# AN ASSESSMENT OF THE REPORTS ON THE PROPOSED HUNTINGTON-POSEIDON SEAWATER DESALINATION PROJECT PREPARED BY THE INDEPENDENT SCIENTIFIC TECHNICAL ADVISORY PANEL

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## EXECUTIVE SUMMARY

I was asked by California Coastkeeper Alliance to review reports prepared by the Independent Scientific Technical Advisory Panel (ISTAP) convened by CONCUR, Inc. to analyze the technical and economic feasibility of sub-surface intakes for the proposed Huntington-Poseidon Seawater Desalination project. The purpose of this report is to comment on whether or not the ISTAP reports are satisfactory for meeting California regulations for new seawater desalination facilities.

While the ISTAP panels indicated that their analyses were not intended to constitute a regulatory compliance report, the Phase 1 and Phase 2 reports were included in the project permit application. The ISTAP reports are being relied upon by the Applicant as evidence that sub-surface intakes are neither technically nor economically feasible, making the Poseidon project eligible for an exemption to the regulatory preference compelling the use of sub-surface intakes. Hence the need for an independent review.

After reviewing the relevant regulations and policies, as well as the ISTAP reports and other relevant studies, I have concluded as follows:

- The ISTAP Phase 1 report erred in finding that slant wells are not technically feasible for the proposed facility;

- The ISTAP Phase 2 report did not adequately demonstrate that sub-surface intakes are not economically feasible for the proposed facility;

- Further, because the Phase 1 report erred in dismissing slant wells, the Phase 2 report lacked any analysis of the economic feasibility of slant wells and or similar subsurface technologies. The lack of an economic analyses of slant wells is a significant flaw because the construction cost of slant wells is lower than that of the Seawater Infiltration Galleries analyzed in the ISTAP Phase 2 report. Other desalination projects in California proposing to use slant wells have shown that technical risks with slant wells can potentially be mitigated and that there would be significant savings in the costs of operation and maintenance compared to the screened open ocean intakes proposed for the Huntington-Poseidon project.

I have concluded that the ISTAP Phase 1 and Phase 2 reports are inadequate for showing that slant wells are neither technically nor economically feasible according to the requirements set forth in the Ocean Desalination Amendment to the California Water Quality Control Plan for Ocean Water.

## 1. INTRODUCTION

I was asked by the California Coastkeeper Alliance to review the Phase 1 and Phase 2 reports produced by the Independent Scientific Technical Advisory Panel (ISTAP) convened and facilitated by CONCUR, Inc. with regard to the feasibility of subsurface intake designs for the proposed Poseidon Water Desalination Facility at Huntington Beach, California (the Poseidon plant). Those reports were prepared between June and September 2014 (Phase 1 Report) and between December 2014 and August 2015 (Phase 2 Report). While the ISTAP reports were being prepared, the California State Water Resources Control Board (SWRCB, State Water Board) was in the process of preparing an amendment to the California Water Quality Control Plan for Ocean Water to address desalination facilities. SWRCB staff released a Draft Amendment and Staff Report/Substitute Environmental Document (SR/SED) on July 3, 2014 and a Draft Final Amendment and SR/SED on April 24, 2015. SWRCB adopted the Ocean Desalination Amendment on May 6, 2015.

As an economist with experience in the analysis of water projects and water policy, I have assessed how well the ISTAP analysis comports with the requirements set forth in the Ocean Desalination Amendment.

Among other items, III.M.2.d.(1)(a) of the Amendment states that "the regional [water quality control] board in consultation with State Water Board staff shall require subsurface intakes unless it determines that subsurface intakes are not feasible based upon a comparative analysis of the factors listed below for surface and subsurface intakes." Taken in combination, the ISTAP reports concluded that subsurface intakes are not feasible for the Poseidon plant.

I was asked to assess whether the ISTAP analysis adequately demonstrates that the Poseidon plant should be exempted from SWRCB's stated preference for a subsurface intake for a new ocean desalination facility to meet State law requiring these facilities to minimize the intake and mortality of marine life. This report sets forth my conclusions and the reasons for them.

In preparing this report, I read both ISTAP reports[1] and both the 2014 and 2015 SWRCB SR/SED reports,[2] as well as the final adopted Ocean Desalination Amendment.[3] I reviewed numerous reports detailing the technical and economic viability of subsurface intakes. I also read three appendices prepared for me by California Coastkeeper Alliance.[4]

## 2. BEST AVAILABLE SITE, BEST AVAILABLE DESIGN, BEST AVAILABLE TECHNOLOGY

Article III.M.2.a(2) of the 2015 Ocean Amendment states: "The regional water board shall conduct a Water Code section 13142.5(b) analysis of all new and expanded desalination facilities. … The regional water board shall first analyze separately as independent considerations a range of feasible alternatives for the best available site, the best available design, the best available technology, and the best available mitigation measures to minimize intake and mortality of all forms of marine life. Then, the regional water board shall consider all four factors collectively and determine the best combination of feasible alternatives to minimize intake and mortality of all forms of marine life."

Another article, III.M.2.b(2), requires the owner or operator of a new facility to: "Consider whether the identified need for desalinated water is consistent with an applicable adopted urban water management plan prepared in accordance with Water Code section 10631, or if no urban water management plan is available, other water planning documents such as a county general plan or integrated regional water management plan." Furthermore, article III.M.2.d.(1)(a) states in part: "A design capacity in excess of the identified regional water need for desalinated water shall not be used by itself to declare subsurface intakes as infeasible."

Based on my understanding of the history of the Poseidon project as recounted in the ISTAP Phase I (pp. 5-9), it does not appear that the site and size of the Poseidon facility were subjected in either ISTAP Phase 1 or Phase 2 reviews to the analysis called for in the 2015 Ocean Amendment.

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[1] *Final Report: Technical Feasibility of Subsurface Intake Designs for the Proposed Poseidon Water Desalination Facility at Huntington Beach, California*, October 8, 2014 (ISTAP 1). *Phase 2 Report: Feasibility of Subsurface Intake Designs for the Proposed Poseidon Water Desalination Facility at Huntington Beach, California*, November 9, 2015 (ISTAP 2).

[2] *Draft Staff Report Including the Draft Substitute Environmental Documentation, Amendment to the Water Quality Control Plan for Ocean Waters of California Addressing Desalination Facility Intakes, Brine Discharge, and the Incorporation of other Non-Substantive Changes,* July 3, 2014 (Draft Staff Report). *Final Staff Report Including the Draft Substitute Environmental Documentation, Amendment to the Water Quality Control Plan for Ocean Waters of California Addressing Desalination Facility Intakes, Brine Discharge, and the Incorporation of other Non-Substantive Changes,* May 6, 2015 (Final Staff Report).

[3] State Water Resources Control Board, *Water Quality Control Plan Ocean Waters of California 2015* (2015 Ocean Amendment).

[4] The appendices are: *Cost Savings from Avoiding Pretreatment*; *Flawed Reliability Premium*; and *Cost of Slant Wells*.

In 1998, around the time that it had put together the proposal to Tampa Bay Water for a 25 mgd desalination facility in Florida, Poseidon developed a proposal for two 50 mgd desalination plants at Carlsbad, in San Diego County,[5] and at Huntington Beach.[6] Both projects were sited with the expressed purpose of co-locating with coastal power plants in order to take advantage of the cooling water intake and discharge systems – systems that are now being abandoned to minimize the intake and mortality of marine life for cooling purposes. A lease of the property on the power plant site for the proposed Huntington Beach project was acquired in 2001, and Poseidon submitted a coastal development permit application in 2002.

Thus, rather than emerging as the outcome of a selection process which identified them as the best alternative in order to minimize the intake and mortality of marine life, the site and scale of the Huntington Beach proposal have been a fixed datum since the project's inception twenty years ago.

Moreover, the scale was not justified on the basis of analysis in an urban water management plan. The 50 mgd scale of the Huntington Beach facility was not chosen because the need for expensive, drought-proof water in Orange County is exactly the same as the need in San Diego County where Poseidon's other 50 mgd plant is located. In fact, Orange County overlies a large groundwater basin allowing the water agencies many alternatives for reliable water supplies that are not available in San Diego County where there is limited groundwater storage availability. Moreover, since 2002 when Poseidon first applied for Coastal Development Permit, total demand for water in Orange County has gone down[7] and alternative sources of water supply have become available.

In short, the 50 mgd scale of the Huntington Beach facility was a pre-determined decision made without the identification of any discrete need for 50 mgd of supplemental water in any Urban Water Management Plan from 2002 through the most recent plan adopted for 2015.

The Draft Staff report for the Ocean Plan Amendment contained an earlier version of article III.M.2.b(2). The earlier version required the owner or operator of a new desalination facility to:[8] "Consider whether the identified regional need for desalinated water identified is consistent with any applicable general or coordinated plan for the development, utilization or conservation of the water resources of the state, such as a county general plan, an integrated regional water management plan or an urban water management plan. A design capacity in excess of the identified regional water need for desalinated water shall not be used by itself to declare subsurface intakes as infeasible."

In comments submitted on August 15, 2014, the Municipal Water District of Orange County (MWDOC) objected to this provision, stating:[9] "This determination is beyond the scope of the

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[5] https://www.water-technology.net/projects/carlsbaddesalination/
[6] https://www.water-technology.net/projects/huntington-beach-desalination-california/
[7] *See* James Fryer, A Review of Water Demand Forecasts for the Orange County Water District (July 2016).
[8] Article 2.b.(1).
[9] Final Staff Report, Appendix H, Comment 6.3, page H-12, 13.

statutory requirement under Section 13142.5 and is not part of the determination of the best available site. We don't see a need for this in the Ocean Plan. …. We are recommending that this provision be deleted since it is not a specified part of a Water Quality Control Plan and is not relevant to the regulation of intakes and brine disposal."

That argument was rejected by SWRCB staff. The staff responded:[10] "Subsurface intakes should be used to the maximum extent feasible. The intent of the language is to ensure that if there is a situation where an Urban Water Management Plan identified a need for 10 MGD of desalinated water, but only 9 MGD could be acquired through subsurface intakes, the regional water board would not automatically reject subsurface intakes as an option. Instead, the regional water board could require the use of subsurface intakes for the 9 MGD and find an alternative means for acquiring the other 1 MGD. The alternative means that 1 MGD could include withdrawing water through a screened surface intake or seeking out other water supply options like recycled water."

The staff went on to observe that: "several parties have commented that large infiltration galleries may not be technically feasible to operate. Some parties have expressed concern that facilities will be proposed that far exceed the reasonable water supply needs of a community in order to "game" the results of the feasibility analysis to allow the project proponent to reject the amendment's preferred intake technology of subsurface intakes in order to avoid potential construction costs."

Whether intentionally or not, the a priori specification of a 50 mgd scale facility without consideration of alternative, smaller scales, may indeed have performed the function of "gaming" the Ocean Amendment amendment process by providing an excuse to declare an otherwise feasible subsurface intake technology as not feasible for the Huntington Beach facility.

To summarize, prior to adoption of the Ocean Plan Amendment sections III.M.2.b(2) and III.M.2.d.(1)(a), there was no requirement for a permit applicant to document a need for the volume of seawater withdrawn and potable water produced. As explained in the Final Staff Report response to comments, this remains true if the applicant is requesting a permit to construct and operate a facility using a subsurface intake. But, if the applicant is requesting a permit for a facility using an open ocean intake, the applicant must document a demand for the volume of product water that could not be met with alternative sources (eg, "other water supply options like recycled water") and/or a combination of subsurface and open ocean intakes.[11] The ISTAP reports did not meet this requirement. They did not address the question of whether there was a documented need for 50 mgd of water from a seawater desalination facility that could not be met with alternative sources.

[10] Final Staff Report, p. H-13.
[11] Final Staff Report, pp. H-12 and H-13.

3. TECHNICAL FEASIBILITY

The ISTAP Phase 1 report was intended to assess the technical feasibility of alternative subsurface intake designs for the Huntington Beach facility. That report evaluated nine types of subsurface intakes for technical feasibility at the Huntington Beach site. It concluded that only two of the nine designs -- seabed infiltration gallery and beach infiltration gallery -- were technically feasible.

However, the definition of technical feasibility employed in ISTAP Phase 1 differs in two significant ways from that used in the 2015 Ocean Amendment.

In article 2.d.(1)(a)(i), the Draft Staff Report specified the following criteria for determining the feasibility of subsurface intakes:

geotechnical data,
hydrogeology,
benthic topography,
oceanographic conditions,
presence of sensitive habitats,
presence of sensitive species,
energy use,
impact on freshwater aquifers,
local water supply, and existing water users,
desalinated water conveyance,
existing infrastructure,
co-location with sources of dilution water,
design constraints (engineering, constructability), and
project life cycle cost.

These criteria were modified in the Final Staff Report and the 2015 Ocean Amendment as adopted. The final list, article 2.d.(1)(a)(i), specifies the criteria for determining the feasibility of subsurface intake as:

geotechnical data,
hydrogeology,
benthic topography,
oceanographic conditions,
presence of sensitive habitats,
presence of sensitive species,
energy use for the entire facility,
design constraints (engineering, constructability), and
project life cycle cost.

The criteria relating to impact on freshwater aquifers, local water supply, and existing water users, desalinated water conveyance, existing infrastructure, and co-location with sources of dilution water were omitted in the final Amendment.

The criteria for technical feasibility used by ISTAP Phase 1 differ from those in the final Amendment in two important ways.

First, ISTAP Phase 1 included impact on freshwater aquifers as a criterion of technical feasibility. The factors considered in ISTAP Phase 1 were given (pp. 23-24) as:

geotechnical data,
hydrogeology,
benthic topography,
oceanographic conditions,
impact on freshwater aquifers, and
design constraints (engineering, constructability).

Thus, for example, ISTAP Phase 1 rejects slant wells as an option because they "would draw large volumes of water from the Orange County Groundwater Basin, which in itself is considered a fatal flaw" (p. 56).

From my perspective as an economist, this is not a valid criterion of technical feasibility – it is an economic consideration. Suppose, for the sake of argument, that a desalination facility with subsurface slant-wells pumps 100 mgd for a usable supply of 50 mgd of desalinated water, and suppose that a fraction, θ, of the amount pumped actually originates from the freshwater aquifer. Then, when 100 mgd of seawater is pumped, the *net* additional supply of usable water obtained is (0.5-θ)*100 mgd instead of 0.5*100 = 50 mgd. Suppose that 5% of the amount pumped with the slant-wells originates from the freshwater aquifer (θ = 0.05).[12] Then each mgd of water seawater pumped for "source water" generates a net "product water" supply of 0.45 mgd instead of 0.5 mgd. The main significance of this adjustment is that it raises the unit cost of the water supplied.

[12] An independent report by Hydrofocus, *Huntington Beach Seawater Desalination Facility Groundwater Model Evaluation*, September 23, 2016 presents a preliminary estimate that θ = 0.04. The Hydrofocus report found that a wide range of potential drawdown volumes were dependent upon the variables used in computer modeling.It recommended utilizing test wells to verify the computer modeling. The report "identified model limitations and uncertainty that affect the ability of the model to accurately predict impacts of project pumping. The model was not calibrated or verified using observed water level data." The report went on to recommend "(1) aquifer tests to determine properties of the Talbert Aquifer, the overlying sediments, and the wetland sediments; (2) an assessment of the effects of the lateral model boundaries; (3) correction of inconsistencies in model construction; (4) calibration/verification using water level data; and (5) incorporation of the US Geological Survey MODFLOW Subsidence Package to preliminarily evaluate the subsidence potential due to slant well pumping." Only then can the improved model "be used to more effectively simulate potential impacts and project feasibility."

The unit cost of the deasalinated water supply needs to be adjusted to reflect the drawdown of aquifer water. Suppose the cost had been estimated at $2,000 per acre-foot ignoring the drawdown of aquifer water. With the drawdown of aquifer water, the true cost per acre-foot of additional supply from desalination becomes $2000*\frac{0.5}{0.5-\theta}=2000*\frac{0.5}{0.45}=2222.$

The drawdown of aquifer water is a factor that increases the effective cost per mgd supplied via desalination using a slant-well intake but, by itself, it does not constitute a "fatal flaw." This may be why SWRCB dropped "impact on freshwater aquifer" from its criteria for technical feasibility.

Further, ISTAP Phase 1 applies a second criterion for technical feasibility that is also not endorsed by SWRCB. The report states (p. 11): "For the Phase 1 Report, the working definition of "Technical Feasibility" was specified in the expert contract documents as: "Able to be built and operated using currently available methods." Thus, an additional reason adduced by the report for declaring a slant-well subsurface intake to be technically infeasible was the following (p. 56):

"The performance risk is considered medium, as the dual-rotary drilling method used to construct the wells is a long-established technology, but there is very little data on the long-term reliability of the wells. Maintainability is also a critical unknown issue."

That argument is questionable. The 2015 Ocean Amendment declares a policy preference for the use of a subsurface intake for desalination, a requirement that did not previously exist.[13] It is not a valid response to say, in effect: "There is not a lot of experience with this technology therefore it should be declared infeasible." A correct response, instead, is to conduct the appropriate testing – as has been done elsewhere in California.

In fact, as evidenced by the CalAm-Monterey and Doheny desalination project proposals, slant well intakes *are* considered "technically feasible" regardless of the potential drawdown of inland waters.[14] Clearly the industry disagrees with the ISTAP finding on the feasibility of slant wells based on performance risks, as witnessed by designed and tested proposals to use slant wells for the Doheny and CalAm-Monterey projects.

## 4. ECONOMIC FEASIBILITY

[13] As the SWRCB staff notes in the *Final Staff Report* (p. H-287), the proposed Desalination Amendment "does not take a technology neutral approach for intakes."

[14] See *Hydrogeologic Working Group, Monterey Peninsula Water Supply Project – HWG Hydrogeologic Investigation Technical Report* (Nov. 6, 2017); available at https://docs.wixstatic.com/ugd/28b094_e3255ac3069c4b6b83bce80604ae6703.pdf; see Municipal Water District of Orange County*, Final Summary Report Doheny Ocean Desalination Project Phase 3 Investigation* (January 2014); available at http://docplayer.net/46522220-Final-summary-report-doheny-ocean-desalination-project-phase-3-investigation.html; and see http://www.mwdh2o.com/FAF%20PDFs/10_MWDOC_SlantWell_FactSheet.pdf.

The 2015 Ocean Amendment defines *feasible* thus: "For the purposes of Chapter III.M, [feasible] shall mean capable of being accomplished in a successful manner within a reasonable period of time, taking into account economic, environmental, social and technological factors" (p. 54).

Article III.M.2.d.(1)(a)I of the Amendment states: "Subsurface intakes shall not be determined to be economically infeasible solely because subsurface intakes may be more expensive than surface intakes. Subsurface intakes may be determined to be economically infeasible if the additional costs or lost profitability associated with subsurface intakes, as compared to surface intakes, would render the desalination facility not economically viable."

In their response to comments received, the SWRCB noted: "The fact that an alternative may be more expensive or less profitable is not sufficient to show that the alternative is financially infeasible. What is required is evidence that the additional costs or lost profitability are sufficiently severe as to render it impractical to proceed with the project."[15]

As an economist, I would argue that reasonableness in a water purchase agreement requires some form of a cost-benefit test. Whether or not an item is economically practical surely can be determined only by reference to the benefit that it generates, and by how those who receive the benefit value it. One cannot meaningfully decide that an item is too costly without also considering its benefit. Too costly relative to what? $20,000 may be an unreasonably high cost for a skate-board, but not for an SUV. A purely cost-based determination without reference to benefit is neither rational nor reasonable.

The ISTAP Phase 2 Report interprets the criterion for the economic viability of an intake technology as an amount "that OCWD might be willing to pay for the water supplied" by the proposed Poseidon facility.[16] From an economic perspective, that interpretation is very problematic.

The mere fact that OCWD states it is unwilling to pay for a subsurface intake for the proposed Huntington Beach facility is not, by itself, a meaningful demonstration of economic non-viability. One has to know what factors were being taken into consideration when the economic viability was being assessed by OCWD.

Two factors are surely relevant: (1) The reliability premium -- the economic value of the heightened reliability associated with desalinated water compared to other sources of water supply for Orange County. And (2) the economic value of the environmental damage avoided when a subsurface intake is used instead of an open ocean intake. There is no evidence that either factor was properly considered by OCWD or by the ISTAP reviews.

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[15] Final Staff Report, p. H-241, comment 15.92; p. J-70, comment 12.7.
[16] ISTAP 2, p. 13.

The ISTAP Phase 2 Report states (p. 13) that it evaluated the price that OCWD might be willing to pay for water from the Poseidon facility "using OCWD's Water Purchase Agreement Term Sheet with Poseidon … as a starting point and assessing the change in that price over time with appropriate escalation factors." It elaborates: "We based the OCWD water price on the amount that OCWD will likely have to pay for water supplied by the Metropolitan Water District (MWD) of Southern California in the future (which OCWD would rely on in the absence of the desalination facility). On top of this price, we have factored in a subsidy that MWD provides local communities for developing local water supplies, as well as a premium that OCWD has indicated it is willing to pay for the increased water supply reliability that the desalination plant will provide."

The ISTAP Phase 2 Report states (p. 60): "Consistent with our understanding of the ongoing contract discussions, in our projections we assume that the reliability premium amounts to 20% of MWD's Tier 1 water price for 10 years after construction. The premium drops to 15% of the Tier 1 price for the next 10 years, to 10% for 10 more years, to 5% for ten years, and then finally to 0%."

I have two comments on this calculation.

First, if this calculation were intended as an estimate of the reliability premium associated with a drought-proof water supply from desalination, it entirely lacks foundation. Where does the 20% premium come from? Why is the premium not 40%? Or, 17%? The value used for the reliability premium appears to be an after-the-fact justification for the cost of seawater desalination, not a meaningful analysis of the final customers' willingness to pay for additional reliability.

Secondly, these estimates have no credibility as a reliability premium. Why would the economic value of increased reliability for water supply in Southern California *decline* over time, having a lower value in 2030-2039 than in 2020-2029, a lower value still in 2040-2049, etc., and zero value from 2060 onwards? The population of Southern California will be growing over time, and global warming will be reducing Southern California's effective surface water supply in 2040 or 2060 compared to the present. It is implausible to presume the projected economic value of increased reliability in Orange County's water supply will decline over the next 40 years and will be zero from 2060 onwards.

There is a technically correct way to estimate the value of a more reliable source of water supply for OCWD as compared to a less reliable source of supply. It would involve three general components.

First, one has to measure the change in the overall reliability of OCWD's water supply portfolio with desalinated water from Huntington Beach versus without it. This would be based on (i) assumptions as to the composition of OCWD's water supply portfolio in 2020-2029, 2030-2039, 2040-2049, etc., with and without the supply from Poseidon, and (ii) probabilistic forecasts of the changed occurrence of shortage (i.e., projected annual demand exceeds projected annual supply) during those time periods, with desalinated water in the supply portfolio versus without.

Second, one has to calculate the loss of economic value associated with the occurrence of shortages in the time periods.

Third, one has to estimate the risk aversion premium that water users potentially affected by the shortage (e.g., water users subjected to rationing) would be willing to pay to reduce or avoid this risk.

I myself conducted the first two elements of this type of analysis in a study for the California Energy Commission in 2006. That study assessed the economic loss for urban water users in Southern California under a climate change scenario.[17] In a paper published in 2016, I conducted all three elements of this type of analysis, including forming an estimate of the risk aversion premium for Central Valley agricultural water users (i.e., estimating what they might be willing to pay to avoid the increased risk of economic loss due the reduction in their water supply under a scenario of climate change).[18]

In the case of Huntington Beach, Peer Swan has presented an example of the type of economic analysis that needs to be conducted.[19] By contrast, the ISTAP Phase 2 Report is deficient precisely because it failed to perform any such an analysis.[20] Because it did not perform a correct economic analysis of the reliability value, the ISTAP Phase 2 analysis cannot be taken as evidence that a subsurface intake would not be economically feasible for the proposed facility.

If the Poseidon facility at Huntington Beach had a subsurface intake it would likely provide water at a lower cost than one with an open ocean intake. But, would it be economically viable? Because the necessary economic analysis is lacking in the ISTAP reports, it is an open question in my mind whether such a facility would be economically viable, let alone optimal. There are too many unanswered questions.

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[17] Michael Hanemann et al., *The Economic Cost of Climate Change Impacts on California Water: A Scenario Analysis*. California Climate Change Center at U.C. Berkeley, Working Paper 06-01, January 2006.

[18] Michael Hanemann et al., The Downside Risk of Climate Change in California's Central Valley Agricultural Sector, *Climatic Change* (2016) 137: 15-27.

[19] For further details of Swan's analysis see California Coastkeeper Alliance's *Appendix 2 Flawed Reliability Premium*. Swan's analysis lacks the third element noted above -- the possible risk aversion premium that water users in Orange County might be willing to pay.

[20] In a memorandum *Reliability Benefits in OC from the Poseidon Project*, dated July 7, 2015, MWDOC staff implicitly acknowledged the validity of the type of analysis conducted by Per Swan and recommended here. The memo stated:"If [MWD] is reliable, say 8 or 9 years out of 10, this means OC [Orange County] would only need Poseidon water 1 or 2 years out of 10. However, ocean desalination projects generally cannot be effectively operated only a few years out of 10 as the financial allocaiton of capital costs to the smaller volume of water produced yields extremely expensive water. … However, if [MWD] is much less reliable, maybe only 1 or 2 years out of 10, the argument in support of the Poseidon Project makes better sense and OC would receive a greater return on investment" (page 8).

It is not obvious just how much a 50 mgd facility, rather than a smaller one, is needed. There are other potential sources of supply for Orange County that would be cheaper. It is not clear just how much the facility as planned with OCWD would actually improve the reliability of Orange County's water supply. It is not obvious whether it is economically sensible to have OCWD as the entity that contracts for the desalinated water.

It is likely that there are many cheaper sources of water for Orange County, including water from the reuse of treated wastewater, or water market purchases, or conservation. For example, I understand that Irvine Ranch Water District (IRWD) has purchased farmland in Palo Verde Irrigation District (PVID) possibly with the purpose of transferring the water directly or indirectly into Orange County. I understand that this water was acquired for a one-time, up-front cost of approximately $3,400/AF, which will turn out to be significantly cheaper than the ultimate cost of water from Poseidon. Other water districts in Orange County, too, are pursuing efforts to obtain water. Thus, Santa Margarita Water Distric has committed to purchase at least 5,000 AF/year from the Cadiz Project.

With regard to the increased reuse of treated wastewater, MWD in partnership with the Los Angeles Sanitation Districts is building an 0.5mgd demonstration plant, the Carson Project, that should start up by the end of this year. If it proves successful, the plan is to scale the program up to as much as 150 mgd. [21]

it is unclear how the desalinated water from the Poseidon facility would actually be put to use. My understanding is that this has not yet been determined by OCWD. The water might be sold directly to water providers or used in some manner for groundwater recharge. The different options may have different implications both for the final cost of the water to users and also for the ultimate impact on supply reliability. MWD allocates water to member agencies during times when there is a shortage of imported surface water in such a way the cumulative water supply in the Orange County region would increase by *less* than the capacity of the desalination facility: it would *not* become more reliable by 50 mgd per year. [22] In fact, "if OC can store the Poseidon water in years when it is not being used to meet demands directly, it becomes a question as to whether the water would result in a <u>significantly</u> higher reliability for OC. … OC would likely be better off by only a small percentage."[23]

One solution might be for MWD pursue the project rather than OCWD. MWD is better positioned to distribute the incremental supply as widely as possible though the entire Southern California area. This might avoid the expense of having OCWD store the bulk of the water in the Orange County groundwater basin and pump it back up intermittently when there

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[21] *See* http://www.mwdh2o.com/DocSvcsPubs/rrwp/assets/mwd_board_item_6-b_staff_presentation_march_2018.pdf. Slide 18 suggests that 60 mgd would be delivered for spreading to the Orange County basin.
[22] "MWDOC: Reliability Benefits in OC from the Poseidon Project", page 4.
[23] Ibid, pp. 6-7.

is a shortage. But, "the problem with this is that MWD has historically evaluated that they have sufficient other supply options, costing less than $1800 per AF." [24]

The questions that should have been addressed by the ISTAP Phase 2 Report, but have not yet been answered, are these: What is the value added for Orange County by obtaining 56,000 AF every year from Poseidon at a cost of $2,200/AF? What is the economic cost to Orange County of intermittent supply shortages? What is the economic value to water users in Orange County of mitigating the risk of these shortages? Does it actually justify the scale, location, and cost of the Poseidon facility?

In short, the ISTAP Phase 2 analysis fails to demonstrate that a subsurface intake is not economically viable compared to the screened open ocean intake proposed for the Poseidon facility. It also fails to demonstrate that the Poseidon facility with any type of intake is economically justified.

## 5. SLANT WELL INTAKE - POTENTIAL LIFE-CYCLE COST SAVINGS

The ISTAP Phase 2 Report considered only one type of subsurface intake, namely a seafloor infiltration gallery (SIG). The ISTAP Phase 2 team had started out with the two subsurface intake options that ISTAP Phase 1 had determined – inadequately, in my view – to be technically feasible, namely SIG and BIG, a beach (or surf zone) infiltration gallery. However, early in its work, the ISTAP Phase 2 team determined that the BIG option analysis "would not be feasible." Along with open ocean option, it focused simply on the SIG option using two possible methods of construction, a trestle (SIG-Trestle) or a float-in construction (SIG-Float In).

A striking inconsistency with the ISTAP Phase 1 Report is that the ISTAP Phase 2 analysis considered alternative scales of plant production capacity for the intake options being considered – open-ocean, SIG-Trestle, and SIG-Float In. Three alternative scales were considered in addition to the 50 mgd of production proposed by Poseidon and analyzed in ISTAP Phase 1 Report; these were production levels of 100 mgd, 25 mgd, and 15 mgd. The per unit cost of delivered water for a 25 mgd facility was estimated to be about only 7.6% to 10.1% higher than for a 50 mgd facility.

As noted above, the ISTAP Phase 1 team was unwilling to consider alternative scales besides Poseidon's 50 mgd design. But, as also noted above, ISTAP Phase 1 rejected slant wells as a subsurface intake technologically because of uncertainty about this technology's ability to provide "the required volume of water" – i.e., 50 mgd. The implication is that, had a smaller scale been permitted, slant wells would have been deemed an acceptable technology. Whether intentionally or not, the inconsistency in the production scale assumed by ISTAP Phase 1 and

[24] Ibid, p. 7.

ISTAP Phase 2 had the effect of eliminating slant well as a technology to be costed and compared alongside open ocean intake.

Also as noted above, the other reason why the ISTAP Phase 1 Team rejected slant wells as a subsurface intake technology relied on a consideration that the SWRCB explicitly rejected – namely the mere existence of some impact on freshwater aquifers.

Together, the reasons why ISTAP Phases 1 and 2 rejected the alternative of a slant well intake lack credibility.

That is an unfortunate omission because there are reasons to believe that slant wells are a cheaper technology than the subsurface intake gallery considered by ISTAP Phase 2 and, quite possibly, a cheaper technology than the ocean intake proposed by Poseidon.

First, information summarized in California Coastkeeper Alliance *Appendix 3 Cost of Slant Wells*, suggests that the construction cost for slant wells might be as much as an order of magnitude lower than the cost of the subsurface infiltration gallery considered by ISTAP 2. Second, as the Abt Associates economic analysis commissioned by the SWRCB suggests, [25] there could be significant cost savings for slant wells because they would not need the full conventional pretreatment that is required for the open ocean intake proposed by Poseidon. The ISTAP 2 Report did not consider the cost savings of subsurface intakes when the need for conventional pretreatment is reduced or eliminated, a surprising omission. Information presented in California Coastkeeper Alliance *Appendix 1 Cost Savings from Avoiding Pretreatment* suggests that subsurface intakes have cheaper life cycle costs compared to open ocean intakes and may produce water cheaper than the proposed Poseidon plant.

6. CONCLUSION

In summary, as an economist with extensive experience in the analysis of water projects and water policy, including having served as the SWRCB's economic staff, I do not believe that the analysis contained in the ISTAP Phase 1 and Phase 2 Reports meets the standards laid down by the SWRCB to determine that a subsurface intake at the Huntington Beach desalination facility is technically or economically infeasible.

The 50 mgd scale of the facility has not been justified as required by the 2015 Ocean Plan Amendment.

The assertion that it is a "fatal flaw" for a slant well intake because it would draw some volume of groundwater does not comport with the assessment criteria specified in the 2015 Ocean Plan Amendment and, by itself, is not a valid reason to reject a slant well intake.

The second reason adduced by the ISTAP Phase 1 Report to reject the option of a slant well intake – that it is not a well established technology – is unpersuasive, given that slant well

[25] Abt Associates, Economic Analysis of the Proposed Desalination Amendment to the Water Quality Control Plan for Ocean Waters of California, Appendix G, Final Staff Report, pp. 4-5, Exhibit 12-4, and Exhibits A-14 and A-15.

intakes are incorporated in both the CalAm-Monterey and Doheny desalination project proposals.

The finding by the ISTAP Phase 2 Report that a subsurface intake at Huntington Beach would not be economically viable lacks foundation. The quantity offered as a measure of the economic value of the increased reliability provided by desalination – the time-varying premium that OCWD is willing to pay to Poseidon – is flawed and does not in any way measure the (likely increasing) economic value of supply reliability in Orange County.

The economic calculation provided by Peer Swan is a sound starting point for the type of economic analysis that should be performed, although it lacks an allowance for a possible risk aversion premium that water users in Orange County might be willing to pay.

Thus, the question that needs to be answered – what is the value added for Orange County by obtaining 56,000 AF of additional supply every year from Poseidon at a cost of $2,200/AF – has not yet been answered.

There are reasons to believe that slant wells are a cheaper technology than the subsurface intake gallery considered by ISTAP 2 and, quite possibly, a cheaper technology than the ocean intake proposed by Poseidon. This option needs to receive a proper consideration.

If the ISTAP analyses were to be corrected, several questions need to be addressed more transparently:

(1) How is the water from the Huntington Beach desalination facility to be used, and priced? Will it be held in reserve primarily for use at times of shortage, and will it be priced specially on those occasions so as to capture the higher value of an increment in water supply during a shortage? Or will it serve mainly as additional baseload supply, and will it be priced no differently than other water sold for baseload supply?

(2) Who will contract with Poseidon? It is not obvious to me that OCWD is the party best placed to be the buyer of this water since it is a groundwater management agency. To maximize the economic value of water obtained by desalination, namely as insurance against disruption of regular surface water supplies, you would want to connect it to as extensive a surface water distribution network as possible. Groundwater injection seems like a sub-optimal solution. Perhaps MWD would be a better fit as the party that contracts with Poseidon and would be better placed to maximize the economic value of this water.

(3) What should the scale be? Alternatives smaller than 50 mgd should be considered. It could be that a smaller scale desalination plant would have greater economic value as substitute source of water when the conventional surface water sources of supply are disrupted.

(4) There is also the question of timing. Why build now – or rather, why build 50 mgd now? Desalination is a relatively modular source of supply. It may not be optimal to invest now to build out the full desalination supply that will be needed in, say, 2060.

# APPENDICES

## EVIDENCE AS TO WHY THE ISTAP REPORTS DO NOT ADEQUATELY EVALUATE SUBSURFACE INTAKE FEASIBILITY AS REQUIRED BY THE DESALINATION OCEAN PLAN AMENDMENT

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## COST SAVINGS FROM AVOIDING PRETREATMENT

### SUMMARY

The question presented is whether the Regional Water Board can rely on the ISTAP conclusions that subsurface intakes are not feasible when the ISTAP never considered the cost savings of slant wells from the avoided need for full conventional pretreatment. Subsurface intake systems use the natural geological properties of sediments and rocks to strain and biologically remove organic matter, suspended sediment, and dissolved organic compounds before they enter the treatment processes. The use of subsurface intake systems improves water quality, increases operational reliability, reduces the pretreatment train complexity, and reduces operating costs – all factors to be considered when determining "feasibility" under the Desalination Ocean Plan Amendment.

The ISTAP did not consider the cost savings of subsurface intakes by avoiding full conventional pretreatment that is required for the proposed open ocean intake. The ISTAP failed to consider life-cycle costs as required by the Desalination Ocean Plan Amendment. Studies have concluded that life-cycle cost analyses show significant cost saving over operating periods of 10 to 30 years. California pilot studies have demonstrated subsurface intakes do not require full conventional pretreatment, have cheaper life-cycle costs compared to open ocean intakes, and that subsurface intakes may produce water cheaper than the proposed Poseidon-Huntington Beach proposal. While cost savings may vary based on site specific characteristics, the ISTAP Report is void of any consideration of this critical information in their analysis.

### SUBSURFACE INTAKES DO NOT REQUIRE COSTLY PRETREATMENT

Natural seawater contains a variety of macro- and micro-organic components that affect the ocean desalination treatment process. Open-ocean intakes are seasonally clogged in some regions by seaweed and some pretreatment systems are periodically fouled by influx of jellyfish.[1] Natural environmental events, such as harmful algal blooms and red tides, can overwhelm full conventional pretreatment systems and cause temporary shut-downs of ocean desalination plants.[2] In comparison, when subsurface intakes are used, improvements in the raw water quality can lead to reduction in the complexity of pretreatment systems, thereby reducing the need for physical cleaning and amount of chemicals used, and increasing the operational reliability of facilities (e.g., avoid loss of production during algal blooms).[3] Commonly, feeding higher quality raw water into the primary membrane process leads to a reduction in the rate of organic biofouling, reduced capital cost for construction of pretreatment processes, and reduced operating costs for maintenance, chemical use, and accessory operations. Further, eliminating the use of chemicals required for full conventional pretreatment also eliminates the discharge of these chemicals into the municipal wastewater treatment facilities or direct ocean discharges.

A key issue in assessing the economic feasibility of slant wells and other subsurface intakes is how to improve the quality of the feedwater and, as a result, decrease the life-cycle cost of desalination or total cost per unit volume of product water. The use of subsurface intake systems is one method to improve water quality, to increase operational reliability, to reduce the pretreatment train complexity, and to reduce operating costs.[4] Subsurface

[1] *See* Attachment One: T.M. Missimer et al., Subsurface Intakes for Seawater Reverse Osmosis Facilities: Capacity Limitation, Water Quality Improvement, and Economics; Desalination 322 (2013) 37–51, pg. 37.

[2] *See* Ry Rivard, Desal Plant Is Producing Less Water Than Promised, Voice of San Diego (August 29, 2017); available at https://www.voiceofsandiego.org/topics/science-environment/desal-plant-producing-less-water-promised/; In April, for instance, the plant shut down for 15 days when an algal bloom along the coast soured the water. The plant was unable to treat any water without fouling up the expensive filters it uses to remove salt and other impurities from water; Loreen O.Villacorte et al., Seawater Reverse Osmosis Desalination and (Harmful) Algal Blooms, Elsevier, Volume 360, 16 March 2015, Pages 61-80; The potential issues in SWRO plants during HABs are particulate/organic fouling of pretreatment systems and biological fouling of RO membranes, mainly due to accumulation of algal organic matter (AOM).

[3] *Supra* Note 1 at 39.

[4] *Id.*

intake systems use the natural geological properties of sediments and rocks to strain and biologically remove organic matter, suspended sediment, and dissolved organic compounds before they enter the treatment processes.[5]

The State Water Board's CEQA documentation for the Desalination Ocean Plan concludes subsurface intakes eliminates the need for conventional pretreatment, thus reducing capital and operational costs. The natural filtration process of a subsurface intake significantly reduces or eliminates the need for pretreatment requirements.[6] For instance, subsurface intakes typically allow for higher quality raw water to be fed into the intake system, minimizing pretreatment and significantly lowering operation and maintenance costs.[7] Surface intakes have lower capital costs relative to subsurface intakes, although a life-cycle analysis shows that surface intakes result in higher operational costs compared to subsurface intakes.[8] The higher quality of feed water with a subsurface intake reduces capital costs for construction of pretreatment processes.[9] Furthermore, subsurface intakes collect water through sand sediment, which acts as a natural barrier to organisms and thus eliminates impingement and entrainment.[10] This gives subsurface intakes a significant environmental advantage over surface water intakes because mitigation for surface intake entrainment will have to occur throughout the operational lifetime of the facility.[11] Overall, subsurface intakes can lower desalination operational plant costs and minimize associated environmental impacts.[12]

**LIFE-CYCLE COST ANALYSIS**

The Regional Water Board cannot rely upon the ISTAP's findings that subsurface intakes at Huntington Beach are not feasible. The ISTAP Report noted "that the Phase 2 ISTAP was not asked to assess the feasibility of the other components of the SWRO Plant including the pretreatment systems, the membrane system or the brine disposal system."[13] The exclusion of these components in the ISTAP Report is not an acceptable feasibility analysis under the Desalination Ocean Plan Amendment. The Amendment requires regional water boards to consider numerous factors when determining feasibility of subsurface intakes, including "energy use for the entire facility…and project life cycle cost."[14] According to the Desalination Ocean Plan Amendment's Final Substitute Environmental Document, "[p]retreatment increases costs and energy requirements, and is an additional step that is often not necessary when using subsurface intakes."[15] Both factors were intentionally omitted from the ISTAP Phase 2 Report, but are pertinent to an economic feasibility analysis and are required by a regional board to consider. Furthermore, the Ocean Plan Amendment requires project life cycle cost to "be determined by evaluating the total cost of planning, design, land acquisition, construction, operations, maintenance, mitigation,

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[5] *Supra* note 1 at 38.
[6] State Water Resources Control Board, Final Staff Report Including the Final Substitute Environmental Documentation, Pg. 51 (May 6, 2015); *available at* https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2015/rs2015_0033_sr_apx.pdf.
[7] *Id*; Pacific Institute. 2013a. Key Issues in Seawater Desalination in California: Marine Impacts; National Research Council (NRC). 2008. Desalination: A National Perspective. Washington, DC: The National Academic Press; Bartak, R., T. Grischek, K. Ghodeif and C. Ray. 2012. Beach Sand Filtration as Pre-Treatment for RO Desalination. International Journal of Water Sciences; San Diego Water Authority Camp Pendleton. December 2009. Seawater Desalination Project Feasibility Study Report Executive Summary.
[8] *Supra* Note 6 at 51.
[9] *Id*; San Diego Water Authority Camp Pendleton. December 2009. Seawater Desalination Project Feasibility Study Report Executive Summary.
[10] *Supra* Note 6 at 64; Municipal Water District of Orange County (MWDOC). 2010. Memorandum to B. Richard from N. Davis; Supra Note 4; Hogan, T. 2008. Impingement and Entrainment: Biological Efficacy of Intake Alternatives. Presented at the Desalination Intake Solutions Workshop. 16-17 Oct. 2008. Alden Research Laboratory, Holden, MA; Pankratz, T. 2004. An overview of Seawater Intake Facilities for Seawater Desalination, The Future of Desalination in Texas. CH2M Hill, Inc. Vol 2: Biennial Report on Water Desalination, Texas Water Development Board. Water Research Foundation. 2011. Assessing Seawater Intake Systems for Desalination Plants [Project #4080] http://www.waterrf.org/ExecutiveSummaryLibrary/4080_ExecutiveSummary.pdf.
[11] *Supra* Note 6 at 64.
[12] *Id*.
[13] Independent Scientific Technical Advisory Panel, Phase II Report: Feasibility of Subsurface Intake Designs for the Proposed Poseidon Water Desalination Facility at Huntington Beach, California, pg. 9 (November 9, 2015).
[14] State Water Resources Control Board, California Ocean Plan, pg. 39 (2015); *available at* https://www.waterboards.ca.gov/water_issues/programs/ocean/docs/cop2015.pdf.
[15] *Supra* Note 6 at 51.

equipment replacement and disposal over the lifetime of the facility, in addition to the cost of decommissioning the facility." The ISTAP Report did not adequately analyze all these factors when determining whether subsurface intakes are feasible.

More importantly, the ISTAP did not consider the cost saving of subsurface intakes not needing full conventional pretreatment. The use of subsurface intake systems for seawater desalination plants significantly improves raw water quality, reduces chemical usage and environmental impacts, decreases the carbon footprint, and reduces cost of treated water to consumers.[16] Subsurface intakes act both as intakes and as part of the pretreatment system by providing filtration and active biological treatment of the raw seawater. Recent investigations of the improvement in water quality made by subsurface intakes show lowering of the silt density index by 75 to 90 percent, removal of nearly all algae, removal of over 90 percent of bacteria, reduction in the concentrations of TOC and DOC, and virtual elimination of biopolymers and polysaccharides that cause organic biofouling of membranes.[17] Economic analyses show that overall seawater desalination plants operating costs can be reduced by 5 to 30 percent by using subsurface intake systems.[18] These important factors in life cycle costs were not included into the ISTAP Report, as required by the Desalination Ocean Plan Amendment. Studies have concluded that "a preliminary life-cycle cost analysis shows significant cost saving over operating periods of 10 to 30 years."[19] The Regional Board should conduct a new independent study of subsurface intakes at Huntington Beach to consider all factors of a project-life cycle cost, as defined by the Ocean Plan Amendment, including the cost savings over the lifetime of the project from not needing pretreatment for subsurface intakes.

