is used by residents for walks and bike riding hence this is a dangerous mix of pedestrian and commercial use. At the very least some level of traffic control will be required. It may be possible to do all the hauling of material during the nighttime hours and stage the material on sight in the potential staging area (Figure 40). Once the trucks get to the park there is a paved path all the way to the beach ending at a concrete boat ramp (Figure 41). This boat ramp would make it easy to use a track truck to deliver gravel material to the seabed making short hauls from the staging area. A design goal is to create a beach extending from the end of the current boat ramp that is accessible at all high tide levels now and with a 1 ft rise in sea level. Alternatively, a barge could be used to haul the material to the site with placement by a crane.

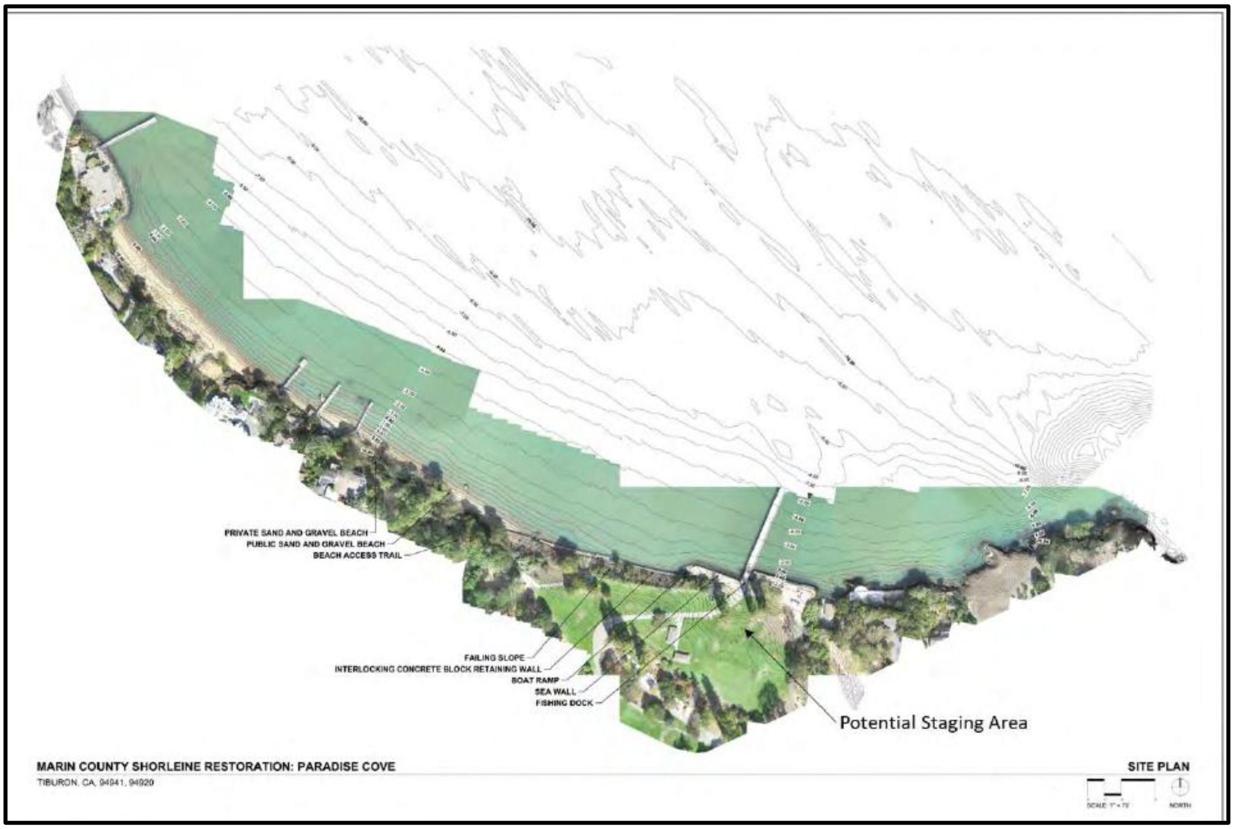


Figure 40: Aerial image of the Paradise Cove beach site showing the location of key features including topography of the tidal flat, distance to mean sea level (red line is mean sea level contour) and access road

through the park ending at the pier and boat ramp. The grassy area above the pier could be used as a staging area for gravel material and heavy equipment. Alternatively, a barge could be used to haul the material to the site with placement by a crane.

Figure 41: Photograph looking down the boat ramp that leads to the intertidal area where the proposed beach would be built. The photograph was taken at a tidal level of +5 ft which is below the MHHT level of 5.84 ft, our design water level. Note that none of the beach area at Paradise Cove park is accessible during high tide conditions. The beach designs will fill this area at the end of the ramp with a gravel beach.

Problem: Tides, Wave Breaking and Bank Erosion

The inter-tidal mud flat fronting Paradise Cove is deepest near the end of the boat ramp (Figure 40 and Figure 41). The concrete seawall that borders the boat ramp has resulted in significant end scour at the end of the boat ramp leaving behind a lag deposit of small boulders and large cobbles and concrete (Figure 39). The angle of wave approach relative to the shoreline orientation results in a dominant net westward transport away from the fishing pier and boat ramp towards the western project boundary (Figure 42).

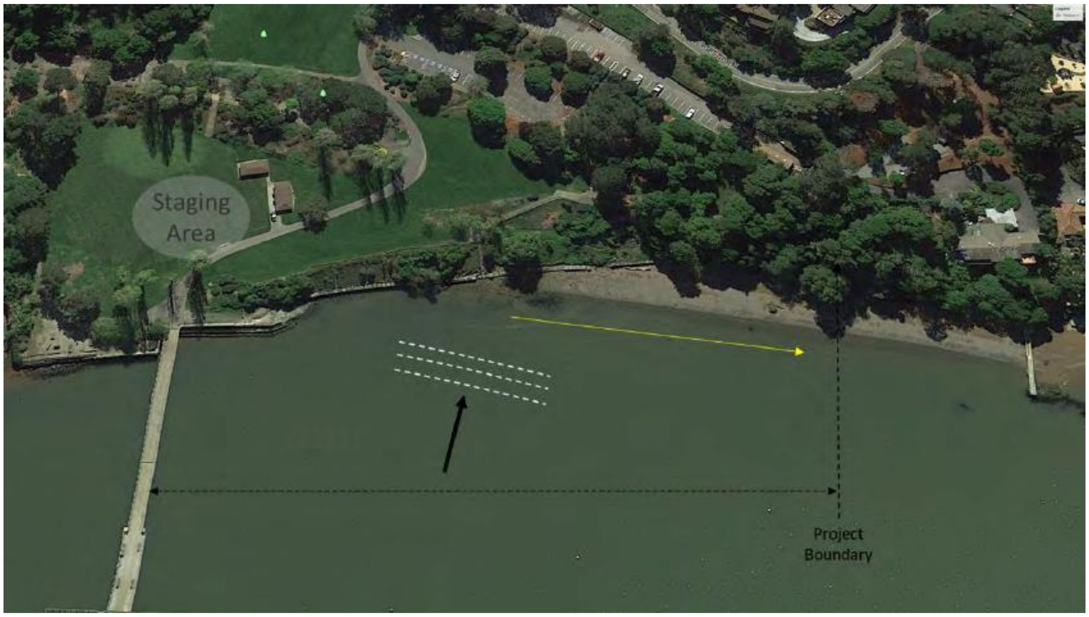


Figure 42: Location map for Paradise Cove showing the main direction of wave approach (black arrow and dotted white lines), the dominate net direction of longshore transport, project boundaries and the potential staging area above the boat ramp.

Currently waves break directly against the seawall protecting the boat ramp during tidal levels ranging from mean sea level and higher. And they break directly against the concrete blocks composing the toe of the slumping bluff (Figure 41 and Figure 43). Exposed sections of the bluff toe have vertical exposed faces due to wave erosion. Material eroded from these surfaces and material that is sloughed downslope from the bluff face provide the only source of sand for the beach (Figure 43). This sand beach is a thin, eroding sand veneer deposited onto a cobble intertidal zone. The goal for the gravel beach designs is to perch this sand beach on top of a cobble beach and above the MHHT level. This approach will dissipate wave energy through wave breaking and run-up swash processes while protecting the toe of current unstable bluff from additional erosion. Design 1 would produce a recreational beach at MHHT and into the future with a 1-ft rise in sea level. When sea-level rises above 1 ft then more gravel material will need to be brought in to maintain public access at MHHT levels and further protect the bluff from wave attack. Design 2 does not provide enough beach at MHHT to allow public access to the bay beach and does not provide adequate protection from storm waves given a 1 ft rise in sea level requiring then additional material to be added much sooner.

Figure 43: Series of four photographs of the bay front at Paradise Cove showing the waves breaking directly against the boat ramp, concrete blocks, and base of the bluff (upper left photo). The beach extending from the base of the boat ramp is composed of a thin sand veneer deposited onto a cobble intertidal zone as shown in the remaining 3 photos. The source of sand is erosion of the bluff (photos in upper right and lower left)

Proposed Solution: Paradise Cove Designs

Two gravel beach designs were put forward for Paradise Cove. Design 1 used the *GBDT* with the goal of complete wave energy dissipation using the MHHT (+5.84 ft above msl) as the design water level and 3.5 ft as the design break depth for a 4.42 ft (1.35 m) design wave height based on the modeled maximum storm wave heights for San Francisco Bay produced by the USGS Coastal Storm Modeling System (CoSMoS). In addition, the gravel beach for design 1 was made to accommodate a 1 ft sea-level rise. Design Alternative 1 called for a substantial layer of cobble-gravel and sand to be built in front of the concrete seawall extending from the fishing pier past the boat ramp all the way to the western property boundary (Figure 44). The reason for building the cobble beach in front of the concrete seawall to the end of the boat ramp was to try and greatly reduce wave reflection from the wall that is creating the strong scouring end-effects that are essentially the source of much of the erosion problem at Paradise Cove.

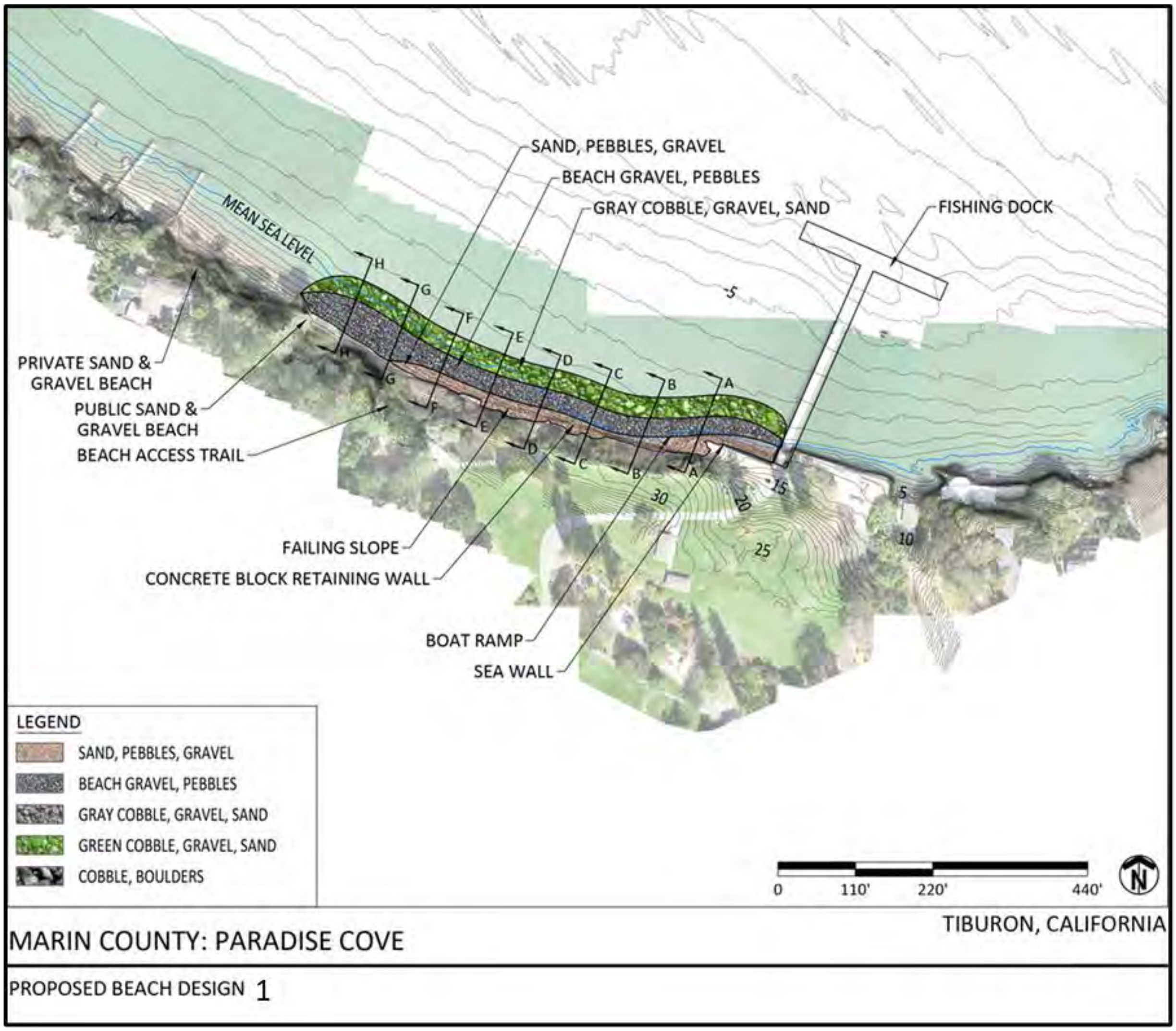


Figure 44: Plan view extent for conceptual design 1 at Paradise Cove. The treatments extend from the fishing pier to the western property boundary and provide full storm wave energy dissipation as well as recreational beach access at all tide levels and including a 1 ft rise in sea level. The locations of beach transects A-H are shown and plotted in figures below.

The cobble fill would extend in front of the existing boat ramp to bring the elevation high enough to force wave breaking more than 30 ft from the concrete sea wall (Figure 45). A mixture of sand and pebbles would be placed on top of these cobbles to provide a sandy recreational beach the length of the Paradise Cove property providing beach access at all tide levels (Figure 46).

Figure 45: Intertidal area in front of the boat ramp during low tide (left) compared with a rendition of what that area would look like after placement of the bottom layer of cobble and gravel for design 1. This figure shows the material placed against the existing concrete blocks which could be left or removed, and another method of slope stabilization, for gravity slumping problems, installed.

Figure 46: Intertidal area in front of the boat ramp during high tide (left) compared with a rendition of what that area would look like with the same tide level but with the sand and pebble layer placed on top of the cobbles and gravel. Note the couple walking on the beach is approximately where the furthest extent of swash would extend during a design wave storm event. After a one-ft rise in sea level the swash would reach the base of the bluff but without the ability to erode the beach.

Design 2 was an attempt to not impact the eel grass by using the *GBDT* to back off on the level of wave dissipation. This would result in not adding any extra beach material that would cover the eel grass by only pushing the breakpoint out as far as the predicted wave dissipation distance of 30 ft. And to not design for a profile that would not accommodate a 1 ft sea level but rather allow for waves to overtop the beach during high tide storms and interact with the backshore. Design 2 also did not extend the cobble-gravel layer extending from the fishing pier in front of the boat ramp (Figure 47). This was done to not cover over and impact important and existing eel grass habitat. However, the end-effect scour will not be reduced hence more cobble-gravel material will need to be used and much larger cobble size will need to dominate the size distribution of material at the end of the ramp. If scour continues then more material will need to be brought in until a stable configuration is found made of material that is semi-static. The sand layer is the only treatment for the western third of the area covered by transects G and H (Figure 47). Both designs used the Pinole Point reference profile as a guide.

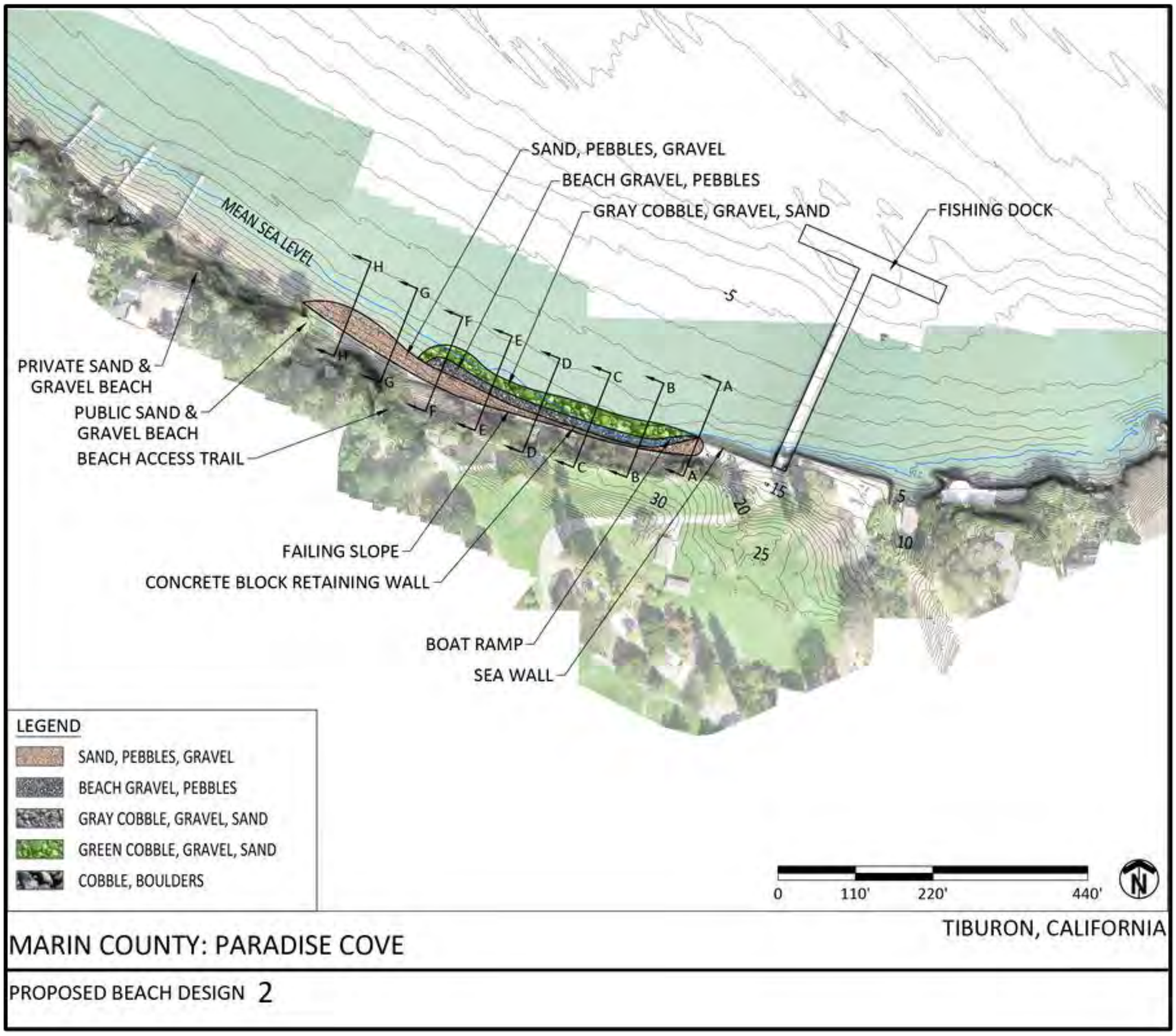


Figure 47: Plan view extent for conceptual design 2 at Paradise Cove. The treatments start at the end of the boat ramp and stop by transect F. This design does not provide full storm wave energy dissipation or recreational beach access at high tide levels and it is not designed to accommodate design waves coupled with a 1 ft rise in sea level. The locations of beach transect A-H are shown and plotted in figures below and sand is the only treatment on the western side beyond transect F. This is what is required to minimize impacting the eel grass.

Paradise Cove has some design challenges based on the topography of the intertidal zone between the fishing pier and the end of boat ramp that extends to section C (Figure 48). This area from section C east to beyond section B is where mean sea level is closest to the failing concrete blocks and where bluff slumping is the most severe. Wave action along this section of the shoreline must be significant at times, enough to move and break up the concrete blocks put there to stop the erosion. The mean sea level contour occurs offshore a bit from the end of the boat ramp through section A about halfway to section B where the contour line bends sharply into the shore (Figure 48). This bend in the mean sea level contour level reflects decades of end-scour impacts caused by the concrete sea wall and boat ramp. This area is filled in with large cobble and boulder size material. From Section C to section E the mean sea level contour trends seaward and the size and shape of the sand layer mimics this trend (see upper right photo in Figure 43).

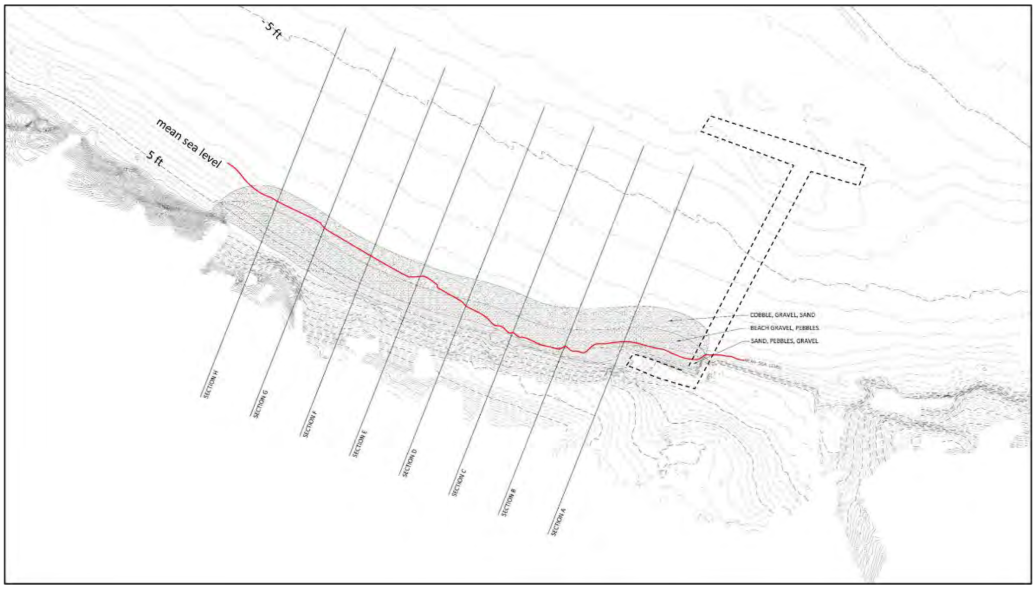


Figure 48: Plan view extent of the gravel treatments for conceptual design 1 at Paradise Cove in relationship to the mean sea level line that is highlighted in red. The location of the boat ramp and fishing pier are shown in the dashed black line. The 5 ft contour elevation for current conditions is shown to better depict where MHHT levels are expressed at the site.

The spatial placement of cobble and gravel material is designed to offset this topography and thereby force wave breaking during large storm events far enough away from the bluff so that waves never again break against it causing beach scour and bluff erosion. Indeed, during MHHT the water depth near sections C and B is 5 ft which is too deep to cause wave breaking. Here, large waves will break and plunge into the bank directly and do so for as long as the tide level is at -1 ft and higher. It is a chronic erosion problem and one that design 2 will not solve. Design 1 is the permanent long-term solution, one that would last through a 1 ft rise in sea level. Design 2 will provide moderate protection during smaller storms and low high tide levels plus the large sand layer will provide a source of sand for down drift beaches that have been historically receiving sand from the eroding bluff.

The following section on profiles is presented in a way that a comparison can be made between where storm waves currently break relative to the backshore bluff and how the two designs presented change those patterns of wave breaking and too what degree. Design 2 was put forward to minimize as much as possible the covering of eel grass habitat occurring at this site. Design 1 completely dissipates the wave power during storms and is above the MHHT level thereby providing unlimited beach access. When people come to the beach, they will always be able to walk on the beach and during storms they can sit on the beach and watch the waves crash and break right in front of them. With Design 2 the beach is underwater for all current MHHT levels and it will not be safe to venture out during a storm. Plotting the profiles in this way allows the reader to assess what level of erosion protection and beach accessibility is provided by each design at the expense of covering up critical eel grass habitat. It is a tough decision that involves a suit of systems level decisions to be made that consider and weigh out what is best for all stakeholders.

Profile Comparison between designs 1 & 2.

Profiles showing the location of design wave, breaker position for current conditions and a 1-ft sea-level rise (Figure 49-Figure 56 top panels in each). Design 1 is the middle panel on each figure and design 2 is the bottom panel (Figure 49-Figure 56). In design 1 and 2 the design wave breakpoint for current MHHT design water level of 5.84 ft is positioned to allow for a complete wave dissipation distance of 30 ft to be accommodated before the wave would reach the backshore (Figure 49-Figure 56). In each case the upper level of the bottom cobble layer for both designs 1 and 2 is brought up to accommodate wave breaking with the toe of the second pebble layer offset equal to or greater than the plunge distance (Figure 49-Figure 56). The slope of the bottom cobble layer extends toward the bay at a 5:1 slope for both designs. For both designs the middle pebble layer rises at a slope of 1:5 until it reaches the Point Pinole reference profile (solid purple line Figure 49-Figure 56). For design 1 the initial break point is moved offshore a distance of 25 to 40 ft for each profile to allow for a sand beach that wide between the current backshore and the initial break point (Figure 49-Figure 56). For design 1 the sand layer is then filled in to match the topography and blend with the Point Pinole reference profile raised 1 ft to accommodate final run-up. For design 2 the sand layer is only brought up to fill the backshore topography and blend with the current Pinole Point reference profile (Figure 49-Figure 56).

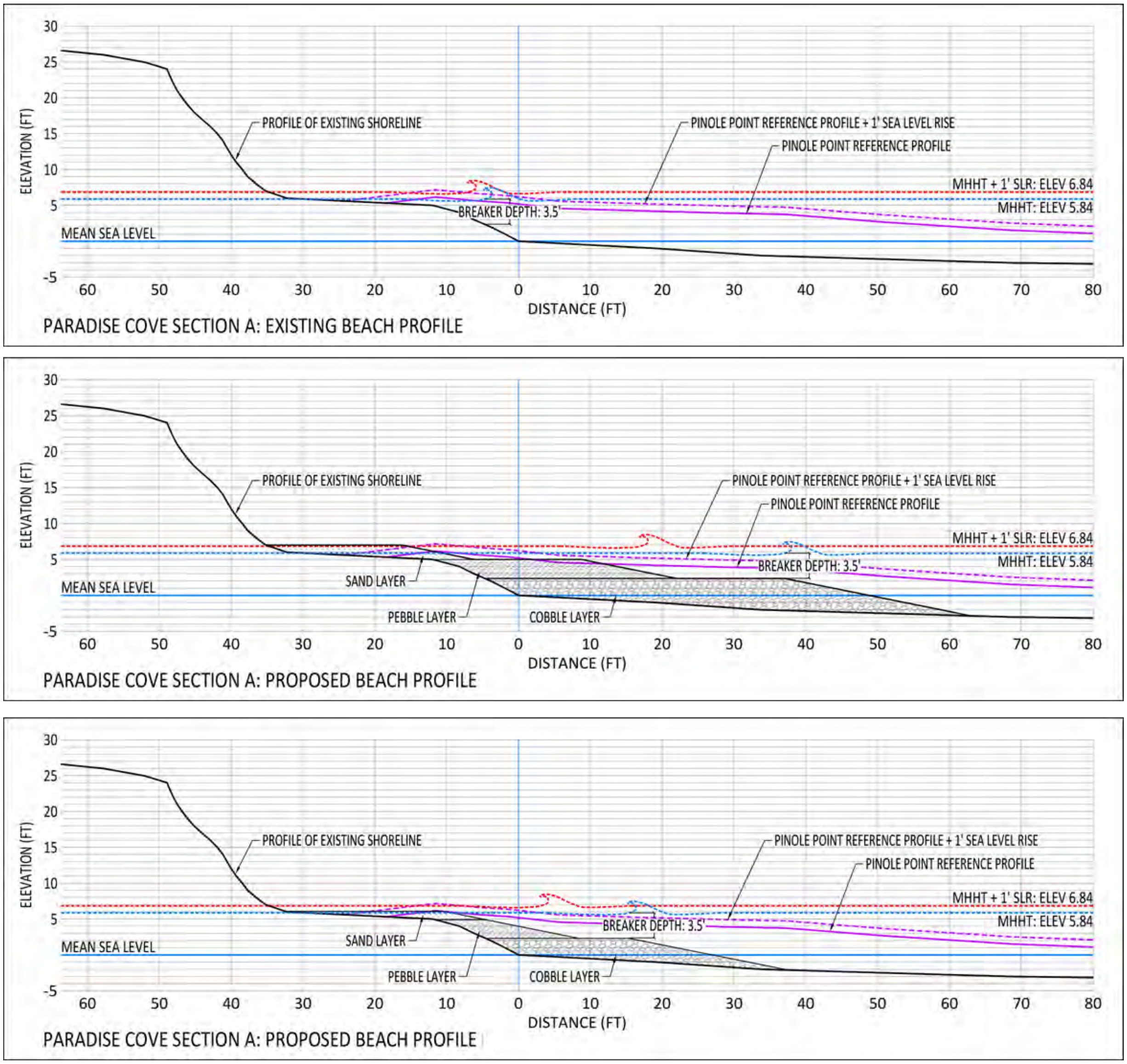
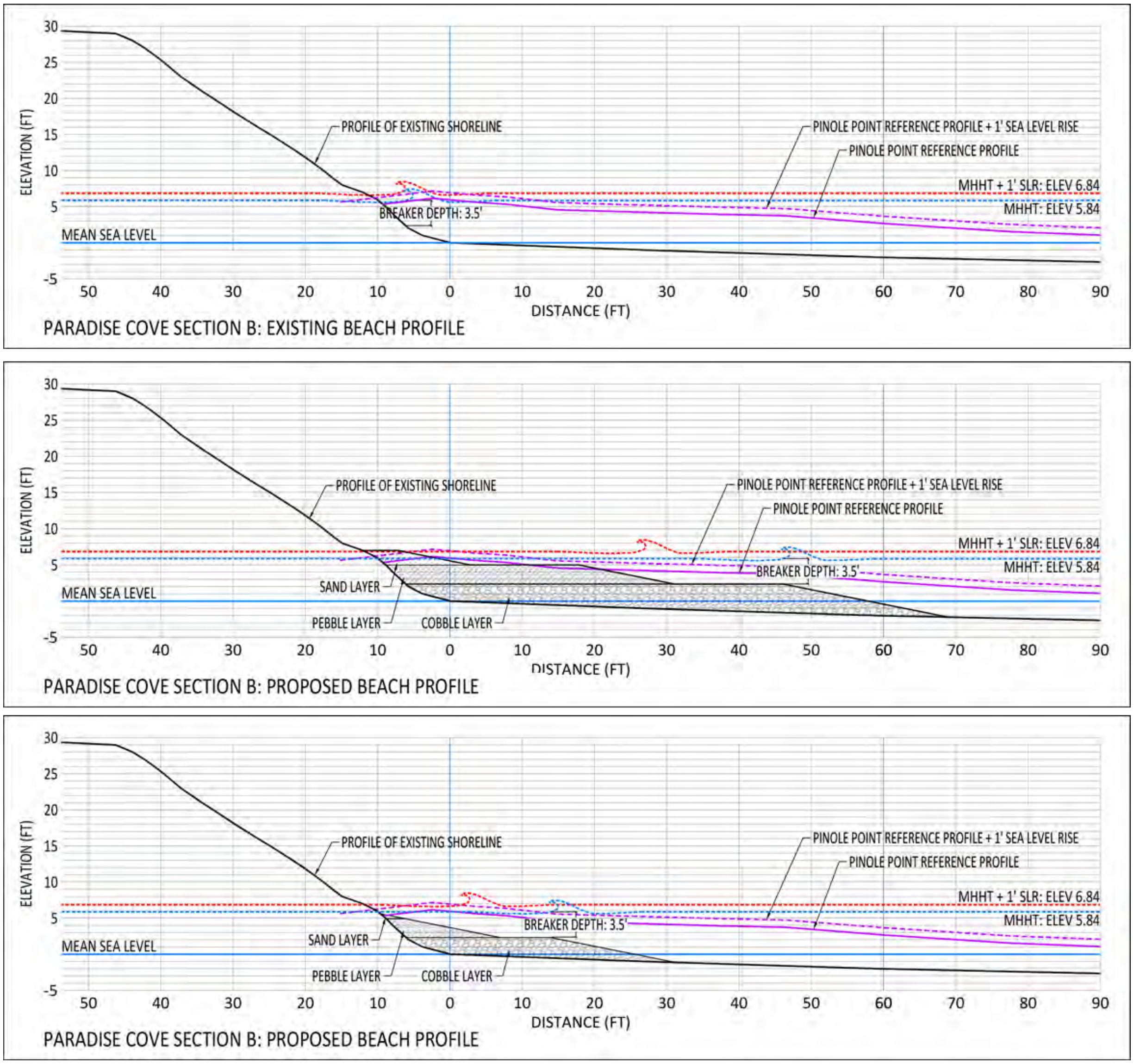


Figure 49: Plot of transect A of Paradise Cove

(see Figure 47 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower two panels with the middle panel representing design 1 and the bottom panel design 2.



PARADISE COVE SECTION B: EXISTING BEACH PROFILE

PARADISE COVE SECTION B: PROPOSED BEACH PROFILE

PARADISE COVE SECTION B: PROPOSED BEACH PROFILE

Figure 50: Plot of transect B of Paradise Cove. (see Figure 47 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower two panels with the middle panel representing design 1 and the bottom panel design 2.

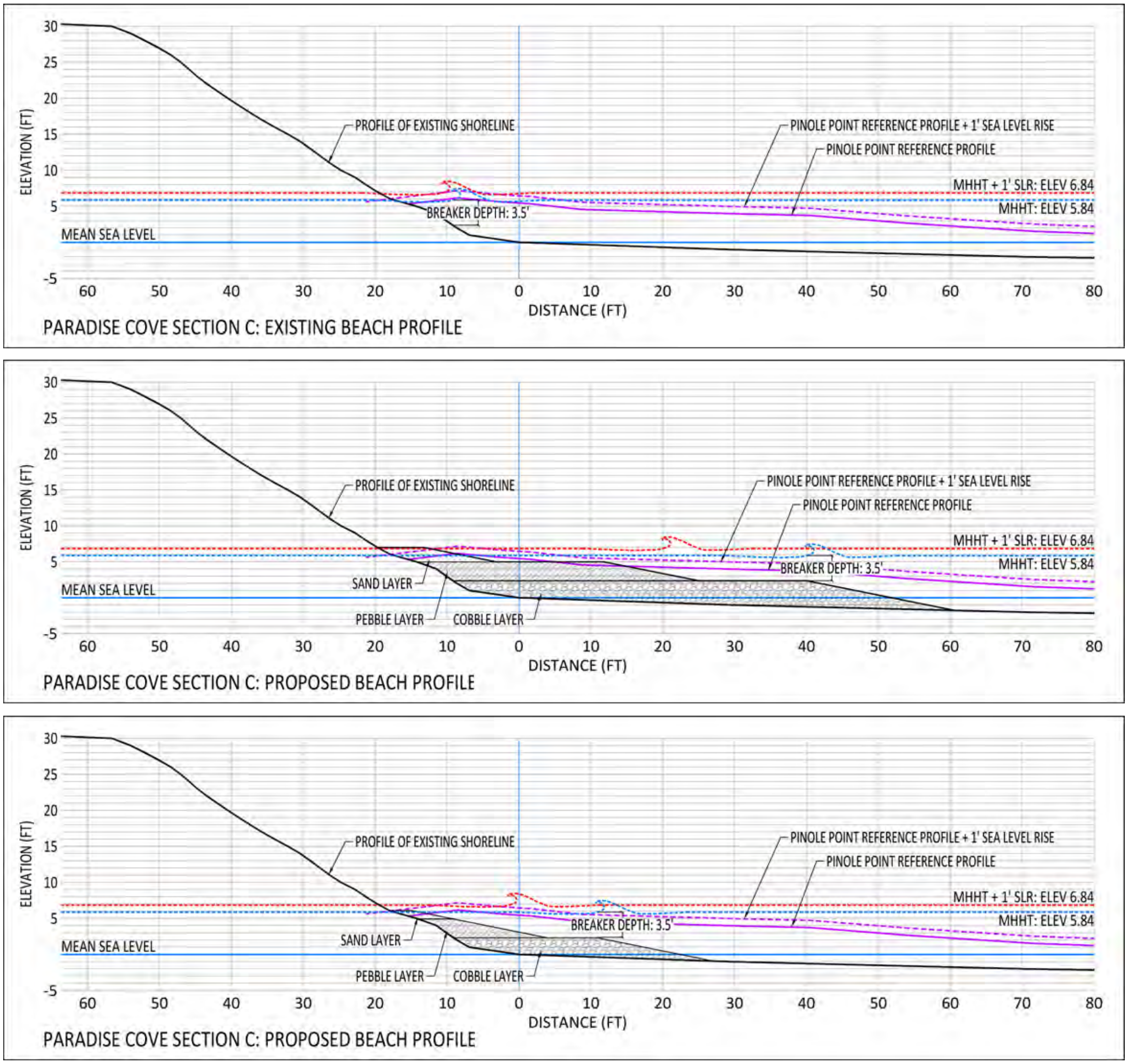


Figure 51: Plot of transect C of Paradise Cove. (Figure 47 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower two panels with the middle panel representing design 1 and the bottom panel design 2.

