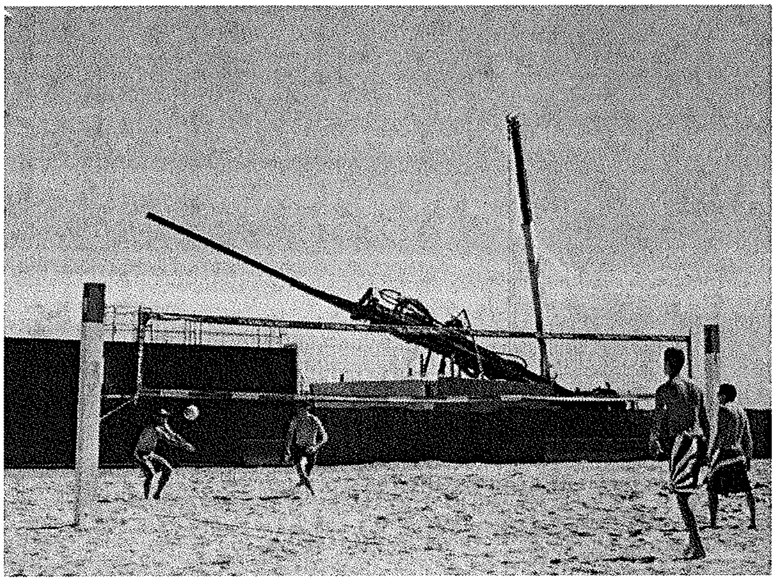


Figure 12
Slant Test Well Drilling Operation at Doheny State Beach, Dana Point, California
(Source: Geoscience Support Services, Inc.)

Figure 13
Slant Test Well Site - Post Construction Operational Phase
Doheny State Beach, Dana Point, California
(Source: Geoscience Support Services, Inc.)

OPERATION AND SCHEDULE

As described above the Slant Test Well would be implemented in two phases. During the Construction/Initial testing Phase, the slant test well will be constructed, developed and pumped within the 5-month non-nesting season for the Snowy Plover from October 1, 2013 to February 28, 2014. The construction equipment will be mobilized on October 1 assuming all permits are secured. The site preparation and drilling and development of the slant test well will be performed around the clock. Once the well is developed, initial and short-term testing will be performed until February. All construction equipment, pumps, protection equipment will be removed from site and the site will be returned to original conditions by February 28. The test well will not be operated from March through September. The Confirmation Phase, if required, would be initiated in October 2014. A construction crane would be mobilized to install a smaller wave protection system. Once the wave protection is in place, a temporary diesel generator, along with supporting equipment, would be mobilized to the site for pumping operations. All wave protection and generator and pumping equipment would be removed from the site by February 28, 2015.

ENVIRONMENTAL ISSUES

Snowy Plover Protection. The test well site will be located entirely within the swash zone adjacent to a beach that could potentially be used by snowy plovers for nesting, during March through September. During a biological survey of May 16, 2012, neighboring sites were chained and posted for snowy plover nests. Slant test well construction and short term pumping is proposed to begin in October 2013, and will be completed during the 5 month non-nesting season. During this construction/initial testing phase, an appropriately trained biologist will be designated to monitor equipment access and construction activities, in order to avoid disturbance to potential neighboring snowy plover habitat.

Management of Drill Cuttings. Cuttings generated during the drilling process will be stored within the sheet piled area. The drill cuttings will be allowed to drain, with water percolating to the ground. Drainage for the drill cuttings will be managed such that all water percolates to the ground within the sheet-piled construction area. Dewatered drill cuttings (estimated volume of less than 100 cubic yards) will be incorporated in backfill operations within the sheet-piled area.

Emissions. Air quality permits may be required for the emissions from diesel-fueled equipment that is necessary for construction operations.

Stormwater Pollution Prevention Plan. It is anticipated that no SWPP will be required because the disturbed area for the project is less than 1 acre, and is entirely within the swash zone.

AVOIDANCE AND MINIMIZATION MEASURES (PROJECT DESIGN FEATURES)

The following summarizes the avoidance measures proposed by the project, in order to address the environmental issues outlined above:

Project Siting. At the request of regulatory agencies, the test well site has been shifted seaward to within the swash zone, to minimize or avoid disruption of the snowy plover wrack and upland beach habitat. The construction zone will be at least five feet below the upper limits of the swash zone as determined in the field. In addition, the construction and operation has been modified to eliminate the need for an electrical supply and water sampling conduit on the east side of the dunes, thereby avoiding all construction impacts in the agricultural and dune area (water sampling will only occur during the five-month construction phase, and potentially during the following non-breeding season "Confirmation Phase"). No sampling, construction traffic, or facility access or maintenance would occur during the snowy plover nesting season.

Construction Limits. CAW will restrict construction activities to the proposed construction area and access route, in order to minimize access impacts to the upland beach and snowy plover wrack area. No construction equipment, materials, or activity will occur outside the specified beach areas and beach access route identified on Figures 1, 2, and 3. Delivery of materials and equipment will be along a carefully monitored path below the swash zone, with biological monitors present. No construction equipment, materials, or activity will be placed on the sandy beach outside of the immediate construction zone. The property owner would be consulted, prior to commencement of construction, in order to schedule construction activities during non-peak hours and provide advance notice of construction activities.

Construction Lighting. The construction area will be isolated from over-wintering snowy plover by the enclosed construction zone (sheet pile perimeter). This will also attenuate noise levels. Night time lighting will be such that is directed toward the construction activity, sufficient for safety and security only.

Timing of Construction and Pumping Activities (Biological Resources). To avoid adverse impacts on the snowy plover, construction activities and pumping activities will be limited to the plover's non-nesting season (October 1st through February 28th).

Biological Education and Monitoring. Prior to initiation of access or construction activities, a designated biologist will conduct an educational session with all construction personnel. An appropriately trained biologist will be designated to monitor equipment access in order to avoid disturbance to sensitive habitat.

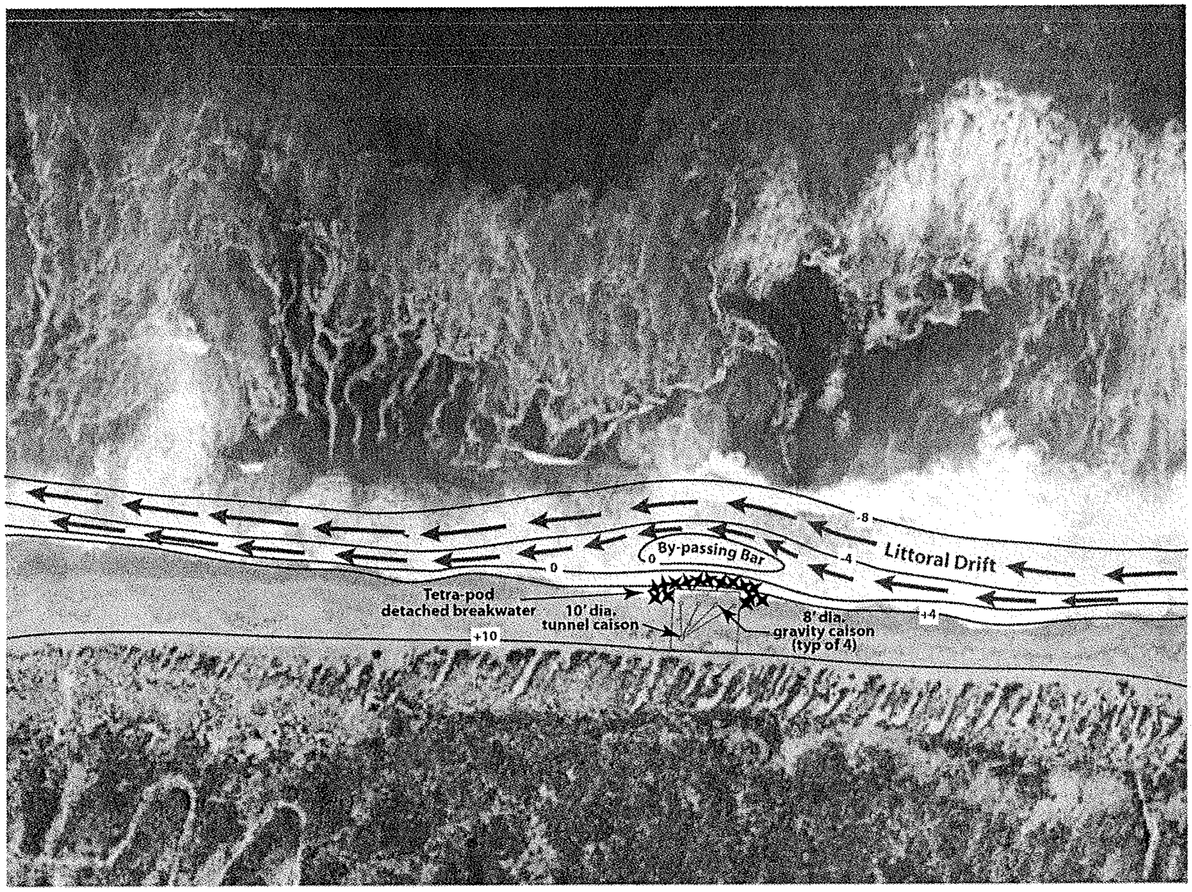
Beach Erosion. The well head will be buried below the beach surface in a well head vault at approximately mean sea level, and covered with 3 to 6 feet of native beach sand. It is expected that this will protect this structure from being exposed or directly impacted by wave action during the period between the Construction/Initial Testing Phase and the Confirmation Phase.