**DOHENY DESALINATION PROJECT AS A REAL-WORLD EXAMPLE**

The Municipal Water District of Orange County (MWDOC) in partnership with five participating agencies, investigated the feasibility of slant wells to extract ocean water for the planned Doheny Ocean Desalination Project. In 2003/04, MWDOC undertook preliminary studies to assess alternative approaches to produce ocean water in the vicinity where San Juan Creek discharges to the ocean in Dana Point. Options included a conventional open intake, a subsurface infiltration gallery, and various types of beach wells. To investigate the feasibility of a subsurface slant well intake, a phased hydrogeology and subsurface well technology investigation was undertaken. In 2004/05, four exploratory boreholes were drilled along the beach to a depth of 188 feet below the ground surface. In 2005/06, after a thorough review of several technologies it was determined that the most cost-effective approach for this location was the use of slant beach wells constructed with a dual rotary drill rig from the beach out under the ocean.

The Doheny Project demonstrates that conventional pretreatment is not necessary for subsurface intakes, leading to additional capital and operational savings. From the four exploratory boreholes it was discovered that "…[t]he produced water showed a very low silt density index (average around 0.5 units) and turbidity (averaged around 0.1 NTU), indicating excellent filtration by the aquifer which eliminates the need for conventional pretreatment filtration and saves costs."[20] Furthermore, "…the produced water showed no presence of bacterial indicator organisms which were found to be present in high concentrations in the ocean and seasonal lagoon," and that "[b]iofilm growths by the end of the test were found to be less than 10 μ in thickness, a level of no concern for biofouling."[21] Pumped well water was run directly to the test RO units continuously for over four months. No fouling or performance deterioration was observed during the test or in the post-membrane autopsy as all the

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[16] *Supra* Note 1.
[17] *Id* at 37.
[18] *Id*.
[19] *Id*; *Supra* Note 6 at 64.
[20] *See* Attachment Two: Municipal Water District of Orange County, Final Summary Report Doheny Ocean Desalination Project Phase 3 Investigation, pg. 14 (January 2014).
[21] *Id*.

dissolved iron and manganese was easily removed as anoxic conditions were maintained throughout the test period.[22]

The MWDOC study concluded that for the Doheny Desal Project, "slant wells are less expensive than open intakes which also require pretreatment systems to remove sediments and organic materials."[23] This conclusion was due to the finding that "slant wells provide highly filtered water via the natural filtration process provided by the marine aquifer, thus avoiding the cost of having to construct and operate conventional pretreatment strainers, filtration and solids handling/disposal facilities."[24] MWDOC "determined from the results of the extended pumping test that the use of a slant well intake system will avoid the need for conventional pretreatment costs estimated at $56 million in capital and about $1 million in O&M costs, thus reducing the costs compared to other sites by more than $300 per AF."[25] The ISTAP failed to do any of this type of analysis demonstrated by the MWDOC study. As such, the Regional Water Board cannot rely on the ISTAP's conclusions.

The MWDOC study also compared the total cost of the Doheny Project using subsurface intakes, verse the cost estimates of the Poseidon- Huntington Beach project. MWDOC concluded that the:

> "Poseidon Huntington Beach project unit cost as of February 2013 is around $1,800 per AF, including all costs and assuming a contribution from MET of $250 per AF. The Doheny Desal Project cost, assuming an escalation of debt repayment similar to the Huntington Beach Project at 2.5%, is currently estimated around $1,200/AF including all costs and assuming a contribution from MET of $250 per AF."[26]

MWDOC's Doheny study concluded that subsurface intakes do not need full conventional pretreatment – the natural filtration by the aquifer eliminates the need for conventional pretreatment filtration. The Doheny study further demonstrated that the use of subsurface intakes – and the avoidance of full pretreatment – resulted in significant cost savings, including $56 million in capital costs and $1 million annually in O&M costs. And finally, the Doheny study determined that the Doheny project using subsurface intakes would produce water for $600 per AF cheaper than that of the Poseidon-Huntington Beach open ocean intake proposal.

The intentional omission of pretreatment considerations in the ISTAP Phase 2 Report, and the requirement to include them expressly stated in the Ocean Plan Amendment, renders the ISTAP Phase 2 report inadequate for granting an exception to the stated preference for subsurface intakes.

**CONCLUSION**

It is clear in the Ocean Plan Amendment that before the Regional Water Board can consider an exemption to the preference for subsurface intakes, there must be a thorough consideration of life-cycle costs. Further, as documented in the Ocean Plan Amendment SED, it is clear that there are significant life-cycle cost savings from the use of subsurface intakes, as well as avoided discharges of chemicals from the use of conventional pretreatment.[27]

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[22] *Id*.
[23] *Id* at 42.
[24] *Id*.
[25] *Id*.
[26] *Id* at 43.
[27] *Supra* Note 6 at 64; Pacific Institute. 2013a. Key Issues in Seawater Desalination in California: Marine Impacts; National Research Council (NRC). 2008. Desalination: A National Perspective. Washington, DC: The National Academic Press; Bartak, R., T. Grischek, K. Ghodeif and C. Ray. 2012. Beach Sand Filtration as Pre-Treatment for RO Desalination. International Journal of Water Sciences; San Diego Water Authority Camp Pendleton. December 2009. Seawater Desalination Project Feasibility Study Report Executive Summary.

The Regional Water Board cannot rely on the ISTAP conclusions that subsurface intakes are not feasible because the ISTAP never considered the cost savings of slant wells from avoiding the construction and operating costs of full conventional pretreatment required for surface intakes. As compared to open ocean intakes with screens, the use of subsurface intakes likely improves water quality, increases operational reliability, reduces the pretreatment train complexity, and reduces operating costs. The ISTAP failed to consider life-cycle costs of subsurface intakes where studies show significant cost saving over operating periods of 10 to 30 years. While the benefits and costs of using subsurface intakes may be site-specific, the Doheny study demonstrates that subsurface intakes in Huntington may not require full conventional pretreatment, have cheaper life-cycle costs compared to open ocean intakes, and that subsurface intakes may produce water cheaper than the proposed Poseidon-Huntington Beach proposal. The ISTAP Report fails to factor any of this critical information into their economic feasibility analysis because of an intentional decision not to consider pre-treatment, membrane system and discharge components of the proposal – all of which are critical considerations of life-cycle costs.

**FLAWED RELIABILITY PREMIUM**

**SUMMARY**

The Regional Water Board needs to determine whether the Independent Scientific Technical Advisory Panel (ISTAP) reports are an adequate justification for allowing Poseidon an exemption to the regulatory preference to use subsurface intakes. The economic analysis of the "reliability premium" in the ISTAP report fails to adequately describe the risk of water shortage, the economic cost of mitigating the risk, and the alternatives for risk mitigation. Further, the ISTAP reports failed to document and analyze the quality of risk mitigation given Metropolitan Water District's (MWD) "allocation formula."

The perceived risk is a function of the intermittent shortages of available imported water to supplement Orange County Water District's (OCWD) basin recharge programs. But the proposed "reliability premium" from the Poseidon proposal is a constant cost in a "take or pay" contract, regardless of intermittent allocations of imported water during times of limited availability. Further, an economic analysis of a particular project should compare marginal costs and benefits of the project to the marginal cost and benefits of alternatives.

ISTAP and OCWD should not have simply accepted the higher cost of the proposed project's product water and characterized the excess cost to consumers of the melded rate increase as a "reliability premium." ISTAP should have factored in the variables below.

**RISK**

As part of the economic analysis of the "risk premium", ISTAP should have more thoroughly considered the nature of the risk. For example, in Attachment One, the Swan presentation assumes the risk of water shortages is primarily a function of interruptions to imported water deliveries from MWD to help replenish the basin – what is called a MWD "period of allocation."[1]

The Swan presentation used a conservative assumption, based on the historical record, that MWD will allocate deliveries based on interruptions to imported water deliveries 2 out of every 10 years.[2] That means that in 8 out of 10 years, the assumption is that there will ample imported water available to meet the demands of OCWD to safely maintain reliable levels in the basin. But, for the project to mitigate the risk of shortages, it is assumed the 50,000 ac/ft/yr from the project will make up the difference in the 2 years of allocation every 10 years. In short, ISTAP failed to consider what Swan rightly characterized as a risk of interrupted imported water deliveries occurring 2 out of 10 years, with a project that charged a "risk premium" for every year regardless of the reasonably foreseeable intermittent risk.

**COST OF RISK MITIGATION**

Swan then calculated the marginal cost of reliability as 8 years of unnecessary purchases of 50,000 ac/ft of the project water, minus the cost of un-purchased imported water from MWD:

8 years * 50,000 * (2200 – 800) = $560 million.

If you apply that to the 2 years of interruption (divide total by 2), the risk premium is calculated at:

$280,000,00 / 50,000 & $2200 = $7800 ac/ft.[3]

[1] *See* Attachment Three: Peer Swan Presentation.
[2] *Id* at Slide 10.
[3] *Id* at Slide 11.

Regardless of whether Swan's numbers are precise for this circumstance, ISTAP failed to use any assumptions and calculations to monetize the "reliability premium." Instead, the panel simply relied on OCWD's stated willingness to pay the difference between what imported water costs and the negotiated cost of Poseidon's product water in a "take or pay" contract. In short, ISTAP failed to offer any meaningful context or analysis of the marginal cost of a "risk premium" from purchasing water from the proposed project.

**VALUE OF RISK MITIGATION**

Importantly, MWD applies an "allocation formula" to each of the member agencies during interruptions in deliveries of imported water. The policy behind the formula is an attempt to disperse risks in a manner that reflects a member agency's reliance on MWD deliveries. Simply put, the more a member agency relies on MWD deliveries (the greater the proportion of the supply portfolio), the lower a percentage of reduced deliveries during an allocation period.

As shown in a presentation by Municipal Water District of Orange County (MWDOC) staff, the "allocation formula" results in a smaller amount of imported water delivered to Orange County during a shortage if the region is less dependent on MWD deliveries after inclusion of the Poseidon water in the portfolio.[4] While the MWD "allocation formula" is somewhat complicated and dependent on real-life variables, the MWDOC report summarizes the impact of the formula on "reliability" as: *"The average person might expect OC to be more reliable by 56,000 AF per year with the Poseidon Project. This is not the case under either of these definitions."*[5] But the ISTAP report failed to consider the actual value of paying for 56,000 ac/ft/yr of Poseidon water as risk mitigation, given that inclusion of the water into the local portfolio will reduce imported water available to local agencies from MWD during periods of interruptions.

**BEST-FIT ALTERNATIVES**

The ISTAP reports failed to compare the "reliability premium" of water purchased from Poseidon to water management and/or supply augmentation alternatives.

ISTAP should have started with an examination of the "elasticity" of water demand. Some water consumption is necessary for people to stay alive – a perfectly "inelastic" demand. But some customers may use water to wash dirt from the street in front of their house – an arguably low-value and extremely "elastic" demand. Conserving water by eliminating low-value uses, either through regulation or by customer response to higher prices, is an important alternative to current usage and must be factored into the consideration of a reasonable "reliability premium." If consumers were compelled to use less water, they would likely eliminate the low value uses and the "reliability premium" would decrease to a better benefit-cost fit. On the other hand, if consumers conserve in response to the higher price of the Poseidon project's "reliability premium", there is either a risk of "stranding the asset" and/or otherwise not maximizing the benefit-cost fit.

Even assuming demand would remain constant, or even increase with the introduction of supply, there are alternatives to increasing reliability in the local supply portfolio that must be considered in an economic analysis. In brief, economists must answer the question: "Is it a prudent investment – compared to what?"

As noted in the most recent MWDOC Urban Water Management Plan and Reliability Study, there are several projects in planning that may offer similar or better reliability in the region at a lower reliability premium. For example, the Carson Wastewater Recycling Project, a partnership between MWD and LA County Sanitation District, may deliver 65,000 ac/ft/yr for injection into the Orange County basin at the same price as imported water – the volume of reliable water would be greater than the proposed Poseidon project and the "reliability premium" would be zero. It is unclear what this alternative would mean to the portfolio when the MWD

[4] *See* Attachment 4: Robert Hunter, Municipal Water District of Orange County, Reliability Benefits in OC from the Poseidon Project: P&O Committee presentation at page 3.
[5] *Id* at page 4.

"allocation formula" is applied, but it would certainly be a preferable economic alternative compared to the proposed Poseidon alternative.

Swan also suggests groundwater management changes that could provide the same reliability as the Poseidon project, but at a much lower cost. These alternatives would seem to avoid the complications and limited local benefits of increased reliability inherent in the MWD allocation formula. Swan suggests purchasing more "untreated" water from MWD when it is readily available and storing it in the basin to ensure ample supply during interruptions to MWD supplies.[6] Of course, there is a risk of purchasing that additional water only to discover that the basin may have recharged through natural rainfall – something akin to purchasing auto insurance and never needing it. Another method would be to have OCWD member agencies purchase "treated water" in lieu of pumping their allotment from the basin – again, allowing the basin to recharge during times when imported water is readily available, and storing that water for times of interruptions to imported water deliveries.[7] Again, there are risks and costs associated with that management change.

ISTAP erred in simply assuming that because OCWD Board members signaled a willingness to pay excess costs for Poseidon water, it is an economically valid "reliability premium." Economics is fundamentally about choices and maximizing efficiency in the allocation of scarce resources. Therefore, an economic analysis must consider alternatives before concluding what is or is not feasible.

**CONCLUSION**

The question presented is whether the ISTAP reports are an adequate justification for allowing Poseidon an exemption to the regulatory preference to use subsurface intakes. The ISTAP report's economic analysis of the "reliability premium" fails to adequately describe the risk of water shortage, the economic cost of mitigating the risk, and the alternatives for risk mitigation. Without these considerations adequately analyzed, the ISTAP reports did not provide the necessary background for analyzing the feasibility of the Poseidon project either with or without subsurface intakes.

[6] *Supra* Note 1, Swan at Slide 12.
[7] *Id* at 13.

## COST OF SLANT WELLS

**SUMMARY**

The Regional Water Board needs to determine whether slant wells are economically feasible as defined by the Desalination Ocean Plan. Due to the ISTAP's determination that slant wells were not technically feasible, the ISTAP did not perform an economic analysis of whether slant wells are economically feasible. The Regional Board cannot rely upon the ISTAP's determination that slant wells are infeasible because it incorrectly dismissed slant wells as technically infeasible, and because a proper economic feasibility analysis was never conducted.

Before the Regional Board can approve an exemption to the Ocean Plan's preference for subsurface intakes to minimize the intake and mortality of marine life, an independent analysis of whether slant wells are feasible under the Ocean Plan Amendment is necessary.

Below we use real world slant well cost estimates to demonstrate the significant cost savings of constructing and operating slant wells as compared to the infiltration galleries. The existing slant well cost estimates demonstrate that slant well construction cost about $120 to $150 million per MGD as compared to the ISTAP's cost estimate for infiltration galleries at $1,000 to $15,000 million per MGD. The Cal Am cost estimate also demonstrates that economies of scale may provide additional unit cost savings from higher production capacity.

**CONSTRUCTION COSTS**

Estimating the cost of developing slant wells is arguably a site-specific task. The cost of mitigating for freshwater drawdown, contaminated water, and potential well performance varies by site characteristics. However, developing slant wells is clearly a lower cost alternative compared to the estimates for developing a SIG in the ISTAP Phase 2 report. Therefore, the ISTAP conclusion that subsurface intakes are not economically feasible is inadequate for an exemption to the Ocean Plan's preference for subsurface intakes.

First, a report on the feasibility of slant wells for the proposed Doheny project was finalized in January 2014.[1] The proposal was a facility producing 15mgd of potable water based on a 30mgd withdrawal of source water through slant wells. The estimated cost of constructing the intake and raw water conveyance system was $44,759,000.[2] For purposes of rough cost comparisons, that cost estimate is approximately $1.5 million for each million gallons per day (mgd) of water withdrawn. Extrapolating that cost estimate to the proposed 100mgd intake for the Poseidon project results in an estimated construction cost of $150 million.

Second, cost estimates for developing slant wells for Monterey-CalAm project were prepared in 2015.[3] The winning bid estimated the cost of constructing slant wells at a lower per unit cost than the Doheny estimate:

[1] *See* Municipal Water District of Orange County, Final Summary Report Doheny Ocean Desalination Project Phase 3 Investigation (January 2014).
[2] *Id* at 33.
[3] *See* Monterey Peninsula Water Supply Project website: https://www.watersupplyproject.org/about1.

| No. of Wells | Total Well Production Capacity (MGD) | Well Construction[4] | Design and Construction Management[5] | Wellhead Completion and Equipping[6] | Total | Cost Per Well | $/MGD of Intake Capacity |
|---|---|---|---|---|---|---|---|
| 7 | 22.2 | $ 19,424,000 | $ 2,136,640 | $ 5,250,000 | $ 26,810,640 | $ 3,830,091 | $ 1,208,994 |
| 9 | 28.5 | $ 24,746,000 | $ 2,227,140 | $ 6,750,000 | $ 33,723,140 | $ 3,747,016 | $ 1,182,770 |

This cost estimate of approximately $1.2 million per million gallon of intake volume is marginally lower than the Doheny per unit cost estimate for constructing slant wells. Also, importantly, this bid shows that there are potential "scale economies" for drilling more wells at a site to withdraw increased volumes.

Regardless of which estimate for slant well construction (Doheny or Monterey), the cost is a small fraction of the ISTAP cost estimate of $1 billion to $1.5 billion for constructing galleries. While a site-specific analysis is required, a rough estimate for developing slant wells for a 100 MGD withdrawal and conveyance to the treatment plant would be in the range of $118,277,000 (CalAm 1MGD estimate times 100) to approximately $150,000,000 (approximate Doheny 1MGD estimate times 100). While these are admittedly rough estimates, and actual cost estimates and any economies of scale would be site-specific, the ISTAP Phase 2 report is void of any cost and economic analysis of a system of slant wells compared to a seawater infiltration gallery and/or the proposed addition of screens to the existing open ocean intake.

In conclusion, the ISTAP Phase 1 report erred in concluding slant wells were not technically feasible. This in turn resulted in an inadequate analysis of all available subsurface intakes for economic feasibility. Therefore, the implication that all subsurface intakes are not economically feasible is inadequate as evidence that the Poseidon proposal should be exempted from the stated regulatory preference mandating subsurface intakes to minimize the intake and mortality of marine life.

**AVOIDED COSTS OF SLANT WELLS COMPARED TO SCREENED OPEN OCEAN INTAKES**

Studies show that slant wells may have significant life-cycle cost savings compared to open ocean intakes.[7] For example, there are cost savings from eliminating the need to construct full conventional pre-treatment required for open ocean intakes, as well as operation and maintenance cost savings from not including full conventional pre-treatment.[8] For example, the Doheny report estimated that annual savings from operation and maintenance costs by avoiding the need for full conventional pretreatment were approximately $1 million for a 30mgd intake system. Arguably, the annual savings from avoided operation and maintenance costs for the proposed Huntington-Poseidon project would be approximately 3 times the savings for the proposed Doheny facility.

However, slant wells may have additional operating costs. For example, if the slant wells withdraw some inland freshwater, that adds to the unit cost of the product water to replace the lost freshwater. Further, there may be costs for mitigating the risk of source water contamination and/or partial well failures to produce the intended volume of 100mgd intake. These potential additional costs need to be identified and included in the economic feasibility analysis.

[4] From Boart Longear Bids on Monterey.
[5] Estimate Based on Monterey Test Well Costs.
[6] Estimate Based on Monterey Test Well Costs.
[7] State Water Resources Control Board, Final Staff Report Including the Final Substitute Environmental Documentation, Pg. 51 (May 6, 2015); *available at* https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2015/rs2015_0033_sr_apx.pdf; National Research Council (NRC). 2008. Desalination: A National Perspective. Washington, DC: The National Academic Press; San Diego Water Authority Camp Pendleton. December 2009. Seawater Desalination Project Feasibility Study Report Executive Summary.
[8] *Ibid.*

In conclusion, the ISTAP Phase One report erred in excluding slant wells as technically infeasible, and the ISTAP Phase 2 findings compounded the error by failing to consider all the associated costs and cost savings from constructing and operating slant wells.

**AVOIDED RISKS**

Scientific papers recognized in the Ocean Plan Amendment SED found that subsurface intakes have a benefit of eliminating risks of damage to the RO treatment train and/or the risk of having to shut down the plant during natural occurrences like algal blooms.[9] And experience with unplanned shut-downs at the recently opened Carlsbad-Poseidon facility shows the papers' analysis of risks from using open ocean intakes are valid and have been confirmed in Southern California.

Again, because the ISTAP Phase One report erred in excluding slant wells from further consideration, the ISTAP Phase Two report failed to document the reliability benefits of subsurface intakes protecting against unplanned shutdowns of the project. This is a critical omission given that the economic feasibility of the project itself is dependent on showing a rationale for the so-called "reliability premium." That is, arguably, paying the "reliability premium" is only a sound economic choice if the project actually produces the reliability it claims – so the added benefit of insurance against plant shutdowns provided by slant wells, especially during times when imported water is in short supply, is an important consideration in determining whether or not a project is economically feasible.

**CONCLUSION**

The questions presented are whether slant wells are economically feasible as defined by the Desalination Ocean Plan. The ISTAP did not perform an economic analysis of whether slant wells are economically feasible. The Regional Board cannot rely upon the ISTAP's determination that slant wells are infeasible because it incorrectly dismissed slant wells as technically infeasible, and because a proper economic feasibility analysis was never conducted.

Real world cost estimates demonstrate the significant cost savings of constructing and operating slant wells as compared to infiltration galleries. The existing slant well cost estimates demonstrate that slant wells cost about $120 to $150 million per MGD as compared to the ISTAP's cost estimate for infiltration galleries at $1,000 to $15,000 million per MGD. The Cal Am cost estimates also demonstrates that economies of scale provide additional cost savings from higher production capacity. The Regional Board must produce an independent new technical and economic feasibility study prior to considering an exemption to the Ocean Plan preference for subsurface intakes.

[9] See Ry Rivard, Desal Plant Is Producing Less Water Than Promised, Voice of San Diego (August 29, 2017); available at https://www.voiceofsandiego.org/topics/science-environment/desal-plant-producing-less-water-promised/; In April, for instance, the plant shut down for 15 days when an algal bloom along the coast soured the water. The plant was unable to treat any water without fouling up the expensive filters it uses to remove salt and other impurities from water; Loreen O.Villacorte et al., Seawater Reverse Osmosis Desalination and (Harmful) Algal Blooms, Elsevier, Volume 360, 16 March 2015, Pages 61-80; The potential issues in SWRO plants during HABs are particulate/organic fouling of pretreatment systems and biological fouling of RO membranes, mainly due to accumulation of algal organic matter (AOM).

# ATTACHMENT ONE

## Subsurface Intakes for Seawater Reverse Osmosis Facilities: Capacity Limitation, Water Quality Improvement, and Economics

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# Subsurface intakes for seawater reverse osmosis facilities: Capacity limitation, water quality improvement, and economics

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## HIGHLIGHTS

- The use of subsurface intake types for seawater RO facilities was documented.
- Feedwater quality improvements by using subsurface intakes were demonstrated.
- Reduced environmental impacts using subsurface intakes were discussed.
- Capacity limits on various subsurface intake types were assessed.
- Life-cycle cost savings using subsurface intakes were preliminarily analyzed.

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## ABSTRACT

The use of subsurface intake systems for seawater reverse osmosis (SWRO) desalination plants significantly improves raw water quality, reduces chemical usage and environmental impacts, decreases the carbon footprint, and reduces cost of treated water to consumers. These intakes include wells (vertical, angle, and radial type) and galleries, which can be located either on the beach or in the seabed. Subsurface intakes act both as intakes and as part of the pretreatment system by providing filtration and active biological treatment of the raw seawater. Recent investigations of the improvement in water quality made by subsurface intakes show lowering of the silt density index by 75 to 90%, removal of nearly all algae, removal of over 90% of bacteria, reduction in the concentrations of TOC and DOC, and virtual elimination of biopolymers and polysaccharides that cause organic biofouling of membranes. Economic analyses show that overall SWRO operating costs can be reduced by 5 to 30% by using subsurface intake systems. Although capital costs can be slightly to significantly higher compared to open-ocean intake system costs, a preliminary life-cycle cost analysis shows significant cost saving over operating periods of 10 to 30 years.



## 1. Introduction

Seawater desalination is an energy-intensive and costly means of treating water to potable standards and has some environmental impacts. With the development of advanced membrane technology and energy recovery systems, the energy consumption and cost of seawater desalination have been significantly reduced over the past several decades [1]. However, membrane fouling is still a major problem at most seawater reverse osmosis (SWRO) facilities, which reduces operational efficiency and the life-expectancy of the membranes [2]. Complex and expensive pretreatment processes are commonly required to reduce the rate of biofouling and the frequency of membrane cleaning (Fig. 1). Possible environmental impacts associated with conventional open-ocean intakes, such as impingement and entrainment of marine biota, can also create large permitting costs and construction delays [3,4]. There are also environmental impacts associated with the use of chemicals to keep the intakes and associated piping clean of organic growth, disposal of coagulants required in the pretreatment processes (e.g., ferric chloride), and disposal of macro-organic debris that accumulates on the traveling screens (seaweed, fish, jellyfish, etc.) and other parts of the pretreatment train [5].

Natural seawater contains a variety of macro- and micro-organic components that affect the treatment process [6]. Open-ocean intakes are seasonally clogged in some regions by seaweed [7] and some pretreatment systems are periodically fouled by influx of jellyfish. Also, natural environmental events, such as harmful algal blooms and red tides, can overwhelm pretreatment systems and cause temporary shut-downs of SWRO plants [8,9]. Improvements in the raw water quality can lead to reduction in the complexity of pretreatment systems,

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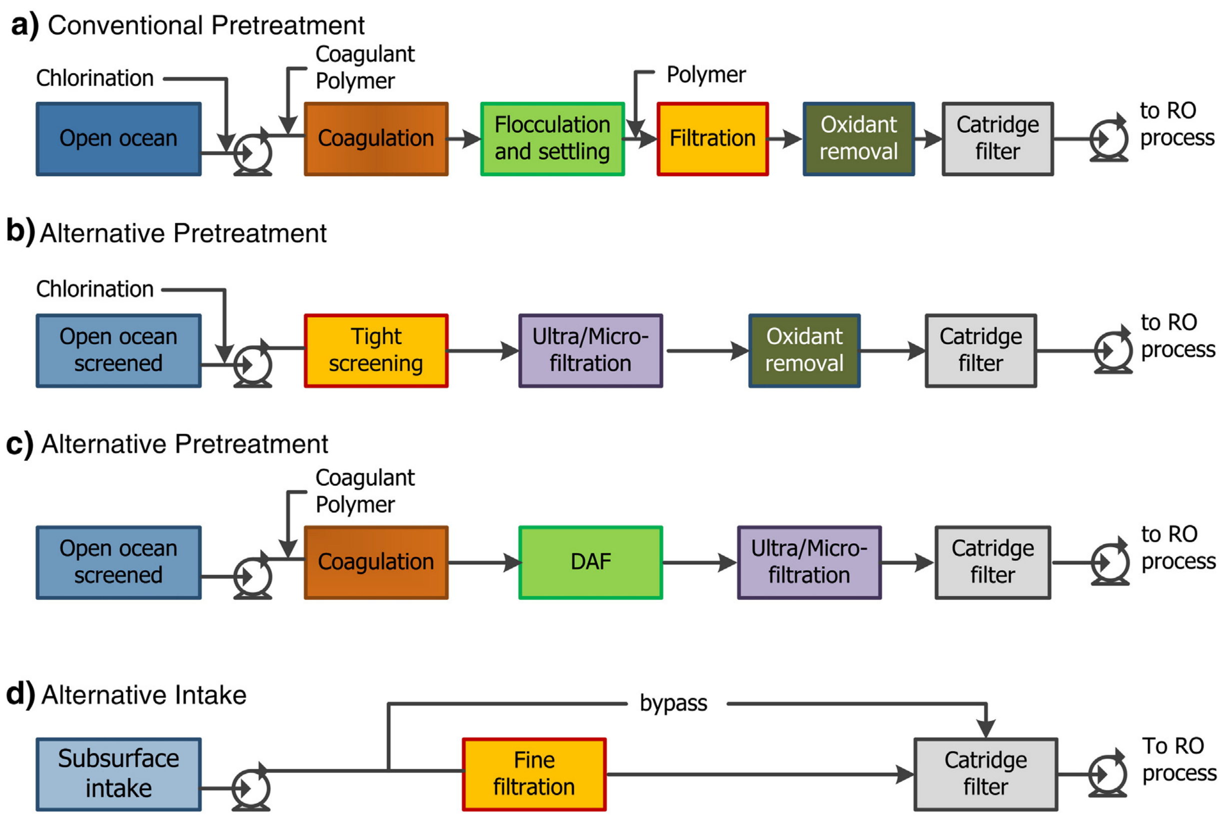


**Fig. 1.** Diagram showing typical pretreatment process trains for a SWRO plant (a, b, c) with the desired simplified system using a subsurface intake (d). A subsurface intake may be any to produce feedwater that can bypass the pretreatment system and flow directly to the cartridge filters.

thereby reducing the need for physical cleaning and amount of chemicals used, and increasing the operational reliability of facilities (e.g., avoid loss of production during algal blooms). Commonly, feeding higher quality raw water into the primary membrane process leads to a reduction in the rate of organic biofouling, reduced capital cost for construction of pretreatment processes, and reduced operating costs for maintenance, chemical use, and accessory operations. A key issue is how to improve the quality of the feedwater and, as a result, decrease the life-cycle cost of desalination or total cost per unit volume of product water.

The use of subsurface intake systems is one method to improve water quality, to increase operational reliability, to reduce the pretreatment train complexity, and to reduce operating costs [10,11]. Subsurface intake systems use the natural geological properties of sediments and rocks to strain and biologically remove organic matter, suspended sediment, and dissolved organic compounds before they enter the treatment processes [11]. Most of the subsurface processes function in a similar manner to river bank filtration (RBF) or bank filtration systems used to treat freshwaters in Europe and the United States for over a century [12,13]. Investigations of RBF systems have conclusively demonstrated that they are very effective in reduction or elimination of pathogens in the filtered water [14–18] and also reduce the concentration of suspended solids and organic matter entering the primary treatment processes [19]. RBF systems have also been effective at reducing algal toxin concentrations [20]. In Europe, RBF commonly is the primary treatment for many potable water systems with little or no subsequent additional treatment.

There are a number of different types of subsurface filtration systems that can be used depending upon the local geology and environmental conditions. Subsurface intake types can be grouped into two categories which include wells and galleries [11]. Wells can be subdivided into conventional vertical wells, horizontal wells or drains, angle/slant wells, and Ranney wells or collectors. Gallery-type intakes include seabed filters or galleries and beach galleries. It is the purpose of this paper to thoroughly review these subsurface intake types in terms of feasibility, design, function, and applicability to various capacity seawater desalination facilities and include an overview of facility economics.

## 2. Materials and methods

A general survey was conducted of SWRO plants located globally to ascertain the types and capacities of subsurface intake systems currently being used. Information was obtained from databases, books, and peer-reviewed publications on desalination. Design information was also collected on construction methods, materials, and pump types. At locations where the facility operators could be contacted, data were collected on the raw seawater, the inflow stream before pre-treatment, and after pretreatment. Information was obtained on the degree of membrane fouling experienced and on the frequency of cleaning required at the plant.

Water quality data were also collected from the literature and from some field surveys to assess the impact of subsurface intakes on removal of algae, bacteria, and organic compounds that tend to produce biofouling of membranes. These data were compiled to assess the effectiveness of subsurface intakes on improving overall feedwater quality.

## 3. Results

### *3.1. Feasibility of subsurface intakes under various natural geological conditions*

Local hydrogeological conditions and the proposed capacity of SWRO plants control the feasibility of subsurface intakes and the specific choice concerning the type of system that best matches the facility requirements [10,11]. Many locations worldwide have local hydrogeological conditions sufficient to develop one or more different types of subsurface intakes while other locations do not have subsurface intake feasibility. A key issue is the pre-design technical assessment of the hydrogeological conditions before the facility design and bid process begin [10,11,21–26]. The pre-design geological and geotechnical investigations should be phased with a preliminary investigation scope developed to assess "fatal flaws" that would eliminate the use of any subsurface intake type and a primary investigation that would provide sufficient data upon which to base at least a preliminary design. In most cases the failure to conduct these investigations would effectively eliminate the use of a subsurface design in the bid process because of the perceived risk factor. The scope of the primary investigation should be developed within the preliminary study report and should contain a minimum amount of field data collection, some groundwater modeling assessment, and some preliminary economic assessments (Table 1). Should a subsurface intake be deemed to be infeasible, then the need for the primary investigation would be eliminated with associated savings in project cost.

There are some general coastal and nearshore characteristics that tend to favor the feasibility of subsurface intake development. The occurrence of permeable rock adjacent to the shoreline is a good indication that a subsurface intake may be feasible. Coastal carbonate aquifers (limestones and/or dolomites) have been commonly used for feedwater supply systems [27,28] (Fig. 2a). Coastal regions underlain by thick deposits of permeable sand, gravel, or a combination of these lithologies also have a high probability of successful development. Sandy beaches that are relatively stable and have adequate wave activity also have a good probability of being useful (Fig. 2b). Unvegetated offshore marine bottom areas that contain quartz or carbonate sands with a low percentage of mud are also acceptable for the development of subsurface intake systems provided that they are not environmentally sensitive (e.g., coral reefs or important marine grass beds are not present) (Fig. 2c). Areas having a high-energy, rocky shoreline containing low permeability rocks are likely not feasible. Low-energy shorelines with associated high-mud content in offshore sediments are also not likely to be feasible.

**Table 1**
Scope of preliminary and permitting investigations for subsurface intake feasibility to be provided to project bidders.

| Regional investigation of coastal characteristics |
|---|
| 1. Provide a detailed description of site for the desalination facility and coastal areas available for development of a subsurface intake system |
| 2. Provide historical aerial photographs of the shoreline to assess shoreline stability |
| 3. Provide geologic maps of the coastal area under consideration |
| 4. Provide a copy of any oceanographic investigations conducted for permitting |
| 5. Provide a bathymetric map of the offshore area adjacent to the coastal area of interest |
| 6. Provide bidders with the overall coastal conditions package and give them a maximum distance from the plant in which they could develop a subsurface intake system |
| **Site-specific investigation of surface and subsurface conditions** |
| 1. Drill test borings on the beach area at the proposed intake site |
| 2. Construct detailed geologic logs |
| 3. Collect sand samples from the beach and have the grain size distribution of the samples analyzed |
| 4. Construct at least one observation well in any aquifer found to have high hydraulic conductivity, collect a water sample, and provide a chemical analysis of the inorganic chemistry, including analyses of all major cations and anions with alkalinity, hardness silica, strontium, barium, boron, arsenic, and any trace metals of concern (with some organic analyses such as TOC, DOC, TEP, biopolymers, and others) |
| 5. Optional — if an aquifer is found in the test drilling that has a possibility of producing the desired quantity of water, an aquifer performance test should be conducted to measure aquifer hydraulic coefficients. |
| 6. For gallery type intakes — obtain sediment samples from the beach offshore to a distance of up to 500 m and a water depth up to 10 m and have the samples analyzed for grain size properties and hydraulic properties. The sample grid should contain the entire area in which the galleries would be constructed and perhaps some additional areas from which sediment could be transported. |
| 7. Produce a site-specific report containing the test data and any potential recommendations for subsurface intake feasibility. |


**Fig. 2.** Typical coastal characteristics acceptable for the use of subsurface intake systems, a. Limestone shoreline at Sur, Oman, that has a high productivity limestone aquifer, b. Sandy beach in the northern Red Sea Coastline of Saudi Arabia which could support a number of subsurface intake types based on lithology, geology, and wave action, c. Shallow limestone and clean sand area of the Red Sea that could be used for seabed gallery development.

## 3.2. Well systems

### 3.2.1. Conventional vertical wells

There are many different types of wells that can be designed and constructed to provide feedwater [11]. The term "beach well" is commonly used to describe the most common type of subsurface intake, but this term is a misnomer that applies to only one class of wells that are directly recharged by seawater close to the beach area. Many well systems used to supply SWRO facilities are located inland away from beaches or even in interior areas of continents where high salinity waters occur at great distance from the sea or in deep regional aquifer systems that contain seawater (Fig. 3) (e.g., New Providence Island systems, Bahamas, the Bolson Aquifer of New Mexico).

The site geology must be adequate to allow individual well yields to be high enough so that the number of production wells needed to meet the required raw water supply is reasonable or cost-competitive with other supply options. In some cases the aquifer hydraulic conductivity found during a preliminary site investigation is insufficient to produce the necessary well yield requirements based on the site size or overall economic considerations. The type and design of a well system should be coordinated with the local hydrogeology and the required capacity needed to supply the facility. Key issues include maximization of the efficiency to withdraw water while meeting the plant capacity requirements as well as improving water quality. The well yields should be designed to match the plant design configuration (e.g., one well per train or two wells per train). Well intake system should have some reserve or emergency standby capacity to meet demands caused by pump failures or scheduled maintenance.

Well intake systems have been successfully used at hundreds of SWRO facilities worldwide with capacities up to 160,000 $m^3$/d (Table 2). Well intake systems have proven to be a reliable means of providing feedwater with positive impacts on water quality [27–35]. A key issue when a well system is contemplated is to obtain sufficient hydrogeologic information to predict well yields and to reduce operational risk to the facility operator [36]. Technical evaluation methods have been used that allow local groundwater system hydraulics to be evaluated prior to construction with positive operational experience as a result [37]. Well design and construction should follow industry standards with strong consideration of materials because of the highly corrosive nature of seawater (non-metallic casings and conveyance pipe should be used) [38].

Comparative analyses of seawater quality between open-ocean intakes and wells show that well intakes produce significantly lower concentrations of particulate matter, algae, bacteria, and organic compounds that promote membrane biofouling [39–46] (Table 3). While conventional vertical wells do significantly reduce organic carbon and bacterial concentrations, care must be taken to maintain the wells to avoid bacterial growth within the wellbore and periodic disinfection of the wells may be necessary to lower bacterial concentrations if regrowth occurs [47,48]. Based on operation of RBF systems, travel distance and residence time influence water quality changes. All conventional vertical wells used for SWRO intakes will require periodic maintenance to remove any buildup of calcium carbonate scale or a biofilm on the "skin" of the well in open-hole designs or the well screens.

The location of true beach wells is important because they must be recharged primarily by direct recharge with seawater or otherwise seaward movement of freshwater could occur. Induced seaward movement of water has been known to draw contaminated groundwater or water

**Table 2**
Selected seawater RO facilities using well intake systems.

| Facility name | Location | Capacity[1] ($m^3$/d) | No. of wells |
|---|---|---|---|
| Sur | Oman | 160,000 | 28 |
| Alicante (combined for two facilities) | Spain | 130,000 | 30 |
| Tordera | Blanes, Spain | 128,000 | 10 |
| Pembroke | Malta | 120,000 | – |
| Bajo Almanzora | Almeria, Spain | 120,000 | 14 |
| Bay of Palma | Mallorca, Spain | 89,600 | 16 |
| WEB | Aruba | 80,000 | 10 |
| Lanzarote IV | Canary Islands, Spain | 60,000 | 11 |
| Sureste | Canary Islands, Spain | 60,000 | – |
| Blue Hills | New Providence I., Bahamas | 54,600 | 12 (?) |
| Santa Cruz de Tenerife | Canary Islands, Spain | 50,000 | 8 |
| Ghar Lapsi | Malta | 45,000 | 18 |
| Cirkewwa | Malta | 42,000 | – |
| CR Aguilas, Murcia | Spain | 41,600 | – |
| SAWACO | Jeddah, Saudi Arabia | 31,250 | 10 |
| Dahab | Red Sea, Egypt | 25,000 | 15 |
| Turks & Caicos Water Company | Providenciales, Turks & Caicos Islands | 23,260 | 6 |
| Windsor Field | Bahamas | 20,000 | – |
| North Side Water Works | Grand Cayman | 18,000 | – |
| Ibiza | Spain | 15,000 | 8 |
| North Sound | Grand Cayman | 12,000 | – |
| Red Gate | Grand Cayman | 10,000 | – |
| Abel Castillo | Grand Cayman | 9000 | – |
| Al-Birk | Saudi Arabia | 5100–8700 | 3 |
| Lower Valley | Grand Cayman | 8000 | 3 |
| West Bay | Grand Cayman | 7000 | – |
| Britannia | Grand Cayman | 5400 | 4 |
| Bar Bay | Tortola, B.V.I. | 5400 | – |
| Morro Bay | California, USA | 4500 | 5 |
| Ambergris Caye | Belize | 3600 | – |

[1] Capacity is for the well intake (approximated based on published reports or estimated based on the reported capacity of the plant divided by the reported recovery rate or a maximum of a 50% recovery rate where it is not reported).

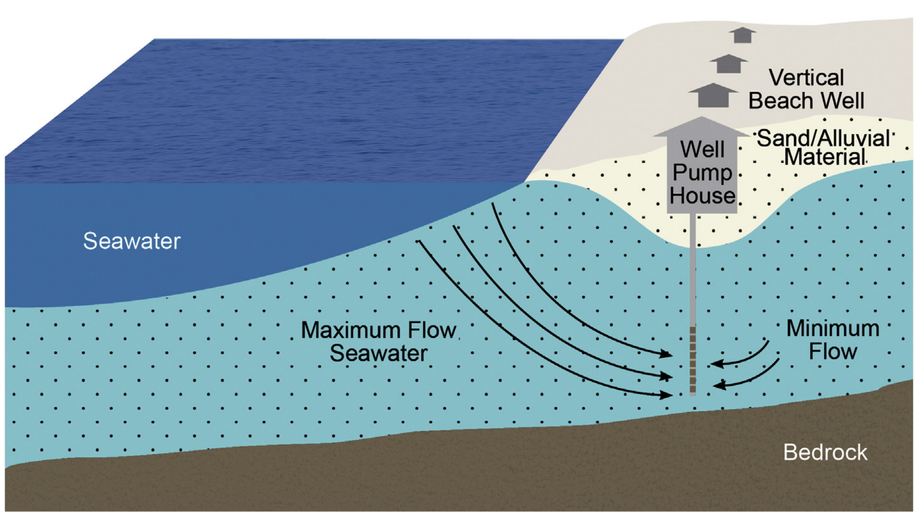


**Fig. 3.** Well intake system located along a shoreline. This is truly a "beach well" system that promotes direct recharge from the sea and minimizes capture of landward water resources. Minimal flow should come from the shoreline direction to avoid aquifer impacts and entry of poor quality water.

**Table 3**
Comparison between bacteria, algae, organic carbon compound concentrations in natural seawater verses well intakes from select sites.

| Location | Parameter | Seawater | Well 1 | Well 2 | Well 3 | Well 4 |
|---|---|---|---|---|---|---|
| Dahab, Egypt [40] | DOC (mg/L) | 1.6 | 1.2 | 2.3 | 0.6 | 0.8 |
| | UV-254 ($m^{-1}$) | 1.4 | 0.8 | 0.9 | 0.8 | 0.6 |
| Fuerteventura Island, Spain [41] | TOC (mg/l) | 0.5 | 0.7 | | | |
| | UV-254 ($m^{-1}$) | 0.36 | 0.55 | | | |
| | Phytoplancton, cell/L | 57,720 | 0 | | | |
| Al-Birk, Saudi Arabia [42] | Dissolved protein (mg/L) | 2.73 ± 0.78 | 0.75 ± 0.08 | ND | ND | |
| | Dissolved carbohydrates (mg/L) | 1.57 ± 0.23 | 0.52 ± 0.15 | 0.77 ± 0.10 | 0.50 ± 0.14 | |
| SWCC Al-Jubail test sites [43] | TOC (mg/L) | 2 | 1.2–2 | | | |
| | Bacteria (CFU/mL), 0, 24, and 72 h | $1.8 \times 10^3$ | $1.3 \times 10^3$ | | | |
| | | $1.1 \times 10^5$ | $3.3 \times 10^5$ | | | |
| | | $5.6 \times 10^4$ | $4.0 \times 10^6$ | | | |
| Dahab beach well system, Egypt [44] | DOC (mg/L) | 1.6 | 1.2 | 2.3 | 0.6 | 0.8 |
| | UV-254 ($m^{-1}$) | 1.4 | 0.8 | 0.9 | 0.8 | 0.6 |
| Mediterranean location-spring [45] | Total picophyto-plankton (cells/mL) | $1.6 \times 10^3$ | $1.3 \times 10^2$ | | | |
| | *Synechococcus* (cells/mL) | $1.3 \times 10^3$ | $1.0 \times 10^2$ | | | |
| | Picoeukaryote (cells/mL) | $1.1 \times 10^3$ | $1.9 \times 10^1$ | | | |
| | Nanoeukaryote (cells/mL) | $1.2 \times 10^2$ | $1.7 \times 10^0$ | | | |
| Site 1 [46] | TOC (mg/L) | 1.2 | 0.9 | | | |
| | Polysaccharides (mg/L) | 0.12 | 0.01 | | | |
| | Humic substances + building blocks (mg/L) | 0.5 | 0.4 | | | |
| | Low-molar mass acids & neutrals (mg/L) | 0.25 | 0.16 | | | |
| | Low molar mass compounds (mg/L) | 0.33 | 0.29 | | | |
| Site 2 [46] | TOC (mg/L) | 0.9 | 0.6 | | | |
| | Polysaccharides (mg/L) | 0.4 | ND | | | |
| | Humic substances + building blocks (mg/L) | 0.26 | 0.16 | | | |
| | Low-molar mass acids & neutrals (mg/L) | 0.22 | 0.13 | | | |
| | Low molar mass compounds (mg/L) | 0.38 | 0.3 | | | |

with high concentrations of dissolved iron or manganese into beach wells (e.g., Morro Beach, California beach well system) [29]. High concentrations of dissolved iron or manganese, greater than those found in normal seawater, can create scaling problems in SWRO membranes. Wells located at significant distances from the shoreline can also cause adverse impacts to wetlands or produce water that has salinity higher than that in the adjacent sea (Flagler County, Florida) [49] or as in the case of Morro Beach, California can have high concentrations of dissolved iron or manganese that is common in the mixing zone between terrestrial freshwater aquifers and seawater.

