scwd² Seawater Desalination Program
Offshore Geophysical Study

3 August 2010 **Final Technical Report**

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ECO-M Reference No. 09-05a

EXECUTIVE SUMMARY

The City of Santa Cruz Water Department (SCWD) and Soquel Creek Water District (SqCWD) depend upon local water supplies to meet the needs of their customers. However, the Water Department's surface waters are frequently diminished by droughts and the District's groundwater supply is threatened by declining water levels and seawater intrusion.

Each agency conducted separate integrated water planning processes and each identified seawater desalination as the best option for delivering an additional flexible and reliable water source. To take advantage of the benefits derived from a cooperative facility, the agencies joined together, forming the **scwd²** Task Force, to address their different needs and to share the investigative costs associated with the potential desalination plant. If the desalination plant is constructed, SCWD will be able to address its drought protection needs and SqCWD will be able to protect its groundwater resources from seawater intrusion. Both agencies will continue to practice conservation and curtailment to maximize efficient use of water resources.

In October 2008, the City, on behalf of **scwd²**, retained EcoSystems Management Associates, Inc., to perform a study of the sediment offshore of Santa Cruz. The study was designed to support the Intake Feasibility Study, which will report on the results of investigations of open screened water intake and a subsurface intake option to supply seawater to the proposed desalination facility. The offshore geophysical study was conducted to provide data about an offshore alluvial basin and two other buried paleochannels that had been formed and filled since the Last Glacial Maximum. The study area extended from west of the municipal wharf to east of the Santa Cruz Harbor, up the beach at the San Lorenzo River mouth approximately 1000 feet (305 m) and offshore approximately 3000 feet (914 m). See Figure 1-1.

The goals of the offshore geophysical study were to:

- Map the extent of the offshore paleochannels in three dimensions. Seismic reflection data collected during the survey were used to map the alluvial basin and paleochannels, identify bedrock and faults, and preliminarily characterize deep channel fill.
- Characterize the sediment within the paleochannels. Seismic reflection data was interpreted to estimate the thickness of alluvial sediment. Sediment cores were tested to identify the geotechnical properties (i.e., soil type, grain size, density, and hydraulic conductivity) to develop an understanding of existing conditions in the shallow portion of the three paleochannels.
- Provide preliminary seawater production information for the San Lorenzo River alluvial basin. Geotechnical and geophysical properties of the alluvial basin were used to evaluate the production capabilities of conceptual-level subsurface design alternatives.

Four key findings of the offshore geophysical study are described below.

Finding One. The Buried Alluvial Channels of the San Lorenzo River, Neary Lagoon, and Woods and Schwan Lagoons Were Found and Mapped in Three Dimensions.

A map of the San Lorenzo River Last Glacial Maximum (LGM) paleochannel and the two other paleochannels (Neary and Woods/Schwan channels) is presented in Figure ES-1. Near the river mouth, the San Lorenzo River alluvial basin paleochannel is 1,000 feet wide (305 m), and ranges from 40 to 128 feet (12.2 to 39 m) deep. Offshore, it has narrow, winding, and steep sides and deepens to approximately 150 feet (46 m). The Neary channel merges with the main channel at the western edge of the main channel meander, which creates an east-west trending alluvial basin channel nearly 5,000 feet (1,524 m) long. The area just north of the wharf consists of an alluvial basin partly filled with a delta channel/levee complex that resulted from ancient meanders of the San Lorenzo River and Neary channel sections.

A zone of northwest-trending faults cuts across the San Lorenzo River channel about 400 to 1,200 feet (122 to 365 m) south of the shoreline. Boomer seismic profiles show these faults cutting into the channel fill sediment so that there may be some impedance of lateral fluid flow if these faults have created significant offset of coarse-grained aquifer layers.

Geophysical data indicate that alluvial sediment is thinner across the western half of the aquifer and is deepest near the present active channel near the San Lorenzo River mouth. A fence diagram showing the channel configuration provided by the offshore survey lines is provided in Figure ES-2.

Finding Two. The San Lorenzo River Paleochannel Contains Sand, Silt, Clay and Gravel Whereas the Other Two Paleochannels Contain Mostly Mud, Clay and Silt.