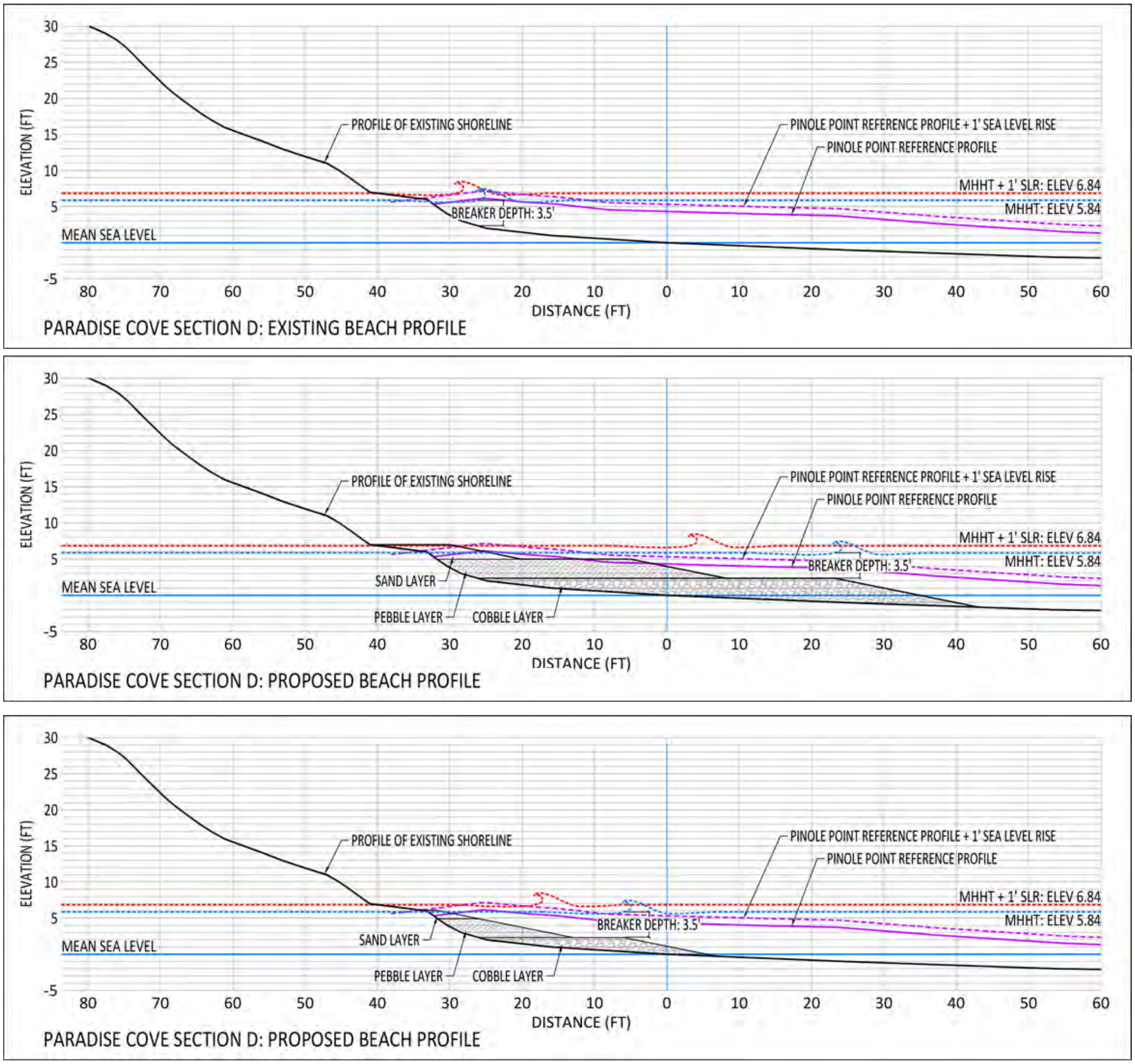


Figure 52: Plot of transect D of Paradise Cove. (see Figure 47 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower two panels with the middle panel representing design 1 and the bottom panel design 2.

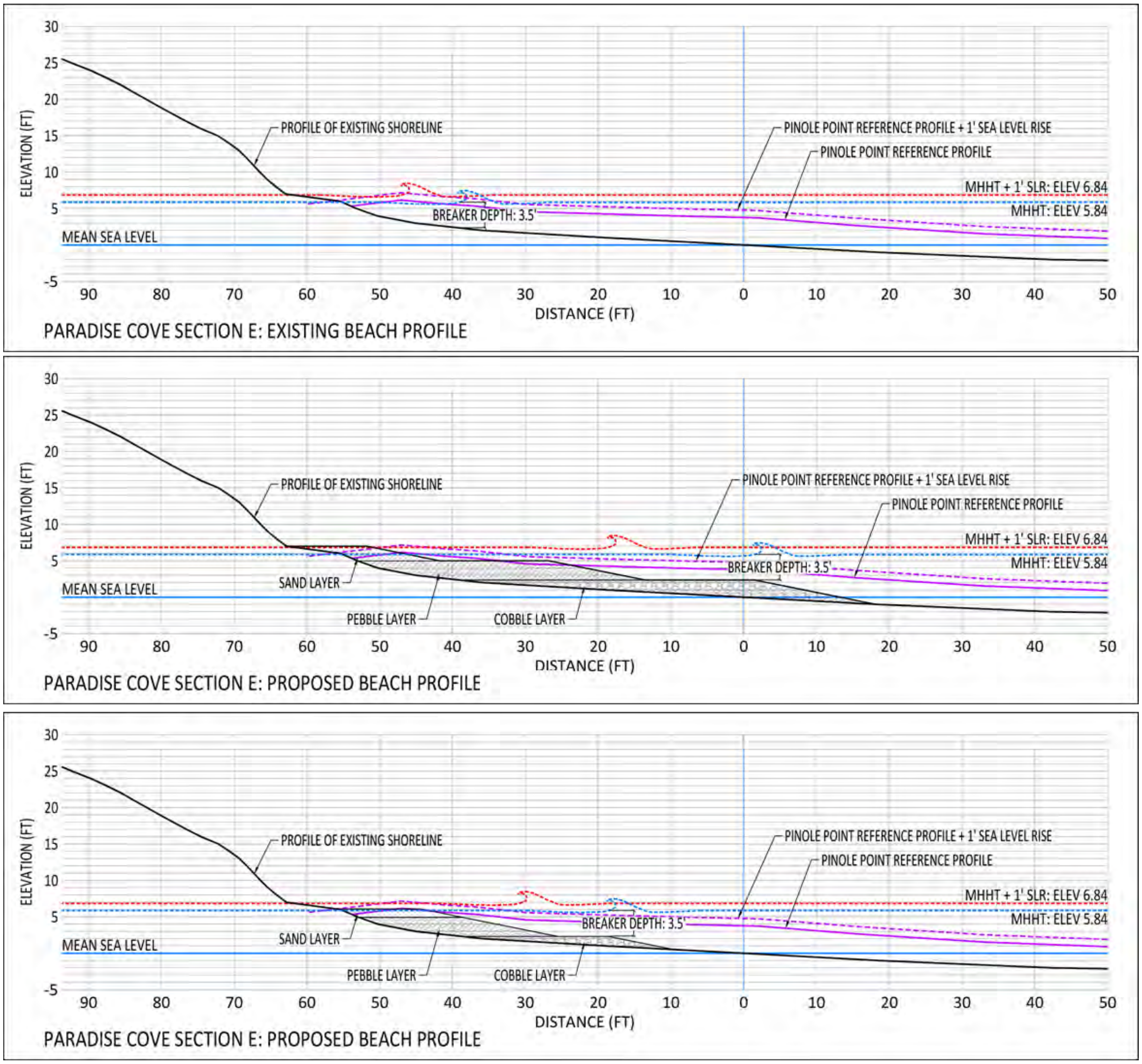


Figure 53: Plot of transect E of Paradise Cove. (see Figure 47 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower two panels with the middle panel representing design 1 and the bottom panel design 2.

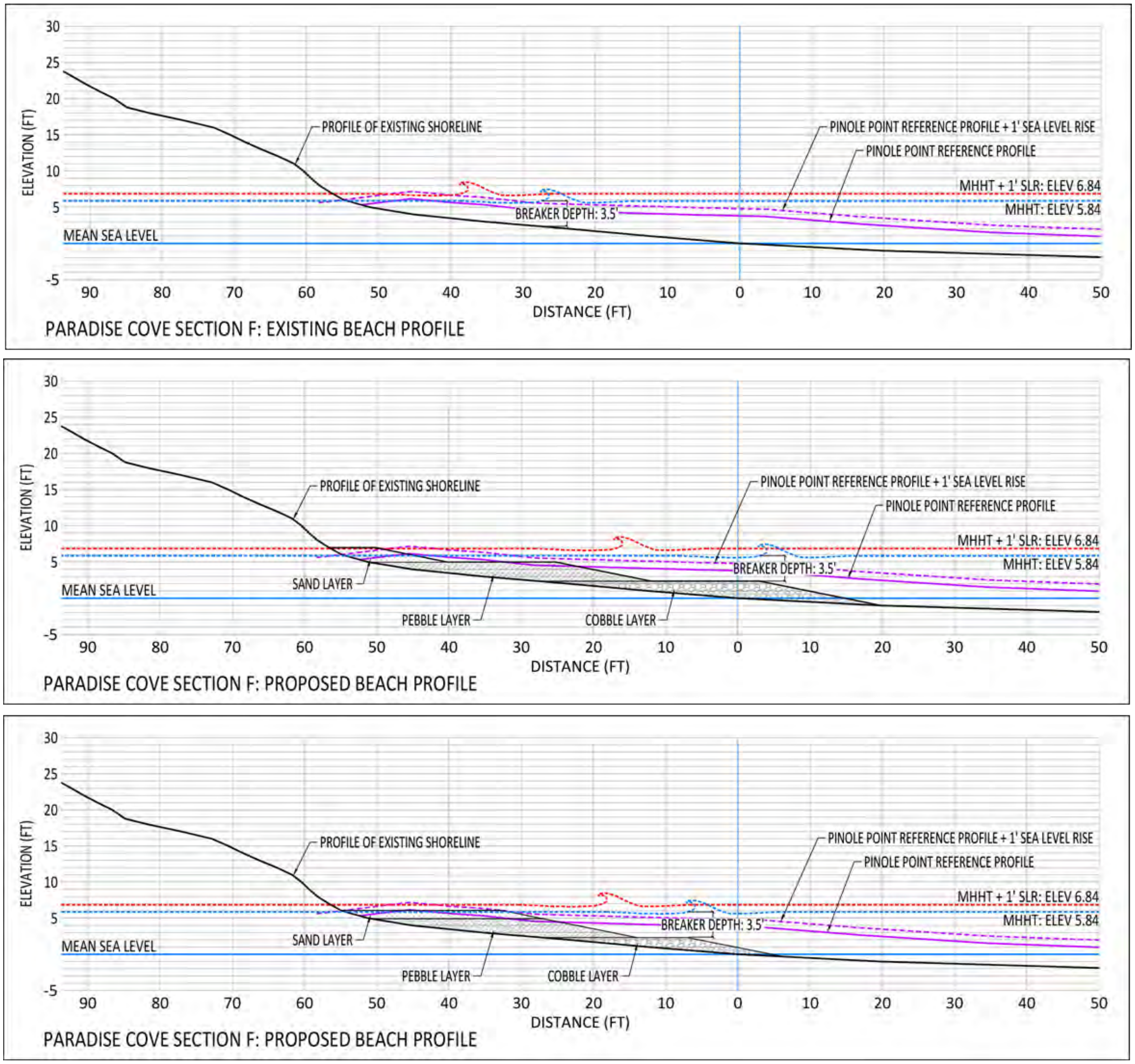


Figure 54: Plot of transect F of Paradise Cove. (see Figure 47 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower two panels with the middle panel representing design 1 and the bottom panel design 2.

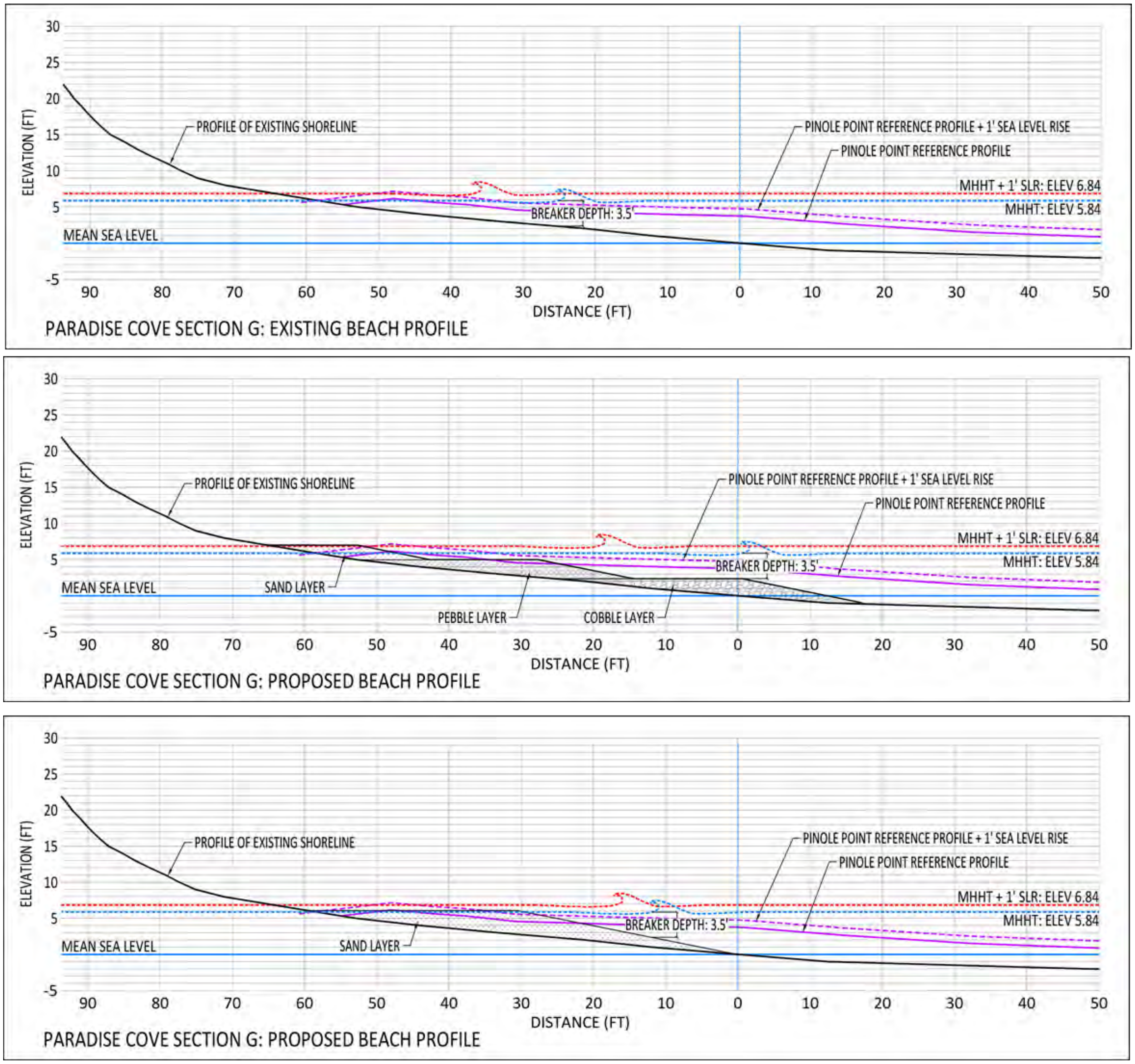


Figure 55: Plot of transect G of Paradise Cove. (see Figure 47 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower two panels with the middle panel representing design 1 and the bottom panel design 2.

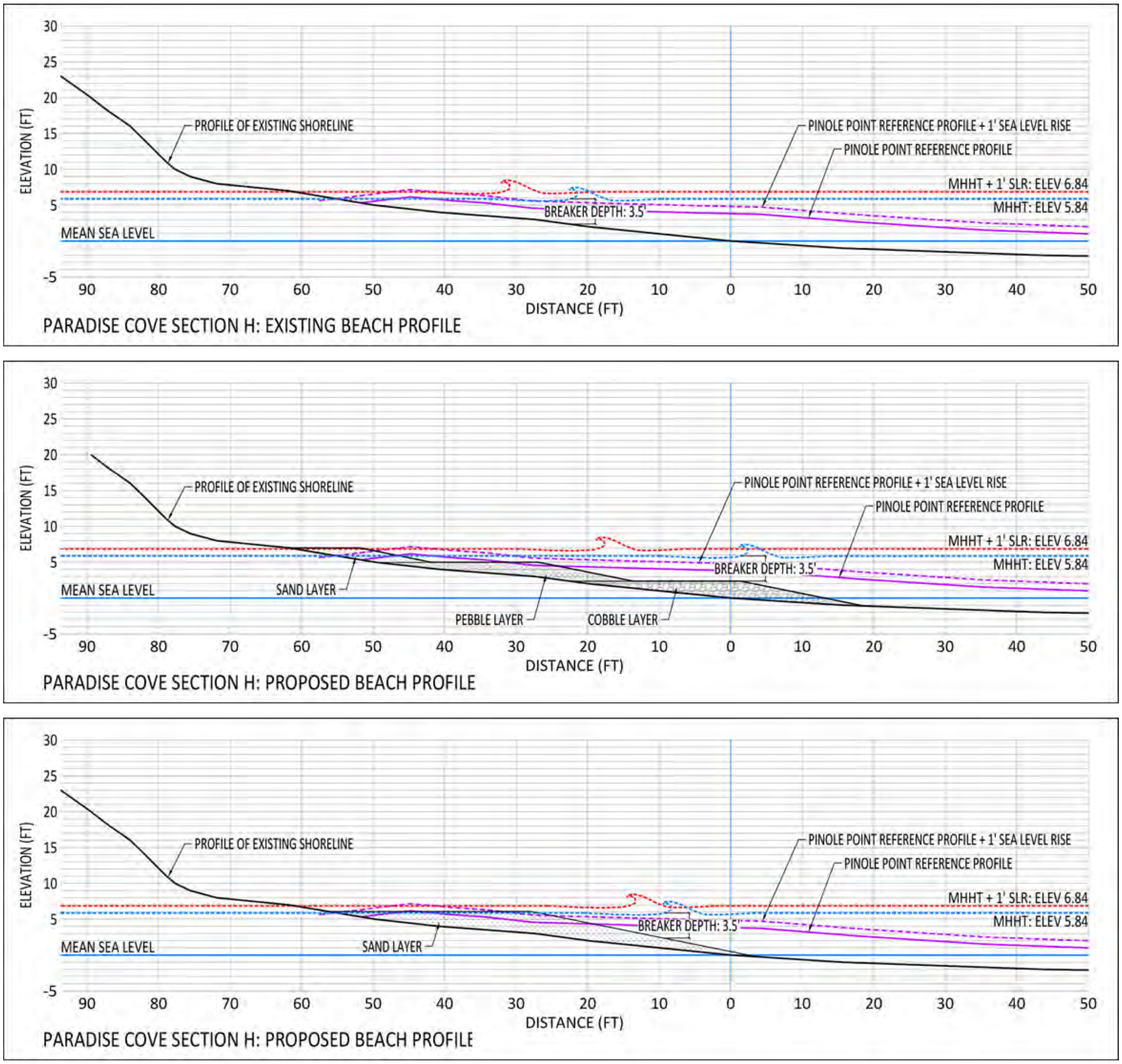


Figure 56: Plot of transect D of Paradise Cove. (see Figure 47 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled on the lower two panels with the middle panel representing design 1 and the bottom panel design 2.

Note that for each profile plot the distance between the red and blue breaking waves and the backshore shows the relative energy level the backshore is exposed to at that location along the beach (top panel) and the distance between these breaking waves for each design graphically depicts the relative level of wave energy dissipation between current conditions and a 1 ft rise in sea level each design where the further apart the more wave dissipation that design imparts (middle and bottom panels) (Figure 54Figure 56). Note that for profiles A-E, which represents most of the beach fronting the concrete blocks that both breaking waves are breaking as plunging breakers against the backshore. This is in part to erosion scour of the intertidal beach in front of those very reflective concrete blocks. The final three transects show wave breaking further offshore nearly approximating full wave dissipation on the existing sand beach. For design 2 this is used as the guide for not using cobble-gravel underlayers and only using sand. This sand layer will wash away over time due to the net longshore transport wave action, hence this layer will like need replenishment as storms remove this material if this plan is chosen as designed. At this point we cannot say exactly how long before replenishment would be required because we do not have sufficient data regarding the rate of longshore transport nor can we predict the future timing of severe storm waves with HHT levels. It could last for decades or wash away during the next storm event occurring during a spring tide. What we could do is build up the profile more like that shown for design 1. This would ensure that renourishment would not be necessary for decades and then only if the beach were beginning to thin beyond a reasonable level to support recreational use. If the city wants a maintenance free gravel beach solution, then design 1 would be the direction to lean when finalizing the plans.

Whatever beach design is chosen it is important to merge that planning phase with the final engineering phase meant to stabilize the sloughing bluff. A conceptual look at what that merger might look like is present below using profiles from design 2. What is clear from such a merger of plans is that design 2 will not stop waves from interacting with the bluff stabilization. They will stop toe-scour however which is a positive outcome for the bluff structures. Perhaps allowing waves during severe storms occurring at high tide to slosh against the toe of the structures built to stabilize the bluff is not a risk to be worried about. This discussion highlights the analysis that needs to occur during the final design phase. The *GBDT* will be especially useful in that process to help quantify the risk in a manner that all stakeholders can understand. Perhaps 25 mph wind events and MHT levels much lower than the MHHT level are the design metrics that meets the needs for solving the wave erosion problems at Paradise Cove.

Design 2 Merged with Proposed Bluff Stabilization Design

Marin County Parks has contracted with Anchor Engineering to come up with a slope stabilization design for Paradise Beach Park. Anchor has developed three alternative conceptual designs to deal with the slumping bluff. Each of the three designs incorporates a traditional hard structure approach to deal with wave erosion issues at the toe of their bluff stabilization design. Wave erosion at the toe of the bluff has been a problem for decades and the historical approach has been to place large concrete blocks along the toe of the beach. These blocks have failed, and riprap has been placed behind the concrete blocks to help hold back the sediments composing the bluff (see Figure 39). Bluff stabilization designs are labeled Alternative 1, 2 and 3. Alternative 1 uses stacked stones for the toe protection and as part of an extensive grading and terracing of the bluff face. Alternative 2 uses a riprapped toe and what appears to be gabions and boulders to shore up the graded terrace. The graded terrace also forms a public foot path to the opposite end of the beach from the concrete boat ramp (Figure 57). Alternative 3 uses what appears to be a rather large concrete seawall at the toe but no grading or terracing of the bluff.

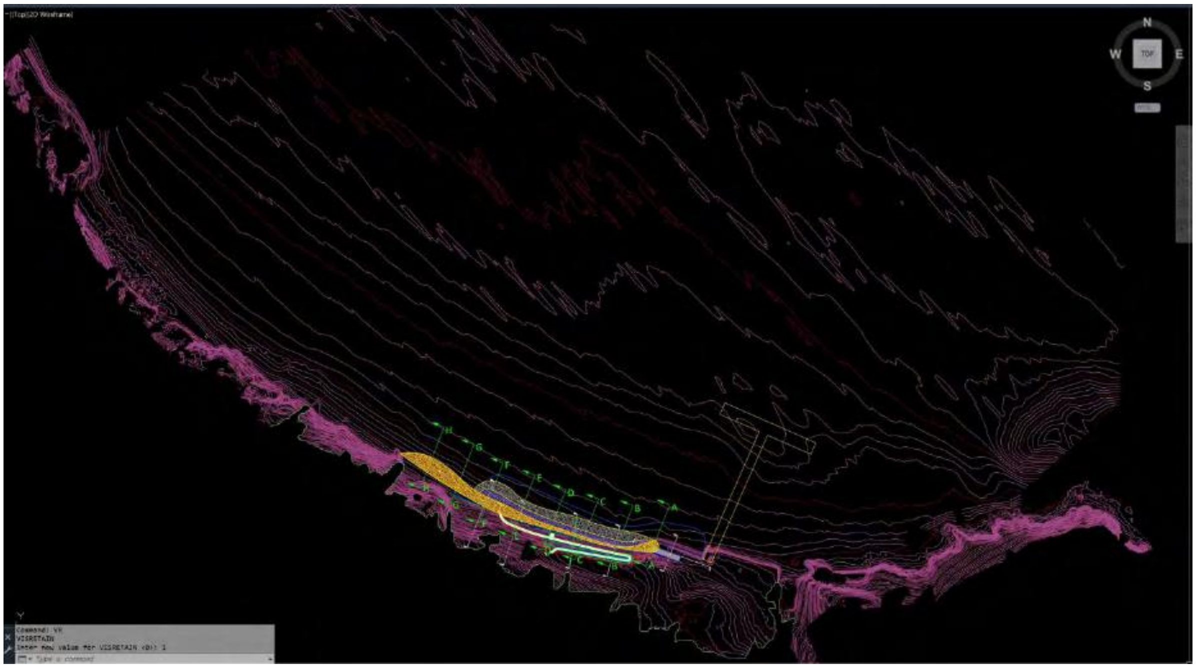


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Figure 57: An AutoCAD map view showing the topography of the bluff connected to the bay bathymetry at Paradise Cove (purple contour lines). The terraced path is shown merged with beach design 2 and location of the transects A-H. The outline of the pier is also shown.

The end of the boulder riprap ends just past transect G (Figure 57 and Figure 63). The concrete ramp and extension of the riprap as well as a single outline of the lower layer of beach design 1 are shown in Figure 57 which is plotted at a larger scale. The position of the project within the littoral cell is shown best at the scale used in Figure 57 and highlights the proposed sand layer. This sand layer provides a beach for Paradise Cove but also serves as a nourishment source of sand for the downdrift beaches. Because erosion to the bluff is a major source of sand for the downdrift beaches (Figure 57).

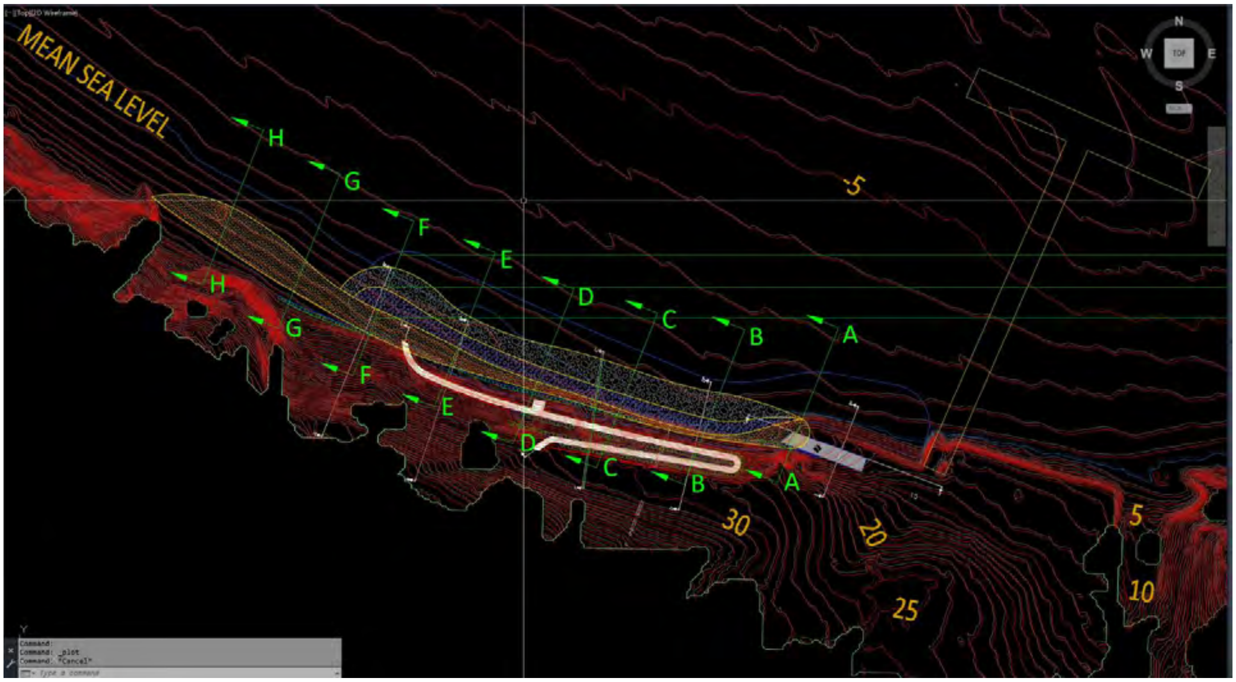

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Figure 58: An AutoCAD map view showing the topography of the bluff connected to the bay bathymetry at Paradise Cove (red contour lines). The terraced path is shown merged with beach design 2 and location of the transects A-H. The outline of the pier is also shown. The extension of the boulder riprap ends just past transect G. The concrete ramp is also highlighted as is the extent of the bottom layer of design 1 with a blue line extending from the pier to transect F.

Beach design 2 beach profiles and Point Pinole profiles including MHHT and 1 ft of sea-level rise plus location of design wave break points were merged for transects A, B, C, and G (Figure 59 - Figure 63).

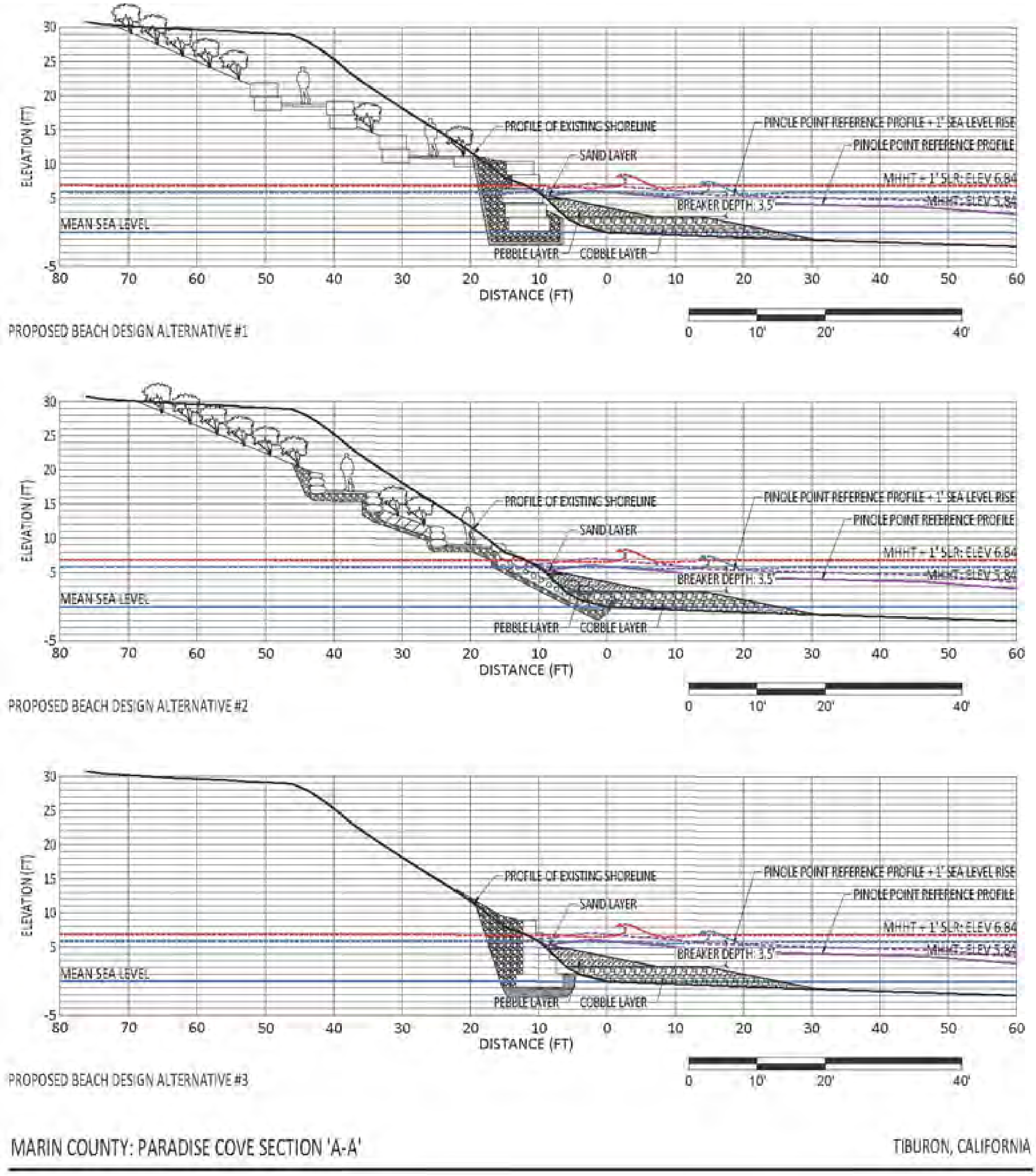


Figure 59: Plots of beach design 2 for transect A with the proposed 3 alternative bluff stabilization plans by Anchor QEA 2020.