While conventional wells can meet the feedwater requirements of small to intermediate capacity SWRO facilities, there is a limit on the use of wells for large-capacity facilities. When the number of wells and associated infrastructure is too large and costly, another intake system may be required. The issue of well pump replacement and maintenance, even with the use of special-order duplex stainless steel, is an important consideration because of the very corrosive nature of seawater. The ratio of well yield to overall feedwater requirement will dictate the feasibility of using wells as intakes. Also, the use of large numbers of beach wells can raise the issue of unacceptable aesthetic appearance which can adversely influence public opinion and make the permitting of well intakes difficult or impossible.

### 3.2.2. Angle wells

Angle wells can be drilled from a position near the shoreline with an extension under the seabed or close to it (Fig. 4). Angle-well intakes are currently being evaluated in field and general research investigations [50,51]. One advantage of using angle well technology is that the wells can be set back further from the shoreline compared to conventional vertical wells. This tends to induce primarily vertical recharge through the seabed, produces water that is stable and of similar quality to the seawater in the area, may have a lesser tendency

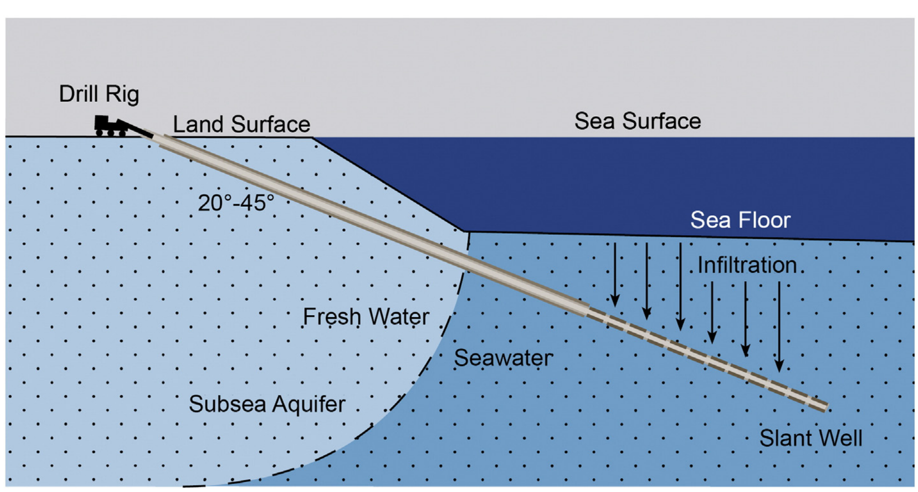


**Fig. 4.** Diagram showing an angle well intake system. Note that the recharge direction is vertical compared to the typical vertical well intake system and the issue of impacts to coastal aquifers can be avoided.

to induce landward to seaward flow that can cause water quality problems, and better protects pumps and associated infrastructure from storm damage. Also, several wells can be drilled from a single location to create clusters [50] (Fig. 4), thereby reducing the land area necessary for construction and infrastructure development.

Construction of angle wells is more complex compared to conventional vertical wells and requires the use of specialized equipment necessitating corresponding skilled operators. In coastal aquifers consisting of lithified rock, angle well construction is essentially no more complex than conventional well construction, but within unconsolidated sediments, dual-rotary drilling equipment may be required so that a filter pack can be installed with screens inside of a temporary steel casing that is subsequently withdrawn before well development [50]. The dual-rotary drilling method does have some limitations regarding the maximum length (or depth) of the well that can be constructed. This length is dependent on the geological materials penetrated and the diameter of the well. Within unlithified sediments it is likely a maximum of about 150 m for a casing diameter of 30.48 cm [50] or greater, but may be up to 400 m depending on the size of the rig and geologic conditions. Angle wells may also be more difficult to maintain, especially where specialized equipment is not locally available.

Although no large-scale seawater desalination facility currently utilizes an angle well intake system, several facilities are being evaluated in terms of feasibility [51]. It is likely that medium capacity SWRO facilities will be constructed using this type of well intake design. There will always be some limit on the overall yield of angle wells to meet very large-scale capacity SWRO facilities. Angle wells may have greater yields then vertical wells. However, a site-specific economic analysis is required to determine whether the potential greater yield per well (and thus less number of wells) offsets the greater construction and maintenance costs of angle wells.

### 3.2.3. Horizontal wells or drains

Horizontal well construction has rarely been used in the water industry, but has a variety of potential applications. A key issue is matching the technology to the specific geologic conditions at a given site to maximize the efficiency of withdrawal within the framework of the fundamental groundwater hydraulics. Most unlithified sediments are deposited in horizontal layers that make vertical wells very effective because the screens can be placed perpendicular to the bedding planes and tend to take advantage of the generally high horizontal to vertical ratio of hydraulic conductivity. If it is the purpose of a horizontal well to induce vertical flow, such as in the case of drilling beneath the seabed, then use of the technology does have the advantage of producing high yields per individual well. If the aquifer to be used is semi-confined or not well connected vertically to the overlying sea, then the wells may not be effective in producing high, sustainable yields. Also, great care must be taken in use of horizontal wells beneath the seafloor in terms of water quality because the well may pass through zones of sediments containing varying oxidation conditions along the axis of the well. Mixing of oxygenated seawater with anoxic seawater within the well, especially where hydrogen sulfide is present, can lead to the precipitation of elemental sulfur that would require removal before entry into the membrane treatment process. Also, the oxidation issue can also cause precipitation of ferric hydroxide or manganese dioxide. The configuration of using horizontal wells as intakes for SWRO plants appears to have considerable advantages [52].

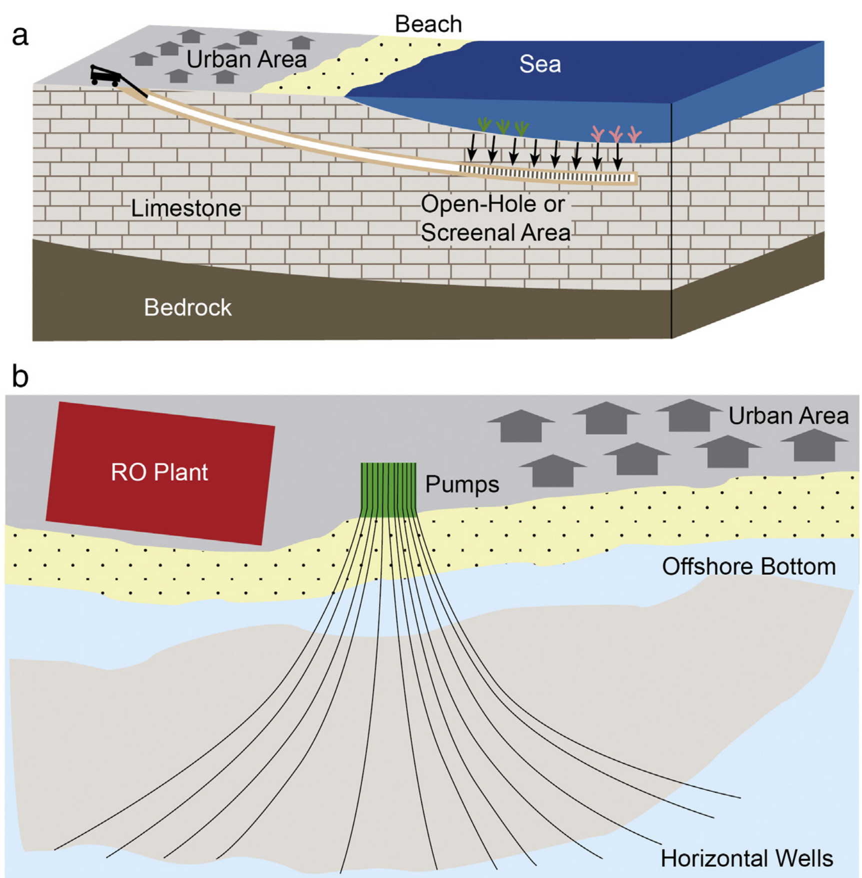


**Fig. 5.** Horizontal wells can be drilled from the shoreline using older mature technology or the Neodren™ system. a. General configuration of a horizontal system. b. Horizontal well systems can be configured to allow multiple wells to be drilled from a compact location, saving land cost and allowing pumps to be housed in a single building.

In recent years horizontal well intakes have been installed in several facilities in Spain with the highest capacity reported at 172,800 $m^3$/d [52–57] (Fig. 5a). The Neodren™ horizontal well system has been touted as being a state-of-the-art technology with potential widespread application [55]. Unfortunately, there have been few operating data reported from the larger capacity SWRO facilities currently using this intake type. Data on silt density index (SDI) for a Neodren™ system compared to multi-media filtration and ultrafiltration show a value of 5.1 compared to 3.4 and 3.2, respectively, on one system and 4.6 compared to 2.6 and 2.4, respectively, on another system with the locations of the systems not given [57]. Typical seawater SDI values commonly are greater than 10 (both $SDI_{10}$ and $SD_{I5}$), which suggest that the horizontal well system does improve water quality. However, no data on organic carbon or bacteria removal are presented in the literature touting this technology.

An issue requiring consideration in the selection of a horizontal well intake is the elimination of feasibility and operational risk. While the assessment of groundwater sources adjacent to the shoreline is rather well established, the hydrogeologic characterization of the offshore sub-bottom requires specialized equipment and methods which are expensive and may still leave questions that cannot be easily answered, such as on sub-bottom oxidation state of the water and horizontal geological variations that could reduce or eliminate productivity of the well(s). The drilling of test borings and obtaining accurate water quality samples can be difficult if not impossible under some conditions, where the offshore bottom slope is very steep or where wave action is intense, not allowing use of barge-mounted drilling equipment.

Another important issue concerning the long-term operation of any horizontal well system is the ability to adequately clean the well when it becomes partially clogged [11]. All well types require periodic maintenance and cleaning which can be easily accomplished in conventional vertical wells using weak acid and various redevelopment processes, such as air or water surging, sonic disaggregation and redevelopment, or some combination of processes depending on the nature of the clogging, such as calcium carbonate scaling, iron nodule precipitation, or biofouling [11,38]. Maintenance work on a horizontal well can be quite complex because of its long distance from the shoreline and the presence of screen in the well that could be damaged during maintenance due to the cleaning pipe traveling on the lower screen surface of the well.

In the event that all obstacles are resolved with construction and maintenance, the use of horizontal well technology has some compelling advantages. An array of horizontal wells can be drilled from a small construction footprint, as shown in Fig. 5b, which allows considerable savings for land acquisition and a single building can house the pumps and associated electrical equipment. Therefore, horizontal well technology should be evaluated if the geology is adequate to support the required well yields, the seafloor does not have a high rate of muddy sedimentation, and the technical and feasibility risks can be minimized. The potential yield of horizontal beds beneath the seabed can be virtually unlimited if the geology is compatible and the risks can be managed. Also, the need for specialized cleaning equipment is likely to be necessary which may not be available in many locations.

### 3.2.4. Radial collector wells or Ranney collectors

Radial collector wells are characterized by a central caisson typically having a 3 to 5 m diameter with a series of laterals which are screened to allow water flow to move into the caisson during pumping (Fig. 6). Radial wells are commonly used to provide large-capacity intake capability along rivers in parts of the United States and in some European locations [11,58–60]. Operational radial collector well capacities range from 380 to 51,400 $m^3$/d [59,60]. The only known operating collector well system used for a SWRO intake is located at the PEMEX Salina Cruz refinery in Mexico [26], which has three wells each with a capacity of 15,000 $m^3$/d.

The geologic conditions that favor a radial collector well design over a conventional or horizontal well design are the occurrence of thick gravel beds at a relatively shallow depth that have a preferentially high hydraulic conductivity compared to the overlying sediments. High-yield radial collector wells could be successfully developed in the gravel unit by installing the collector laterals in the gravel that extend under the seabed. Collector laterals could be installed only on the seaward side of the well to eliminate impacts to fresh groundwater resources occurring in the landward direction and to also eliminate the potential for drawing contaminated water or water having high concentrations of undesirable metals, such as iron and manganese, into the wellfield (Fig. 6).

Proper aquifer characterization is required in the design of a radial collector well intake system. While the test program to determine potential yield of individual wells and the required space between them is relatively easy to perform (same as conventional wells), the assessment of water quality within the sediments can be more complex. It is quite important to assess the redox state of the water to be pumped because radial wells have a caisson that allows air to come in contact with the water originating in the laterals. If the water flowing into the well from the coastal aquifer contains hydrogen sulfide, iron ($Fe^{2+}$),

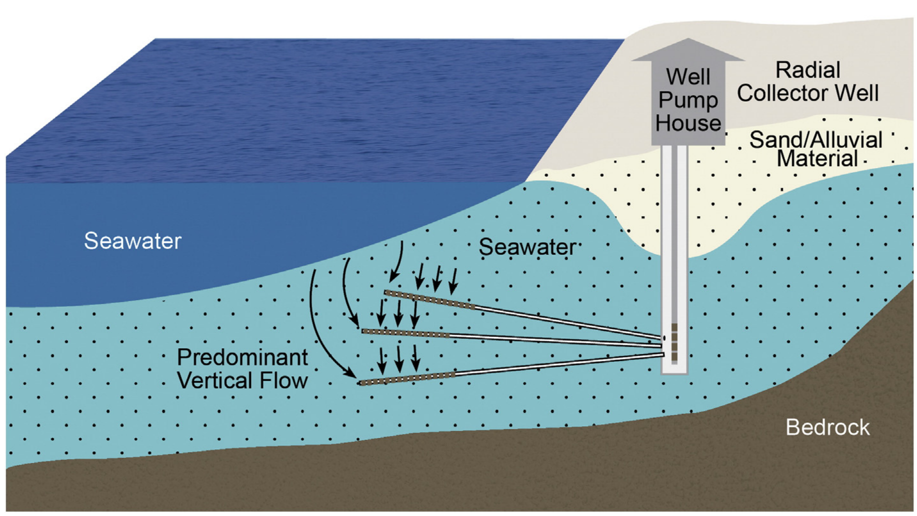


**Fig. 6.** Typical design from a radial collector or Ranney well. The laterals can be designed to extend beneath the seabed to all only vertical recharge through the seabed, precluding landward impacts. Note that the laterals occur on a single plane and many can be installed.

or manganese ($Mn^{2+}$), it could react with the dissolved oxygen in the water temporarily stored in the caisson and precipitate elemental sulfur, ferric hydroxide, or manganese dioxide respectively, any of which can foul the cartridge filters and membranes [11,59].

Radial collector wells have an advantage over conventional vertical wells in that the individual well yields can be very high. However, they do require location near the shoreline and are therefore subject to beach erosion and storm wave damage. They could be used to produce large quantities of feedwater in areas where the geology is supportive and the tidal water is relatively calm with low wave action. Since individual wells can yield up to about 50,000 $m^3$/d, they could be used to supply feedwater to very large capacity SWRO systems. However, no long-term operating data are available on the radial collector wells used for SWRO intakes. There is potentially greater risk associated with radial collector wells because a greater investment in their construction occurs before their performance can be known with certainty.

### 3.3. Gallery systems

#### 3.3.1. Concept

A gallery intake system design for SWRO intakes is based on the concept of slow sand filtration used in the water industry for more than two centuries [61]. A classical gravity fed slow sand filter, depending on the turbidity of the water being treated, can operate at infiltration rates ranging from 0.1 to 0.4 m/h (2.4 to 9.6 m/d) [61] with minimal need to clean the upper layer of the filter. Modern design criteria for slow and rapid sand filtration tend to have a lower range for the recommended design filtration rate at 0.05 to 0.2 m/h (1.2 to 4.8 m/d which may reflect the treatment of higher turbidity waters [62]).

Gallery intake usage is very applicable to SWRO treatment because sand filters of various designs are commonly used in the pretreatment train in most plants. Slow sand filtration improves water quality by straining and biological activity that can bind or break down many different organic compounds commonly occurring in seawater. Particulate materials are commonly trapped and bound in the upper part of the filter in a layer termed the "schmutzdecke" which is a biologically active layer containing bacteria, bound particulates, and organic carbon compounds. While the entire filter is biologically active, the greatest activity of bacterial treatment occurs in the upper 10 cm of the sand column. Retention time of the water within the filter will tend to increase the assimilation of organic compounds to a greater degree. Therefore, a balance between hydraulic flow rate, which governs the area of the filter footprint, and the retention time that controls the quality of the filtered water, must be achieved. Cleaning a slow sand filter is commonly accomplished by scraping and removing the upper few centimeters of sand with the full sand column being replaced perhaps within a multi-year timeframe.

Testing of slow sand filtration of seawater on a pilot scale has demonstrated significant improvements to feedwater quality [63]. The piloting work was conducted during periods of normal marine bioactivity and during periods of harmful algal blooms. The experimental work on slow sand filtration by Desormeaux et al. [63] showed that the $SDI_{15}$ was reduced to <4.0 99% of the time and <3.0 90% of the time, the removal of particles >2 microns in diameter was greater than or equal to 99%, and the total organic carbon (TOC) concentration was reduced to less than or equal to 2.0 mg/L. The concentration of spiked kainic acid, used as a proxy for algal toxin, was reduced by 89–94%. The operation of the pilot SWRO unit did not require cleaning during the 56-week pilot program and had the lowest amount of foulant observed on the membranes compared to the other pretreatment processes evaluated. The slow sand filter process required no coagulants or other chemicals to be added.

Gallery intakes use the concept of slow sand filtration by creation of an engineered filter that can be located on the beach near or above the high tide line, within the intertidal zone of the beach, or in the seabed. These intake types can be used as part of the pretreatment process, but eliminate the need for a large water treatment plant footprint required by in-plant slow sand filtration and/or dissolved air floatation (DAF).

#### 3.3.2. Seabed galleries

The conceptual design of a seabed gallery or filter has existed since the early 1980's [10,11,64]. To assess the general feasibility and associated operational risks, a marine survey can be conducted to determine the presence of potentially sensitive environmental conditions on the bottom (e.g., marine grass beds or coral reefs), the type of bottom sediment, the general sedimentation rate, and the turbidity of the seawater. At locations where the marine bottom contains clean sand devoid of significant concentrations of mud, there is a high probability that the system is feasible. Since the filter media will be engineered, a key issue is the composition of the naturally-occurring sediment which is an indication of the natural processes acting at a given location. Muddy bottoms have questionable feasibility because mud deposition would clog the top of the gallery. Commonly, muddy bottom areas are associated with river or stream discharges into the sea. Favorable marine processes include currents that keep fine-grained sediment in suspension and move sediment across the bottom, thereby stirring the top of the filter which tends to clean it. Natural macro-scale biological processes, such as bioturbation within the sediment column, can also aid in making the gallery fully functional. Many marine infauna including polychaete worms and mollusks are deposit feeders that ingest sediments to extract nutrients and excrete fecal pellets that act hydraulically similar to sand grains. The deposit feeders act to prevent the building of a biological clogging layer at the sediment–water interface.

Only one large-scale operating SWRO system, the Fukuoka, Japan facility, has been constructed and operated utilizing this type of intake (Fig. 7). The capacity of the Fukuoka gallery is 103,000 $m^3$/d [65]. It has an infiltration rate of 5.1 m/d with a corresponding retention time of 7 h. Although the gallery infiltration rate is slightly above the normal recommended range for slow sand filtration, it has been operating successfully for 8 years without the need to clean the offshore gallery and with minimal cleaning of the membranes [66]. Monitoring of the feedwater pumped from the gallery shows a very significant improvement in water quality with the SDI being reduced from background levels exceeding 10 to consistently below 2.5 to the beginning of 2010 and mostly below 2.0 thereafter (Fig. 8).

Another seabed gallery has been designed and constructed at the City of Long Beach, California [67,68]. This system has been in the testing phase for a significant time period with infiltration rates ranging from 2.9 to 5.8 m/d [69]. This testing revealed substantial reduction in turbidity, $SDI_{15}$, total dissolved carbon (TDC), and heterotrophic total plate counts (mHPCs) with some reduction in concentrations of DOC and AOC (Table 4).

The filter media used in slow sand filters in the treatment of freshwater typically consists of graded quartz sand. It has been recently suggested that naturally-occurring carbonate sands may have a greater degree of bioreactivity, thereby potentially causing a greater removal rate of organic compounds [70,71]. Further research will be required to assess this possibility.

Large-scale seabed galleries can be technically complex to construct. In offshore locations where the bottom sediment is unconsolidated, construction requires the use of sheet piling, dredging and temporary dewatering to allow the placement of the bottom intake screens and the filter media (Fig. 9). In locations where the nearshore bottom contains soft rock, the gallery cells can be constructed in the wet using a backhoe resting atop a temporary access road [71]. The development of an artificial filter on the sea floor has been suggested to lessen the difficulty of marine construction [72]. As a greater number of large-capacity systems are constructed, more efficient construction methods will likely be developed to reduce overall construction costs.

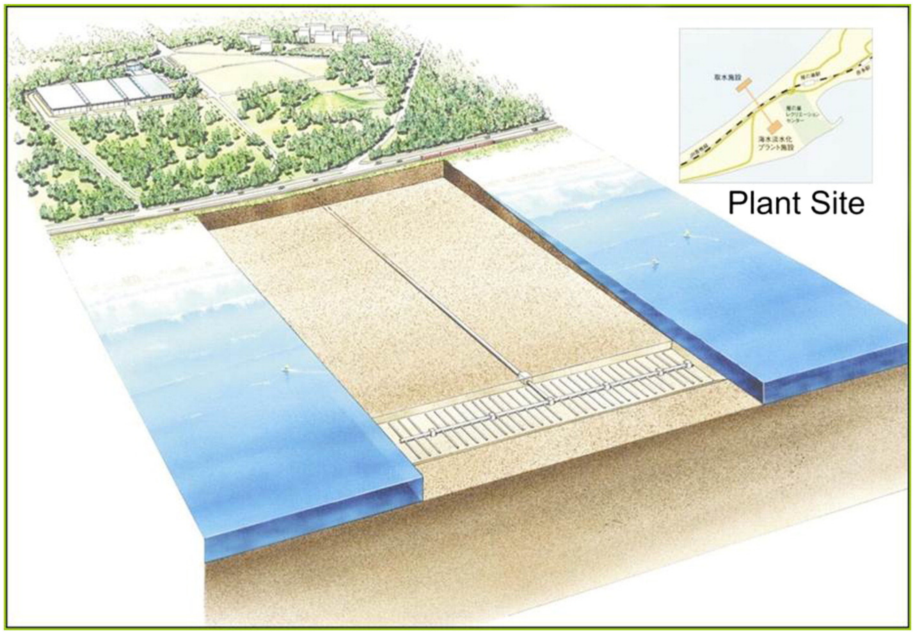


**Fig. 7.** Seabed gallery at Fukuoka, Japan. This gallery has a capacity of 103,000 $m^3$/day and has been operating successfully for 8 years [11,23].

Seabed galleries have a minimal environmental impact which occurs only during the initial construction. The major environmental impacts associated with impingement and entrainment of marine organisms in open-ocean intakes are eliminated. The post-construction marine bottom may actually be more productive in terms of infauna due to the increased flux of organic carbon compounds into the filter media over the top of the gallery.

*3.3.3. Beach galleries*

Another gallery intake type that has very great potential for use in large-capacity SWRO systems is the beach gallery [10,11]. Beach gallery intakes may be preferred over seabed galleries because they can be designed and constructed to be essentially self-cleaning [73]. The gallery is constructed within the intertidal zone of the beach with the mechanical energy of breaking waves being used to continuously clean the face of the filter (Fig. 10).

There are several key criteria that must be met to make beach gallery intakes feasible [74,75]. The shoreline should have significant wave height and a reasonable tidal range to allow the self-cleaning function to work properly. The beach should be relatively stable. While an eroding beach will still allow the gallery to function with the entire gallery continuously submerged, an accreting beach is problematical because the percolating seawater would require a longer flow path and the gallery could dewater if the hydraulic conductively is insufficient to maintain recharge into the gallery at the desired pumping rate. Beach galleries can be constructed successfully only on sandy or gravelly beaches with sufficient thickness of sediment to protect the underlying screens and to eliminate the potential for damage during storms. Care must be taken to design the galleries with sufficient sediment thickness to meet the water quality improvement needs and also to protect the media from storm damage. The thickness of the filter media would be likely greater than that for a seabed gallery.

While no large-scale beach gallery intakes have been constructed to date, several are in design or have been proposed [74]. The use of beach galleries for intakes is compelling because of the potential use for large-capacity systems, the self-cleaning aspect of the design, the lower construction cost compared to seabed galleries, and the minimal environmental impacts.

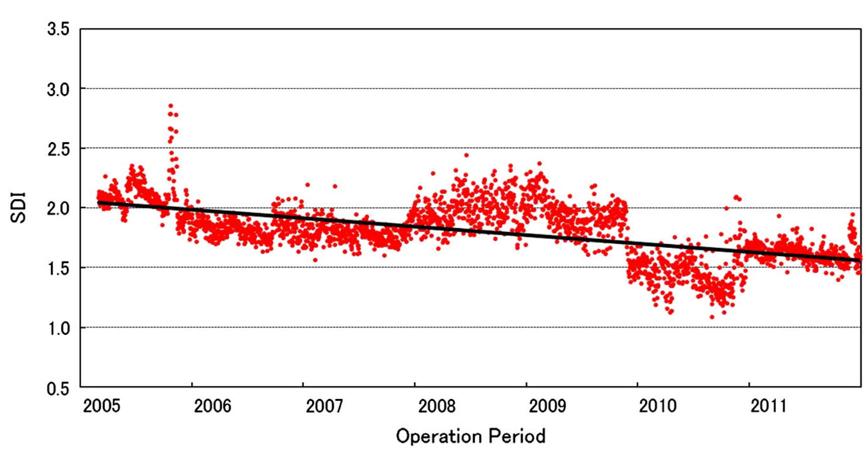


**Fig. 8.** Long-term variation in the silt SDI of water coming from the seabed gallery at Fukuoka, Japan. The water quality has been consistently good and has improved during the life of the facility [23].

**Table 4**
City of Long Beach, California seabed gallery water quality test data [68].

| Parameter | Infiltration rate (m/d) | Raw seawater (range/mean) | Gallery effluent (range/mean) |
|---|---|---|---|
| Turbidity (NTU) | 2.9 | 1.42–4.8/3.04 | 0.41–0.70/0.66 |
| Turbidity (NTU) | 5.8 | 1.86–4.56/3.10 | 0.38–1.23/0.48 |
| $SDI_{15}$ | 2.9 | Not reported | 4.42–5.53/4.56 |
| $SDI_{15}$ | 5.8 | Not reported | 2.74–5.45/4.06 |
| ATP (mg/L) | 2.9 | 1–1000/6.0 | 1.50–21.0/2.60 |
| TDC (cells/mL) | 2.9 | 3400–1,210,000/54,400 | 8500–241,000/13,300 |
| mHPC (cfu/100 mL) | 2.9 | 750–470,000/4500 | 156–5500/1000 |
| DOC (mg/L) | 2.9 | 0.39–0.70/0.41 | 0.30/0.35/0.35 |
| AOC (mg/L) | 2.9 | 11.0–17.6/12.0/12.0 | 8.9–11.0/9.8 |

## 4. Subsurface intake improvement to feedwater quality

A number of investigations have shown that significant water quality improvements can be achieved by using subsurface intakes instead of open-ocean intakes (Table 3). Recently collected data from the Sur, Oman site demonstrates that subsurface intake systems produce high quality seawater by removing nearly all of the algae, a high percentage of the bacteria, a significant amount of the organic carbon, and a high percentage of the marine biopolymers that are currently believed to facilitate membrane biofouling [76] (Table 5). The removal of virtually all of the turbidity, algae, and the large bacteria allows the use of a simpler, less expensive pretreatment system with a corresponding reduction in operating costs.

**Fig. 9.** Construction of the City of Long Beach, California seabed gallery system. This gallery required the use of sheet-piling and temporary dewatering to install the gravel and screen system.

In many cases, the water produced from a subsurface intake can be transmitted directly to the cartridge filters, thereby eliminating mixed media filtration, coagulation processes, and the need to use various chemicals (e.g., ferric chloride, chlorine). An example is the Fukuoka, Japan facility that uses a seabed gallery coupled to a membrane filtration pretreatment system, which is likely not needed based on the water quality obtained from the intake. The goal of all subsurface intake systems is to provide seawater that requires no additional pretreatment with the corresponding plant design being similar to brackish-water desalination systems that utilize well intakes and use only cartridge filters (with some chemical additives to prevent scaling) [10,11,77].

## 5. Economics of subsurface intake systems

Improvement of feedwater quality has a significant impact on the economics of desalination, particularly on operating cost. Therefore, the use of subsurface intakes should reduce the overall cost of desalination. However, the use of subsurface intakes will increase the capital cost for the construction of large-scale desalination facilities in many, but not all cases. While capital cost is important, it is not the major factor determining overall, long-term cost of desalination based on a simple life-cycle analysis. The cost analysis of a SWRO facility is commonly divided into capital or investment cost (CAPEX) and operating cost (OPEX) [78]. Therefore, each type of cost is discussed separately for general input into a preliminary life-cycle cost analysis.

The comparative CAPEX costs of a conventional intake system coupled with pretreatment versus a subsurface intake systems are instructive. For a typical, stand-alone SWRO facility having a capacity of 100,000 $m^3$/day, the combined cost for the intake, associated pumping station, and outfall is about roughly $30 million USD or about 13.9% of the total facility cost (Table 6). If the intake is separated from this cost, it is about $10 million USD or about 4.6% of total cost. The pretreatment system using conventional gravity filters with coagulation and periodic chlorination/dechlorination has a cost of $25 million USD or constitutes about 11.6% of the total CAPEX. If a dissolved air flotation system and/or a membrane pretreatment system are used, the pretreatment process train cost would be considerably greater. While a subsurface intake system will have a greater CAPEX compared to a conventional open-ocean intake, there will be a corresponding reduction in the pretreatment train cost. If no pretreatment equipment is required, a total of $35 million USD could be used to construct a subsurface intake system without altering the overall project CAPEX. If only polishing filtration is required, the reduction in CAPEX for the subsurface intake system associated pretreatment train would still significantly reduce pretreatment CAPEX cost. Therefore, in some cases the CAPEX cost differential between use of open-ocean and subsurface intakes may be similar and have a minimal impact on overall project cost.

OPEX costs have an overall much greater impact on the net water cost delivered to the consumer compared to CAPEX cost, especially as the useful life expectancy of the facility or the contract duration increases. It is clear that operational cost savings occur as a result of using subsurface intake systems [81–84]. Specific operational cost savings include: 1) reduced cost associated with maintaining an open-ocean intake, such as the use of divers to physically clean it and the periodic or continuous feed of chlorine to control accumulation of biological growth, 2) no need to operate traveling screens with associated removal of debris and disposal of biological waste, 3) no need to operate fish recovery and release programs, 4) no need to add coagulants in the pretreatment system, 5) reduced electrical costs associated with a complex pretreatment system, 6) no use of chlorination/dechlorination, 7) reduction in the frequency of required membrane cleanings, 8) increased life-expectancy of membranes, and 9) reduced labor costs. It is also probable that the higher quality water

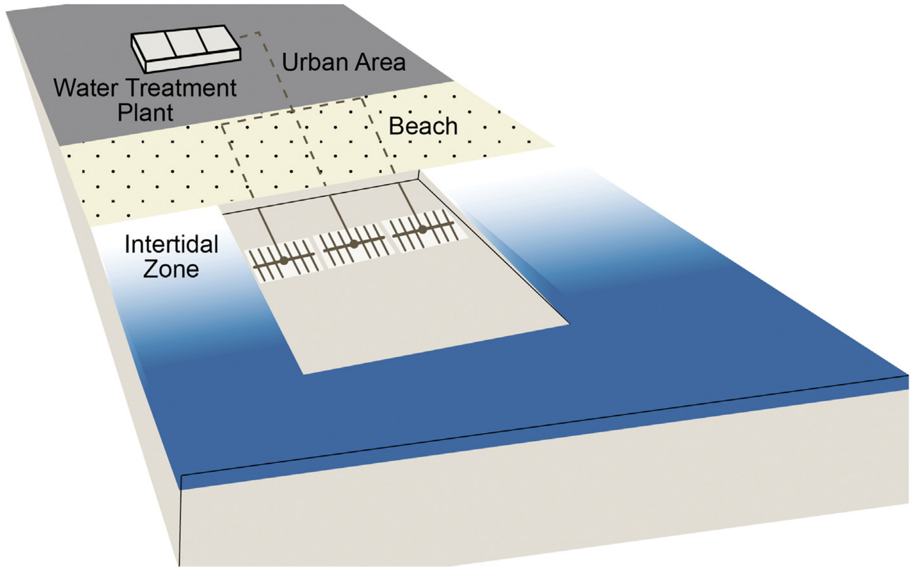


**Fig. 10.** Beach gallery intake system showing the concept of allowing the breaking waves at the shoreline to mechanically clean the face of the filter, reducing the potential for clogging.

would allow the membrane process to be operated at a higher efficiency by increasing the permeate flux without fear of increasing biofouling. Reverter et al. [85] found at the Palms III plant in the Canary Islands (Spain) that raw water treated from an open-ocean intake required the permeate flux rate to be between 11.8 and 13.4 L/m$^2$-h, while raw water obtained via beach wells allowed the permeate flux rate to be increased to 16.8 L/m$^2$-h or an increase of 20 to 30% efficiency. This saves up to 8% in operating cost. Another cost consideration is a reduction in the required environmental monitoring associated with permit special conditions for an open-ocean intake.

**Table 5**
Comparison of raw seawater and well intake water quality at the Sur, Oman SWRO facility [76].

| Parameter | Seawater | Well 1W | Well 9W | Well 12C | Aggregated |
|---|---|---|---|---|---|
| *Physical* | | | | | |
| TDS (mg/L) | 55.4 | 54.3 | 55.8 | 55.8 | |
| Turbidity (NTU) | 0.91 | 0.61 | 0.38 | 0.30 | |
| $SDI_{15}$ | 16.52[a] | 0.819 | 0.996 | 1.193 | |
| *Organics* | | | | | |
| DOC (ppm) | 0.544 | 0.101 | 0.170 | 0.133 | 0.128 |
| Biopolymers (ppm) | 222 | 1 | 8 | ND | 2 |
| Humic substances (ppm) | 520 | 85 | 41 | 91 | 93 |
| Building blocks (ppm) | 425 | 80 | 59 | 77 | 83 |
| LMW neutrals (ppm) | 458 | 95 | 150 | 125 | 117 |
| LMW acids (ppm) | 155 | 32 | 49 | 38 | 26 |
| *Algae* | | | | | |
| *Prochlorococcus* sp. (cells/mL) | 4400 | <100 | <100 | <100 | <100 |
| *Synechococcus* sp. (cells/mL) | 113,040 | <100 | <100 | <100 | <100 |
| Piconanoplankton (cells/mL) | 1900 | <100 | <100 | <100 | <100 |
| *Bacteria* | | | | | |
| Total bacteria (cells/mL) | 995,310 | 3270 | 8540 | 13,630 | 11,000 |
| LNA bacteria (cells/mL) | 582,750 | 2270 | 6110 | 9520 | 7540 |
| HNA bacteria (cells/mL) | 396,850 | 940 | 2230 | 3900 | 3266 |

[a] Seawater SDI was for 5 min instead of 15 min.

There is a large suggested range in potential OPEX savings by using subsurface intakes. If solely pretreatment cost is assessed, the annual savings could be as high as 35% based on a comparison of open-ocean intake versus a beach well system where challenging water quality occurs [81]. A review of relatively small-capacity seawater RO systems showed an OPEX savings range from 10 to 25% [83]. A preliminary analysis of the OPEX savings for all capacities of SWRO facilities using any type of subsurface intake showed a savings range from 10 to 30% based on the plant capacity and the duration of the operating life or contract [84]. A more detailed analysis between plants having open-ocean intakes and conventional pretreatment and those having a beach well system showed a cost reduction of 33.8% [81].

A preliminary life-cycle analysis was conducted to assess how much additional CAPEX cost could be absorbed using a subsurface intake system versus using a conventional intake with a corresponding pretreatment system (Table 7). The cost for a 100,000 m$^3$/day capacity stand-alone SWRO plant was used as a baseline (Table 6). The cost of a conventional open-ocean intake was assumed to be $10 million USD based on one-third of the line item shown in Table 6. Two scenarios were considered; a facility that would have a subsurface intake with a polishing filtration system with a corresponding reduction in pretreatment CAPEX cost from $25 million USD to $10 million USD and a facility that has a subsurface intake that allows direct discharge of water from the intake to the cartridge filters, which would reduce the pretreatment CAPEX to 0. If it is assumed that there would be zero savings in OPEX for using a subsurface intake, then the maximum CAPEX intake cost that could be induced without increasing the overall cost of water production would be $25 million USD for scenario 1 and $35 million USD for scenario 2. The range of potential OPEX savings using a subsurface intake system was 0 to 30%. The analysis considered OPEX or life-cycle durations of 10, 20, and 30 years. This exercise is significant because there is wide variation in the subsurface intake type that can be used for a specific site, thereby causing extreme variation in intake construction cost. An analysis of the numbers shows that a very large CAPEX investment in the construction of a subsurface intake system can be made without increasing the overall water cost. Considering case 2 with a 30-year operating period, the cost of using a subsurface intake could be as much as 86% of the overall facility CAPEX without increasing the cost of water. In most cases, there will be a clear reduction in cost. Also, this analysis does not consider any cost savings associated with reduction in environmental impacts.

**Table 6**
CAPEX cost of typical SWRO plant with a capacity of 100,000 $m^3$/day, including pretreatment [79,80].

| Systems | System cost (USD) | Cost partitions (%) | Specific cost (USD/$m^3$/day) | Supplemental information |
|---|---|---|---|---|
| Intake, pump station, and outfall | 30,000,000 | 13.9 | 300.0 | |
| Pretreatment system | 25,000,000 | 11.6 | 250.00 | |
| –Membranes (MF/UF) | | – | – | |
| –Without membranes | 25,000,000 | 11.6 | 250.0 | |
| Reverse osmosis part total | 80,000,000 | 37.5 | 800.0 | Isobaric ERD |
| –Membranes (without vessels) | 8,000,000 | 3.7 | 80.0 | |
| –Reverse osmosis without membranes | 72,000,000 | 33.4 | 720.0 | |
| Potabilization plant | 10,000,000 | 4.6 | 100.0 | |
| Drinking water storage and pumping | 10,000,000 | 4.6 | 100.0 | |
| Wastewater collection and treatment | 5,000,000 | 2.3 | 50.0 | |
| Mechanical equipment without membranes | 152,000,000 | 70.6 | 1520.0 | |
| Auxiliary systems | 7,000,000 | 3.3 | 70.0 | |
| Civil works | 16,000,000 | 7.4 | 160.0 | |
| Electrical works | 15,000,000 | 7.0 | 150.0 | |
| I. & C. Works | 7,000,000 | 3.3 | 70.0 | |
| Total | 205,000,000 | | 2050.0 | |
| Contingencies (5%) | 10,250,000 | 4.8 | 102.5 | |
| Seawater RO plant total | 215,250,000 | 100.0 | 2152.5 | |
| | USD/year | | USD/year | |
| Annual capital cost (annuity) | 16,838,301 | | 0.46 | |

Notes: SWRO plant net capacity = 100,000 $m^3$/day.
Type of pretreatment = gravity filters.
Type of potabilization = lime/$CO_2$.
Type of intake = open.
Plant lifetime = 25 years.
Interest rate = 6%/year.

Another economic consideration is the location of the RO plant in proximity to an acceptable site on which a subsurface intake could be developed versus using an open-ocean intake at a more proximal location to the distribution system. In locations where seawater quality is challenging, a considerably greater water transmission distance may be cost-effective to locate the plant at a site where treatment cost OPEX would be more favorable, especially where the cost reduction per cubic meter is greater than 20%.

## 6. Discussion

It is a common misbelief that subsurface intake systems are limited for use on only moderate and small capacity SWRO systems [86,87]. Greenlee et al. [88] stated "Today, as larger and larger RO plants are designed, beach wells cannot always provide enough water, and open seawater intakes are the only feed source option." While these authors may be correct concerning beach wells and their limitations on yield and numbers, beach wells are not the only subsurface intake option available. Horizontal and radial collector wells have the potential to yield very large quantities of water to meet the requirements of a large range of SWRO plant capacities. Beach and seabed gallery systems have the capability under favorable geologic circumstances to meet the requirements of virtually any capacity SWRO system.

Subsurface intake systems are largely a modular design, in which capacity can be increased by the construction of additional wells or galleries. Modular designs thus tend to be more flexible, but have a

**Table 7**
Economics of subsurface intakes showing the amount capital cost that can be spent on a subsurface intake verses an open ocean intake and not have an impact on the total life-cycle cost based on OPEX savings.

| Type of intake | Open ocean intake | Detailed subsurface intake analysis | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Operational period (years) | 10 years | 10 years | | | | | | |
| % of potential saving in operation cost for subsurface | | 0% | 5% | 10% | 15% | 20% | 25% | 30% |
| Operation cost ($/$m^3$) | 1 | 1 | 0.95 | 0.9 | 0.85 | 0.8 | 0.75 | 0.7 |
| CAPEX cost | 215,250,000 | 215,250,000 | | | | | | |
| Annual OPEX cost* | 36,500,000 | 36,500,000 | 34,675,000 | 32,850,000 | 31,025,000 | 29,200,000 | 27,375,000 | 25,550,000 |
| Total OPEX cost along the operational period | 365,000,000 | 365,000,000 | 346,750,000 | 328,500,000 | 310,250,000 | 292,000,000 | 273,750,000 | 255,500,000 |
| Annual capital cost** | 29,245,578 | 29,245,578 | | | | | | |
| OPEX cost saving | 0 | 0 | 18,250,000 | 36,500,000 | 54,750,000 | 73,000,000 | 91,250,000 | 109,500,000 |
| Annual OPEX cost saving | 0 | 0 | 1,825,000 | 3,650,000 | 5,475,000 | 7,300,000 | 9,125,000 | 10,950,000 |
| Annual capital cost amortization + annual OPEX cost saving** | | | 31,070,578 | 32,895,578 | 34,720,578 | 36,545,578 | 38,370,578 | 40,195,578 |
| Principal cost | 215,250,000 | 215,250,000 | 228,682,159 | 242,114,318 | 255,546,477 | 268,978,635 | 282,410,794 | 295,842,953 |
| Capital cost that can be added to the subsurface intake | | 0 | 13,432,159 | 26,864,318 | 40,296,477 | 53,728,635 | 67,160,794 | 80,592,953 |
| Case 1 (25,000,000): 10 years of operation | | 25,000,000 | 38,432,159 | 51,864,318 | 65,296,477 | 78,728,635 | 92,160,794 | 105,592,953 |
| Case 2 (35,000,000): 10 years of operation | | 35,000,000 | 48,432,159 | 61,864,318 | 75,296,477 | 88,728,635 | 102,160,794 | 115,592,953 |
| Case 1 (25,000,000): 20 years of operation | | 25,000,000 | 45,932,606 | 66,865,212 | 87,797,819 | 108,730,425 | 129,663,031 | 150,595,637 |
| Case 2 (35,000,000): 20 years of operation | | 35,000,000 | 55,932,606 | 76,865,212 | 97,797,819 | 118,730,425 | 139,663,031 | 160,595,637 |
| Case 1 (25,000,000): 30 years of operation | | 25,000,000 | 50,120,817 | 75,241,634 | 100,362,451 | 125,483,267 | 150,604,084 | 175,724,901 |
| Case 2 (35,000,000): 30 years of operation | | 35,000,000 | 60,120,817 | 85,241,634 | 110,362,451 | 135,483,267 | 160,604,084 | 185,724,901 |

Plant capacity = 100,000 ($m^3$/day), Interest rate = 6% per year, operation cost = 1($/$m^3$).
* Annual OPEX cost = plant capacity ∗ operation cost ∗ no. of operation days.