The subsurface diffuser will be placed with a minimum of 4 feet of beach sand cover material. If required, a flexible cable and concrete block mesh will be placed and buried directly over the subsurface diffuser to minimize possibility of wave damage.

If the buried well head vault becomes exposed due to erosion, shifting sand, or other factors, the exposure will be remedied by excavating the well head vault and moving it deeper. If the diffuser becomes exposed, it will be excavated and either buried deeper (if it is still being used for testing), or removed (if testing has been completed). Unless otherwise permitted or ordered, construction of the remedy will be scheduled during the non-nesting season.

ATTACHMENT 2

Technical Memorandum: Littoral Sand Transport and Equilibrium Beach Profile Change at Updated Monterey Peninsula Water Supply Project Slant Test Well Site



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Revised: 18 February 2013

ABSTRACT:

This technical memorandum evaluates littoral sand transport (littoral drift) and beach profile change in the neighborhood of slant intake wells proposed as part of the Monterey Peninsula Water Supply Project (MPWSP). Construction of the intake wells in the swash zone will require a temporary barrier and sheet piling forming a box coffer dam around the well heads and associated hydraulic conveyance to protect equipment and personnel during construction. The seaward face of the sheet pile coffer dam will be protected from wave impact and scour by a temporary detached breakwater constructed from pre-cast concrete *tetrapods* or sand-filled *geo-bags or geo-tubes*. These construction techniques have the advantage of ease in placement and recovery. Conventional rubble mound breakwater construction with quarry stone is prone to scour and burial on sandy beaches, and is extremely difficult to remove once constructed, as each stone must dug out with a clam shell type of apparatus. The tetrapod or sand-filled geo-bags/geo-tubes on the other hand are resistant to wave scour and burial. Tetrapods have a steel lift ring and geo-bags are made of geo-textile fabrics which render both easy to place and recover with conventional rigging and mobile crane operations. These features also reduce placement and recovery schedules, which is an important attribute since construction will need to be accomplished within the five-month (October through February) non-nesting season for the Snowy Plover, and the temporary barrier and sheet piling must be removed prior to March 1.

The beach and bluff dunes at the MPWSP test well site derive their sand supply from proximity to the Salinas River, only 2.2 km up-coast (to the north) from the MPWSP test well site. The net littoral drift of sand in this quadrant of Monterey Bay is southward, from the Salinas River towards the MPWSP test well site and the CEMEX plant further to the south. The southward direction of net littoral drift insures that the beach and dune bluff system at the MPWSP test well site and CEMEX plant is continually nourished by the sediment yield of the Salinas River, the most sediment productive river in California south of the Sacramento River delta. The decisive question to be addressed in this technical memorandum is whether or not the coffer dam and detached breakwater around the test well site will interrupt or prevent this southward directed net littoral drift, and thereby create a beach sand supply deficit in the neighborhood of the CEMEX sand mining operations. We utilized the Coastal Evolution Model (Jenkins and Wasyl, 2005) to make preliminary quantitative assessments of net littoral drift of sand and equilibrium beach profile change at the new MPWSP test well site; and to make comparisons with similar calculations made for the former MPWSP well site in Jenkins (2012). The algorithms of this model have been published in the peer reviewed literature, with the equilibrium beach profile algorithms appearing in Jenkins and Inman (2006), and the divergence of drift and shoreline evolution algorithms appearing in Jenkins et al 2007.

The model simulations show a positive divergence of drift with beach accretion along the reach of shoreline from about 2.5 km north of the Salinas River and extending south for about 4 kilometers beyond the MPWSP test well site in the neighborhood of the CEMEX sand mining operation. This calculation is consistent with the wide beaches and bluff dunes found in the neighborhood of the Salinas River and test well site in aerial photos. Wind-blown losses of beach sand have been neglected in this simulation, but the positive divergence of drift, (that averages 15 m^3/day at the MPWSP test well site and

about 5 m^3/day at the CEMEX sand mining plant) provide a continual source of sand at both sites to sustain adequate beach sand volumes; so much so that wind effects have formed sand dunes in front of the bluff formations, as evident in aerial photos. Beaches with long-term averages of positive divergence of drift are not prone to erosion. The positive divergence of drift at this new MPWSP test well site is about double the positive divergence of drift at the former MPWSP test well site evaluated in Jenkins (2012) that was located about 2.5 km further down drift to the south; indicating the new well site is a better location with respect to beach stability. Furthermore, there is no discernible difference between the littoral drift and divergence of drift at the CEMEX plant in the present calculations (that include the effects of the sheet pile box coffer dam and tetrapod detached breakwater around the new MPWSP test well site), versus similar calculation in Jenkins (2012) for the former MPWSP test well that did not incorporate any shore protection structures.

The envelope of variability of the equilibrium beach profiles calculated by the model, (as applied to the new MPWSP well site with coffer dam and detached breakwater), shows that over the long term, beach profiles around the well site can cause sand levels to vary vertically by as much as 6 ft., (generally accreting 2 ft. above present grade, and eroding 4 ft. below present grade). The average significant wave height in the 1984-2008 period of record was $\overline{H}$ = 2.1 m, the average wave period was $\overline{T}$ = 11.3 sec, while the average direction of the waves in was $\overline{\alpha}$ = 286 degrees true. These extreme sand level variations do not allow wave run-up to overtop the sheet pile coffer dam or tetrapod detached breakwater, nor do the extreme sand level variations undercut the foundation of either shore protection structure. A critical feature in all of these beach profiles is the formation of an equilibrium sand bar immediately seaward of the tetrapod detached breakwater. Bar formation seaward of hardened shore protection devices are well known to coastal engineering, and are a consequence of the increase in the beach reflection coefficient caused by the steep seaward facing slopes of these structures. In the site-specific case of the new MPWSP well site, the shore protection structures (coffer dam and detached breakwater) are situated high enough upslope on the bar-berm portion of the beach profile that the reflection-induced sand bar remains inside the surf zone (landward of the wave break point). Here, the bar function provides a by-passing pathway for the long shore transport of sand (littoral drift). The preponderance of the littoral drift moves inside the surf zone, where it will flow around the coffer dam and detached breakwater structures following a pathway provided by the by-passing bar. In essence, the by-passing bar causes the local bathymetry to develop a seaward bulge. This seaward bulge in the local bathymetry causes the surf zone to likewise develop a seaward bulge; and where the surf zone goes, the littoral drift follows. Consequently the shore protection structures of the new MPWSP well site will not intercept or cut-off the littoral drift in the manner of a shoreline normal jetty structure; and will not diminish the longshore transport rates of sand in the littoral drift that reaches the CEMEX sand mining plant.