Shallow offshore vibracore data and 42 ft (12.8 m) deep onshore data confirm that the San Lorenzo River alluvial basin's shallow sediment is heterogeneous. Samples show fine sand and silty sand interbedded with silt, clay, and coarse-grained deposits.

The Neary paleochannel and Woods/Schwan paleochannel appear to be filled with mostly fine-grained sediment (i.e., mud, clay and silt) and to contain significant quantities of gas. Given the certainty of the low permeability of the shallow sediment in these two channels and the strong reflective horizons noted in seismic profiling, further study of these paleochannels is not recommended.

Eleven vibracores were collected in the study area to sample depths that ranged between 4.5 and 15.5 feet (1.4 and 4.7 m) below the ocean floor (Figure ES-1.) Six cores were collected from the San Lorenzo River paleochannel (VC-2, 3, 4, 5, 6, and 14). These core lengths varied from 6 ft (1.8 m) (VC-5) to 15.5 ft (4.7 m) (VC-6). Fine sand or silty sand was found on average in the top 3 to 5 ft (0.9 m to 1.5 m) of the cores. The core nearest the beach, VC-2, primarily reflects the active layer of sand that outwashes from the San Lorenzo River and is deposited on the nearshore seabed. Seasonal wave action transports this sediment along the shore and farther offshore,