** Annual capital cost (annuity cost) = $P\left(i + \frac{i}{(1+i)^n - 1}\right)$, where P = amount of principal (Capital), i = interest rate, and n = number of years.

**Table 8**
Comparative viability of subsurface intake types.

| Type | Capacity limit ($m^3$/d) | Water quality improvement | Technical limitations | Maturity of technology |
|---|---|---|---|---|
| Conventional wells | <250,000 | Major | Local geology, large capacity requirement | Mature |
| Angle wells | <250,000 | Untested | Local geology, large capacity requirement | Immature |
| Radial collector wells | <500,000 | Untested | Local geology, beach stability, large capacity requirement | Mature-non-seawater intake applications |
| Horizontal wells | Unknown | Minimal testing | Local geology, seabed sedimentation rate, water turbidity | Immature |
| Seabed galleries | Unlimited | Major | Offshore sedimentation rate, water turbidity | Moderate (one operational system) |
| Beach galleries | Unlimited | Untested | Shoreline stability | Immature |

relatively small economy of scale. Conventional intakes, on the contrary, have a relatively large economy of scale with regard to construction costs. For example, increasing the size (diameter) of a screen and subsea intake pipe can accommodate twice the flow results in a much lower construction cost per unit volume of capacity. Operational costs (e.g., energy and chemical costs) are more proportional to system capacity. Hence for small and mid-sized systems, subsurface intakes can provide both CAPEX and OPEX savings. For large systems, the benefits are predominantly in OPEX costs.

A preliminary life-cycle economic analysis conducted shows that the increased capital cost of using a subsurface intake system is offset by a reduction in capital cost of the pretreatment train (reduced number of processes) and reduced operating costs make subsurface intakes quite attractive. There are a number of specific cost savings in operations which include elimination of traveling screens operation, elimination of solid waste disposal of marine debris, such as fish, jellyfish, and seaweed, reduction or elimination of chemical usage, reduction or elimination of electrical and maintenance costs for the pretreatment systems, and potential increases in the flux rate of seawater across the membranes resulting in increased productivity.

The economic analysis shows that the capital costs for the use of a subsurface intake can be increased by as much as factors of 54, 75, and 86% for corresponding operating periods of 10, 20, and 30 years using the summed life-cycle costs for these timeframes based on a cost reduction factor range of 30% for a SWRO plant with a capacity of 100,000 $m^3$/day. Therefore, from a purely economic viewpoint, the use of subsurface intake systems is preferred over an open-ocean intake system. It is anticipated that the operational cost reduction would be greater than 15% in nearly all cases. Also, this assessment does not include the elimination of environmental impacts associated with impingement and entrainment of marine organisms which could also be assigned a true cost. This cost includes a reduction in the permitting costs required to demonstrate that a facility does not have a significant impact or can include an elimination of mitigation measures required to offset environmental impacts.

Another factor in the use of subsurface intakes that has been raised is the issue of potential risk for bidders or facility owners in terms of the applicability of a given intake type to a specific site, operational risk for failure or unexpected upsets, and the proverbial question of maturity of technology. There are limits on the use of various subsurface intake types based on the local geology of a site and on the maximum capacity of a type based on the costs associated with operating a large number of wells (Table 8). In general, there are limits on the use of conventional vertical wells, angle wells, and radial collector wells for very large SWRO systems. These intakes likely are limited to feedwater capacity requirements ranging from no greater than a range of 250,000 to 500,000 $m^3$/day, which equates to permeate capacities ranging from 87,500 to 250,000 $m^3$/day, depending on the conversion rate (salinity based from 35 to 50%). The technical limitations on use of each intake type are shown, which are most commonly geologic factors or a high sedimentation rate that could produce filter clogging. Conventional well intake systems have been used for the longest time period and must be considered to be the most mature technology with demonstrated success. Radial well and horizontal well systems are operating and have shown to be successful for seawater intake use. The radial well technology is very mature based on applications associated with freshwater intakes adjacent to rivers and streams. Gallery intakes are relatively new and the application to SWRO intakes cannot be considered to be “mature technology”, but the Fukuoka, Japan site has proven to be a quite successful demonstration of the technology. However, the design concept is analogous to the slow sand filtration process that has been used in water treatment for over a century. A fundamental advantage of gallery intake systems is that they can be used to supply virtually any capacity SWRO facility.

## 7. Conclusions

Fundamental goals for future desalination of seawater include reductions in the quantity of energy and chemicals, in the carbon footprint, and the overall cost of water to the consumer. The use of subsurface intake systems, wherever possible, helps achieve these goals. Subsurface intakes always produce a higher quality feedwater compared to conventional open-ocean intakes. This improvement in water quality leads to the simplification of required pretreatment processes with the elimination of many or all processes. The use of chlorine, coagulants, and other chemicals can be essentially eliminated by the use of subsurface intake systems. Reduction in chemical use and power consumption in operation of pretreatment systems causes a reduction in the carbon footprint of a SWRO system and in potential environmental impacts. Elimination of impingement and entrainment impacts on the environment is also an added advantage of using a subsurface intake system. Finally, the life-cycle cost analysis of virtually any capacity, stand-alone RO treatment system will show that the use of subsurface intake systems reduces the cost of desalination to the consumer, provided that the technology is locally available to construct the system. While not all facility locations can use subsurface intakes, it should always be a priority of a utility, project owner, or project developer to consider the use of a subsurface intake and provide tender bidders with sufficient technical information concerning subsurface or offshore conditions to allow a subsurface intake to be bid without great risk.

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## References

[1] N. Ghaffour, T.M. Missimer, G. Amy, Technical review and evaluation of the economics of desalination: current and future challenges for better supply sustainability, Desalination 309 (2013) 197–207.
[2] H.S. Vrouwenvelder, J.A.M. van Paassen, H.C. Folmer, J.A.M.H. Hofman, M.M. Nederlof, D. van der Kooij, Biofouling of membranes for drinking water production, Desalination 118 (1–3) (1998) 157–166.
[3] S. Lattemann, T. Hopner, Environmental impact and impact assessment of seawater desalination, Desalination 220 (2008) 1–15.
[4] WateReuse Association, Desalination Plant Intakes: Impingement and Entrainment Impacts and Solutions, WateReuse Association White Paper, 2011.
[5] WateReuse Association, Seawater Concentrate Management, WateReuse Association White Paper, 2011.

[6] D.-H. Hellmann, H.F.R. Rosenbeger, E. Tusel, Seawater intake systems for desalination plants, Proceedings of the International Desalination Association World Congress on Desalination and Water Reuse, Manama, Bahrain, 2002.
[7] S.A. Kreshman, Seawater intakes for desalination plants in Libya, Desalination 55 (1985) 493–502.
[8] A. Berktay, Environmental approach and influence of red tide to desalination process in the Middle East region, Int. J. Chem. Environ. Eng. 2 (3) (2011) 183–188.
[9] D.M. Anderson, S. McCarthy (Eds.), Red Tides and Harmful Algal Blooms: Impacts on Desalination Systems, Middle East Desalination Research Center, Muscat, Oman, 2012.
[10] T.M. Missimer, Water Supply Development for Membrane Water Treatment Facilities, CRC Press, Boca Raton, Florida, 1994.
[11] T.M. Missimer, Water Supply Development, Aquifer Storage, and Concentrate Disposal for Membrane Water Treatment Facilities, 2nd edition Schlumberger Limited, Sugar Land, Texas, 2009.
[12] C. Ray, G. Melin, R.B. Linsky (Eds.), Riverbank Filtration: Improving Source Water Quality, Klumer Academic Publishers, 2002.
[13] S.A. Hubbs (Ed.), Riverbank Filtration Hydrology — Impacts on System Capacity and Water Quality, Springer, Dordrecht, 2005.
[14] W.J. Weiss, E.J. Brouwer, R. Aboytes, M.W. LeChevallier, C.R. O'Melia, B.T. Le, K.J. Schwab, Riverbank filtration for control of mircoorganisms: results from field monitoring, Water Res. 39 (10) (2005) 1990–2001.
[15] C. Ray, F. Laszlo, A. Bourg (Eds.), Riverbank Filtration: Understanding Biochemistry and Pathogen Removal, Kluwer Academic Publishers, Dordrecht, The Netherlands, 2002.
[16] W.B. Gollnitz, J.L. Clancy, Whittenberry, J.A. Vogt, RBF as a microbial treatment process, J. Am. Water Works Assoc. 95 (12) (2003) 56–66.
[17] W.B. Gollnitz, J.L., B.L. Whittenberry, J.A. Vogt, Riverbank filtration: induced infiltration and groundwater quality, J. Am. Water Works Assoc. 96 (12) (2004) 98–110.
[18] W.B. Gollnitz, J.L. Clancy, J.B. McEwen, S. Garner, Riverbank filtration for IESWTR compliance, J. Am. Water Works Assoc. 97 (12) (2005) 64–76.
[19] A.-L. Kivimaki, K. Lahti, T. Hatva, S.M. Tuominen, I.T. Miettinen, Removal of organic matter during bank filtration, in: J.H. Peters, et al., (Eds.), Artificial Recharge of Groundwater, A.A. Balkema, 1998, pp. 107–112.
[20] G. Grutzmacher, G. Bottcher, L. Chorus, Cyanobacterial toxins in bank filtered water from Lake Wannsee, Berlin, in: P. Dillon (Ed.), Management of Aquifer Recharge for Sustainability, A.A. Belkema Publishers, Lisse, The Netherlands, 2002, pp. 175–179.
[21] S.W. Taylor, L.C. Headland, Analysis and design of infiltration seawater intakes, Proceedings, World Water and Environmental Resources Congress, Anchorage, Alaska, May 15–19, 2005.
[22] G. Cartier, P. Corsin, Description of different water intakes for SWRO plants, Proceedings of the International Desalination Association World Congress on Desalination and Water Reuse, Maspalomas, Gran Canaria, Spain, October 21–26, 2007, IDAWC/MP07-185, 2007.
[23] T. Pankratz, Seawater desalination technology overview, Presentation for Georgia Joint Comprehensive Study Committee, St. Simons Island, Georgia, August 22–23, 2006.
[24] T. Pankratz, A review of seawater intake, pretreatment and discharge technologies, Proceedings, of the International Desalination Association Seminar on Water Desalination Technologies, Tehran, Iran, Nov. 19–20, 2006.
[25] E.D. Mackey, N. Pozos, W. James, T. Seacord, H. Hunt, D.L. Mayer, Assessing Seawater Intake Systems for Desalination Plants, Water Reuse Foundation, 2001.
[26] N. Voutchkov, Thorough study is key to large beach-well intakes, Desalin. Water Reuse Q. 14 (1) (2005) 16–20.
[27] A. Ko, R. King, Guantanamo Bay, Cuba, seawater desalination plant operation and experience, Proceeding, American water Works Association Membrane Technology Conference, Phoenix, Arizona, 2005.
[28] B. David, J.-P. Pinot, M. Morrillon, Beach wells for large scale reverse osmosis plants: the Sur case study, Proceedings of the International Desalination Association World Congress on Desalination and Water Reuse, Atlantis, The Palm, Dubai, UAE, November 7-12, 2009, IDAW/DB09-106, 2009.
[29] N. Voutchkov, SWRO desalination process: on the beach–seawater intakes, Filtr. Sep. 42 (8) (2005) 24–27.
[30] W.T. Andrews, R.A. Bergman, The Malta seawater RO facility, Desalination 60 (1986) 135–144.
[31] T.M. Missimer, H. Winters, Seawater supply wells for reverse osmosis desalination facilities on Grand Cayman Island, Proceedings, Third International Symposium on Tropical Hydrology and the Fifth Caribbean Islands Water Resources Conference, Am. Water Resources Assoc, 1998, pp. 219–223.
[32] J. Schwartz, Beach well intakes for small seawater reverse osmosis plants, Middle East Desalination Research Center Project 97-BS-015, August 2000.
[33] A.T.M. Jamaluddin, A.M. Hassan, A.A. Reweli, M.O. Saeed, Operation of Al-Birk Plant introducing beachwell intake system, Technical Report, Saline Water Desalination Research Institute, Al-Birk SWRO Plant, Saudi Arabia, 2005.
[34] A.T.M. Jamaluddin, A.M. Hassan, A. Al-Reweli, M.O. Saeed, L.M. Bakhit, M.M. Al-Amri, Operation of Al-Birk plant introducing beachwell intake system, Saline Water Conversion Corporation Technical Report No. TR 3807/APP02005, 2005.
[35] N. Kammourie, T.F.F. Dajani, S. Cioffi, S. Rybar, SAWACO — North Obhor SWRO plant operational experience, Desalination 221 (2008) 101–106.
[36] F. Bertone, B. David, A. Alcolea, P. Renard, G. Mariethoz, Using a stochastic approach to reduce risks in groundwater resources development: a case study in Sur, Oman, Proceedings, IAH Congress XXXVIII Groundwater Quality Sustainability, Krakow, Poland, Sept. 12–17, 2010, pp. 93–99.
[37] A. Alcolea, P. Renard, G. Mariethoz, F. Bertone, Reducing the impact of a desalination plant using stochastic modeling and optimization techniques, J. Hydrol. 365 (2009) 275–288.
[38] F.G. Driscoll, Groundwater and Wells, 2nd edition Johnson Division, St. Paul, Minnesota, 1986.
[39] J. Schwartz, Beach Well Intakes Improve Feed-Water Quality, Water & Wastewater International, November 2003.
[40] A. Hassan, A.T.M. Jamaluddin, A. Rowaili, E. Abart, R. Lovo, Investigating intake system effectiveness with emphasis on self-jetting well-point (SJWP) beachwell system, Proceedings, 2nd Acquired Experience Symposium on Desalination plants O & M, Al-Jubail, Saudi Arabia, Sept.29–Oct. 3, 1997, p. 1350-1350.
[41] A. Teuler, K. Glucina, J.M. Laine, Assessment of UF pretreatment prior to RO membranes for seawater desalination, Desalination 125 (1999) 89–96.
[42] A.T.M. Jamaluddin, A.M. Hassan, A. Al-Reweli, M.O. Saeed, Operation of Al-Birk Plant Introducing Beachwell Intake System, International Desalination Association World Congress on Desalination and Water Reuse, Singapore, 2007.
[43] A.M. Hassan, A.T.M. Jamaluddin, A. Rowaili, E. Abart, R. Lovo, Investigation intake system effectiveness with emphasis on self-jetting well-point (SJWP) beachwell system, Proceedings, 2nd Acquired Experience Symposium on Desalination Plants O & M, Al-Jubail, Sept. 29–Oct 3, 1997, pp. 1350–1365.
[44] R. Bartak, T. Grischek, K. Ghodeif, C. Ray, Beach sand filtration as pre-treatment for RO desalination, Int. J. Water Sci. 1 (2) (2012) 1–10.
[45] P. Choules, J.-C. Schotter, J. Leparc, K. Gai, D. Lafon, Operation experience from seawater reverse osmosis plants, Proceedings, American Membrane Technology Conference and Exposition, Las Vegas, Nevada, 2007.
[46] J. Laparc, J.-C. Schotter, S. Rapenne, J.P. Croue, P. Lebaron, D. Lafon, K. Gaid, Use of advanced analytical tools for monitoring performance of seawater pretreatment processes, Proceedings, International Desalination Association World Congress on Desalination and Water Reuse, Maspalomas, Gran Canaria, Spain, October 21–26, 2007, IDAWC/MP07-124, 2007.
[47] T.M. Missimer, H. Winters, Effects of well design and maintenance on biofouling at a seawater reverse osmosis plant, Grand Cayman Island, B.W.I. Proceedings, American Desalting Association Meeting & Technical Program, Lake Tahoe, Nevada, 2000.
[48] T.M. Missimer, H. Winters, Reduction of biofouling at a seawater RO plant in the Cayman Islands, Proceedings, International Desalination Association World Congress on Desalination and Water Reuse, BAH03-190, 2003.
[49] R. Cowles, S. Niekamp, M. Black, P. Pagello, Source water investigation for the Coquina Coast seawater desalination project, Fla. Water Resour J. (February 2012) 46–54.
[50] D.E. Williams, Research and development for horizontal/angle well technology, U.S. Department of the Interior, Bureau of Reclamation, Desalination and Water Purification Research and Development Program Report No. 151, 2008.
[51] D.E. Williams, Multiple advantages of slant wells for ocean desalination feedwater supply, Abstracts and Program of the National Ground Water Association Summit, 2012.
[52] J.-P. Delhomme, D. Labregre, J.-P. Rogala, D. McCann, Horizontal wells: a solution for desalination feedwater intake and brine disposal, Proceedings, International Desalination Association World Congress on Desalination and Water Reuse, Singapore, 2005.
[53] J.J. Malfeito, San Pedro del Pinatar desalination plant: first year of operation with a horizontal drilled intake, Proceedings, International Desalination Association Association Desalination and Water Reuse International Forum and Exposition, Tianjin, China, Sept. 6–8, 2006.
[54] J. Malfeito, A. Jimenez, Horizontal drains for seawater desalination — experience of Cartagena, Proceedings, American Membrane Technology Conference and Exposition, Las Vegas, Nevada, 2007.
[55] T. Peters, D. Pinto, E. Pinto, Improved seawater intake and pre-treatment system based on Neodren technology, Desalination 203 (2007) 134–140.
[56] M. Farinas, L.A. Lopez, New and innovative sea water intake system for the desalination plant at San Pedro del Pinatar, Desalination 203 (2007) 199–217.
[57] T. Peters, D. Pinto, Seawater intake and partial pre-treatment with Neodren — results from investigation and long-term operation, Desalin. Water Treat. 24 (2010) 117–122.
[58] H. Hunt, Filtered seawater supplies-naturally, Desalin. Water Reuse 6 (2) (1996).
[59] T.M. Missimer, Technical evaluation of Ranney collectors for raw water supply to seawater reverse osmosis treatment facilities, Proceedings, International Desalination Association World Congress on Desalination and Water Reuse, Madrid, Spain, 1, 1997, pp. 439–454.
[60] H. Hunt, American experience in installing horizontal collector wells. , Chapter 2 Riverbank Filtration: Improving Source Water Quality, Kluwer Academic Publishers, 2002. 29–34.
[61] L. Huisman, W.E. Wood, Slow Sand Filtration, World Health Organization, Geneva, Switzerland, 1974.
[62] J.C. Crittenden, R.R. Trussell, D.W. Hand, K.J. Howe, G. Tchobanoglous, Water Treatment: Principles and Design, 2nd edition John Wiley & Sons, New York, 2005.
[63] E.D. Desormeaux, P.F. Meyerhofer, H. Luckenbach, Results from nine investigations assessing Pacific Ocean seawater desalination in Santa Cruz, California, Proceedings of the International Desalination Association World Congress on Desalination and Water Reuse, Atlantis, The Palm, Dubai, UAE, November 7–12, 2009, IDAW/DB09-291, 2009.
[64] T.M. Missimer, L.E. Horvath, Alternative designs to replace conventional surface–water intake systems for membrane treatment facilities, Proceedings, International Desalination Association World Congress on Desalination and Water Reuse, 1991, pp. 131–140.
[65] T. Hamano, H. Tsuge, T. Goto, Innovations perform well in first year of operation (Fukuoka SWRO), Desalin. Water Reuse Q. 16 (1) (2006) 31–37.
[66] A. Shimokawa, Fukuoka District desalination system with some unique methods, National Centre of Excellence in Desalination, International Desalination Intakes and Outfalls Workshop Proceedings, Adelaide, South Australia, May 16–17, 2012.
[67] S. Wang, E. Leung, R. Cheng, T. Tseng, D. Vuong, D. Vuong, D. Carlson, J. Henson, S. Veerapaneni, Under sea floor intake and discharge system, Proceedings, International Desalination Association World Congress on Desalination and Water Reuse, Maspalomas, Gran Canaria, Spain, October 21–26, 2007, IDAWC/MP07-104, 2007.

[68] S. Wang, J. Allen, T. Tseng, R. Cheng, D. Carlson, J. Henson, Design and performance update of LBWD's under ocean floor seawater intake and discharge system, Alden Desalination Intake/Outfall Workshop, October 16 2009.

[69] J.B. Allen, T.J. Tseng, R.C. Cheng, K.L. Wattier, Pilot and demonstration-scale research evaluation of under-ocean floor seawater intake and discharge, Proceedings, AWWA Water Quality Conference, and Cincinnati, Ohio 16–20, 2008.

[70] K. Sesler, T.M. Missimer, Technical feasibility of using seabed galleries for seawater RO facility intakes and pretreatment: Om Al Misk Island site, Red Sea, Saudi Arabia, IDA J. 4 (4) (2012) 42–48.

[71] A.H.A. Dehwah, T.M. Missimer, Technical feasibility of using gallery intakes for sweater RO facilities, northern Red Sea coast of Saudi Arabia: The King Abdullah Economic City site, Desalin. Water Treat. (2013), http://dx.doi.org/10.1080/19443994.2013.770949.

[72] A.T. Jones, Can we reposition the preferred geological conditions necessary for an infiltration gallery? The development of a synthetic infiltration gallery, Desalination 221 (2008) 598–601.

[73] R.G. Maliva, T.M. Missimer, Self-cleaning beach gallery design for seawater desalination plants, Desalin. Water Treat. 13 (1–3) (2010) 88–95.

[74] T.M. Missimer, W.S. Manahan, R.G. Maliva, Technical and economic analyses of intake options for the proposed 700 L/s Tia Maria seawater RO treatment facility in southern Peru, Proceedings of the American Membrane Technology Conference & Exposition, San Diego, California, July 12–15, 2010.

[75] T.M. Missimer, R.G. Maliva, A.H.A. Dehwah, D. Phelps, Use of beach galleries as an intake for future seawater desalination facilities in Florida, Proceedings of the Florida Section, American Water Works Association Conference, Orlando Florida, 2012.

[76] R.M. Rachman, T. Merle, S. Li, S.K. Al-Mashharawi, T.M. Missimer, Removal of algae, bacteria, and organic carbon by the beach well intake system at Sur, Oman SWRO facility, Proceedings of the International Desalination Association World Congress on Desalination and Water Reuse, Tianjin, China, 2013.

[77] W. Arras, N. Ghaffour, A. Hamou, Performance evaluation of BWRO desalination plant — a case study, Desalination 235 (2009) 170–178.

[78] K.V. Reddy, N. Ghaffour, Overview of the cost of desalinated water and costing methodologies, Desalination 205 (2007) 340–353.

[79] The World Bank, Renewable Energy Desalination: an Emerging Solution to Close the Water Gap in the Middle East and North Africa, International Bank for Reconstruction and Development/The World Bank, Washington, D.C., 2013

[80] Fichtner (Fichtner GmbH, Co. KG), DLR (Deutsches Zentrum fur Luftund Raumfahrt e.V.), MENA regional water outlook, Part II, desalination using renewable energy, task 1 — desalination potential; task 2 — energy requirements; task 3 — concentrate management, Fichtner and DLR, http;//www.dlr.de/tt/Portaldata/41/Resources/dokumenteinstitute/system/projects/MENA_REGIONAL_WATER_OUTLOOK.pdf 2011.

[81] M. Abdel-Jawad, S. Ebrahim, Beachwell seawater intake as feed for an RO desalting system, Desalination 99 (1994) 57–71.

[82] S. Bou-Hamad, M. Abdel-Jawad, S. Ebrahim, M. Al-Mansour, A.A. Al-Hijji, Performance evaluation of three different pretreatment systems for seawater reverse osmosis technique, Desalination 110 (1997) 85–92.

[83] R.R. Wright, T.M. Missimer, Alternative intakes for seawater membrane water treatment plants, Proceedings of the International Desalination Association World Congress on Desalination and Water Reuse, Madrid, Spain, 1997.

[84] T.M. Missimer, R.G. Maliva, M. Thompson, W.S. Manahan, K.P. Goodboy, Reduction of seawater reverse osmosis treatment costs by improvement of raw water quality, innovative intake design, Desalin. Water Reuse 20 (3) (2010) 12–22.

[85] J.A. Reverter, S. Talo, J. Alday, Las Palmas III, the success story of brine staging, Desalination 138 (2001) 201–206.

[86] V. Bonnelye, M.A. Sanz, J.-P. Durand, L. Plasse, F. Gueguen, P. Mazounie, Reverse osmosis on open intake seawater: pre-treatment strategy, Desalination 167 (2004) 191–200.

[87] A. Brehant, V. Bonnelye, M. Perez, Assessment of ultrafiltration as a pretreatment of reverse osmosis membranes for surface seawater desalination, Water Sci. Technol. Water Supply 3 (5–6) (2003) 437–445.

[88] L.F. Greenlee, D.F. Lawler, B.D. Freeman, B. Marrot, P. Moulin, Reverse osmosis desalination: water sources, technology, and today's challenges, Water Res. 43 (2009) 2317–2348.

# ATTACHMENT TWO

## Final Summary Report Doheny Ocean Desalination Project Phase 3 Investigation

MUNICIPAL WATER DISTRICT OF ORANGE COUNTY

South Coast Water District

LAGUNA BEACH COUNTY WATER DISTRICT

Moulton Niguel Water

# FINAL SUMMARY REPORT
# DOHENY OCEAN DESALINATION PROJECT
# PHASE 3 INVESTIGATION

## Extended Pumping and Pilot Plant Test
## Regional Watershed and Groundwater Modeling
## Full Scale Project Conceptual Assessment

PREPARED BY

MUNICIPAL WATER DISTRICT OF ORANGE COUNTY

JANUARY 2014

# Final Summary Report
# Doheny Ocean Desalination Project
# Phase 3 Investigation

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## Extended Pumping and Pilot Plant Test
## Regional Watershed and Groundwater Modeling
## Full Scale Project Conceptual Assessment


**Prepared by**

**Municipal Water District of Orange County**



**January 2014**

This report was printed on recycled paper.

# *Acknowledgements*

MWDOC wishes to extend its appreciation to Nancy King and Rich Mills of the California Department of Water Resources for their help throughout the project. In addition, we wish to thank Bruce Macler, U.S. Environmental Protection Agency for his guidance and assistance throughout this multi-year investigation. Furthermore, MWDOC wishes to thank Leslie Cleveland, William Steele and Saied Delegah of the U.S. Bureau of Reclamation for their help on the iron and manganese pilot plant element.

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MWDOC also wishes to acknowledge the funding support and valuable contributions provided by the MWDOC staffs of the participating agencies throughout the project and their help and guidance provided in numerous technical advisory committee meetings and workshops, without which this project would not have been possible: City of Can Clemente (Dave Rebensdorf), City of San Juan Capistrano (Keith Van Der Maaten and West Curry), Laguna Beach County Water District (Renae Hinchey, Rich Mathis), Moulton Niguel Water District (Joone Lopez, Matt Collings), and South Coast Water District (Betty Burnett, Dave Youngblood, Mike Dunbar, Joe Sovella).

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# GLOSSARY

| | |
|---|---|
| **AFY** | acre-feet per year. |
| **Alluvial/Alluvium** | A geologic term describing beds of sand, gravel, silt, and clay deposited by flowing water through which groundwater can readily flow. |
| **Aquifer** | A geologic formation or group of formations which store, transmit, and yield significant quantities of water to wells and springs. |
| **Anoxic** | A common condition in older natural groundwater where the water is completely devoid of any dissolved oxygen. |
| **ARB** | California Air Resources Board |
| **California Ocean Plan** | The water quality control plan for the ocean that is established and periodically updated by the State Water Resources Control Board. The plan sets out the standards under which wastewater discharge permits are based upon. |
| **dFe/dMn** | Reduced, divalent iron and manganese occur in the dissolved form, primarily as hydroxides in anoxic waters. |
| **D.O.** | **D**issolved oxygen |
| **Drawdown** | The change in hydraulic head or water level relative to a background condition. |
| **Dual Rotary Drill Rig** | A water well drilling rig that combines the ability to drill and construct an outer casing to protect the open hole without the use of drilling muds. |
| **DWR** | California Department of Water Resources |
| **Evapotranspiration** | The combined loss of water from a given area by evaporation from the land and transpiration from plants. |
| **Fault** | A fracture in the earth's crust, with displacement of one side of the fracture with respect to the other. Faults may be impervious to the flow of water due to the grinding of adjacent formation materials into very fine sediments. |
| **Fe/Mn** | Iron and manganese |
| **gpm** | gallons per minute |
| **Groundwater** | Water contained in interconnected pores located below the water table in an unconfined aquifer or located in a confined aquifer. |
| **He/Tr** | Helium and Tritium isotopes |

| | |
|---|---|
| **LBCWD** | Laguna Beach County Water District |
| **MET** | Metropolitan Water District of Southern California |
| **MGD** | million gallons per day |
| **mg/l** | milligrams per liter |
| **MNWD** | Moulton Niguel Water District |
| **MWDOC** | Municipal Water District of Orange County |
| **Natural Isotope Tracer** | Naturally occurring radioactive isotopes provide information about a groundwater's age, which refers to the last time the water was in contact with the atmosphere. They can be used to evaluate the sources of pumped groundwater over time. |
| **NTU** | nephelometric turbidity units, a measurement of turbidity and clarity of water. |
| **O&M** | Operation and maintenance |
| **OTE** | Operations, testing and evaluation |
| **R & R** | Repair and Rehabilitation |
| **Ranney or Radial Well** | A horizontal well built from a central large shaft with radial intakes horizontally pushed out into the formation, usually spaced equidistantly around the circumference of the shaft. These types of wells allow water to be drawn from the lower portion of river or stream channels to maintain yield during dry periods. |
| **RO** | Reverse Osmosis. A treatment process that uses high pressure to force water through very fine membranes. |
| **SDCWA** | San Diego County Water Authority |
| **SDG&E** | San Diego Gas & Electric |
| **SCWD** | South Coast Water District |
| **SDI** | Silt Density Index, a measure of the suspended solids in water commonly used to measure the clogging potential of feedwater to reverse osmosis membrane systems. |
| **SJBA** | San Juan Basin Authority |
| **Slant Well** | A water supply well-constructed at a relatively flat angle. |

| | |
|---|---|
| **SOCOD** | South Orange Coastal Ocean Desalination Project. Former name of the Doheny Ocean Desalination Project. |
| **SOCWA** | South Orange County Wastewater Authority |
| **SWP** | State Water Project |
| **TDS** | Total Dissolved Solids |
| **UCI** | University of California Irvine |
| **UF** | Ultra Filtration |
| **USBR** | United States Bureau of Reclamation |
| **USEPA** | United States Environmental Protection Agency |
| **USGS** | United States Geological Survey |
| **WHOI** | Woods Hole Oceanographic Institute |
| **µ** | Micron |

# A. Project Information

1. Type: Ocean Desalination Feasibility Investigation
2. Title: Phase 3 Doheny Ocean Desalination Project – Extended Pumping and Pilot Plant Test, Regional Watershed and Groundwater Modeling, and Full Scale Project Conceptual Assessment
3. Start Date: January 11, 2008
4. End Date: December 31, 2013
5. Grant and Funding Information:
    a. California Department of Water Resources, Prop 50 Grant Agreement No. 4600007435 for $1,500,000.
    b. U.S. Environmental Protection Agency, STAG Grant Agreement No. XP-00T40501-0, for $848,000.
    c. U.S. Bureau of Reclamation, WaterSmart Grant R10AP35290 for $499,000
    d. Project Participants (South Coast Water District, City of San Clemente, City of San Juan Capistrano, Moulton Niguel Water District) Local Funding totaling $3,300,000.
6. Grantee and Managing Agency: Municipal Water District of Orange County
7. Contact: Mr. Karl W. Seckel, PE, Program Manager; Mr. Richard B. Bell, PE, Project Manager and Principal Engineer
8. Phase 3 Total Project Cost: $6,147,000.

# B. Executive Summary

The Municipal Water District of Orange County (MWDOC) in partnership with five participating agencies, investigated the feasibility of slant wells to extract ocean water for the planned Doheny Ocean Desalination Project (aka Dana Point and South Orange Coastal Ocean Desalination (SOCOD) Project). The Phase 3 Extended Pumping and Pilot Plant Test, Regional Watershed and Groundwater Modeling and Full Scale Project Conceptual Assessment work were initiated in January 2008. The five participating agencies provided technical review and elected official decision-maker direction through a project governing committee structure. MWDOC provided overall project management, project development and permitting, technical support work, and staffed the committee.

### Project Location and Development of the Doheny Ocean Desalination Project

The Phase 3 test facilities are located in Doheny State Beach in Dana Point, California. The test facilities consisted of the Test Slant Well, submersible pump, control vault, two monitoring wells, conveyance lines, the Mobile Test Facility, electrical service, and a temporary diffuser for discharge to the surf zone.

The full scale project would produce 15 MGD of drinking water (95% operational load factor = 15,961 AFY) and would be situated on a nearby 5-acre parcel being reserved for the project by South Coast Water District. The project site is crossed by the two regional imported supply pipelines and the adjacent San Juan Creek Ocean Outfall has sufficient brine disposal capacity. The major technical issue for the project was to determine the most cost-effective method to produce ocean water.

**Figure 1A - Schematic of Test Slant Well**

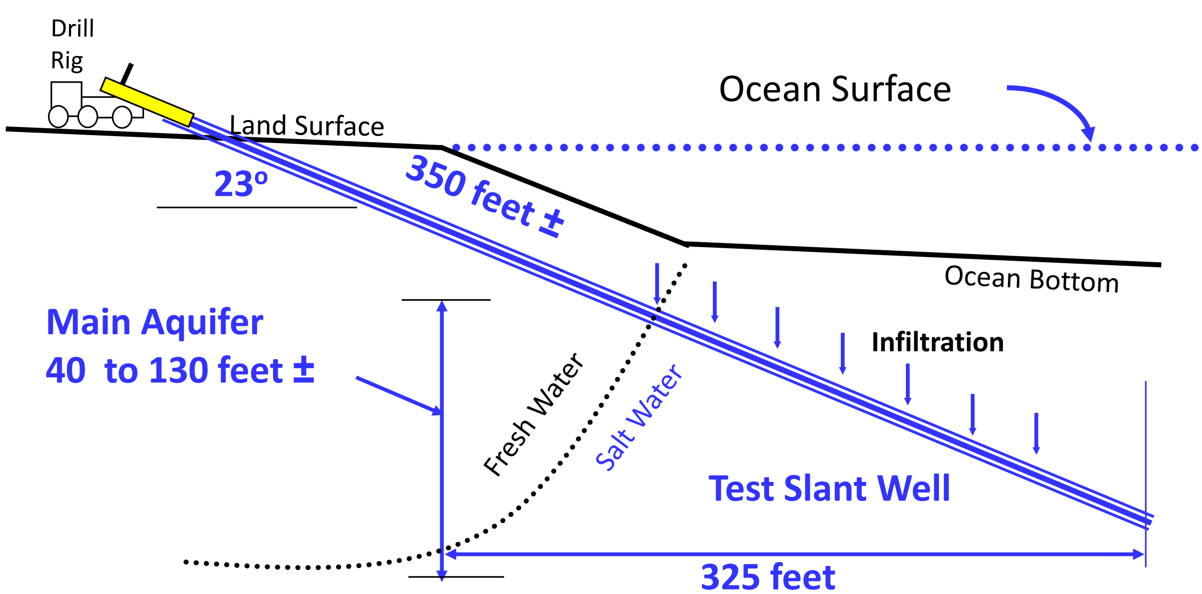
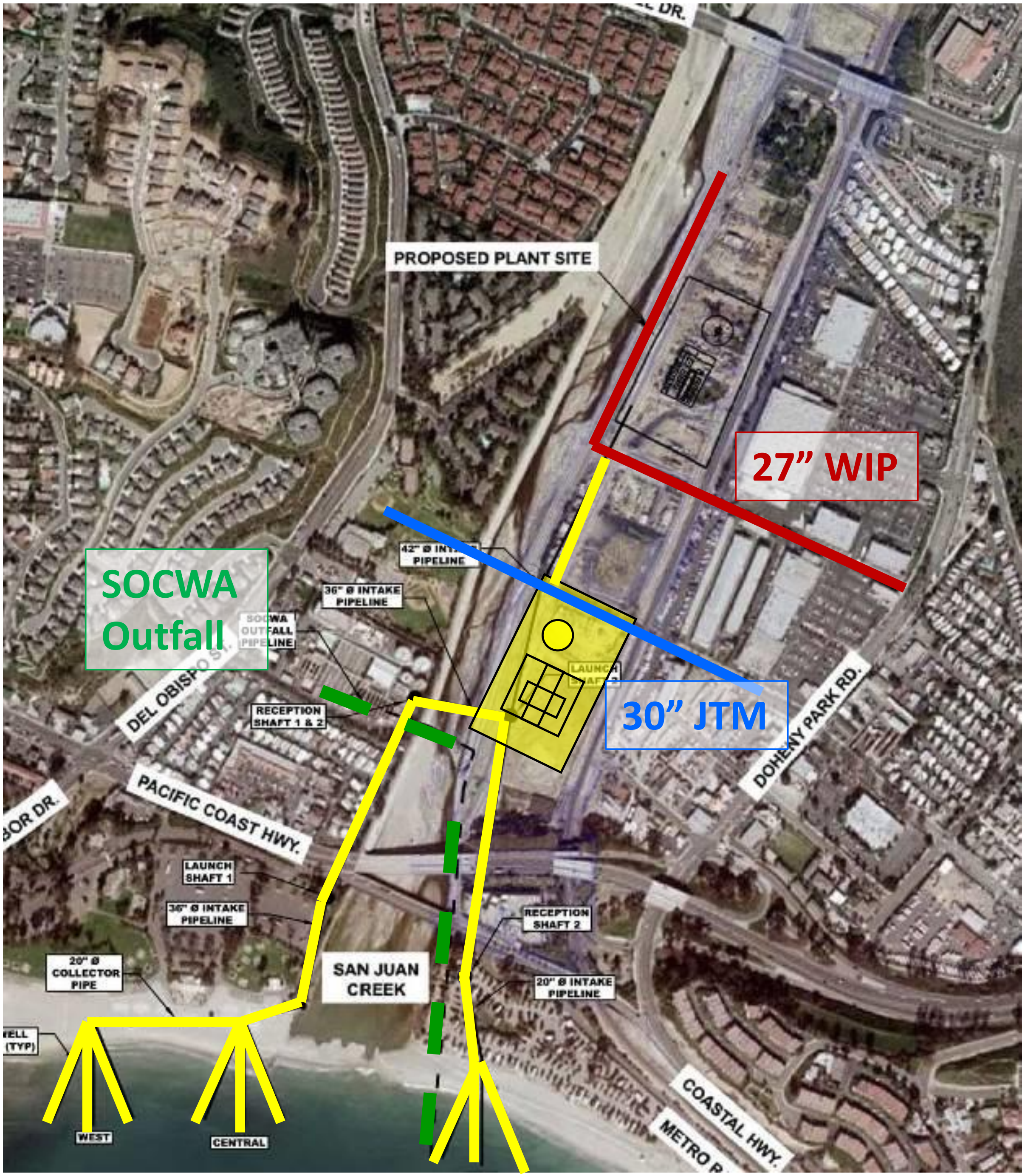
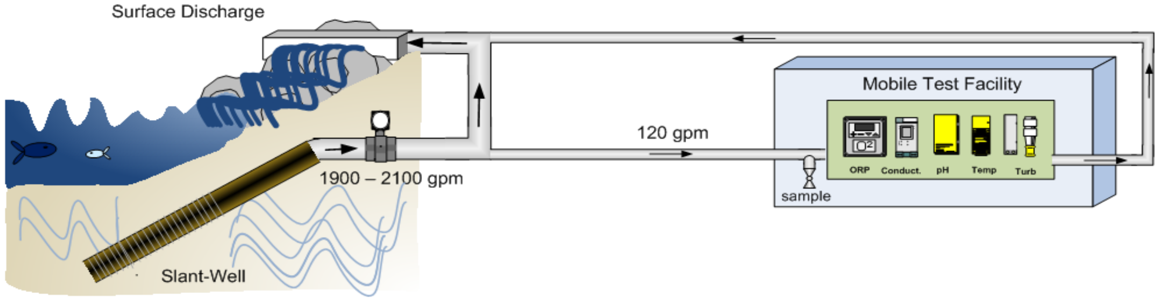


**Figure 1B - Schematic of Doheny Desal Project Layout**



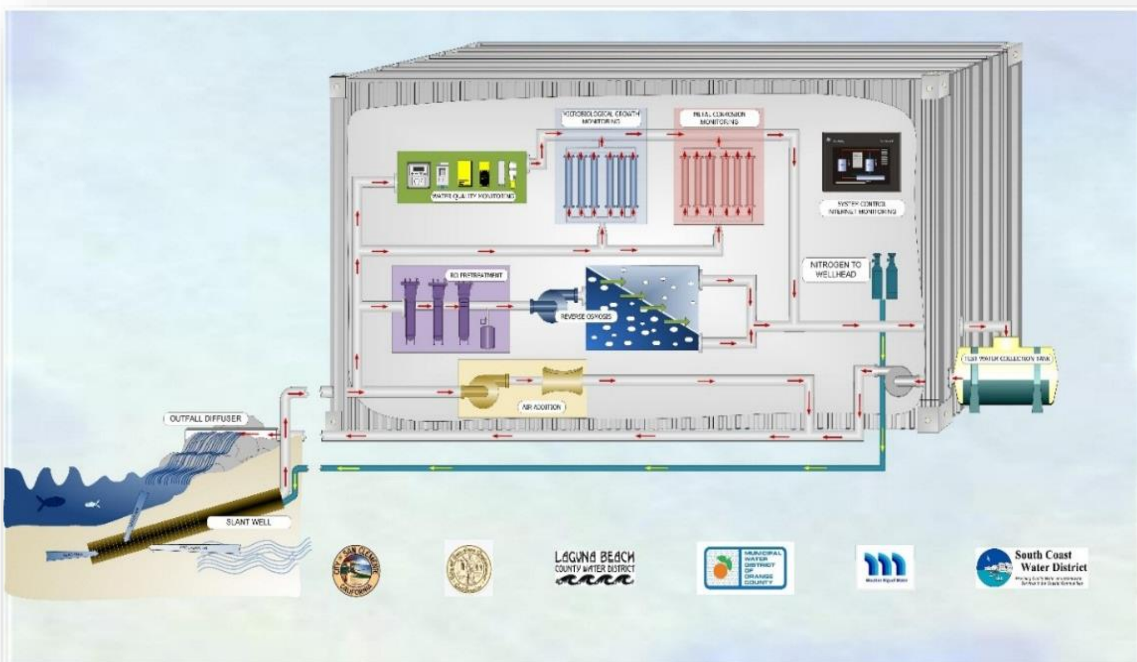
## Figure 2 - Schematic of Test Facility




## Figure 3 - Layout of Test Facilities

In 2003/04, MWDOC undertook preliminary studies to assess alternative approaches to produce ocean water in the vicinity where San Juan Creek discharges to the ocean in Dana Point. Options included a conventional open intake, a subsurface infiltration gallery, and various types of beach wells. A flat continental shelf in this location would require that a conventional open intake be situated about 7,000 feet offshore to provide sufficient depth for protection of the intake. Due to the

**Figure 4 - Mobile Test Facility (MTF)**




expected high cost and difficult permitting for an open intake system and based on early discussions with the California Coastal Commission staff, a decision was made to investigate the feasibility of constructing a subsurface intake system using a horizontal or angled well construction method. Infiltration galleries were deemed infeasible due to high costs, ocean floor impacts, clogging, decreasing yields and maintenance challenges. Radial wells (aka Ranney Wells) were deemed infeasible due to high costs, a long construction period that would exceed the 8-month off-season construction window allowed by State Parks, limitations on the ability to gravel pack the laterals, and the limitation to extend the laterals at significance distance out under the ocean.

To investigate the feasibility of a subsurface slant well intake, a phased hydrogeology and subsurface well technology investigation was undertaken. In 2004/05, four exploratory boreholes were drilled along the beach to a depth of 188 feet below the ground surface. The boreholes encountered highly permeable alluvium throughout their depth. In 2005/06, after a thorough review of several technologies it was determined that the most cost-effective approach for this location was the use of slant beach wells constructed with a dual rotary drill rig from the beach out under the ocean. A test slant well was deemed necessary to evaluate the aquifer response, water quality, and aquifer filtration. Groundwater modeling was also necessary to evaluate the impacts of the project draw on the groundwater basin associated with San Juan Creek and to determine the potential capacity of a slant beach wellfield.

In 2005/06 with grant funding support from the California Department of Water Resources, U.S. EPA and U.S. Bureau of Reclamation and MWDOC, a demonstration Test Slant Well was permitted, designed and constructed and a short-term aquifer pumping test was performed. Initial groundwater modeling indicated a full scale slant wellfield could produce about 30 million gallons per day at acceptable drawdowns to wells in the local vicinity. The results from this demonstration well were encouraging and it was then determined that an extended pumping and pilot plant test was necessary.

### Phase 3 Extended Pumping and Pilot Plant Test – AN OVERVIEW

The extended pumping and pilot plant test required the installation of a submersible pump, vault with control valves, a diffuser for surf zone discharge of the pumped water, conveyance lines to and from a mobile test facility, and electrical service. MWDOC conducted the planning, environmental documentation and permitting with the assistance of consultants. The mobile test facility was designed by Dr. Mark Williams and the submersible pump was designed by Bayard Bosserman under contracts to MWDOC. The Mobile Test Facility was procured from Intuitech and the submersible pump was procured from INDAR. The remainder of the test facility infrastructure was designed by Carollo Engineers and awarded to and constructed by SCW Contractors. This work was conducted in 2008 to 2010.