1) Introduction:

This technical memorandum evaluates littoral sand transport (littoral drift) and beach profile change in the neighborhood of Slant Test Wells (STW) proposed as part of the Monterey Peninsula Water Supply Project (MPWSP). These wells are a component of the proposed MPWSP northern project facilities that will ultimately provide the

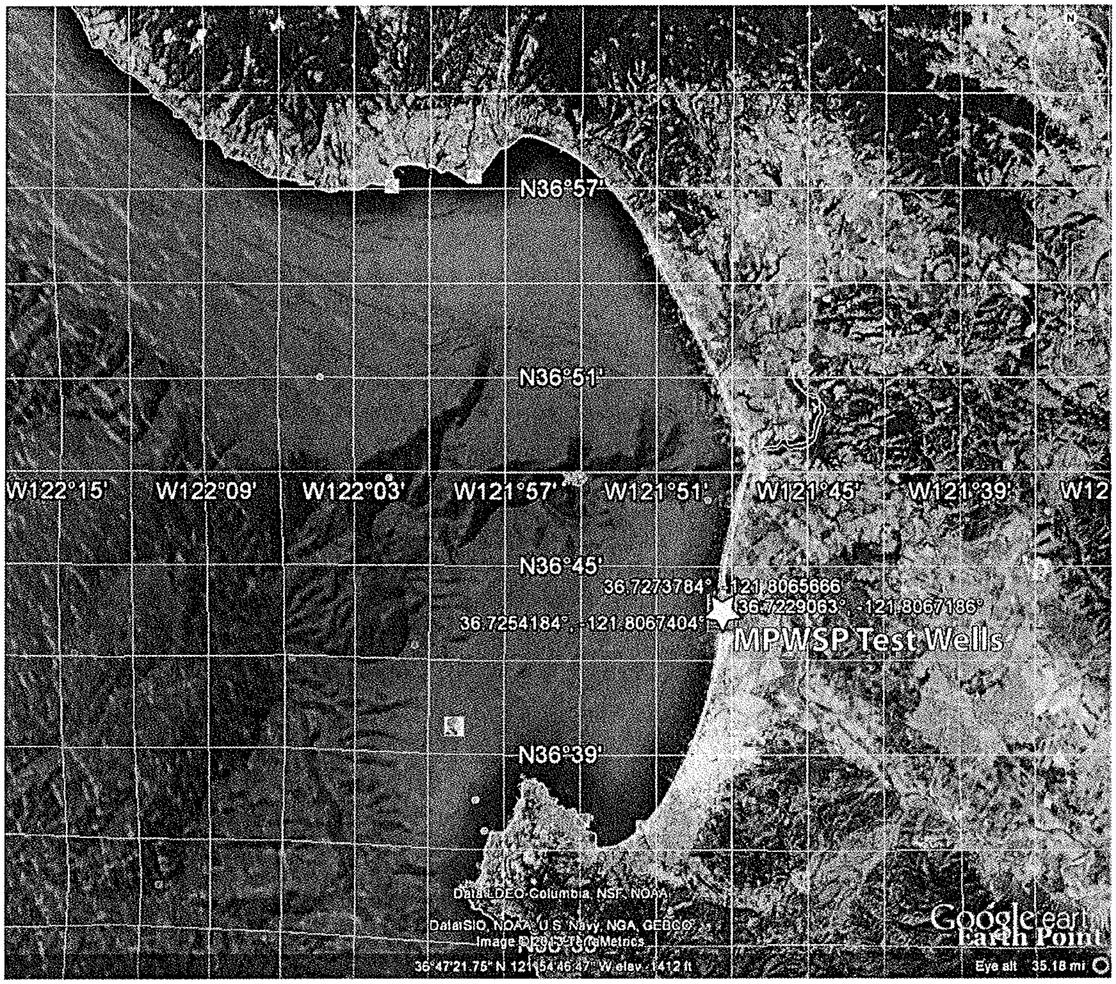
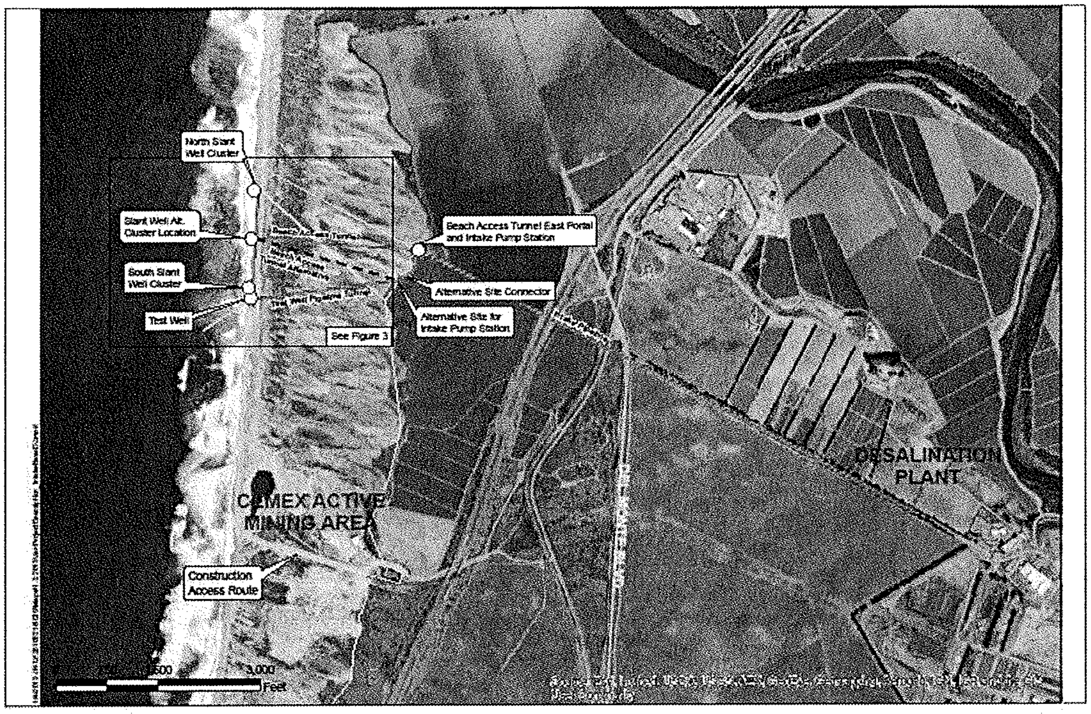


Figure 1: Farfield location of MPWSP Slant Test Well Alternative Site Locations in Monterey Bay.

feedwater intake system to the desalination plant (6.4 MGD or 9.6 MGD). Figure1 shows the location of the well sites in far field of Monterey Bay, while Figure 2 shows the near field configuration of feedwater intake wells, feedwater intake pump station, and feedwater intake pipelines in the MPWSP. Feedwater for the MPWSP desalination plant would be extracted from subsurface slant wells that would draw seawater from beneath the shoreline. A slant well is a well that is drilled at an angle using modified vertical well construction methods. This allows construction of wells that extract water from as close to the coastline as possible, in order to extract water with higher salinity than can be obtained with conventional vertical wells. Angled drilling is beneficial because it results in a substantially increased screen length in the targeted water-bearing formations.

For the 9.6 MGD desalination option, the total well capacity required is approximately 23 MGD to meet the feedwater requirement for a 9.6 MGD desalination plant operating at an overall recovery of 42 percent. Nine wells operating at 1,800 gpm can meet this requirement. For the 6.4 MGD desalination option, the total well capacity required is approximately 15 MGD which can be met by seven wells operating at 1,500 gpm per well.