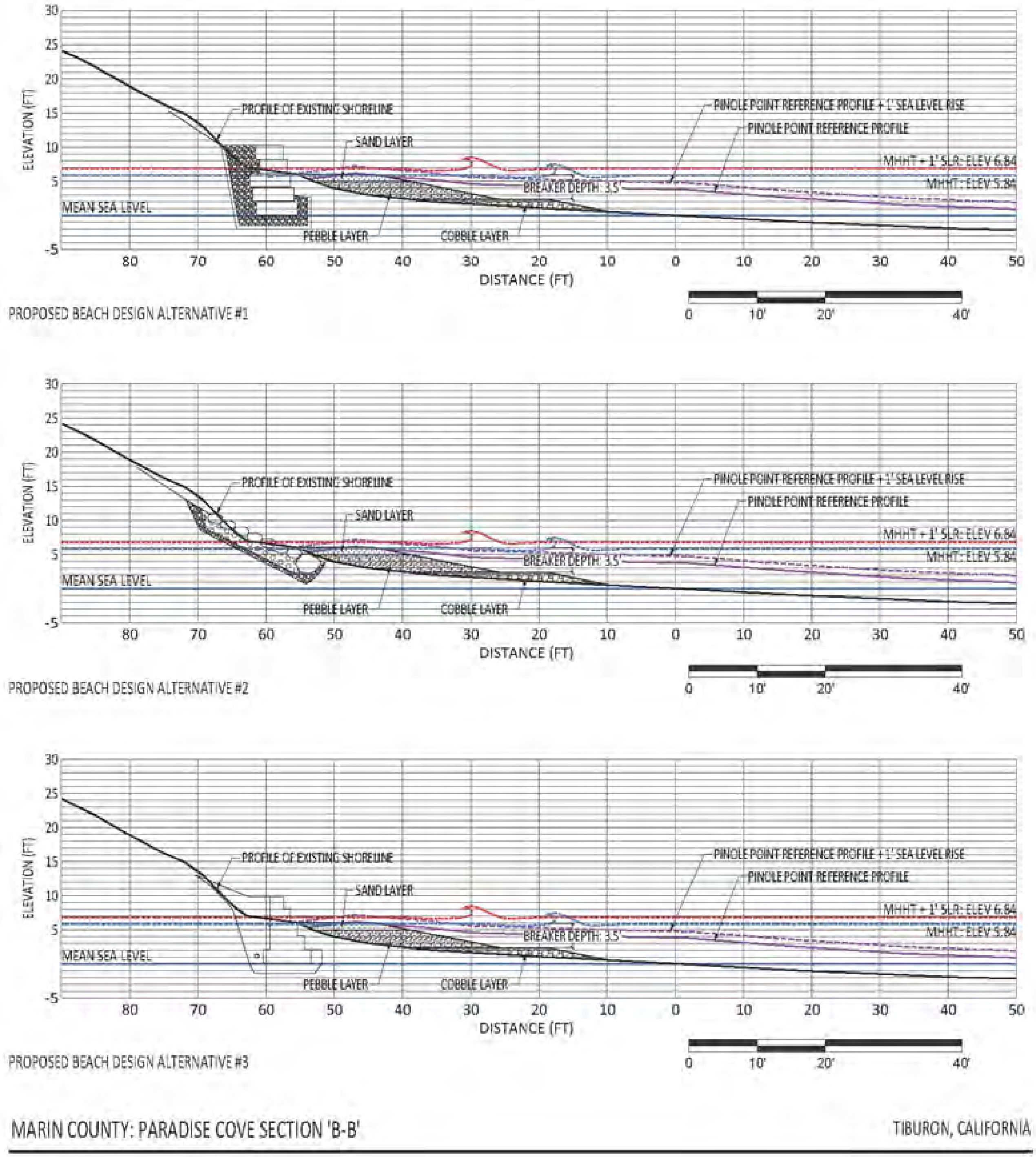


Figure 60: Plots of beach design 2 for transect B with the proposed 3 alternative bluff stabilization plans.

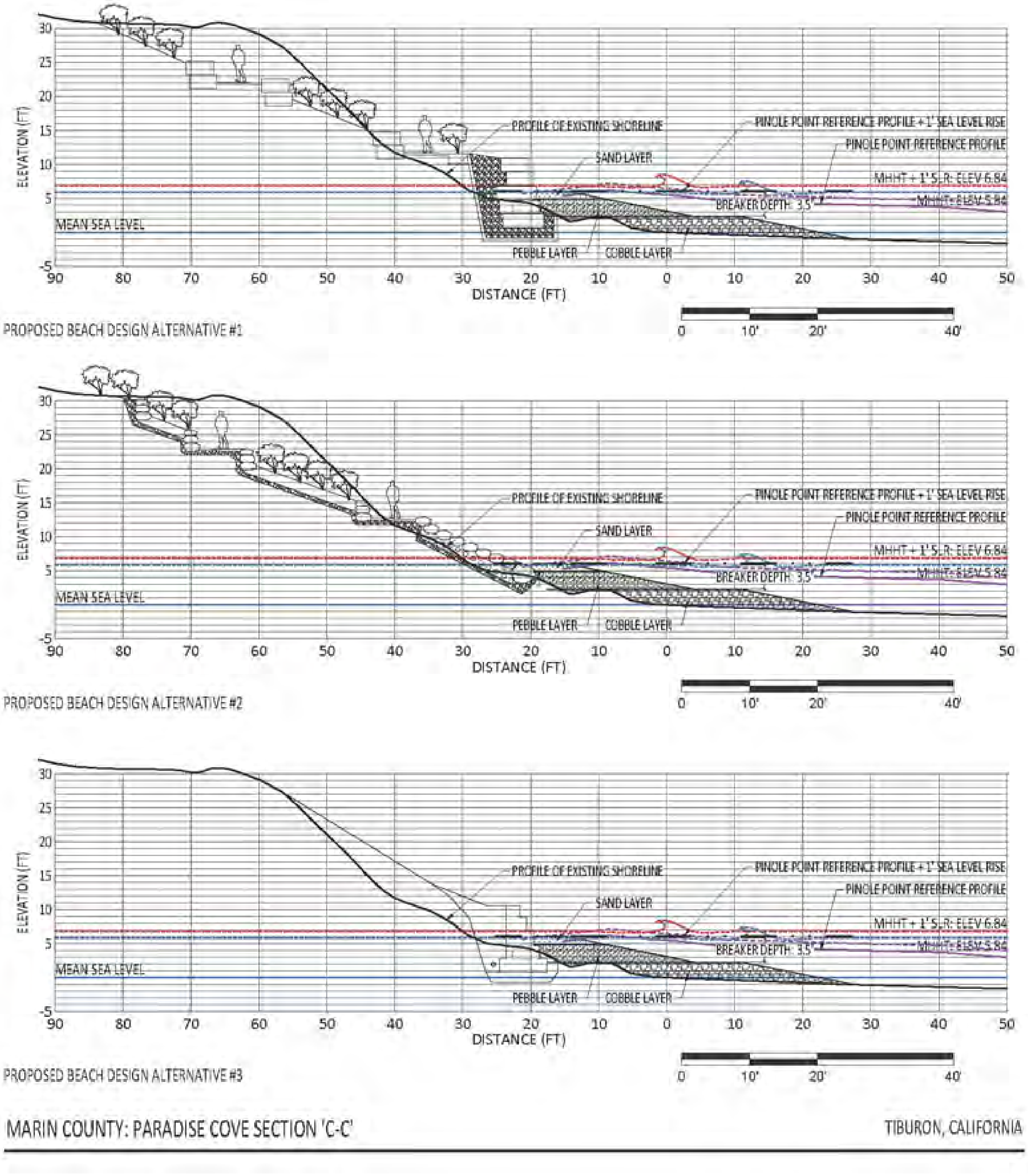


Figure 61: Plots of beach design 2 for transect C with the proposed 3 alternative bluff stabilization plans by Anchor QED (2020).

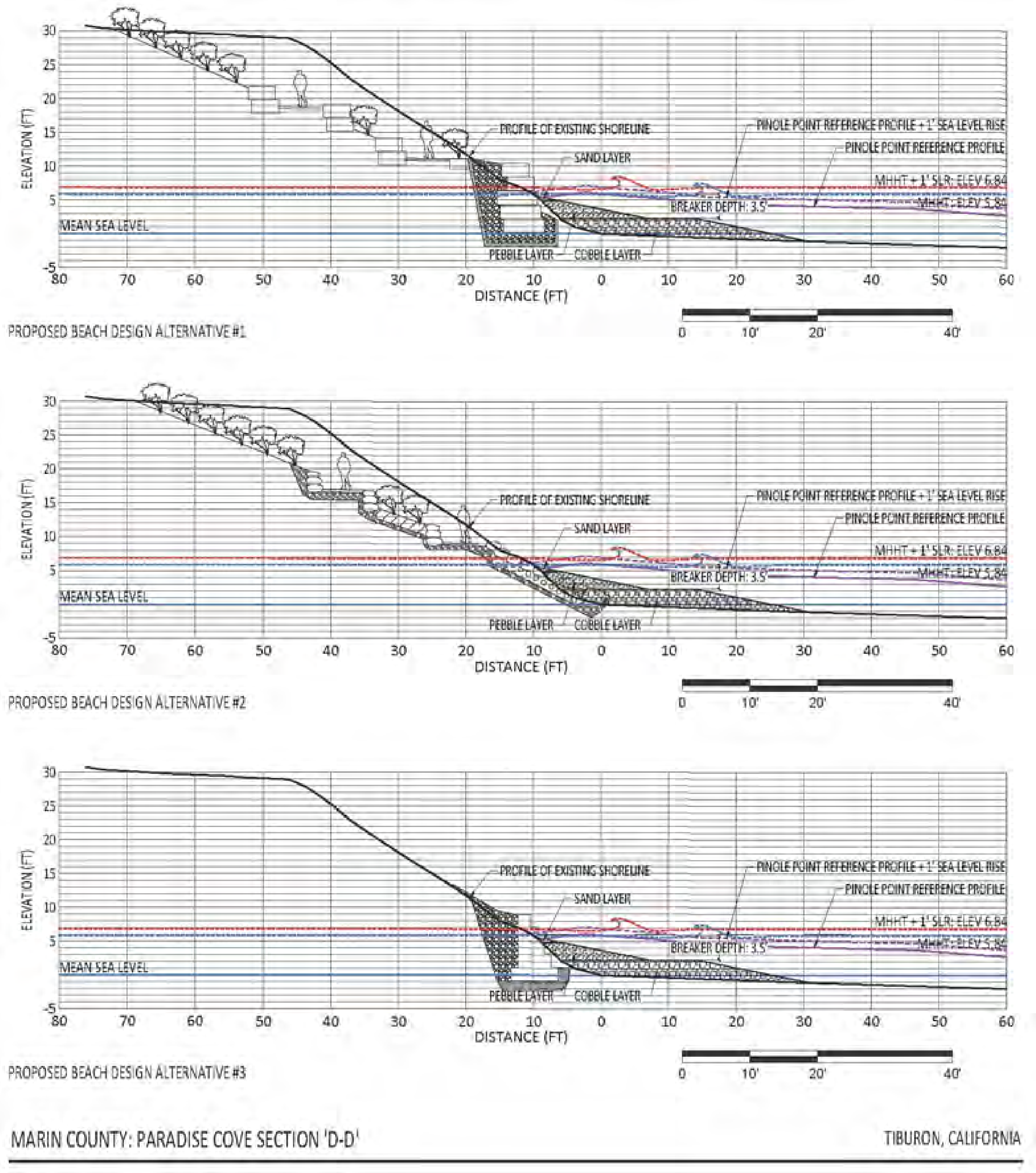


Figure 62: Plots of beach design 2 for transect D with the proposed 3 alternative bluff stabilization plans by Anchor QED (2020).

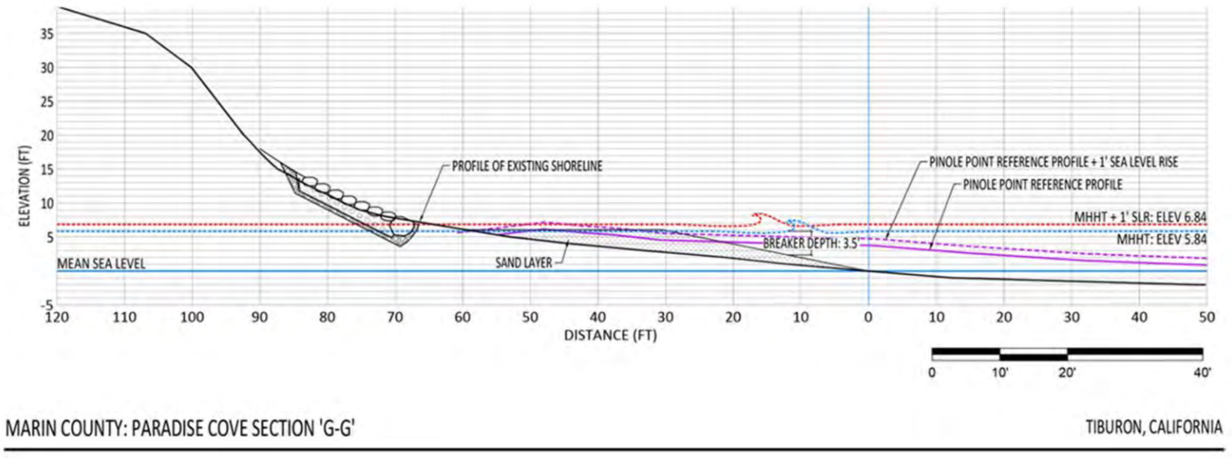


Figure 63: Plots of beach design 2 for transect G with the proposed 3 alternative bluff stabilization plans by Anchor QED (2020).

The western section of Paradise Cove beach from transect G to and beyond transect H does not show bluff slumping. Indeed the bluff toe near transect G is rock outcrop as can be seen in the photograph of Figure 42. This brings up the question of why the boulder riprap is extended so far west (Figure 57). The transect G shows where the MHHT and the plus 1 ft SLR elevation intersect the bluff as well as where they intersect the toe of the boulder riprap (Figure 63) More importantly the plot of transect G reflects the perception of the erosion threat by the engineers who put forth these designs. These types of differences are common and expected with first draft and independent design ideas are created and compared. And they underscore the work ahead that is required to come up with a final design. This sand layer will most likely erode away given the fact that the mean sea level contour (0 on the x-axis) occurs at the toe of the sand (Figure 63). For this reason high waves will break and swash directly onto this sand wedge and also with a high angle of approach. The result is that this proposed sand wedge will likely wash away in a single storm. If the beach is not quickly replenished with sand waves will scour the toe of the riprap causing it to fail and require more maintenance work. The best solution would be to extend the gravel beach beyond transect G so that this situation does not happen.

Quantities and Constructability

This site is well set up for use of a track-truck to deliver material to the final placement location where an excavator can place the final material. It is also conducive to using a barge. The main drawback with a barge is the increased cost to bag the gravel material and then the cost of a barge itself.

There are two designs for consideration. Design 1 will protect the backshore bluff from wave erosion by inducing wave breaking far enough offshore to ensure complete dissipation of the largest expected storm waves and it will provide for a sand beach public access to the bay beach for all tidal levels. It will deliver these attributes thorough a 1-ft rise in sea level. It will require a total of 7,054 yd^3 of material.

Design 2 will not fully protect the backshore bluff from wave erosion during the largest expected storm waves and it will not provide for public beach access during high tide events. It will provide the backshore bluff with minimal protection from wave erosion during common storm events and MHT levels but if those events occur during MHHT levels waves will break against the bluff. Perhaps the slope stabilization structure will also provide protection from wave erosion to the toe of the bluff during these coupled high tide and storm events. However, vertical walls associated with sheet pile or other slope stabilizing structures will result in significant wave reflection and scour both at the toe and on the end of the wall. The long-term result is that the beach will likely wash away just as it did in the past especially in the light of rising sea level. Hence, design 2 will likely require maintenance and nourishment of material at a volume and rate that is dependent on the occurrence of storms and high tides. Both factors are expected to increase over time in the face of a changing climate.

Summary of Impacts and Permitting Implications

Habitat data for the Paradise Beach Park Site was obtained from SF Bay Subtidal Habitat goals GIS layers. Note that these layers are very approximate and only meant to provide a rough estimate for evaluation and comparison between alternatives and not for project permitting. At Paradise Beach Park, the major existing ecological habitats are mudflats and eelgrass (Figure 64), the latter being an important habitat resource for a variety of species and subject to a higher level of regulatory concern. Aerial extents for the beach treatments for each design were derived from CAD files or hand drawings and converted to GIS polygons. For each beach design, the estimated total habitat covered by all beach treatment was determined (

Table 5). These estimates provide a good measure of what habitats will be initially covered by each beach design.

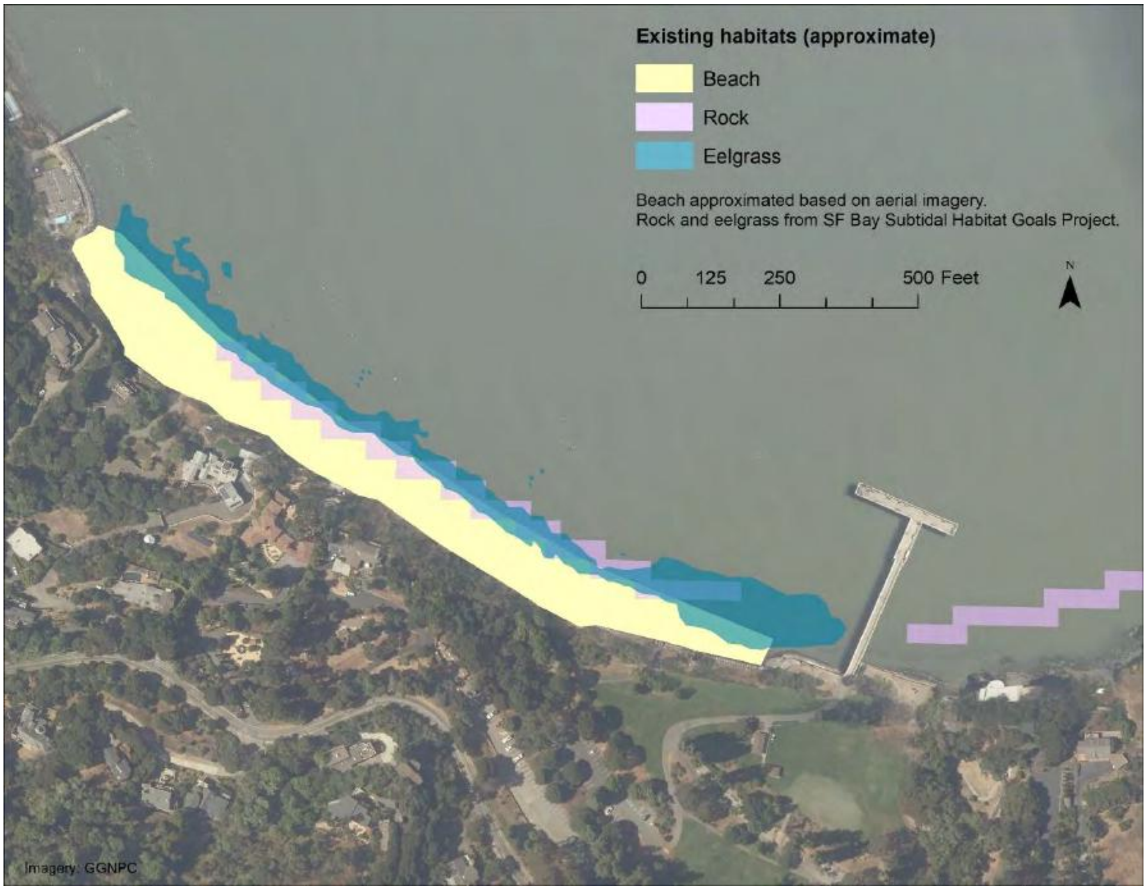


Figure 64: Existing Mapped Habitat Types at Paradise Beach Park, based on SF Bay Subtidal Habitat Goals data 2010 (beach approximated based on aerial imagery)

Table 5 gives areas of specific habitats at the site that would be covered by gravel material if they were built to that design while the spatial distribution of each habitat and the spatial overlap of each design are plotted on maps. These maps make it easy to see where the gravel treatments cover the existing habitat polygons. The goal for design 2 was to greatly reduce the amount of eel grass habitat that would be covered up by cobble material. That goal was accomplished by reducing the area of eel grass covered from 15,004 ft^2 to 593 ft^2, a 3-order of magnitude reduction in area covered and more that a factor of 3 cost reduction. What areas of eel grass habitat that are covered by design 1 compared to design 2 are mainly near the fishing pier and along the sea wall of the boat ramp. These benefits come at a cost of limited protection for the backshore bluff to wave erosion and limited public access to the intertidal beach except during low tide conditions of + 2 ft above mean sea level and lower when the top surface of the cobble layer would be exposed.

The mapped areas of proposed sediment placement for beach construction for Approach A (Dynamic estuarine beach) are shown below.

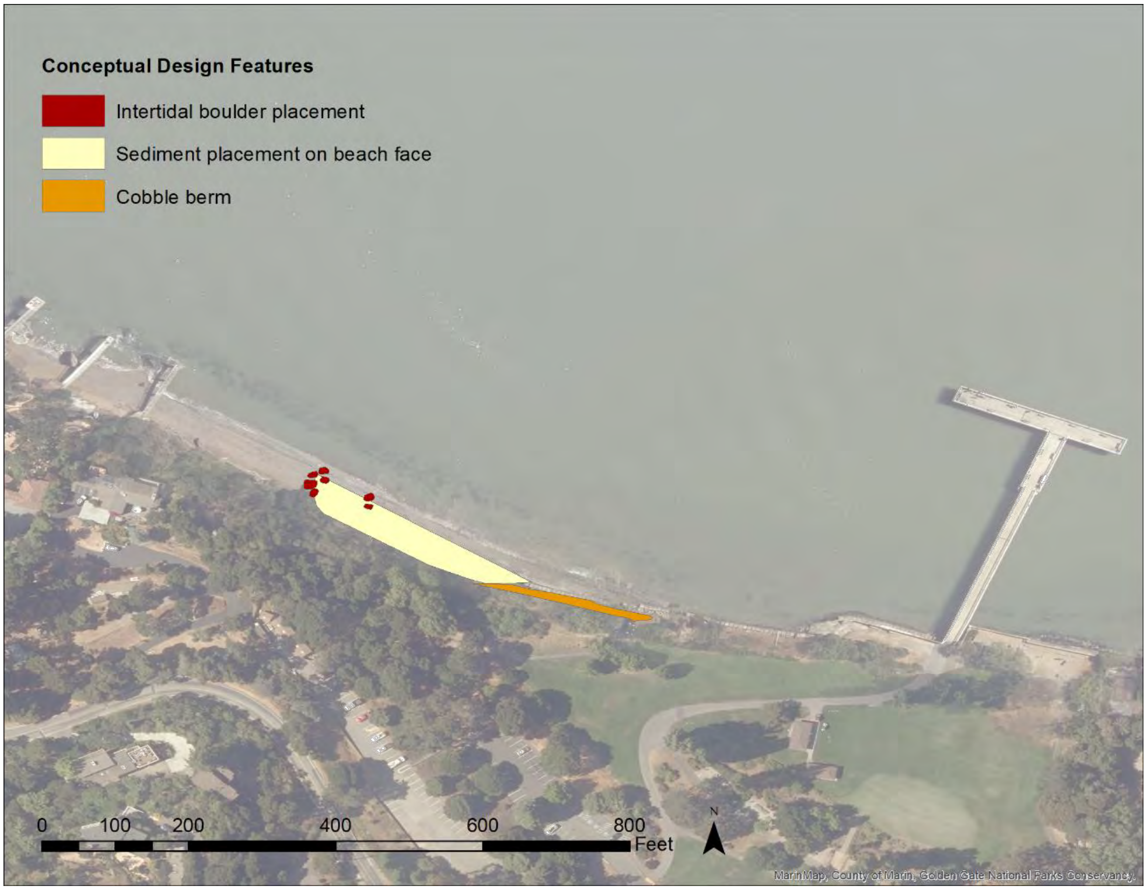


Figure 65: Areas of proposed sediment placement for Approach A: dynamic beach nourishment

For Approach A the Dynamic Nourishment Approach the designs were provided as sketches that were dimensioned but are not scaled drawings. As such they are not as accurately developed as the Approach B designs which were developed in AutoCad and then exported to GIS for the impacts analysis and are thus to scale. To assess impacts for this approach, SFEI staff fitted the sketches onto the landscape as polygons shown in Figure 65. As such, these are approximate and only intended to provide an approximate assessment of the potential habitat impacts from both approaches.

Table 5: Summary table of approximate impacts, Paradise Beach Park

	Area impacted (acres)		
Habitat Type	**GBDT Alt 1**	**GBDT Alt 2**	**Dynamic Beach Nourishment**
Beach	0.9	0.5	0.2
Eelgrass	0.3	0.0	0.0
Rock	0.0	0.0	0.0

	Area impacted (ft^2)		
Habitat Type	**GBDT Alt 1**	**GBDT Alt 2**	**Dynamic Beach Nourishment**
Beach	40,300	21,500	8,600
Eelgrass	12,400	600	0
Rock	900	0	0

The results demonstrate the trade-offs implicit in design approaches. The most robust and likely successful wave reduction approach is Lorang Alt 1 but this results in some impacts to mapped eel grass areas. But a smaller footprint design may result in continued shoreline erosion which may also include erosion of sediments into the eel grass habitat areas. Continual maintenance also has impacts due to construction mobilization as well as increased costs.

Approach B: Preliminary Project Construction Cost Estimate – GBDT

A feasibility level cost estimate has been prepared to develop a possible range of costs. At this preliminary stage of project development, the costs are approximate and subject to significant revision upon future analysis during future design phases. Costs are primarily provided for the GBDT design since it is larger and likely more expensive initially than the dynamic beach nourishment approach, however, the latter approach may require more maintenance events to provide sediment overt time as sediment leaves the system.

Costs have been divided into the following categories:

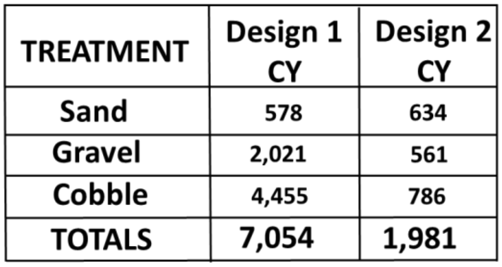
- *Construction and Site Operations* – including site preparation, material and equipment staging and implementation of site environmental protection measures. These costs also include. Silt fencing will be installed around identified special status plants and to inhibit inflow of sediments into mosquito ditches.
- *Engineering Design and Permitting* Costs - This section includes cost for the next stages of design and permitting assuming a mitigated negative declaration for the project… These assumptions will be checked during subsequent design phases.
- *Monitoring and Reporting* – A first cut estimate for costs associated with monitoring and reporting for five years following project construction have been developed and contained in the cost table. Note that only what we believe will be permit required monitoring and reporting is included. There may be additional monitoring useful and important for research and to collect data for refinement and improvement of the design models, but these costs are not included.

As a rough estimate, we used approximately \$180 to 190/yd^3 to acquire and place sediments. Those cost estimates will likely be different than an actual bid but they do give us an objective cost factor to use for assessing each design plan given all the material costs can be related to the volume of material the design requires for each site. Costs for coarse-grained sediments are difficult to estimate because they are not as commercially available outside of the landscape trade.

There are two designs for consideration. Design 1 will protect the backshore bluff from wave erosion by inducing wave breaking far enough offshore to ensure complete dissipation of the largest expected storm waves and it will provide for a sand beach public access to the bay beach for all tidal levels. It will deliver these attributes thorough a 1-ft rise in sea level. It will require a total of 7,054 yd^3 of material and perhaps up to a month to build.

Design 2 will not fully protect the backshore bluff from wave erosion during the largest expected storm waves and it will not provide for public beach access during high tide events. It will provide the backshore bluff with minimal protection from wave erosion during common storm events and MHT levels but if those events occur during MHHT levels waves will break against the bluff. Perhaps the slope stabilization structure will also provide protection from wave erosion to the toe of the bluff during these coupled high tide and storm events. However, vertical walls associated with sheet pile or other slope stabilizing structures will result in significant wave reflection and scour both at the toe and on the end of the wall. The long-term result is that the beach will wash away just as it did in the past especially in the light of rising sea level. Hence, Design 2 will likely require regular maintenance and nourishment of material at a volume and rate that is dependent on the occurrence of storms and high tides. Both factors are expected to increase over time in the face of a changing climate.

Table 6: Material volumes per treatment for both GBDT Paradise Beach Park designs



TREATMENT	Design 1 CY	Design 2 CY
Sand	578	634
Gravel	2,021	561
Cobble	4,455	786
TOTALS	7,054	1,981

The results of the cost estimate are summarized in Table 7. Note that we have provided two results; the estimate total cost (design, permitting, construction and monitoring) with the 30% contingency, and the total costs without the contingency. Appendix A contains a detailed summary backup for these costs. Note that these costs will be further refined in future phases of the project. Note that no mitigation cost have been included in this estimate since these costs are not known and the goal is a self-mitigating project.

Table 7: Summary of Paradise Beach Park preliminary cost estimate for GBDT (detailed cost estimate in Appendix B)

Cost Item	Design 1 (no contingency to 30%)	Design 2 (no contingency to 30%)
Construction costs	\$1,430,000 to \$1,860,000	\$500,000 to \$645,000
Engineering final design, plans and specifications and permitting	\$305,000	\$305,000
5 year monitoring and reporting	\$380,000	\$380,000
TOTALS:	\$2,025,000 to \$2,540,000	\$1,090,000 to \$1,325,000

Site Specific Preliminary Design: Seminary Drive Shoreline Erosion

This section describes the site-specific preliminary designs at Seminary Drive. For this site, only the Gravel Beach Design Template was used to develop a site design. This is primarily because there is only a single design objective for this site to reduce roadway shoreline erosion without using riprap. This provides a demonstration site of a beach system immediately adjacent to existing riprap and a road infrastructure to inhibit erosion while providing habitat benefits instead of rip-rap. This site would thus be applicable to other sites where shoreline erosion is the primary design goaland minimum follow-up maintenance is desired. To this end, it was decided to only forward the more engineered design approach of the GBDT.

Seminary Drive Site Background

The Seminary Drive shore site is located at the west end of Seminary Cove, a shallow embayment of Richardson Bay. The shore is located at the toe of a steep road embankment that extends to a boulder-armored convex headland west of the site. The road and embankment are a cut/fill bench below a hillslope that originally formed a cliffed rocky shore at the edge of the bay, similar to exposed sandstone and shale shore cliffs at Tiburon Linear Park and Richardson Bay Audubon Sanctuary. The boulder armoring of the road embankment headland terminates abruptly, exposing an earthen bank with a basal near-vertical wave erosion scarp at its east end.

Figure 66: Seminary Cove study area and setting along shore below Seminary Drive embankment, Richardson Bay. Google Earth photo September 2017.

Figure 67: Seminary Cove study area. Google Earth photo August 2018. Arrow indicates location of stormwater drainage point discharge, and brackish influence on tidal marsh (saltgrass) vegetation and algae.

Figure 68: Seminary Cove shore adjacent and east of project study area. (A) Angular cobble and gravel rocky shore, grading to tidal mudflat, fine gravel beach, salt marsh (background) and riparian oak and bay woodland; view east. (B) Gravel beach berm (shale and sandstone from past erosion of bluffs and slope failures) above rocky shore and mudflat, below coast live oak and bay woodland on cliffs; view west.

Figure 69: Rocky upper intertidal shore below rocky salt marsh, above tidal mudflats, Seminary Drive shore study site. February 2019.

Below the upland embankment scarp, a wave-cut sloping bench supports a narrow rocky shore salt marsh belt about 10-20 ft wide, extending from the backshore scarp to the unvegetated rocky intertidal zone. The rocky salt marsh substrate consists of angular cobbles, gravel, and boulders, with a veneer of mud and salt marsh vegetation in the upper intertidal zone. The marsh substrate is a thin veneer over rocky shore; no fringing salt marsh platforms (accreted peaty bay mud) occur along the bay shore bordering the vicinity of the wave-exposed rocky shore along Seminary Drive. Small, thin, discontinuous storm gravel berms also occur near the high tide line of rocky salt marsh zone.

Figure 70: Rocky salt marsh bench after full growing season of vegetation development, above rocky unvegetated upper intertidal shore below Seminary Drive embankment scarp at the study site. Saltgrass (*Distichlis spicata*) turf is dominant vegetation in salt marsh. October 2012 (left) and October 2018 (right).

Figure 71: Continuous rocky salt marsh bench above rocky unvegetated upper intertidal shore below Seminary Drive embankment scarp. Prostrate saltgrass turf is wave-scoured during winter. February 2019. Note stormwater discharge pipe and scour pool.

The lower rocky salt marsh zone includes thin interstitial peaty mud partly stabilized by vegetation mats of saltgrass (*Distichlis spicata*), and small patches of pickleweed (*Sarcocornia pacifica*), Jaumea (*Jaumea carnosa*), and occasional colonies seaside plantain (*Plantago maritima*) and the brackish marsh clustered field sedge, Carex praegracilis. The presence of the sedge indicates local fresh-brackish influence into the upper intertidal zone from terrestrial sources (possibly seepage of groundwater or landscape irrigation). Two non-native invasive sea-lavender species widespread in southern Richardson Bay, *Limonium ramosissimum* and *L. duriusculum,* also occur in occasional colonies in the rocky salt marsh zone. Annually variable shoreline salt-tolerant weeds including saltwort (*Salsola soda*) and orach (*Atriplex prostrata*) are present with low frequency and cover. The prostrate salt marsh mats are well-vegetated (over 50% vegetation cover outside of debris drift-lines) during the summer-fall growing season, but are often sparse or defoliated and wave-scoured during the winter storm season.

The rocky unvegetated cobble lag shore extends east towards the shallow flats of Seminary Cove, where the intertidal profile is dominated by mudflats, small gravel and organic debris beaches, and narrow fringing salt marsh dominated by California cordgrass (*Spartina foliosa*).

Protection of Existing Biological Resources

Fringing rocky salt marsh in the footprint of the proposed cobble-gravel beach berm below Seminary Drive would be buried. The depth of burial and the large size of cobbles is unlikely to be compatible with regeneration of saltgrass or other salt marsh vegetation. The salt marsh acreage is estimated as less than 0.1 acre (0.08 acre).

Mitigation for tidal salt marsh fill could be incorporated into the beach itself by modifying some of the profile to become perched cobble salt marsh above normal high tides, flooded by extreme wave runup or high tides. The back of the cobble-gravel berm could be modified to support similar high salt marsh dominated by saltgrass and alkali-heath by filling interstitial spaces between cobbles and gravels with a bay mud slurry, and shallowly (5-10 cm below surface) burying salt marsh sod fragments with embedded dormant (winter) rhizomes of these species. This would effectively convert much of the cobble-gravel beach berm to cobble salt marsh. Conversion of the cobble berm to cobble salt marsh as mitigation for wetland fill may involve some trade-offs with wave attenuation functions of the berm. Interstitial mud and salt marsh roots would increase shear strength of the berm and reduce its mobility in response to storm wave action (increase stability), but also reduce infiltration of storm waves. Stabilization of a cobble berm with interstitial mud and vegetation reduce some of the wave attenuation capacity of the cobble berm caused by infiltration of wave runup, but it may also increase wave attenuation due to increased vegetative surface roughness of the beach ridge.

Figure 72: Local brackish tidal marsh indicator, clustered field sedge (*Carex praegracilis*) indicates some freshwater seepage influence in the rocky salt marsh zone of the study site.

Figure 73: Invasive non-native Algerian sea-lavender (*Limonium ramosissimum*) occurs scattered along the Seminary Drive rocky shore and salt marsh, including the study area. February 2019.

Impacts to Existing Public Access and Usage

There is no public access to this site and no nearby parking available to even allow for public access. Therefore, this is not a concern for this demonstration project. A trail connection could potentially be added but beyond the scope of this assessment.

Approach B: Seminary Drive Gravel Beach Design by Dr. Mark Lorang

Problem: Wave Erosion threatening Seminary Drive

The Seminary Drive site is a section of an eroding road bank along Seminary highway (Figure 74). Currently waves erode the vertical bank threatening Seminary Drive which is immediately on top of this vertical bank (Figure 74). The design presented not only protects the road and bike trail but provides for improved public access to a new recreational beach. And a project at this location would be useful for agencies involved in protecting critical infrastructure (in this case a County road) with limited space as an alternative rock riprap. This project is intended to provide the most direct demonstration of use of beach systems for the primary and singular purpose of protecting existing infrastructure as an alternative to riprap to protect a trail and roadway and provide some habitat benefits even if it takes time for the nature to complete the re-naturalization process.

Figure 74: Riprap used to protect the slumping bay cliff that forms the edge of Seminary Drive and the eroding vertical bank that is not protected and exposed to wave action during high tides.

Opportunities and Constraints

Access to this site for heavy equipment is limited without some level of traffic control. However, the fact that the highway runs right alongside of the site (Figure 75) makes delivery and placement of material much easier and perhaps this site would be the cheapest to construct. Trucks would be to drive alongside the road and dump directly over the bank and on to the seabed where excavators could spread and place the material (Figure 76). This site would be conducive to the use of side dump trucks that can haul 2 to 3 times the volume of material that a conventional dump truck can haul. They would simply pull alongside the location where the material needed to be dumped, dump and then go with no staging or reloading required (Figure 77). Most of the material would be dumped onto an existing gravel and cobble bed intertidal zone that appears to be part of the history of road construction (Figure 76 and Figure 77).