Separation Processes (SPI) was the contractor selected for the extended pumping and pilot plant Operations, Testing and Evaluation (OTE) work. They were awarded the work through a competitive proposal/interview process that consisted of staff from the participating agencies and outside experts. The OTE work consisted of pumping the test slant well for a period over 21 months to evaluate the performance of the pump, well and aquifer and to determine water quality produced from the marine aquifer, filtration performance of the aquifer, and corrosion and microbial fouling potential. In addition, the work included iron/manganese pretreatment pilot tests.

The testing work found that the pump and aquifer performed exceptionally well. The well experienced some sand clogging that was due to insufficient well development which was a result of a decision to construct the test slant well with only a 12-inch internal diameter (to reduce costs) and to utilize a high speed submersible pump that would enable a shorter test duration at high pumping rates to adequately stress the aquifer. This problem should not occur in the full scale project as proper and full development would be provided and the well would be equipped with a lower speed production pump.

Over the extended test period, the salinity increased from 2,500 mg/l to over 17,000 mg/l, which was fairly close to what was predicted by the initial variable density groundwater model. It is estimated, that under constant pumping it would have eventually reached about 32,000 mg/l when fully connected with the ocean assuming 95% ocean water at 33,700 mg/l (average of analyses during Phase 3) and 5% brackish groundwater at 2,200 mg/l. The increase in salinity showed that ocean water was slowly being pulled into the well over the test period. A major and unexpected finding was the high level of dissolved iron and manganese contained in the pocket of old marine groundwater that lies under the ocean. This water was anoxic (devoid of oxygen) and slightly acidic, and was found to be about 7,500 years old. From the groundwater modeling work, it was estimated that under full production capacity, the old marine groundwater would be mostly pumped out and replaced by ocean water within a year or so. However, further work is needed to zero in on this time estimate.

The pump out of the old pocket of marine groundwater will likely significantly reduce or potentially eliminate the need for iron/manganese pretreatment. There is also some uncertainty whether the pumped water would remain anoxic under full scale production. In all other respects, the produced water showed a very low silt density index (average around 0.5 units) and turbidity (averaged around 0.1 NTU), indicating excellent filtration by the aquifer which eliminates the need for conventional pretreatment filtration and saves costs.

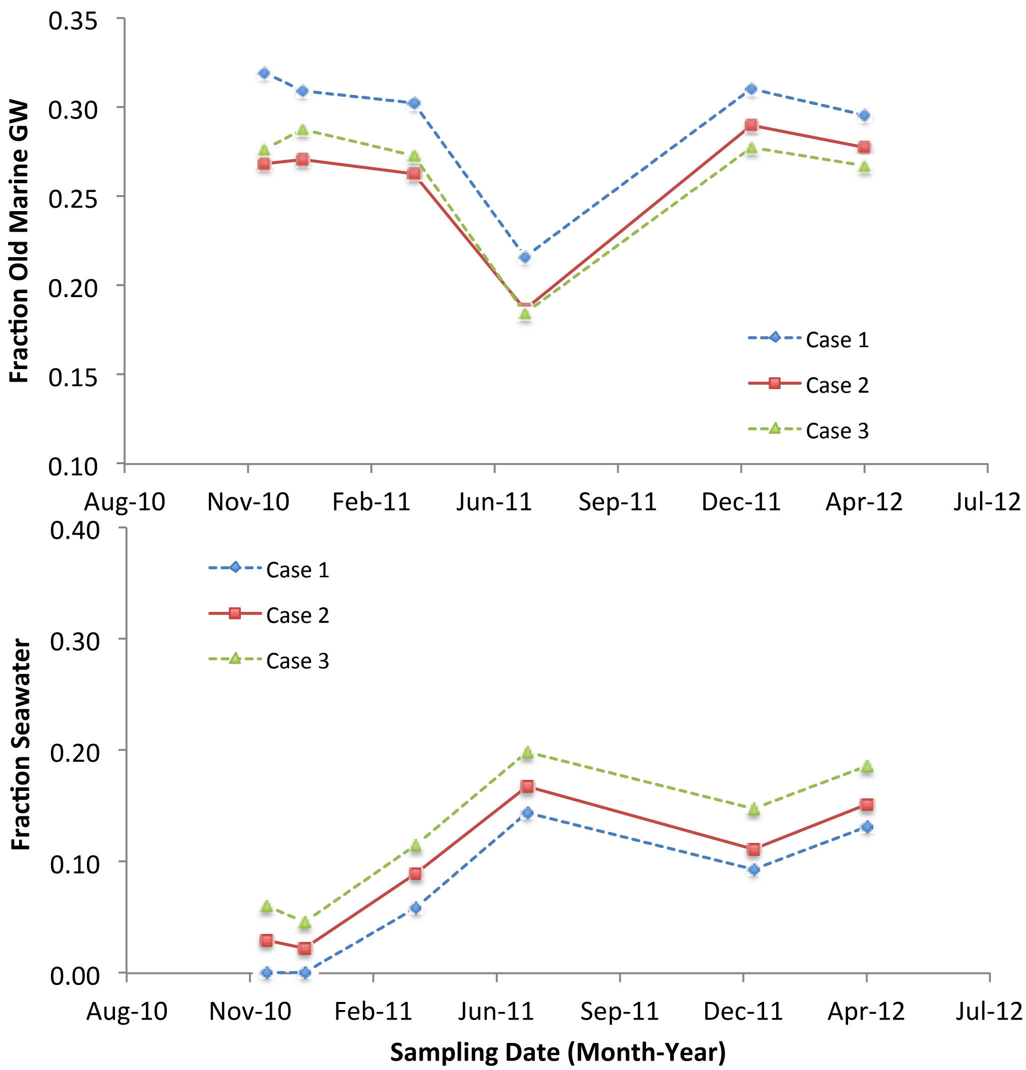
In addition, the produced water showed no presence of bacterial indicator organisms which were found to be present in high concentrations in the ocean and seasonal lagoon. Initial pump out of the brackish groundwater showed higher levels of TOC (Total Organic Carbon) which decreased with increasing production of marine groundwater and ocean water. During the initial period of pump out, a higher level of groundwater bacteria were observed which steadily decreased to extremely low levels. Biofilm growths by the end of the test were found to be less than 10 µ in thickness, a level of no concern for biofouling.

Pumped well water was run directly to the test RO units continuously for over four months. No fouling or performance deterioration was observed during the test or in the post-membrane autopsy as all the dissolved iron and manganese was easily removed as anoxic conditions were maintained throughout the test period.

A pilot plant study was conducted to test advanced iron/manganese removal pretreatment systems. The tested pretreatment processes were oxidized pressure filtration and pre-oxidized UF membrane filtration. Column tests were performed to determine the best media, oxidants, and dosages. Oxidation and sedimentation tests were also performed to evaluate approaches for use during well development to meet discharge requirements. The results showed that the oxidized advanced media filtration process provided higher levels and consistency of removal. A final decision on whether pretreatment would be required must wait until the initial period of pump out of the old pocket of marine groundwater is accomplished. It is recommended that prior to final design, that a final pilot plant test be conducted on the produced water after it has stabilized and the old pocket of marine groundwater has been pumped out.

To determine how much ocean water was being recharged into the aquifer and pumped, natural isotope testing and analyses were conducted throughout the test. This work utilized a multiple tracer approach to quantify the groundwater source captured by the slant well intake. Tracers included natural isotopes of radium, helium, tritium and radiocarbon. Three iterations of a mixing model that utilized the multiple tracer dataset were performed. The model runs suggested ocean water recharge capture was 14-20% by the end of the test with the remainder being a mixture of old marine and brackish groundwater. At the beginning of the test the capture was 0-6%. The 6% range in the model estimates can be narrowed by sampling of the old marine groundwater (see Figure 5).

**Figure 5 - Natural Isotope Model - Slant Well Source Production**




If the pumping test were to have continued, the old marine groundwater would have been most likely fully pumped out of the offshore formation and replaced by ocean water. Under steady state pumping conditions, there is a high probability that the pumped water would contain very low levels of dissolved iron/manganese. This would result from a combination of the infiltration and plug flow movement of the oxic and slightly alkaline ocean water into and through the aquifer that is reduced to either slightly oxic or anoxic groundwater as a result of microbial activity that consumes dissolved oxygen depending on the amount of available organic carbon. Furthermore, given the observed levels of dissolved Fe and Mn in the old marine groundwater, it is unlikely that their in-situ precipitation from any boundary mixing of oxygenated seawater recharge flows would have a measurable impact on the aquifer permeability at the expected Fe and Mn concentrations, especially under the plug flow conditions that would largely occur. Further, the accumulation of Fe (and Mn) oxides is likely present within the upper shallow aquifer where there is a likely redox boundary where iron precipitation would occur under groundwater ocean discharge conditions. With pumping, ocean water would flow down into the aquifer.

There are two likely locations for precipitation: (1) in the shallow zone of the terrestrial-marine groundwater interface before the water discharges into the ocean and (2) in the shallow sediments on the ocean side of the ocean water interface, where wave and tide driven pore water exchange drive high pH and oxygen rich groundwater into the aquifer. Altogether, under steady-state pumping conditions, this zone would likely contribute little iron to the ocean water that would infiltrate and move through the aquifer to the wellfield. The presence of organic carbon and aerobic bacteria in the shallow seafloor sediments utilizes the oxygen in the ocean water rendering it anoxic, as demonstrated over the extended pumping test. Further evaluation of the organic carbon content in the shallow sediments and sources should be evaluated to determine if the anoxic condition of the recharged ocean water would be maintained over the long run.

### Initial Pump Out and Disposal of Old Marine Groundwater

The alluvial channel within the continental shelf offshore of San Juan Creek was submerged by the ocean following the end of the last ice age. Under current conditions, subsurface outflows from San Juan Creek discharge out under and up into the ocean within the area shoreward of the saltwater interface. On the ocean side of this interface, the ocean filled alluvium groundwater has remained isolated since its inundation about 7,500 years ago. We have termed this “older” ocean groundwater as “old marine groundwater”.

Testing found that the old marine groundwater is slightly acidic, anoxic and enriched with reduced, divalent, dissolved iron and manganese. Dissolved iron and manganese concentrations increased by the end of the test to a peak of about 11 mg/l and 5 mg/l, respectively. Their concentrations in the old marine groundwater may range from 11 mg/l to as high as 30 mg/l, but the current range is inconclusive due to a lack of offshore aquifer water quality and microbial community conditions.

Water quality and isotope testing provided data to estimate the relative mix by source of the pumped groundwater over the test period. Based on the natural isotope data/model, the pumped water was first mostly brackish groundwater which then steadily decreased as ocean water steadily increased from zero to about 17%, and old marine groundwater. The fraction of old marine groundwater started out at zero, reached an apparent maximum of about 29% before decreasing and in time would have been fully replaced by replaced by recharged “young” ocean water. See Figure 6 for an illustration of how the change in source water would occur over time. Under the full production rate of 30 mgd ocean water recharge would be greatly accelerated from what was observed under the Phase 3 test of 3 mgd.

As illustrated, the source of water being pumped out will continually change in make up until it reaches a steady state condition. For the full scale project, initial modeling suggested that under steady state conditions the extracted well water would reach about 5% brackish groundwater and about 95% ocean water ("young" marine groundwater).

The Phase 3 test data is planned to be utilized in the calibration of a fine grid coastal groundwater flow, variable density, and geochemical model. The fine grid model will help to better predict pumped water quality over time and by source, to evaluate drawdown effects, and seawater intrusion and controls.

Under the full scale project, during the period of initial pumping when the pocket of old marine groundwater is being pumped out and replaced by "young" ocean water, there are two major questions:

(1) How long will it take to pump out the pocket of old marine groundwater?

(2) What is the best approach for handling the old marine groundwater?

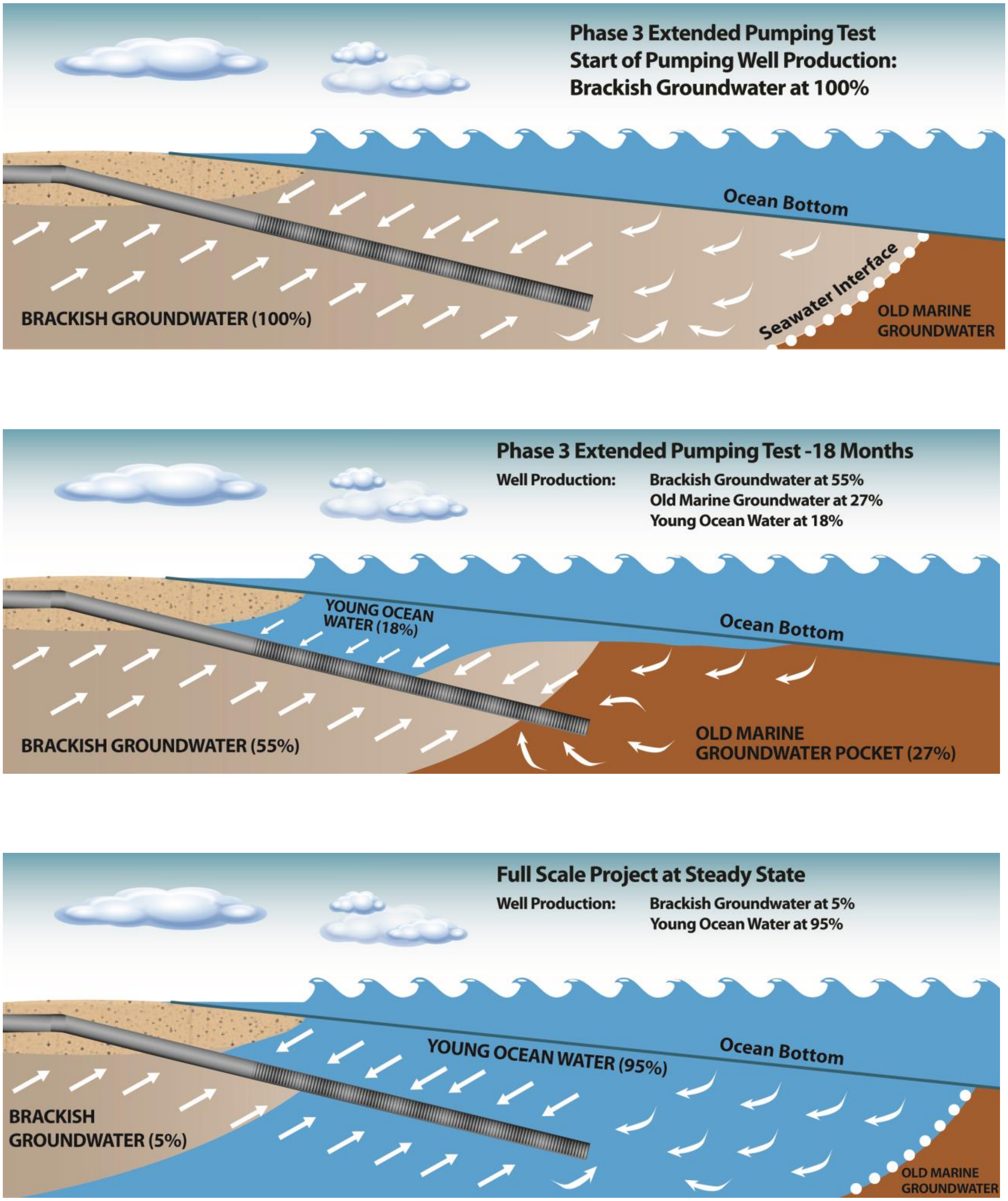
We see two basic approaches for construction of the full scale 30 mgd slant well intake capacity project: (1) include in the desalination plant an iron/manganese pretreatment unit (capital cost estimated at $50 million), or (2) pump out the old pocket of marine groundwater before completing the design and construction of the desalination plant, since it is expected that levels will drop significantly under steady state conditions to levels which will either significantly reduce or avoid the need for Fe/Mn removal.

In addressing the first approach, Arcadis (Malcolm Pirnie) assumed that the steady state iron concentration would remain constant at 6 mg/l and developed capital and O&M cost opinions for handling this amount of dissolved iron. This approach assumes a constant high level of iron/manganese throughout the project life. This is unlikely the case.

It should be noted that during the Phase 3 test, the iron concentration in the pumped water reached 11 mg/l and was fairly constant for several months. However, when considering the full scale project slant well intake production rate of 30 mgd, based on initial modeling, it would be expected that the old marine groundwater would be pumped out in about one year, reducing the concentration of iron/manganese in the feedwater to very low levels. As previously noted, the fine grid, variable density, geochemical model will aid in better understanding the old marine groundwater pump out time as well as aiding in understanding changes in water quality during the pump out period and what might be expected under steady state conditions.

For the second approach to be feasible, we need to better know how long it will take to pump out the old marine groundwater until it is fully replaced with "young" ocean water and reaches steady state conditions. During the Phase 3 test, the iron levels increased steadily and then stayed relatively constant after reaching about 10 mg/l after 8 months of pumping and then slightly increased to 11 mg/l near the end of the test; the increasing amount of "young" ocean water and the slightly decreasing fraction of old marine groundwater kept the iron concentrations relatively flat over the last year of the test. The isotope data showed a slightly decreasing fraction of old marine groundwater being pumped over the test, as the "young" ocean water recharged the marine aquifer area where brackish groundwater had discharged out under the ocean. The location of the seawater interface was previously estimated at about 1,100 feet offshore under 2005 wet hydrologic conditions and lower basin pumping. For comparison, it is worth noting that the estimated volume of the brackish water from the shoreline to the saltwater interface was about 1200 AF (at a specific yield of 10 percent) under 2005 conditions and over the Phase 3 test the pumped volume of brackish water was estimated at about 3,600 AF out of a total volume of 5,286 AF by a salinity model that used actual test data (see Figure 6).

**Figure 6 - Illustration of Slant Well Source Water Production vs. Time**



Modeling will be required to evaluate the change in fraction of source water reaching the full scale project wells as a function of pumping rate and duration. Based on the earlier Phase 2 modeling, it had been roughly estimated that the old marine groundwater could be fully pumped out within about a year or so at the much higher 30 mgd production rate. The fine grid model will improve this estimate. At steady state after pump out of the old marine groundwater, the wells were predicted to produce about 95% "young" ocean water and 5% brackish groundwater.

The blended concentration at steady state is expected to be low from the large dilution of the "young" ocean water component. The iron/manganese concentrations at steady state are largely dependent on the concentration of iron/manganese in the brackish groundwater reaching the wells and if there is any trace amount of old marine groundwater remaining. Ocean water in the vicinity of the project is fully oxidized and would be expected to have a very low level of iron/manganese (levels are higher near the shoreline and decrease offshore away from San Juan Creek). As the ocean water is recharged into the aquifer, it is anticipated that the ocean water will pick up some dissolved Fe. Under steady state conditions, the produced water is expected to have a dissolved iron concentration around 0.10 mg/l assuming brackish groundwater iron at 2.0 mg/l. At this low total iron concentration the RO membrane should not have a problem removing any oxidized portion of the dissolved iron/manganese in the produced water. However, some chemical conditioning may be required to minimize cleaning. If higher concentrations occur, higher oxidized media filtration rates than assumed by the Arcasdis cost estimate could be used to remove iron/manganese at much lower capital and O&M cost.

If an injection barrier is found to be necessary to reduce drawdown impacts, in time both the injected and slant wellfield produced water would likely be largely free of dissolved iron/manganese.

Further fine grid flow, variable density and geochemical modeling is necessary to provide a better estimate of the pump out time, to estimate produced water quality over time, and to estimate pumped water quality under typical or steady state conditions. Offshore hydrogeology borehole lithology and water quality data and geophysical surveys for alluvial channel structural data will be necessary to fine tune these estimates during the project design, but are expensive to obtain. With operational data, the best method of handling the old marine groundwater iron/manganese loads can then be determined.

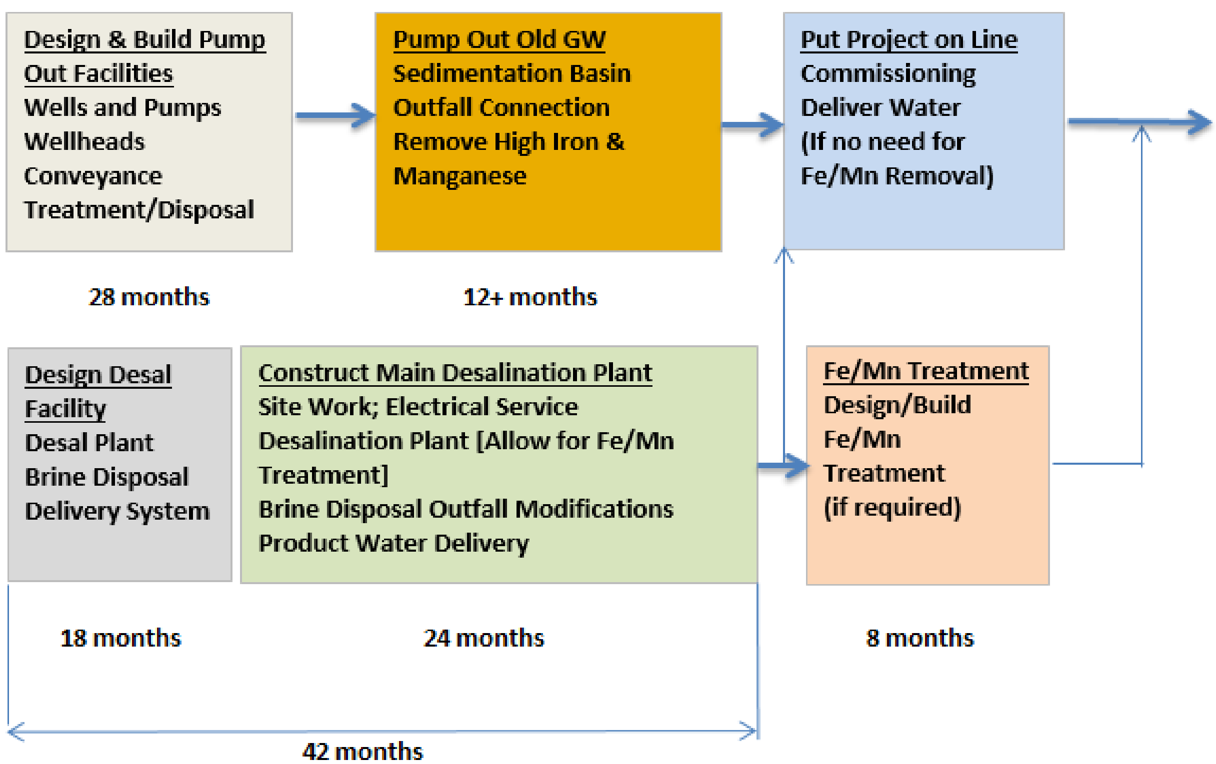
Assuming that the old marine groundwater can be pumped out in about a year or so under full scale production at 30 mgd, the second approach would be preferred. This approach would require that the project be constructed in two stages: (1) wellfield, conveyance and disposal system constructed and operated to pump out the old marine groundwater, complete pilot plant testing to finalize feedwater quality for treatment process design, and (2) complete construction of the remainder of the project. This may be necessary in any event due to the unknown steady state pumped water quality.

During the initial period of pump out of the old marine groundwater, it would be necessary to install a system to remove iron/manganese to levels that can meet discharge requirements through the SOCWA ocean outfall. The current NPDES permit does not have an iron/manganese numerical discharge limitation, but does have limits on settleable solids and turbidity, which would be impacted by the discharge of oxidized iron/manganese.  This operation would require permitting through SOCWA and under its NPDES discharge permit.

To meet discharge requirements, iron/manganese will need to be reduced to acceptable levels in a cost-effective manner.  During the Phase 3 iron/manganese pilot plant testing work, data were obtained on the effectiveness of oxidizing soluble iron/manganese followed by sedimentation to reduce the iron/manganese load.  It was found that chlorine addition was necessary to provide effective oxidation followed by sedimentation at 15 minutes detention, which nearly fully removed all the iron and manganese.  The cost for this short-term operation, for one year would include the costs for outfall use, slant well pumping energy, outfall O&M, ocean monitoring, and treatment equipment with chemicals and O&M.  The cost for one year of operation is estimated around $4.5 Million. If a longer period is required, a second year is estimated to cost about $3.5 M. Compared to the cost of installing a full scale iron/manganese removal plant at $50 Million, the two stage approach is warranted.

Figure 7 "Full Scale Project Design and Construction Staged Implementation" illustrates the sequence for the major design and construction activities for the full scale project following the recommended approach to pump out the old marine groundwater prior to a decision on Fe/Mn treatment.

**Figure 7 - Full Scale Project Design and Construction Staged Implementation**



### Regional Watershed and Groundwater Modeling

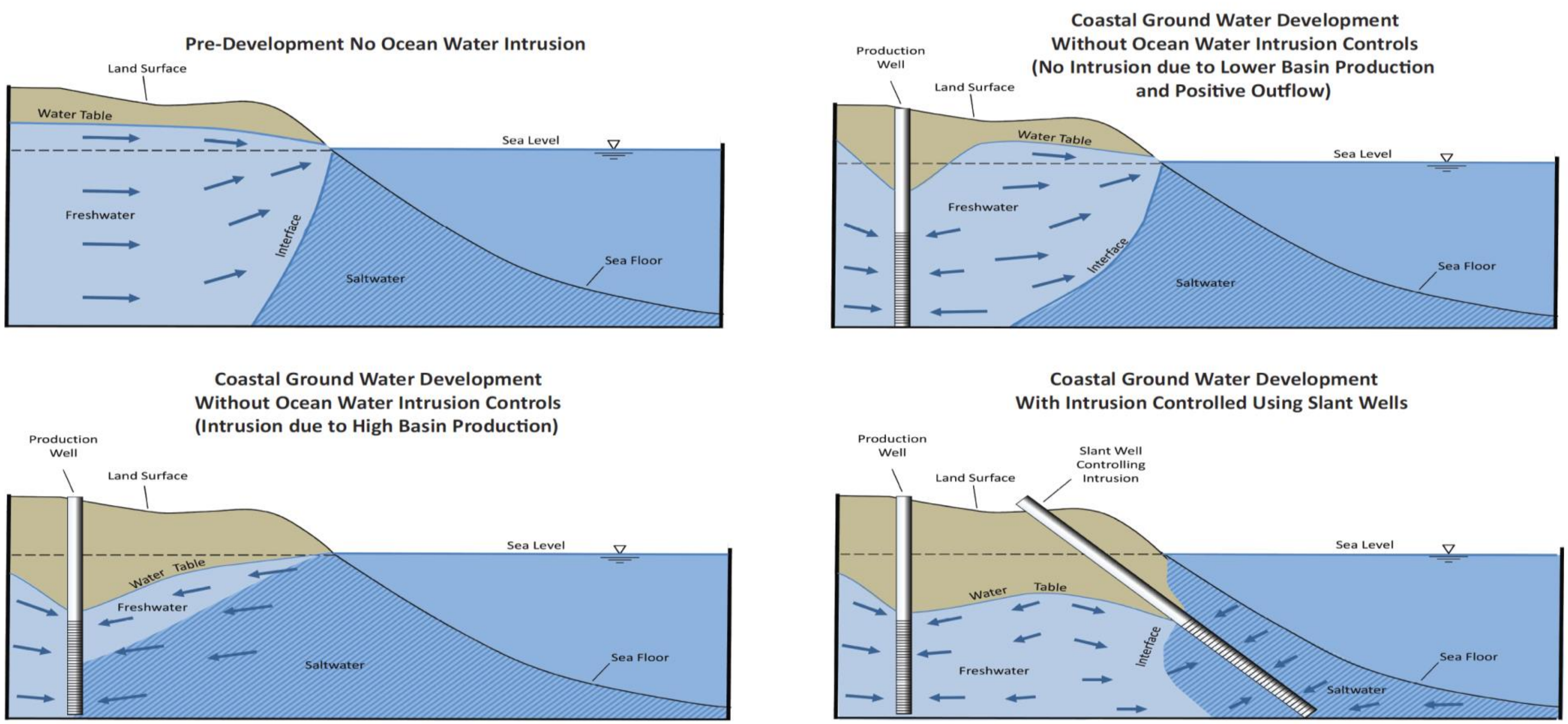
In this location, the paleo San Juan Creek alluvial channel extends out under the ocean within the continental shelf for about three miles. This paleo-channel offers a permeable connection to the ocean. The slant wells would tap into this alluvial structure to pull in filtered ocean water. Under steady state conditions, about 5% of the pumped water would be pulled in from the landward portion of the aquifer, which is brackish groundwater. Groundwater development of the Lower San Juan Basin has occurred over the last several years with the construction of two groundwater recovery desalter plants. To determine the Doheny Desal project impact on the basin and the desalter plant wells, it was necessary to develop analytical models to evaluate drawdown and groundwater take impacts on the basin.

To determine these impacts, a regional surface watershed and groundwater model was developed to determine the basin operable yield using a 64 year hydrology record (1947-2010) which included a 31 year dry period. The first tasks were to determine the basin operable yield without the ocean desalination project. This work which required nearly three years of effort, determined that the lower basin total storage capacity is about 46,000 acre-feet, about 12% less than previously estimated by DWR in 1972 and that the actual volume of water in storage in 2010 was about 30,000 af. The modeling also showed that basin yields over an extended dry and average periods would be about 8,040 AFY and 9,150 AFY, respectively, less than previously believed. Over the 64 year hydrology, it was found that basin storage levels would drop to about 25% of capacity during the long dry period and would refill relatively rapidly under average and wet periods. The model also indicated that seawater intrusion would occur over both dry and average conditions and would reach the SCWD wells in 9 to 12 years, assuming the higher production levels at the long-term sustainable yield levels, rendering them inoperable if additional desalination process treatment were not constructed. Accounting for the seawater intrusion would reduce the yields noted above by 300-400 AFY. Further work is necessary to refine these estimates.

As previously noted, about 5% of the 30 mgd slant well field production (about 1,660 AFY) would be basin brackish groundwater. In addition, the slant well field would provide seawater intrusion control through a coastal trough created from pumping. To mitigate the drawdown and take impacts on impacted producers, make-up water from the desalination project up to 1,660 AFY could be provided to them, less the amount that the basin would otherwise have to use to curtail production to avoid seawater intrusion impacts. Also, seawater intrusion control benefits that would be provided by the Doheny Desal Project should greatly reduce or fully avoid SJBA seawater intrusion control costs.

Future detailed coastal groundwater and geochemical modeling are required to fine tune drawdown impacts and to predict pumped water quality over time. This work will also evaluate physical mitigation using injection wells to create an artificial barrier by raising groundwater levels in the coastal area. This analysis will help to determine the least cost mitigation approach. Other work by the SJBA will investigate the ability to augment the groundwater supplies through stormwater conservation and recycled water and means to protect against seawater intrusion. The two monitoring wells constructed by MWDOC in Doheny State Beach should be maintained and used to monitor for seawater intrusion under upstream groundwater operations.

# Figure 8 - Illustration of Seawater Intrusion and Extraction Control



## Full Scale Project Conceptual Assessment

The full scale Doheny Desal Project will consist of five major components: (1) feedwater supply system, (2) power supply, (3) desalination plant, (4) brine disposal and (5) system integration. Following is a brief description of each major system component.

**Feedwater Supply System.** At this time, it is expected that 30 MGD of ocean water supply can be drawn from a slant beach well system consisting of nine wells constructed in three clusters of three wells each along the mouth of the paleo-channel of San Juan Creek along Doheny State Beach. The wells will be fully buried and will extend out under the ocean. Seven wells will be fully operational with two standby wells for operating flexibility and redundancy. The slant wells, wellhead vaults, submersible pumps, power supply, instrumentation cables, nitrogen feed lines, and conveyance pipelines will all be fully buried. Since the wells will be constructed on Doheny State Beach, the construction and maintenance periods are restricted to the off-peak recreational use season, September 15 to May 15.

The wells will be constructed from the beach upslope of the ordinary high water line near the back of the sandy beach, at a 23 degree angle from horizontal, fully penetrating the offshore paleo-channel alluvial deposits. The preferred construction method is Dual Rotary Drilling which avoids the need for drilling muds by advancing an outer pipe shield casing that also prevents cave ins. The well lengths will be approximately 520 feet, consisting of about 280' of 24-inch diameter blank pump housing and 240' of 12 to 16-inch diameter well screen. The long pump housing permits maximum drawdown and yield.

The wells will be constructed in arrays of three wells each with a single construction location and common well vault. The three vaults will be buried to a depth of about five feet below the beach. The vaults will contain the well headers, distribution pipeline, well spools for well cleaning, control valves, flow meters, check valves, isolation valves, nitrogen gas feed lines, and power and instrument cable connections. The nitrogen gas is required to prevent air being pulled into the well in order to minimize any potential oxidation of dissolved iron and manganese prior to the treatment processes.

Preliminary vault drawings are shown in Figure 9. Acoustical damping of the submersible pump noise to very low levels on the beach may be required.

Conveyance from the slant wells to the Desalination Plant site will be by pipeline/tunneling. Preliminary alternative alignments were identified in the Boyle Engineering Corporation Engineering Feasibility Study (March 2007). Two candidate alignments were recently laid out and costs estimated by Kiewit. A collection pipeline to each of the three well vaults will parallel the shoreline and then combine into a single line to cross under PCH and/or cross under San Juan Creek and then to the Desalination Plant. Excavation and microtunneling construction methods, with launch and reception shafts for construction under the beach, PCH and San Juan Creek will be required. The conveyance system will terminate at the Desalination Plant at the Feedwater Supply High Pressure Pumping Station. This pumping station must be in-line without a wet well to prevent air entrainment and oxidation of iron/manganese which is expected in the feedwater at low concentrations, at least during the initial start-up period.

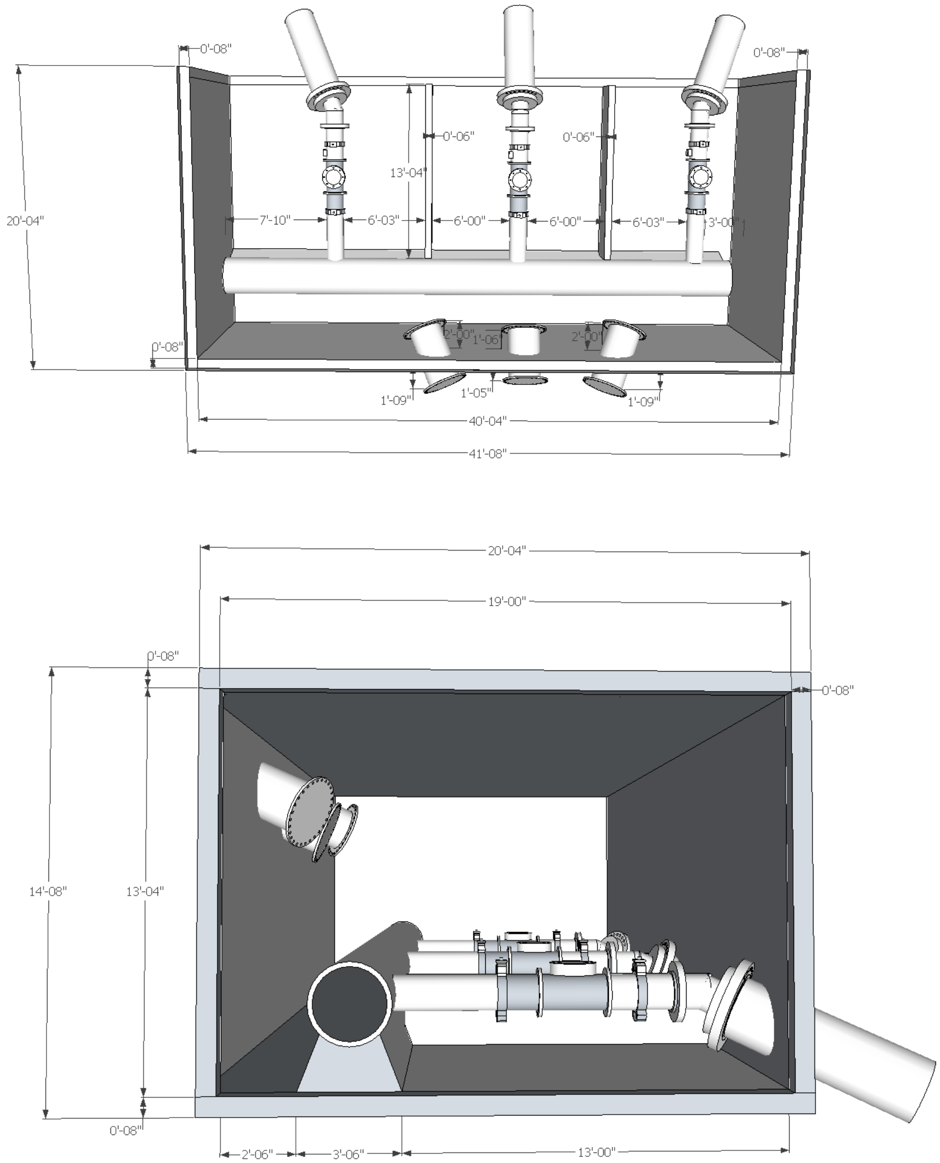



**Figure 9 - Top and Side Views of Conceptual Wellhead Vault**

**Power Supply.** Electrical service to the facility will be provided by San Diego Gas & Electric Company. SDG&E prepared an “Engineering Study for Electric Service at the Dana Point Ocean Desalination Plant” dated March 2007. An updated study will be required and is being discussed at this time. Based on an estimated load of 8.3 MW, one to two 12kV transmission circuit feeds would be extended to the plant site, with transformer, panels, cables and meter. About 1,000 feet in new trenches for 4-5” conduits would be required to extend existing feeds to the plant site. Additional facilities and equipment to step voltage down to 4kV or lower voltages would be the responsibility of the project and would be placed on the desalination plant site. The capital cost of these facilities is about $700,000 with the bulk of the power supply costs being built into the rates by SDG&E. The full options for power service will need to be evaluated. In addition, it may be possible to enter into a “demand shedding” agreement with SDG&E

for short-term "called" interruptions in the power supply to help them manage loads during peak demand periods. In exchange, a discount on the energy rate is provided. These options have not been fully explored at this time. Clearwell storage and/or reservoir storage would be used to maintain supplies during the few hours of "load shedding".

Renewable energy capabilities at the site and within the ocean are quite limited. Solar panels may be placed on the building roofs, but would only support minimal energy needs. Wave energy is considered infeasible in this location. Third party wheeling of renewable energy sources developed outside of the area is not available to water utilities at this time. Further, it would be expected that the costs for these types of renewable projects would be higher than what the electrical utility can develop. If the same requirements are placed on the project as incurred by the Poseidon Resources project, offset energy would be required to make the project carbon neutral with imported water deliveries. The cost of providing this mitigation is modest, estimated at about $50,000 per year.

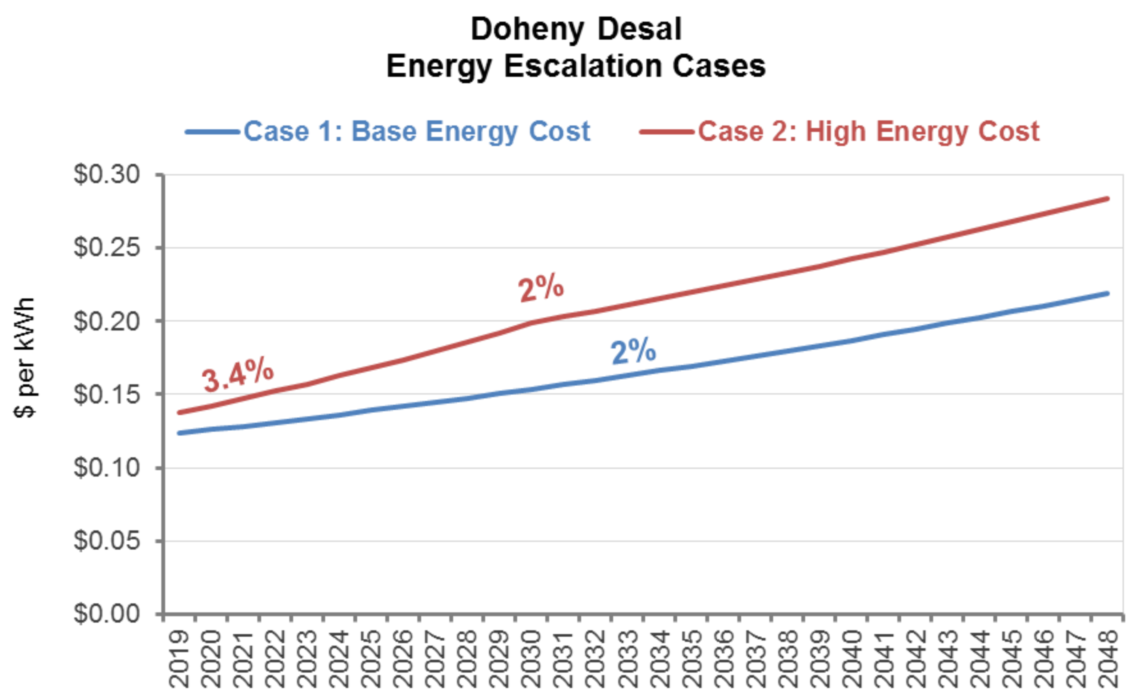
**Projected Cost of Electricity for the Plant.** Electricity charges are projected to bump up over the next 7 years and then level off due to several coincidental factors. There are three main causes for the bump up in rates: (1) California's mandate to achieve 33 percent renewable energy by 2020 which includes solar, wind and ocean generation, energy storage, and new transmission and distribution facilities, (2) phase out of once-through cooling systems and retirement of older inefficient generation facilities, and (3) closure of the San Onofre Nuclear Generation Station. Long-term estimates of electrical energy costs to supply the plant are difficult to make in California given the uncertainty in how far California will pursue renewable energy goals beyond the 2020 mandate, the effect of future increased distributed user generation and storage systems, long-term natural gas fuel prices, efficiency standards and usage, future population and economic growth drivers, and general inflation.

For the Doheny Desal economic analysis, two rate projection scenarios were evaluated. These rate projections were developed by SDCWA in July 2012 for their energy cost analysis for the Carlsbad Desalination Project and are considered applicable at this time. It should be recognized that actual energy prices will likely be higher or lower than the forecasts. It should be remembered that the Doheny Desal would be a base-loaded 24-7, 365 day per year operating facility. Recent changes by SDG&E in their cost of service have favored these types of facilities compared to typical residential customers, which has resulted in a lowering of the rates. The two cases analyzed are:

- Base Case 1 – Assumes significant RPS (renewable portfolio standard) and AB 32 implementation with electricity cost escalation at 2% annually through 2030 (5 successive 6% rate case increases from July 2012 – actual rate effective in July 2012 was 10.5¢ per kwhr) and then at 2% thereafter. The first bump up in rates occurred in late September 2013 when the AL-TOU rate increased from 10.54¢ to 11.54¢ per kwhr, a 9.5% increase in 15 months (7.6% annualized rate of increase).
- Higher Rate Scenario Case 2 – Assumes high RPS/AB 32 implementation with electricity costs escalation at 3.4% annually through 2030 (6 successive 10+% rate case increases from July 2012) and then reversion thereafter to 2%.

Figure 10 below shows a comparison of the two rate forecasts.  Since energy costs account for about 30% of the project cost, the issue of future energy costs needs to be carefully tracked.  Depending on future regulatory policy, renewable technology advancements, and shale gas production and natural gas prices, self-generation or investments in outside projects to deliver the energy to the site may be viable options, but competing with SDG&E at their cost of energy and based on the level of reliability they bring will be difficult.

**Figure 10**




**Desalination Plant.** The Desalination Plant site is a 5-acre parcel situated on the east side of San Juan Creek just north of PCH on land owned by South Coast Water District.  This parcel is situated within the jurisdictional boundary of the California Coastal Commission under the category of "Appeal Jurisdiction". The parcel is currently rough graded to an elevation of approximately 22 feet msl.  A geotechnical study is required to determine the design measures to reduce geotechnical hazards from either an earthquake, flood or tsunami.  It is anticipated that the site will need to be raised to provide flood control protection with an allowance for sea level rise.  100 or 200 year storm flood protection and flow criteria will need to be determined for protection of the site. In addition, it is anticipated that the site will need to be excavated, compacted and stabilized to provide an adequate foundation for the facility structures.

The Desalination Plant will consist of the following main system components: (1) Electrical Service Sub-Station and Equipment, (2) High Pressure Feedwater Supply Pumping Station, (3) possible Pretreatment Facilities, (4) Reverse Osmosis Desalination Building and Equipment, (5) Post-Treatment Facility, (6) Concentrate Brine Holding Storage and Discharge Connection to the adjacent San Juan Creek Ocean Outfall, (7) a potable clearwell reservoir and (8) a booster pumping station. The site will also consist of roads, parking areas and other related storage, equipment, chemical storage and feed system, and related appurtenances. The structures will need to be constructed in an architecturally pleasing style fitting to the area and will be constructed to be energy efficient with possible solar roof panels and/or green roofs and other related "green" energy systems.