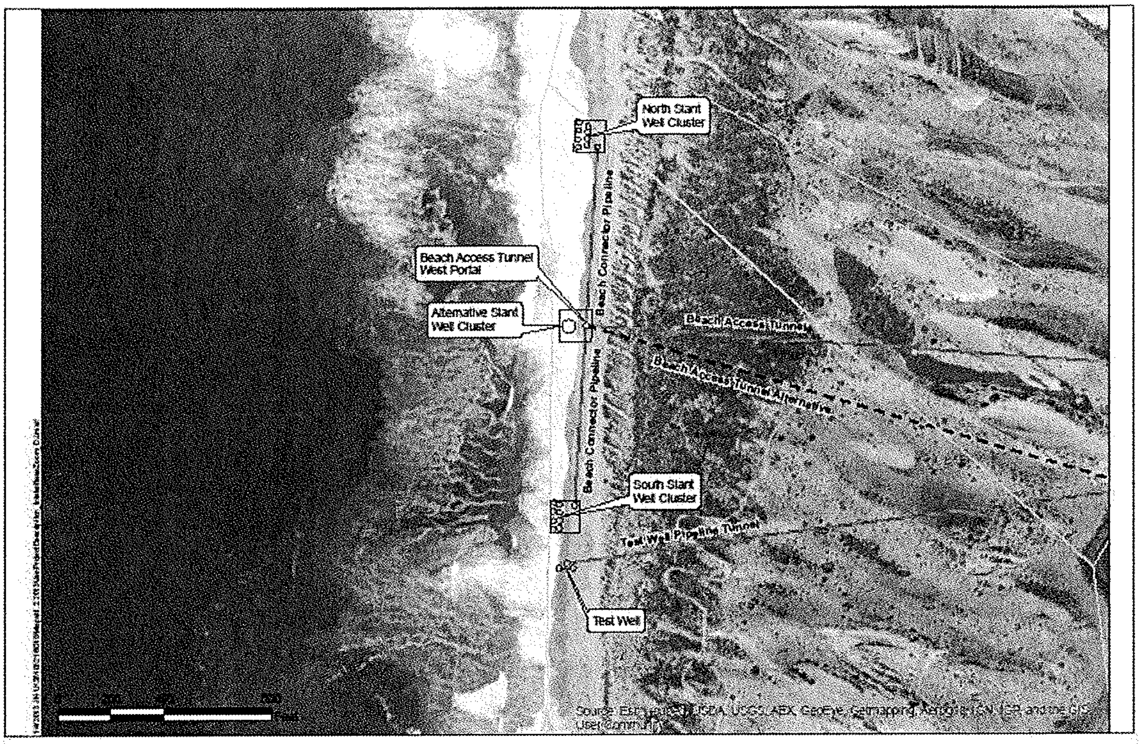
Monterey Peninsula Water Supply Project

Intake Facilities

Figure 2

The preferred site (APN Number: 203 011 019 000) for construction of the slant wells is adjacent to a 376-acre parcel of land owned by the CEMEX corporation located due west of the proposed desal plant site and west of Highway 1. This property borders the Pacific Ocean and includes disturbed and undisturbed areas and approximately 7,000 feet of ocean shoreline. The wells would be constructed in two clusters along a 2000-foot stretch of this shoreline, at two of the three candidate cluster locations shown on Figure 2 and Figure 3 Most, if not all, of the facilities in the well clusters will actually be constructed on land owned by the State of California, under the authority of the California State Lands Commission.

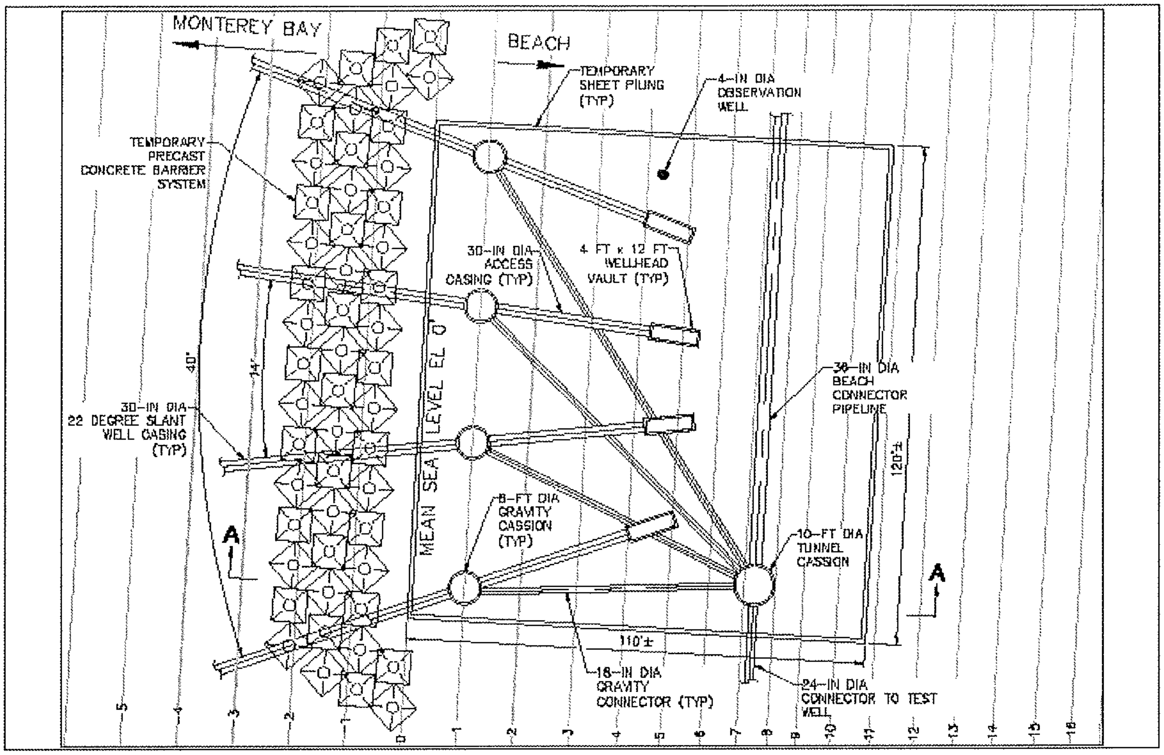
One of the clusters would be constructed near the test well site, which is being separately permitted as a test facility, and the expectation is that the test well facility would be connected to this southern cluster, allowing the test well to be converted to a permanent facility. Four wells would be constructed at each cluster for the 9.6 MGD desalination option and three wells would be constructed at each cluster for the 5.4 MGD option. A preliminary layout and profile view of the well cluster is shown on Figures 4 and 5. Each slant well would be drilled at a 22 degree angle from horizontal to the bottom of the surface aquifer, which is referred to as the Sand Dunes Aquifer (SDA). In the proposed locations, the length of the wells is expected to range from 530 LF to 630 LF, measured from ground surface, and the length of the well screens is expected to range from 370 LF to 470 LF. The wells will be designed as gravity wells such that they will not require submersible well pumps or electrical power.



Monterey Peninsula Water Supply Project

Intake Wells

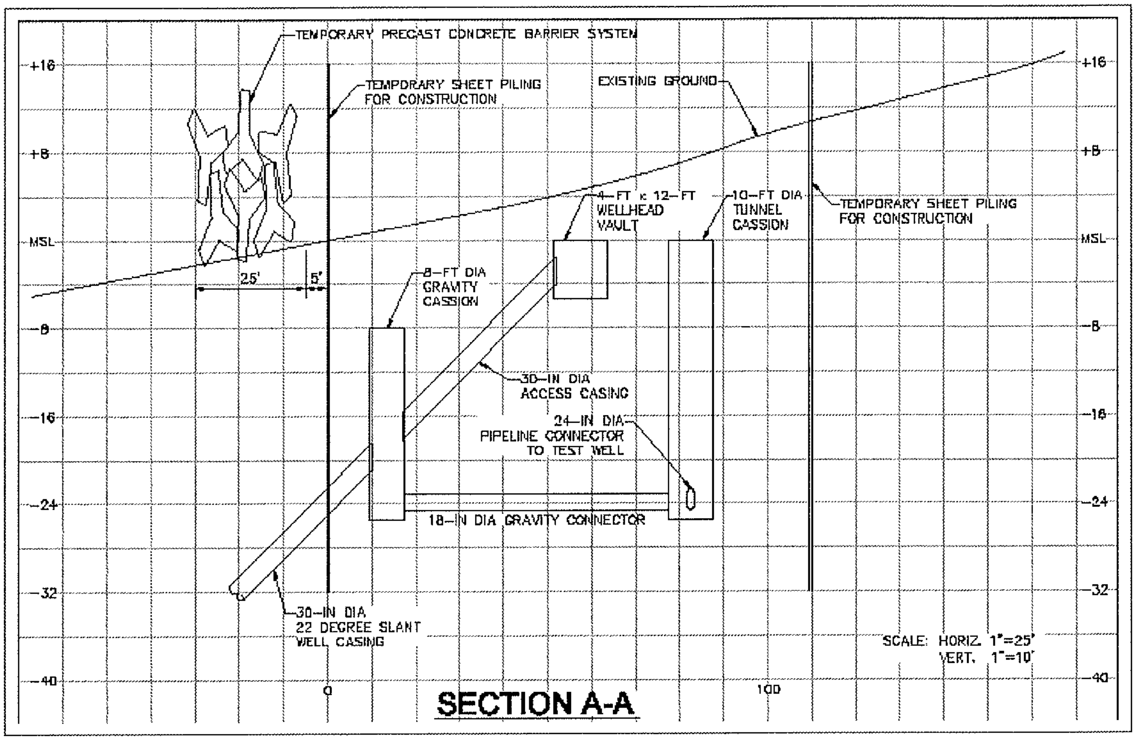
Figure 3



Monterey Peninsula Water Supply Project

Southern Intake Well Cluster

Figure 4



Monterey Peninsula Water Supply Project

Profile A-A of Southern Intake Well Cluster

Figure 5

In order to protect the wellheads from wave damage, to eliminate any visual profile after construction, and to eliminate impacts on Snowy Plover nesting habitat, the wellheads will be completely buried below the beach surface in the area known as the "swash zone", which is the portion of the beach that lies within the run-up of waves at normal high tide. In order to eliminate any possibility that the wellheads or any associated structures will be exposed by the combined effects of coastal erosion and sea level rise, they will be capped at or below mean sea level.