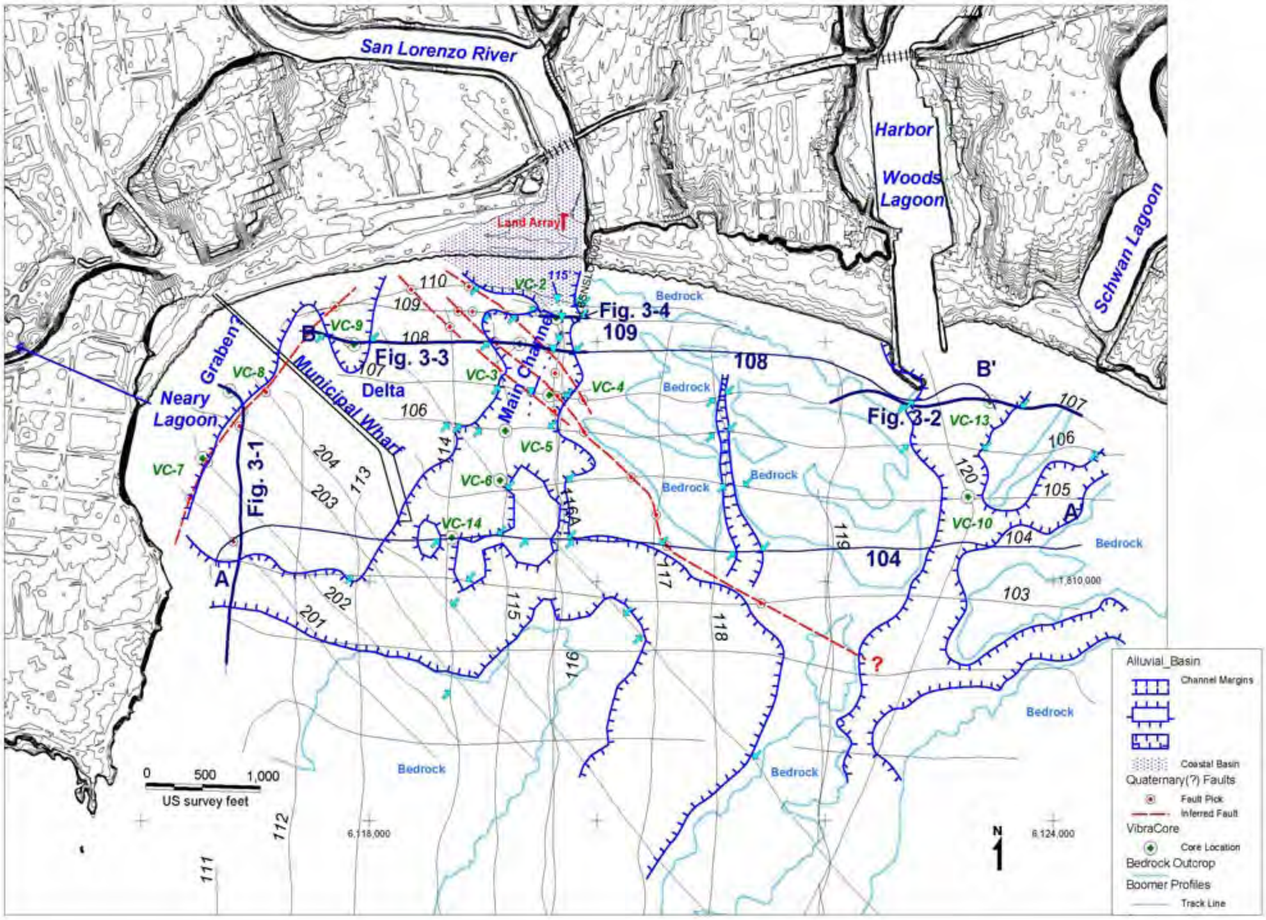

Figure ES-1. Offshore paleochannel location map. The hatch-marked lines in the center left of the map (hatches pointing down slope) show the channel boundary. Vibracore sites are noted with "VC."

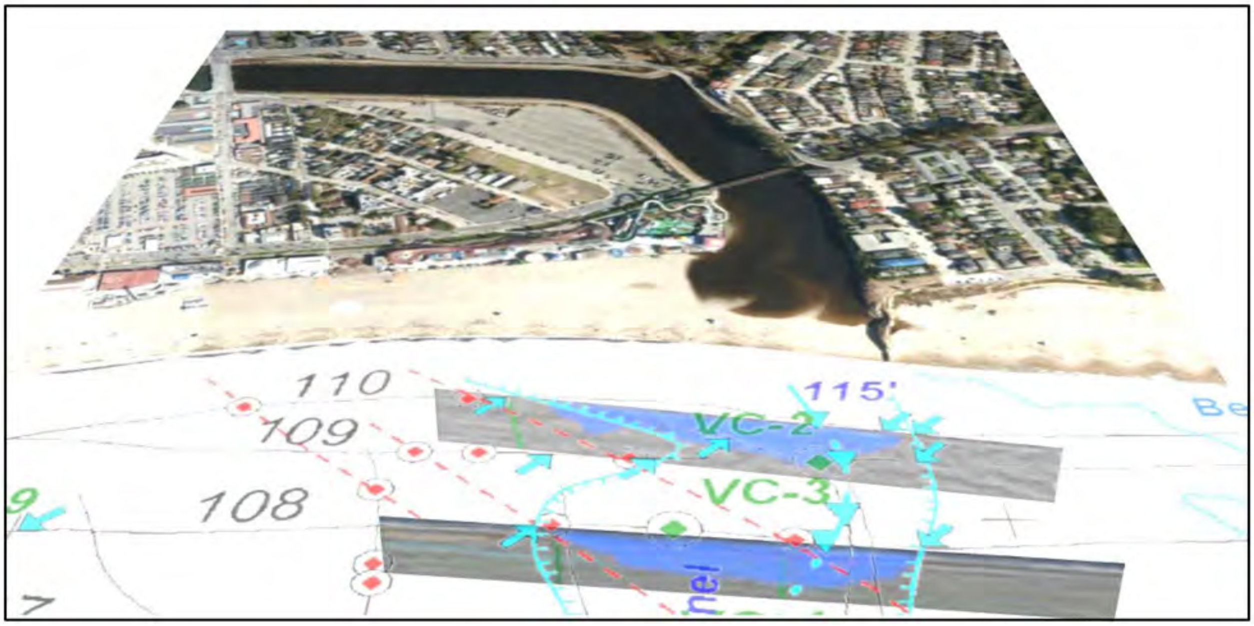

Figure ES-2. Fence diagram of alluvial aquifer using offshore geophysical survey lines showing nearshore portion of the paleochannel within the light blue lines.

where it remains until strong episodic storm events cause complete removal and redeposition farther offshore into the Monterey Bay.

Moving offshore, the active coarse-grained sand layer comprises much less (a thinner section) of the top portion of the cores. The middle of the cores is composed of varying percentages of coarse-grained materials in each core location, and sediment ranges across the full grain size spectrum from gravel to clay. The bottom of the cores consists of a poorly sorted material within which the coarse, gravelly sand caused core refusal. Coarse sand thickness varied from 1 to 10 ft in the cores (0.3 m to 3 m). Silt/clay layers were found in three of the cores: a 0.1 ft (0.03 m) thick layer in VC-4, a 1 ft (0.3 m) thick layer in VC-6, and a 3 ft (0.9 m) thick layer in VC-14. Reddish-brown iron-stained deposits are visible in the cores containing older sediment that had been deposited and reworked in the past.