The plant will receive feedwater at 30 MGD. Due to the limitations on yield, it is recommended that a recovery rate of 50% be designed in order to yield 15 MGD of product water. Energy recovery pressure exchanger devices will be utilized to recover 95% of the energy in the high pressure brine stream.

Subject to regulatory and economic feasibility, the Doheny Desal project may be designed to recover the RO concentrate streams from the City of San Juan Capistrano and South Coast Water District groundwater recovery plants by using those flows as feedwater. It is estimated that both of these plants will be enlarged from their current combined 6 MGD capacity to 10 MGD in the future, producing about 2 MGD of brine at a concentration of approximately 10,000 mg/l. This could result in an increased Doheny Desal Project plant yield by up to 1 MGD. This approach appears promising as it would reduce costs to both the City of San Juan Capistrano and South Coast Water District and to the Doheny Desal Project. The feasibility of an integrated brine recovery plan should be evaluated.

Post-Treatment for the RO permeate will be required to stabilize the water so that it is not corrosive to the distribution system. The standard method is to add in lime to the permeate to produce a stabilized water. Some locations, such as Israel now also require the addition of magnesium to achieve a more balanced cation mix. One option that will be considered for regulatory and economic feasibility is to further condition the water with about 1 MGD of brackish water, potentially from one of the SCWD wells, treated for removal of dissolved iron and manganese, disinfected and blended back with the permeate. This will allow production of water that more closely resembles in quality imported water, including providing a more natural blend of cations (calcium, magnesium, potassium) and anions (carbonate, bicarbonate, chloride, sulfate). Additional stabilization with respect to calcium carbonate saturation will be required.

Product water quality criteria will be developed for the desalination system. Key considerations are the level of bromide and boron in the product water. A second pass system at a minimum of 40% capacity is being planned to lower bromide to acceptable levels that prevent accelerated decay of chloramine disinfection residuals in the finished water. Boron levels will also be reduced when achieving the bromide levels. This will provide a product water that is fully protective of ornamental landscape plants.

**Brine Concentrate Disposal.** The waste brine concentrate from the Reverse Osmosis unit process will be co-disposed with treated municipal wastewater in the adjacent San Juan Creek Ocean Outfall. Due to the diurnal flow pattern of the wastewater flows, a regulatory storage basin at the desalination plant will be required. The concentrate will have a concentration of approximately 66,000 mg/l and will be combined with wastewater having a concentration about 800 mg/l. The current average dry weather municipal wastewater flow in the outfall is 17 MGD.  It is anticipated that this flow rate will decrease in the future with additional upstream recycling.

The SWRCB (State Water Resources Control Board) is in the process of amending its California Ocean Plan for Ocean Desalination Intakes and Brine Disposal.  When the plan is amended it is anticipated that more stringent requirements for brine discharges will be required.

The ocean outfall diffusers may need to be modified to meet the new SWRCB Ocean Plan Amendment requirements.  Modifications might include new diffusers, such as tidal or rosetta valves, or other diffuser devices to increase initial dilution to meet new regulatory requirements.  The San Juan Creek Ocean Outfall has an estimated hydraulic capacity of 85 MGD.  Plant operations and brine disposal will be ceased only during major storms when total wastewater and infiltration/inflow rates exceed the ability to discharge the brine.  This is a rare event and only occurs during very wet years when the collection system trenches are saturated and when stormflows greater than an estimated 25 year intensity occur.

The existing outfall requires structural improvements at the ocean junction structure and at the surge chamber connection from the Latham Plant to the outfall where it joins with the Santa Margarita Water District land outfall on the east side of San Juan Creek.  These improvements would be undertaken by South Orange County Wastewater Authority as they are needed for wastewater disposal.  The brine concentrate line would connect to the surge chamber structure which is located adjacent to the project site.  Flow and water quality monitoring will be required for the discharge.  SOCWA approval is required.  For project participants not discharging wastewater to the San Juan Creek Outfall, it will be necessary to acquire capacity in the system.  The current San Juan Creek Ocean Outfall capacity and ownership are shown in the following Table 1. Cost allowances for the outfall capacity have not been included in the Project Cost Estimate because final capacity selection by agencies have not yet been made and nor has an engineering study been completed, which needs to be held off until the new SWRCB Ocean Plan Amendments are finalized.

**Table 1 – SOCWA San Juan Creek Ocean Outfall – Agency Ownership**

| Agency | Ownership Percentage (%) | Capacity Ownership (mgd) | |
|---|---|---|---|
| | | 80 mgd | 85 mgd |
| Moulton Niguel WD | 15.51 | 12.42 | 13.18 |
| San Clemente | 16.62 | 13.30 | 14.13 |
| San Juan Capistrano | 11.08 | 8.86 | 9.42 |
| Santa Margarita WD | 44.32 | 35.46 | 37.67 |
| South Coast WD | 12.47 | 9.98 | 10.60 |
| | 100.00 | 80.00 | 85.00 |

Ref: SOCWA Hydraulic Capacity Evaluation, Carollo Engineers, June 2006

**System Integration.** The project water will be pumped into the Joint Transmission Pipeline and the Water Importation Pipeline. The hydraulic grade line is approximately 450 feet in both pipelines. Both pipelines cross near the Desalination Plant site on South Coast Water District property, requiring short pipelines to the two points for interconnection. Connections to Laguna Beach County Water District will require a small pump station addition at the existing SCWD/LBCWD interconnection station. Some additional provisions to assure maintenance of the disinfection residual at sag points may be required.

**Conceptual Level Cost Opinion**

Arcadis (Malcolm Pirnie) prepared a conceptual level cost opinion update for the project in 2011. The cost estimate was modified for the RO system cost, based on cost reviews provided by three firms.

Operation and Maintenance costs were estimated for labor, replacements and repairs, chemicals and feed systems, maintenance materials, and energy. These costs are shown in Table 2. Without energy, the O&M costs are estimated at about $5.8 million per year which is equal to $363/AF. Energy costs are estimated at $7.1 million per year which is equal to $446/AF. Total O&M, plus energy is estimated at $809/AF.

The overall adjusted project capital cost opinion was $152,800,000 (2012$) for the case without iron/manganese removal as shown on the following Table 3. The reviewers had more recent bid data and recommended reducing the RO system cost by 20% ($8 million). The costs include a 25% contingency ($22.6 million) and 15% for professional services ($18.8 million).

The unit cost of water from the project, in current dollars, assuming high iron and manganese removal is not required, is estimated at:

- $1,611 per AF without the MET subsidy of $250 per AF
- Capital at $588 per AF (includes contingency and professional services)
- O&M at $363 per AF
- Energy at $446 per AF
- Land Lease at $47 per AF
- GW Mitigation at $167 per AF for take of 1,660 AFY on average

- Accounting for the MET subsidy results in a cost of water of $1,361 per AF (2012 dollars)
- For comparison purposes, MET avoided water costs in 2013 (Tier 1 + Capacity Charge  Readiness to Serve Charge) amounts to $953 per AF

More detailed cost information is shown in the subsequent cost and economic analysis section.

Areas of greatest cost uncertainty are: (1) electrical energy and (2) brine disposal.  The projected rate of increase in electrical energy costs over the next decade is a major uncertainty due to a combination of factors: implementation of AB32 and renewable energy, elimination of coastal power plants once through cooling systems, and the shutdown of the San Onofre Nuclear Generation Station (SONGS). These costs will need to be closely followed and incorporated into the project economic analysis.

Brine disposal costs for purchase of capacity in the San Juan Creek Ocean Outfall for those needing new or additional capacity are not yet included in the costs.  The costs to modify the outfall diffuser to allow meeting discharge requirements are unknown at this time and no estimates have been included.  A placeholder for modifications to the outfall junction structure at $2 million has been included.  The outfall costs may further increase if significant recycling depletes the wastewater discharge.  Evaluation of new diffuser systems and the performance of the system under the forthcoming SWRCB brine disposal regulations will need to be undertaken to determine the cost for brine disposal. This work also will require brine dispersion modeling and possibly some marine biology assessments.

**Table 2 - Full Scale Doheny Desal Project O&M Cost Opinion**

| Excluding Electrical Energy<br>Malcolm Pirnie (2011) | |
|---|---|
| | No Pretreatment |
| Labor | $1,260,000 |
| Replacements/Repairs (Includes RO membranes & other) | $1,937,000 |
| Chemicals/Feed Systems | $1,300,000 |
| Maintenance Materials | $750,000 |
| Other | $550,000 |
| Subtotal O&M | $5,797,000 |
| O&M $/AF | $363 |
| Energy | $7,112,900 |
| Energy $/AF | $446 |
| Total - $/AF | $809 |

Notes

1. Average Labor rate updated to $105,000/year (OCWD GWRS O&M labor cost plus benefits)
2. Malcolm Pirnie assumed 12 FTE no Pretreatment
3. Replace First Pass RO Membranes every 3 years and Second Pass every 5 years; plus includes all other equipment replacements.
4. Energy at 4,228 kwhr/af and 10.5¢/kwhr
5. O&M increases to $421 per AF if high iron and manganese treatment is required.

## Table 3 - Doheny Ocean Desalination Project Capital Cost Opinion

| South Orange Coastal Ocean Desalination Project<br>Conventional Design-Bid-Build Project Cost Opinion (Oct 2011) | | | | |
|---|---|---|---|---|
| **Major Activity Cost Item** | **Description/Sub-Activities** | **Estimated Schedule (Months)** | **Case 1 Fe/Mn Pretreatment** | **Case 2 No Pretreatment** |
| **PRE-CONSTRUCTION PHASE** | | | | |
| **Preliminary Engineering Work** | Engineering Work and Support for Environmental and Permitting Work | 24 | $750,000 | $750,000 |
| **CEQA/NEPA Work** | Baseline Environmental Monitoring | 12 | $300,000 | $300,000 |
| | Prepare and Process EIR/EIS | 18 | $500,000 | $500,000 |
| **Additional Studies & Investigations** | Outfall Modeling & Modification Engineering | 15 | $250,000 | $250,000 |
| | San Juan Creek Property Geotechnical and Site Investigations | 15 | $100,000 | $100,000 |
| | Offshore Geophysical Investigation | 12 | $400,000 | $400,000 |
| | Offshore Hydrogeology/Downcoast Drilling/Testing Investigation | 12 | $3,600,000 | $3,600,000 |
| | Power Supply Plan | 12 | $100,000 | $100,000 |
| **Permitting and Approvals** | Agency Meetings (Parks, CDPH, RWQCB, ACOE, CCC, SLC etc) | 24 | $400,000 | $400,000 |
| | Permit Applications Supporting Technical Data/Analyses | | | |
| | Permit Applications Preparation and Submittals | | | |
| | Permit Processing and Approvals | | | |
| **JPA Formation, Legal/Financial Advisors** | JPA Formation | 12 | $300,000 | $300,000 |
| | Legal and Financial Advisor | | | |
| **Design/Construction Team Selection** | RFP Development and | 12 | $300,000 | $300,000 |
| | Design Engineer Selection | | | |
| **SUBTOTAL UP FRONT ACTIVITIES COST** | Subtotal | | $7,000,000 | $7,000,000 |
| | Contingency at 20% | | $1,400,000 | $1,400,000 |
| | Total | | **$8,400,000** | **$8,400,000** |
| **DESIGN & CONSTRUCTION PHASE** | | 30 | | |
| **Design/Construction Project Costs** | Intake and Raw Water Conveyance | | $44,759,000 | $44,759,000 |
| | Pretreatment for Fe/Mn Removal | | $43,300,000 | $0 |
| | RO Treatment | | $53,534,000 | $53,534,000 |
| | Post Treatment | | $15,636,000 | $15,636,000 |
| | Miscellaneous (Brine, SDGE, State Parks, Mitigation) | | $11,648,000 | $11,648,000 |
| | **Subtotal Construction Contractor Cost** | | **$168,877,000** | **$125,577,000** |
| | Base Construction Contractor Cost | | $138,503,250 | $102,991,000 |
| | Contingency (25%) **(1)** | | $30,373,750 | $22,586,000 |
| | **Prof Services (Design & Construction Phases at 15%)** | | $25,331,550 | $18,836,550 |
| | **Subtotal Contstruction Cost** | | **$194,208,550** | **$144,413,550** |
| **Total Project Duration and Capital Cost** | | **70** | **$202,608,550** | **$152,813,550** |

**(1) Cost of pump-out and treatment of high iron and manganese laden water prior to start of operations estimated at $4.5 million, assumed part of contingency**

## Cost Comparison to Imported Water and Economic Analyses

Local projects that develop new sources of supply provide both source and system reliability benefits. In the case of ocean desalination, there is also a water quality benefit derived by production of desalinated water that has lower salts and hardness than the imported supply. Typically, when evaluating new projects, the cost of the new supply is first compared to the projected cost of MET water. The desalination supply will offset MET water purchases and in time these costs are projected to be less than imported water costs resulting in a net positive savings (benefit #1). In addition, ocean desalination improves system reliability (benefit #2), provides a drought proof supply (benefit #3) and provides improved water quality (benefit #4). The question is how to more accurately account for these benefits. Since the local agency drought benefit is reduced under the current approach taken in MET's Water Supply Allocation Plan and water quality benefits are derived by the end-user through longer water fixture life, the analysis conducted focused only on the direct supply and reliability benefits.

The unit costs were favorably compared to the projected costs of imported water, showing a possible cross over in about 10 years after start of operations. The investment cost was also favorably compared to the value of system reliability provided by the project when compared to alternative emergency reservoir costs and capabilities.

**Cost of MET Water.** MET has recently updated the projected cost of water to 2017. MET staff believes the near-term projection of rates is a reasonable estimate. Many factors that will result in upward pressure on MET rates have been reflected in these projections including a lower water sales assumption. The effect of a lower water sales assumption by MET is more conservative and, hence, is able to provide more flexibility for covering unexpected rate impacts in the future. Discussions with MET staff indicated that out-year projections beyond 2017 would best be covered by looking at a range of escalation factors from 3 percent on the low side to 6 percent on the high side.

The future cost of water from MET is sensitive to a number of variables, making it difficult to develop an accurate long-term projection. Following are potential factors that could impact rates into the future:

- Energy Costs – The impact of California's Global Warming and Solutions Act (AB 32) on electricity prices is not factored in and is unknown at this time. Higher energy rates are forecasted due to several factors: AB32 mandated requirement for a higher mix of renewable energy sources, replacements and expansions in the Statewide electrical transmission system, phase out of Once-Thru-Cooling coastal power plants, and the shutdown of the SCE SONGS Plant (San Onofre Nuclear Generation Station) and its replacement. MET and the State Water Project Contractors are also facing a particular nuance of the AB 32 legislation whereby the electricity they import from out-of-state for Colorado River Aqueduct and State Water Project pumping may be assessed by California Air Resources Board as an "energy generator" in the state. MET staff is in the process of negotiating a method to provide relief and at this time ARB has indicated that they may provide MET some allowances, but not to the SWP. The impact of this decision could impact MET costs on the order of several million dollars per year.

- Bay-Delta Conservation Plan (BDCP) – A portion of the future costs of the BDCP have been factored into the near-term forecasts with the remaining portion of the costs to be included in the escalation range. The most recent estimate of costs for the fix, assuming MET pays for about 25%, is the cost of water for capital amortization and O&M costs estimated around $200 per AF on the MET water rate. Depending on what actually occurs, the costs could likely be either higher or lower, but would probably tend to cluster towards a higher cost. These are factored in between now and 2026 when the project is expected to start-up. Inflation is not included in these costs.
- MET Rehabilitation and Repair (R&R) Costs of Infrastructure (PAYGO funding) – MET has over $6 billion of investments in the ground not including their share of the SWP. These assets require periodic R&R or replacement. MET's asset management analysis completed several years ago estimated that the R&R program can be achieved at an annual cost of $125 M per year. This program is funded annually through the Pay-As-You-Go (PAYGO) funding, which is still considered sufficient at this time. When inflation picks up, the spending over time will have to correspondingly increase to keep in step with the R&R and replacement needs.
- SWP R&R – It is widely reported that the SWP is not maintained in nearly as good a condition as the MET system. Currently, the SWP is limited by facility conditions to about 70% of the delivery capacity of the SWP and hydropower generation has been reduced because of the failure at the Oroville facilities. MET has included some additional costs of future requests for SWP R&R funding in their budget (higher than what the State is requesting). This may or may not be sufficient to cover the deficiencies in the SWP needs. The SWP contracts expire in 2035 and as the contracts are renewed, it is possible that the renewed contracts will allow for additional levels of R&R and replacement funding without rate increases when the original debt of the SWP is fully repaid. MET and DWR are currently looking at options for the SWP R&R needs.
- Treatment Costs – The full capital and O&M costs associated with the ozone retrofit project at all five of MET's treatment plants are fully captured in the near-term projected water rates.
- Pension/Health Costs – A portion of the (not all) MET pension costs are already built into the rate projections. Other Post Employment Benefits (OPEB) have about a $500 million unfunded liability. MET believes they can eliminate the exposure with an annual contribution of about $50 M per year over the next 10 years. This is not fully reflected in the near term water rates. The other possibility is that by setting a more conservative assumption on water sales, any excess revenue, should it occur, could be used to fund this liability.
- The most recent population projections for the MET service area show an increase of 7.5 million by 2060. This increase in population will require additional new water supply at an increased cost to the region. The share of these costs between MET and the retail suppliers is the subject of future decisions.
- MET staff is examining methods to increase their fixed revenue. One such method is to change the basis of future AV tax revenue so that the percentage of tax levy remains fixed into the future at the current level rather than having the tax levy transition to zero between now and 2035 as planned. The additional tax levy, if successful, would tend to hold rates down in the future because of the estimated $80 million or so in fixed revenue that would accrue each year.

Figures 11 and 12 provide a summary of historical and projected MET water rates. Note the stair step pattern seen in the historical chart. This pattern is caused by water sales, costs and reserve variations.

**Figure 11 - MWD Water Rate History (1980-2012)**

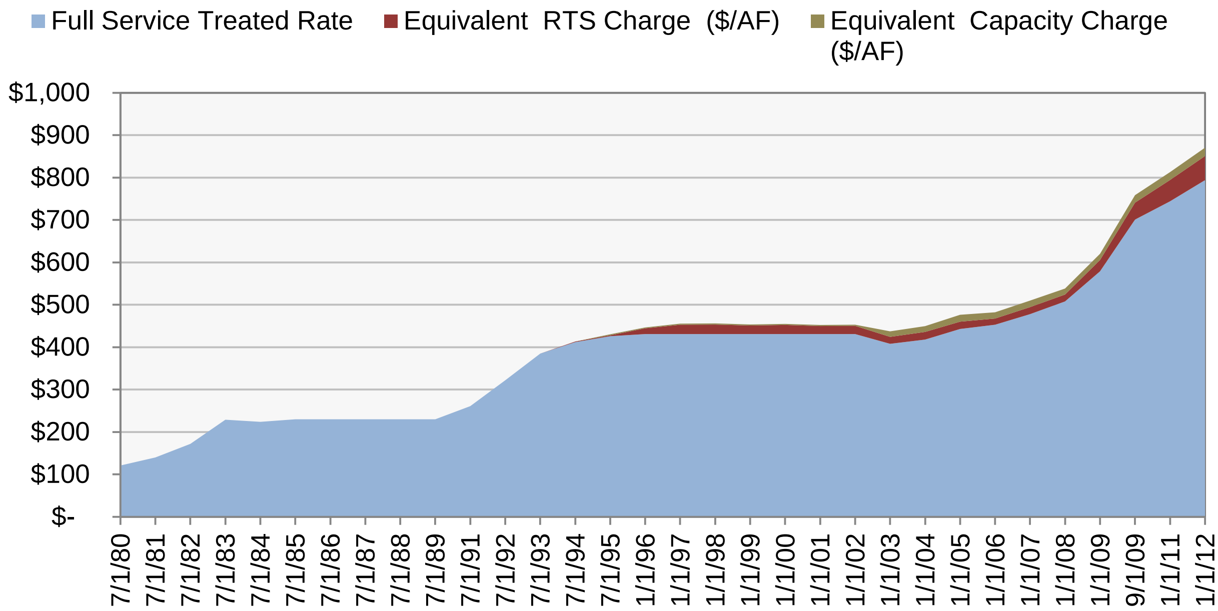
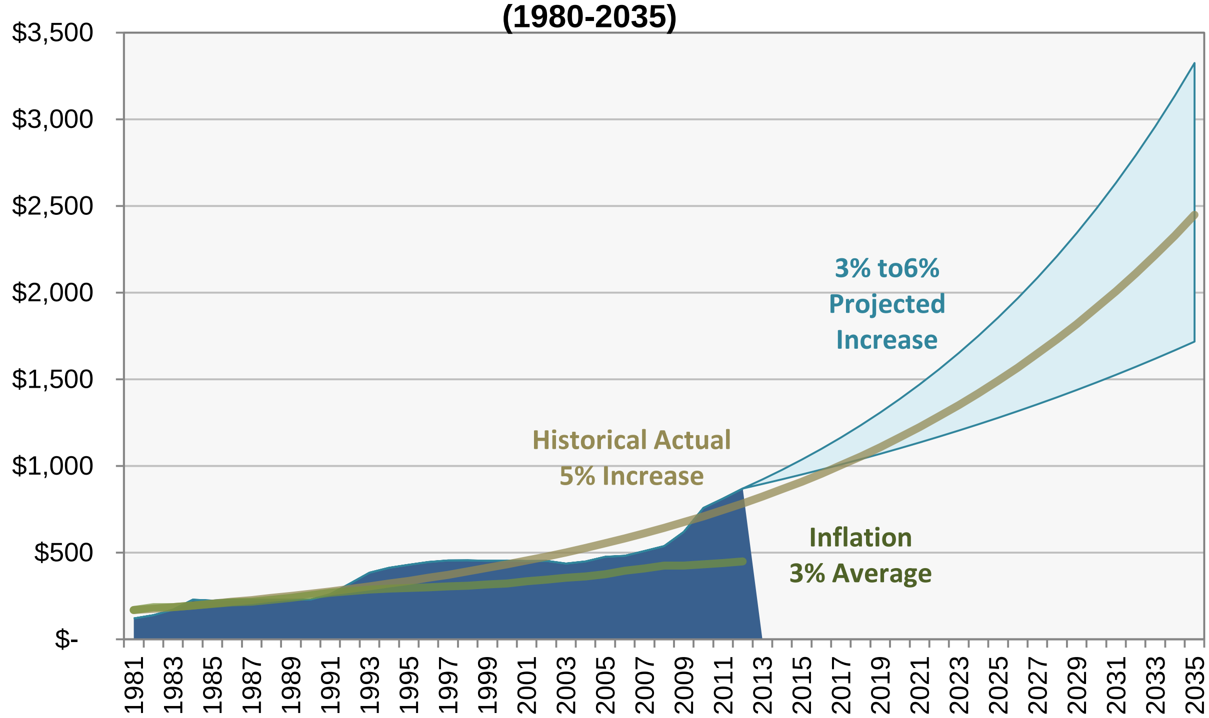



**Figure 12 - Historical and Projected MWD Water Rates (1980-2035)**



Discussions with MET staff indicate that outyear cost projection beyond 2017 ranging from an annual escalation of about 3% per year on the low side to about 6% per year on the high side can be expected. Discussions with various sources in the industry note more cost pressures pushing rates towards the higher side of this range although recent discussions with MET staff indicate the potential that MET costs will trend towards the lower side of the range over both the near and mid-term, depending on future inflation rates and other potential unexpected costs.

**Sensitivity Modeling.** A sensitivity analysis approach was utilized to set up an economic analysis which would allow various input assumptions to be tested to understand the effects on both the cost of water from the Doheny Desal Project and to evaluate the project cost cross over point with MET rates (the point in time when the project cost would be less than imported water costs). This allows an analysis of the potential net present value difference between Doheny Desal and MET water rate scenarios. Figure 9 presents the "base case" analysis. The model provides the ability to vary the following parameters:

- Cost and escalation assumptions for Doheny Desal, the level of contingency assumed and whether or not pre-treatment facilities for iron and manganese will be needed
- Energy consumption and cost information can be varied. Two periods of energy escalation were provided, 2012 to 2030 and then after 2030 to allow the rate assumptions to be tested
- General inflation rates
- Project financing assumptions including the bond interest rate and whether any grant funds will be provided
- For the economic analysis, the Present Value factor can be modified
- A place-holder for land costs and an escalation factor is provided
- The MET rates are hard coded into the analysis through 2017 and then an escalation rate is used for rates beyond 2017
- The calculation summary provides the capital and O&M cost breakdown
- The Net Present Value function calculates the difference between the project rate and the MET rate and provides a present value to 2012 dollars. The purpose of this calculation is to understand the amount of costs above the MET rates up to the point of cross over and then it also quantifies the amount of costs less than the MET rate after the cross over and summarizes the full 30-year Net Present Value (positive = savings).
- A Reliability Benefit is the last input function. This is a measure of the system reliability benefit for the project. There are good reasons for investing in a project, even if the initial cost of water

from the project may be above the cost of MET water. These include the reliability provided by having a local production facility able to supply system needs during an outage of the imported system in the event of a major earthquake or other cause and through an extended drought, as the desalination supply is independent of hydrology. The project would provide a significant emergency supply, system reliability benefit to protect the area from an outage of the imported water system as well as a drought supply benefit.

**Discussion of Economic Assumptions in Table 4.** Nine different economic scenarios were run to test the sensitivity of the assumptions in the sensitivity model, and the results can be found in Table 4. The findings indicated that the Doheny Desal Project supply cost is generally competitive with projected imported water costs. When considering the system reliability benefit of avoided investment in other local projects, the project provides a substantial cost savings and economic value to the community. The cross over point and net present value savings is most sensitive to future MET rates escalation assumption, e.g. higher MET rates improve the project comparisons. The detailed presentations of the nine sensitivity cases are included in the Appendix. The nine scenario runs include the following assumptions:

- **Reliability Benefit**. A project benefit is the ability to continue providing water into the local system in the event of an outage of the import system. The ocean is analogous to an emergency reservoir. Santa Margarita WD recently constructed the Upper Chiquita Reservoir Project at a cost of $50 M. This facility can provide emergency water supply at 23 cfs for about 2 weeks. The Doheny Desal Project can supply 23 cfs continuously. For a one month outage, the desal project provides the same emergency supply as two Upper Chiquita Reservoirs. The cost of two reservoirs would be about $100 M, which is the equivalent emergency reliability benefit that would be provided by the Doheny Desal Project assuming a 30 day outage. The value increases with the length of outage. Taking this benefit into account by amortizing it at the same rate and period as the overall project results in lowering the “cost” line (shown below by a second “project cost line” by about $385 dollars per AF (amortized cost of $100M). Accounting for the second benefit does not truly lower the cost of the project, but it does help identify and account for the emergency supply value of the project and the avoided cost of new reliability projects.

- **Fe/Mn Treatment.** The basis for the iron/manganese pretreatment system cost estimate was the assumption that Fe/Mn concentrations would remain at 6 mg/l throughout the project life, resulting in a capital cost for the oxidized filtration system at $50 million. Based on our expert panel review, it is expected that the old marine groundwater which is high in Fe/Mn would be pumped out in about a year, leaving just the 5% contribution from the brackish groundwater which has Fe/Mn concentrations around 2 mg/l. Under this scenario, the steady state Fe/Mn concentration would be 0.10 mg/l, not 6 mg/l. At this low level, pretreatment is not likely necessary, or if it is the costs would be substantially below the $50 million estimate as much higher loading rates could be utilized in the oxidized media filters. Also, use of an injection barrier along the coast to mitigate the project’s take of brackish groundwater would eliminate in about a year or so the Fe/Mn contribution from brackish groundwater, thus eliminating any need for Fe/Mn removal.

- **Energy Scenario.** For the base case, energy costs have been escalated at 2% per year and have been projected at that same rate based on studies by SDG&E and others before the shutdown of the SONGS and increase in renewable requirement to 33% by 2020.  For the high energy rate escalation scenario, 3.4% was used out to 2030 and 2% thereafter, based on work done by SDCWA.
- **Project Financing.** Project financing was assumed at an interest rate of 4.5% (current municipal AA bond rates).  It is likely the project could receive a low interest loan from the State Water Resources Control Board State Revolving Fund that would further reduce the interest rate (at one-half of the State's prior year's general obligation bond rates).

- **Additional Benefits.** The project would also provide seawater intrusion control and water quality benefits to the basin, avoiding the need for a dedicated seawater intrusion control barrier.  The project supports optimum utilization of the San Juan Basin without the basin having to incur the cost for seawater intrusion control. The basin benefits have not been factored into the economic analysis.  This benefit was NOT specifically addressed in this analysis and is likely better to be accounted for in any future mitigation discussions.

## Figure 13 – Doheny Ocean Desalination Project Economic Analysis – Base Case

### Doheny Ocean Desalination Project - Economic Analysis - DRAFT VERSION 1.8

## Input

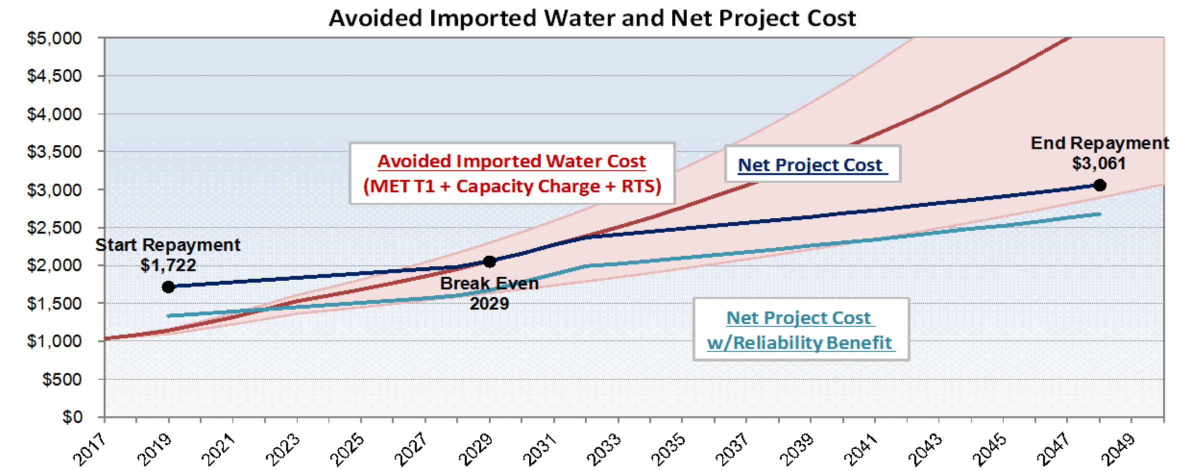
| Capital Cost | | |
|---|---|---|
| Fe/Mn Treatment? | No | |
| **Contingency of Const.** | **25%** | |
| **Start of Construction** | | 2017 |

| O&M Costs | | |
|---|---|---|
| **Energy Costs** | | |
| **Energy Usage (kWh)** | | **4,228** |
| **Base Energy Rate ($/kWh)** | | **$ 0.105** |
| **Energy Escalation 2012 - 2030** | | **2.0%** |
| **Energy Escalation after 2030** | | **2.0%** |
| **Land Cost** | | |
| Land Cost per AF (2011) | **$ 47** | |
| Lease Escalation Rate | **2.5%** | |
| **General Inflation Rate** | | |
| *Current - 2020* | **2.5%** | |
| *2021 - Future* | **2.5%** | |

| Project Financing | | |
|---|---|---|
| Grant Amount | | $ - |
| **Bond Repayment** | Select → | 30 |
| Bond Interest Rate | 4.50% | |
| **PV Discount Rate** | **4.00%** | |

| MET Avoided Costs | | |
|---|---|---|
| Esc. Rate After 2017 | 5.0% | |
| Melded Rate- % Tier 1 | 100% | |

## Output




| Project Capital Costs | |
|---|---|
| **Capital Cost (2012)** | **$130,227,550** |
| **Grants** | **$0** |
| **Contingency** | **$22,586,000** |
| **Total Cost (2011)** | **$152,813,550** |
| Total Cost Escalated to Midpt. of Const. | $181,647,290 |

| | Current Year | First Year |
|---|---|---|
| **Costs per AF** | **2012** | **2019** |
| Capital Cost | $588 | $699 |
| O&M | $363 | $489 |
| Energy | $446 | $522 |
| Annual Cost | $1,397 | $1,709 |
| Annual Cost w/ Land | $1,444 | $1,767 |
| Mitigation Costs | $167 | $205 |
| Total w/ MET Subsidy | $1,361 | $1,722 |

| Net Present Value | |
|---|---|
| Up to Break Even | ($31,436,811) |
| Break Even to End | $72,613,733 |
| Total Savings | $41,176,923 |

| Additional Reliability Benefit | |
|---|---|
| Storage Reservoir | $100,000,000 |

| Table 4 - Summary of Economic Analyses | | | | | | | |
|---|---|---|---|---|---|---|---|
| Case | Description | Fe/Mn Treat.? | Energy Scenario | MET Esc. | Cross Over Year | 30 Year PV Savings | With Reliability Added |
| 1 | Base Case – Expected w/ 4.5% Finance | No | Base | 5% | 2029 | $41 M | $141 M |
| 2 | With Fe/Mn | Yes | Base | 5% | 2032 | $-6 M | $94 M |
| 3 | High Electrical Costs | No | High | 5% | 2032 | $7 M | $107 M |
| 4 | Expected with $15 M Grant | No | Base | 5% | 2028 | $55M | $155 M |
| 5 | Low Interest Rate at 2.5% | No | Base | 5% | 2026 | $72M | $172M |
| 6 | Base w/Low MET Costs | No | Base | 3% | 2046 | $-7M | $93M |
| 7 | Fe/Mn with High Energy | Yes | High | 5% | 2035 | $-10 M | $90 M |
| 8 | Fe/Mn with Low MET Costs | Yes | Base | 3% | 2048 | $-10M | $90M |
| 9 | Low Interest & Low MET Costs | No | Base | 3% | 2040 | $-5M | $95M |

## Cost Comparison to the Poseidon Resources Huntington Beach Project

Comparison of the cost of ocean desalination projects from location to location can be difficult, especially when comparing a public project to a private project. Typically, public financing offers cost advantages compared to private equity financing. Private projects can be crafted in a manner to take on additional responsibilities and risks when they are providing water to public entities. Site characteristics can also vary and result in cost differences from project to project.

For the Doheny Desal Project, there are several site and other factors that make the costs very competitive:

- For the size of the Doheny Desal Project, slant wells are less expensive than open intakes which also require pretreatment systems to remove sediments and organic materials. Slant wells provide highly filtered water via the natural filtration process provided by the marine aquifer, thus avoiding the cost of having to construct and operate conventional pretreatment strainers, filtration and solids handling/disposal facilities. It has been determined from the results of the extended pumping test that the use of a slant well intake system will avoid the need for conventional pretreatment costs estimated at $56 million in capital and about $1 million in O&M costs, thus reducing the costs compared to other sites by more than $300 per AF.

- Co-disposal with wastewater through an existing outfall with sufficient hydraulic capacity avoids construction of a new brine discharge line and should make compliance with brine discharge easier to meet.

- System integration is relatively simple as the regional pipelines cross the desalination plant site and the pumping lift is relatively moderate at 450 feet. The savings of this integration system when comparing to other locations can be over $100 per AF or more.

- Public financing costs are typically lower than private financing

For the Huntington Beach site:

- Quite a bit of work has been done at the site and the engineering and permitting for moving forward with a construction project is nearly complete.

- Initially, the project can use the existing intake and outfall system. Uncertainties exist with the need for potential regulatory driven future changes to the intake and outfall systems. Use of the open ocean intakes also requires investments for the pre-treatment of the water.

- System integration is more complex than at the Doheny site.

- The methodology for capital recovery is on an escalated basis at 2.5% per year and has the result of lowering the early year costs and increasing the later year cost. This is an appropriate technique for phasing the costs of the project with future escalation; however, it results in a "different" cost compared to equalized annual debt recovery. The approximate first year impact is a decrease of about $300 per AF. If Doheny Desal used the same technique, the first year cost would be about $180 per AF lower.

- The costs also include repayment of private equity at considerably higher interest rates than available to public financed projects, project development costs, profit, and franchise tax and related payments. However, Poseidon has also agreed to take on much of the construction and performance risks for providing potable drinking water that meets specific quality criteria at the purchased water price.

The Poseidon Huntington Beach project unit cost as of February 2013 is around $1,800 per AF, including all costs and assuming a contribution from MET of $250 per AF. The Doheny Desal Project cost, **assuming an escalation of debt repayment similar to the Huntington Beach Project at 2.5%**, is currently estimated around $1,200/AF including all costs and assuming a contribution from MET of $250 per AF. Most of the differential in costs between the two projects can be explained by the factors noted above with the exception that:

- Poseidon found that their early cost estimates were overly optimistic compared to what was finally agreed upon. We will not have a more detailed estimate for Doheny until additional work is completed

- The element of "risk" taken on by Poseidon is not able to be defined as a cost per AF value.

## Conclusion and Recommendations

The project is awaiting decisions by the project participants, SJBA and MWDOC on the next activities for the Project. The only work scheduled at this time is the upcoming Foundational Action Plan work; each of the Phase 3 Participants are now considering what their interest and role will be in that work. Key remaining issues for the project include how best to mitigate the drawdown and take impacts from the project on the San Juan Basin, the produced water quality from the slant wellfield over time, energy costs, and project costs. The groundwater basin and project mitigation alternatives questions will be answered through the work to be undertaken through the MET Foundational Action Program proposed work. This work includes groundwater basin management planning and additional project groundwater modeling work that will be completed over the next year or two by both SJBA and several of the Doheny Desal partners. This work will be important in formulation of the final project concepts and configuration.

Over the past several years of work, a great deal of information on the basin and the project has been developed. Our understanding of the basin and the project interaction has evolved over these years but additional information, study and project development work remain necessary. With respect to the groundwater basin, the necessary work falls under the following areas:

- Complete project impact analysis using a more detailed coastal model
- Evaluate alternative project mitigation measures – providing make-up water from the project or injecting recycled water along the coast to mitigate the drawdown and take impacts of the project on the basin.

- Evaluate seawater intrusion control effectiveness with a more detailed, coastal model

- Evaluate any project impacts to the seasonal coastal lagoon water levels

- Coordinate and track work with the SJBA on its implementation of the Groundwater Management Plan Recommended Alternative No. 6 and opportunities for coordinated and/or joint facility development and use.

The work has resulted in a "lot of new news" and a better understanding of the relationship among these various parameters. At this time, both the work to be conducted by the SJBA and several of the Doheny Desal partners needs to occur to focus in on the final projects configuration.

At any time, the pre-design CEQA and permitting work could be started. The critical path items are the environmental baseline monitoring, offshore geotechnical work, and preliminary engineering for the ultimate project, or the schedule could include a waiting period to finish the work at hand. Discussions with the five Doheny Desal Participants regarding how they would like to move forward will be occurring over the next several months.

The Participants recommended staff develop a "watch" list of issues that could ultimately impact the cost and/or feasibility of the Project. The following Table 5 identifies issues to keep within our monitoring efforts as we move forward.

| Table 5<br>Doheny Desal Cost Impact "Watch" List |
|---|
| These are issues that could impact the ultimate cost of water from the Doheny Desal Project and so should be reviewed from time to time for their status and impact to the project assessment: |
| |
| 1. Financing has been at record low levels. |
| 2. Outside funding may be available from State or Federal sources, either via grants or legislative actions; the State Revolving Fund and anticipated Water Infrastructure Finance and Innovation Authority (WIFIA) funding and 2014 State Bond are examples. |
| 3. Technology Improvements can lower the costs of desalination. |
| 4. The bidding environment has been at record low levels; many companies are interested in getting involved in ocean desalination in the U.S. and California. |
| 5. The cost of energy is difficult to predict in the State of California due to implementation of AB 32, related regulatory policies and programs, hydraulic fracking and natural gas prices, changes in solar energy technology and costs, etc. |
| 6. Iron and manganese pretreatment may be necessary (the costs have been estimated) but at what level is uncertain at this time. |
| 7. The State Water Resources Control Board Ocean Plan Amendment is pending and the cost implications are unknown. New regulations could impact brine discharge through the SOCWA outfall. |
| 8. Other regulatory issues that might arise during permitting. |
| 9. Future costs will be higher due to inflation but are uncertain on a real dollar basis with improvements in technology and increased competition. |
| 10. Mitigation costs with the San Juan Groundwater Basin have to be negotiated – a placeholder has been included in the conceptual level cost opinion. |
| 11. Fisheries issues (e.g., southern Steelhead) in San Juan Creek and the Seasonal Coastal Lagoon due to groundwater drawdown may need to be worked out. |
| 12. Design/Build and Operate, and Design/Build/Operate delivery mechanisms could offer savings in life cycle project costs compared to the conventional Design, Bid, Build, Operate method. |
| 13. As other projects in California get up and operating, relevant knowledge can be transferred to the project. |
| 14. Drought supply shortages and an increasingly greater public recognition of the value of water may spur increased public and political support and willingness to pay for improved supply reliability. |

# C. Goals and Objectives

The three main goals for Phase 3 were:

- Conduct an extended pumping and pilot plant test to determine the performance of the well and aquifer, to determine water quality over time, and to determine the pretreatment effectiveness of the aquifer

- Evaluate the project impacts and mitigation approaches on the groundwater basin using a regional watershed and groundwater model by first estimating the basin yield and its performance without the project and then determine the effect on the basin with the project.

- Conduct a conceptual level assessment of the full scale project and its costs.

To support the overall goals of the Phase 3 work, 10 specific objectives were developed:

1. Obtain long-term well performance, salinity, and drawdown data and use in validating and refining the groundwater model that will be used in aiding in the design of the feedwater supply system and evaluating project impacts. Conduct natural isotope testing on the extracted water to quantify the sources of water pumped from the well over the extended test period.

2. Collect and analyze slant test well water quality to determine the character of groundwater produced over the extended pumping period. Assess how water quality may change over time as the well pulls in offshore marine groundwater and ocean water. Evaluate how potential changes in ocean water quality, such as red tides, may influence the produced well water. This information will also help to validate the existing SEAWAT groundwater model predictive capability and develop source water quality specification that can be used for project environmental review and permitting.

3. Conduct corrosion studies to determine appropriate materials for the wells, pumps, and system piping and valves.

4. Evaluate the effectiveness of using a nitrogen blanket in the test slant well headspace to minimize introduction of air into the well. This step is intended to control microbiological growth and oxidation/precipitation of dissolved iron and manganese in the produced well water and to facilitate evaluation of any oxygenated ocean water entry into the well over the test period.

5. Conduct studies to identify and measure the extent of microbiological growth over the extended pumping period on the well and selected materials, which are anticipated to result from both brackish and ocean water influences. Determine the speciation of natural organisms that may grow in the well/conveyance facilities and evaluate control approaches as necessary.

6. Evaluate the pretreatment effectiveness of the aquifer and well through the use of standardized testing procedures (e.g., silt density index (SDI), turbidity, pilot unit RO membrane performance); evaluate microbial, colloidal, and particulate fouling; and determine and test any additional pretreatment that may be necessary.

7. Conduct an extended "Under the Influence of Surface Water" study for determining if the well production is affected by San Juan Creek water quality, evaluate applicable California Department of Public Health (DPH) treatment requirements, and develop testing protocols with DPH review.

8. Test RO process performance using test slant well water initially without pretreatment then with the addition of pretreatment, if necessary.

9. Develop a regional watershed model to generate streamflows and a groundwater model to determine groundwater basin yield over an extended period of time including a dry period and to determine the impact of the project on the basin and mitigation approaches.

10. Conduct conceptual level assessment of the full scale project to develop an opinion of probable construction and O&M costs.

The Phase 3 investigation accomplished all of the above objectives.

# D. Phase 3 Project Implementation

MWDOC was responsible for carrying out the implementation of the Phase 3 test project. This work included:

### Environmental Documentation

A consultant was retained who prepared the project description and mitigated negative declaration for the Phase 3 facilities construction and their operation and maintenance, publication, processing and adoption. This work was done by Chambers Group, an environmental consulting firm.

### Permitting and Approvals

This work included the preparation of information and special studies for the permit applications, the permitting process, including agency meetings, and execution of the permits. The following permits and approvals were required and issued: (1) California Department of Parks and Recreation (Right of Entry Permit), (2) State Lands Commission (amended lease), (3) California Regional Water Quality Control Board (NPDES Discharge Permit and a Water Quality 401 Certification), (4) California Department of Fish and Game (Streambed Alteration Agreement), (5) U.S. Army Corps of Engineers (404 Outfall Nationwide Permit), and (6) California Coastal Commission (Coastal Development Permit).

### Design, Procurement and Construction of the Test Facilities

This work included consultant selection and design, procurement and construction of the test facilities. The test facilities were designed, procured, or constructed under the direction of MWDOC, who served as the project manager. This work included: (a) well inspection and redevelopment, (b) design and procurement of a submersible pump, (c) installation of the submersible pump, (d) design and procurement of a Mobile Test Facility, and (e) design and construction of appurtenant test facility infrastructure (placement of the Mobile Test Facility, pipelines, conduits, control and metering vault, outfall diffuser and electrical service).