Construction of the intake wells in the swash zone will require a temporary barrier and sheet piling forming a box coffer dam around the well heads and associated hydraulic conveyance to protect equipment and personnel during construction (Figures 4 and 5). Sheet pile structures have been used successfully for shore protection for over a century. A properly designed sheet pile coffer dam will provide adequate protection for the intake well cluster and construction area during the construction phase. The sheet pile specification will be determined based upon the expected scour level on the beach during the construction phase and the anticipated grade elevation on the landward site of the pile. Based upon our experience with similar sheet pile shore protection projects on high wave energy sand beaches a reasonable preliminary design would be a "Z" shaped pile with a length of about 50 feet and a section modulus of about 33 in^3/ft. This size sheet should be capable of withstanding the construction phase design wave conditions and scour conditions. The height of the sheet above sea level will be determined such that the potential for wave overtopping is not significant. It should be noted that the sheets will deflect when loaded by wave slam. However, deflection of several inches will not impact the construction site behind the wall.

The seaward face of the sheet pile coffer dam will be protected from wave impact and scour by a temporary detached breakwater constructed from pre-cast concrete *tetrapods* (Figures 6a & 6b) or alternatively with sand-filled *geo-bags* or *geo-tubes* constructed of geotextile fabric (Figure 7). In addition to providing toe-protection to the sheet pile coffer dams, regulatory agencies have expressed concerns over the reflective nature of a vertical wall and the resulting potential for impacts to the alongshore movement of sand as the wave energy is redirected offshore. The use of either the tetrapod toe projection or a geo-bag/geo-tube toe protection will reduce the reflective nature of the vertical walls of the coffer dams and therefore reduce the potential of impact to sediment transport.

The tetrapod construction technique has the advantage of ease in placement and recovery. Conventional rubble mound breakwater construction with quarry stone is prone to scour and burial on sandy beaches, and is extremely difficult to remove once constructed, as each stone must dug out with a clam shell type of apparatus. The tetrapod on the other hand is resistant to wave scour and burial, and each tetrapod has a steel lift ring (Figure 6b) that renders it easy to place and recover with conventional rigging and mobile crane operations. This feature also reduces placement and recovery schedules, which is an important attribute since construction will need to be accomplished within the five-month (October through February) non-nesting season for the Snowy Plover, and the temporary barrier and sheet piling must be removed prior to March 1.

Geo-tube/geo-bag (geo-containment) technology has been used as an integral component in the design and construction of a variety of marine and hydraulic engineering structures such as breakwaters, levies, and marine spoil-containment structures. For more than 40 years, this technology has protected shorelines, rebuilt beaches, and reclaimed land from the sea. Geo-tube/geo-bag containment technology is a proven, cost-effective method for a variety of shoreline protection and marine construction projects. This technology has been used to produce sand dune cores; wetlands and other habitats; jetties, dikes, and groins; and underwater structures -- and to even raise brand new islands from under water.

Geo-tubes and geo-bags are cost-effective, durable, easy to install, and highly flexible. The technology works well for both short-term and long-term solutions. Geotube structures are fabricated from a high-strength, specially engineered, woven textile with special high-strength seaming techniques to resist pressures during pumping operations. No special equipment is required to install and the tube is easily removed when it is no longer needed.

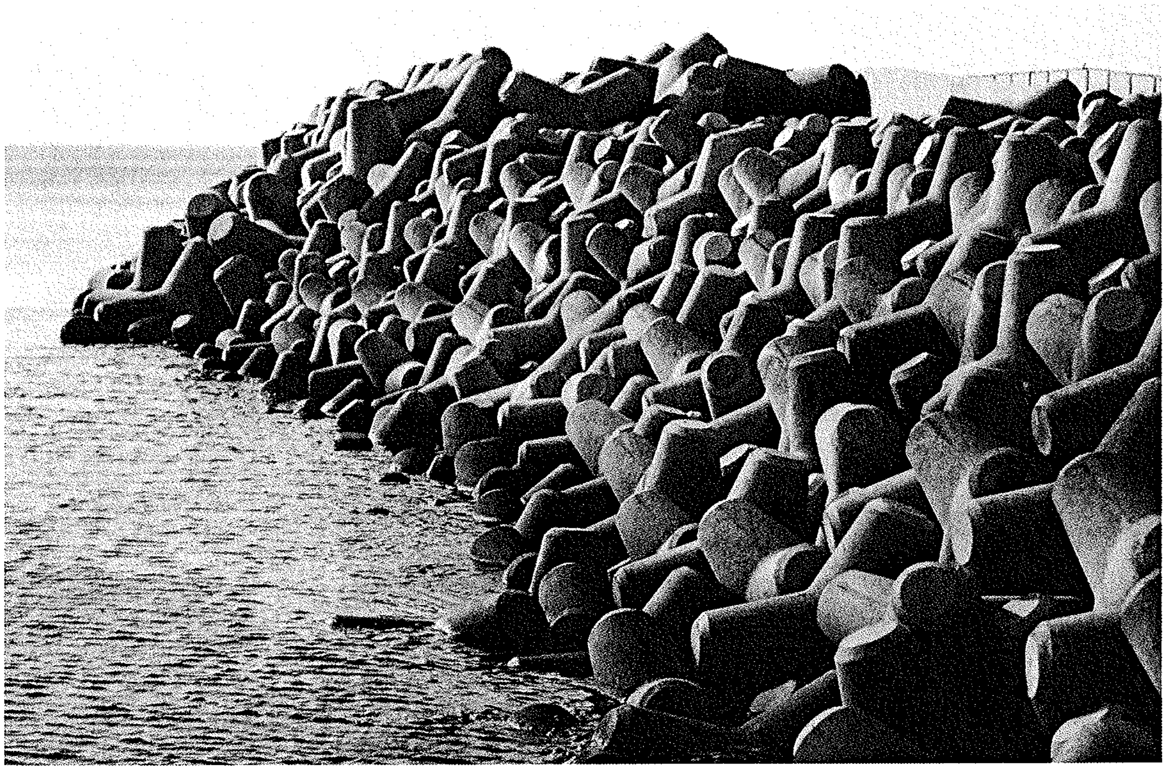


Figure 6a: Concrete *Tetrapods* used in breakwater construction and shore protection as an alternative to convention rubble mound construction techniques.