The evidence of sand, silt, clay and gravel in the San Lorenzo River alluvial basin's main offshore paleochannel was reinforced in the report by the production of a stratigraphic column, which is a model based on a compilation of data from soil samples (vibracores and U.S. Army Corps of Engineers (USACE) borehole data from the nearby San Lorenzo River levee study) and seismic profiling. This was done to characterize the sediment fill of the entire channel. The USACE boreholes taken up the river are in an area where the geological record is not expected to be very different from the paleochannel fill in the nearshore area where the cores were taken. The stratigraphic column (Figure E-1, Appendix E), showing a representation of channel fill sequence lithology, was constructed by extrapolating the layering identified in the USACE borehole data to the base of the offshore paleochannel, basing some of it on inference from the boomer seismic profiles of the nearshore area. The part of the stratigraphic column deeper than the USACE borehole data, about 42 feet (12.8 m), was modeled based on the shallow core data and typical channel fill deposits from similar environments.

Finding Three. Laboratory Analysis Demonstrated the Geotechnical Properties of the Soil Samples for Estimation of the Alluvial Aquifer's Productivity.

Twenty-three sediment samples were taken from the cores and analyzed for grain size, and 11 samples were analyzed for hydraulic conductivity and moisture density. Grain size analysis, data, and moisture density values are shown in Tables 5-3, 5-4 and 5-5. The laboratory results showed a range of hydraulic conductivities within the San Lorenzo River paleochannel from $1x10^{-2}$ cm/sec to $1x10^{-7}$ cm/sec. For comparative reference, productive aquifers generally are composed mostly of sediment with hydraulic conductivities of $1x10^{-1}$ cm/sec to $1x10^{-3}$ cm/sec. The following points are highlights of the hydraulic analysis of the alluvial aquifer's shallow sediment.

- The mobile active layer of fine sand with silt on the seabed had a hydraulic conductivity of 1×10^{-4} cm/sec, which was observed in VC-2, VC-3 and VC-5.
- Hydraulic conductivities of $1x10^{-3}$ cm/sec were observed in the coarse-grained sand samples from VC-3, VC-4, VC-6 and VC-14. The exception was VC-3, which had a section at a depth of 4.8-6 ft (1.5-1.8 m) with an order of magnitude higher conductivity of $1x10^{-2}$ cm/sec.

- The depths of the coarse-grained samples ranged from 4.8 to 6 feet (1.4-1.8 m) for the vibracore closer to shore, VC-3, to deeper than 9 ft (2.7 m) for VC- 4 and VC-6.
- In the upper portion of the vibracores farther from shore, fine-grained low conductivity lenses were found, specifically in VC-6 at 4-5 ft subsea with a hydraulic conductivity of $1x10^{-7}$ cm/sec, and in VC-14 at 4-5 ft (1.2-1.5 m) subsea (sample was 95% silt and clay).
- Several vibracore samples taken from San Lorenzo paleochannel showed seasonal grain-size grading that was fining upward in the sediment section. These deposits showed coarser-grained layers that were deposited during high river flow conditions (medium to coarse-grained sand with fine gravel), which gradually fined to a very fine-grained grayish colored sand.

The characteristics of the alluvial materials (fine sand, silt and clay) will impact production of a subsurface intake located to take advantage of sand and alluvial materials hydraulically connected to the ocean. For example, fine to very fine sand is the main sediment particle that controls seepage through the seafloor into the more productive layers of the aquifer. This is referred to in the report as a "confining layer." The geotechnical properties (grain size analysis and hydraulic conductivity) of the vibracores sampled indicate that there is some productive aquifer material (gravel and coarse sand layers), some marginally productive aquifer material (fine to very fine-grained sand), and some unproductive aquifer material (silt and clay). Overall, the estimated hydraulic conductivity of the aquifer may be an order of magnitude too low to be of use for a 2.5 mgd facility.

Finding Four. The San Lorenzo River Paleochannel Sub-basin Map in Three Dimensions Was Delineated to Define Preliminary Concepts for the Location of Subsurface Intakes.

