Expert Panel Workshop Report
Offshore Hydrogeology/Water Quality Investigation Scoping

Utilization of Slant Beach Intake Wells for Feedwater Supply
South Orange Coastal Ocean Desalination Project

October 9, 2012

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Executive Summary

On March 23, 2012, the Municipal Water District of Orange County (MWDOC) convened an Expert Panel to assist in the evaluation of data from the Phase 3 Extended Pumping and Pilot Plant Testing, and to provide recommendations regarding additional data needs, investigations, and design of the planned full-scale facility. The Expert Panel addressed questions relating to the source(s) of water to the full-scale facility, the chemical composition of the source water, the likely productivity of the well field, the properties of the offshore aquifer, and how these characteristics might change over time and affect facility design.

The Expert Panel concluded that the Phase 3 Testing and associated analyses indicate with reasonable certainty that the aquifer formation is likely to provide significant filtration of ocean particulates and bacteria, and to dampen the effects of variations in ocean water quality. Test results to date indicate excellent filtration by the aquifer formation, with very low Silt Density Index (SDI) and turbidity levels in water reaching the test well. The Phase 3 Testing facility also demonstrated excellent SWRO membrane performance over several months of operation with the slant well water. The water from the slant well remained anoxic over 18 months of pumping, and had relatively high levels of dissolved iron and manganese. Rates of biofilm growth under these anoxic conditions were low, and very little or no corrosion was observed for the recommended stainless steel specification. These data, along with the findings from the SPI pilot testing study, are sufficient to specify pretreatment design criteria for iron and manganese removal under Phase 3 test conditions.

The Expert Panel also concluded that additional testing is warranted to address uncertainties that remain following Phase 3 testing. Specifically, additional information is needed to characterize offshore hydrogeology and the aquifer structure, and to design the full-scale wellfield. Additional characterization of the aquifer structure will also be instrumental in assessing flow paths and travel times for source water to reach the wells from three primary sources (young-midage meteoric water, young marine groundwater drawn through the ocean floor from the overlying ocean, and “old” marine groundwater resident in the aquifer formation), and thus for anticipating changes in source water chemistry over time as old, enriched marine groundwater is depleted by further pumping. More information is also needed to describe the amount of available organic carbon in the ocean and sediments for microbial uptake of dissolved oxygen, and to model long-term aquifer and wellfield anoxia and iron/manganese concentrations. The Expert Panel made a number of specific recommendations for tests, analyses, and modeling to further investigate offshore hydrogeology and water quality, and to supplement the results and analyses from the Phase 3 testing.

Expert Panel Workshop Final Report
Offshore Hydrogeology/Water Quality Investigation Scoping

Utilization of Slant Beach Intake Wells for Feedwater Supply
South Orange Coastal Ocean Desalination Project

Background and Panel Charge

On March 23, 2012, the Municipal Water District of Orange County (MWDOC) convened an Expert Panel to review information and data related to the Slant Beach Intake Wells proposed for the South Orange Coastal Ocean Desalination (SOCOD) Project.

The SOCOD Project is planned to utilize nine slant wells at full scale. The slant wells will be arranged in three clusters of three wells that would be drilled out under the ocean from Doheny State Beach. These wells would provide filtered ocean feedwater for the desalination plant to produce potable water for improving the reliability of water supply to the area. As part of project planning, MWDOC has conducted a number of scientific and engineering investigations to characterize conditions in the proposed slant well field, feedwater quality, and treatment process requirements. MWDOC installed the first full-scale demonstration slant beach well intake in spring 2006 in Doheny State Beach, and conducted a short-term aquifer pumping test at that time to determine aquifer properties and to provide data for the development of a variable density groundwater-ocean water flow model (Modflow/Seawat).