These facilities were located entirely within Doheny State Beach. GEOSCIENCE/Boart Longyear provided the well work and Carollo Engineering provided the design and construction observation services for the test facility. Williams McCaran, Inc. designed the Mobile Test Facility, which was then procured by MWDOC. MWDOC procured this item due to its long-lead time in manufacturing and special features that were required for the Phase 3 extended pumping and pilot plant test. This also allowed MWDOC to control overall quality of the facility. MWDOC also solicited bids as part of this effort. Intuitech, a company specializing in assembling pilot water and wastewater process test equipment, manufactured the test facility. Prior to installation at Doheny State Beach, Intuitech performed shakedown testing using a freshwater supply to make sure that all process equipment, instrumentation, and electrical equipment was functioning properly. This work was observed by WMI to ensure all work was completed in compliance with the design.

### Pilot Facilities Start-up and Operation

After installation and construction of the test facilities, SPI was selected to operate the test facility and to conduct the various testing work over the extended pumping test.

### Remove/Destroy/Abandon Test Facilities and Restore Site

Participant funds are being reserved to eventually remove the test facilities and restore the project site. Currently, an agreement with State Parks allows the test facility to remain in place. Permits are also maintained. The temporary facilities that will eventually be removed are: (1) the mobile test facility (this is planned to be salvaged and moved to the full scale plant site for use during start up and for future testing work); (2) test slant well submersible pump, wellhead, discharge piping and outfall diffuser; (3) temporary electrical and instrument conduits run from the test facility to the wellheads and; (4) the meter and electrical conduit supply to the test facility. Additionally, the test horizontal/slant well and nested monitoring well MW1 located on the beach will be abandoned or destroyed if there is no future use for these facilities. MW1 is expected to be transferred to San Juan Basin Authority which will require a long-term use agreement with State Parks.

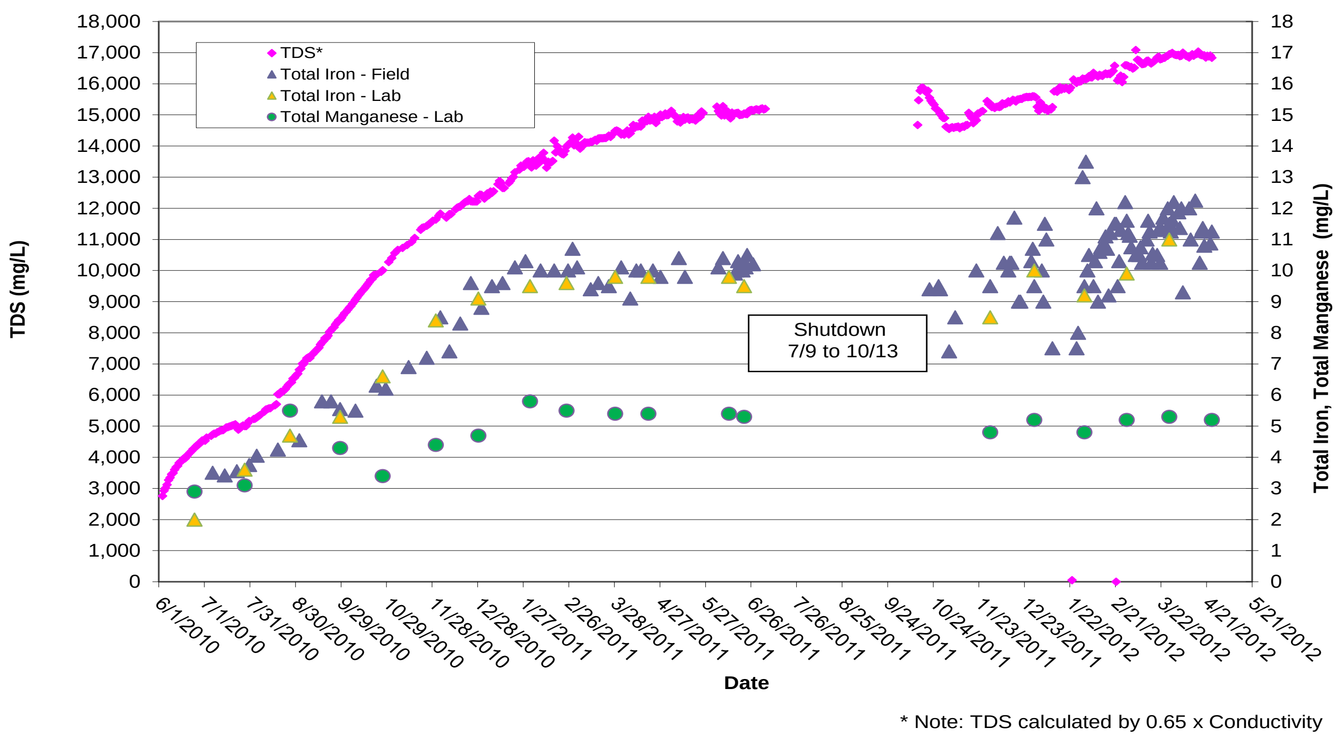
# E. Project Results – What Was Learned

Following is a summary of results, findings and conclusions gained from the Phase 3 work.

### Feedwater Supply

1. Construction and operation of slant wells along Doheny State Beach is feasible.
2. Old Marine groundwater was encountered and was found to be enriched with dissolved iron and manganese and remained anoxic (without oxygen) throughout the nearly two year extended pumping test. This test showed a continuing increase in salinity and of ocean water (from isotope data) being pulled into the well. See Figure 14.

**Figure 14 - Slant Well TDS, Total Iron and Total Manganese**




3. We believe the pocket of old marine groundwater will be pumped out over time. Geochemical modeling or offshore geophysics and borings are required to more accurately estimate the time required to pump out the old water.
4. The Marine Aquifer provides excellent filtration as evidenced by nearly two years of pumping and testing data.

5. The natural isotope study provided excellent information on the rate of connection to the ocean and the data can be used to refine the coastal groundwater model calibration. The data clearly showed an increasing trend in the amount of ocean water being pumped (which is a good trend).
6. The corrosion study recommends 2507 Super Duplex Stainless Steel for the wells. This was the material used to construct the test submersible pump.
7. The microbial biofouling study showed very low levels of microbial biofilm growth.
8. The slant wellfield configuration is expected to consist of 3 clusters of 3 wells located along Doheny State Beach for a total of nine wells. Preliminary study indicates that the wells would be about 520 feet long at an angle of about 23 degrees. The actual wellfield configuration, well and wellhead design, and wellfield capacity needs to be determined. In the future, the offshore geophysics survey will be needed for both the coastal groundwater model update and wellfield configuration design work.
9. The slant wellfield can be permitted as a water supply. The subsurface intake is regarded favorably by the regulatory agencies based on verbal comments and staff reports by the Coastal Commission for other projects. Further, the State Water Board draft Ocean Desalination Policy is also supporting a slant well subsurface intake approach. Using a subsurface intake will save significant permitting time and costs. Drawdown impacts on the lagoon are expected to be minor. Environmental baseline monitoring is required to support the environmental impact report and permitting activities.
10. Based on work being conducted by West Basin MWD, an open ocean intake system may also be feasible with the use of wedge wire screens. However, conceptual work indicates that it will be a very expensive proposition to construct a "new intake" structure via tunneling if pursued at the Doheny site. Another potential option is to put the intake in the easterly basin in Dana Point Harbor, but limited depths and fueling operations would make this option problematical. This approach was not investigated.

**Lower San Juan Basin Groundwater Yield and Integrated Operations**

1. The 2007 preliminary groundwater model has been significantly improved through development of a basin wide surface water flow model and updated groundwater model for the Lower San Juan Basin completed in April 2013. This work was developed in close cooperation with San Juan Basin Authority (SJBA) and with their Groundwater Management Plan development work.

2. The groundwater model has been recently re-calibrated to a reasonable level of accuracy for planning purposes over the more recent period, 2004-2010, a period with higher groundwater pumping than under historical operations.

3. Groundwater production in the basin during the period 2004-2010 averaged 5,370 AF per year. Under this level of production, groundwater discharges to the ocean from rising water and subsurface outflow were estimated at 1,880 AFY. The near-term pumping by San Juan Capistrano and South Coast in the Lower San Juan Basin will increase over these historical levels which will

significantly reduce the rising water and subsurface outflow losses. Continued increased pumping can result in seawater intrusion.

4. Without the Doheny Desal Project, the 2013 modeling results indicate that net basin water supply on average came out to 9,150 afy and during a repeat of the 30-year dry period the supply would decrease to 8,040 afy. These values include ocean water intrusion, rising groundwater outflow to the ocean, subsurface outflow to the ocean and change in basin storage. Under this run, ocean water intrusion began to occur; the South Coast wells were turned off after nine years when the salinity reached 2,600 ppm. It is likely these basin yield values are over estimated by about 300-400 AFY as the modeled pumping amounts results in seawater intrusion. The breakdown of this analysis is shown below in Table 6:

**Table 6 - Groundwater Modeling Production Analysis – Base Case (2i/2j)**
**Pumping Water Level Constraint with Salinity Constraint**

| | Groundwater Pumping Yield (afy) | |
|---|---|---|
| Producer | Dry | Average |
| City's GWRP Wells | 5,808 | 6,690 |
| City's Other Wells | 823 | 942 |
| Subtotal City | 6,631 | 7,632 |
| SCWD | 559 | 664 |
| Private Wells | 850 | 850 |
| Total | 8,040 afy | 9,146 afy |

5. With the Doheny Desal Project intake production at 30 mgd, the groundwater modeling indicates that on average about 5% of the slant well production (1.5 mgd, 1,660 afy) will be San Juan Creek brackish groundwater. This estimate was made by averaging the Doheny Desal draw on the basin of 1,495 afy in dry periods and 1,820 afy in average periods, averaging about 1,660 afy.

6. The modeling indicates that South Coast Water District wells (the wells in the basin closest to the ocean) would be potentially impacted by a drop in groundwater elevation between 15' to 20' with slant wellfield production level at 30 mgd. The drawdown impacts to the City of San Juan Capistrano wells further up in the basin would be approximately 1 to 3 feet.

7. The 30 mgd slant wellfield production level will protect the SCWD wells and the lower basin (e.g., Latham WWTP) from ocean water intrusion.

8. The leaking underground storage tanks at the gasoline stations in the vicinity are in the process of being cleaned up and are not expected to impact the project start up. Continued coordination with the Orange County Heath Care Agency (OCHCA) and oversight is required.

9. Drawdown impacts to the San Juan Creek seasonal lagoon at the ocean interface will likely be small as the lagoon is underlain by a shallow highly permeable aquifer and an areal extensive clay layer. The seasonal lagoon receives ocean water recharge as well as streamflow from storms and urban runoff. A more detailed coastal groundwater model will be needed in the future to assess this impact as well as intrusion through the shallow aquifer.

**Desalination Facility, Product Water Quality and System Integration**

1. The desalination facility site (5 acres) is proposed to be located just north of PCH on existing South Coast Water District property. South Coast Water District has generally reserved the site for the project. Negotiations for use of the plant site will have to be completed. The current cost estimate has a placeholder lease cost for the site. The site will require geotechnical work to prepare the foundation for location of a new plant. The rough grade of the site will need to be raised to protect against flooding including an allowance for sea level rise.

2. Product water quality will be driven by the level to which bromide and boron need to be reduced. A bromide level of 0.3 mg/l will provide adequate protection for disinfection residual stability. This requires about a 40% second RO pass. This will also produce a boron level around 0.5 mg/l which will be protective for ornamental plants. Typical second pass RO configurations for plants range from 30% to 100%.

3. System integration is relatively low in cost, as both imported water pipelines cross near the Plant site. The water would be boosted out of a clearwell reservoir to a 450 foot hydraulic grade line to match with the imported water system (Joint Regional Water Supply System (JRWSS) and Water Importation Pipeline (WIP)). Additional pumping of about 110 feet would be required to supply the water to the Laguna Beach 400 zone from the SCWD 290 zone.

**Brine Disposal**

1. The San Juan Creek Ocean Outfall has adequate capacity to dispose 15 mgd of brine flow from the Doheny Desal Project. The outfall has a capacity of about 85 mgd and present day average daily dry weather flow is about 17.5 mgd; the current permitted capacity is 30 mgd. In the future the average daily dry weather flow will likely decrease with additional recycling and water use efficiency measures.

2. The brine disposal point of connection would be into the surge chamber junction, located adjacent to the Desalination Facility site.

3. A brine disposal study needs to be undertaken with South Orange County Wastewater Authority (SOCWA) to determine if any modifications are necessary to the outfall and its diffuser for compliance with SOCWA's National Pollution Discharge Elimination Standard (NPDES) permit. The study would need to evaluate ranges of blending with wastewater for co-disposal of 0% up to about 50%.

4. Non participants in the SOCWA outfall will have to acquire capacity from agencies with excess capacity.

5. The SWRCB is in the process of amending its California Ocean Plan which will include new regulations and standards for brine disposal. This amendment is expected to be completed either late this year or in early 2014.

**Energy Supply and GHG Offsets**

1. The project will have an electrical load of about 8.2 megawatts (MW). The project is estimated to consume 4,228 kilowatt-hours (kwhr) of electrical energy per acre-foot (AF) of produced water, including the pumping lift for system integration. For comparison purposes, imported water delivered to the area from the East Branch of the SWP through the Water Importation Pipeline uses a net of about 3,440 kwhr/af.

2. An electrical service study by SDG&E was completed in 2007; we are working with SDG&E to update this study. As of this time we don't have any response from SDG&E on the cost of the new work or time required to complete the update.

3. SDG&E is embarking on a $500 million reliability upgrade to their electrical distribution system in its Orange County service area.

4. The SDG&E reliability improvements include a new enlarged San Juan Capistrano substation. This should reduce the cost of running a 12 kV service to the Desalination Facility (the previous study ran the 12 kV line from the Laguna Niguel substation).

5. SDG&E has indicated that their worst case power outage would be for 12 hours. Based on this, no back-up power would be required for this short of an outage. This does not include any electrical reliability issues that have arisen with the recent SONGS plant closure.

6. SDG&E offers programs to shed load for electrical cost savings. The two main programs are their Critical Peak Pricing and Base Interruptible schedules. These will be further explored to reduce costs to the project.

7. A new law allows an agency, not a Joint Powers Authority (JPA), to build and wheel up to 3 MW of renewable energy through the PUC regulated agency grid. However, typically these costs are higher than grid energy from SDG&E.

8. SDG&E service environmental impacts could be covered under the Doheny Desal Project EIR.

9. SDG&E indicated that 2 years are required to design and construct their service facilities.

10. Energy costs will increase due to reliability improvements, expansion of the State's transmission and distribution system, meeting renewable energy targets of 33 percent by 2020, phase out of power plants using Once Thru Cooling (OTC) technology, impact of SONGS closure and replacement power, and general rate increases. However, natural gas fuel costs continue to stabilize the cost of energy from natural gas fired power plants. Predicting future energy costs with a reasonable degree of certainty is difficult at this time. Future decisions on SONGS replacement (assumed) and consumer liability by the PUC and SDG&E have not yet been made and no projections are available.

11. Greenhouse gas (GHG) offsets will likely be required by the State Lands Commission and Coastal Commission. Without any mitigation, the annual cost for GHG offsets is not expected to be significant, at about $50,000 per year at today's market rate.

**Project Costs and Economics**

1. Project capital cost is estimated at $153 million ($2012).

2. Capital and Project Unit Costs ($/AF) are lower than other desalination projects due to the attractive project location: slant wells avoid pretreatment costs compared to an open intake system, land is available near the coast, outfall capacity is available, system integration and pumping lift costs are very low, and SDGE is investing $500 million to improve electrical service reliability to the area (which should slightly reduce the electrical service cost to the Doheny Desal Project). Slant well intakes have unit costs per capacity similar to open intake systems, but can be built at lower capacities at much reduced capital cost than open intakes, which are best suited to large scale plants.

3. Estimated project unit costs (at this time) in 2012 dollars without grants or low interest loans are:

    - $1,611 per AF without the MET subsidy of $250 per AF
    - Capital at $588/AF (includes a 25% contingency and a 15% allowance for professional services)
    - O&M at $363/AF
    - Energy at $446/AF
    - Land at $47/AF
    - GW Mitigation at $167/AF for take of 1,660 afy on average
    - Total of all costs = $1,611 per AF.
    - Accounting for the MET subsidy results in a cost of water to the local agencies in 2012 dollars of $1361 per AF
    - For comparison purposes, MET avoided water costs in 2013 (Tier 1 + Capacity Charge + Readiness to Serve Charge) amounts to $953/AF.

4. Projected imported and desalination water costs cross about 8 to 10 years out (or further depending on the assumptions used) from which point on the desalination water costs would be

lower than imported water costs.   Nine different economic scenarios were run to test the sensitivity of the assumptions.  The most sensitive assumption was the out-year escalation of MET water rates (a higher MET escalation makes the Doheny Desal Project look more favorable and a lower escalation of MET rates is not favorable to the economics of the project).

5. One of the scenarios included higher energy cost escalation, which would increase the cost of the project.  Current energy escalation costs are somewhat speculative. Future work should focus on refining the energy costs inputs to the project.

6. The system reliability benefit of the project has been estimated at about $100 Million when valued on the cost of storage at Upper Chiquita Reservoir Project.  The project also provides benefits during droughts and helps prevent water shortages during emergency situations – these last two benefits have not been captured in the economic analysis.

# F. Conclusions Regarding Slant Wells

Water supply wells when properly designed, constructed and developed can last for 75 years or more. There is no difference with Slant Wells as these will be built using tried and true water well technology along with the design and construction experience and innovations gained from the construction and operation of the Test Slant Well. We expect the Slant Wells to perform very well over the long- term and expect a useful life of 75 years.

### Well Production Capacity

Based on the Test Slant Well pumping test at 2,100 gpm and recent groundwater modeling, we expect the full scale wells will be able to produce 3,000 gpm. Drawdowns, including well interference, will be approximately 90 feet vertically from mean sea level to the pumping water level in the well to produce the 30 mgd from seven pumping wells with two wells on rotational standby. The aquifer thickness is about 200 feet along the coastline, which is sufficient to allow the expected drawdowns and well yield. Should a problem occur during the summer when beach access is restricted there will be two standby wells that can then be turned on to continue uninterrupted production at the 30 mgd level. Drawdown impacts to wells in the San Juan groundwater basin will only be significant to the most nearby wells owned by South Coast Water District.

### Well Design, Construction and Development

Design and construction of the full scale slant wells will need to be approached similarly to conventional water well design and drilling, but since the wells will be relatively flat in slope, additional care must be taken in gravel placement and well development. The design and construction will be aided through the experience gained in design and construction of the Test Slant Well. A key to the long-term success of the wells will be to provide thorough development work to assure minimum levels of sand clogging to the gravel pack. Sand clogging can occur over time in a well when it is not properly designed, constructed and/or developed. Causes include too large of well screen slot spacing, too large of gravel size in the gravel pack, gaps in the gravel pack, and most commonly, insufficient development of the well. The well screen and gravel pack size can be properly sized assuming the well designer has good technical capability and experience. Improper well development can occur due to insufficient swabbing, bailing and/or air lifting and due to insufficient development pumping rate and time.

For the full scale slant wells development, the development pumping rate needs to be around 1.5x the production rate with development pumping over a sufficient period of time to allow complete removal of entrainable fines from the near borehole formation. Assuming the full scale well capacity at 3,000 gpm, the development pumping rate should be specified at 4,500 gpm.

To assure adequate development pumping, procurement of high speed 4,500 rpm pump(s) in advance of the construction will be required. Well contractors typically do not stock submersible pumps of this capacity that would be able to fit into the well. Contractors often use suction development pumping, but this option will not be possible, as these pumps are limited to a suction or drawdown of 32 feet and a greater lift will be required. The designed drawdown will be approximately 45 feet below sea level (lower low water) and the wellhead floor elevation will be approximately minus 2 feet MSL, a differential of 43 feet, exceeding suction limits.

Another consideration in the construction of the nine wells is the ability to complete the work within the 8-month winter time window. This will likely require three well drilling crews working concurrently. The advantage of three wells drilled from a single site is the time and cost savings from moving the drill site. The well driller will need to possess well in advance of construction three large dual rotary drill rigs (DR-40) and trained crews. Sufficient lead time will need to be provided to acquire any additional rigs from the manufacturer.

### Well and Pump Materials and Corrosion Protection

The Slant Wells will be constructed with Super Duplex 2507 Stainless Steel, an alloy which showed very little corrosion over the extended pumping test and which is considered suitable for achieving a long useful life for the well. Over the nearly two year extended pumping test, this alloy showed no corrosion. It is used in many ocean desalination projects worldwide. Super Duplex 2507 will not support biofouling iron bacteria that are common in carbon steel cased wells. It is considerably less costly than AL-6XN, another superior stainless steel used in ocean applications.

### Long-Term Aquifer Performance

Over the nearly two-year extended pumping test, the step drawdown test indicated no observable change in aquifer losses. Aquifer loss can occur in certain types of aquifers that are susceptible to biochemical in-situ encrustation or precipitation, especially in limestone formations. For the alluvial aquifer system offshore of San Juan Creek this condition will not occur.

During the initial start up pumping period, the wells will pump out the old (age 7500 years) marine groundwater that is anoxic and enriched with dissolved iron and manganese. As the wells pump, the ocean water, which is oxic and has only trace levels of iron and manganese, will slowly recharge the aquifer and flow towards the well. No mixing will occur along the boundary of the marine groundwater and recharge front of ocean water, except for trace convective diffusion effects which will have no observable effect on aquifer permeability due to any minimal oxidation along the front as the masses in the boundary zone are insignificant.

The oxic ocean water will slowly become less oxic as microbial activity consumes the available organic carbon and dissolved oxygen as the recharging ocean water flows through the aquifer to the wells. Since the ocean water will have some dissolved oxygen over part of its flow course to the wells, this oxic condition will not cause any further dissolution of iron and manganese minerals that might remain in the sediments. Likely all of the iron and manganese mineral oxides in the original sediments were fully dissolved out of the formation since the time the ocean flooded these sediments, some 7,500 years ago ("old marine groundwater"). Over the extended pumping test, the well was pulling in about 20% ocean water, which became anoxic by the time it reached the well. This ocean recharge most likely entered the well near its upper screens that are only 50 feet below the ocean floor. Sufficient organic carbon was available to the naturally occurring aerobic bacteria in the seafloor sediments. The travel path to the remainder of the screens is longer and will allow for further uptake of any dissolved oxygen in the recharging water. The San Juan Creek and lagoon produce significant organic carbon loads which are swept out to the ocean by periodic storms. This condition is likely to indefinitely continue into the future.

Within the aquifer, where the ocean water groundwater flow and brackish groundwater flow boundary occurs, there will be a small mass reaction over time along this boundary due to slowly varying heads and tidal forces that will result in some convective diffusion along the boundary area which would cause some iron oxide precipitation within this brackish/ocean water flow boundary. However, the masses are quite small compared to the volume of the alluvium pore space that it would take a very long time to seal this flow boundary with iron oxy-hydroxide precipitates. The effect would be to reduce the amount of brackish groundwater that would enter the wells, which is a desirable outcome.

The project microbiologist, Dr. Sunny Jiang from UCI studied biofouling rates over the two year extended pumping test. Biofouling rates were found to be very low with biofilms less than 10 µm in thickness on the stainless steels. She does not expect much biofouling activity in the full scale wells.

Under the initial period of pump out, a large portion of the pumped water was brackish groundwater. This water has a much higher TOC than the old marine groundwater and ocean water. Initial levels of naturally occurring bacterial growths were fairly high but declined dramatically as the TOC levels dropped significantly as the ocean water was pulled into the well. It is uncertain what impact if any the project will have on the seasonal lagoon associated with San Juan Creek, as this area is underlain by an extensive 4-foot plastic clay layer that minimizes drawdown effects on water levels in the lagoon. The reverse condition is also true – the lagoon should have very little if any effect on the water quality produced from the slant wells.

### Well Oxidation Control

The wells will be designed to be fed nitrogen gas into the headspace in the well above the pumping water level to prevent oxygen transfer into the water. This was used successfully over the Phase 3 extended pumping test and performed quite well.

### Well and Pipeline Cleaning

If the ocean water that enters the wells contains some dissolved oxygen it will then mix with any anoxic brackish groundwater that has dissolved iron and manganese that enters the well. Once the mixing is initiated the oxidation reaction times are fairly rapid. If the DO levels are above about 1 ppm, this will lead to oxidation during the movement of water through the pipeline to the plant of dissolved iron and manganese. Under this condition, some accumulations of iron deposits along the walls in the upper well screen area, through the pump column, and along the conveyance pipeline can be anticipated. A mitigation design measure is to size the conveyance system to maintain high velocities around 8 to 9 fps, within a reasonable headloss, to help to scour and minimize iron deposition accumulations.

The submersible pumps will be serviced or replaced once every 5 to 10 years along with well inspection and any required maintenance. It may be necessary to acquire a dual rotary drill rig with angled set up to allow for less costly well maintenance, as the mobilization costs can be high as these rigs are often kept out of state as they are frequently used in the mining industry. In the future, the merits of this approach should be evaluated.

### Phase 3 Final Reports

Separately published Project reports from Phase 3 are listed below in Table 7.

**Table 7 - Phase 3 Final Reports**

| # | Title | Author | Issued |
|---|---|---|---|
| 1. | Project Summary Report | MWDOC | Final<br>Jan 2014 |
| 2. | Volume 1 – Phase 3 Project Development Report | MWDOC & Carollo Engineers | Final<br>Sep 2013 |
| 3. | Volume 2 – Pilot Plant Operations, Testing, Evaluation Report | SPI | Final<br>Aug 2013 |
| 4. | Volume 3 – Phase 3 San Juan Basin Regional Watershed and Groundwater Models Report | Geoscience | Final<br>Nov 2013 |
| 5. | Pilot Testing of Slant Well Seawater Intakes and AWT Pretreatment Technologies for Control and Removal of Iron and Manganese | SPI | Final<br>July 2013 |
| 6. | Expert Panel Workshop Report: Offshore Hydrogeology/Water Quality Investigation Scoping, Utilization of Slant Beach Intake Wells for Feedwater Supply | Dr. Susan Paulson, Flow Science and MWDOC | Final<br>Oct 2012 |
| 7. | Final Report: Desalination Corrosion Study | Dr. Joseph King, Engineering Materials | Final<br>May 2012 |
| 8. | Natural Isotope Tracer Study: Test Slant Well Phase 3 Extending Pumping Test | Matthew A. Charette, Ph.D. - Coastal Groundwater Consulting & WHOI | Final<br>Nov 2012 |
| 9. | TECHNICAL MEMORANDUM: Aquifer Pumping Test Analysis and Evaluation of Specific Capacity and Well Efficiency Relationships, SL-1 Test Slant Well | Geoscience | Final<br>Sept 2012 |
| 10. | Microbial Testing – Phase 3 Extended Pumping Study | Dr. Sunny Jiang, UCI | Final<br>Nov 2012 |

# Appendix

## Project Photographs

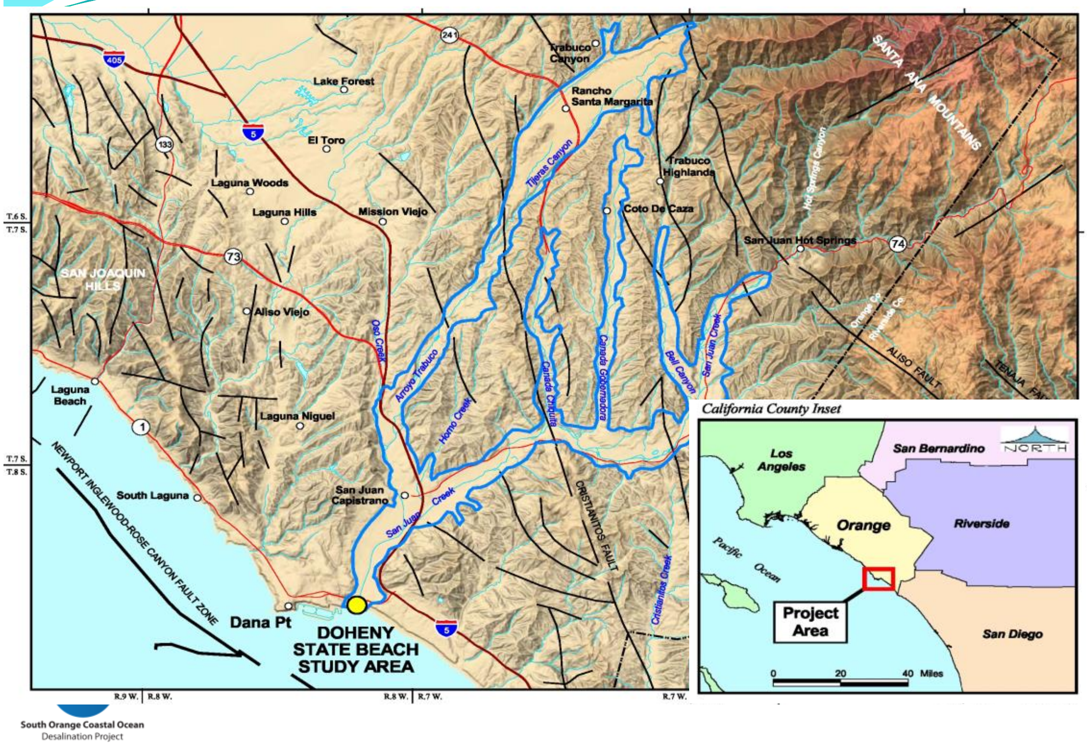
## Groundwater Modeling Exhibits

## Project Economic Analyses Scenarios

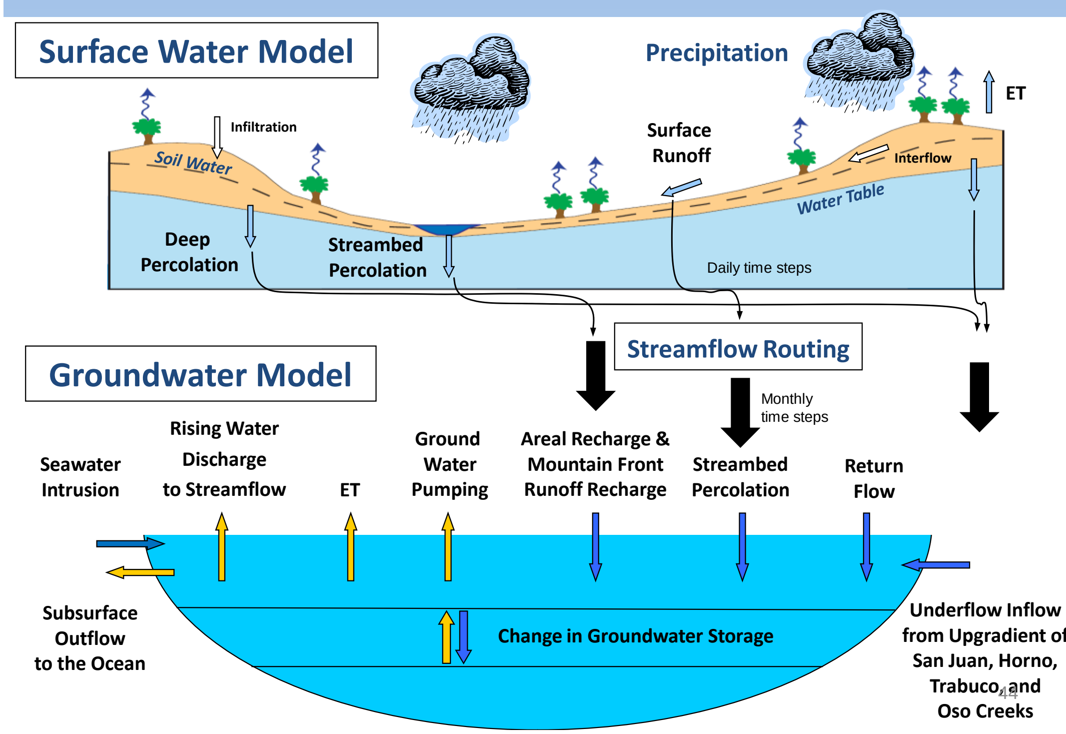
## View of Slant Well and Test Facility Site Doheny State Beach


## Mobile Test Facility

# San Juan Groundwater Basin




# Surface Water Model/Groundwater Model Interface



# Project Economic Analyses Cases

## Economic Analysis – Case 1 Base
## No Fe/Mn Pre-treatment (with MITIGATION costs)

### Doheny Desalination Project - Economic Analysis - Draft Version 1.8

#### Input

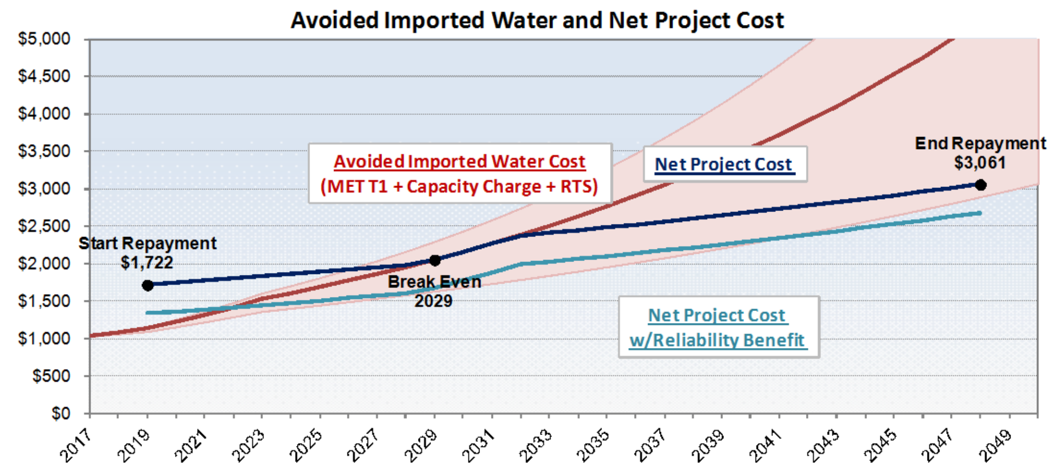
| Capital Cost | | |
|---|---|---|
| Fe/Mn Treatment? | No | ☐ |
| **Contingency of Const.** | **25%** | |
| **Start of Construction** | | 2017 |

| O&M Costs | | |
|---|---|---|
| **Energy Costs** | | |
| **Energy Usage (kWh)** | | **4,228** |
| **Base Energy Rate ($/kWh)** | **$** | **0.105** |
| **Energy Escalation 2012 - 2030** | | **2.0%** |
| **Energy Escalation after 2030** | | **2.0%** |
| **Land Cost** | | |
| Land Cost per AF (2011) | $ | 47 |
| Lease Escalation Rate | | 2.5% |
| **General Inflation Rate** | | |
| *Current - 2020* | | 2.5% |
| *2021 - Future* | | 2.5% |

| Project Financing | | |
|---|---|---|
| Grant Amount | | $ - |
| **Bond Repayment** | Select → | 30 |
| Bond Interest Rate | 4.50% | |
| **PV Discount Rate** | **4.00%** | |

| MET Avoided Costs | |
|---|---|
| Esc. Rate After 2017 | 5.0% |
| Melded Rate- % Tier 1 | 100% |

#### Output




| Project Capital Costs | |
|---|---|
| **Capital Cost (2012)** | **$130,227,550** |
| **Grants** | **$0** |
| **Contingency** | **$22,586,000** |
| **Total Cost (2011)** | **$152,813,550** |
| Total Cost Escalated to Midpt. of Const. | $181,647,290 |

| Costs per AF | Current Year 2012 | First Year 2019 |
|---|---|---|
| Capital Cost | $588 | $699 |
| O&M | $363 | $489 |
| Energy | $446 | $522 |
| Annual Cost | $1,397 | $1,709 |
| Annual Cost w/ Land | $1,444 | $1,767 |
| Mitigation Costs | $167 | $205 |
| Total w/ MET Subsidy | $1,361 | $1,722 |

| Net Present Value | |
|---|---|
| Up to Break Even | ($31,436,811) |
| Break Even to End | $72,613,733 |
| Total Savings | $41,176,923 |

| Additional Reliability Benefit | |
|---|---|
| Storage Reservoir | $100,000,000 |

## Economic Analysis – Case 2
## Base Case with Fe/Mn Pretreatment (with MITIGATION costs)

### Doheny Desalination Project - Economic Analysis - Draft Version 1.8

#### Input

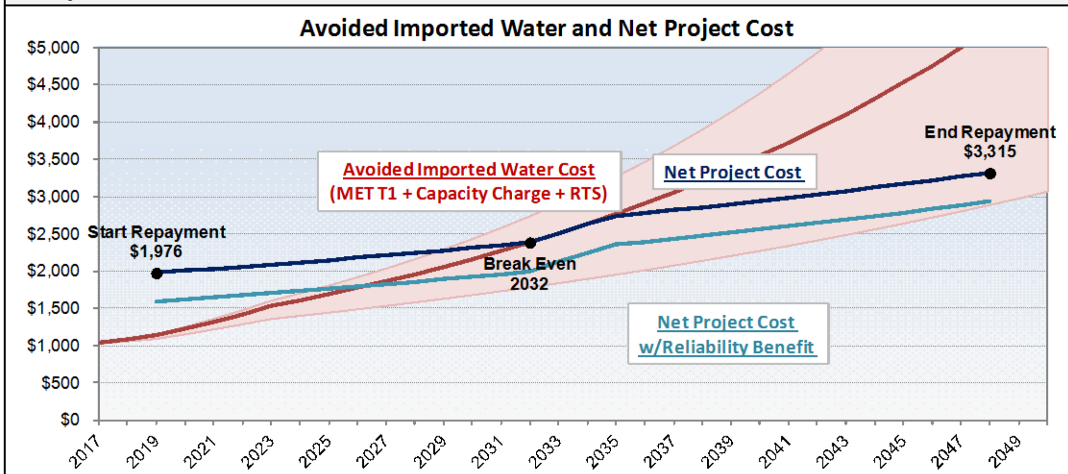
| Capital Cost | | |
|---|---|---|
| Fe/Mn Treatment? | Yes | ☑ |
| **Contingency of Const.** | **25%** | |
| **Start of Construction** | | 2017 |

| O&M Costs | | |
|---|---|---|
| **Energy Costs** | | |
| **Energy Usage (kWh)** | | **4,259** |
| **Base Energy Rate ($/kWh)** | **$** | **0.105** |
| **Energy Escalation 2012 - 2030** | | **2.0%** |
| **Energy Escalation after 2030** | | **2.0%** |
| **Land Cost** | | |
| Land Cost per AF (2011) | $ | 47 |
| Lease Escalation Rate | | 2.5% |
| **General Inflation Rate** | | |
| *Current - 2020* | | 2.5% |
| *2021 - Future* | | 2.5% |

| Project Financing | | |
|---|---|---|
| Grant Amount | | $ - |
| **Bond Repayment** | Select → | 30 |
| Bond Interest Rate | 4.50% | |
| **PV Discount Rate** | **4.00%** | |

| MET Avoided Costs | |
|---|---|
| Esc. Rate After 2017 | 5.0% |
| Melded Rate- % Tier 1 | 100% |

#### Output




| Project Capital Costs | |
|---|---|
| **Capital Cost (2012)** | **$172,234,800** |
| **Grants** | **$0** |
| **Contingency** | **$30,373,750** |
| **Total Cost (2011)** | **$202,608,550** |
| Total Cost Escalated to Midpt. of Const. | $240,837,897 |

| Costs per AF | Current Year 2012 | First Year 2019 |
|---|---|---|
| Capital Cost | $779 | $926 |
| O&M | $421 | $489 |
| Energy | $446 | $522 |
| Annual Cost | $1,646 | $1,937 |
| Annual Cost w/ Land | $1,693 | $1,994 |
| Mitigation Costs | $196 | $231 |
| Total w/ MET Subsidy | $1,640 | $1,976 |

| Net Present Value | |
|---|---|
| Up to Break Even | ($59,808,624) |
| Break Even to End | $53,308,026 |
| Total Savings | ($6,500,598) |

| Additional Reliability Benefit | |
|---|---|
| Storage Reservoir | $100,000,000 |

## Economic Analysis – Case 3
## No Fe/Mn; High Electrical (with MITIGATION costs)

### Doheny Desalination Project - Economic Analysis - Draft Version 1.8

#### Input

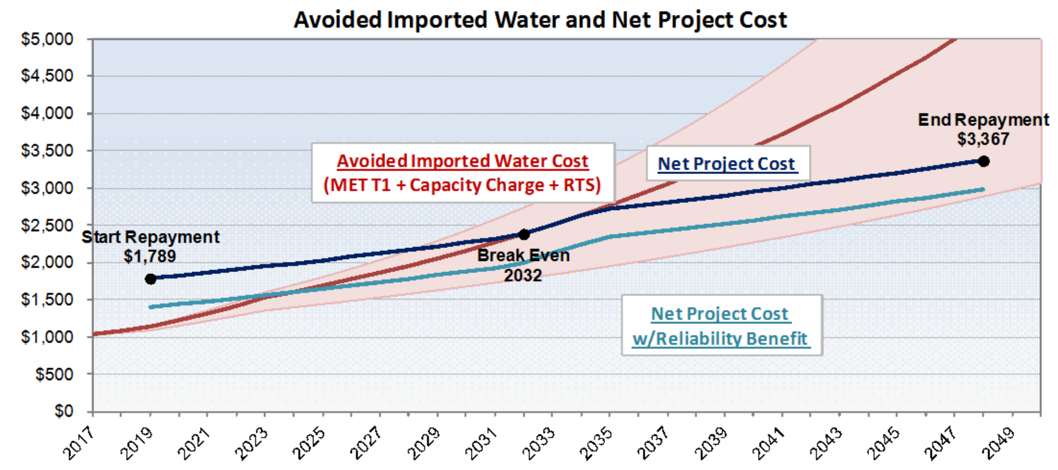
| Capital Cost | |
|---|---|
| Fe/Mn Treatment? | No |
| Contingency of Const. | 25% |
| Start of Construction | 2017 |

| O&M Costs | |
|---|---|
| **Energy Costs** | |
| Energy Usage (kWh) | 4,228 |
| Base Energy Rate ($/kWh) | $ 0.105 |
| Energy Escalation 2012 - 2030 | 3.4% |
| Energy Escalation after 2030 | 2.0% |
| **Land Cost** | |
| Land Cost per AF (2011) | $ 47 |
| Lease Escalation Rate | 2.5% |
| **General Inflation Rate** | |
| *Current - 2020* | 2.5% |
| *2021 - Future* | 2.5% |

| Project Financing | | |
|---|---|---|
| Grant Amount | | $ - |
| Bond Repayment | Select → | 30 |
| Bond Interest Rate | | 4.50% |
| PV Discount Rate | | 4.00% |

| MET Avoided Costs | |
|---|---|
| Esc. Rate After 2017 | 5.0% |
| Melded Rate- % Tier 1 | 100% |

#### Output




| Project Capital Costs | |
|---|---|
| Capital Cost (2012) | $130,227,550 |
| Grants | $0 |
| Contingency | $22,586,000 |
| Total Cost (2011) | $152,813,550 |
| Total Cost Escalated to Midpt. of Const. | $181,647,290 |

| Costs per AF | Current Year 2012 | First Year 2019 |
|---|---|---|
| Capital Cost | $588 | $699 |
| O&M | $363 | $489 |
| Energy | $446 | $582 |
| Annual Cost | $1,397 | $1,769 |
| Annual Cost w/ Land | $1,444 | $1,827 |
| Mitigation Costs | $167 | $212 |
| Total w/ MET Subsidy | $1,361 | $1,789 |

| Net Present Value | |
|---|---|
| Up to Break Even | ($45,288,833) |
| Break Even to End | $52,460,361 |
| Total Savings | $7,171,528 |

| Additional Reliability Benefit | |
|---|---|
| Storage Reservoir | $100,000,000 |