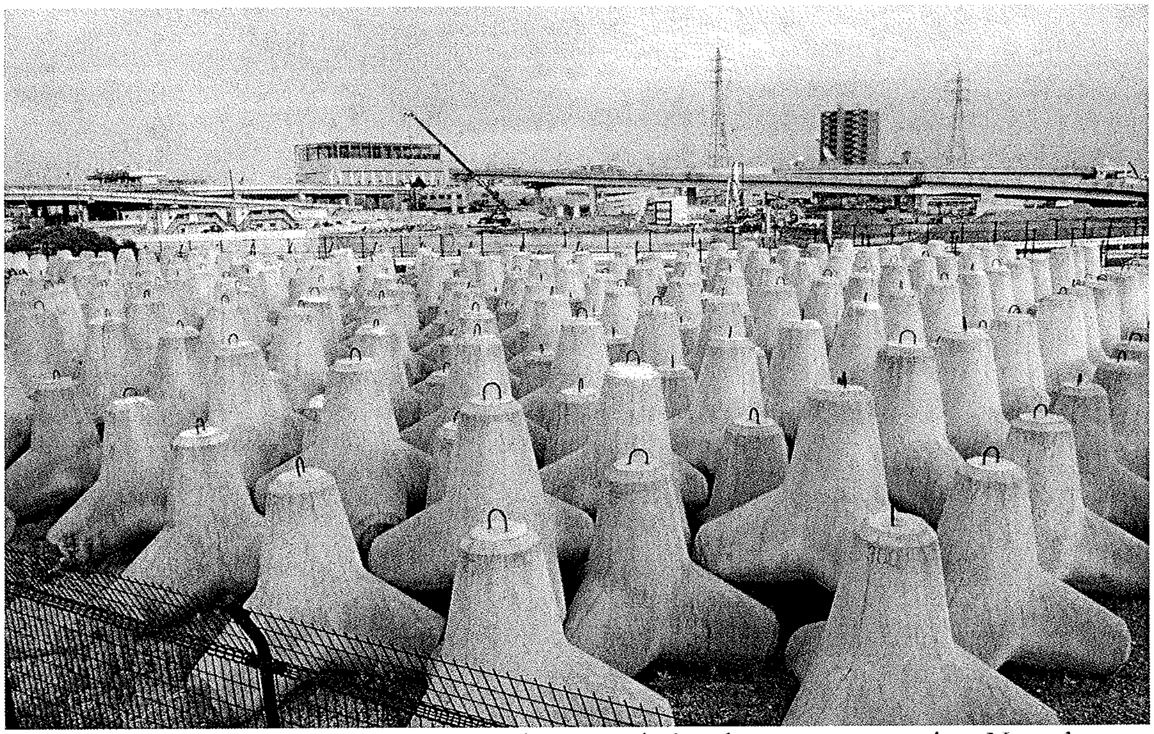


Figure 6b: Concrete *Tetrapods* prior to placement in breakwater construction. Note the steel lift rings which facilitate placement and removal by convential rigging and mobile crane operations.

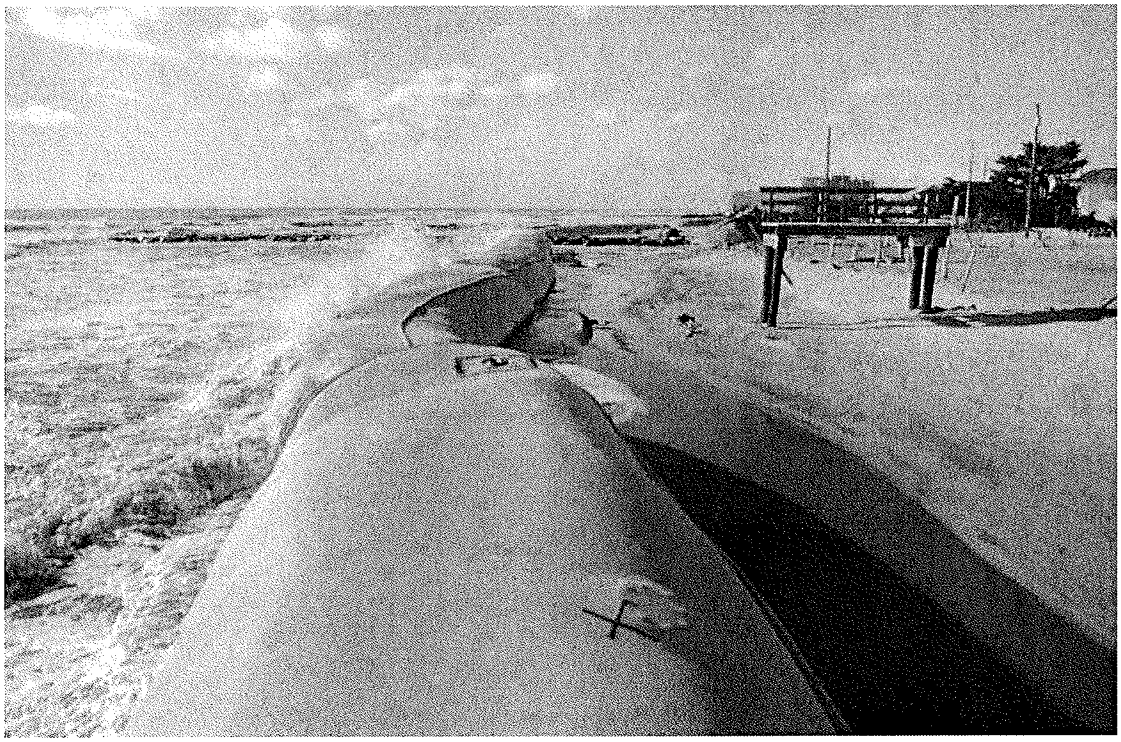


Figure 7: Sand-filled geo-tube (geo-bag) for shore protection from wave run-up.

2) Statement of the Problem:

From Figure 8 it is apparent that the beach and bluff dunes at the MPWSP test well site derive its sand supply from proximity to the Salinas River, only 2.2 km upcoast (to the north) from the MPWSP test well site (Jenkins, 2012). By zooming in on Figure 8, a very wide beach is found in the immediate neighborhood of the Salinas River. This beach thins rapidly to the north of the river; but only gradually narrows to the south of the river, and merges with the bluff dune system at the MPWSP test well site. This north/south asymmetry in beach width indicates that the net littoral drift of sand in this quadrant of Monterey Bay is southward, from the Salinas River towards the MPWSP test well site and the CEMEX plant further to the south. The southward direction of net littoral drift insures that the beach and dune bluff system at the MPWSP test well site and CEMEX plant is continually nourished by the sediment yield of the Salinas River, the most sediment productive river in California south of the Sacramento River delta (Inman and Jenkins, 1999). With this continual nourishment, the test well site is insulated from chronic, progressive beach and bluff erosion, and is insured a resident sand supply in excess of the critical mass volume requirements. The decisive question to be

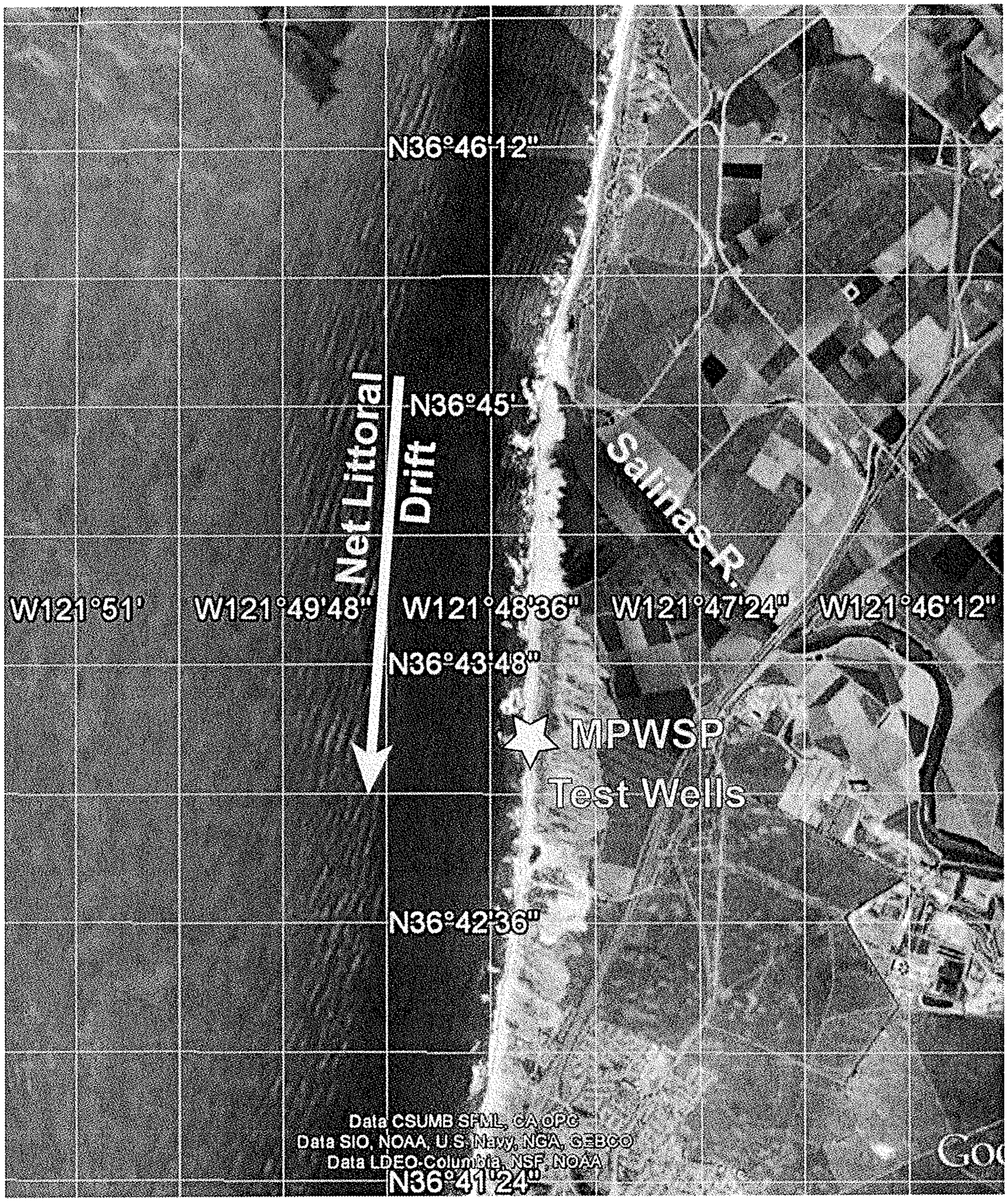


Figure 8: Farfield view of the beach and dune system at the MPWSP test well site the net littoral drift that feeds the sand mining operation of the CEMEX from the sand source of the Salinas River..

addressed in this technical memorandum is whether or not the coffer dam and detached breakwater around the test well site will interrupt or prevent this southward directed net littoral drift, and thereby create a beach sand supply deficit in the neighborhood of the CEMEX sand mining operations. This issue will be quantified in following sections.