In 2009/10, the Phase 3 Extended Pumping and Pilot Plant Testing facilities were permitted, designed, and constructed with start-up of the 18-month test on June 3, 2010. Phase 3 was designed to develop information on well and pump performance and design criteria, to characterize the marine aquifer yield and connection to the ocean, to characterize ocean and groundwater quality, and to facilitate development of a highly calibrated groundwater basin and offshore marine aquifer flow model. Phase 3 also involved an evaluation of feedwater quality and desalination process treatment requirements.

The Expert Panel was convened by MWDOC to assist in the evaluation of data from the Phase 3 investigations and to provide recommendations regarding additional data needs, investigations, and design of the planned full-scale facility. The technical team leaders and members of the Expert Panel were selected to include a broad range of expertise, as detailed below.

Phase 3 Technical Team Leaders

- Dr. Dennis Williams, President, Geoscience Support Services, Inc. and Adjunct Professor of Geohydrology, USC – Responsible for hydrogeology, slant well design/construction, aquifer performance and groundwater modeling
- Mr. Gerry Filteau, President, SPI (Desalination Process Treatment and Contractor for Phase 3 Extended Pumping and Pilot Plant Test - Operations, Testing and Evaluation)

- Dr. Matthew Charette, Coastal Groundwater Consulting, Senior Scientist, Woods Hole Oceanographic Institution (Geochemistry and Iron/Manganese Chemistry in Coastal Groundwater Systems)
- Dr. Sunny Jiang, Professor of Environmental Engineering, UCI (Marine Microbiology and Biofouling)

Expert Panel Members

- Dr. Jed Fuhrman, Section Head, Marine Biology and Biological Oceanography, USC (Aquatic and marine microbial ecology)
- Dr. Doug Hammond, Professor of Earth Sciences, USC (Biogeochemistry in Aqueous Systems)
- Mr. Roy Herndon, Chief Hydrogeologist, Orange County Water District
- Dr. Eric M. V. Hoek, Professor of Environmental Engineering, UCLA (Ocean Desalination, Process Treatment)
- Dr. Sun Liang, Metropolitan Water District of Southern California (Water Quality)
- Dr. Susan Paulsen, Vice President and Senior Scientist, Flow Science Incorporated

The Expert Panel was tasked with addressing several questions:

- Do data from the Test Slant Well Phase 3 Extended Pumping test indicate a connection with the ocean? Can existing information, including data regarding hydrogeology, groundwater modeling, iron and manganese concentrations, microbial populations, and anoxia, be used to inform the conditions that will occur at full-scale pumping steady state conditions?
- What do the data collected to date indicate regarding biofouling and clogging of the near-borehole area and gravel pack by sand, geochemical precipitation and/or biomediated encrustation?
- What are the geometry and properties of the offshore aquifer, and how do the hydrogeology and groundwater quality vary offshore within the planned slant wellfield recharge area? What methods can be used to obtain additional information to characterize the offshore alluvial channel structure and to support evaluations of anoxia, iron and manganese concentrations, and biogeochemical data to inform the project?
- Will pumping over time cause any significant loss in permeability as source waters recharge and flow through the aquifer to the wellfield? What would be the causative factors, and how could those be investigated and modeled?
- Under full-scale pumping, will the pumped water remain anoxic and enriched in iron and manganese as ocean water is pulled down into the aquifer, and how will the composition of the source water change over time? Can analysis of cuttings from existing on-shore boreholes be useful?
- Can the offshore aquifer data and estimates of iron and manganese reaction kinetics be used with the groundwater flow model to predict steady-state, long-term iron and manganese concentrations in the wellfield pumped water?

- What approach should be taken to address these issues? What measures can be taken to reduce costs and to optimize the results of future field work and analysis?

Panel Response

Overview. The Expert Panel was highly complimentary of the work that MWDOC and its consultants have completed to date and of the understanding they have obtained of the issues likely to face the SOCOD project. The Expert Panel indicated that the work done to date has been carefully planned and designed, and has yielded significant and detailed information that will provide a solid foundation for the project as it progresses. In particular, the Panel observes that the construction and pump tests conducted thus far confirm that the Beach Slant Well concept can produce useful, high quality water at suitable pumping rates. The current work has defined some of the geohydrologic connections with the ocean, the stream, and the seasonal lagoon and confirms that the aquifer provides good filtration. The use of geochemical tracers has defined some important constraints on the water sources that have been evaluated, and perhaps could be refined further to yield additional information from the existing data. The biological analyses have indicated the types of biogeochemical reactions that may be dominant within the formation and well, and that will be important to consider in designing future project phases.