Figure 75: Riprap used to protect the slumping bay cliff that forms the edge of Seminary Drive and the eroding vertical bank that is not protected and exposed to wave action during high tides. Note the existing cobble intertidal seabed at the base of the vertical bank.

Figure 76: Top of the vertical bank near the road and bike trail at the edge of Seminary Drive. Note the existing cobble intertidal seabed extending from the base of the vertical bank. The photo was taken at mean sea level.

Figure 77: Top of the vertical bank near the road and bike trail at the edge of Seminary Drive. Note the existing cobble intertidal seabed extending from the base of the vertical bank. The photo was taken at mean sea level. The dotted yellow line shows where the proposed beach would blend into the existing downdrift beach. This downdrift beach would receive sand over the years effectively naturally widening the beach along the trees in that location and increasing the recreational benefits as well.

This site provides a very public and stellar opportunity to demonstrate how gravel beaches can be a viable alternative to riprap and the opportunity to demonstrate that to the highway department, agency that places the most riprap. There is also a great opportunity to provide a recreational beach for the biking and hiking public given there is not a parking lot for cars. However, people out biking and or walking the trail could easily access the beach to enhance their outdoor activity (Figure 78 and Figure 79). Stairs and a bike rack would need to be added to allow for ease of access.

Figure 78: Current conditions of the intertidal zone at Seminary and rendition of the conceptual beach plan. The rendition is representative of MHHT levels once the beach is built.

Figure 79: Current conditions of the intertidal zone at Seminary and rendition of the conceptual beach plan. The rendition is representative of MHHT levels once the beach is built. Adding a ladder or steps of some kind would greatly improve public access to what could be a nice recreational beach accessible at all tidal levels. In addition, a bike rack could be added to facilitate people out for a bike ride that might want to stop and enjoy the beach. Public access can be complex and is beyond the scope of this assessment.

Seminary Drive Design Plan View

The gravel beach design at Seminary Drive attaches to the existing riprap by extending further west of where the riprap current ends (Figure 80). The reason for extending the beach design westward is to smooth out the transition with the existing riprap that waves will encounter from both the west-southwest direction and from the south. This will reduce impact to the existing riprap, however that riprap is not designed to deal with wave action as much as it is a cover layer for the bank. It is much too steep to be able to withstand gravity slumping as well as wave action during high tide levels. The design also blends into a natural cuspate feature in the intertidal zone on the east side (Figure 77). This intertidal cuspate cove is visible in the contours of Figure 80 as well as the photo in Figure 77.

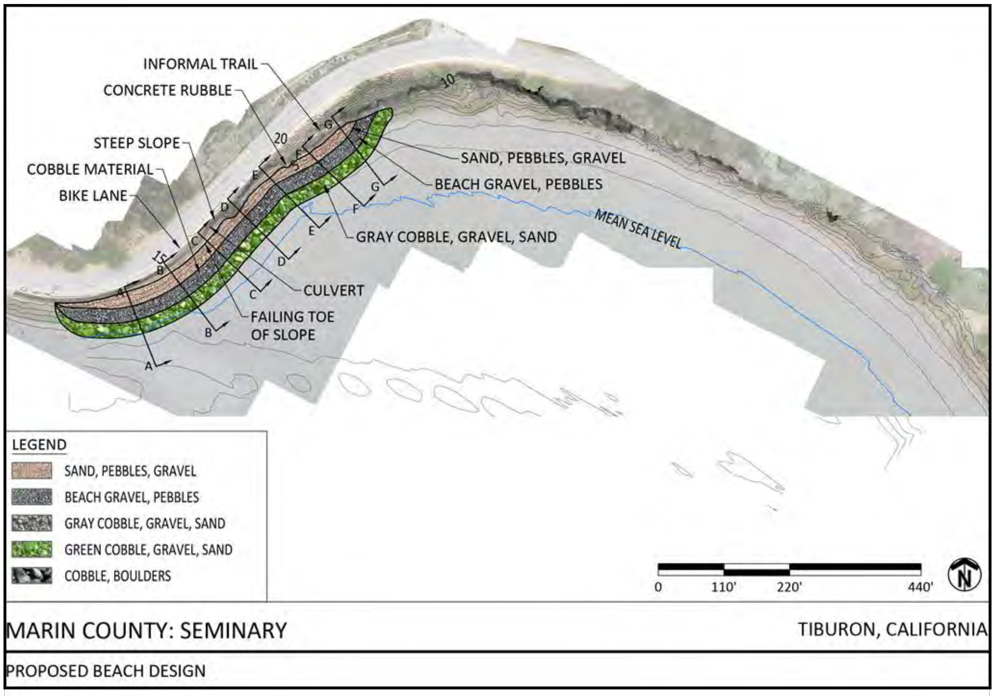
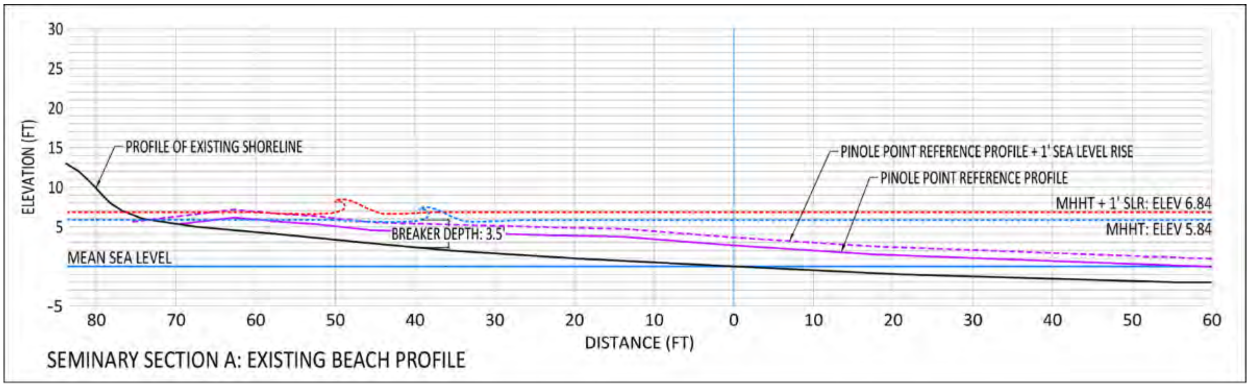


Figure 80: Plan view of the gravel beach design for Seminary Drive.

Design Profiles

The gravel beach design for Seminary Drive set the goal of complete wave energy dissipation using the MHHT (+5.84 ft above msl) as the design water level and 3.5 ft as the design break depth for a 4.42 ft (1.35 m) design wave height based on the modeled maximum storm wave heights for SF Bay produced by the USGS Coastal Storm Modeling System (CoSMoS). In addition, the gravel beach was designed to accommodate a 1 ft sea-level rise. This design calls for a substantial layer of cobble-gravel and sand to be built in front of the existing vertical bank of the road to fully dissipate all wave action during severe storms. This site presents a good and easy opportunity to demonstrate the ability of the gravel beach design approach to protect critical infrastructure under current and sea-level rise conditions in direct comparison to traditional riprap armoring.

Profiles showing the location of design wave, breaker position for current conditions and a 1-ft sea-level rise (Figure 81 Figure 87 top panel in each). The bottom panel on each figure (Figure 81 Figure 87) shows the gravel beach design profile for each transect section line shown in the plan view design (Figure 80). For each section, the design wave breakpoint for current MHHT design water level of 5.84 ft is positioned to allow for a complete wave dissipation distance of 30 ft to be accommodated before the wave would reach the backshore bank of Seminary Drive (Figure 81 Figure 87). In each case the upper level of the bottom cobble layer is brought up to accommodate wave breaking with the toe of the second pebble layer offset equal to or greater than the plunge distance (Figure 81 Figure 87). The slope of the bottom cobble layer extends toward the bay at a 1:5 slope for all sections. For both designs the middle pebble layer rises at a slope of 1:5 until it reaches the Point Pinole reference profile (solid purple line Figure 81 Figure 87). The initial break point is moved offshore a distance of 30 ft for each profile to allow for a sand beach wide enough to accommodate public recreation at all tide levels. The sand layer is then filled in to match the topography and blend with the Point Pinole reference profile.



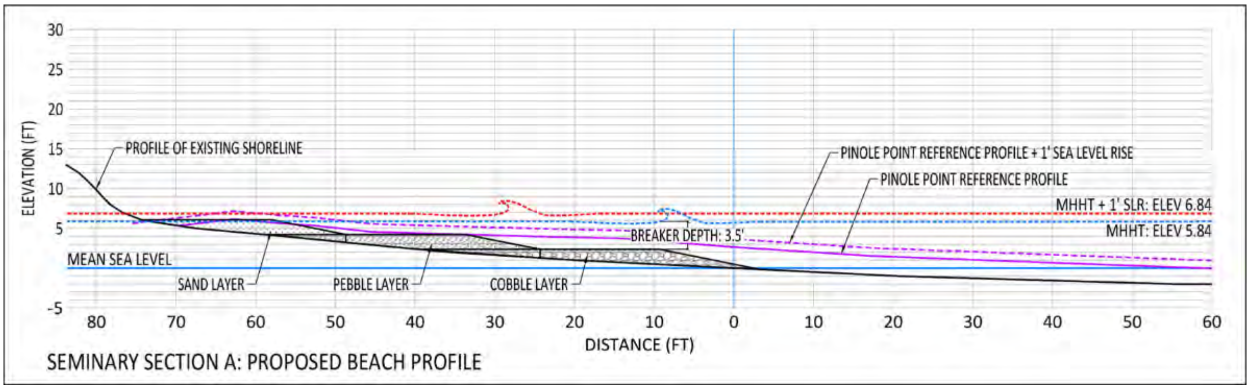
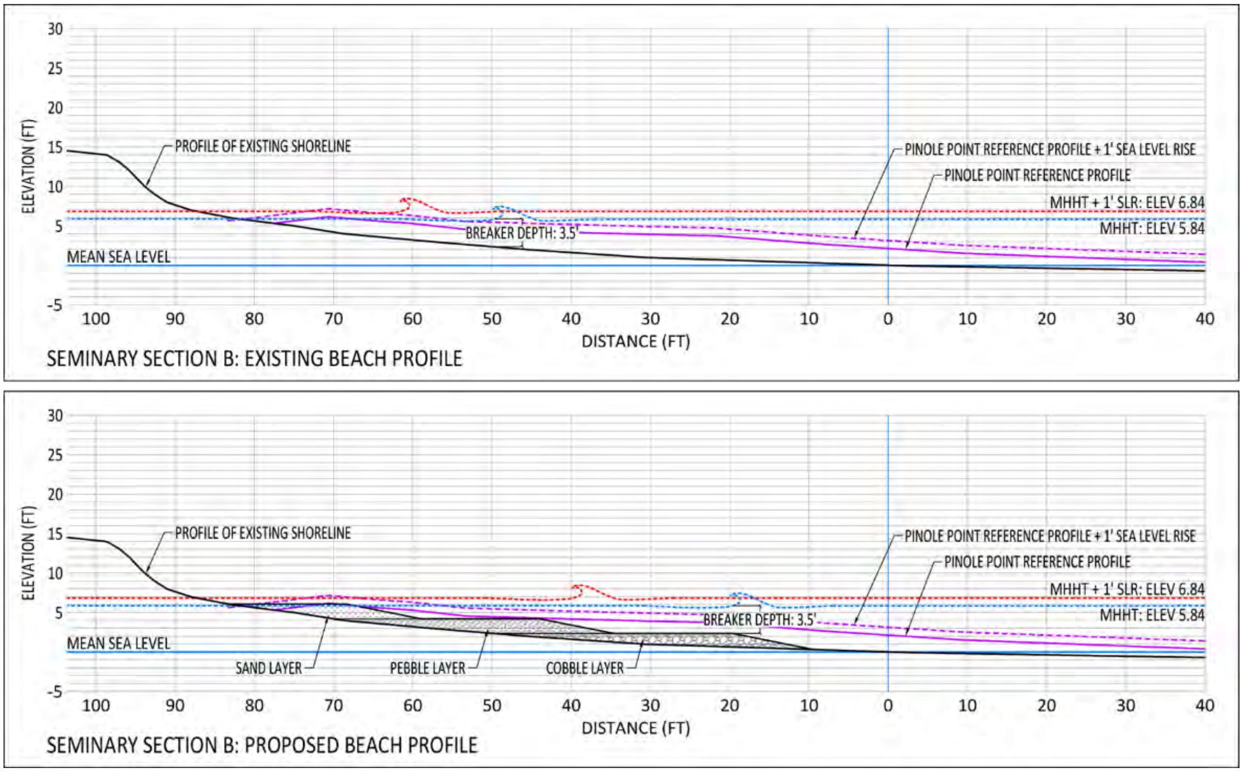


Figure 81: Plot of transect A for Seminary Drive (see Figure 80 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled.


SEMINARY SECTION B: EXISTING BEACH PROFILE

SEMINARY SECTION B: PROPOSED BEACH PROFILE

Figure 82: Plot of transect B for Seminary Drive (see Figure 80 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled.

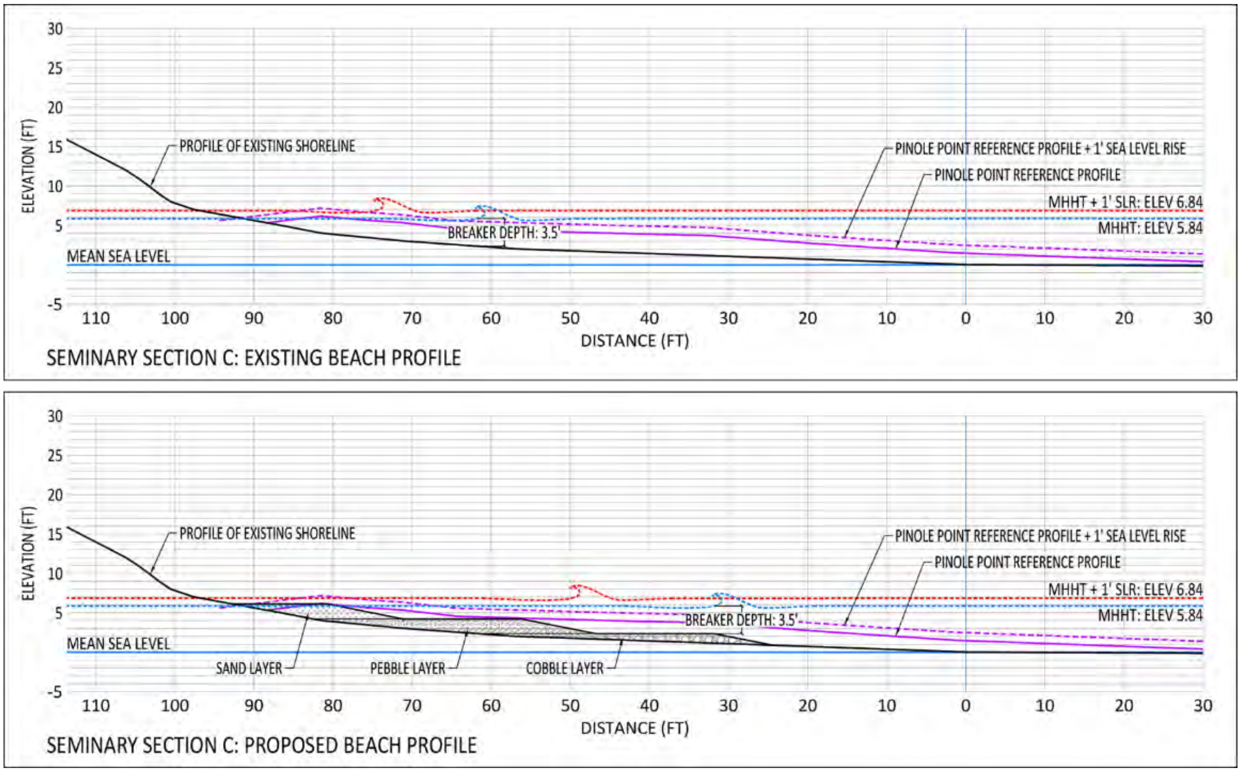


Figure 83: Plot of transect C for Seminary Drive (see Figure 80 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled.

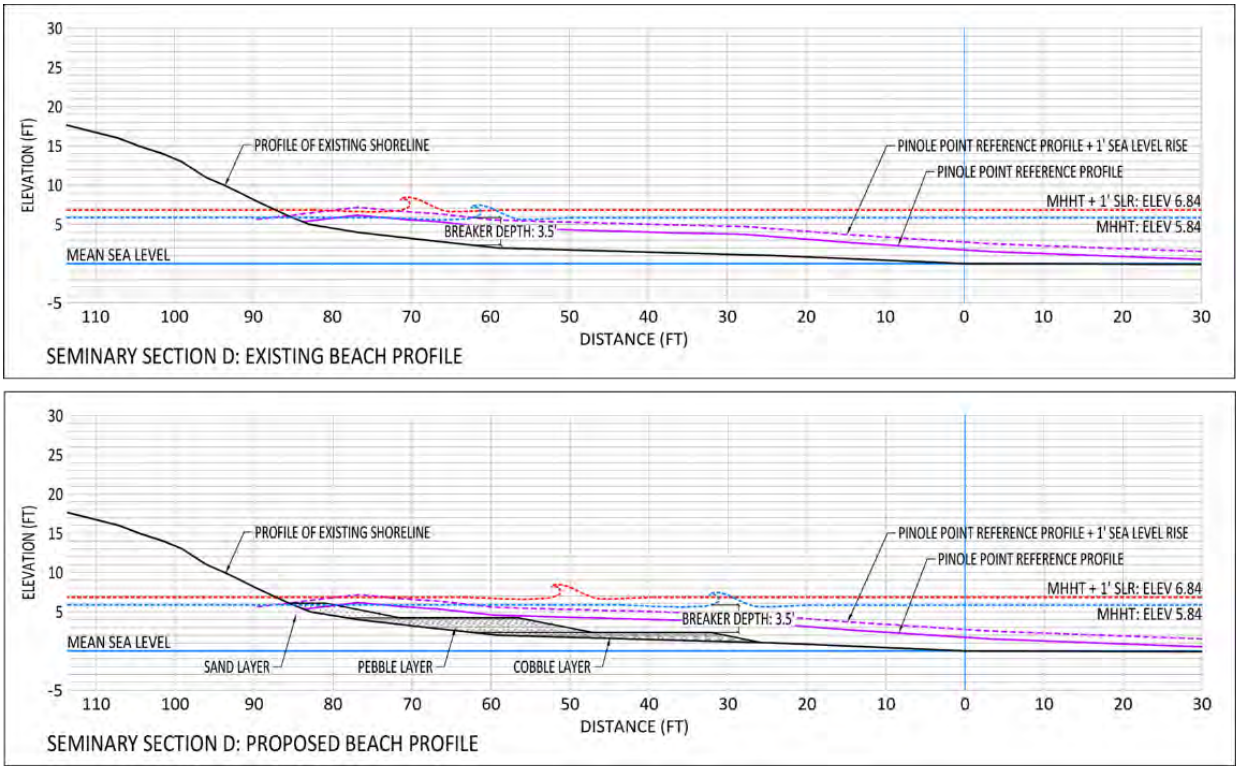


Figure 84: Plot of transect D for Seminary Drive (see Figure 80 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled.

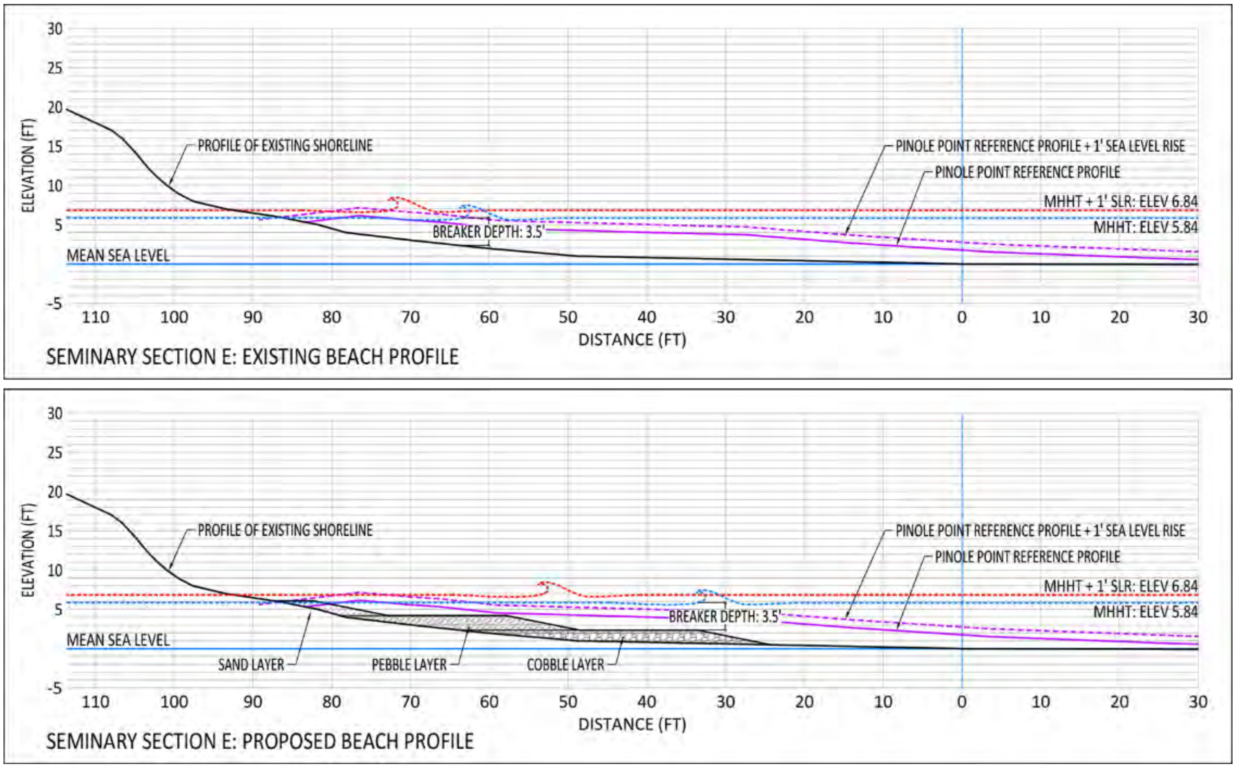


Figure 85: Plot of transect E for Seminary Drive (see Figure 80 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled.

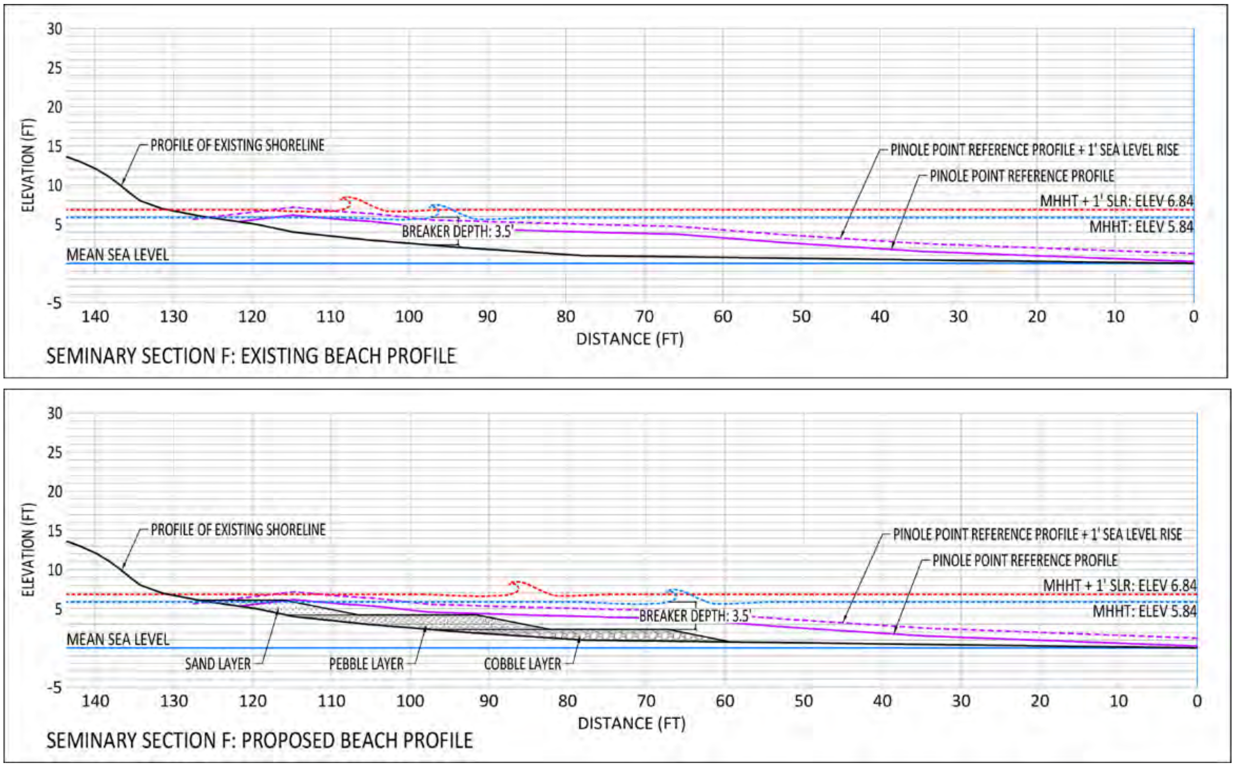


Figure 86: Plot of transect F for Seminary Drive (see Figure 80 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled.

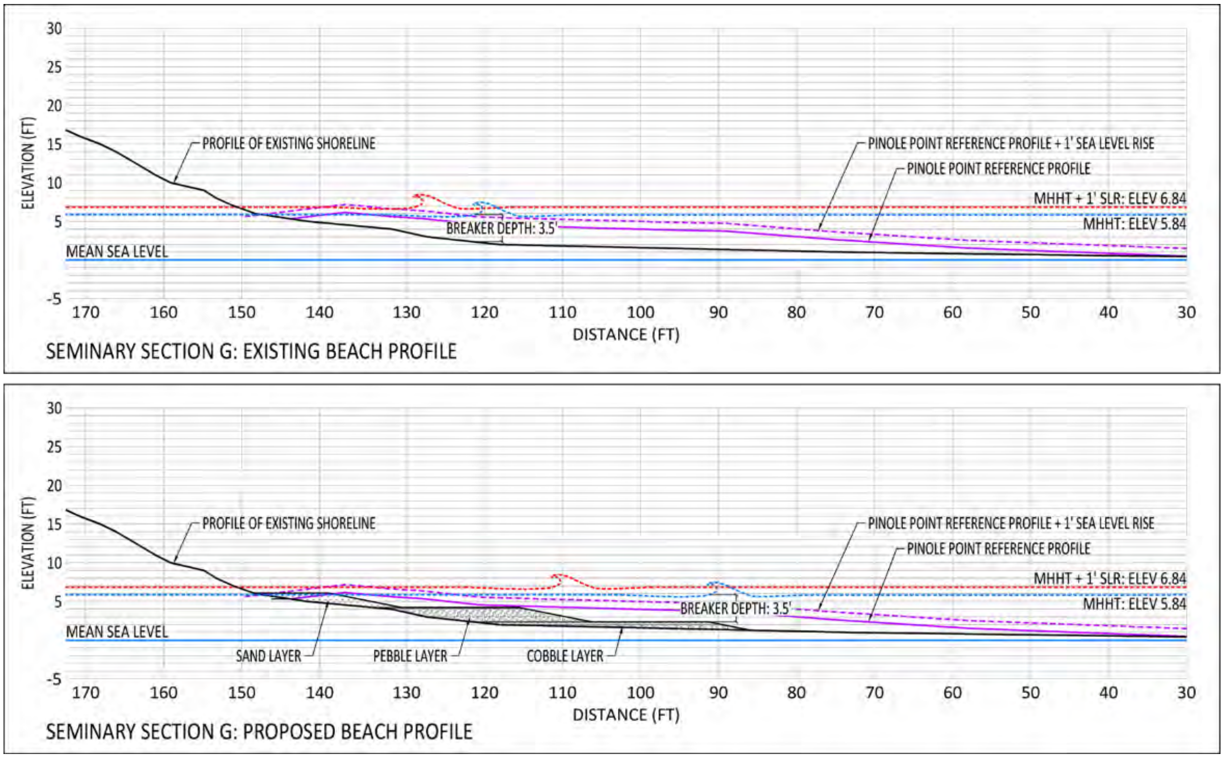


Figure 87: Plot of transect G for Seminary Drive (see Figure 80 for location). The two purple lines are survey transect data from Point Pinole with the dotted purple line representing that data elevated 1 ft to represent a 1-ft sea-level rise. Mean sea level is plotted as a solid blue line. The dotted blue and red lines represent MHHW and MHHW+1ft with the location of the breaking wave position (breaker depth) plotted as a wave. The width and thickness of each treatment layer is plotted and labeled.

Note that for each profile plot the distance between the red and blue breaking waves and the backshore shows the relative energy level the backshore is exposed to at that location along the beach (top panel) and the distance between these breaking waves for each design graphically depicts the relative level of wave energy dissipation between current conditions and a 1 ft rise in sea level where the further apart the more wave dissipation that design imparts (bottom panels) (Figure 81 Figure 87).

Summary of Impacts and Permitting Implications

This section presents a summary of the possible impacts from both designs. This is only intended to allow for an evaluation between alternatives for initial construction impacts versus the impacts from repeated nourishment events over time.

Habitat Impacts

The Seminary site has the least existing ecological resources of all three study sites and also has the least pubic visibility. The habitat impacts are primarily limited to intertidal salt marsh to rocky intertidal where coarse grained rock is placed to reduce shoreline erosion. The habitat impacts to the mapped habitat layers are shown below. The other inter-tidal zones above the mud flats are mainly revegetated rubble most likely from road building in the past.

Habitat data were obtained from the San Francisco Estuary Institute. The overall habitat data layers included mudflats (derived from elevation data) and beach (approximated based on aerial imagery). (Table 8 and Figure 88) and the observed salt marsh did not show up on the GIS database maps. For Seminary Drive, mudflats, salt marsh and existing beach are shown within the footprint of the proposed constructed beach system. Area extents for the beach treatments for each design were derived from CAD files and converted to GIS data. For each beach design, the estimated total habitat covered by all beach treatment was determined including the small estimated area of salt marsh to be impacted which is based on observations and Google Earth measurements (Table 8). These estimates provide an approximate measure of what habitats will be initially impacts by the proposed Seminary beach design.

Figure 88. Existing habitat types at Seminary Beach, approximated based on aerial imagery and elevation data

Table 8: **Potential habitat impacts for the Seminary Drive design**

Habitat Type	Square feet impacted
Beach	8,200
Mudflat	16,100
Salt Marsh *	3500

*Estimated from observation and Google Earth, To be delineated during the next phase of project design

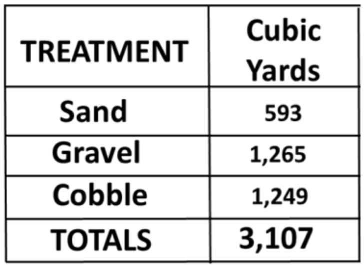
Approach B: Preliminary Project Construction Cost Estimate – GBDT

Cost and Construction

This site is well set for use of a side-dump trucks to pull up along the vertical bank and dump their load on to the existing cobble intertidal zone with proper traffic control along Seminary Drive. A ramp of material will need to be built to allow an excavator to be staged on the seabed to place material. Another smaller one can be staged on the road bank during construction. Traffic control will be required during construction but hauling and dumping could be done at night to limit the impact to the public.

The design considered here will protect the backshore bank from wave erosion by inducing wave breaking far enough offshore to ensure complete dissipation of the largest expected storm waves and it will provide for a sand beach public access to the bay beach for all tidal levels.

Table 9: Material volumes per treatment for the Seminary Drive design



TREATMENT	Cubic Yards
Sand	593
Gravel	1,265
Cobble	1,249
TOTALS	3,107

A preliminary level cost estimate has been prepared to develop a range of construction and O&M costs. At this preliminary stage of project development, the costs are approximate and subject to significant revision upon future analysis during future design phases.

Costs have been divided into the following categories:

- *Construction and Site Operations* – including site preparation, material and equipment staging and implementation of site environmental protection measures. These costs also include. Silt fencing will be installed around identified special status plants and to inhibit inflow of sediments into mosquito ditches.
- *Engineering Design and Permitting* Costs - This section includes cost for the next stages of design and permitting assuming a mitigated negative declaration for the project… These assumptions will be checked during subsequent design phases.
- *Monitoring and Reporting* – A first cut estimate for costs associated with monitoring and reporting for five years following project construction have been developed and contained in the cost table.

The results of the cost estimate are summarized in

Table 10. Note that we have provided three results; the estimate total cost (design, permitting, construction and monitoring) with the 50% contingency, the total costs without the contingency and the costs for just the proposed design based on quantities from the GBDT design. It is anticipated that the nourishment-based approach would be less expensive at least initially due to a reduced quantity of placed sediments, especially the more expensive larger sized sediment. Appendix A contains a detailed summary backup for these costs. Note that these costs will be further refined in future phases of the project.

Table 10: Summary of Seminary Drive preliminary cost estimate for GBDT (detailed cost estimate in Appendix B)

Cost Item	Costs with no contingency	Costs with 30% Contingency ($)
Construction costs	$630,000	$825,000
Engineering final design, plans and specifications and permitting	$289,000	$288,000
10 year monitoring and reporting (assumes 5 events in 10 years)	$205,000	$270,000
TOTALS:	$1,124,000	1,383,000

General Evaluation of Both Designs for All Project Sites

This section provides an overall discussion of the general pros and cons and trade-offs associated with two design approaches. It is important to restate that both design approaches are for nature-based beach systems and achieve multi-benefit goals for habitat benefits as well as for solving real world shoreline erosion problems. They are both more natural alternatives to traditional engineering armoring of the shoreline.

The goal of this section is to highlight some of the design decisions and implications for the widespread application of nature-based solutions to solve the eroding shorelines all around the Bay under current future sea-level rise conditions.

Differences Between Design Approaches

As noted above, this report is not the typical consultant lead design report which presents a single site design and explains why it is the best for the project site. This study brings together two experienced beach designers both of whom have actually designed, built and constructed projects of this type, although the GBDT approach has been more extensively built outside of San Francisco Bay and published. Both design approaches presented above are using the principles of natural beach design and nature-based solutions to achieve project goals. However, the two designs take markedly different design approaches that in many ways forms bookends. This is potentially very useful because beach systems may have different project objectives and requirements and as such having different design tool boxes may allow for trade-offs to be considered and the most appropriate design to be implemented.

The main differences are as follows:

- the Gravel Beach Design Template (GBDT) approach places larger sized material generally greater than 2-inches (i.e. cobbles) lower down into the tide level to break and dissipate waves prior to breaking on the shoreline. While the GBDT approach is adjustable to design objectives for design wave height and water level, the template puts coarser-grained sediments upfront and finer-grained sediment towards the back beach. By design, this approach is more capital intensive and may have a larger footprint that impacts some ecological habitat types more, such as mudflats.
- In contrast, the dynamic beach nourishment approach emphasizes feeding the beach system with sediments of the specified type, size, and location and allowing natural processes to rework the sediments into its proper location. There is a coarser-grained gravel berm buried at the back of the profile to serve as a back-stop to prevent continued beach erosion. This approach likely requires more frequent nourishment to maintain beach volume over time as sediment moves in and out of the system and as sea-level rises. Given that Greenwood Beach is a cove, placed sediments would be expected to be more stable over time as wave energy is focused perpendicular to the shoreline and thus the longshore movement is sediment is less than other sites.

