MEMORANDUM

Date: April 2013

To: Heidi Luckenbach
From: Jonathan Dietrich
Re: Intake Alternatives – Review and Status of Subsurface Intakes
Subject: scwd[2] Regional Seawater Desalination Project

BACKGROUND

Subsurface intake systems[1] offer an alternative to open-ocean intake systems as source water to seawater desalination facilities. Such systems are proposed as a potential solution to two issues facing open intakes:

- Impingement and entrainment (I&E)[2] of marine life;
- Need for pretreatment upstream of the reverse osmosis membranes to remove a comparatively greater amount of suspended material from the source water body compared to other traditional intake systems; resulting in improved pretreated water quality.

The following provides a discussion of these two issues, how they relate to open intakes and how subsurface intakes are understood as providing mitigation to the issue.

Impingement and Entrainment: Oceans, large lakes and rivers have historically provided cooling water to condense steam generated within electrical power generating plants throughout the world. A very common cooling water configuration involves withdrawal of the source cooling water through an intake structure and subsequent discharge of the warmed-up cooling water. This configuration, known as once-through cooling (OTC), was constructed "decades ago before the adverse impacts of their intake structures were understood and before many of the current federal environmental legislation and regulations were in

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[1] For discussion purposes, subsurface is defined as a collection of alternative intake methods when compared to open ocean intakes. Subsurface intake systems as a group are considered as alternative intakes which are not in the "open ocean" or in the water column of rivers and lakes. Examples of subsurface intake systems include directionally drilled slant wells, horizontal well systems, infiltration galleries, shallow beach wells, river bank filtration, and constructed/engineered intakes.
[2] Impingement mortality of fish and shellfish occurs when these organisms are taken in by the intake flow of water; entrainment is the capturing of eggs and larvae of fish and shellfish in the open intake.

place."[3] In the United States, the advent of the Federal Clean Water Act (CWA) in 1972 ushered in a number of subsequent regulations including those applicable to cooling water intakes in the power generating industry (widely referred to as Section 316(b)). The standards established and proposed by the EPA require application of a "Best Technology Available (BTA)" approach for power plant intake structures in order to minimize impingement mortality of fish and shellfish and the entrainment of (their) eggs and larvae; also referred to as impingement and entrainment (I&E). For example, screens placed over the opening for the water intake are widely being used to reduce the potential to entrain fish from the body of water in which the intake is located.[4]

In the early 2000's, an increased number of seawater desalination facilities were proposed in the United States. These were configured such that the source feed seawater was the discharge of a power generating facilities' cooling system prior to its return to the ocean (also known as "co-location"). A side-stream of this warmer water, having already passed through a power facilities' intake, was thought to be exempt from any 316(b) permit compliance requirements because the source supply was "inside the fenceline" of the power plant (assuming the power plant is already operating in compliance with all Federal and State regulations). And, warmer water is more efficiently desalinated than cooler water.

Natural resource protection agencies and non-governmental organizations have challenged this approach in the interest of increasing the protection offered to marine life to reduce environmental stressors. For co-located facilities, as long as the power plant is operating, the desalination facility's use of the cooling water as source water will not increase impacts on marine life. However, should the power plant discontinue operating, or if once-through cooling practices are phased out, water withdrawals would need to be continued to supply the desalination plant. Therefore, although 316(b) was promulgated for power generating facilities, the potential source water impacts of desalination plants are considered during the permitting phase of a project.

Impingement and entrainment standards protect marine life by reducing impacts associated with the withdrawal of water below a level considered *de minimus* by some scientific experts. United States I&E standards are currently under scrutiny by regulatory agencies and are therefore in flux. A significant amount of research is being invested into the understanding of I&E effects and how to reduce them through other technologies[5], including use of alternative intakes. Because subsurface intakes are below the seafloor or beach, and therefore not in an open water column, they are presumed by many to circumvent the I&E issues associated with open intakes.