The Panel indicated that additional testing and analyses will be useful in further defining the conditions that may be observed during operation of a full-scale project, as detailed below. However, because the project is one of the first of its kind, the Panel also indicated that there may be areas where uncertainty cannot be fully resolved up front, such that the project should be designed to accommodate various outcomes. For example, one area of uncertainty is how the source water chemical composition may change over time, and therefore the level of pretreatment that may potentially be required.

Detailed Conclusions. The Expert Panel agrees with MWDOC and the project participants that the groundwater model, which is currently being significantly updated and refined, will provide a useful tool for evaluating aquifer response, and that it would benefit from additional data collection to refine the characteristics of the aquifer. For example, additional geophysical and test boring investigations should be undertaken (as discussed below) to define the lateral and offshore area contributing recharge to the aquifer (i.e., the geometry and extent of the alluvial channel that will receive ocean recharge), to identify the extent and thickness of clay layers, and to refine estimates of vertical and horizontal conductivity.

The current model assumes that the water that could be drawn into the well would originate from three sources:

(1) "young-midage" meteoric water (rainfall/streamflow percolation water) and brackish groundwater, which has an age of months and years, respectively, a low oxygen content, and a significant dissolved Fe/Mn content (in the range of 2 to 4 mg/l) [the

fraction of this water has declined in the Slant Well over time, from about 25% of the water at the start of the test, to about 11-20% at the end of the test]

(2) young marine groundwater drawn through the ocean floor from the overlying ocean, which has a very low water age, high dissolved oxygen content, and low dissolved Fe/Mn content [estimated to contribute 2-5% at the start of the test to about 8-20% at the end of the test]

(3) "old" marine groundwater, which underlies the young marine groundwater, has an age of perhaps 7500 years, low dissolved oxygen, and high Fe/Mn content [the remainder (about 60-70%) of the water drawn from the Test Slant Well]

The Expert Panel agrees that additional sampling and analysis should be conducted to better define the source water (particularly the old marine groundwater), which would permit more refined estimates of the fraction of each in the water taken into the Test Slant Well.

The pumped groundwater drawn into the test facility throughout the Phase 3 test has consistently shown no dissolved oxygen and negative oxidation reduction potential (ORP) values, very low turbidity, low silt density index (SDI), low levels of organic carbon, low level of bacterial community, and the absence of both indicator bacteria (total coliform, fecal coliform, *E. Coli*, and *Enterococcus*) and pathogenic cysts (giardia and cryptosporidium). Groundwater pumped from the test slant well has exhibited increasing and relatively high concentrations of dissolved Fe/Mn (dissolved Fe concentrations as high as about 12 mg/L were reached), and salinity levels in pumped groundwater have increased to more than 17,000 mg/L.

Although the analytical procedure used during the Phase 3 testing appears to have understated the actual levels of total organic carbon (TOC) typically found in coastal ocean waters, slant well TOC appears to have decreased to about 0.4 mg/l, a level significantly lower than typical coastal ocean waters but typical of fairly old marine groundwater. These water quality data appear to indicate that the amount of ocean water and old marine groundwater has increased in the pumped groundwater over time. Ammonia levels indicate only modest levels of degradation of organic carbon. No sulfide odors have been detected, consistent with the high ferrous iron levels that are present and further supported by the relatively conservative behavior of sulfate during mixing of the initial brackish water produced by the test well and a seawater endmember. While some sulfur-reducing bacteria were identified in the cultures, their activities have not strongly impacted the chemistry of the groundwater that is being pumped.