The pros and cons for each approach are summarized in Table 11 which identifies a number of design and permitting issues and provides a relative comparison between them as to specific criteria. Note that this table is subjective and the individual designers may take exception and disagree with some of how it has been characterized. To some extent, this is fine and appropriate to the state of the science in San Francisco Bay at this moment in time. There have not been enough projects designed, permitted, built and monitored to allow for a thorough assessment of the best and most cost-effective approach to solving shoreline flooding and erosion issues using nature-based solutions. Technical disagreements can be enlightening and prompt discussion and potentially focus monitoring in a direction that provides answers.

Table 11: Summary table of potential difference between the two approaches

Criteria	GBDT	Dynamic Beach Nourishment
Shoreline erosion benefits	**Larger** more certain outcome under current and sea-level rise conditions. The design described above assumes one-foot of sea-level rise. Additional sediment would be added to accommodate sea-level rise above one foot.	**May be sufficient**, less certainty, monitor and adjust as the system evolves. The design described above did not include sea-level rise. Additional sediment would be added to accommodate sea-level rise.
Habitat benefits	**Likely** somewhat less habitat benefits since larger sediment sizes may form lag deposits except under larger storm conditions and may inhibit some shorebird uses.	**Likely** higher as sediment is positioned by natural wave forces. However, the benefits may be small and difficult to quantify
Agency permitability (habitat impacts and benefits)	**Harder to permit. Larger footprint,** impacts to existing habitat types, conversion to rocky intertidal	**Smaller footprint, lower** upfront impacts, **greater habitat benefits**, **easier** to permit and lowered cost
Visual impacts	**Greater** with minor visual impacts due cobble/gravel layer just offshore	**Likely lower** - Primarily sand in the shoreline
Public access and walkability	**Improved** over existing, sand added to backshore where primarily public usage is located	**Improved** over existing, sand added to backshore
Maintenance	**Less maintenance** - Design approach allows for overbuilding to account for sea-level rise. Easier to find funding for capital costs then maintenance	**More maintenance** and require funding for replenishment events. Less certainty.
Cost ($)	**Higher** upfront capital cost. **Lower** maintenance cost	**Lower** capital cost and potentially **higher** maintenance costs

While both design approaches may require some nourishment during its life, the dynamic beach nourishment approach requires regular nourishment over a 7-10 year cycle, instead of upfront construction which would likely need less nourishment/maintenance. This is an important design decision to be highlighted for further discussion. Every one of our three sites has different characteristics and while our sites may not be as prone to longshore movement given the wave direction, there are many other sites around the bay (i.e. Aramburu) that are highly vulnerable depending on the angle of wave energy. This report is interested in highlighting issues for consideration beyond the three sites of this study. The beach design approach described above is based on an analysis of geomorphic setting and analysis of particularly dominant wave direction. The dynamic beach nourishment design emphasizes an approach that minimizes impacts to existing habitat areas and resources while building those beach elements that work with the local setting to self-construct and nourish to the extent possible, and adjust as climate conditions change. This approach is will likely require more maintenance over time with associated funding and permitting issues.

Both Approaches: Summary of Permitting Implications

Permitting a project of this type requires bay fill which triggers regulatory scrutiny over the type, quantity and impacts of fill. Permitting issues of this type were explored in a Bay Restoration Regulatory Integration Team (BRRIT) meeting held on February 20, 2021 in which both designs for the Greenwood Beach site were described and the regulatory agencies gave informal feedback. The feedback has been incorporates into the following sections.

The BRRIT indicated that both approaches were likely to be permitable although it was not their role to decide which approach was appropriate to which site. They are interested in alternatives to riprap that are beneficial to species and they are very supportive of pilot projects to gain knowledge on these alternatives. The BRRIT encourages more research backed by long-term monitoring and adaptation plan (MAMP).

The choice of approach is dependent to a degree on the goals of the project – each site has a clear goals for shoreline stabilization, while the habitat goals are less clear. To clarify the habitat goals and determine impacts of each design, there needs to be a better understanding of both the use of the site by listed species (such as the Ridgway Rail, Salt Marsh Harvest Mouse, Longfin Smelt, Green Sturgeon) and their presence in the area. Sensitive habitat such as saltmarsh, mudflat and eelgrass beds were highlighted for being a concern; mudflat in particular was highlighted for its use by shorebirds and Green Sturgeon. The general feeling was that the biggest impact to address would be those related to the mudflats which would be a loss under the Endangered Species Act and beach would not be considered a replacement. The BRRIT would be in favor of whichever approach has fewer impacts to listed species and to sensitive habitat.

Given the relatively small areas that may be impacted, the BRRIT suggested a USACE Nationwide permit may be appropriate. Nationwide 27 addresses aquatic habitat restoration projects but this requires a clear articulation of which aquatic functions are being restored. Nationwide 13 for bank stabilization projects was also discussed. Both permits need more information on the likely benefits and impacts of each design. In particular, impacts in terms of linear feet of shoreline and volumes of fill need to be reported. Nationwide 54 specific to Living Shorelines approaches could potentially work although in practice it has been difficult to apply and is limited to projects of less than 500 linear feet.

Tradeoffs will also be important. A key permitting question is the impacts and longer term ecological benefits for overbuilding upfront for improved shoreline erosion benefits. Overbuilding may mean a single construction event versus a nourishment approach that relies on periodic addition of sediments. Of course, the permitting considerations are also site-specific so for at least two of the sites (Greenwood and Paradise) the park setting may favor a softer upfront approach that involves more frequent maintenance. But given the goal of this project to serve as a demonstration project for other sites that includes non-park settings, this trade-off discussion is worth highlighting.

Specifically, the main take-aways and trade-offs can be summarized as follows:

- Construction of a beach type that may not have been historically present at the site in order to minimize shoreline erosion, i.e. a constructed beach at a location where a beach may not be restoration but rather designed to serve a practical function to inhibit shoreline erosion as an alternative to riprap. There may be a practical goal to prevent shoreline erosion but that provides minimal habitat values and does impact some offshore habitat types such as mudflats as they are converted to coarser-grained sites.

- Tradeoff between impacts to certain habitat types (i.e. mudflats) that are found in abundance to others such as rocky intertidal that may provide different but somewhat equivalent habitat benefits in addition to achieving shoreline erosion reduction benefits.
- Minimize permitting and mitigation costs to allow beaches to be used instead of riprap.
- Quantifying, or at least estimating, quantities and costs for maintenance and replenishment
- Evaluating impacts and benefits to public access and recreation

Both Approaches: Possible Mitigation Measures

This section describes potential monitoring and mitigation measures that may be required by the permitting agencies based on our experience working in the bay tidal systems. The actual monitoring and mitigation measures will be determined during the next phase of the project design and may differ significantly from those described below. This list is not intended to be complete but only to provide a list of likely or possible mitigation measures as part of our feasibility level analysis and cost estimates for the project. Temporary construction impacts to scenic and recreational uses (esthetic, noise, access impacts), salt marsh (wetland vegetation), special-status wildlife, invasive species spread, and special-status plants are foreseeable, but they can be mitigated to less-than-significant levels by the following mitigation measures.

Mitigation requirements are usually tied to impacts. Although in recent years the permitting agencies have acknowledged the need for bay fill to address the impacts of sea-level rise, there is a regulatory permitting preference for minimum fill and for mitigation due to fill impacts. The details of the mitigation measures will be worked out in the next phase of project final design and permitting negotiations.

Following discussions with the BRRIT, potential mitigation measures may include the following:

- Protection of the Brunini saltmarsh from erosion;
- Addition of subtidal enhancements such as subtidal reef balls;
- Reduction in eroded fill and asphalt entering the Bay;
- Removal of additional fill and eroded materials from the shoreline to expand tidal habitat.
- Offsite mitigation to the extent that on-site mitigation is not feasible
- Reduction of constructions impacts by placing sediment only at low tide from the land,

While the first four measures could be, or are, part of the designs, the last two measures could significantly increase the scope and cost of the project.

Both Approaches: Proposed Monitoring Program

This section presents a concept monitoring program for the proposed project. Actual project monitoring requirements with a revised budget will be further developed during subsequent project phases and following discussions with the permitting agencies. The goal is a robust monitoring program that allow for development of a “lessons learned” summary of the project success and failures and dissemination of this information. The BRRIT would like to this monitoring coupled with a monitoring and adaptive management plan (MAMP). Note that the bay is considering a regional wetlands monitoring program of which projects like this one would fit in perfectly and provide a larger bay wide assessment of monitoring performance and success well beyond each individual site. A larger bay wide effort would also allow for more detailed and potentially more costly monitoring of larger physical processes that may be beyond the scope of any individual project.

The MAMP would need to identify clear goals for the projects and set performance criteria. There is a basic requirement that the project should function as intended for a period of time – 10 years was suggested at the BRRIT meeting. A 5- or 10-year monitoring period was suggested by the BRRIT, after which an assessment would be made of how the project was performing, an analysis undertaken of significant issues, and a consultation with agencies on a course of action.

Monitoring objectives and measures may include the following:

- Assessment of geomorphic and vegetation including monitoring the changes in the development of the beach system.
- Quantitatively and qualitatively measure the movement of placed sediments in order to develop a more accurate assessments of levels of sand and potential gravel loss to inform maintenance requirements and costs.
- Assess shoreline erosion over several years in order to assess the effectiveness of the design in slowing or arresting continued erosion.

The project site may be photographed annually with high-resolution digital aerial photography using commercial UAV overflights. Digital aerial photographs will be ground-truthed with well-distributed plots (releves) to record plant species composition and cover-classes of vegetation, and fixed-perspective permanent ground photo stations. Topographic changes may be determined using Structure form Motion (SfM) analysis of 2-dimensional images or by LiDAR in years 1, 3, and 5 after construction with the details will be developed during the permitting phase of the project.

Next Steps

The report investigates and highlights two design approaches. Four actions have been identified for next steps:

1. Meet with stakeholders to decide what approach to move forward with at each site as it comes to meting project specific goals and objectives. Take the selected approach forward to final design, permitting and preparation of construction documents for implementation.
2. If they choose to move forward with the GBDT approach, then the stakeholders can make decisions regarding what water levels, design waves and sea-level rise estimates should be used.
3. Upon obtaining of funding, survey more reference beaches and assess their morphology. Assess the wave energy climate for each beach as well as for each of the design sites. This will allow the appropriate reference beach to be matched with each site.
4. Construct and monitor pilot projects of this type to learn what works and under what site conditions.

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Appendix A:

Historical and Modern Estuarine Beaches of San Francisco Bay

APPENDIX

Historic and Modern Estuarine Beaches of San Francisco Bay

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Figures

1.0 Introduction: Estuarine Beaches of the San Francisco Estuary

This appendix provides introductory background on geographic variation in San Francisco Bay beaches, and context about similar “low energy” beaches studied in bays of other regions. In the original Baylands Ecosystem Goals Project (Goals Project 1999) and its science update edition in 2015, beaches in San Francisco Bay were treated as a discrete estuarine habitat category, like tidal marsh or mudflats. But just as tidal mudflats and marshes intergrade by ecological succession, and by erosion and depositional processes, estuarine beaches can also intergrade with marshes and mudflats, or exist as discrete shore landform types that are independent of tidal marsh-mudflat systems. Prior to widespread reclamation and diking of tidal marshes in the 19th century, the Central and South Bay beaches occurred predominantly as widespread marsh-fringing sand and shell hash barrier beaches and related, intermediate beach-wetland landforms within a tidal marsh landscape. In contrast, “pure” estuarine beaches outside of large tidal marsh landscapes were mostly limited to embayments or pockets in cliffed upland shorelines (rocky or unconsolidated bluff shorelines), like some of the Marin, San Francisco, and Richmond baylands segments. Although most of the extensive original estuarine marsh-fringing beaches of the Central Bay were destroyed before the 20th century, at least one old relict marsh-fringing beach system persists (Whittell Marsh, Point Pinole, Richmond), along with a few ancient pocket beaches unrelated to marshes (Angel Island beaches, China Camp Beach, Point Molate and Richmond pocket beaches;Figures 1,2,7,12, 14) In addition, and many new estuarine beaches have spontaneously re-formed in artificially filled shoreline settings, through interactions between natural processes and both natural and artificial beach sediment sources (e.g., Foster City shell hash beaches, and Marina Bay barrier beach, Richmond;Figures 10, 16)

2.0 Geomorphology of San Francisco Estuary beaches

2.1. Estuarine “low energy” beaches

Estuarine (bay) beaches are one of the coastal settings of “low energy” beach, a category that is distinct from typical ocean beaches in terms of wave climate, size, form, dynamics, and the relative influence of different beach processes. Low energy beaches are associated with bays, gulfs, sounds, or sheltered lagoons and estuaries where ocean swell influence is negligible, and where limited open-water fetch (conventionally estimated at 25 km or less) restricts non-storm significant wave heights to less than 0.25 m. Significant wave heights of low energy beaches during strong onshore winds are typically to less than 0.5 m (Jackson *et al*. 2002a). Low energy beaches also are likely to differ from dynamic morphological responses of beaches from maritime (ocean) coasts to storm and fair-weather waves. Low energy beaches exhibit more persistent morphological features left over from storm events, in contrast with more rapid seasonal storm and post-storm recovery of maritime beach profiles. In the absence of long-period, low-steepness swell, onshore transport of sand transported offshore during storms is relatively slow, potentially delaying post-storm beach profile recovery (Goodfellow and Stephenson 2005, Jackson *et al*. 2002a).

One of the outstanding contrasts between maritime and estuarine beaches is the prominent role of fine-grained, muddy low tide terraces like estuarine tidal flats (Figure 1). Estuarine beaches, like those of San Francisco Bay, are fronted by wide low tide terraces composed of very wide, muddy intertidal flats with highly dissipative profiles. Cohesive fine silts and clays of estuarine low tide terraces can restrict onshore wave transport of larger sand or shell hash sediments embedded in muddy low tide terraces. Low energy beaches are exposed to variable wave approach by short-period wind-waves that undergo less refraction than swell, increasing the potential for longshore transport along open shorelines.

The intertidal zone of estuarine beach systems bordering tidal mudflats is therefore divided between narrow, steeply sloping upper foreshores with coarse-grained beachfaces (sand, shell hash, or gravel; and broad, flat finer-grained low tide terraces with smaller amounts of beach-sized sediments embedded in cohesive muds. The beach step (the outer edge of the sloping beachface) is usually marked by an abrupt change in grain size from coarser sand or gravel, to fine silts and sands (bay mud), at the limit of wave backwash (Figure 2). This estuarine beach profile, typical of most San Francisco Bay beaches, represent the low end of the "low energy" beach spectrum, where incident wave energy is fully dissipated over mudflats at tide levels near Mean Sea Level and below, and wave breaking, swash, and backwash, occur primarily on the narrow sloping beachface. (Figures 1, 3)

Wave action is negligible at the estuarine beachface until tide levels submerge the fine-grained low tide terrace, providing sufficient depth above tidal flats for wave propagation. Most tidal mudflats in San Francisco Bay grade up to elevations near mean sea level. Thus, the active estuarine beachface, where swash and backwash transport sand, shell hash, or gravel, is largely restricted to mid-high tidal elevation ranges above mean sea level. The abrupt edge between beach (swash/backwash of coarse sediment) and tidal flat (prevalent fine sediment) is visually conspicuous at most San Francisco Bay beaches at low tide, where the beach step (lower edge of the beachface) terminates with a sharp line of coarser sand or gravel over cohesive mud, sandy mud, or other shelf material rather than a continuous beach profile. (Figure 2).

In contrast, typical maritime beaches usually have broad surf zones and intertidal profiles dominated by beach-sized sediments where wave breaking and wave bores pass over the tidal cycle. The wide surf zone below the beachface of maritime beaches allows both cross-shore and alongshore transport by waves and currents at all tide stages. Ocean beach profiles may exhibit one or more intertidal or nearshore subtidal bars, where beach sediment can be transported and exchanged across the whole beach profile between storm and post-storm recovery phases. (Davis and Fitzgerald 2004, Komar 1976, 1988). The nearshore subtidal "closure depth" concept of coastal engineers (theoretical equilibrium beach profile depth beyond which beach sediment transport is negligible) for maritime beaches may be inapplicable to most estuarine beach profiles with muddy low tide terraces, or it may have limited application to the shoreward limits of the low tide terrace, close to the beach step.

In San Francisco Bay, most estuarine beaches are very narrow compared with maritime (ocean coast) beaches, with moderately steep or slightly concave-upward profiles on estuarine sand beaches and very steep profiles on shell hash and gravel estuarine beaches. The calm-weather backshore beach zone (sparsely vegetated high tide beach above normal tides and wave runup) within San Francisco Bay is typically very narrow (a few meters wide) compared with maritime beaches that are exposed to high ocean swell during winter storms (10s of meters wide). Maritime beaches, in contrast, typically have wide berms backed by substantial coastal dunes, bluffs, or cliffs. Maritime beaches are shaped in part by exposure to long-distance high swell, including storm waves, which can widen the beachface into a broad, dissipative profile, or spread out the backshore with very extensive, high-energy bores (turbulent, broken waves) that form wide storm washover fans or flats. Estuarine beaches are primarily exposed to locally generated, steep, short-period wind-waves, with significant breaking wave heights normally less than 0.25 m (0.1-0.25 m; Jackson *et al*. 2002). Low wind-waves build relatively narrow, steep beachfaces (swash slopes) and beach berms (with flat-topped, backshore dry sand beach areas), often only a few meters to at most a few tens of meters wide. Where storm washovers do occur, they are associated with super-elevated high tides and short-period storm wave bores transporting sediments and coarse debris over the submerged estuarine barrier beach and backbarrier salt marshes.

2.2. San Francisco Bay beaches and sediment types

San Francisco Bay beaches vary geographically in the relative importance of contrasting beach sediment types and sources. Sand beaches and their provenance are by far the most extensive type and best studied (Barnard *et al*. 2013), but regionally unique estuarine beaches composed of fossil oyster shell hash were historically extensive along the San Francisco Peninsula bay shores, and many still regenerate there today. Natural gravel beaches, mixed sand and gravel beaches and even cobble beaches are more narrowly distributed along rocky cliff and bluff shorelines of Richmond and Marin, and (historically) southern San Francisco. These beach sediment types, and the dynamic beach forms they comprise, are summarized below.

2.2.1. Estuarine sand beaches. Sand sources of estuarine beaches in the Central Bay are primarily associated with erosion of Pleistocene Merritt Sands of eastern Central Bay (Bonilla 1971, Barnard *et al*. 2013b) and Colma Formation deposits of the San Francisco Peninsula. Merritt Sands are composed of well-sorted paleodune sand, with some raised beach deposits. These were originally derived from Sierran glacial outwash, reworked by waves and wind when the antecedent San Francisco Bay lowland was a marine embayment (Witter *et al*. 2006). Colma Formation on the San Francisco Peninsula (Bonilla, 1971), has been described as a marine, estuarine and fluvial, unconsolidated fine to medium sand with some silt and clay. The stabilized paleodune sand hills of Oakland (oak woodland and grassland vegetation, soils) formed wave-exposed sand bluffs along the bay edges of Oakland and Alameda (Figure 4), supplying pre-sorted medium beach sand to form barrier sand spits. Seasonal and ephemeral streams in gulches and valleys draining Colma and Merritt deposits also transported sand to bay shores, supplying beach sediment to longshore drift processes (e.g., mid-19th c South Oakland, Alameda, Bay Farm Island). Dredging and sandy dredge spoil deposition in industrial era also mobilized buried Merritt paleodune sand, making it available for wave erosion and transport onshore and alongshore. Similarly, bay fill along the San Francisco Peninsula and Oakland delivered Pleistocene sands to the modern bayshore locally, adding to sands transported by stream channels and flood control channels to the bay. (Figures 3, 5)

Watershed-derived sand sources for San Francisco Bay estuarine beaches are associated with stream deltas that reach the bay tidal flats, or reached historical tidal marshes, delivering local watershed sediment from local ridges. An outstanding regional example is San Lorenzo Creek (flood control channel), which contains coarse to medium sand extending far into Central Bay tidal flats, forming a delta platform capped with multiple sand bar forms and patterns rare or absent elsewhere in the Bay, and associated with intermediate beaches (emergent swash bars) and stabilized sandy salt marsh berms. (Figure 6). Smaller creeks around the Central Bay also delivered sand to deltas in bay flats that were reworked into historical and modern estuarine beaches. Examples include unnamed pocket barrier beaches of pre-reclamation Richardson Bay. Local sand beaches at Blackies' Pasture open space shore in Tiburon, for example, are associated with an active depositional intertidal delta (the mouth of a flood control channel), where storm discharges deposit sand and gravel over the surrounding muddy low tide terrace. The deltaic sand deposits appear to have been reworked by wave action to form fringing beaches near the historic location of an extinct barrier beach across a former (reclaimed) marsh-filled valley.

Sand grain size distribution and sorting patterns vary geographically around San Francisco Bay and San Pablo Bay. Well-sorted medium sand grain sizes are prevalent in Central Bay beaches, associated with Merritt Sands and Colma Formation sand sources, particularly from the Golden Gate, south Richmond, West Berkeley, Oakland, Alameda, and San Francisco. Heterogeneous (variously well-sorted to poorly sorted) medium to coarse sands beaches are prevalent in Marin beaches derived from hillslope gulches (ephemeral streams) or headland erosion in Richardson Bay, Corte Madera, San Rafael Bay, and China Camp, and Richmond beaches from Point Molate, Point San Pablo, and Point Pinole (Figure 7).

With the exception of the artificially nourished Crown Beach (filled to a backshore width significantly larger than any historical natural bay beaches represented in U.S. Coast Survey maps), most sand beaches in the SF estuary today, formed under the influence of low fair-weather wind-wave energy, are small compared to swell-dominated beaches of the outer coast. Wind-wave dominated sand beaches of around the Bay are usually only about 15-25 ft wide at high tide (backshore beach; dry berm tops), with intertidal beachfaces 30-60 ft wide. Some bay beaches exposed to limited refracted swell in the Golden Gate (e.g. Crissy Field, Angel Island beaches) are often wider than beaches influenced only by local wind-waves.

During storm erosion events and extreme high winter tides, sand beaches are overtopped or energetically overwashed (barrier beaches), or scarped (vertical wave-cut low cliff in moist sand) by erosional storm waves, which flatten the beachface to a wider, dissipative profile. Where bay beaches are oriented oblique to wave approach during storms, without headland or other restrictions on longshore drift, rapid longshore drift of sand can occur during storm wave events. Low-energy sand beaches with narrow beachfaces, limited cross-shore transport (muddy low tide terraces), and limited sand supply, often undergo relatively slow post-storm recovery (Jackson *et al*. 2002a)

Coarse sand beaches in San Francisco Bay are wind-immobile, and form at most minimal dune veneers where medium sand is available to deflate in the beachface. Coarse sand beaches, when relatively inactive, become vegetated with mixed high salt marsh vegetation and beach vegetation. In contrast, medium sand beaches, depending on orientation to dominant westerly winds and beach width, can develop foredune vegetation. Foredune vegetation in San Francisco Bay can be composed of burial-tolerant high salt marsh vegetation (especially saltgrass, alkali-heath), or typical beach and foredune plants (beach wildrye, beach-bur). Non-native creeping perennial shoreline vegetation, such as iceplant (*Carpobrotus edulis* and hybrids) can also build low foredunes. These burial-tolerant bay shore vegetation types (see section 3.5 below) are capable of sustaining accretion of low foredunes by sequential eolian sand deposition, trapping sand within roughness of standing vegetation, and regenerating vegetation canopies that recover after sand burial. Taller, erect shoots of creeping perennial plants, with shoots that persist over winter, are most efficient and building low foredunes in

San Francisco Bay. The range of naturally accreted foredune morphology in San Francisco Bay includes scattered low (0.5-1.5 m) dome-like dune mounds on washovers (e.g. Roberts Landing "Long Beach", San Leandro), narrow foredune ridges (e.g., Radio Beach, Bay Bridge toll Plaza [Figure 3], and Crissy Field, Presidio), and low foredune terraces (flat-topped dune veneers; Swimmer's Beach, Angel Island). Historical mid-19th century dune landforms on barrier spits between Oakland (Brooklyn) and Bay Farm Island are delineated on U.S. Coast Survey T-sheets. They were associated with larger west-facing sand barrier beaches, and included multiple dune ridges and blowouts with apparently greater size and relief than exists today.

2.2.2. Estuarine shell hash beaches

Extensive, large oyster shell hash beach ridges and spits are a shoreline type unique to San Francisco Bay on the Pacific North American coast. Historically, massive oyster shell hash beaches were the prevailing beach type along the San Francisco Peninsula bayshore south of San Francisco (Hart 1978), from San Mateo (Guano Island) to Ravenswood (Palo Alto). Remarkable and extensive spits, barriers, and marsh-fringing barriers in San Francisco Bay were composed of native oyster (*Ostrea lurida*) shell hash (shells and disintegrating shell flakes). They formed a "white glistening" barrier beach and bar chain of discontinuous beaches extending for about 12 miles or more south from San Mateo (Townsend 1893:355). The shell hash deposition rate was reportedly massive along the San Mateo bayshore "shellbanks" in the late 19th century, described as a "constantly increasing deposit of shells that covers everything alongshore and forms bars extending into the bay" (Townsend 1893:355).

Equivalent or nearly identical large oyster shell hash beach ridges, spits, and complex cuspate or scrolled (highly recurved) forelands develop today along the Foster City shoreline to Belmont Slough mouth, most of southern Bair Island and Bird Island. The most complex shell hash beach forms on Bair Island are associated with evolution of shell deltas (mouths of breached, beach-dammed tidal marsh channels) reshaped by longshore drift and wave action as strongly recurved, oblique, offset flying spits (Figure 8a) like those of the Caspian and Black Sea (Zenkovich 1967). Topographic and tidal drainage pattern signatures of vegetated shell hash berms (stabilized beaches) are evident along both modern shell hash beach-fringed marsh shores (Figure 8b) and mid-19th century salt marsh edges of the U.S. Coast Survey T-sheets covering these localities (Figure 9).

Oyster shell hash is a mixture of wave-abraded Olympia oyster shells and partially disintegrated shell flakes. Olympia oyster shells are eroded from extensive exposures of mid-Holocene (fossil) shell-rich mud deposits, including shell lenses and veneers (Figure 10), by wave and current action that transports shell onshore (Hart 1978). Abundant Olympia oyster shell deposits in bay mud are remnants of past Holocene climates associated with low bay turbidity and high salinity, at lower sea levels than today (Hart 1978). The late Holocene age of shell-rich muds are probably associated with oyster-dominated strata of California Indian shell mounds (middens) of the East Bay (Nelson 1906, Gifford 1916). The abundant oyster shell muds deposits are relict mid-late Holocene legacies, with the last phase of oyster abundance ending relatively abruptly around 430 C.E., based on archaeological data (Milliken *et al.* 2007). This is consistent with evidence of a climatic shift of the Little Ice Age in San Francisco Bay (LIA I and LIA II) from 650 to 280 cal yr BP (McGann 2008), with rapidly increased fine sediment accretion and tidal marsh expansion (Watson and Byrne 2013). Some subtidal living Olympia oyster reefs, however, were reported from San Francisco Bay as recently as the 1970s (Hart 1978), and were presumably still generating shell sediments. Between 1924 and the 1970s, up to 30 million tons of Olympia oyster shell were dredged from San Francisco Bay, for industrial manufacturing processes. Shell mining continues today at a rate of 80,000 cy/yr (40,000 tons/yr) (California State Lands Commission 2018). The cumulative effect of historic and modern shell mining on sediment supply to South Bay shell beaches and mixed sand/shell beaches is unknown.

Low-density Olympia oyster shell hash is sorted by wave action, concentrated and deposited in shallow subtidal bay and intertidal mudflats as variable bars forms. Depositional bar and beach forms include relatively stationary and mobile submerged bars, intertidal swash bars, barrier beaches, spits, and transverse bars (Figure 10). Onshore shell hash transport along marsh edges or artificially armored shores today still generates highly dynamic, large estuarine beach ridges, spits, and cuspate forelands. The most extensive and largest shell hash beaches today occur along the Foster City and south Bair Island shorelines. Olympia oyster shell hash is physically dissimilar from heavy shells of introduced Pacific oysters (*Crassostrea gigas*) of mariculture operations.

Studies of beach morphology and dynamics of oyster shell hash beaches are scarce in the global literature on coastal geomorphology, probably owing to their geographic rarity. Oyster shell hash beaches in some respects behave like gravel beaches (rapid infiltration of backwash, high, steep berm and beachfaces), and in some respects like sand beaches (rapid entrainment in turbulent backwash and wave-generated longshore currents). Low-density shell hash flakes, with discoid shape and high surface/volume ratio, have relatively low settling velocities compared with sand and gravel. They can be extensively transported in suspension by turbulent wave action, as well as in bed load (swash/backwash) during storm events. Natural San Francisco Bay shell hash berms and bars can deposit very rapidly: transient swash bars at Bair Island can visibly form in minutes under the influence of boat wake series, or during short periods of high wind-wave action or tide heights (Figure 11). Significant shell hash beach accretion (progradation) alongshore can also be very rapid, occurring during single tidal cycles or single storm events. Once deposited by swash, the packing arrangement of horizontally bedded, settled shell (interlocking, imbricate internal structure) can resist remobilization by lower energy waves, leaving sharp-crested scarps and relict ridges above the active beachface.

Dynamics of oyster shell hash beaches in San Francisco Bay vary with their shoreline setting and wave exposure. Oyster shell hash beaches can be highly dynamic in wave-exposed, drift-aligned convex shorelines, rapidly prograding or migrating alongshore as cuspate beach ridges (often multiple beaches), “scrolled” (highly recurved) cuspate forelands, and spits along the Foster City and Bair Island (south) shores. Extensive gradual onshore transgression of salt marsh-fringing shell hash barrier beaches also occurs by rollover and gradual marsh scarp retreat. Shell hash spits also can rapidly migrate onshore over tidal flats by “rollover” (overwash deposition landward, bayward erosion and shoreline retreat; Figure 10). During relatively stable positions, shell spits compress and deform bay mud platforms over which they migrate, leaving a one or more low-relief mudwave “footprints” in the low tide terrace as the barrier retreats. Relatively stable, gradually transgressive fringing or pocket oyster shell hash beach ridges, in contrast, can develop in heads of shallow embayments between low headlands (such as artificial fill or marsh peat outcrops). Relict (inactive, wave-sheltered) shell hash beach ridges can be stranded within sequences of prograding marshes and beach ridges, such as the Foster City shore near the mouth of Belmont Slough. Relict shell hash beach ridges, up to a meter above adjacent salt marsh plain elevations, become stabilized with high salt marsh and transition zone vegetation (high salt marsh berms resembling artificial berms).

The imbricate structure of overlapping disc-like shell hash in enables it to develop very steep beachface slopes, like gravel beaches, but under the influence of relatively lower wave energy. Wave-cut scarps in shell hash ridges can persist as nearly vertical banks. Progradation of shell beach ridges (bayward accretion) often results a composite structure of closely spaced, steep, high berm crest series.
Older, stabilized shell hash beach ridges can undergo weak cementation, and increase in resistance to erosion. Shell hash beach ridges are subject to rapid colonization by high salt marsh vegetation once active mobility of the surface is significantly reduced for a year or more (no significant winter storm wave action), converting them to high salt marsh berms. (Figure 8)

The supply of oyster shell hash for beach accretion may be influenced by commercial oyster shell mining at permitted rates up to 80,000 cubic yards/year (San Francisco Bay Conservation and Development Commission) under a subtidal lease area approximately 1560 acres offshore from the Foster City-Bair Island shell beaches (California State Lands Commission 2011). Limited data are available on the distribution and abundance of shell and shell-rich mud shoals that supply beach sediment.

2.2.3. Estuarine gravel beaches

Estuarine gravel beaches in San Francisco Bay occur naturally along bay shores with erodible rocky cliffs or bluffs containing gravel-sized sediment (2-63 mm;Figure 12), and also along artificial bay fill or armored shorelines that supply gravel-sized sediment from erosion of disintegrating concrete or other anthropogenic materials (Figure 13). Naturally well-sorted, nearly pure gravel beaches are uncommon in San Francisco Bay, compared with poorly sorted, mixed sand and gravel beaches with characteristics more similar to sand beaches (Jennings and Shulmeister 2002). Most gravel beaches in the San Francisco Estuary occur as poorly sorted mixed sand and gravel beaches, or (less often) well-sorted composite gravel and sand beaches (stratified profiles with gravel berms above sand beachfaces;Figure 12).Augmented (nourished) natural gravel beaches and artificially constructed gravel beaches in relatively low-energy bays are increasingly used in the Puget Sound (WA) region as nature-based shoreline erosion control alternatives to rip-rap (Johannesen *et al*. 2014).

Estuarine composite sand and gravel beaches, characterized by a sandy beachface and a steep storm gravel berm in the backshore (Jennings and Shulmeister 2002) are rare, local, and seasonal in the San Francisco Estuary, occurring at a few shoreline segments at Point Pinole, Richmond, and Tiburon, Marin County. (Figure 13). Storm gravel beaches (Buscombe and Masselink 2006) are coarse gravel beach ridges (including gravel barrier beaches) that are relict deposits of extreme high storm wind-waves during extreme high tides, when sand beachfaces (if present) are eroded and flattened to dissipative profiles. The coarse gravel storm berm contrasts with sand or gravel beachfaces deposited in normal fair-weather, constructive wave action. Much of the storm gravel bermis effectively stranded outside the active beach system, since it lacks a mechanism for offshore transport during calmer conditions. Storm gravel berms and relict storm gravel ridges in San Francisco Bay range from relatively small cliff-toe fringing gravel beaches, to wide marsh-fringing gravel barrier beaches with coarse sand beachfaces.

Estuarine mixed sand and gravel beaches and poorly sorted coarse sand beaches are common along pocket beaches along cliffed shores and canyon or valley mouths (Figure 12) in Marin County (Richardson Bay, San Rafael Bay) and Richmond (Point Molate, Point San Pablo). Gravel beaches derived from erosion of artificial bay fills, armored shores, and old landings around in South San Francisco Bay also occur in small shoreline pockets or around relatively resistant forelands and headlands, or at the mouths of flood control channels.

Gravel beaches and very coarse sand beaches develop steeper, wave-reflective beachfaces, and higher crests than sand beaches with grain sizes smaller than about 1.5 mm. Gravel and very coarse sand beaches coarser than this threshold grain size have hydraulic conductivity exceeding 1 cm/second. Gravel and very coarse sand beaches exhibit rapid infiltration of swash and backwash in large pore spaces, resulting in asymmetry in the volume and energy of swash and backwash, favoring net onshore transport and steep beachfaces of gravel and very coarse sand beaches (Masselink and Li 2001, Buscombe and Masselink 2006). Mixed sand and gravel beaches, however, tend to have pore spaces filled with sand, resulting in hydraulic conductivity, swash/backwash processes, and slopes more like those of sand beaches. The inherent capacity of permeable gravel beaches to accrete vertically and maintain berm profiles even, during storm wave action that typically erodes sand beaches, makes them especially useful for shore erosion control objectives.

Gravel beaches in San Francisco Bay are usually associated with local erosional sources of gravel at the bay shore, including wave-cut cliff and bluff erosion, slope failures, erosion of artificial fill, and disintegration of old concrete shoreline armoring. Estuarine gravel beaches occur primarily in Marin and Richmond bay shores where steep wave-cut hillslopes and intertidal benches form the bay shore instead of wide alluvial fans and plains and salt marshes. Small natural estuarine gravel beaches are common along cliffed shorelines of Marin (north Richardson Bay, San Rafael Bay, McNear’s, China Camp), where they often intergrade along wave exposure gradients with mixed sand and gravel beaches. The largest natural gravel beaches in San Francisco Bay occur along the west-facing bluffs of Point Pinole (Figure 14). Natural lithology of gravel beaches in San Francisco Bay ranges from relatively erodible sedimentary rocks (shale and sandstone) to relatively hard metamorphic rocks (Figure 14). Anthropogenic gravel beaches dominated by “seaglass”, metallic slag, metal fragments, concrete rubble, brick, ceramic shards occur locally near some old landfills in the bay (e.g., West Berkeley, Richmond; Figure 13).