Figure ES-3 is a structural contour map in 3-D, which was generated from geophysical data about the seafloor and shallow (<650 feet, 200 m) subsurface sediment offshore. In the sub-basin location map, the divisions are made artificially in an alluvial basin that is geologically continuous. The three areas are identified as onshore, nearshore, and offshore alluvial sub-basins. These three areas were designated based on the different anticipated aquifer conditions and the potential challenges to installation and operation of groundwater extraction facilities. Preliminary concepts for subsurface intakes discussed in Section 6.4 include:

- onshore vertical wells
- onshore caisson collector wells
- shoreline vertical wells
- shoreline slant wells
- offshore caisson collector well
- offshore infiltration gallery

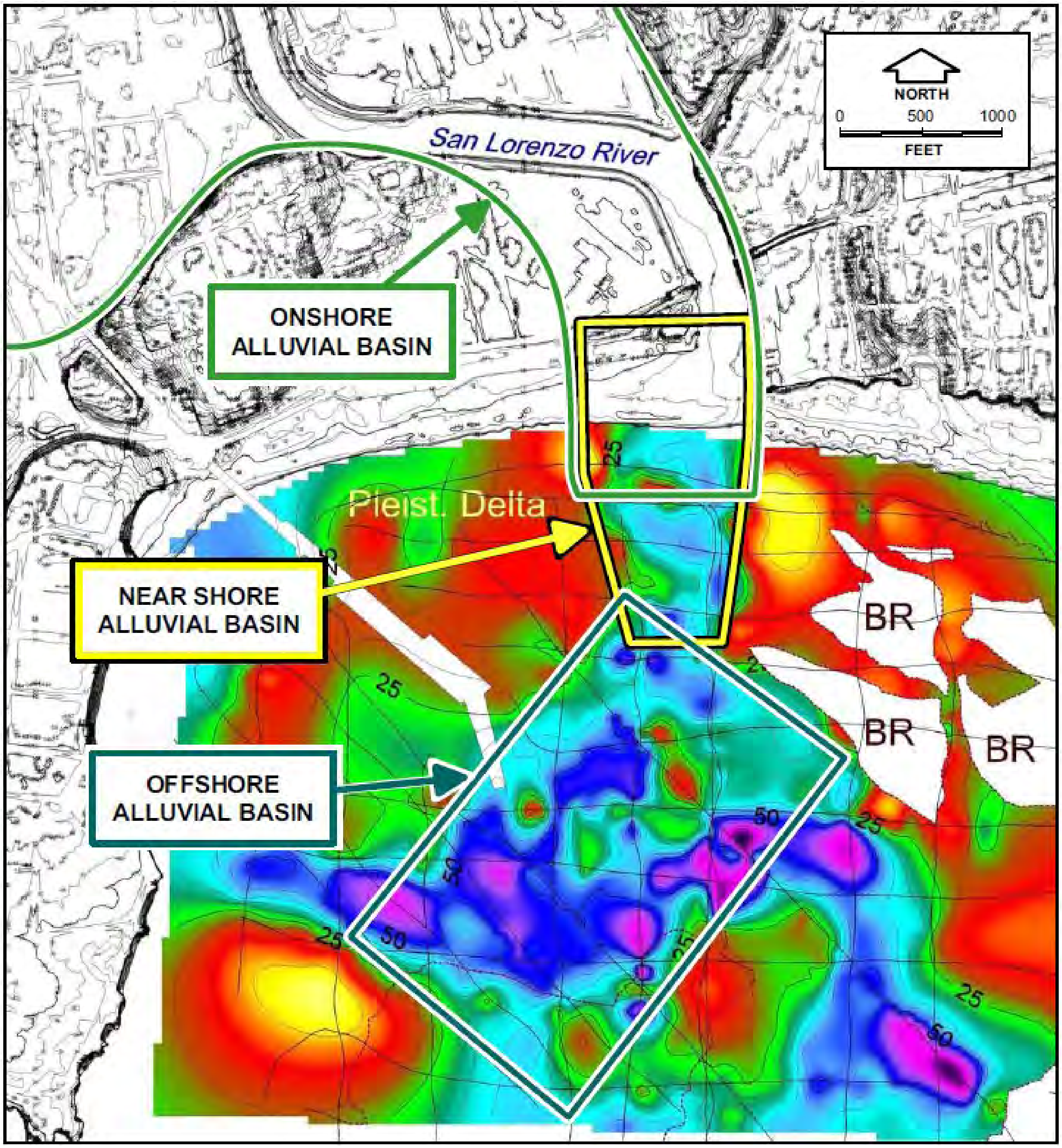

Figure ES-3. San Lorenzo River structural contour map delineated into three sub-basins.