The test facility currently treats pumped groundwater directly without pre-treatment, and an anoxic condition is maintained throughout the treatment system (a condition that is aided by the use of a nitrogen environment within the Test Slant Well headspace above the pumping water level). A potential water quality consideration for the full-scale system, albeit a low likelihood, is the potential for mixing of an oxygenated source water with anoxic, Fe/Mn-rich water within the well collection system, resulting in the potential for Fe/Mn precipitation in the well, conveyance and/or treatment system and the potential for RO membrane clogging. There is also a potential concern that iron precipitation (whether biologically mediated or not) within the aquifer formation near the well might occur, resulting in some clogging of the formation and decrease in the productivity of the well(s) if the wells are not periodically cleaned.

MWDOC's analysis indicates that the most likely shortest preferential pathway to the upper shallowest screen interval (50 feet below the shoreline) has a travel time of at least 130 days (no SF6 tracer from the lagoon tracer test was picked up in that period) and less than 12 months (based on helium and tritium isotope data that indicated that 8 to 20 percent of young ocean water was detected in the pumped water in the 12^{th} month sample). The pumped water remained anoxic throughout the entire test. MWDOC believes that this is good evidence that the microbial uptake of DO may occur within a time frame of about 5 months or less, and probably less than 12 months—i.e., the time of travel for the water that entered the test slant well under the 3 mgd extraction rate—under the conditions present during the Phase 3 testing. The full scale model will have to evaluate the change in both travel times and DO uptake.

In addition, under full-scale pumping the groundwater flow path to the wells will be primarily plug flow, such that the ferrous iron-rich old marine groundwater is not expected to mix significantly with the oxygenated ocean water except at the flow interface boundary. Since this interface will move in response to pumping, it would be expected that any iron oxidized along the boundary would be deposited back onto the sediments along the flow path. This is unlikely to cause any significant decline in permeability of the sediments as the mass amounts involved along the plug flow boundary layer would be quite low. In time, the old pocket of iron-rich marine groundwater will be pumped out and replaced with ocean water. Furthermore, over time the oxygenated ocean water recharge will ultimately titrate the reservoir's content of ferrous iron.

It has been hypothesized that an "iron curtain" may exist as a layer in the seabed and shallow aquifer sediments. Under the natural coastal aquifer-groundwater flow discharge process, as the brackish groundwater dissolved Fe/Mn flowed up into the shallow aquifer, a zone of oxidation and precipitation of iron oxides would have likely occurred, causing the typical coastal alluvial yellow/orange coloration of sands/gravels ("iron curtain") in the shallow zone. Cutting samples from the onshore boreholes indicated the possible presence of this layer down to 13 feet below the beach (to about sea level). Under pumping conditions, the flow pattern would be reversed as oxygen-rich, low Fe/Mn ocean water would slowly flow downwards towards the well. As the recharge ocean water flows downwards towards the well, it will lose dissolved oxygen through aerobic bacterial uptake. As long as the flowing ocean recharge water contains oxygen, any iron-rich sediments it passes through would not yield dissolved iron. Should the oxygen become depleted, bacteria would turn to nitrate, Fe III (oxidized), and then Mn IV (oxidized) (likely in that order) to continue to degrade organic matter. Both the ocean water and sediments contain sources of organic matter for microbial uptake of the dissolved oxygen in the ocean water recharge. However, the long-term capacity for uptake of ocean water dissolved oxygen is unknown at this time as the organic carbon content of the coastal waters off San Juan Creek and of recharge area sediments is unknown.

Although panelists agree that an "iron curtain" is likely already present in seafloor sediments, the offshore location and thickness of the curtain are unknown, and it is unknown to what extent the curtain's location would be affected by long-term pumping operations. The behavior and distribution of Fe/Mn that may be resident in the alluvial sediments, and thus the Fe/Mn content of source water, as noted above is one of the largest unknowns for the project. Additional study has been proposed to quantify organic carbon and three phases of Fe in the seafloor sediments and alluvial formation (in order of how easily they are reduced by bacteria: amorphous, crystalline oxides, and total surface-bound iron) via a sequential leaching experiment, and to evaluate the effect of various water quality parameters (e.g., DO, pH) on iron precipitation.