## Economic Analysis – Case 4
## Base Case with $15M Grant; No Fe/Mn (with MITIGATION costs)

### Doheny Desalination Project - Economic Analysis - Draft Version 1.8

#### Input

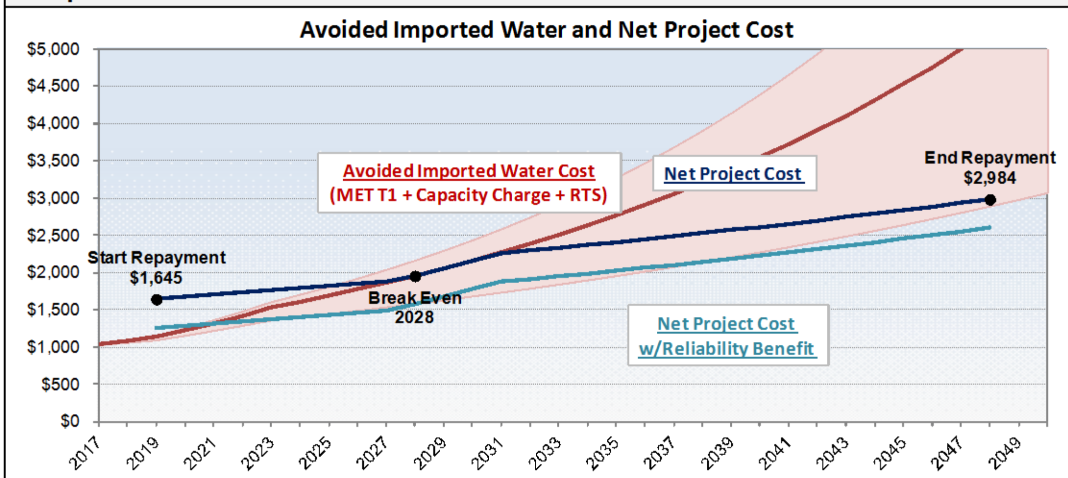
| Capital Cost | |
|---|---|
| Fe/Mn Treatment? | No |
| Contingency of Const. | 25% |
| Start of Construction | 2017 |

| O&M Costs | |
|---|---|
| **Energy Costs** | |
| Energy Usage (kWh) | 4,228 |
| Base Energy Rate ($/kWh) | $ 0.105 |
| Energy Escalation 2012 - 2030 | 2.0% |
| Energy Escalation after 2030 | 2.0% |
| **Land Cost** | |
| Land Cost per AF (2011) | $ 47 |
| Lease Escalation Rate | 2.5% |
| **General Inflation Rate** | |
| *Current - 2020* | 2.5% |
| *2021 - Future* | 2.5% |

| Project Financing | | |
|---|---|---|
| Grant Amount | | $ 15,000,000 |
| Bond Repayment | Select → | 30 |
| Bond Interest Rate | | 4.50% |
| PV Discount Rate | | 4.00% |

| MET Avoided Costs | |
|---|---|
| Esc. Rate After 2017 | 5.0% |
| Melded Rate- % Tier 1 | 100% |

#### Output




| Project Capital Costs | |
|---|---|
| Capital Cost (2012) | $130,227,550 |
| Grants | $15,000,000 |
| Contingency | $22,586,000 |
| Total Cost (2011) | $137,813,550 |
| Total Cost Escalated to Midpt. of Const. | $163,817,004 |

| Costs per AF | Current Year 2012 | First Year 2019 |
|---|---|---|
| Capital Cost | $530 | $630 |
| O&M | $363 | $489 |
| Energy | $446 | $522 |
| Annual Cost | $1,339 | $1,641 |
| Annual Cost w/ Land | $1,386 | $1,698 |
| Mitigation Costs | $161 | $197 |
| Total w/ MET Subsidy | $1,297 | $1,645 |

| Net Present Value | |
|---|---|
| Up to Break Even | ($24,278,982) |
| Break Even to End | $79,452,496 |
| Total Savings | $55,173,514 |

| Additional Reliability Benefit | |
|---|---|
| Storage Reservoir | $100,000,000 |

## Economic Analysis – Case 5
## Low Interest Rate; No Fe/Mn (with MITIGATION costs)

### Doheny Desalination Project - Economic Analysis - Draft Version 1.8

#### Input

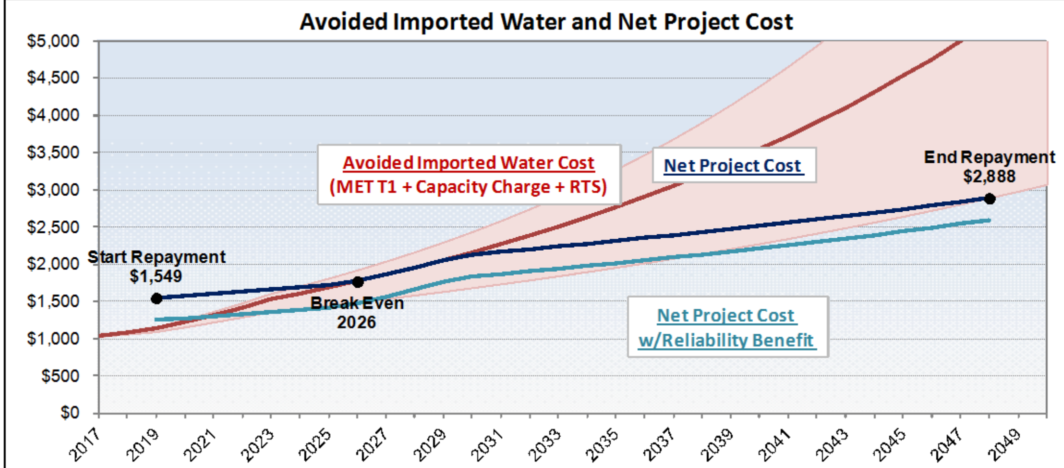
| Capital Cost | | |
|---|---|---|
| Fe/Mn Treatment? | No | |
| Contingency of Const. | 25% | |
| Start of Construction | | 2017 |

| O&M Costs | | |
|---|---|---|
| **Energy Costs** | | |
| Energy Usage (kWh) | | 4,228 |
| Base Energy Rate ($/kWh) | $ | 0.105 |
| Energy Escalation 2012 - 2030 | | 2.0% |
| Energy Escalation after 2030 | | 2.0% |
| **Land Cost** | | |
| Land Cost per AF (2011) | $ | 47 |
| Lease Escalation Rate | 2.5% | |
| **General Inflation Rate** | | |
| *Current - 2020* | 2.5% | |
| *2021 - Future* | 2.5% | |

| Project Financing | | |
|---|---|---|
| Grant Amount | | $ - |
| Bond Repayment | Select → | 30 |
| Bond Interest Rate | 2.50% | |
| PV Discount Rate | 4.00% | |

| MET Avoided Costs | |
|---|---|
| Esc. Rate After 2017 | 5.0% |
| Melded Rate- % Tier 1 | 100% |

#### Output




| Project Capital Costs | |
|---|---|
| Capital Cost (2012) | $130,227,550 |
| Grants | $0 |
| Contingency | $22,586,000 |
| Total Cost (2011) | $152,813,550 |
| Total Cost Escalated to Midpt. of Const. | $181,647,290 |

| Costs per AF | 2012 (Current Year) | 2019 (First Year) |
|---|---|---|
| Capital Cost | $457 | $544 |
| O&M | $363 | $489 |
| Energy | $446 | $522 |
| Annual Cost | $1,266 | $1,554 |
| Annual Cost w/ Land | $1,313 | $1,612 |
| Mitigation Costs | $152 | $187 |
| Total w/ MET Subsidy | $1,216 | $1,549 |

| Net Present Value | |
|---|---|
| Up to Break Even | ($16,445,195) |
| Break Even to End | $88,913,956 |
| Total Savings | $72,468,761 |

| Additional Reliability Benefit | |
|---|---|
| Storage Reservoir | $100,000,000 |

## Economic Analysis – Case 6
## Base with Low MET Escalation; No Fe/Mn (with MITIGATION costs)

### Doheny Desalination Project - Economic Analysis - Draft Version 1.8

#### Input

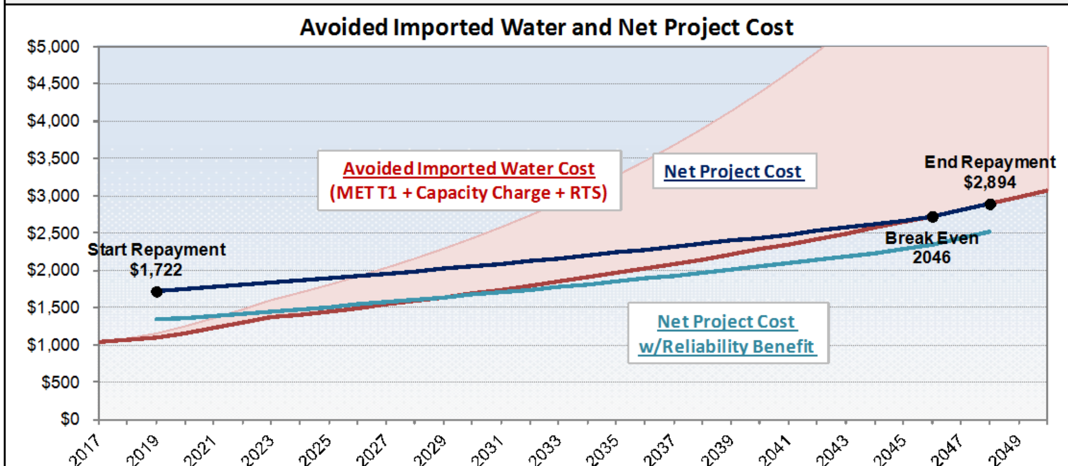
| Capital Cost | | |
|---|---|---|
| Fe/Mn Treatment? | No | |
| Contingency of Const. | 25% | |
| Start of Construction | | 2017 |

| O&M Costs | | |
|---|---|---|
| **Energy Costs** | | |
| Energy Usage (kWh) | | 4,228 |
| Base Energy Rate ($/kWh) | $ | 0.105 |
| Energy Escalation 2012 - 2030 | | 2.0% |
| Energy Escalation after 2030 | | 2.0% |
| **Land Cost** | | |
| Land Cost per AF (2011) | $ | 47 |
| Lease Escalation Rate | 2.5% | |
| **General Inflation Rate** | | |
| *Current - 2020* | 2.5% | |
| *2021 - Future* | 2.5% | |

| Project Financing | | |
|---|---|---|
| Grant Amount | | $ - |
| Bond Repayment | Select → | 30 |
| Bond Interest Rate | 4.50% | |
| PV Discount Rate | 4.00% | |

| MET Avoided Costs | |
|---|---|
| Esc. Rate After 2017 | 3.0% |
| Melded Rate- % Tier 1 | 100% |

#### Output




| Project Capital Costs | |
|---|---|
| Capital Cost (2012) | $130,227,550 |
| Grants | $0 |
| Contingency | $22,586,000 |
| Total Cost (2011) | $152,813,550 |
| Total Cost Escalated to Midpt. of Const. | $181,647,290 |

| Costs per AF | 2012 (Current Year) | 2019 (First Year) |
|---|---|---|
| Capital Cost | $588 | $699 |
| O&M | $363 | $489 |
| Energy | $446 | $522 |
| Annual Cost | $1,397 | $1,709 |
| Annual Cost w/ Land | $1,444 | $1,767 |
| Mitigation Costs | $167 | $205 |
| Total w/ MET Subsidy | $1,361 | $1,722 |

| Net Present Value | |
|---|---|
| Up to Break Even | ($72,772,358) |
| Break Even to End | $65,495,638 |
| Total Savings | ($7,276,720) |

| Additional Reliability Benefit | |
|---|---|
| Storage Reservoir | $100,000,000 |

## Economic Analysis – Case 7
## High Electrical & Fe/Mn Pre-Treatment (with MITIGATION costs)

### Doheny Desalination Project - Economic Analysis - Draft Version 1.8

#### Input

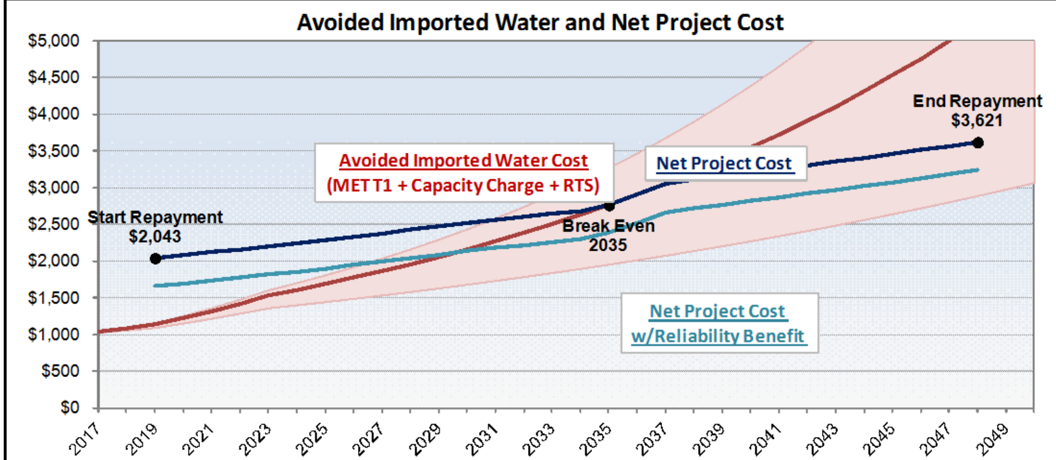
| Capital Cost | | |
|---|---|---|
| Fe/Mn Treatment? | Yes | ☑ |
| Contingency of Const. | 25% | |
| Start of Construction | 2017 | |

| O&M Costs | |
|---|---|
| **Energy Costs** | |
| Energy Usage (kWh) | 4,259 |
| Base Energy Rate ($/kWh) | $ 0.105 |
| Energy Escalation 2012 - 2030 | 3.4% |
| Energy Escalation after 2030 | 2.0% |
| **Land Cost** | |
| Land Cost per AF (2011) | $ 47 |
| Lease Escalation Rate | 2.5% |
| **General Inflation Rate** | |
| *Current - 2020* | 2.5% |
| *2021 - Future* | 2.5% |

| Project Financing | | |
|---|---|---|
| Grant Amount | | $ - |
| Bond Repayment | Select → | 30 |
| Bond Interest Rate | 4.50% | |
| PV Discount Rate | 4.00% | |

| MET Avoided Costs | |
|---|---|
| Esc. Rate After 2017 | 5.0% |
| Melded Rate- % Tier 1 | 100% |

#### Output




| Project Capital Costs | |
|---|---|
| Capital Cost (2012) | $172,234,800 |
| Grants | $0 |
| Contingency | $30,373,750 |
| Total Cost (2011) | $202,608,550 |
| Total Cost Escalated to Midpt. of Const. | $240,837,897 |

| | Current Year | First Year |
|---|---|---|
| Costs per AF | 2012 | 2019 |
| Capital Cost | $779 | $926 |
| O&M | $421 | $489 |
| Energy | $446 | $582 |
| Annual Cost | $1,646 | $1,997 |
| Annual Cost w/ Land | $1,693 | $2,054 |
| Mitigation Costs | $196 | $238 |
| Total w/ MET Subsidy | $1,640 | $2,043 |

| Net Present Value | |
|---|---|
| Up to Break Even | ($78,811,738) |
| Break Even to End | $68,285,103 |
| Total Savings | ($10,526,635) |

| Additional Reliability Benefit | |
|---|---|
| Storage Reservoir | $100,000,000 |

## Economic Analysis – Case 8
## Low MET Escalation with Fe/Mn Pre-Treatment (with MITIGATION costs)

### Doheny Desalination Project - Economic Analysis - Draft Version 1.8

#### Input

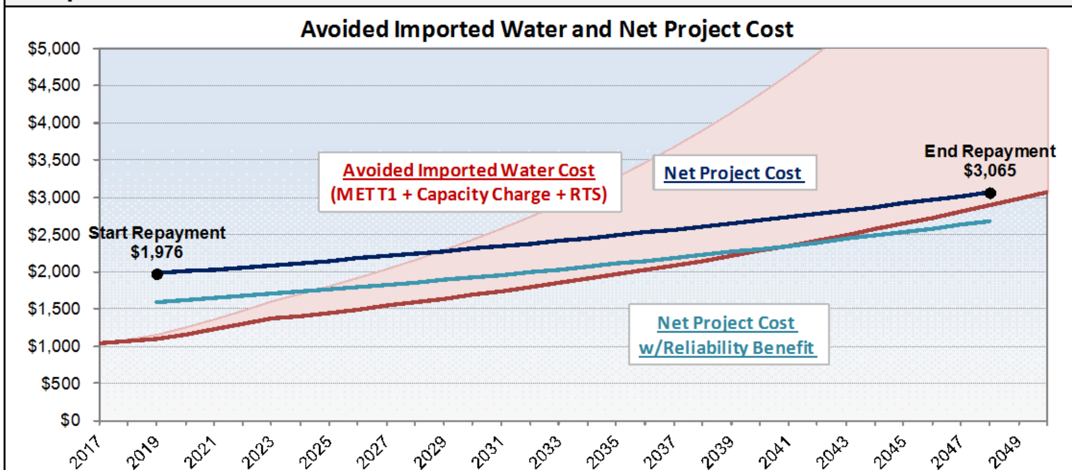
| Capital Cost | | |
|---|---|---|
| Fe/Mn Treatment? | Yes | ☑ |
| Contingency of Const. | 25% | |
| Start of Construction | 2017 | |

| O&M Costs | |
|---|---|
| **Energy Costs** | |
| Energy Usage (kWh) | 4,259 |
| Base Energy Rate ($/kWh) | $ 0.105 |
| Energy Escalation 2012 - 2030 | 2.0% |
| Energy Escalation after 2030 | 2.0% |
| **Land Cost** | |
| Land Cost per AF (2011) | $ 47 |
| Lease Escalation Rate | 2.5% |
| **General Inflation Rate** | |
| *Current - 2020* | 2.5% |
| *2021 - Future* | 2.5% |

| Project Financing | | |
|---|---|---|
| Grant Amount | | $ - |
| Bond Repayment | Select → | 30 |
| Bond Interest Rate | 4.50% | |
| PV Discount Rate | 4.00% | |

| MET Avoided Costs | |
|---|---|
| Esc. Rate After 2017 | 3.0% |
| Melded Rate- % Tier 1 | 100% |

#### Output




| Project Capital Costs | |
|---|---|
| Capital Cost (2012) | $172,234,800 |
| Grants | $0 |
| Contingency | $30,373,750 |
| Total Cost (2011) | $202,608,550 |
| Total Cost Escalated to Midpt. of Const. | $240,837,897 |

| | Current Year | First Year |
|---|---|---|
| Costs per AF | 2012 | 2019 |
| Capital Cost | $779 | $926 |
| O&M | $421 | $489 |
| Energy | $446 | $522 |
| Annual Cost | $1,646 | $1,937 |
| Annual Cost w/ Land | $1,693 | $1,994 |
| Mitigation Costs | $196 | $231 |
| Total w/ MET Subsidy | $1,640 | $1,976 |

| Net Present Value | |
|---|---|
| Up to Break Even | ($125,500,571) |
| Break Even to End | $115,260,666 |
| Total Savings | ($10,239,905) |

| Additional Reliability Benefit | |
|---|---|
| Storage Reservoir | $100,000,000 |

## Economic Analysis – Case 9
## Low MET Escalation with Low Interest (with MITIGATION costs)

### South Orange Coastal Desalination Project - Economic Analysis - DRAFT VERSION 1.8

#### Input

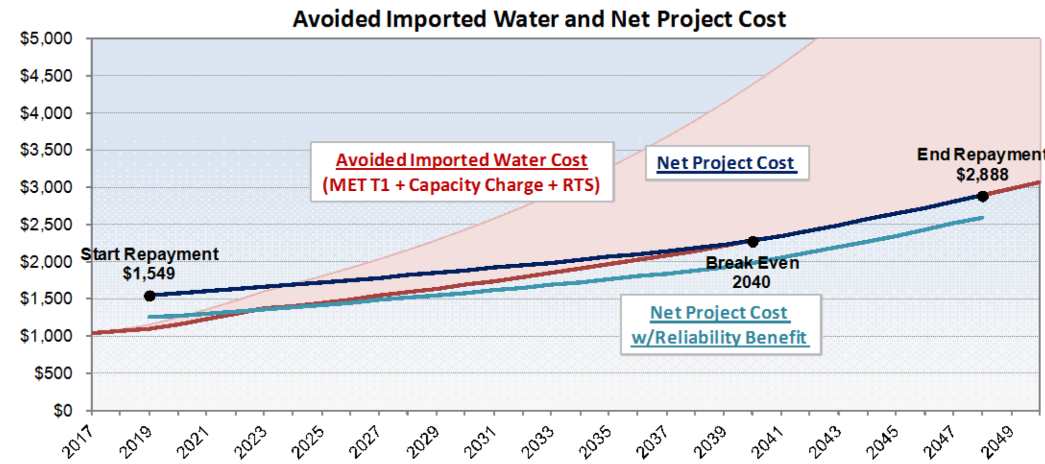
| Capital Cost | | |
|---|---|---|
| Fe/Mn Treatment? | No | |
| Contingency of Const. | 25% | |
| Start of Construction | | 2017 |

| O&M Costs | | |
|---|---|---|
| **Energy Costs** | | |
| Energy Usage (kWh) | | 4,228 |
| Base Energy Rate ($/kWh) | | $ 0.105 |
| Energy Escalation 2012 - 2030 | | 2.0% |
| Energy Escalation after 2030 | | 2.0% |
| **Land Cost** | | |
| Land Cost per AF (2011) | $ 47 | |
| Lease Escalation Rate | 2.5% | |
| **General Inflation Rate** | | |
| *Current - 2020* | 2.5% | |
| *2021 - Future* | 2.5% | |

| Project Financing | | |
|---|---|---|
| Grant Amount | | $ - |
| Bond Repayment | Select → | 30 |
| Bond Interest Rate | 2.50% | |
| PV Discount Rate | 4.00% | |

| MET Avoided Costs | |
|---|---|
| Esc. Rate After 2017 | 3.0% |
| Melded Rate- % Tier 1 | 100% |

#### Output




| Project Capital Costs | |
|---|---|
| Capital Cost (2012) | $130,227,550 |
| Grants | $0 |
| Contingency | $22,586,000 |
| Total Cost (2011) | $152,813,550 |
| Total Cost Escalated to Midpt. of Const. | $181,647,290 |

| | Current Year | First Year |
|---|---|---|
| Costs per AF | 2012 | 2019 |
| Capital Cost | $457 | $544 |
| O&M | $363 | $489 |
| Energy | $446 | $522 |
| Annual Cost | $1,266 | $1,554 |
| Annual Cost w/ Land | $1,313 | $1,612 |
| Mitigation Costs | $152 | $187 |
| Total w/ MET Subsidy | $1,216 | $1,549 |

| Net Present Value | |
|---|---|
| Up to Break Even | ($40,765,490) |
| Break Even to End | $35,505,320 |
| Total Savings | ($5,260,170) |

| Additional Reliability Benefit | |
|---|---|
| Storage Reservoir | $100,000,000 |

# ATTACHMENT THREE

## Peer Swan Presentation

# HB Desalination

## Residents for Responsible Desalination

March 5, 2015

Peer Swan

# About the Speaker

- Director, Irvine Ranch Water District - 35 yrs.
- former Director, OC Sanitation District - 15 yrs.
- former Director, Metropolitan Water District
- former Director, National Water Research Institute
- Director, Association of California Water Agencies

# Outline of the Talk

- IRWD position on the Huntington Beach project
- My view
  - Current Water Picture
  - Need for future projects
  - Process for matching needs with projects
  - Alternatives to the HB Desalter
  - How current MWD allocation rules impact
  - The HB Desalter
  - Why this is not the right project

# IRWD Position

- NOT opposed to the Project but adopted policies that preclude IRWD interest because:
  - Water from the project exceeds cost of MWD water
  - No water agency financing of project
  - Water quality has to meet IRWD needs

# Current Water Picture

- Multiple Dry Years
- No Allocation or Mandatory Cutbacks YET
- About  half  a year water supply in MWD storage
- Dry year and little snow pack 20% State Allocation
- Warmer temperatures
- Significant groundwater overdraft in San Jouquin Valley
- OC Basin ¾'s through operating range

# Need for future Projects

- Water usage has been declining on a per capita basis – is this permanent?
- What is a prudent reserve supply?
- Declining flow in Santa Ana River
- What is the frequency and duration of allocations? or MWD curtailments of deliveries?

# Alternatives

- Base load on MWD supply instead of local supply and build storage in the OC basin
- Slow the leakage into LA Central Basin
- Contract or purchase water from outside OC
- Expand the Ground Water Replenishment project from 100,000 MGD to 130,000 MGD
- Actively push Conservation
- HB Desalination

# Current MWD Allocation Rules

- MWD is a supplemental supplier
- During allocations MWD offsets portions of local supplies to EVEN OUT total supplies within the MWD seven county service area
- So during periods of allocation local project benefits are distributed to others while the obligation to pay for them remains local

# HB Desalter

- 50  MGD Plant or 50,000 af/yr
- Take or pay contract
- Pipeline to connect to customers
- Prior attempts to get direct purchase contracts
- OCWD negotiations
- Project costs ?  $ 1,800 – 2,300 per acre foot versus current MWD water cost of about $600/af for untreated and about $1,000/af for treated

# What cost for reliability?

- Assume HB Desalter $2,200/af
- Assume MWD interruption happens two times during a ten year period into the future
- Assume that MWD water purchases that are foregone cost $800/af
- Assume that the HB Desalter plant produces 50,000 af per year

# Cost of reliability

- Eight years of unneeded purchases
- 8yrs x 50,000 af x ($2,200-800)/af = $560 million
- So would pay $560 million over what would pay for otherwise available MWD supplies
- If applied this amount to the two years of interruption it would be $280 million a year over he contract amount or $280,000,000 / 50,000 AF plus $2,200/af or $7,800/af
- If MWD offset benefit by 30% the reliability cost would exceed $10,100/af

# Can this be done CHEAPER?

- If OCWD purchased extra untreated water during the eight years when it would be available and put it into the basin as stored water at the $600 rate, pumped and treated it at $100/af OCWD would save ($10,100-700)/af X 50,000 af X 2 yrs or a total
- $940,000,000 every 10 years or more than the cost of the HB Desalter Plant and Pipelines

# Can this be done CHEAPER?

- If OCWD purchased Treated Water at $1,000/af and delivered it in lieu (in place of pumped water) it would save ($10,100-1,000) /af X 50,000 af X 2 yrs or a total of
- $910,000,000 every ten years (or more than the cost of the HB Desalter Plant and Pipeline)

# HB Desalter versus MWD rates

- Currently half the cost of Desalter water is for for energy versus less than 20% for MWD water
- MWD has long term contracts for most of its power at rates that are a small fraction of those paid by the HB Desalter.
- Over 80 % of MWD current rates are fixed with the largest amount for the State Contract and the existing debt
- The bulk of OCWD purchases from MWD are for and will continue to be Untreated Water currently at $600 /af
- Not likely to change relationship with S2,200 desalter water

# Other unresolved issues

- Will MWD allow Desalter water in its pipelines?
- Can OCWD deliver non Groundwater to customers?
- Can OCWD deliver water outside its boundaries?
- Can OCWD assume the Desalter take or pay contract without a serious downgrade of its credit?

# Questions?

# ATTACHMENT FOUR

## Reliability Benefits in OC from the Poseidon Project

MUNICIPAL WATER DISTRICT OF ORANGE COUNTY

**Item No.**

**DISCUSSION ITEM**
July 7, 2015

**TO:** **Planning & Operations Committee**
(Directors Osborne, Barbre, Hinman)

**FROM:** Robert Hunter
General Manager

Staff Contact: Karl Seckel

**SUBJECT:** **Reliability Benefits in OC from the Poseidon Project**

## STAFF RECOMMENDATION

Staff recommends the P&O Committee discuss and receive and file the report.

## DETAIL REPORT

The Poseidon Project is being discussed in many venues at this time. Staff would like to update the P&O Committee on several issues related to the Poseidon Project. The questions being discussed are:

1. Does the Poseidon Project **qualify** for the MET Local Resources Program (LRP) subsidy?
2. Will the Poseidon Project **receive** the MET LRP subsidy?
3. Is there an improvement in water supply **reliability** in OC and the MET service area from the Poseidon Project? If so, then how much of an improvement?
4. What other issues are related to the water supply reliability discussions?

Staff will attempt to clarify several of the issues imbedded in the questions, although the issues can be complex, difficult to explain and difficult to comprehend. The discussion provided is just a starting point in understanding how the Poseidon Project and other projects fit into the reliability equation in OC and MET. This discussion does not necessarily address all questions raised to date. We will have many such discussions as the work

| | | | |
|---|---|---|---|
| **Budgeted (Y/N):** | Budgeted amount: | Core __ | Choice __ |
| **Action item amount:** | Line item: | | |
| **Fiscal Impact (explain if unbudgeted):** | | | |

continues under the OC Water Reliability Study. The following discussions should be considered as preliminary and incomplete at this time, but will serve as a focus point for receiving input into these complex issues.

## 1. Does the Poseidon Project qualify for the MET Local Resources Program (LRP) subsidy?

Short Response: **Yes. Qualifying for the LRP subsidy requires that the project results in "supplies that replace an existing demand or prevents a new demand on MET's imported water deliveries either through direct replacement of potable water or increased regional groundwater production." Based on the program requirements and past MET actions, MWDOC staff believes the project qualifies for the LRP subsidy.**

**Discussion:** Some seem to believe that OCWD will not be able to demonstrate that the OCWD demand on MET will be reduced once the Poseidon Project is in place compared to NOT having the Poseidon Project. MWDOC's view is that OCWD **will qualify** for the subsidy. MWDOC notes that offsetting of MET supplies is not only associated with groundwater replenishment deliveries but is also associated with offsetting of full service supplies to the retail agencies within OCWD, which today is on the order of 300,000 acre-feet (AF), far exceeding the 56,000 AF from the Poseidon Project. MWDOC concurs that work with MET staff will be required on how best to measure the imported water demand reduction (or the increase in local production due to the Poseidon Project), but MWDOC does not anticipate a problem. (This remains just staff opinion until the MET Board actually agrees.) MWDOC has discussed with MET Local Resources Program staff how the Poseidon Project LRP Agreement provisions could be developed to demonstrate compliance for qualifying production of the Poseidon water for any of the three distribution options being considered:

- Seawater barrier operations
- Direct delivery to retail agencies
- Injection or percolation in the groundwater basin

While the MET staff cannot make commitments for their Board, it was noted that the current method for determining withdrawal of water from MET's Conjunctive Use Storage Account could possibly be utilized. There are other options. The final LRP Agreement is always subject to approval by the MET Board and cannot be brought forward until such time as Poseidon has received all permits for the project, including the final Coastal Commission permit. Once the final Coastal Commission permit is received, the LRP Agreement would be agendized for MET Board consideration.

## 2. Will the Poseidon Project receive the MET LRP subsidy?

__Short Response__: **Unknown. As noted above, once the final permits have been obtained by Poseidon, the LRP subsidy agreement will be taken to the MET board. It will be up to the MET board to make a final decision. MWDOC's role is to assist in the process.**

## 3. Is there an improvement in water supply reliability in OC and the MET service area from the Poseidon Project? If so, then how much of an improvement?

__Short Response__: **Yes, there is a water supply reliability improvement to both OC and MET from implementation of the project. The Poseidon Project will produce a new annual water supply of 56,000 AF. During periods of MET water supply allocations, OC would receive a direct benefit equivalent to whatever MET imported supply demand reduction percentage has been requested, say 10% to 50%, times the project yield. The remaining reliability benefit, 50% to 90% of the project yield, accrues to the MET service area. Out of the MET service area, OC purchases about 20% of MET's supplies, so OC gains a 20% benefit of the 50% to 90% benefit that accrues MET-wide. Tables 1 & 2 below track through sample calculations. It should be noted that all percentages in this response are generalized for discussion purposes. The more severe the allocation cut from MET (i.e., mandatory supply reduction) the greater the percent supply benefit to OC.**

**__Discussion:__** To completely answer this question, we need to first define "improvement in water supply reliability." In general terms, reliability relates to the percent of normal water demand that can be provided under water shortages. This can include drought conditions when MET has enacted formal supply reductions through their water supply allocation process. Reliability improvement is a measure of the difference in reliability by having implemented an additional local project, such as the Poseidon Project. The following attempts to characterize the reliability improvements that occur directly and indirectly:

a. From a narrow perspective, during years in which we are under water supply allocations from MET (such as this current year starting July 1), if OC will have more water available from a combination of local sources plus its allocation of water from MET, OC would be determined to be "more reliable". Thus, the "reliability improvement" is the increased supply of water (an acre-foot or percentage amount) over and above the amount of water that would have been available in OC in the absence of the Poseidon Project.

b. In a broader sense, the Poseidon Project would reduce the demands OC has for purchases of MET water. Thus, MET would sell less water and would retain or add more water in their various storage accounts (unless they were all full). As a result, all of Southern California (within the MET system) would be more reliable because of the additional water in MET's storage accounts resulting from the Poseidon Project. Since OC is part of the MET system, OC would be somewhat more reliable with the Poseidon Project. Having these supplies in storage can also help MET (and OC) to stay out of a water supply allocation situation, reduce the allocation reduction or shorten the duration of the shortage situation. As noted above, OC purchases about 20% of MET's supplies, so we could say OC roughly accrues 20% of this benefit.

c. The narrow and broader perspective will be called "direct" and "indirect" benefits in the discussion below. The direct benefits accrue directly to OC while the indirect benefits accrue to the MET service area and hence help out all of MET, including OC.

The average person might expect OC to be more reliable by 56,000 AF **<u>per</u>** year with the Poseidon Project. This is not the case under either of these definitions.

The detailed "how much" answer is somewhat complicated and has several parts:

- During a water shortage allocation by MET, the basis MET uses to provide water allocations to their various member agencies is based on the principle of the "need for MET water" to meet retail demands. This is measured based on the actual use of MET water during agreed upon base years plus current local water supply conditions. If a NEW Ocean Desalination supply project producing 56,000 AF of water is brought into operation, the "need" for MET water in OC is lowered by 56,000 AF of water. This results in a lower allocation from MET. The methodology is structured to always result in a higher reliability for whomever has developed a local project compared to not having developed the local project. However, the higher "direct" reliability is not increased by the entire project yield (in our example 56,000 AF) but only by the percentage of the project yield proportional to the MET allocation level (i.e., the percent reduction in supply).
- Why was the MET water supply allocation developed in such a manner? Beginning in the early 1990's, MET's IRP adopted a more regional, cooperative approach to providing reliable supplies over the long run by the combined actions of MET, their member agencies and the subagencies, rather than MET providing the full reliability for all of Southern California. The IRP depends on MET accomplishing certain water supply actions and depends on local agencies accomplishing certain water supply actions. Collectively, these actions and investments are brought together to provide the overall water supply reliability for Southern California. Under this "cooperative" approach, the goal is to provide regional reliability for all while allowing a certain **<u>additional</u>** level of reliability for those who do more by developing local projects. This philosophy of everybody working together has been characterized as "sharing the pain" under water supply allocation events, but the overriding goal is to be fully reliable which would mean the region would not ever have to utilize water supply allocations.

- As an approximation, the reliability from the project yield under MET's current water supply allocation methodology can be estimated by the following calculation:
  - With a MET allocation reduction of 15%, areas that are 100% dependent on MET have to reduce water use by about 15% in round numbers. In the OCWD service area, with the Basin Production Percentage for groundwater production set at 70%, the overall demand reduction for the groundwater producers would be 15% of 30% or 4.5% (in round numbers). For OC as a whole, being roughly 50% dependent on MET, the overall reliability for a 15% reduction is shown in Table 1 at 92.5%. The reliability GAP would then be 7.5% of demands.
  - The "direct" reliability improvement in acre-feet is approximately equal to the MET regional percentage reduction they have requested in the allocation multiplied by the Project yield (Level 3 Allocation = 15% reduction in supply; 15% x 56,000 AF = 8,400 AF reliability improvement).
  - This means that OC would directly have about 8,400 AF more than they otherwise would have had if they had NOT constructed the Poseidon Project.
  - The other portion of the project yield, 47,600 AF, benefits the MET service area, including OC, because less MET supplies in this amount are required to be delivered in the MET service area.
  - Assuming OC is 20% of MET, the "indirect" benefit is 9,520 AF.
  - The two benefits combined are 17,920 AF or 32% of the Poseidon project yield. The reliability GAP has been reduced from 7.5% to 4.5%, about a 40% reduction.
- Tables 1&2 below are not exact, but provide sample calculations showing that if the Poseidon Project were operational when the baseline calculations were set for the current MET allocations (baseline years = 2012-13 & 2013-14), OC's reliability would be improved by 17,920 AF today. Table 2 extends the estimates and provides the sample calculations for two additional examples.

## 4. What other issues are related to the water supply reliability discussions?

- The definition of reliability used in this discussion regarding MET's water allocation methodology has been completely undermined by the Governor's 25% reduction scheme. The Governor's emergency reductions are focused solely on demand reduction and do not consider local supply conditions or increases in supply. Adding an additional 20 Poseidon Plants would not help under this situation.

- Under the MET allocation formula, the more unreliable MET is (situations with deeper allocation cutbacks), the more reliability improvement OC receives from having implemented a local project such as Poseidon. At a 50% allocation from MET, OC would have an improved reliability of about 28,000 AF (50% of 56,000 AF).
- Can the MET allocation formula be changed? This aspect of the allocation program has remained unchanged since about 1994. The support for "share the pain" is philosophical in nature and central to MET as a regional organization. The issue has been raised in a number of forums at MET but has never gotten enough support from other member agencies to be changed. It is a highly charged issue and it is perceived that a change would adversely affect many MET agencies and subagencies. The MET allocations are a zero sum game. In an allocation you are limiting the available supply of water. If Agency A receives a higher allocation, other agencies receive a lower allocation.
- Simply focusing on what happens during an allocation does not account for the years when MET is <u>not</u> in an allocation.
    - If OC implements the Poseidon Project, we would simply purchase less MET water, MET's sales will go down and the unsold water will likely be stored in one of MET's storage accounts for subsequent use in dry years. Overall, this would result in MET having more water in storage, being more reliable and Southern California and OC would be in shortage situations less frequently. This is a good thing, but OC is paying more for their water as a result. OC purchases about 20% of MET's supplies and so the additional benefit needs to be accounted for.
    - Some would observe that the MET LRP incentive funds actually result from water purchase payments paid by all of the MET member agencies, including OC. In return for this funding, the MET service area receives improved reliability. Under the LRP, MET would be providing about $400 million over 15 years towards the Poseidon Project; this has been estimated at about 23% of the cost of the Poseidon Project over the 50-year term now being considered (OC has contributed about 20% of the LRP funds to be provided via water rates paid to MET). Some question whether the funding provided by OC ratepayers is commensurate with the return on this investment as an OC investment (OC pays roughly 77% of the costs and receives 32% to 60% of the water supply reliability benefits (Table 2) – this does not account for the SYSTEM reliability benefits discussed below nor for the portion of the LRP payments contributed by OC.)
    - If OC can store the Poseidon water in years when it is not being used to meet demands directly, it becomes a question as to whether the water would result in a <u>significantly</u> higher reliability for OC under those circumstances, without a change in how MET approaches water

allocations. Again, MET looks at the “need” for MET water to meet demands. If local supplies are available, because water was stored in other years, it would likely be counted as “additional local supplies” during a MET allocation in a similar manner to how the Poseidon yield would be counted. OC would likely be better off by only a small percentage.

- One solution to this dilemma is to have MET pursue the project and incorporate the supplies into their water resources mix. The problem with this is that MET has historically evaluated that they have sufficient other supply options, costing less than $1800 per AF, to help meet their demands and to put into their storage accounts during wet years for use during dry years. MET will soon be releasing their 2015 IRP projections; it is possible that MET could determine that it is time to consider ocean desalination and/or other similar supplies to improve their reliability over time. In addition, the OC Water Reliability Study will be modeling MET supplies over the long range to develop our own estimate of MET’s reliability and how other supply options might improve MET’s or OC’s reliability.
- “<u>Extraordinary supplies</u>”, as defined by MET, are “deliberate actions taken by member agencies to augment the total regional water supply only when MET is allocating supplies through the Water Supply Allocation Plan (WSAP)”. Extraordinary supplies cannot be base-loaded supplies such as the Poseidon Project (i.e., they can’t be used except during allocations). The only projects deemed by MET so far to meet this definition come from either the Strand Ranch Project or from transfers entered into only during years when a WSAP applies. The Strand Ranch Project was developed specifically to store wet year water to be used only when MET implements a WSAP. However again, the value of these extraordinary supplies was undermined by the Governor’s 25% reduction because they are focused only on demand (use) and not supply.
- **<u>SYSTEM RELIABILITY IMPROVEMENTS</u>:** The entire discussion above has focused on SUPPLY reliability benefits. The other benefit that accrues from developing some local projects is SYSTEM reliability benefits – having the capability to continue supplying water during emergency events such as following damaging earthquakes. If an earthquake knocked out the Diemer Filtration Plant in Yorba Linda, there would be a benefit to having an ocean desalination project in Huntington Beach continuing to produce 77 cubic feet per second (cfs) of supplies into the system. None of the discussions above have placed a value on the peak system capacity provided by the Poseidon Project. This represents 77 cfs of peak capacity that could be of value during an emergency event. There are other ways of providing this amount of system reliability, but the value of having this benefit available should be included in the reliability evaluations. MWDOC is in the process of completing a SYSTEM reliability study under the OC Water Reliability Study and should have results within the next several months. This will enable us to place a value on this benefit.

- This discussion has not included the "economic value" of being reliable. Shortages, whether short-term or longer-term, can have a significant impacts on our economy. The prior work by MWDOC and OCBC from 2004 provided estimates of the cost impacts of "not being reliable", which were quite high.
- IRWD has been heavily involved in the discussions relative to the Poseidon Project, including presentations made to the OCWD Citizens Advisory Committee and in the Groundwater Producer's meetings. For informational purposes only, MWDOC has attempted to summarize the main points they have made (without taking a stance on the statements).
    - Historically, MET has been very reliable, having gone into shortage allocations only in 1976-77, 1991-92, 2008-09, and now 2015-16 (4 times in 40 years). If OC knows MET will be reliable in the future and has water to sell to replenish the groundwater basin, OC should plan on purchasing the water to do so. This would always be our least cost option for OC and if we kept the groundwater basin at a higher level, we would have more protection during future shortages.
    - If MET is reliable, say 8 or 9 years out of 10, this means OC would only need the Poseidon water 1 or 2 years out of 10. However, ocean desalination projects generally cannot be effectively operated only a few years out of 10 as the financial allocation of capital costs to the smaller volume of water produced yields extremely expensive water. Operating the project to provide yield only in a few years out of 10 or simply operating in a manner that results in building up storage in MET's storage accounts also results in a high unit cost of the project in OC, based on the limited reliability improvements available at this time.
    - However, if MET is much less reliable, maybe only 1 or 2 years out of 10, the argument in support of the Poseidon Project makes better sense and OC would receive a greater return on investment.

## Table 1
## Approximate Direct and Indirect Water Reliability Improvement During a MET 15% Water Allocation Reduction With and Without the Poseidon Project
## Acre-Feet (AF)

| Row | Category | Current Supplies | With Poseidon | Approximate Reliability Improvement From Poseidon (3) |
|---|---|---|---|---|
| 1 | Total OC Demands | 600,000 | 600,000 | |
| 2 | Existing Local Supplies Today | 300,000 | 300,000 | |
| 3 | Poseidon Project | 0 | 56,000 | |
| 4 | Demands on MET | 300,000 | 244,000 | |
| 5 | | | | |
| 6 | Call for a 15% Reduction = Reliability GAP (1) | 45,000 | 36,600 | |
| 7 | Reduced MET Demands | 255,000 | 207,400 | |
| 8 | Local supplies remain (2) | 300,000 | 356,000 | |
| 9 | Total supplies during allocation | 555,000 | 563,400 | |
| 10 | Reliability = Row 9 % of Row 1 | 92.5% | 93.9% | 1.4% |
| 11 | Direct Benefit = difference in Row 9 | | | 8,400 |
| 12 | Remaining Poseidon Yield to MET | | | 47,600 |
| 13 | Assume OC = 20% of MET | | | 9,520 |
| 14 | Total Direct + Indirect Benefit | | | 17,920 |
| 15 | Percentage of Poseidon Yield | | | 32.0% |
| 16 | Percentage of Reliability GAP Covered by Poseidon | | | 39.8% |

(1) Reduction is in demands for MET water

(2) With and without the Poseidon Project

(3) Reliability in acre-feet and % higher supplies under a MET allocation with the Poseidon Project

## Table 2
## Approximate Direct & Indirect Reliabilty Improvement From the Poseidon Project Under Three Scenarios

| | | MET Supply Allocation Reduction Scenarios | | |
|---|---|---|---|---|
| **Row** | | **15%** | **30%** | **50%** |
| | | | | |
| 1 | Reliability % Without Poseidon | 92.5% | 85.0% | 75.0% |
| 2 | % Reliability GAP Without Poseidon | 7.5% | 15.0% | 25.0% |
| 3 | Reliability GAP in AF Without Poseidon | 45,000 | 90,000 | 150,000 |
| 4 | | | | |
| 5 | | | | |
| 6 | Direct Poseidon Reliability to OC - AF | 8,400 | 16,800 | 28,000 |
| 7 | Direct Poseidon Reliability to MET - AF | 47,600 | 39,200 | 28,000 |
| 8 | Portion of MET Poseidon Reliability to OC (20% of MET) | 9,520 | 7,840 | 5,600 |
| 9 | | | | |
| 10 | Direct + Indirect Poseidon Reliability to OC - AF | 17,920 | 24,640 | 33,600 |
| 11 | % of Poseidon Project Yield | 32.0% | 44.0% | 60.0% |
| 12 | % Reliability Improvement from Poseidon | 3.0% | 4.1% | 5.6% |
| 13 | Remaining Reliability GAP | 4.5% | 10.9% | 19.4% |
| 14 | | | | |
| 15 | Portion of Reliability GAP Covered by Poseidon | 39.8% | 27.4% | 22.4% |