3) Technical Approach:

As detailed in Jenkins (2012), long term beach and shoreline monitoring data in Monterey, and at the test well site in particular, suffer from a number of shortcomings, principally aliasing. Therefore, we take an analytic approach to providing preliminary erosion analysis at the project site. We will utilize the Coastal Evolution Model commissioned by the Kavli Foundation to make preliminary quantitative assessments of net littoral drift of sand equilibrium beach profile change at MPWSP test well site (Figure 3)

The Coastal Evolution Model (CEM) is a process-based numerical model. It consists of a Littoral Cell Model (LCM) and a Bedrock Cutting Model (BCM), both coupled and operating in varying time and space domains (Figure 9) determined by sea level and the coastal boundaries of the littoral cell at that particular sea level and time. At any given sea level and time, the LCM accounts for erosion of uplands by rainfall and the transport of mobile sediment along the coast by waves and currents, while the BCM accounts for the cutting of bedrock by wave action in the absence of a sedimentary cover.

In both the LCM and BCM, the coastline of the littoral cell is divided into a series of coupled control cells (Figure 10). Each control cell is a small coastal unit of uniform geometry where a balance is obtained between shoreline change and the inputs and outputs of mass and momentum. The model sequentially integrates over the control cells in a down-drift direction so that the shoreline response of each cell is dependent on the exchanges of mass and momentum between cells, giving continuity of coastal form in the down-drift direction. Although the overall computational domain of the littoral cell remains constant throughout time, there is a different coastline position at each time step in sea level. For each coastline position there exists a similar set of coupled control cells that respond to forcing by waves and current. Time and space scales used for wave forcing and shoreline response (applied at 6 hour intervals) and sea level change (applied annually) are very different. To accommodate these different scales, the model uses multiple nesting in space and time, providing small length scales inside large, and short time scales repeated inside of long time scales.

The LCM (Figure 9, upper) has been used to predict the change in shoreline width and beach profile resulting from the longshore transport of sand by wave action where sand source is from river runoff or from tidal exchange at inlets (e.g., Jenkins and Inman, 1999). More recently it has been used to compute the sand level change (farfield effect) in the prediction of mine burial (Jenkins and Inman, 2002; Inman and Jenkins, 2002). Time-splitting logic and feedback loops for climate cycles and sea level change were added to the LCM together with long run time capability to give a numerically stable couple with the BCM.

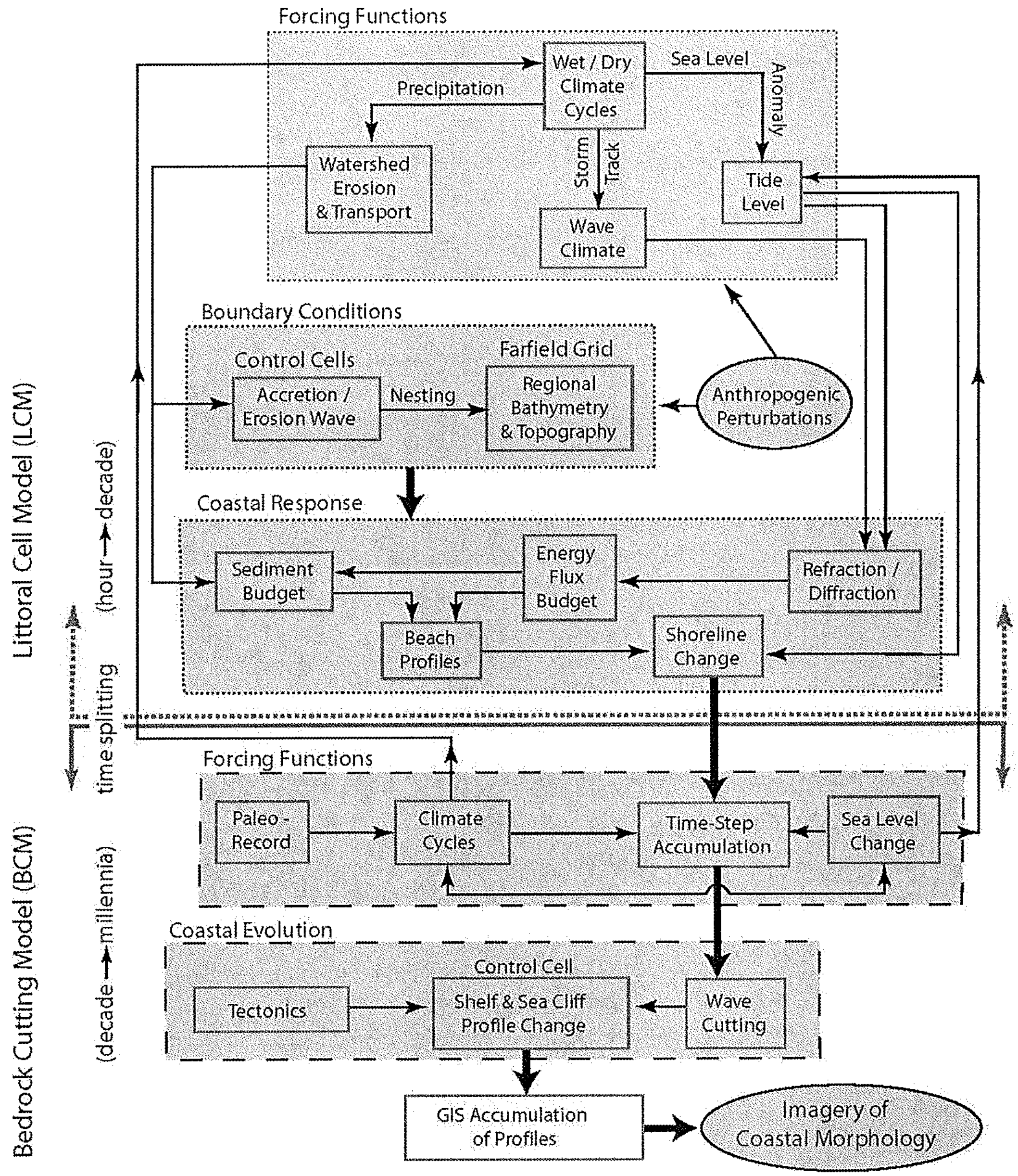


Figure 9: Architecture of the Coastal Evolution Model consisting of the Littoral Cell Model (above) and the Bedrock Cutting Model (below). Modules (shaded) are formed of coupled primitive process models. (from Jenkins and Wasly, 2005).