Subsequent to the Expert Panel Workshop, Dr. Charette provided additional information and input to the panel. As noted above, the analytical procedure (Weck Laboratories, Standard Methods 5310C) used during the Phase 3 testing may have understated the actual levels of TOC in samples collected for this study. While the pumped groundwater TOC results seem reasonable, he is confident that ocean water TOC in this location is likely no lower than 0.85 mg/L (0.071 mmol C/L) [Beaupre and Druffel, 2009[1]], rather than the Phase 3 laboratory testing results of around 0.20 mg/L (0.017 mmol C/L). Dr. Charette believes that the old marine groundwater will have TOC levels in the range of 0.25-0.5 mg/L (0.02 to 0.04 mmol C/L), not 0 mg/L, as refractory organic carbon compounds that cannot be broken down by bacterial processes are typically present. He noted that this should not reflect poorly on the analytical lab used for TOC measurements in this project as very few labs are capable of producing reliable TOC data at levels <0.5 mg/L.

Concentrations of dissolved Fe, Mn, and ammonia increased over time during the Phase 3 testing. All of these suggest that organic material in the aquifer was degrading during the test and that the seawater component carried the reaction products to the pumped region. The source of the organic matter could be DOC in the formation waters or organic matter sorbed to the aquifer solids. If the degrading organic matter is Redfieldian (C:N atomic ratio of 6:1), the ammonia increase indicates more than enough degradation to account for the observed Fe and Mn increase. Some sulfate reduction could also be occurring to fuel organic matter decomposition, and to partially sequester any ferrous iron that was produced, but this is hard to discern given the background levels of sulfate present in the aquifer endmembers. DOC in the aquifer waters showed a bigger decrease with time than can be explained by

[1] Steven R. Beaupré, Ellen R.M. Druffel, Constraining the propagation of bomb-radiocarbon through the dissolved organic carbon (DOC) pool in the northeast Pacific Ocean, Deep Sea Research Part I: Oceanographic Research Papers, Volume 56, Issue 10, October 2009, p. 1717-1726.

endmember mixing; although DOC is a possible reactant that could be utilized by bacterial degradation processes, DOC is difficult to measure accurately at these low concentrations, and the evidence is inconclusive. Analyses of the aquifer solids may shed light on the potential carbon degradation rates. Another potential DOC source to the slant well is water from San Juan Creek, which hosts a large colony of seagulls and other shorebirds that visit and rest in the mouth of the creek and its seasonal lagoon, adding significant organic carbon loads to the area.

An additional sink for dissolved oxygen in the inflowing seawater could be oxidation of sedimentary sulfides in the aquifer. This would produce sulfuric acid, potentially up to 200 µEq (µ-equivalents/liter) for a dissolved O_2 level of 200 µM in the incoming seawater. This may be occurring at present, as the recently produced seawater is quite calcium-rich (about 6 mM above levels expected based upon endmember mixing alone). Some calcium enrichment could come from the reaction of this strong acid with $CaCO_3$ in the aquifer solids, although there is far more calcium present than expected from this reaction. The source of the excess calcium is enigmatic, as it is not accompanied by any apparent increase in alkalinity. This suggests that additional input of a strong acid may be occurring, as oxidation of sulfides with dissolved O_2 from the seawater is insufficient to account for all of the calcium excess.

The mass, distribution, and bioavailability of the organic carbon in the sediments in this area is unknown, yet they could provide additional carbon resulting in biological consumption of DO. Sulfides in the aquifer sediment should also be characterized. Further work needs to be done to establish the composition of the aquifer solids and the kinetics of reactions that may occur when they are exposed to oxygenated seawater.