2.2.4. Estuarine cobble beaches and lag shores

The least common beach type in the San Francisco Estuary is composed of the coarsest, least mobile beach sediments: cobbles, coarser than very coarse gravel (63-200 mm). In low wave energy shorelines like estuaries otherwise dominated by cohesive fine sediments, cobbles can behave much like boulders (over 200 mm), which embed in mud and form immobile lag armor deposits or veneers over mud, peaty mud, or muddy sand. Rounded cobbles roll and pivot under higher storm wave energy levels, and can form storm cobble berms like gravel berms. One of the only natural occurrences of rounded cobble beaches in the Estuary occurs at Point Pinole's western shoreline, where rounded cobbles locally erode out of bluffs. (Figure 15) The lower foreshore of the cobble-dominated shoreline is a natural, immobile lag surface (cobbles embedded in peaty mud or basal bluff clays), and an upper foreshore cobble storm berm that is active during high tides and high wave action.

Other cobble beaches in San Francisco Bay are more like rocky shores, because angular, interlocking cobbles behave like rip-rap, and exhibit little erosion or deposition even under storm wave action. Estuarine beaches intermediate with rocky shores, composed of angular cobbles mixed with gravel from colluvium below cliffs and bluffs, occur on East and West Marin Island (San Rafael Bay), Red Rock Island, and scattered cliff-toe shorelines at Point San Pablo, north of Point Molate(Figure 15). Angular cobble and boulder shores in the San Francisco Estuary are relatively stable or static rocky shore types, rather than sedimentary environments like beaches. They are ecologically and structurally similar to armored (rock slope protection with rip-rap) shorelines, except that natural rock outcrops in San Francisco Estuary are mostly erodible sedimentary rocks, and rarely highly resistant metamorphic rock like greenstone or blueschist.

Cobble lag deposits embedded in estuarine muds or wave-cut benches in clay sediments (cliff outcrops) can also form ecotones between salt marsh, rocky shore habitats, and cobble beaches in San Francisco Bay, albeit rarely. They combine relatively static mid-intertidal zones (lag armor shoreface and marsh), and dynamic upper intertidal zones (cobble beachface and berm). A gradient between cobble-armored, wave-sheared salt marsh, cobble-armored mudflat, and cobble-gravel beach occurs locally below erosional wave-cut unconsolidated bluffs at western Point Pinole (Figure 15). Cobble salt marshes (Kennedy and Bruno 2000) are primarily known from glaciated, retreating coasts.

2.3. San Francisco Estuary beach provinces

There are significant geographic patterns of variation in low-energy beaches within the San Francisco Estuary. Many beach types are expressions of multiple nearshore and backshore interactions that may persist despite anthropogenic modification, such as bay fill or shore armoring. They correspond with sediment types, sediment texture, wave exposure (fetch, offshore depths, nearshore and intertidal shore profiles), shore orientation to waves and wind, and most importantly, shore setting (backshore influences on wave approach and sediment transport, such as headlands, embayments, reefs, outcrops, marshes, beach sediment supply from streams or cliff erosion, etc.).

Geographic patterning of modern San Francisco beach forms and types in many cases echo or replicate their historic antecedents; in some cases, direct descendants of pre-historic beaches persist in situ (e.g.

China Camp pocket beaches, Whittell Marsh Beach, Point Pinole, and south-facing Angel Island beaches). Where urban bay fill dominates the shore, anthropogenic changes erase and override historic sediment types and beach forms, and introduce novel low-energy beach types on artificial built-out diked and filled bayshores (e.g., most northern San Francisco Peninsula shores, and most East Bay shores from south Richmond south to Dumbarton Bridge). The diversity of novel anthropogenic beaches also provides indicators of how local wave climates and sediment types interact over decades to form relatively persistent new beach forms. The correspondence between beach type, scale, form, and geographic setting can provide a starting point for planning beach nourishment, restoration, or creation where local reference systems have been eliminated or severely reduced. For these reasons, a preliminary classification of geographic provinces of beach types within the San Francisco Estuary is provided below and described in the supplemental map and table at the end of this appendix.

Golden Gate, Central Bay

- *Wave climate*: mix of refracted swell and relatively long fetch over the greatest water depths in Central San Francisco Bay. Oblique wave approach prevalent except west-facing Emeryville-Oakland shore. Ferry wakes are locally significant (Angel Island, San Francisco).
- *Nearshore bathymetry and sediments*: Deepwater bay abruptly shelving near shore within the Golden Gate (Marin Headlands, San Francisco, Angel Island, Yerba Buena Island). Flood tidal delta littoral exchange and sand transport in submerged shoals, sand waves (subtidal dunes). Reworking of dredged Merritt Sand (Pleistocene lagoon, beach, dune deposits) in Emeryville-Oakland and vicinity, within tidal mudflats.
- *Backshore topography and sediments*: steep headlands and cliffs, landslides, bluffs with some local relict Pleistocene dune sand deposits (Angel Island, Yerba Buena Island) or alluvium (Marin), and filled bayshore (San Francisco barrier beaches, lowlands). Gully erosion of upland Pleistocene sand deposits. Minor depositional foredune terraces or low ridges (Swimmer's Beach, Angel Island; Presidio SF; Radio Beach, Oakland)
- *Modern beach sediment type, grain size*: predominantly well-sorted quartz-rich medium sand; minor or trace shell, gravel.
- *Historic beach sediment type*: (inferred) similar medium sand reworked from erosion of Pleistocene and Holocene dune deposits, flood tidal delta and inlet shoal transport.
- *Beach plan form, orientation, alignment to wave approach*: Predominantly pocket and fringing beaches bounded by headlands, swash-aligned (Angel Island beaches, Radio Beach); spits and drift-aligned fringing beaches (Presidio SF – modern), cuspate spits (Presidio – historic). West-facing swash-aligned barrier beaches, tombolos and spits (Oakland-West Berkeley).
- *Reference beaches*:
  - Swimmer's Beach and Coast Guard Beach, Angel Island
  - Crissy Field Beach-Presidio Beach, San Francisco
  - Radio Beach, Emeryville (Bay Bridge Toll Plaza)

Marin (Sausalito, Richardson Bay, Tiburon, Corte Madera Bay, San Rafael Bay, China Camp State Park)

- *Wave climate:* Wind-waves range from local short fetch in shallow embayments with nearshore tidal flats (San Rafael Bay, Corte Madera Bay, Richardson Bay) to long fetch wind-waves from deeper San Pablo Bay, shoaling across wide, dissipative tidal flats (China Camp, north San Rafael), and long fetch wind-waves and relatively steep nearshore profiles lacking wide tidal flats (Tiburon Peninsula). Most beaches face away from dominant westerly winds, but face winds from SE storm approach direction, and high pressure strong offshore winds from N to NE.
- *Nearshore bathymetry and sediments:* Fine silt and clay, wide low tide terraces, except Tiburon Peninsula (rocky shore platform and mixed mud)
- *Backshore topography and sediments:* Hillslope gulches, slumps, arroyos (ephemeral to seasonal creeks) deliver local alluvium from Franciscan sandstones, shales, and metamorphic rocks to the bayshore. Local cliff and bluff erosion (Tiburon Peninsula, Mill Valley, Strawberry); rock slope protection, boulder armoring of fill (Tiburon Peninsula, Mill Valley, Corte Madera)
- *Modern beach sediment type, grain size:* Mixed medium to coarse sand and gravel beaches (Tiburon Peninsula), angular gravel beaches; infrequent cobble-boulder rocky shore and mixed gravel-sand (Strawberry, Tiburon Peninsula).
- *Beach plan form, orientation, alignment to wave approach:* Predominantly cliff or bluff-backed pocket beaches and gulch or alluvial fan pocket beaches, low drift or swash-aligned plan form; local beach sediment sources (cliff, bluff, ephemeral stream mouth or alluvial fan erosion). Relatively stable beach planforms are associated with some natural coarse sand-gravel pocket beaches (China Camp Beach).
- *Reference beaches:*
    - San Francisco State University Estuary and Ocean Science Center (Romberg) pocket beaches
    - Paradise Beach and vicinity beaches (private)
    - Brickyard Beach, San Pedro Avenue, San Rafael
    - McNear's Beach, San Rafael
    - China Camp Beach, China Camp State Park
    - Rat Island Cove Beach, China Camp State Park

Richmond and Point Pinole Beaches

- *Wave climate:* Long wind-wave fetch aligned with dominant west and northwest winds across deep San Pablo Bay and north Central San Francisco Bay.
- *Nearshore bathymetry and sediments:* Variable wide tidal flats, predominantly mudflats and sandy mudflats; areas of submerged aquatic vegetation (eelgrass) beds. Some dredged sediment sources of shell and sand (Brooks Island).
- *Backshore topography and sediment.* Variable: tidal marshes, stream mouths and deltas, low Tertiary sedimentary bluffs (clayey to sandy, gravelly, and cobble), Franciscan bedrock cliffs (sandstone, shale, chert colluvium)

- *Modern beach sediment type, grain size:* The most variable in the Estuary, ranging from unique rounded cobble-gravel bluff-toe and barrier beaches (west Point Pinole shore), angular cobble-gravel beaches (transition to rocky shore; Point San Pablo) mixed sand and gravel beaches (Giant), medium to coarse sand (Whittell Marsh Beaches, Marina Bay beach) well-sorted medium sand (Molate Beach, Keller Beach), and shell hash-sand beaches (Brooks Island).
- *Beach plan form, orientation, alignment to wave approach.* Variable, ranging from pocket and fringing headland-bound beaches, to marsh-fringing barriers (Whittell Marsh), tombolos (Brooks Island, Marina Bay)
- Reference Beaches:
    - Brooks Island,
    - Marina Bay beach,
    - Keller Beach,
    - Molate Beach,
    - Point San Pablo Beaches,
    - Giant Beach,
    - West Point Pinole Beaches,
    - Whittell Marsh Beaches

Oakland-San Lorenzo East Bay beaches.

- *Wave climate:* Long wind-wave fetch from dominant westerly wind direction, and from south and southwest storm wind approach, shoaling over very wide tidal flats. No significant refracted swell influence south of the Port of Oakland.
- *Nearshore bathymetry and sediments:* Predominantly fine silt and clay low tide terraces, with local prograded sandy mud flats (San Lorenzo Creek delta), with abundant woody debris (riparian detritus) near the mouths of larger flood control channels. Some areas of shell-rich muds (Olympia oysters and clams) are associated with local marsh-fringing shell hash barriers.
- *Backshore topography and sediments:* Historically abundant sources of medium sand from bluff, beach, and nearshore sand erosion (Oakland, "Brooklyn" sand hills with oak savannah or woodland) formerly supplied an extensive series of southerly drift-oriented marsh-fringing spits and barriers, many with single or multiple dune ridges, extending to Bay Farm Island and San Lorenzo (Hayward vicinity). The largest barrier beach chain in San Francisco Bay was replaced by dredged ports and armored diked shorelines in the late 19th-20th century. Low foredunes about 1.5 m high persisted at Long Beach, Roberts Landing (San Leandro) until the 1980s, but were reduced to washover terraces by the 1990s.
- *Modern beach sediment type, grain size*. Medium sand is winnowed from the sandy mud tidal delta of San Lorenzo Creek, forming sand bars (ridge and runnel low tide terrace) and beaches. Small, unstable marsh-perched shell and sand beach ridges with abundant woody debris wracks occur in eroded shallow embayments or coves of retreating salt marsh edges where levees have failed. Crown Beach (Alameda) is artificially nourished with dredged sand from the Port of Oakland, near historic but smaller beaches that existed in the vicinity

before salt marsh reclamation. Small gravel spits occur where wave erosion of decomposing old concrete rip-rap armoring of levees, or historic landings, supplies gravel at receptive shorelines as far south as the vicinity of Alameda Flood Control Channel.

- *Beach plan form, orientation, alignment to wave approach.* Small crescentic pocket beaches occur within narrow, eroded salt marsh embayments. Long Beach is a relatively straight drift-aligned beach, exposed to wind-waves from SW to NW. Cuspate beach protuberances are associated with local refraction around marsh peat outcrops in the beachface and inner low tide terrace.
- *Reference Beaches*:
  - Long Beach, Roberts Landing, San Leandro
  - Crown Beach, Alameda (artificial)

Southeast San Francisco-Brisbane (North San Francisco Peninsula)

- *Wave climate:* Long fetch wind-wave approach from SE (storm), N (thermal breezes, Golden Gate). Locally sheltered embayments (India Basin, Hunters Point)
- *Nearshore bathymetry and sediments:* Wide tidal mudflat low tide terrace; locally shell-rich muds. Deep water nearshore at Port of San Francisco fill shorelines, local headlands (Hunters Point).
- *Backshore topography and sediments:* Predominantly artificial fill sediments including gravel, sand. Historical shorelines included paleodunes, Pleistocene sand deposits, Franciscan mélange bedrock (chert, serpentinite)
- *Modern beach sediment type, grain size:* Medium sand, anthropogenic gravel, shell.
- *Beach plan form, orientation, alignment to wave approach:* Predominantly pocket beaches in shallow embayments; some recurved spits, and drift-aligned fringing beaches on artificial headlands. Historical beaches included bay-head barrier beaches (Visitacion Valley).
- *Reference beaches*:
  - Pier 94
  - Pier 98 (Heron's Head)
  - Brisbane gravel spit

San Mateo-Ravenswood (South San Francisco Peninsula)

- *Wave climate:* Long fetch wind-wave approach from N and NE (thermal breezes, Golden Gate), storm wind-wave approach SE.
- *Nearshore bathymetry and sediments:* Wide mudflats and shell-rich mudflats with shell hash shoals, bars (Foster City to Ravenswood)
- *Backshore topography and sediments:* Tidal salt marshes, levees, urban bay fill, armored bay fill shorelines; local stream mouths and deltas (e.g. San Francisquito Creek, Colma Creek)
- *Modern beach sediment type, grain size:* Predominantly Olympia oyster shell hash beach ridges, spits, marsh-fringing barriers, and some mixed sand-shell hash beaches, above tidal mudflat or shell-rich mudflat.
- *Beach plan form, orientation, alignment to wave approach:* Predominantly drift-aligned marsh-fringing transgressive barrier beaches. Down-drift single and multiple prograded shell

hash ridges, ridge and marsh swale sequences, spits, cuspate spits, cuspate forelands. Local swash-aligned pocket beaches.

- *Reference beaches:*
  - Foster City beaches
  - Bair Island SE shore barrier beach

2.4. Estuarine beach plan form and shoreline setting

The relative stability of estuarine beaches depends on their surrounding backshore shoreline features that influence wave sheltering and exposure, wave approach direction, and littoral obstacles that impede longshore drift. Small variations in shoreline settings modify local wave exposure and sediment transport, which can have have significant effects on beach morphology and dynamics. Backshore settings (supratidal coastal zone, above normal high tides) of estuarine beaches in the San Francisco Estuary historically included free tidal marsh islands and platforms; drowned valley tidal marshes enclosed between upland headlands; alluvial valley shorelines; and resistant rocky cliffs and erodible bluffs. Modern beach settings include some early historic beaches in their original relative positions and settings, such as Angel Island beaches, China Camp beaches (Marin County), and Point Pinole, Point Molate, and Richmond beaches (Contra Costa County).

Most modern beaches in San Francisco Bay, however, have regenerated in artificially altered shorelines formed by marsh and tidal flat reclamation (upland fill conversion), dikes, or shore armoring structures, with new patterns of headlands and sheltered embayments deviating from the historical shoreline. Where remnants of the original sediment supply persist, and local wave climates and sediment transport processes remain effective, modern beaches sometimes re-establish semi-natural, self-regenerated beaches resembling the form and pattern of their historical antecedents, but in new artificial settings. Irregular shoreline configurations caused by resistant rocky headlands or foreshore outcrops, armored bay fill, protruding erosional marsh peats, or shoreline orientation changes provide strong local controls of beach form and dynamics (Jackson and Nordstrom 1992, Phillips 1986).

2.4.1. Beach plan form orientation: swash-aligned and drift-aligned beaches. One of the most fundamental influences of shoreline setting on beach form and dynamics is the effect of embayments and relatively resistant headlands on beach orientation and potential longshore drift. Embayments and headlands restrict wave approach, create pockets that effectively traps beach sediment, and provide obstacles to longshore drift within the embayment.

Embayed beach plan forms tend to adjust their orientation to the long-term average wave approach, wobbling or swiveling with drift caused by short-term variations in wave approach. Such embayed or “swash-aligned” beaches (Davies 1980) tend to develop smooth, concave-bayward (arcuate) to nearly straight plan forms that are relatively symmetrical (or very gradually asymmetric alongshore) in the long-term. Swash-aligned “pocket” sand beaches within relatively narrow embayments can approach zero net long-term drift conditions, depending on the degree of wave sheltering and variability in wind-wave approach in estuarine settings (Figure 16).

Swash-aligned beaches on maritime coasts are more influenced by wave refraction (bending) of long-period ocean swell, which tends to reduce the angle of oblique wave approach in the swash zone within embayments. Short-period, steep local wind-waves drive longshore drift of estuarine beaches, in contrast. Local wind-waves tend to be variable in approach direction to the shore, and are less affected by wave refraction than long-period swell. Strong wave-sheltering and confinement of wave approach by headlands or narrow embayments, however, can result in stable swash-aligned natural estuarine beach plan forms, such as China Camp Beach, but also artificial estuarine beaches (Figure 16). Large-scale, headland-controlled embayments defined by natural rocky shorelines and armored shorelines provide settings for potential swash-aligned fringing or pocket beaches.

Irregular shoreline configurations common in San Francisco Bay, such as crenulate, eroding salt marsh edges, remnants of rocky eroded bay fill, bends or indentations in armored levees and revetments, (landings, pier footings, etc.) provide settings for small-scale swash-aligned pocket beaches even where large-scale embayments are absent. Because San Francisco Bay estuarine beaches are generally narrow and built by low wind-waves, even small shoreline drift obstacles like large driftwood, boat and dock wrecks, and old pilings, can establish small, local pocket beaches.

Natural examples of strongly swash-aligned San Francisco Bay reference beaches include natural headland-bound shorelines such as Keller Beach, Richmond, and China Camp Beach, San Rafael (SFEI and Baye 2020). Naturally formed swash-aligned beaches along artificially filled San Francisco Bay shorelines (Figure 16) include Marina Bay, Richmond, Starkweather Shoreline Park Beach, San Rafael, and Radio Beach, Emeryville. Among the swash-aligned beaches within this study (SFEI and Baye 2020), long-term shoreline changes were too small, relative to variability of backshore beach width, to detect significant beach retreat or progradation trends. Swash aligned beach plan forms are typically either symmetrical or exhibit relatively stable gradients (gradual widening or tapering).

In contrast, open straight or convex shorelines with few obstacles to longshore drift result in more irregular and dynamic beach plan forms, termed drift-aligned beaches (Davies 1980). Drift-aligned estuarine beaches, including spits and other barrier beaches, are usually irregular or convex bayward in plan form, exposed to highly variable wind-wave approach, and are relatively dynamic in position and shape (Figure 17). The spectrum between swash-aligned, low-drift or zero net drift embayed beach settings, and drift-aligned beaches of unsheltered, convex or straight open shorelines exposed to variable oblique wave approach, is a fundamental distinction for assessment and planning of estuarine beaches

Physical controls	**Swash-aligned beach**	**Drift-aligned beach**
Predominant wave approach (after refraction)	Shore-parallel or low-angle; low variability	Oblique, variable from one or more directions
Shoreline configuration	Embayment, cove, pocket shore position	Straight or convex, smooth, exposed open shore
Shoreline position	Bay head, cove head; sheltered or recessed	Bay side, headland, foreland
Headlands, outcrops, retention structures (groins), other alongshore obstructions	Present, sufficient to impede longshore transport over part or or whole beach plan form	Absent or weak; unimpeded longshore transport

Table 1. Summary of physical controls of swash-aligned and drift-aligned beaches

2.4.2. Pocket and Fringing Estuarine Beaches

The most significant dichotomy in San Francisco Bay beach settings is between embayed fringing and pocket beaches backed by upland cliffs, bluffs, or high artificial fills which have resistant headland or emergent foreshore features (rock outcrops, boulders, groins, or other barriers to longshore drift), and drift-aligned beaches associated with either convex or straight to irregular irregular shorelines lacking headland controls (marsh and artificial levee or low bay fill shorelines).

Pocket estuarine beaches occur in relatively steep-sided coves or narrowly indented embayments, and are effectively closed littoral cell traps for beach sediment; fringing beaches occupy shallower, more linear shorelines punctuated by relatively shorter headland features. Pocket estuarine beaches are typically swash-aligned, and so have inherently limited potential for significant long-term net longshore drift, despite potential seasonal fluctuation in drift. Bay head or pocket beaches are therefore generally swash-aligned and inherently relatively stable in plan form. The signature plan form of estuarine pocket beaches ranges from concave-bayward to nearly straight, and often symmetrical or gradually and regularly tapering in width alongshore.

Fringing estuarine beaches can be associated with headlands or not. Fringing estuarine beaches with relatively weak influence by small headlands or similar drift-obstacles may impose less significant restriction of net long-term longshore drift. Fringing estuarine beaches lacking headlands, with oblique orientation to prevailing or highly variable wind-wave directions, are most prone to significant net longshore drift. Fringing beaches that are drift-aligned, and have little or no headland influence significant net long-term drift, are commonly indicated by dynamic asymmetry alongshore: proximal narrowing, distal widening, variable or increasing over time. The artificially nourished Crown Beach, Alameda, which has a terminal groin (artificial headland, barrier to longshore drift), is a fringing beach that exhibits drift-asymmetry.

Pocket and fringing beaches in San Francisco Bay are mostly limited to natural distribution along rocky or bluff shores with local supplies of sand and gravel sediment from seasonal or ephemeral creeks in gulches and valleys (e.g., San Rafael and Tiburon, Marin County; Point Molate, Richmond, Contra Costa County), bluff erosion (e.g., Point Pinole, Richmond, Contra Costa County) or erosion of cliffs, landslides and earthflows (Tiburon, Marin County). (Figures 7, 12). Pocket beaches also occur locally along urban shorelines with rip-rap, often forming in irregular shoreline indentations. The sediment supply of urban-edge pocket beaches often derives from decomposition and wave erosion of old concrete slabs, or erosion of old unconsolidated mixed rocky fill.

2.4.3. Marsh-fringing barrier beaches

In contrast with headland-bound pocket and fringing beaches attached to uplands, marsh-fringing barrier beaches (spits and island-like marsh fringing barriers) are perched over the outer edges of salt marsh platforms, and often exhibit highly variable drift-aligned plan forms. (Figures 4, 9, 17). Marsh-fringing barrier beaches are fetch-limited, low-energy beaches that develop along edges of tidal marshes within larger tidal lagoons, bays, or sounds, often in the shelter of maritime barrier islands of oceanic or gulf coasts (Pilkey *et al*. 2009, Cooper *et al*. 2007, Cleary et al. 1979). Historical and modern marsh-fringing barriers of San Francisco Bay fit this category, though they were not included in global inventories (Pilkey *et al*. 2009).

Marsh-fringing barriers form by overwash and beach ridge deposition at the outer edge of eroding salt marshes (Pilkey *et al.* 2009). They were originally described as "marsh bars" (Johnson 1919), who distinguished them from barrier beaches by their secondary origin in relation to the marshes they shelter. In contrast with classic barrier islands and spits, which shelter and promote the deposition ofsecondary backbarrier tidal marshes (wave-sheltered platforms of washover fans, abandoned inlet shoals, muds), marsh-fringing barrier beaches deposit along older, erosional marsh scarps (peaty mud outcrop) bay shorelines, and their sediment supply (sand and shell hash) may arise from erosion and sorting of coarser sediment from marshes and flats, as well as longshore drift or shoreward bar/shoal migration.

Marsh-fringing barriers shoreline configurations in San Francisco Bay today can vary between smooth, arcuate (concave bayward) plan forms, to irregular and unstable ones dominated by undulating forelands (large asymmetric beach protuberances, blunt or acute), irregular protuberances related to large driftwood or marsh peat outcrops (temporary, unstable functional headlands), or even drifting short spit recurves. Small pockets of marsh-fringing barriers in San Francisco Bay can occur in shallow marsh embayments between eroding peaty mud outcrops or headlands of salt marsh, or they may occur as "wraparound" fringing barriers along convex marsh islands like southwestern Bair Island (Figures 9, 17). Highly irregular, complex large spits – apparently including true "primary" barrier beaches as well as secondary marsh-fringing barriers were characteristic features of historic mid-19th century tidal marsh shorelines of the Central Bay to South Bay (Oakland to San Lorenzo, San Mateo to Ravenswood), with fine details of beach and marsh forms represented in some early U.S. Coast Survey T-sheets (T664, 1857).

Map signatures of true barrier beaches within the early historical Oakland ("Brooklyn")-San Lorenzo marsh shoreline include wide beach ridges with multiple recurves extending over mudflats, enclosing distinct swales (wetlands). Other primary spits, composed of oyster shell hash, occurred on the San Mateo bayshore. Historical marsh-fringing barrier beach signatures in some 1850s San Francisco Bay T-sheets include very narrow beach ridges along salt marsh edges that were mapped with both hatching (marsh symbol) and fine stippling (sand symbol) overlapping, or in sequence alongshore within the same linear ridge. (Figures 9, 17)

The significance of marsh-fringing barrier beaches for evolution and conservation of salt marshes is twofold. First, bay beaches can act as an important, primary line of defense against storm wave erosion impacts and rising sea levels (Barnard *et al*. 2013b). Just as important, as marsh-fringing barriers retreat over their salt marshes, the high salt marsh vegetation colonizing temporarily stabilized beach ridges and associated overwash deposits can maintain "hotspots" of high plant species diversity (Elsey-Quirk *et* *al.* 2019), elevated beach-high salt marsh ecotone topography, and associated high tide refuge habitat during net shoreline erosion and retreat (Johnson 1919, Pilkey *et al.* 2009). Barrier beach washovers intergrade with high marsh plains at Long Beach, Roberts Landing (Figure 18). These modern salt marsh washovers and correspond with silty washover terraces of high salt marsh at outer China Camp (Baye 2012), where marsh-fringing beaches no longer occur.

The backshore zone of most San Francisco Bay marsh-fringing barriers (above non-storm spring high tides) today supports mostly washover flats or fans with at most a thin veneer of wind-blown sand (minor incipient foredunes around tidal debris and beach or high marsh transition zone vegetation). Dune sand transport is limited by the narrow backshore and upper beachface (dry sand deflation zone) of typical estuarine sand beach profiles. Low foredune ridges are uncommon and local today, but larger sand spits and barriers evident in 19th century U.S. Coast Survey maps developed substantial dune ridges and coastal dune vegetation, confirmed by many herbarium records of Pacific coast dune plants from Alameda County shores that face dominant westerly onshore winds. Coarser sand beaches (Marin, North Richmond) and shell hash beaches (San Mateo to Palo Alto) are not associated with low backshore dunes.

Marsh-fringing barriers and true sand spits were the most extensive and widely distributed type of estuarine beach in San Francisco Bay prior to bayland reclamation, fill, and development. Marsh-fringing sand beaches and spits were typical features of the northern San Francisco-San Mateo embayments, (Point San Bruno north to Black Point). Large and complex spits and marsh-fringing barriers extended intermittently along the East Bay from Fleming Point (near modern Aquatic Park, Berkeley) to the vicinity of San Lorenzo Creek (near modern Roberts Landing, San Leandro). Small, crescent-shaped pocket barrier beaches also occurred across the mouths of small coves (some enclosing lagoon,; others, marshes) Along the rocky cliff shorelines of Point Molate and Richardson Bay.

2.5. Interactions between estuarine beach and wetland geomorphic processes

Natural estuarine beaches in San Francisco Bay exhibit dynamic intermediate states between active beachfaces and berm with minimal perennial vegetation, to stabilized, vegetated beach ridges dominated by high salt marsh, beach/foredune, or intermediate (ecotone) vegetation gradients. Estuarine beach and salt marsh vegetation globally plays a major role in the formation and morphological evolution of low-energy estuarine beaches, including marsh-fringing barriers (Cooper *et al.* 2007, Pilkey *et al.* 2009). The classic New England geomorphic landform originally described as a "marsh bar" (Johnson 1919) is essentially a marsh-capped stabilized low-relief beach ridge (like a sandy chenier), or washover (Cleary *et al.* 1979).

Thin washover deposits of beach sand, shell, or gravel over salt marsh edges (wave-eroded peaty mud platforms) occur under relatively low estuarine wave energy conditions, and maintain high marsh islands, or zones of high salt marsh above normal tidal elevations (Cleary *et al*. 1979). These can be ecological "hotspots" (or refuges) of high salt marsh plant diversity where salt marshes are otherwise undergoing submergence and loss of diversity due to sea level rise (Elsey-Quirk *et al.* 2019; see section 3.0 below). Thus, estuarine beaches (including sandy or shell-rich washovers) are part of a spectrum of estuarine landforms bridging salt marsh, inactive (vegetatively stabilized) beach, and “pure” active or intermittently active beaches and washovers. This global relationship also applies to San Francisco Bay marsh-fringing barriers and intermediate high marsh berms. (Figures 18, 19)

Estuarine beach processes also have significant indirect effects on salt marsh hydrology and aquatic or wetland habitats. Where beach ridges transgress across salt marsh platforms with tidal creeks, they can impound them (beach dams) and convert them to elongated non-tidal or spring-intertidal pools (“channel pans” of Yapp *et al.* 1917). (Figure 20). Even where no salt marsh channels occur, estuarine spit recurves or barriers migrating over existing salt marsh platforms can vegetatively stabilize as high salt marsh berms and enclose shallow pools, pans, or lagoons (Figure 21). Whole barrier beaches can enclose and impound salt marshes that become largely non-tidal, overwashed or stream-flooded brackish to hypersaline ponds (Figure 22). High beach crests of fringing estuarine beaches along valley or alluvial fan mouths can also form backshore swales that become freshwater seasonal wetlands (Figure 23). Many of the diverse tidal marsh sub-habitats that are artificially designed in tidal marsh restoration projects by earthmoving and fill to replicate natural features are equivalent to tidal marsh wetland features naturally generated by interactions with natural estuarine beach processes and landforms.

3.0 Ecological Relationships Among Beaches, Salt Marshes, and Artificial Levees in the San Francisco Estuary

Eroding salt marsh and levee edges, and estuarine beaches, are related as the first line of shoreline exposure and interaction with wind-waves and sea level rise. These shoreline types and their responses to changing sea levels and wind-wave climates also critically influence the distribution and abundance of wildlife habitats. Marsh edge erosion increases the area of unvegetated upper intertidal flats, exposing the eroded, consolidated marsh mud platform beneath tidal salt marsh, but marsh erosion can also remove or degrade limited high tide roost habitats of migratory shorebirds. Marsh submergence and edge erosion can also reduce the abundance of critical high tide refuge habitats - cover and shelter provided by local tall vegetation canopies that remain emergent above extreme high tides that submerge the vegetation of tidal marsh plain. Estuarine beaches, controlled by the local supply of coarse sediment and shoreline setting, can mediate shoreline dynamics at eroding marsh and levee edges, and modify wildlife and plant habitat interactions there.

Estuarine beaches as natural dynamic analogs of static artificial levees. Estuarine beaches, and related transitional, intermediate landforms between sandy high salt marsh and estuarine beaches, have a potentially important ecological management role in providing resilient, self-constructing, depositional supratidal habitats, such as high tide roost, foraging, and nesting habitats for shorebirds, and high tide refuge cover (tall perennial vegetation, coarse debris) for salt marsh wildlife including small mammals and rails. In local wind-wave climates that induce significant erosion of cohesive bay mud and marsh, sufficient supplies of coarse sediment can potentially maintain estuarine beach depositional processes that support local high tide roost and refuge habitats, and “hotspots” of species and habitat diversity.

Artificial bay mud levees and salt marsh platforms are composed of cohesive fine sediments (clay, silt) that are eroded by high waves generated during strong onshore winds. Levee and salt marsh scarps (wave-cut vertical cliffs) reflect wave energy and intensify turbulence, forming unstable profiles where fine sediment budgets deficits prevail. Their eroded fine sediments are resuspended and dispersed by tidal currents. Artificial levees generally do not spontaneously recover through natural processes after erosion events in estuary settings where their adjacent mudflats are themselves erosional and wind-wave energy is high. Eroding salt marsh edges in the San Francisco Estuary have exhibited a significant progressive net erosional trend for decades (SFEI and Baye 2020).

Artificial bay mud levees have largely replaced equivalent natural, historical form and function of estuarine beaches: linear, partially unvegetated, high-albedo, topographically elevated ridges parallel to erosional marsh edges, raising topographic elevation thresholds for tidal and wave overtopping, located next to tidal mudflats and shallow open bay waters. Leveed bay shores occur today where widespread marsh-fringing barrier beaches historically established shorelines in the Central Bay.

For example, estuarine marsh-fringing barrier beaches, can rebuild vertically during landward transgression over marsh platforms (beach "rollover"; Davis and FitzGerald 2004), maintaining beach-high marsh topographic gradients by wave deposition (overwash). Post-storm recovery of estuarine beach profiles occurs during calm-weather low wave activity, where beach sediment supplies are sufficient. Thus, two critical salt marsh wildlife habitats may be maintained by interactions between estuarine beaches and salt marsh edges: (a) partially barren, sparsely vegetated linear island-like habitats, and (b) high salt marsh vegetation canopies above normal high tides and wave runup elevations.

Large woody debris, tidal litter, and habitat dynamics of estuarine beaches. Additional interactions between beaches, washovers, and salt marsh are provided by increased thresholds elevations for trapping driftwood and coarse debris along the bay edge of salt marshes. Driftwood and other coarse tidal litter provide beach roughness that can facilitate low-level eolian sand accretion on estuarine beaches with medium sand, and shelter pioneer seedlings, facilitating colonization and succession of beach-salt marsh ecotone vegetation following storm erosion or deposition events. Driftwood deposition also provides local topographic heterogeneity, cover, and potential structural support for some species of native high salt marsh vegetation, enabling their shoots to clamber (climb) above extreme high tide water levels, enhancing potential high tide refuge habitats (see plants, below).

The relationships between selected wildlife and plant guilds, marsh edge erosion, submergence, and estuarine beaches are summarized below.

3.1. Shorebird estuarine habitat units: low tide foraging, high tide roosting

High tide shorebird roost habitats in the modern artificial diked bayland landscape are supplied in abundance by non-tidal seasonal wetlands and salt pond flats, and bare levee road tops that are closed to frequent human disturbance (Takekawa *et al*. 2000). Along other coasts where estuarine beaches remain a significant shoreline habitat, they provide significant high tide foraging or roost habitats where they are not subject to excessive human disturbance (Burger *et al*. 1996, 2004). Similarly, terns and plover species with high conservation priority in San Francisco Bay commonly exploit artificial playa-like diked bayland, levee, and salt pond habitats, although they typically inhabit beach habitats range-wide (Ryan 2000, Feeney 2000). High tide refuge habitats in recently formed, young salt marshes are often provided by artificial levee edges, and remnants of former berms and other artificial fills that are challenging to maintain by traditional methods as sea level rises (Goals Project 2015)

As salt marshes retreat, the area of potential tidal flat foraging habitat for migratory shorebird increases. Shoreline erosion in the San Francisco Estuary (marsh, artificial levee, beach) can also affect the distribution and linear extent of high tide roost habitats of shorebirds (unvegetated or sparsely vegetated flat areas emergent at high tide, including levee roads, salt ponds, salt pans, tidal debris wracks, and beaches), where they rest and conserve energy when productive tidal flats are submerged. (Figure 24) Ecologically, tidal flat foraging habitats and associated high tide roost habitats of shorebirds are a functional unit (Luis and Goss-Custard 2005). Shorebird use of intertidal flat foraging habitat can be limited by the distribution of high tide roost areas in San Francisco Bay (Takekawa *et al*. 2000) and globally (Rogers 2003, Rogers *et al*. 2006, Dias *et al*. 2006). Long-distance flights between tidal flat foraging habitats and high tide refuges are energetically expensive. Levee breaching or collapse due to wave erosion can cause extensive local loss of high tide shorebird roost habitats. Estuarine shoreline retreat and erosion can interact with human recreational disturbance of high tide shorebird habitats (Burger *et al*. 1997), reducing the availability of otherwise suitable high tide roosts along levees or beaches.