Aquifer conditions in the onshore alluvial basin would vary based on the salinity of the groundwater from the San Lorenzo River, which would be affected by the impedance of the landward movement of seawater when the sand bar is in place. The successful production of groundwater from this area from vertical wells would likely draw in freshwater horizontally, and from caisson collector wells, production would be dependent on placing the wells in an area where recharge would come from the tidal flows of the San Lorenzo River. The major limitation of these two approaches for recharge with saline water is that they would be dependent on maintaining saturation within the tidal portion of the San Lorenzo River.

Production in the onshore alluvial basin area would induce infiltration of surface water from flows in the river and along the shoreline, which is anticipated to result in a blend of freshwater and seawater. The use of freshwater from the San Lorenzo River from wells in the onshore alluvial basin raises concerns regarding water rights, endangered species issues, and seawater intrusion landward in the groundwater basin. Other issues related to development of an onshore supply of groundwater include variations in water quality, such as changes in salinity, high concentrations of iron, and turbidity associated with high winter flows.

Aquifer conditions in the nearshore alluvial basin would not be affected as much by changes in river conditions, but would limit production potential above the alluvial nearshore aquifer because of the limited length of shoreline with exposure available for infiltration of seawater in the saturated nearshore environment. Another factor limiting production would be controlled by the shallow depth of the aquifer zone, which ranges from 40 to 125 ft (12.2 to 38.1 m) deep (see Figure 6-7).

Using an empirical method, estimates for conventional well production along the river and along the shoreline are up to 400 gpm with a specific capacity on the order of 12 gpm per foot of drawdown. Since 4,400 gpm would be required for a 2.5 mgd desalination facility, eleven wells would be required along the river and along the shoreline to produce sufficient water supply. Actual production potential would be affected by boundary conditions that confine flow (bottom and sides of the aquifer) or provide recharge (river bottom and vertical conductance).

If slant wells were placed along the shoreline into the nearshore alluvial aquifer underneath the seabed, the conceptual location of slant wells along the shoreline would accommodate four facilities, extending 500 ft (152 m) to depths of (from west to east) 45, 65, 115, and 95 feet (13.7, 19.8, 35, and 29 m), constructed at angles ranging between 5 and 13 degrees from the horizontal. The relatively shallow depth to the base of the alluvial aquifer in the nearshore area would limit the depth. The groundwater produced from slant well facilities drilled offshore is anticipated to contain high concentrations of iron, but not vary as much in salinity and turbidity.

Another potential for saline groundwater production is the conceptual location of an offshore caisson collector well in the alluvial aquifer 1,500 feet (450 m) offshore near the end of the Santa Cruz Wharf. Conditions in the offshore alluvial aquifer that could limit production potential include the low vertical conductance of the finer-grained sediment on the seafloor, the likelihood of thick silt and clay layers with very low permeability below the depth of those sampled, and heterogeneous layering (i.e., lateral changes in formation materials) which could inhibit drawdown of flow to the wells.

Calculations of the expected yield are in Section 6.4 and 6.5. The single greatest influence on well production in these shallow aquifer basins will be the rate of induced recharge. The higher the rate of recharge and the closer the extraction point is to the source of recharge, the greater the production rate that can be obtained under shallow aquifer conditions that limit available drawdown.

Next Steps

The data gathered by ECO-M and subsequent lab tests and interpretations were shared with a Technical Working Group (TWG) that consisted of consultants, scientists, academics and regulators. The TWG was established specifically for this study in order to review the study plan, field investigation, and findings, and to make professional recommendations as to the viability of a subsurface intake and the next steps. While some of this discussion may also be found in the Feasibility Study as it fits within the larger context of evaluating intakes, it is worth noting the significant recommendations here as they relate to this study's findings.