Pumping will remove the pocket of old marine water that has high concentrations of Fe/Mn and a minimum age of about 7,500 years. Whether a long-term pumping state where oxic water with a low Fe/Mn content would prevail is uncertain at this time. It is likely that the long-term condition will see much lower dissolved Fe/Mn concentrations. Further, production pumping rates will be 30 mgd, ten times larger than the Phase 3 pumping rates. However, the first screened interval of the full-scale system may be 100 ft below the seafloor (rather than 50 ft for the current Slant Test Well), which may result in travel times long enough to lead to complete removal of the dissolved oxygen in the ocean water as it passes through sediments that contain some reactive organic carbon (e.g., organic loading to the coastal receiving waters and sediments from periodic lagoon and stream discharges).

In summary, the Expert Panel suggests that while additional offshore data collection is necessary to better resolve the current uncertainties, significant unknowns may remain even after additional testing. Consequently, the project may need to be designed to allow flexibility to respond to changing source water conditions. Based on the information available to date, and if additional data to be collected do not resolve uncertainties regarding the long-term source water quality, the Expert Panel concludes that it may be wise to construct the facility with a modular design, such that pre-treatment for Fe/Mn could be added to the final facility if and when needed.

Some reduction in the flow rate of the Test Slant Well has also occurred during the pump tests; flow rates have decreased from about 2,150 gpm to approximately 2,000 gpm, but the submersible pump has performed well. A preliminary evaluation by MWDOC indicated that the decline in flow rate has occurred due to a gradual lowering of the pumping level (a total decline of 10 ft, or about 8 ft greater than the 2-ft response predicted by the initial groundwater model). MWDOC's preliminary evaluation suggested that the decline in pumping level is most likely due to sand clogging due to lack of full development of the well (and which was understood during the test), and perhaps partially to low level biofouling or biomediated encrustration primarily along the well screen and near well zone, or a combination of these factors.[2]

Extensive microbiological testing has been conducted to evaluate the potential for biofouling and the biofouling rates on different materials ("coupon" test samples), including both the 316L stainless steel used in the Test Slant Well and the SS 2507 which is currently being considered for the full-scale system. Results indicated that the water flowing into the Test Slant Well does contain a microbial community that could colonize coupon surfaces, but growth rates were quite low, apparently particularly after the application of a nitrogen blanket at the well head, which minimizes oxygen levels in the test chambers. Biofilm growths were less than 10 microns, a level far lower than what would cause any measurable clogging in the well screens. Current data also indicate low organic carbon levels in water pumped to date. It is unclear, based on current tests, whether or not bioclogging within the well would occur with the introduction of oxygen into the well head space above the pumping water level. The organic carbon content of the aquifer sand (particularly the level of biodegradable dissolved organic carbon, or BDOC) may be a factor; BDOC (and available organic carbon, or AOC) levels are as yet unknown but may be low, as is often observed in coarse-grained sediments. There may also be some sulfide minerals that could play a role in providing a redox buffer. Corrosion test results for a range of materials were reported by Dr. King. To date, the tests indicate low levels of corrosion, and additional data are expected to be available sometime after the completion of the test at the end of April.[3]

Panel Recommendations

1. The proposed step drawdown test should be carefully analyzed to help differentiate water level declines in the Test Slant Well due to both well loss and aquifer response. This information is critical to calibration of the groundwater model. The Expert Panel agrees with MWDOC that results of step drawdown tests should be interpreted carefully in order to ascertain that portion of the observed groundwater level decline that was due to aquifer response vs. well clogging. Well

[2] Subsequent to the Expert Panel workshop, MWDOC retained Geoscience Support Services Inc. and SPI to conduct a Step Drawdown Test on the well in early May 2012. The final Technical Memorandum "Aquifer Pumping Test Analysis and Evaluation of Specific Capacity and Well Efficiency Relationships SL-1 Test Slant Well, Doheny Beach, Dana Point, California" was finalized on September 7, 2012. The reader is referred to this study for more details on this analysis.