3.2. Terns and western snowy plovers

On the Central California Coast outside San Francisco Bay, tern species that occur in San Francisco Bay (Caspian tern, *Sterna caspia*; Forster's tern, *S. forsteri*; Elegant tern, *Thalasseus elegans*; California least tern, S. *antillarum browni*) are associated with sand beach and washover flat habitats near open shallow estuarine and marine foraging habitats of bays and lagoons (Ryan 2000, Feeney 2000; Figure 25. Tern nesting areas are typically located near open water, usually along coastal beaches and estuaries. Similarly, western snowy plovers (*Charadrius alexandrinus nivosus*) are primarily associated with beach and washover habitats on the maritime Central Coast, but inhabit artificial salt pond beds, playa-like saline seasonal wetland flats in San Francisco Bay – habitats with ample invertebrate prey, bare high albedo substrate, with sparse or absent vegetation. Historically, western snowy plovers were reported from locations of past estuarine beaches at Berkeley, Alameda, Bay Farm Island, at the same time of early reports of common nesting and foraging in salt pond edges of Alvarado (Grinnell and Wythe 1927). Extensive estuarine sand and shell beach systems of Central San Francisco Bay were eliminated by reclamation and fill for urban development and salt ponds in the 19th century, prior to regional scientific bird surveys (Grinnell and Wythe 1927).

3.3. Small mammals and rails: extreme high tide refuge habitat

Small mammals, including the endangered salt marsh harvest mouse (*Reithrodontomys raviventris*), are dependent on emergent cover providing refuge from extreme high tide flooding. High tide refuge for small salt marsh mammals is provided by taller vegetation and trapped tidal debris, and old song sparrow nests, that occur in the narrow band of tall high salt marsh along tidally well-drained salt marsh banks (Johnston 1956, 1957). The tall perennial vegetation canopies of gumplant (2-4 ft; Johnston 1956), robust pickleweed, are climbed by small mammals and used as local high tide refuge (cover) when extreme high tidal flooding submerges the vegetation canopy of salt marsh platforms (Hulst *et al.* 2001), or brackish tidal marshes (Smith *et al.* 2014). The endangered California Ridgway's rail (*Rallus obsoletus obsoletus*) is similarly dependent on high tide refuge cover to survive avian predation during marsh-submerging extreme high tides (Albertson and Evens 2000, Overton *et al*. 2015). Tall high marsh vegetation is also essential nesting and foraging habitat for endemic tidal marsh-dependent song sparrow subspecies (Marshall 1948, Johnston 1957).

Sea level rise and salt marsh bank erosion in the San Francisco Estuary are likely to reduce the abundance of high tide refuge and high tide roost habitats, their structure, and their distribution pattern. Sea level rise rates that increase tidal submergence time of pickleweed can reduce its height (Woo and Takekawa 2012), and eventually convert higher salt marsh zones to low marsh and unvegetated tidal habitats (Thorne *et al*. 2016). Acceleration of tidal marsh bank erosion along tidal creeks, due to increased tidal prism forced by sea level rise, may increase lateral erosion rates of tall high marsh vegetation. The erosional loss of high tide refuge habitat along salt marsh banks, coupled with accelerated sea level rise and increased storm high tide flooding impacts (Thorne *et al.* 2013), are likely to limit the availability of critical high tide refuge and roost habitats before tidal marshes are submerged to low marsh and mudflat.

3.4. Estuarine beach invertebrates

Estuarine beaches provide habitats for terrestrial and estuarine invertebrates, including rare species of tiger beetles, carrion-feeding and deadwood-feeding beetles, ground-nesting wasps and solitary bees. The marginal terrestrial (supratidal) sand and shell substrate habitats of estuarine marsh-fringing beaches allow specialist insect species to inhabit tidal marsh landscapes at locations remote from uplands, including important pollinators like native solitary bees.

Maffei (2000) identified remnant localities of tiger beetle species (*Cicindela* spp.) in San Francisco Bay diked habitats, including species with typical range-wide habitat preference for beaches and wet, sandy beach-like areas, (*C. senilis, C. oregona, C. haemorrhagica*). *C. oregona* was last identified at Bay Farm Island, an historic beach locality, in 1996 (Maffei 2000; Figure 26). Remnant sand and shell beaches of San Francisco Bay have apparently not been surveyed for tiger beetles in decades. *Cicindela* species occur along maritime beaches of the Central Coast, including sandy lagoon shores and washover flats (Abbott's Lagoon, Point Reyes; Manchester Beach State Park, Mendocino; W. Ericson, pers. comm. 2020).

Ground-nesting wasps and solitary bees opportunistically colonize supratidal beach and washover sands (and artificially deposited sandy sediments, such as dredge disposal sites) with sufficient trace silt content, providing sand grain cohesion sufficient to support small burrows. Ground-nesting wasps (*Bembix, Diadasia* spp.) and solitary bees (*Agapostemon*, *Anthophora, Bombus, Cerceris, Philanthus, Melissodes* spp.) are expected to colonize coherent sandy soils and sands above normal tides along the Central Coast, and occur in San Francisco Bay terrestrial habitats.

Sand beaches and washovers with decaying driftwood and other detritus provide habitats for darkling beetles (Tenebrionedae), including *Eleodes, Coniotis*, and *Coelus* spp. (Figure 26). Other beetles associated with sandy shores with detritus include carcass-feeding clown beetles (Histeridae*; Neopachylopus, Hypoccacus* spp.), carabid beetles (Carabidae), rove beetles (Staphylinidae), and weevils associated with sandy substrates and vegetation (Curculionidae; *Trigonoscuta* spp.). These beetle taxa are large potential prey items for western snowy plovers that also have range-wide habitat preferences for sandy beach and washover habitats (Page *et al*. 2000).

The intertidal beachface (foreshore) of estuarine beaches accumulate high tide drift-lines of decaying organic wrack (tidal litter), composed of tidal marsh and riparian (watershed) vegetation detritus, macroalgae, woody debris fragments, and anthropogenic materials. The moist, warmed thick organic debris layers provide microhabitats for high densities of beach insects, isopods amphipods, including abundant *Traskorchestia traskiana* (Pacific beach hopper, present in San Francisco Bay pickleweed marshes). Estuarine beach wrack deposits provide potential significant to macroalgal subsidies to shorebirds foraging during rising tides, as they do on maritime beaches (Dugan *et al*. 2003). Shorebird foraging for beachhoppers, and other upper intertidal invertebrates feeding on decaying organic matter in drift-lines, often tracks moist-drift-line series on the on estuarine beachface (Jackson *et al*. 2002b)

3.5. Plants and Vegetation of San Francisco Bay Estuarine Beaches, Washovers, and Marsh Berms

Estuarine beaches and related sandy washover flats support two overlapping or intergrading vegetation types: sandy high salt marsh and beach/foredune. Estuarine beaches undergoing active erosion and deposition at supratidal elevation ranges maintain bare or wrack-dominated beach substrate, or sparse backshore vegetation mixed with wrack. Permanently or temporarily stabilized beaches (marsh berms) and washovers become extensively colonized with beach and foredune vegetation, or ecotones between beach and high sandy salt marsh. Vegetation stabilization is usually associated with prolonged periods of low storm intensity and frequency, such as during multi-year droughts)

The San Francisco Bay beach flora today is composed of subsets of maritime and inland sandy riparian and alkali shore plant communities. They include pioneer beach and foredune species typical of maritime Central Coast beaches, including beach-bur (*Ambrosia chamissonis*), non-native sea rocket (*Cakile maritima*), and rarely beach wildrye (*Leymus [Elymus] mollis;* Figure 27). A richer historical dune flora, now extirpated, formerly occurred along East Bay estuarine dunes, documented by interior San Francisco Bay herbarium specimen localities of species now restricted to the maritime dune flora. These maritime beach species co-occur with widespread interior sandy shore and alkali flat pioneer plants, including western ragweed (*Ambrosia psilostachya*), alkali-wildrye (*Leymus triticoides*), cressa (*Cressa truxillensis*), poverty-weed (*Iva axillaris;* Figure 28) and some species that occur in both maritime and inland sandy shores like heliotrope (*Heliotropium curassavicum*).

These mixed maritime/inland sandy shore plant assemblages of supratidal zones on San Francisco Bay estuarine beaches intergrade with robust forms of high salt marsh (spring high tide zone) including native dominant species like gumplant (*Grindelia stricta* var. *angustifolia*), saltgrass (*Distichlis spicata*), pickleweed (*Sarcocornia pacifica*), alkali-heath (*Frankenia salina*) and Jaumea (*Jaumea carnosa*). Common non-native pioneers from the high tidal marsh flora also occur in drift-lines and well-drained sandy washover gradients over salt marsh, including perennial pepperweed (*Lepidium latifolium*) and orach (*Atriplex prostrata*). Gumplant and pickleweed typically develop robust, tall phenotypes on well-drained stable low-relief beach ridges and washovers with deposits of organic wracks. Saltgrass and pickleweed also can slowly interact with structural support provided by beach driftwood (woody debris), facilitating development of clambering, elevated vegetation canopies (Figure 29). Thus, vegetated estuarine beach-salt marsh ecotones with woody debris deposits may contribute to regional distribution of high tide cover for salt marsh wildlife, if they have connectivity to tidal marshes. These native climbing salt marsh species exhibit significant tolerance to shallow, repeated burial by sand deposition, and provide sand-trapping roughness, like washover fans of barrier beach/salt marsh ecotones globally (Maun 1998).

Rare plant diversity is also associated with ecotones between sandy washovers and salt marshes. Historical collections of now-rare annual salt marsh plants like salt marsh bird's-beak (northern subspecies *Chloropyron maritimum* subsp. *palustre*), smooth goldfields (*Lasthenia glabrata* subsp. *glabrata*) and salt marsh ecotypes of owl's-clover (*Castilleja ambigua* subsp. *ambigua*) were associated with historical San Francisco Bay beach localities (Baye 2000), and are still associated with old stabilized washover-salt marsh ecotones at Limantour Spit and Kent Island (Bolinas Lagoon) in maritime salt marshes of west Marin County(Figure 30). This pattern of plant diversity "hotspots" on depositional sandy washover-high salt marsh ecotones corresponds with research on Atlantic coast tidal marshes that are prone to tidal marsh plant diversity loss due to sea level rise submergence (Elsey-Quirk *et al*. 2019).

An ecologically important rare plant, California sea-blite (*Suaeda californica*), was historically associated with high salt marsh and estuarine sand beach localities of Central San Francisco Bay, and some South Bay peninsula salt marshes where shell hash beaches occurred (USFWS 2013, Baye 2006). This endangered plant was extirpated in San Francisco Bay by the 1960s, but pilot reintroduction projects have re-established experimental research populations (San Francisco State University, Boyer Wetland Laboratory) in San Francisco, Marin, and Oakland. In Morro Bay, California sea-blite is a robust, salt-tolerant subshrub that colonizes sandy high salt marsh berms and scarps, dunes, sandy low shoreline bluffs, and estuarine beaches. It also has an adaptable, burial-tolerant mounding, spreading, or climbing growth habit that can clamber over driftwood and low-branched trees and shrubs along shorelines, elevating its dense leafy canopy above highest tides and waves. (Figure 31) Studies of interactions between structural support of woody debris and sea-blite growth habit have recently been conducted (K. Santos, San Francisco State University, in prep.), in context of high tide refuge habitat management. No research has been conducted on the sand burial tolerance or sand-trapping (foredune or marsh berm-building) capacity of California sea-blite.

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FIGURES

Figure 1. Typical examples of low energy estuarine sand beach profiles in SF Bay: (A) Steeply sloping west-facing medium sand beachface at Roberts Landing, San Leandro (Long Beach), above a wide low tide terrace (muddy tidal flats). (B) Medium sand north-facing beachface with gravel step, above mudflats at Whittell Marsh Beach. (C) Toe of coarse east-facing sand and gravel beachface above mudflats attenuating wind-waves around mid-tide at China Camp Beach, San Rafael. (D) West-facing medium sand pocket beach with saturated (seepage) lower beachface and narrow backshore beach, above sandy mud tidal flats with eelgrass colonies extending to the inner low tide terrace below the step, Albany Frontage Road beach, Berkeley.

Figure 2. Typical examples of low energy estuarine beach profiles in SF Bay: **beach step.** Estuarine beach steps in San Francisco Bay are abrupt breaks in slope and grain size at the toe of the beachface, at the junction of sand or gravel deposited by swash and backwash at the beachface toe, and fine-grained tidal flats of the low tide terrace. (A) Rat Island Cove at Camp State Park (2015). (B) Beach step composed of coarse shell hash and sand above fine-grained mudflats (low tide terrace) with embedded shell hash. Foster City shell beach above shell-rich mudflats (2010).

Figure 3. Typical fair-weather estuarine sand beach profile: Radio Beach, Emeryville/Oakland (north of Bay Bridge toll plaza). West-facing Central Bay medium sand beach, swash-aligned plan form, provides a typical example of a low-energy estuarine beach morphology. The beach is exposed to local wind-waves and weak refracted swell from the Golden Gate. Low tide terrace: intertidal flats (mud or muddy sand) below Mean Sea Level. Step: break in slope at the toe of the beachface, outer edge of low tide terrace, lower foreshore zone. Beachface: intertidal swash slope, upper foreshore zone. Berm: dry beach above normal high tides (supratidal) beach, flat top to gently sloping, backshore zone. Foredunes, terraces, low plains, washovers or artificial fill may occupy the backshore (above tides)

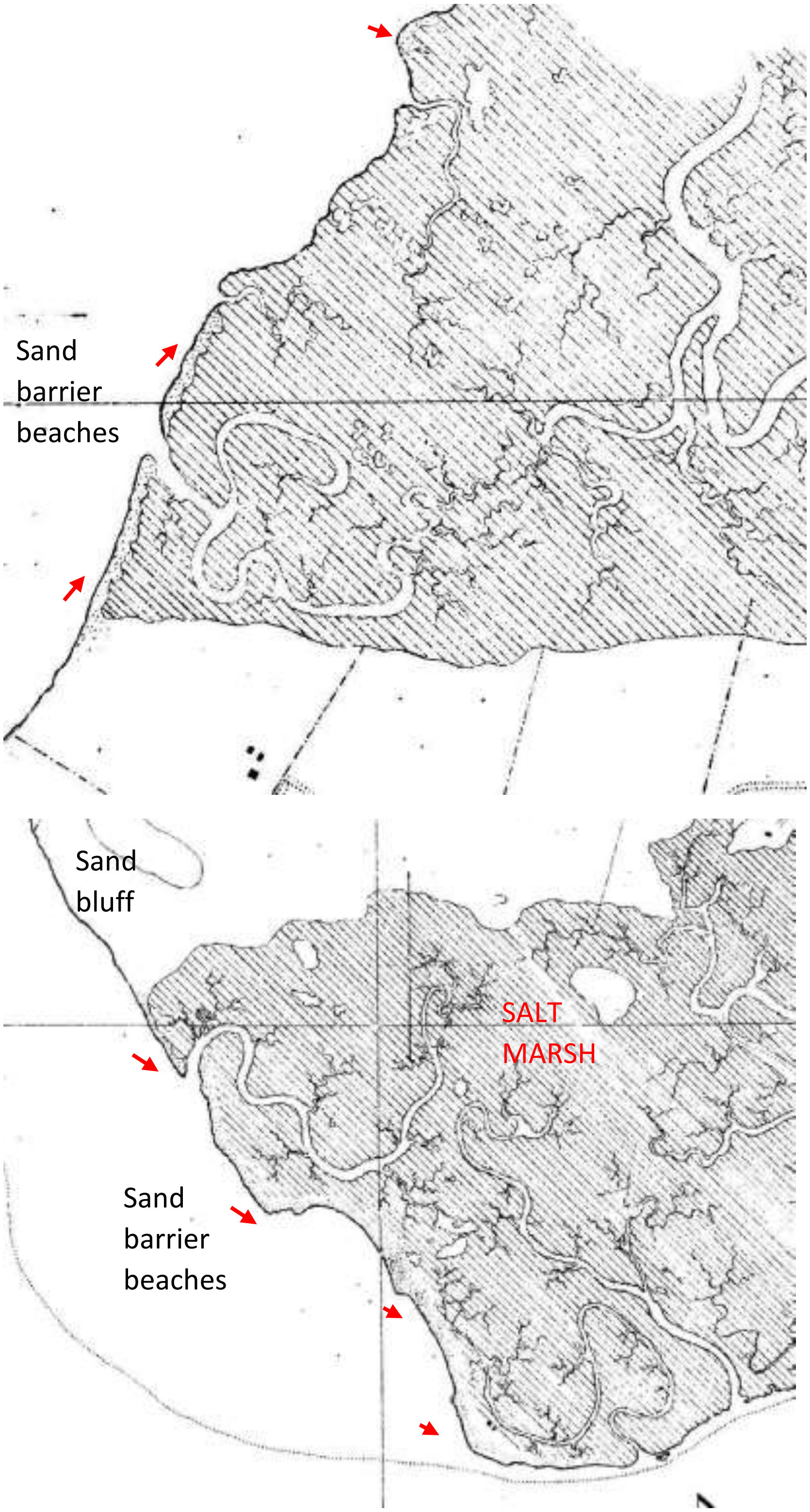


Figure 4. Historic mid-19th century Sand marsh-fringing barrier beaches of historical Oakland (Brooklyn). Red arrows show extensive sand barriers (stippled; contrast with hatched salt marsh) north and south of San Antonio Point were linked to erosional sand bluff sources through longshore drift. USCS T-sheet T-592 (1856).

Figure 5. Modern erosion of old bay fill supplies Pleistocene (Colma) beach sand to the modern bay shore. forming new beaches and low dunes at India Basin's south shore, San Francisco. Low backshore vegetation (high salt marsh plant species) traps wind-blown sand, forming transient low foredunes (2006)

Figure 6. Ebb tidal delta of the San Lorenzo Creek flood control channel. The ebb tidal delta includes fluvial flood-transported sand, reworked by waves. It supplies sand to a wide deltaic low tide terrace, with multiple sand bars (classic ridge and runnel morphology) and shoals migrating onshore onto beaches and prograded deltaic salt marshes, south of Long Beach, Roberts Landing, San Leandro. (A) aerial image, Google Earth, October 2018. (B-C) Ebb tidal delta of the San Lorenzo Creek flood control channel. Wave erosion and onshore transport of sand from the delta forms a mud and sand low tide terrace, with multiple low-relief sand bars and shoals migrating into salt marshes, adjacent to Long Beach, Roberts Landing, San Leandro. 2010.

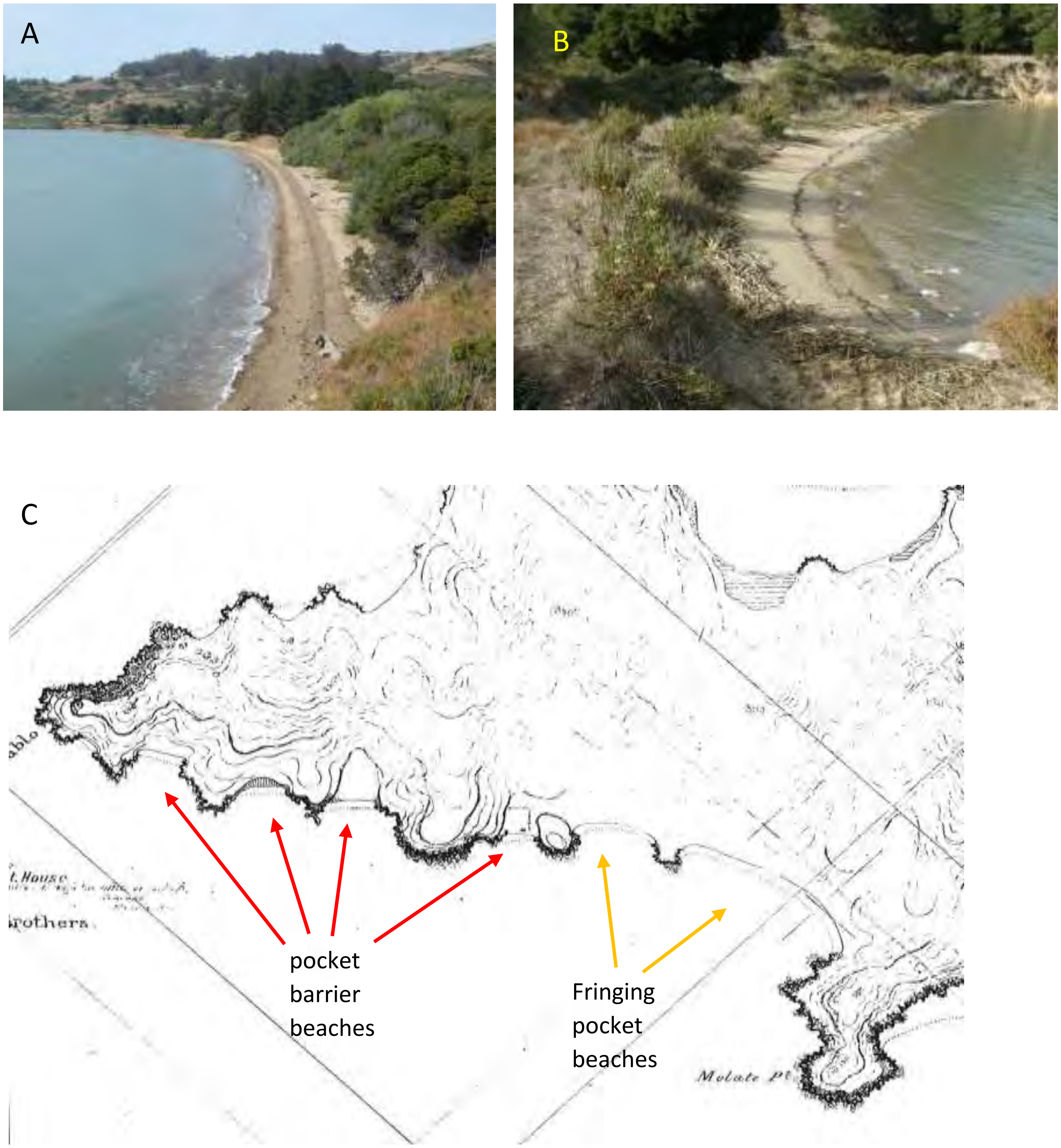


Figure 7. Pocket estuarine sand or mixed sand-gravel estuarine beaches. Pocket beaches are embayed between headlands include barrier and fringing beaches along cliffed, rocky shores with coves, valleys or canyons. (A) Modern Point Molate Beach, Richmond in 2017, corresponding with early historic pocket beach shown in 1963 U.S. Coast Survey Map (figure 6b). (B) China Camp State Park, San Rafael pocket beach within Rat Island Cove, at the mouth of a lowland gulch. (C) Point Molate pocket beaches in 1853 U.S. Coast Survey T-561), with multiple pocket barriers and lagoons (shown with multiple pocket barrier beaches prior to filling and development. The largest pocket beach next to "Molate Pt" headland corresponds with the modern beach in Figure 6a.

Figure 8. Olympia oyster shell hash shell barrier beaches, southwestern San Francisco Bay. (A) recurved spit rapidly formed by longshore drift bayward of marsh-fringing barrier with multiple ridges. March 2010. (B) Compound barriers (multiple ridges with closed lagoons), free flying spits, cuspate and looped spits, associated with episodic deltas and variable longshore drift. Google Earth, October 2018. (C-D) Modern vegetative stabilization of estuarine shell beach ridges converts them to high salt marsh berms, an alternative ecological state. Foster City southeast shore, near Belmont Slough.

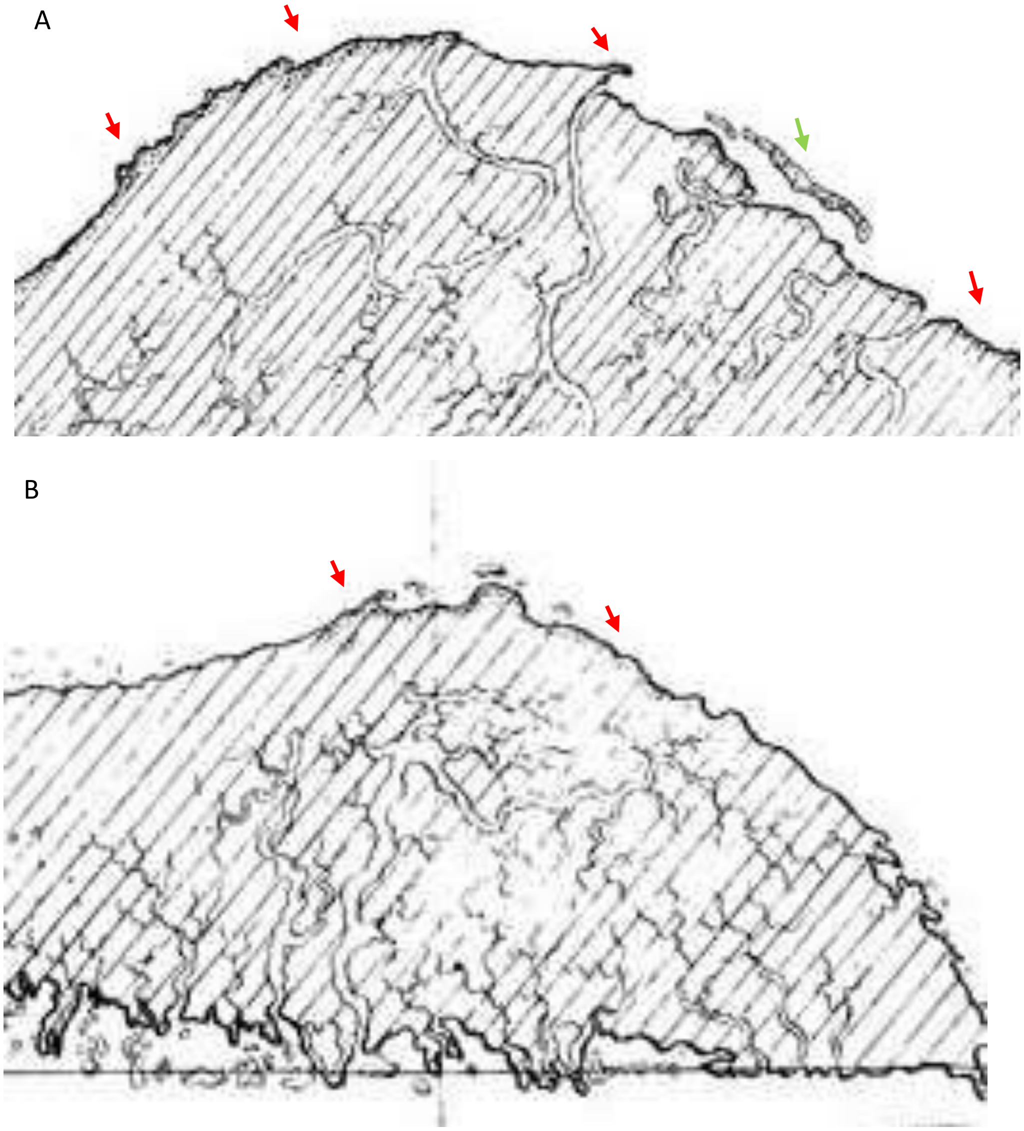


Figure 9. U.S. Coast Survey t-sheets represent vegetated shell berms ("banks") at salt marsh bayshores. Vegetated marsh-fringing shell barrier beaches of Ravenswood salt marshes, U.S. Coast Survey T-sheet 664 (1857). Red arrows indicate discrete marsh shores mapped as discrete features that grade between stippling (coarse sediment, beach) and hatching (salt marsh), or overlapped stippling and hatching, consistent with transitions between active bare beach sediment and vegetated beach ridges (marsh berms). T664, Ravenswood marsh shore south of shore locality labelled "Shellbank". These locations correspond with proximity to modern oyster shell hash beaches and marsh berms. These obstruct drainage at the bayward marsh edge, in a zone excluding most tidal creeks, which have drainage patterns oriented away from the marsh berm edge.

Figure 10. Oyster shell hash beaches. (A) Narrow barrier beach migrates onshore and encloses sheltered backbarrier tidal flats (recent deposited barrier beach) at Foster City. (B) Low tide terrace bayward of shell beaches at Foster City have high content of shell hash in mud matrix; erosion and sorting of shell supplies coarse sediment for beach accretion. (C) Close-up view of shell hash, composed of whole Olympia oyster shells and fragments (cm scale).Marsh-fringing estuarine shell hash barrier beaches, Southeast Bair Island, Redwood City; 2010. (D) Extensive “wrap-around” fringing barriers occur along the perimeter of convex salt marsh islands, supplied by erosion and onshore transport of ancient oyster shell layers in nearshore muds. May 2010.

Figure 11. Rapid wind-wave deposition of oyster shell hash bars during a falling tide. A descending series of multiple small swash bars are rapidly deposited during a single ebbing tide. Bair Island, southeast shore at Redwood Creek, March 2010.

Figure 12. Estuarine mixed sand and gravel beaches. (A) Mixed (poorly sorted) sand-gravel beaches are widespread along the cliffed Tiburon coast, as at this example at Paradise Beach, Marin County Parks. Sediment sources include local erosion of natural cliffs and bluffs, ephemeral stream beds and banks in steep gulches, and artificial fill. (B-C) Composite estuarine gravel and sand beach profiles are rare in SF Bay. Well-sorted narrow gravel berm occurs in the toe of the bluff scarp, above a predominantly sand beachface. Richardson Bay Audubon Sanctuary in Tiburon, Marin County. (D) rounded to subangular gravel of mixed sedimentary and metamorphic rocks (cm scale) at Paradise Beach, Tiburon, Marin County.

Figure 13. Anthropogenic estuarine gravel beaches. (A) Marsh-fringing estuarine gravel barrier beach, South SF Bay. Pocket gravel barriers (bay levee, salt pond 4A Newark near Coyote Hills; 2014) shelter small salt marshes and salt pond levees, where erosion of old fills with gravel locally supply coarse sediment. (B) An example of a purely anthropogenic San Francisco Bay gravel beach (spit) formed from various eroded fill materials (seaglass, ceramics, metal, asphalt, and concrete) from an old landfill scarp near the mouth of Strawberry Creek, West Berkeley, Eastshore State Park.

Figure 14. Natural estuarine gravel beaches. (A) West Point Pinole bluffs are fringed by one of the largest natural coarse gravel beaches in San Francisco Bay, formed from erosion of gravelly bluff sediments (B). (C) a mixed gravel-dominated coarse barrier beach with exceptionally mixed coarse sediment types, ranging from gravel, cobble, coarse sand, to shell, occurs downdrift (south) of wave-cut bluffs at west Point Pinole, Richmond. The mixed composition of the beach reflects the diversity of local sediments eroded from nearshore and backshore sources, and seasonally variable wave energy. (D) gravel pocket beach between headlands at the west shore of Point San Pablo, north of Point Molate.

Figure 15. Estuarine cobble beaches. (A-B) A large natural coarse cobble fringing beach along wave-cut bluffs, composed of rounded cobbles and some gravel, extends along the bluffs of west Point Pinole, and grades into a relatively immobile gravel lag beachface (indicated by attached membranous green algae on cobbles) embedded in a clayey wave-cut bench and bay mud. (C) a depositional cobble barrier beach and backbarrier salt marsh south of bluffs, west Point Pinole. (D) cobble beach intermediate with rocky shore, composed of angular sandstone cobbles and small boulders in the upper foreshore, and (E) stable embedded algae-covered cobbles in the lower foreshore.

Figure 16. **Examples of stable swash-aligned sand beach plan forms in artificial San Francisco Bay shores.** Swash-aligned beaches naturally formed in embayments between rock-armored artificial fill headlands or fills, San Francisco Bay. (A) Marina Bay barrier tombolo (coarse sand), Richmond, showing shore-parallel wave crests along the beach, and oblique waves along the rock-armored “headlands”. (B) Starkweather Shoreline Park Beach (medium sand), Francisco Boulevard, San Rafael. (C) Radio Beach, Oakland. Images: Google Earth.

Figure 17. Examples of complex, irregular drift-aligned beach shoreline morphology in SF Bay. Examples include (A) Whittell Marsh sand spit, Point Pinole, Richmond, San Pablo Bay, with a drifting swash bar complex on a wave-dominated ebb tidal delta. March 2018; and (B) Marsh-fringing shell hash barriers, spits, and forelands along a convex shoreline with variable orientation to wave approach, wrapping around the marsh edge of southwestern Bair Island, Redwood City, South SF Bay. Note locally reversing drift directions of overlapping relict spits within the shoreline reach in the shelter of the complex cuspate foreland. Both beach systems have apparent updrift (eroding headland) or nearshore (eroding shoals) sources of beach sediment. August 2018. Google Earth images.

Figure 18. Sand washovers from estuarine beach to backbarrier salt marsh. Washovers are deposited by storm wave action during extreme high tides at Long Beach, Roberts Landing, San Leandro (2015). Thin landward washover deposits (<15 cm thick) partially bury dominant salt marsh vegetation, which directly regenerates in spring.

Figure 19. Intermediate estuarine beaches, washovers, and tidal wetlands. Intermediate states between active estuarine beaches and washovers, relict vegetated beach ridges, and high salt marsh berms in different stages of erosion, deposition, and vegetation establishment, intergrade without sharp distinctions. (A) A high salt marsh berm Pinole Creek (2006) is an emergent gently sloping ridge composed of interbedded sand, tidal litter, and coarse silt capped with tall gumplant and pickleweed vegetation, above mixed organic/mineral sand beachface resembling peat. (B) Stabilized shell beach ridges are similarly mantled with high salt m

Figure 20. Estuarine sand and shell beach ridges choke or impound tidal creeks. Marsh-fringing barriers and berms can temporarily or permanently dam channels and marsh drainage, forming enlarged, broad to elongated pools or channel pans. Examples occur at SE Bair Island (A, B), and Whittell Marsh, Point Pinole (C).

Figure 21. Estuarine barrier beach ridge impounds salt marsh pool. A typical example of a recurved beach ridge and pool impoundment in Morro Bay in San Luis Obispo is shown above. Similar features occur in San Francisco Bay (figure 23), Drakes Estero, and Bodega Harbor on the North Central coast. Compare Figure 22.

Figure 22. Estuarine barrier beach ridge impounds a brackish lagoon (seasonal pond). Rat Island Cove within China Camp Sate Park, San Rafael, includes a barrier beach enclosing a valley alluvial fan, pond, and non-tidal salt marsh.

Figure 23. Estuarine beach ridge impounds a freshwater swale. The beach ridge at south China Camp Beach obstructs drainage of runoff from alluvial fans (ephemeral canyon streams), as well as tidal overtopping from storms, creating backshore fresh to brackish seasonal wetland swales. China Camp Beach, 2018.

Figure 24. Shorebirds roosting and foraging movements between tidal flats and estuarine beaches. Shorebirds forage on productive muddy low tide terraces at low tide (A, Roberts Landing low tide terrace below Long Beach), and move to high tide roosts on adjacent beaches (B, Crown Beach, Alameda; C, Foster City beach) where disturbances from pedestrians and dogs are infrequent.

Figure 25. Estuarine beach roost habitat of terns and plovers. Terns and plovers in SF Bay primarily roost in artificial salt pond habitats in the modern estuary, but they also utilize typical sand beach habitat types (now much reduced in extent) that preceded salt ponds. (A) Caspian terns roost on mixed sand and gravel beach east of Point Pinole, April 2009. (B-C) Western snowy plover forages in backshore beach and washover habitats at Long Beach, Roberts Landing, April 2006.

Figure 26. Uncommon or rare insects of estuarine sand beach habitats. Estuarine sand beaches support uncommon to rare insects specialized for sand beach and sandy lagoon shore habitats. as well as generalist species of decaying wood, detritus, or carrion shoreline microhabitats. Rare insects in SF Bay beaches include three tiger beetle species (a) *Cicindela oregona*, (b) *C. haemorrhagica*, (c) *C. senilis*, which are also found on the maritime coast. Sand-inhabiting darkling beetles include (d) *Coelus* spp., and (e) *Eleodes* spp.