Scientists and academics from USGS and UCSC continue investigations with regards to bathymetry, subsurface characteristics, erosion/accretion, sediment transport, and river discharges into the ocean. As part of the TWG, much of this data has been brought forward in discussions with **scwd²** to advise us with regard to the feasibility of placing a subsurface intake in the area. In general, USGS and UCSC scientists found the data gathered for this study to be consistent with current knowledge and understanding. Some debate about the shape and extent of the paleochannels occurred in the TWG due to the difficulty of interpreting the seismic reflection data. While it was agreed that in order to truly understand the nature and extent of materials below 40'+, one must drill and collect samples, it was further argued that 1) borings would need to be exhaustively located to provide a meaningful assessment of vertical and horizontal properties in the channel; 2) while an extensive drilling program could provide additional information, to really understand the abilities of a subsurface intake, a test facility should be installed and operated; and 3) there is no reason to believe that offshore, subsurface characteristics would be any better than what was found in the shallow sediment or than what has been discovered at depth onshore.

The following table shows the next step(s) that could be taken should **scwd²** decide to pursue a subsurface intake. Each step in the table below can be implemented independently to gather information to 1) further understand the nature of the offshore basin, and 2) determine whether or not the program should proceed further or if a fatal flaw has been encountered.

It is important to stress that this study and the following potential work items were developed from the standpoint of findings from this study, findings from other existing studies and data, and lengthy discussions with experts in the field. In addition and equally important to the field conditions evaluated here are other feasibility factors being considered by Kennedy/Jenks

Consultants in the **scwd²** Intake Feasibility Study. It is the combination of all of these factors that must be taken into consideration when determining how best to move forward.

Step	**Reason**	**Advantage**	**Disadvantage**
Conduct a paper study of onshore geologic information to enhance the correlation with offshore properties.	Provides for additional information and understanding of the geology.	Easy to do. Requires no permitting.	Provides information in the onshore setting that may not represent offshore.
Using the data found above, develop a preliminary model of the offshore alluvial channel to assist in the prediction of flows, salinity/recharge, drawdown, zone of influence, etc.	Expands on existing understanding of offshore production potential	Easy to do. Adds to body of knowledge.	Interim step. Model output may give an indication of simplified conditions, but may not represent true production potential.
Drill deeper geologic borings onshore in an area where the river has met the ocean over the centuries or in the nearshore environment to further understand offshore subsurface properties. See Table Notes 1 and 3.	Provides for additional information and understanding of the geology.	Onshore borings would be easy to do, with limited permitting. Provides more info on production potential in the onshore and/or nearshore alluvial sub-basin.	Offshore more complicated, expensive, and could take 12+ months of permitting.
Expand the previously developed model with the new data. See Table Note 2 for the reason to redo the model.	Expands on existing understanding of alluvial basin production potential.	Adds to body of knowledge.	Model output may give a better indication of conditions than the previous model, but still may not represent true production potential.
Test well and pump test.	Provides hydrological information for estimating the productivity of the groundwater in the alluvial basin. (See Table Notes 4 & 5.)		

Table Notes:

1. One well-defined layer boundary is recognized in the geophysical data at about 47 feet (14.32 m) below Mean Lower Low Water (MLLW), just below the deepest samples from the USACE boreholes. This layer boundary may correlate with a significant change in sea level rise, which may have created a distinctive sedimentary deposit at that level, possibly including fine-grained material from soil formation, flood deposit, or other geologic processes. Deeper boreholes would be required to sample and quantify the sediment layering in the lower part of the channel.
2. While the hydraulic conductivity and permeability of the aquifer sediment in the paleochannel appear to be on the low end of a productive aquifer, some uncertainty remains with respect to the samples being representative of the whole. Deeper core samples could be taken and examined for hydraulic qualities. What remains unclear at this time is the extent of layers with low permeability throughout the aquifer and the influence these layers would have on overall transmissivity and permeability of the aquifer materials with respect to providing recharge to a buried subsurface intake system.
3. Scientific information about the study area with respect to river discharges and coastal processes (i.e., how littoral drift of sand, ocean waves and river discharges of fine sediment have affected the fill of the channel or may affect a future subsurface intake) could be factored into a feasibility analysis.
4. The horizontal continuity of the channel layers has been disrupted by faults in the nearshore sub-basin.
5. The impacts of the intake(s) on groundwater (seawater intrusion, water rights, special status species) should be studied. A pump test would help to evaluate how much freshwater might be pulled into a subsurface intake's wells.