[3] The reader is referred to "Desalination Corrosion Study, Engineering Materials," May 29, 2012.

inspection and video logs may also be useful to evaluate corrosion in the well or biofouling growths on well screens, but they are not quantitative and can only provide qualitative information. Comparison of observed water levels in the nearby monitoring wells with the pumping water levels and the step drawdown test will provide a reasonably good comparative evaluation of the magnitude of well losses (e.g., sand clogging) and aquifer response in the observed water level decline.

2. The planned offshore geophysical seismic reflection surveys will yield useful information regarding the lateral and offshore extent of the aquifer and clay layers present in the subsurface, and should proceed. MWDOC may wish to consider conducting this work in two phases—a coarse-grid survey, followed by a fine-grid survey where added resolution is needed—if this would reduce costs and if the work could be readily permitted for two phases. If no cost savings would result, the work should be conducted in a single phase to obtain detailed, high-resolution data (as currently envisioned).
3. The planned offshore borings and collection of lithologic and water quality data will likewise yield useful information on the hydraulic conductivity of the aquifer, the extent and thickness of clay layers, and water quality (e.g., depth-specific data on salinity and inorganics, Fe/Mn content on the sediments and in water, dissolved oxygen/ORP profiles, microbial community), including information on organic carbon content, distribution, and bioavailability to flowing ocean recharge water. Characterization of sediment sulfide abundance and its reactivity under oxic conditions is also desirable. Boring locations should be determined based upon the results of the seismic reflection survey. If possible (based on seismic survey data), the feasibility of using drilling borings from the Dana Point Harbor jetty should be investigated as a means that could reduce the cost of ocean drilling boats/platforms. Options for collection of borings include:
    a. Small gravity corers (to assess the uppermost sediment column, including organic carbon content)
    b. Vibracores or other shallow cores (to a depth of about 15 ft, if possible, to characterize vertical permeability, thickness of the shallow aquifer, extent of clay layer, and to collect additional information on water quality, geochemistry, and microbiology)
    c. Large, deep boreholes (to the full depth of the planned slant wells, and in which piezometers could be left). The Expert Panel agreed that three (3) to ten (10) deep borings should be drilled and data collected to characterize hydraulic conductivity and conditions within the aquifer and to obtain samples of "old" marine groundwater for analysis. A minimum of three borings is necessary to establish a plane. Due to the likely extent of the offshore aquifer and the contributory area to the well, additional borings would be likely to provide a more representative description of the area. The seismic survey may provide insight into the need for additional borings, as it may provide insight into the complexity of the subsurface units. As an example, onshore work to date has indicated an important four-foot clay layer at approximately -13 ft msl, whose areal offshore extent is not yet known but

which may play an important role in defining the area contributing to recharge to the planned wells and which may affect subsurface flow paths and flux rates.

d. Downcoast boreholes along the shoreline should also be considered to obtain lithologic samples over the extent of the proposed full-scale wellfield.