Figure 27. Native maritime foredune plants of Central Bay sand beaches. (A) Beach wildrye (*Leymus mollis*; syn. *Elymus molllis*) is nearly extirpated in unmanaged sandy shores of the Bay. (B) Beach-bur (*Ambrosia chamissonis*) is widespread in Central Bay.

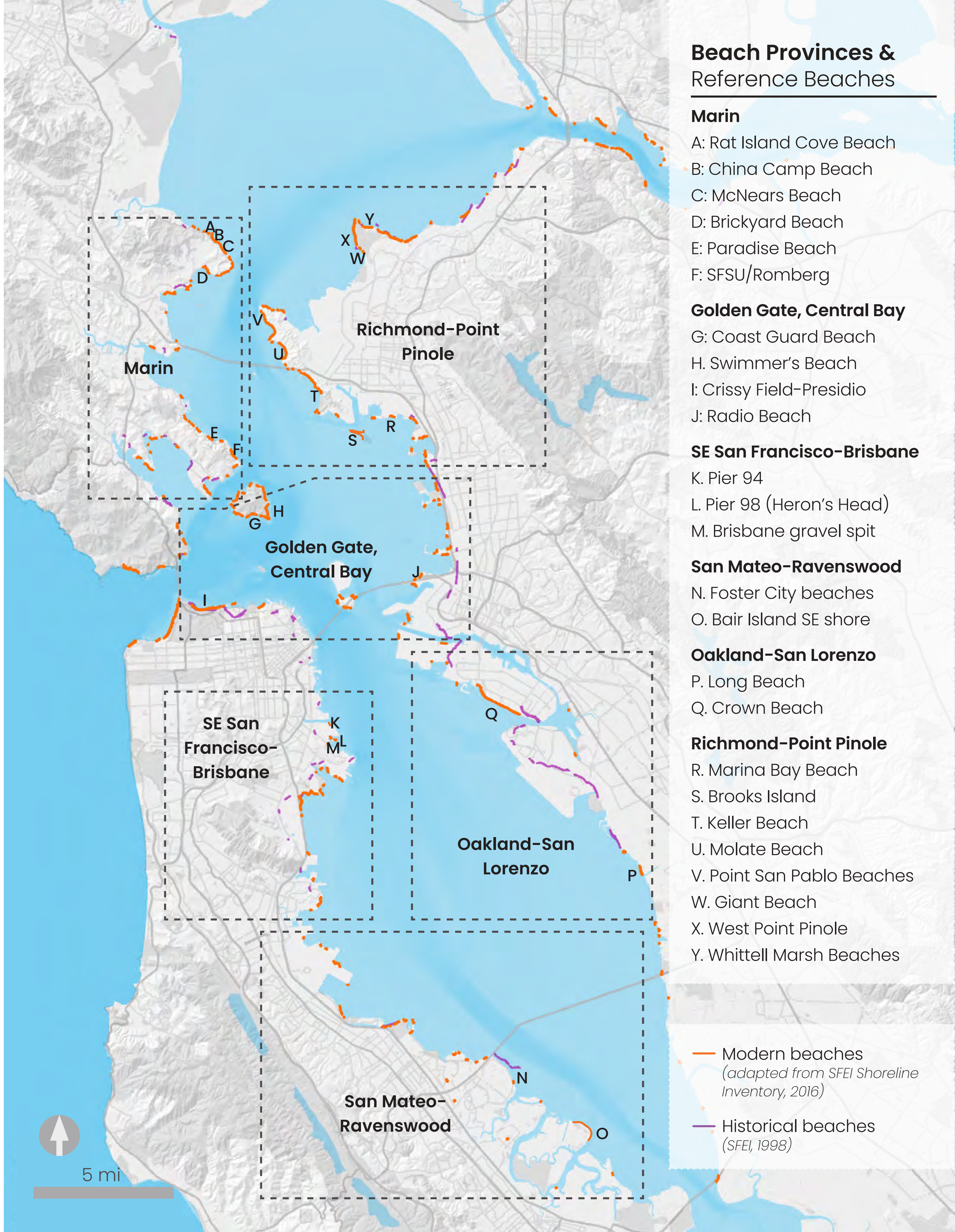
Figure 28. Native beach plants of the SF Estuary from alkali sandy inland habitats. Native plants of interior sandy alkali habitats adapt to bay beaches, including (A) alkali (creeping) wildrye (*Leymus triticoides*), (B) poverty-weed (*Iva axillaris*) and (C) alkali weed (*Cressa truxillensis*), all present at Point Pinole and Point Molate, Richmond beaches, as well as other San Pablo Bay beaches.

Figure 29. Native high salt marsh plants with climbing growth habits interact with driftwood. Pacific pickleweed (*Sarcocornia pacifica*) and saltgrass (*Distichlis spicata)* interact with structural support of driftwood and locally develop perched, climbing canopies elevated above high tides. China Camp Marsh, 2011.

Figure 30. Stabilized old sandy washovers intergrade with species-rich high salt marsh transition zones. “Hotspots” of high salt marsh plant diversity occur in ecotones (transition zones) of beach washovers on the Central Coast, including uncommon to rare annual salt marsh plants (smooth goldfields, *Lasthenia glabrata*; salt marsh owl’s-clover or Johnny-nip, *Castilleja ambigua*). These species and habitats are rare today in SF Bay, but remain extensive in this example from Limantour Estero, Point Reyes (2017).

Figure 31. California sea-blite *(Suaeda californica)* vegetatively stabilizes estuarine beaches and low sandy bluffs. California sea-blite is a robust salt marsh subshrub vegetatively stabilizes estuarine beaches and low sandy bluffs at Fairbanks Point, Morro Bay. It can readily develop climbing canopies high above the highest tides and wave action where support from driftwood, bluffs, or dead or living tree branches. San Francisco Bay is the type locality for the species, which survives as wild populations only in Morro Bay.

Beach province	Wave climate	Low tide terrace and nearshore	Sediment type	Sediment supply	Description
Golden Gate, Central Bay	Mixed refracted Golden Gate swell, wind-waves with long fetch over deep water	Steep nearshore & foreshore; no wide low tide terrace	Mostly medium well-sorted quartz-dominant sand	Littoral zone and nearshore	Mostly pocket and fringing beaches
Marin (Sausalito, Richardson Bay, Tiburon, Corte Madera Bay, San Rafael Bay, China Camp State Park)	Limited exposure to prevailing westerly winds, but high exposure to S-SW and NE storm wind directions. *Shallow embayments*: short fetch, restricted wave approach, lower energy. *Headlands*: long fetch, variable wave approach, higher energy	*Shallow embayments*: wide dissipative tidal mudflats, gently sloping shallow nearshore. *Headlands*: narrow or no tidal flats; rocky intertidal shelf with local macroalgal beds, submerged aquatic vegetation	Mostly sand and mixed sand-gravel beach sediments; local cliff-backed cobble	Erosion of bluffs, cliffs, local stream mouth deposits	Mostly pocket and fringing beaches; local spits and barriers
Richmond-Point Pinole	High exposure to dominant westerly winds over long fetch; variable wave approach directions	*Embayments*: wide dissipative tidal mudflats, gradual sloping, shallow nearshore *Headlands, cliffs*: narrow or no tidal flats; narrow low intertidal rocky intertidal shelf or nearshore submerged aquatic vegetation	Mostly sand and mixed sand-gravel beach sediments; local cliff-backed cobble; local shell hash (Brooks Island)	Erosion of local bluffs, cliffs, artificial fill	Mostly pocket and fringing beaches; local remnant barrier beaches; former barrier beaches
Oakland-San Lorenzo	Long westerly fetch, variable wave approach and drift	Wide dissipative tidal flats	Medium sand; local shell sand-shell hash mixed beaches, minor local artificial gravel beaches	Erosion of tidal flats, artificial dredged material and fill, and flood control channel mouth deposits	Mostly modern fringing beaches; local spits and barriers; former widespread barrier beaches downdrift of sand bluffs
San Mateo-Ravenswood (South San Francisco Peninsula)	Low exposure to prevailing westerly winds; variable wave approach direction and drift, with high exposure to S-SW storm wind-waves	Wide dissipative tidal flats, shallow subtidal muds	Mostly local shell sand-shell hash mixed beaches, some mixed shell-sand	Erosion of tidal flats with shell deposits; onshore transport of local shell bars and shoals; local artificial fill erosion	Mostly modern fringing beaches and marsh-fringing barriers
Southeast San Francisco-Brisbane (North San Francisco Peninsula)	Low exposure to prevailing westerly winds; high exposure to S-SW storm wind approach	Wide dissipative tidal flats except SE San Francisco (deepwater)	Medium sand; local shell sand-shell hash mixed beaches, minor local artificial gravel beaches	Erosion of artificial fill, tidal flats with shell and sand, and flood control channel mouth deposits	Mostly modern pocket beaches; local spits and barriers; former extensive San Mateo shell hash barrier beaches



Appendix B:

Preliminary Cost Estimates

Project Name: Greenwood Beach Preliminary Level Cost Estimate - Pilot Project
Preparer: RDL
Date Last Revised 1/21/2021
Level of Estimate: Preliminary level (+-30%)

item	*quantity*	*units*	*unit cost ($)*	*total cost ($)*	*comments*
CONSTRUCTION					
Site Preparation - Mobilization and Set-Up					
Overhead and PM	1	ls	$ 40,000.00	$ 40,000.00	H-A draft estimate 11/27/19
Mobilization	1	ls	$ 24,000.00	$ 24,000.00	H-A draft estimate 11/27/19
Stormwater Plan and Reporting	1	ls	$ 5,000.00	$ 5,000.00	engineer's estimate
Install construction entrance and temp haul road	1	ea	$ 5,000.00	$ 5,000.00	H-A draft estimate 11/27/19
Deploy Off-Shore Turbidity Curtains	600	lf	$ 20.00	$ 12,000.00	Unclear if final permit will require a turbidty curtain off-shore for sedment placement - assume 50 foot sections plus $8 for installation
Construction area set-up	230	lf	$ 50.00	$ 11,500.00	engineer's estimate
			SUBTOTAL Site Prep:	$ 57,500.00	
Shoreline Regrading and Boulder Replacement					
Remove and Stockpile Concrete Rubble	1200	tons	$ 37.00	$ 44,400.00	H-A draft estimate 11/27/19 quantity backcalculated from HARC total cost needs to be confirmed in final design
Shoreline Grading	700	lf	$ 30.00	$ 21,000.00	H-A draft estimate 11/27/19
Replace Usable Concrete and Boulders	142	tons	$ 106.00	$ 15,000.00	H-A draft estimate 11/27/19
Dispose of Aspahlt and Misc Debris	50	tons	$ 120.00	$ 6,000.00	Engineer's estimate - needs to be confirmed during final design
Beach Construction					
Preconstruction survey	1	ls	$ 15,000.00	$ 15,000.00	H-A draft estimate 11/27/19
Provide and place boulders	62	cy	$ 200.00	$ 12,400.00	
Provide and place 3-inch by 1-inch cobble and bay mud mixture (70/30)	996	cy	$ 190.00	$ 189,240.00	H-A draft estimate 11/27/19
Provide and place 1-inch by 3/8-inch gravel mixture (50/50)	740	cy	$ 170.00	$ 125,800.00	H-A draft estimate 11/27/19
Provide and place gravel and sand mixture (80/20)	0	cy	$ 200.00	$ -	
Import sand for beach augmentation	524	CY	$ 80.00	$ 41,920.00	
	2323		SUBTOTAL Shoreline and Beach Construction:	$ 470,760.00	
Mitigation Measures					
Currently unknown if required	1	ea	$ 1.00	$ 1.00	Assume no mitigation costs TBD during final design and permitting
			SUBTOTAL Mitigation Measures	$ 1.00	
Site Placement Staff Construction Monitoring					
DPW Senior Engineer	100	hours	$ 150.00	$ 15,000.00	
Consulting Ecologist	100	hours	$ 120.00	$ 12,000.00	
Consulting Biologist	60	hours	$ 120.00	$ 7,200.00	
			SUBTOTAL Staff Construction Monitoring	$ 34,200.00	
			Sub-Total Construction and Monitoring:	$ 562,460.00	
			contingency (30%)	$ 168,738.00	
			TOTAL CONSTRUCTION	$ 731,198.00	

DESIGN AND PERMITTING					*Estimated staff time (Town and County)*
Final design	1	ls	$60,000.00	$ 60,000.00	$ 10,000.00
Preparation of Final Plans and Specifications	1	ls	$50,000.00	$ 50,000.00	$ 3,000.00
Permitting	1	ls	$35,000.00	$ 35,000.00	$ 5,000.00
CEQA	1	ls	$70,000.00	$ 70,000.00	$ -
Public Outreach and Education	1	ls	$33,000.00	$ 33,000.00	$ 10,000.00
Reference Beach Surveying -Wave Power Analysis	1	ls	$170,000.00	$ 170,000.00	$ 10,000.00
Project Management and Meetings	1	ls	$ 50,000.00	$ 50,000.00	$ 50,000.00
			SUBTOTAL Design and Permitting:	$ 468,000.00	$ 88,000.00
			TOTAL DESIGN AND PERMITTING	$ 468,000.00	Grant pays $380,000
MONITORING and REPORTING					Estimates; final not known until permits are issued
Post construction surveys (5 events in 10 years)	5	events	$ 3,000.00	$ 15,000.00	Assuming monitoring rquired years 1, 2, 3, 5 and 10 but wont know unti permits come
assessment of geomorphic and vegetation development of the system	5	events	$ 10,000.00	$ 50,000.00	
Annual reporting (assume years 1, 2, 3, 5, and 10) - consultant	5	events	$ 25,000.00	$ 125,000.00	
Annual reporting DPW staff	5	events	$ 3,000.00	$ 15,000.00	
			SUBTOTAL Montioring and Reporting:	$ 205,000.00	
			contingency (30%)	$ 61,500.00	
TOTAL MONITORING AND REPORTING (5 reports in 10 years)				$ 266,500.00	$ 53,300.00
			TOTAL WITH 30% CONTINGENCY	$ 1,465,698.00	
		TOTAL W/O CONTINGENCY		$ 1,235,460.00	

Project Name: Greenwood Beach Preliminary Level Cost Estimate - Alternative 1
Preparer: RDL
Date Last Revised 1/21/2021
Level of Estimate: Preliminary level (+-30%)

item	*quantity*	*units*	*unit cost ($)*	*total cost ($)*	*comments*
CONSTRUCTION					
Site Preparation - Mobilization and Set-Up					
Overhead and PM	1	ls	$ 40,000.00	$ 40,000.00	H-A draft estimate 11/27/19
Mobilization	1	ls	$ 24,000.00	$ 24,000.00	H-A draft estimate 11/27/19
Stormwater Plan and Reporting	1	ls	$ 5,000.00	$ 5,000.00	engineer's estimate
Install construction entrance and temp haul road	1	ea	$ 5,000.00	$ 5,000.00	H-A draft estimate 11/27/19
Deploy Off-Shore Turbidity Curtains	1000	lf	$ 20.00	$ 20,000.00	Unclear if final permit will require a turbidty curtain off-shore for sedment placement - assume 50 foot sections plus $8 for installation
Construction area set-up	230	lf	$ 50.00	$ 11,500.00	engineer's estimate
			SUBTOTAL Site Prep:	$ 65,500.00	
Shoreline Regrading and Boulder Replacement					
Remove and Stockpile Concrete Rubble	2160	tons	$ 37.00	$ 79,920.00	H-A draft estimate 11/27/19 quantity backcalculated from HARC total cost needs to be confirmed in final design
Shoreline Grading	1100	lf	$ 30.00	$ 33,000.00	H-A draft estimate 11/27/19
Replace Usable Concrete and Boulders	255	tons	$ 106.00	$ 15,000.00	H-A draft estimate 11/27/19
Dispose of Aspahlt and Misc Debris	90	tons	$ 120.00	$ 10,800.00	Engineer's estimate - needs to be confirmed during final design
Beach Construction					
Preconstruction survey	1	ls	$ 15,000.00	$ 15,000.00	H-A draft estimate 11/27/19
Provide and place boulders	62	cy	$ 200.00	$ 12,400.00	
Provide and place 3-inch by 1-inch cobble and bay mud mixture (70/30)	2265	cy	$ 190.00	$ 430,350.00	H-A draft estimate 11/27/19
Provide and place 1-inch by 3/8-inch gravel mixture (50/50)	1062	cy	$ 170.00	$ 180,540.00	H-A draft estimate 11/27/19
Provide and place gravel and sand mixture (80/20)	0	cy	$ 200.00	$ -	
Import sand for beach augmentation	568	CY	$ 80.00	$ 45,440.00	
	3958		SUBTOTAL Shoreline and Beach Construction:	$ 822,450.00	
Mitigaiton Measures					
Currently unknown if required	1	ea	$ 1.00	$ 1.00	Assume no mitigation costs TBD during final design and permitting
			SUBTOTAL Mitigation Measures	$ 1.00	
Site Placement Staff Construction Monitoring					
DPW Senior Engineer	100	hours	$ 150.00	$ 15,000.00	
Consulting Ecologist	100	hours	$ 120.00	$ 12,000.00	
Consulting Biologist	60	hours	$ 120.00	$ 7,200.00	
			SUBTOTAL Staff Construction Monitoring	$ 34,200.00	
			Sub-Total Construction and Monitoring:	$ 922,150.00	
			contingency (30%)	$ 276,645.00	
			TOTAL CONSTRUCTION	$ 1,198,795.00	

DESIGN AND PERMITTING					*Estimated staff time (Town and County)*
Final design	1	ls	$60,000.00	$ 60,000.00	$ 10,000.00
Preparation of Final Plans and Specifications	1	ls	$50,000.00	$ 50,000.00	$ 3,000.00
Permitting	1	ls	$35,000.00	$ 35,000.00	$ 5,000.00
CEQA	1	ls	$70,000.00	$ 70,000.00	$ -
Public Outreach and Education	1	ls	$33,000.00	$ 33,000.00	$ 10,000.00
Reference Beach Surveying -Wave Power Analysis	1	ls	$170,000.00	$ 170,000.00	$ 10,000.00
Project Management and Meetings	1	ls	$ 50,000.00	$ 50,000.00	$ 50,000.00
			SUBTOTAL Design and Permitting:	$ 468,000.00	$ 88,000.00
			TOTAL DESIGN AND PERMITTING	$ 468,000.00	Grant pays $380,000
MONITORING and REPORTING					Estimates; final not known until permits are issued
Post construction surveys (5 events in 10 years)	5	events	$ 3,000.00	$ 15,000.00	Assuming monitoring rquired years 1, 2, 3, 5 and 10 but wont know unti permits come
assessment of geomorphic and vegetation development of the system	5	events	$ 10,000.00	$ 50,000.00	
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Annual reporting DPW staff	5	events	$ 3,000.00	$ 15,000.00	
			SUBTOTAL Montioring and Reporting:	$ 205,000.00	
			contingency (30%)	$ 61,500.00	
			TOTAL MONITORING AND REPORTING (5 reports in 10 years)	$ 266,500.00	$ 53,300.00
			TOTAL WITH 30% CONTINGENCY	$ 1,933,295.00	
		TOTAL W/O CONTINGENCY		$ 1,595,150.00	

Project Name:	Greenwood Beach Preliminary Level Cost Estimate - Alt 2 GBDT				
Preparer:	RDL				
Date Last Revised	1/21/2021				
Level of Estimate:	Preliminary level (+-30%)				
item	*quantity*	*units*	*unit cost ($)*	*total cost ($)*	*comments*
CONSTRUCTION					
Site Preparation - Mobilization and Set-Up					
Overhead and PM	1	ls	$ 40,000.00	$ 40,000.00	H-A draft estimate 11/27/19
Mobilization	1	ls	$ 24,000.00	$ 24,000.00	H-A draft estimate 11/27/19
Stormwater Plan and Reporting	1	ls	$ 5,000.00	$ 5,000.00	engineer's estimate
Install construction entrance and temp haul road	1	ea	$ 5,000.00	$ 5,000.00	H-A draft estimate 11/27/19
Deploy Off-Shore Turbidity Curtains	1395	lf	$ 20.00	$ 27,900.00	Unclear if final permit will require a turbidty curtain off-shore for sedment placement - assume 50 foot sections plus $8 for installation
Construction area set-up	230	lf	$ 50.00	$ 11,500.00	engineer's estimate
			SUBTOTAL Site Prep:	$ 73,400.00	
Shoreline Regrading and Boulder Replacement					
Remove and Stockpile Concrete Rubble	2400	tons	$ 37.00	$ 88,800.00	H-A draft estimate 11/27/19 quantity backcalculated from HARC total cost needs to be confirmed in final design
Shoreline Grading	1500	lf	$ 30.00	$ 45,000.00	H-A draft estimate 11/27/19
Replace Usable Concrete and Boulders	283	tons	$ 106.00	$ 15,000.00	H-A draft estimate 11/27/19
Dispose of Aspahlt and Misc Debris	100	tons	$ 120.00	$ 12,000.00	Engineer's estimate - needs to be confirmed during final design
Beach Construction					
Preconstruction survey	1	ls	$ 15,000.00	$ 15,000.00	H-A draft estimate 11/27/19
Provide and place boulders	62	cy	$ 200.00	$ 12,400.00	
Provide and place 3-inch by 1-inch cobble and bay mud mixture (70/30)	4653	cy	$ 190.00	$ 884,070.00	H-A draft estimate 11/27/19
Provide and place 1-inch by 3/8-inch gravel mixture (50/50)	2467	cy	$ 170.00	$ 419,390.00	H-A draft estimate 11/27/19
Provide and place gravel and sand mixture (80/20)	0	cy	$ 200.00	$ -	
Import sand for beach augmentation	1042	CY	$ 80.00	$ 83,360.00	
	8225		SUBTOTAL Shoreline and Beach Construction:	$ 1,575,020.00	
Mitigaiton Measures					
Currently unknown if required	1	ea	$ 1.00	$ 1.00	Assume no mitigation costs TBD during final design and permitting
			SUBTOTAL Mitigation Measures	$ 1.00	
Site Placement Staff Construction Monitoring					
DPW Senior Engineer	100	hours	$ 150.00	$ 15,000.00	
Consulting Ecologist	100	hours	$ 120.00	$ 12,000.00	
Consulting Biologist	60	hours	$ 120.00	$ 7,200.00	
			SUBTOTAL Staff Construction Monitoring	$ 34,200.00	
			Sub-Total Construction and Monitoring:	$ 1,682,620.00	
			contingency (30%)	$ 504,786.00	
			TOTAL CONSTRUCTION	$ 2,187,406.00	

DESIGN AND PERMITTING					*Estimated staff time (Town and County)*
Final design	1	ls	$60,000.00	$ 60,000.00	$ 10,000.00
Preparation of Final Plans and Specifications	1	ls	$50,000.00	$ 50,000.00	$ 3,000.00
Permitting	1	ls	$35,000.00	$ 35,000.00	$ 5,000.00
CEQA	1	ls	$70,000.00	$ 70,000.00	$ -
Public Outreach and Education	1	ls	$33,000.00	$ 33,000.00	$ 10,000.00
Reference Beach Surveying -Wave Power Analysis	1	ls	$170,000.00	$ 170,000.00	$ 10,000.00
Project Management and Meetings	1	ls	$ 50,000.00	$ 50,000.00	$ 50,000.00
			SUBTOTAL Design and Permitting:	$ 468,000.00	$ 88,000.00
			TOTAL DESIGN AND PERMITTING	$ 468,000.00	Grant pays $380,000
MONITORING and REPORTING					Estimates; final not known until permits are issued
Post construction surveys (5 events in 10 years)	5	events	$ 3,000.00	$ 15,000.00	Assuming monitoring rquired years 1, 2, 3, 5 and 10 but wont know unti permits come
assessment of geomorphic and vegetation development of the system	5	events	$ 10,000.00	$ 50,000.00	
Annual reporting (assume years 1, 2, 3, 5, and 10) - consultant	5	events	$ 25,000.00	$ 125,000.00	
Annual reporting DPW staff	5	events	$ 3,000.00	$ 15,000.00	
			SUBTOTAL Montioring and Reporting:	$ 205,000.00	
			contingency (30%)	$ 61,500.00	
			TOTAL MONITORING AND REPORTING (5 reports in 10 years)	$ 266,500.00	$ 53,300.00
			TOTAL WITH 30% CONTINGENCY	$ 2,921,906.00	
		TOTAL W/O CONTINGENCY		$ 2,355,620.00	

Project Name:	Paradise Beach Preliminary Level Cost Estimate - Larger Design GBDT				
Preparer:	RDL				
Date Last Revised	1/21/2021				
Level of Estimate:	Preliminary level (+-30%)				
item	*quantity*	*units*	*unit cost ($)*	*total cost ($)*	*comments*
CONSTRUCTION					
Site Preparation - Mobilization and Set-Up					
Mobilization	1	ls	$ 30,000.00	$ 30,000.00	Engineers estimate
Stormwater Plan and Reporting	1	ls	$ 5,000.00	$ 5,000.00	
Install construction entrance and staging area	1	ea	$ 5,000.00	$ 5,000.00	Engineers estimate
Deploy Off-Shore Turbidity Curtains	600	lf	$ 20.00	$ 12,000.00	Unclear if final permit will require a turbidty curtain off-shore for sedment placement - assume 50 foot sections plus $8 for installation
			SUBTOTAL Site Prep:	$ 52,000.00	
Shoreline Regrading and Boulder Replacement					
Reposition existing blocks	5	days	$ 6,000.00	$ 30,000.00	Engineers estimate - daily crane costs
Minor Shoreline Grading	525	lf	$ 30.00	$ 15,750.00	Engineers estimate
Beach Construction					
Preconstruction survey	1	ls	$ 10,000.00	$ 10,000.00	Engineers estimate
Provide and place 6-inch by 1-inch cobble	4455	cy	$ 190.00	$ 846,450.00	
Provide and place sand and gravel mixture	2599	cy	$ 170.00	$ 441,830.00	
	7054		SUBTOTAL Shoreline and Beach Construction:	$ 1,344,030.00	
Mitigaiton Measures					
Currently unknown if required	1	ea	$ 1.00	$ 1.00	Assume no mitigation costs TBD during final design and permitting
			SUBTOTAL Mitigation Measures	$ 1.00	
Site Placement Staff Construction Monitoring					
DPW Senior Engineer	100	hours	$ 150.00	$ 15,000.00	
Consulting Ecologist	100	hours	$ 120.00	$ 12,000.00	
Consulting Biologist	60	hours	$ 120.00	$ 7,200.00	
			SUBTOTAL Staff Construction Monitoring	$ 34,200.00	
	Sub-Total Construction and Monitoring:			$ 1,430,230.00	
			contingency (30%)	$ 429,069.00	
			TOTAL CONSTRUCTION	$ 1,859,299.00	

DESIGN AND PERMITTING					
Final design	1	ls	$80,000.00	$ 70,000.00	
Preparation of Final Plans and Specifications	1	ls	$50,000.00	$ 50,000.00	
eel grass surveys	1	ls	$20,000.00	$ 20,000.00	
Permitting	1	ls	$60,000.00	$ 60,000.00	
CEQA (neg dec)	1	ls	$60,000.00	$ 60,000.00	
Public Outreach and Education	1	ls	$25,000.00	$ 25,000.00	
Project Management and Meetings	1	ls	$ 20,000.00	$ 20,000.00	
			SUBTOTAL Design and Permitting:	$ 305,000.00	
			TOTAL DESIGN AND PERMITTING	$ 305,000.00	
MONITORING and REPORTING					Estimates; final not known until permits are issued
Post construction veg surveys (5 events in 10 years)	5	events	$ 3,000.00	$ 15,000.00	
assessment of geomorphic and vegetation development of the system	5	events	$ 25,000.00	$ 125,000.00	
Annual reporting (assume 10 years) - consultant	5	events	$ 25,000.00	$ 125,000.00	
Annual reporting DPW staff	5	events	$ 5,000.00	$ 25,000.00	
			SUBTOTAL Montioring and Reporting:	$ 290,000.00	
			contingency (30%)	$ 87,000.00	
TOTAL MONITORING AND REPORTING (5 reports in 10 years)				$ 377,000.00	$ 75,400.00
					Annual MMR is $22,750 per year in
			TOTAL WITH 30% CONTINGENCY	$ 2,541,299.00	
		TOTAL W/O CONTINGENCY		$ 2,025,230.00	

Project Name:	Paradise Beach Preliminary Level Cost Estimate - GBDT Smaller Design				
Preparer:	RDL				
Date Last Revised	1/21/2021				
Level of Estimate:	Preliminary level (+-30%)				
item	*quantity*	*units*	*unit cost ($)*	*total cost ($)*	*comments*
CONSTRUCTION					
Site Preparation - Mobilization and Set-Up					
Mobilization	1	ls	$ 30,000.00	$ 30,000.00	Engineers estimate
Stormwater Plan and Reporting	1	ls	$ 5,000.00	$ 5,000.00	
Install construction entrance and staging area	1	ea	$ 5,000.00	$ 5,000.00	Engineers estimate
Deploy Off-Shore Turbidity Curtains	600	lf	$ 20.00	$ 12,000.00	Unclear if final permit will require a turbidty curtain off-shore for sedment placement - assume 50 foot sections plus $8 for installation
			SUBTOTAL Site Prep:	$ 52,000.00	
Shoreline Regrading and Boulder Replacement					
Reposition existing blocks	5	days	$ 6,000.00	$ 30,000.00	Engineers estimate - daily crane costs
Minor Shoreline Grading	525	lf	$ 30.00	$ 15,750.00	Engineers estimate
Beach Construction					
Preconstruction survey	1	ls	$ 10,000.00	$ 10,000.00	Engineers estimate
Provide and place 6-inch by 1-inch cobble	786	cy	$ 190.00	$ 149,340.00	
Provide and place sand and gravel mixture	1195	cy	$ 170.00	$ 203,150.00	
	1981		SUBTOTAL Shoreline and Beach Construction:	$ 408,240.00	
Mitigaiton Measures					
Currently unknown if required	1	ea	$ 1.00	$ 1.00	Assume no mitigation costs TBD during final design and permitting
			SUBTOTAL Mitigation Measures	$ 1.00	
Site Placement Staff Construction Monitoring					
DPW Senior Engineer	100	hours	$ 150.00	$ 15,000.00	
Consulting Ecologist	100	hours	$ 120.00	$ 12,000.00	
Consulting Biologist	60	hours	$ 120.00	$ 7,200.00	
			SUBTOTAL Staff Construction Monitoring	$ 34,200.00	
	Sub-Total Construction and Monitoring:			$ 494,440.00	
			contingency (30%)	$ 148,332.00	
			TOTAL CONSTRUCTION	$ 642,772.00	

DESIGN AND PERMITTING					
Final design	1	ls	$80,000.00	$ 70,000.00	
Preparation of Final Plans and Specifications	1	ls	$50,000.00	$ 50,000.00	
eel grass surveys	1	ls	$20,000.00	$ 20,000.00	
Permitting	1	ls	$60,000.00	$ 60,000.00	
CEQA (neg dec)	1	ls	$60,000.00	$ 60,000.00	
Public Outreach and Education	1	ls	$25,000.00	$ 25,000.00	
Project Management and Meetings	1	ls	$ 20,000.00	$ 20,000.00	
			SUBTOTAL Design and Permitting:	$ 305,000.00	
	TOTAL DESIGN AND PERMITTING			$ 305,000.00	
MONITORING and REPORTING					Estimates; final not known until permits are issued
Post construction veg surveys (5 events in 10 years)	5	events	$ 3,000.00	$ 15,000.00	
assessment of geomorphic and vegetation development of the system	5	events	$ 25,000.00	$ 125,000.00	
Annual reporting (assume 10 years) - consultant	5	events	$ 25,000.00	$ 125,000.00	
Annual reporting DPW staff	5	events	$ 5,000.00	$ 25,000.00	
			SUBTOTAL Montioring and Reporting:	$ 290,000.00	
			contingency (30%)	$ 87,000.00	
TOTAL MONITORING AND REPORTING (5 reports in 10 years)				$ 377,000.00	$ 75,400.00
					Annual MMR is $22,750 per year in reporting years
		TOTAL WITH 30% CONTINGENCY		$ 1,324,772.00	
		TOTAL W/O CONTINGENCY		$ 1,089,440.00	

Project Name:	Seminary Drive Preliminary Level Cost Estimate				
Preparer:	RDL				
Date Last Revised	1/30/2021				
Level of Estimate:	Preliminary level (+-30%)				
item	*quantity*	*units*	*unit cost ($)*	*total cost ($)*	*comments*
CONSTRUCTION					
Site Preparation - Mobilization and Set-Up					
Mobilization	1	ls	$ 30,000.00	$ 30,000.00	Engineers estimate
Stormwater Plan and Reporting	1	ls	$ 5,000.00	$ 5,000.00	
Install construction entrance and staging area	1	ea	$ 5,000.00	$ 5,000.00	Engineers estimate
Deploy Off-Shore Turbidity Curtains	600	lf	$ 20.00	$ 12,000.00	Unclear if final permit will require a turbidty curtain off-shore for sedment placement - assume 50 foot sections plus $8 for installation
			SUBTOTAL Site Prep:	$ 52,000.00	
Shoreline Regrading and Boulder Replacement					
Shoreline Grading	1	lf	$ 1.00	$ 1.00	Engineers estimate
Beach Construction					
Preconstruction survey	1	ls	$ 10,000.00	$ 10,000.00	Engineers estimate
Provide and place 6-inch by 1-inch cobble	1249	cy	$ 190.00	$ 237,310.00	
Provide and place gravel and sand mixture (80/20)	1265	cy	$ 200.00	$ 253,000.00	
Import sand for beach augmentation	593	CY	$ 80.00	$ 47,440.00	
	3107		SUBTOTAL Shoreline and Beach Construction:	$ 547,751.00	
Mitigaiton Measures					
Currently unknown if required	1	ea	$ 1.00	$ 1.00	Assume no mitigation costs TBD during final design and permitting
			SUBTOTAL Mitigation Measures	$ 1.00	
Site Placement Staff Construction Monitoring					
DPW Senior Engineer	100	hours	$ 150.00	$ 15,000.00	
Consulting Ecologist	100	hours	$ 120.00	$ 12,000.00	
Consulting Biologist	60	hours	$ 120.00	$ 7,200.00	
			SUBTOTAL Staff Construction Monitoring	$ 34,200.00	
			Sub-Total Construction and Monitoring:	$ 633,951.00	
			contingency (30%)	$ 190,185.30	
			TOTAL CONSTRUCTION	$ 824,136.30	

DESIGN AND PERMITTING					
Final design	1	ls	$60,000.00	$ 60,000.00	
Preparation of Final Plans and Specifications	1	ls	$50,000.00	$ 50,000.00	
Permitting	1	ls	$35,000.00	$ 35,000.00	
CEQA	1	ls	$70,000.00	$ 60,000.00	
Public Outreach and Education	1	ls	$33,000.00	$ 33,000.00	
Project Management and Meetings	1	ls	$ 50,000.00	$ 50,000.00	
			SUBTOTAL Design and Permitting:	$ 288,000.00	
			TOTAL DESIGN AND PERMITTING	$ 288,000.00	
MONITORING and REPORTING					Estimates; final not known until permits are issued
Post construction veg surveys (5 events in 10 years)	5	events	$ 3,000.00	$ 15,000.00	
assessment of geomorphic and vegetation development of the system	5	events	$ 20,000.00	$ 100,000.00	
Annual reporting (assume 10 years) - consultant	5	events	$ 15,000.00	$ 75,000.00	
Annual reporting DPW staff	5	events	$ 3,000.00	$ 15,000.00	
			SUBTOTAL Montioring and Reporting:	$ 205,000.00	
			contingency (30%)	$ 61,500.00	
			TOTAL MONITORING AND REPORTING (5 reports in 10 years)	$ 266,500.00	$ 53,300.00
			TOTAL WITH 30% CONTINGENCY	$ 1,378,636.30	
		TOTAL W/O CONTINGENCY		$ 1,126,951.00	