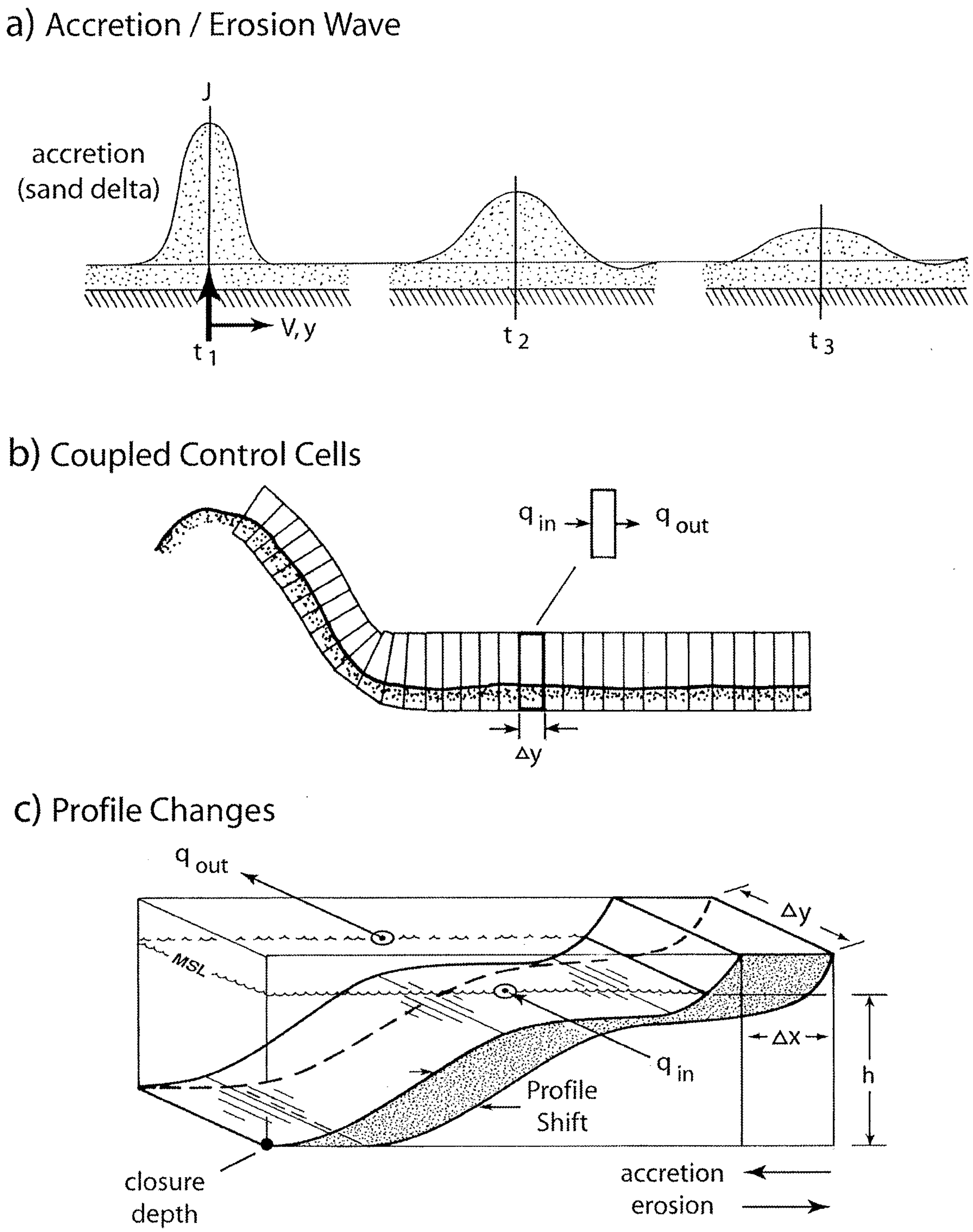


Figure 10 Computational approach for modeling shoreline change after Jenkins, et. al., (2007).

In the LCM, the variation of the sediment cover with time is modeled by time-stepped solutions to the sediment continuity equation (otherwise known as the *sediment budget*) applied to the boundary conditions of the coupled control cell mesh diagramed schematically in Figure 3. The sediment continuity equation is written (Jenkins, et al, 2007):

$$\frac{\partial q}{\partial t} = \frac{\partial}{\partial y}\left(\varepsilon \frac{\partial q}{\partial y}\right) - V_l \frac{\partial q}{\partial y} + J(t) - R(t) \qquad (1)$$

Where q is the sediment volume per unit length of shoreline (m^3/m), ε is the mass diffusivity, V_l is the longshore current, *J(t)* is the flux of new sediment into the littoral cell from watrersheds and *R(t)* is the flux of sediment lost to sinks , typically submarine canyons, lagoons, spits, harbors or windblown losses. The first term in (1) is the surf diffusion while the second is divergence of drift. For any given control cell in Figure 10, (1) may be discretized in terms of the rate of change of beach volume, *V*, in time t, given by:

$$\frac{dV}{dt} = J(t) + q_{L1} + q_{RE} - q_{L2} \qquad (2)$$

Sediment is supplied to the control cell by the sediment yield from the rivers, $J(t)$, by the influx littoral drift from up-coast sources, q_{L1} and by new sediment that recharges the system q_{RE} as a consequence of bluff erosion within the control cell. Sediment is lost from the control cell due to the action of wave erosion and expelled from the control cell by exiting littoral drift, q_{L2}. Here fluxes into the control cell (*J(t)* and q_{L1}) are positive and fluxes out of the control cell (q_{RE} and q_{L2}) are negative. The beach sand volume change, *dV/dt*, is related to the change in shoreline position, *dX/dt*, according to:

$$\frac{dV}{dt} = \frac{dX}{dt} \cdot Z \cdot l \qquad (3)$$

where $$Z = Z_1 + h_c \qquad (4)$$

Here, Z is the height of the shoreline flux surface equal to the sum of the closure depth below mean sea level, h_c, and the height of the berm crest, Z_1, above mean sea level; and l is the length of the shoreline flux surface. Hence, beaches and the local shoreline position remain stable if a mass balance is maintained such that the flux terms on the right-hand side of equation (2) sum to zero; otherwise the shoreline will move during any time step increment as:

$$\Delta x(t) = \frac{1}{\Delta y(Z_1 + h_c)} \int \left(\frac{\partial}{\partial y}\left(\varepsilon \frac{\partial q}{\partial y}\right) - V \frac{\partial q}{\partial y} + J(t) \right) dt \qquad (5)$$

where ε is the mass diffusivity, *V* is the longshore drift , *J* is the flux of sediment from river sources, Δy is the alongshore length of the control cell, and Z_1 is the maximum run-up elevation from Hunt's Formula. River sediment yield, J, is calculated from streamflow, Q, based on the power law formulation of that river's sediment rating curve after Inman and Jenkins, (1999), or

$$J = \gamma\, Q^{\omega} \tag{6}$$

where γ, ω are empirically derived power law coefficients of the sediment rating curve from best fit (regression) analysis (Inman and Jenkins,1999). When river floods produce large episodic increases in J, a river delta is initially formed. Over time the delta will widen and reduce in amplitude under the influence of surf diffusion and advect down-coast with the longshore drift, forming an accretion erosion wave (Figure 16a). The local sediment volume varies in response to the net change of the volume fluxes, q, between any given control cell and its neighbors, referred to as divergence of drift = q_{in} - q_{out} , see Figure 16b and 16c. The mass balance of the control cell responds to a non-zero divergence of drift with a compensating shift, Δx , in the position of the equilibrium profile (Jenkins and Inman, 2006). This is equivalent to a net change in the beach entropy of the equilibrium state . The divergence of drift is given by the continuity equation of volume flux, requiring that dq/dt is the net of advective and diffusive fluxes of sediment plus the influx of new sediment, J. The rate of change of volume flux through the control cell causes the equilibrium profile to shift in time according to (5).

The BCM (Figure 9, lower) is a new effort to model the erosion of country rock by wave action during transgressions, regressions, and stillstands in sea level (Jenkins and Wasyl, 2005). Because bedrock cutting requires the near absence of a sediment cover, the boundary conditions for cutting are determined by the coupled mobile sediment model, LCM. When LCM indicates that the sediment cover is absent in a given area, then BCM kicks in and begins cutting. BCM cutting is powered by the wave climate input to LCM but applied only to areas where mobile sediment is absent. Bedrock cutting involves the action of wave energy flux ECn to perform the work required to abrade and notch the country rock. Both abrasion and notching mechanisms are computed by the newly developed wave-cutting algorithms. These algorithms use a general solution for the recession R (in meters) of the shelf and sea cliff. The recession rate dR/dt is a function of the incident wave energy flux,

$$\frac{dR}{dt} = \frac{\rho}{\rho_s} f_e\, ECn \tag{7}$$

where ρ is the density of seawater; ρ_s is the density of the bedrock, and f_e is a function that varies from 0 to 1 and is referred to as the erodibility. The units of the erodibility are the reciprocal of the wave force per unit crest length (m/N). The erodibility is given separate functional dependence on wave height for the platform abrasion and wave notching of the sea cliff. For abrasion, the erodibility varies with the local shoaling wave height $H_{(x)}$ as

$$f_e = K_a \Theta_{ij}\, H_{(x)}^{\;1.63} \;(\text{abrasion}) \tag{8}$$