4. The conversion of the boreholes into piezometers that could subsequently be sampled for water quality and microbial data was considered a good approach to help answer the anoxia and Fe/Mn oxidation questions. However, this work would require very careful installation and sampling procedures to obtain representative samples. Other issues included the elevation to which the top of the piezometer sampling port should be set so as to handle seasonal shifting sands.
5. The "old" marine groundwater is currently only characterized as a mixed component in the pumped slant well water. Further characterization would require sampling from deep bores for analysis of typical parameters (DO, pH, salinity, inorganics, etc.), for organic carbon (BDOC or AOC), and for the isotopes used to identify groundwater end members. Results of the isotope analysis should be used to refine the isotopic source water analysis. The isotope source water analysis should also be refined so that the mathematical formulation utilizes all available information in arriving at a solution (i.e., solves the over-specified system for all isotopes and for salinity).
6. The groundwater flow model should be refined using data from the proposed seismic reflection survey and borings. In particular, the lateral and vertical extent and offshore characteristics of the alluvial aquifer should be defined, and information on clay layers and hydraulic conductivity (vertical and lateral) should be incorporated into the flow modeling. The groundwater flow model should also be refined using the information on the groundwater end members to improve its calibration against the measured salinity in the Test Slant Well and to adjust model parameters to reproduce the results of the isotope analysis to the extent possible.
7. Once refined as discussed above, the groundwater flow model should be used to help evaluate possible outcomes regarding changes in the composition of the source water over time. This could be done in two ways: a "simple" analysis using information on source water end member composition, or a "complex" analysis that would incorporate geochemical reactions and reaction rates into the numerical groundwater model. The Expert Panel recommends that the simple analysis method be used first, as it may provide sufficient information regarding the likely source water composition over time. In either case, the geochemical formulation should be designed carefully in light of the questions to be addressed by the model.
   a. In the simple analysis, the model might be used to calculate the "end member composition" of the source water (i.e., the fraction of source water from old marine groundwater, new marine groundwater, and brackish water) for a range of potential aquifer conditions. The model would also be used to estimate the travel time for groundwater from various sources (particularly new marine groundwater and brackish water) to reach the full-scale slant wells. This information would, in turn, be used to evaluate the likely chemical composition (especially oxygen and

Fe/Mn content) of the source water over time, considering the origin and travel time of the source water.

b. A complex analysis that incorporates geochemical reactions and rate constants could also be constructed (e.g., using a USGS add-on to MODFLOW and SEAWAT), but the level of effort would be far greater than for a "simple" analysis, and it is not clear that the information provided would be more useful.

8. The conceptual design of the full-scale treatment facility should consider a range of possible source water conditions. For example, the potential future presence of colloidal or particulate Fe/Mn, which could necessitate additional pretreatment, should be analyzed in greater detail, and the presence of higher bromide concentrations (due to a higher fraction of ocean water in the source water) may necessitate a second-pass RO system.
9. The full-scale wellfield should be designed in anticipation of biofouling, a common occurrence in most municipal water supply wells. The Expert Panel endorses the existing concept of constructing the system with more wells than are needed at any given time, and, for anoxic source water, the use of a nitrogen blanket within the well.
10. The Expert Panel agrees with project participants that additional source water options could be considered, including water from the upstream groundwater desalter facility. The implications of using upstream groundwater desalter brines to enhance water supply recovery need to be carefully evaluated and considered during project conceptual design (e.g. introduction of dissolved oxygen and other contaminants, reliability of operations by others, etc.).
11. The Expert Panel endorses the concept of conducting a full "autopsy" on the membranes used in the test facility, to evaluate their performance and the degree of fouling, and to incorporate results into final facility design.
12. Dr. Sunny Jiang's tag sequencing analyses can provide valuable information about the range of organisms in biofouling communities and how they develop and change. Her proposed genomic (and transcriptomic) measurements may indicate the activities of many of the bacterial types in these biofilms that are not known from culture studies and therefore may be important, although this part of the field is still young and it is hard to predict success.
13. The Expert Panel recommends doing a limited number of incubation experiments using solids obtained from the boreholes and fresh ocean water. These experiments could provide information that is useful for assessing the reactivity of the organics and metal-rich phases, and provide a rough indication of the kinetics of these reactions. Incubations should be done under both anoxic and oxic conditions, to evaluate the potential range of conditions that will develop as pumping continues. The solids used in these experiments should be characterized as described above in recommendation 3. This data set could be quite useful in formulation of the simple geochemical model discussed above. MWDOC may also wish to consider developing a plug flow model if feasible.
14. The Expert Panel agreed that there is a significant uncertainty regarding the usefulness of data that could be obtained using thermal measurements of water at the ocean floor as the discharge

zone would likely have a considerably smaller footprint than the recharge contributory area. Although such information could in theory be used to identify preferential pathways within the discharge zone (estimated by Geoscience to extend as far out as 1,100 feet offshore under wet hydrologic conditions), results might be confounded by natural variations in ocean temperatures and other factors, and this study concept is not recommended at this time.

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