<u>Improved Water Quality</u>: The primary technical reason for an increase in the occurrence of proposed subsurface alternative intakes is that the source water from them may offer improved water quality to the seawater desalination facility compared to open-ocean intake systems. Insulation from source water upsets could have significance for locations where, for example, the intake is proposed at the confluence of the ocean and a nearby river with varying seasonal water quality. Improved source water quality and insulation from significant variations in quality[6] are factors that can affect plant capital and operational

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[3]Committee on Advancing Desalination Technology, National Research Council. "5 Environmental Issues." *Desalination: A National Perspective*. Washington, DC: The National Academies Press, 2008. Referenced on 12/3/2012 http://www.nap.edu/openbook.php?record_id=12184&page=109.
[4]Ibid.
[5] For a discussion of the technologies for open ocean intakes see "scwd[2] Seawater Desalination Intake Technical Feasibility Study", Kennedy/Jenks Consultants, September 2011.
[6] Such variations and the extent of which these could affect a desalination facility are site-specific to each locale.

costs. Subsurface intakes using a constructed, engineered seabed or the natural seabed as the filtering medium are thought to potentially lessen the overall cost of a desalination facility because the feedwater is partially "pretreated" offshore. A comparative open-ocean alternative at the same location may have higher levels of suspended matter such as silt and dirt, as well as biomass associated with harmful algal blooms (HABs); which must be treated onshore at the desalination facility in the pretreatment process – potentially increasing costs relative to the cost of an alternative intake configuration.

DISCUSSION

Do existing subsurface intakes address the issues of I&E and the need for adequate source water pretreatment for a desalination plant? The goal of this memo is to derive a clearer understanding of these intakes as an alternative to open intake systems with respect to these two issues. Additionally, two closely associated questions will also be discussed:

- are sufficient and sustainable quantities of source water being drawn into alternative subsurface intakes to meet design capacity; and
- are operational challenges associated with the need for adequate pretreatment sufficiently addressed with an alternative subsurface intake system?

The author cast a wide net to support an understanding of where and what kind of subsurface intakes are utilized throughout the world. Relatively few subsurface seawater intake systems exist in commercially operating water supply projects[7]. Each subsurface seawater intake system has its site-specific set of issues and challenges[8]. As a result, it is difficult to draw any significant conclusions associated with their design, installation, operation, maintenance, capital costs, water quality, and associated potential environmental impacts. However, the information does serve as a primer of practical experience with subsurface intakes.

Construction of a seawater intake requires significant evaluation regardless of its location above or below the seafloor. Issues that need to be addressed include the magnitude and significance of the impact of I&E with open intakes; costs associated with pretreatment processes; cost associated with installation; construction time frame; and the associated impacts of constructing and operating intakes.

For additional perspective, such issues cannot and should not be overshadowed by secondary challenges associated with the capability of the pretreatment system to reliably operate during impaired water quality events (such as algal blooms). While conceivably a subsurface intake may offer some degree of insulation from the effects of an algal bloom, in Santa Cruz the scientifically-derived determination was made that the required quantity of source water from a subsurface intake may not be available given the risk factors.[9]If an intake cannot reliably produce the quantity of source water needed, subsequent or secondary issues become irrelevant as a different source water must be pursued. As a supplementary thought, in practice, one common mitigation measure to treat algal blooms for open intake desalination plants is the inclusion of

[7]Due to the lack of accessible technical data at the time this memorandum is being written, the information presented herein is representative of alternative intake systems installed worldwide. It is not all-inclusive.

[8] A number of projects are not mentioned here since the conceptual intake configuration desired could not conclusively produce the necessary feed water quantities for a drinking water production facility. These projects did not proceed past an initial assessment of feasibility.

[9]Some of the current technical, engineering and operational aspects of open ocean intakes and intake alternatives are discussed in a 2011 Technical Memorandum,Intake Technical Feasibility Study, produced by scwd[2(9)]. That Memorandum also provides a convenient reference source capturing the work that the City and District have conducted on the subject since 2001.

dissolved air flotation (DAF) in the pretreatment step; which seems to obviate secondary treatment challenges offered by alternative intakes.

The vast majority[10] of alternative intake systems for seawater desalination facilities are beach wells located in the Middle East and North Africa (MENA) regions along the Mediterranean, Red Sea, Indian Ocean, and Arabian Gulf having a suitable coastal geological formation. Although the actual number of installations and associated operating histories are unpublished, a literature search in the subject field supports a system count around two dozen or less. Many systems are small and some were installed as early as the 1960's along the coastal plain of Israel where water was used for cooling installations and swimming pools[11] (not for seawater desalination). These, as well as the vast majority of beach well systems,by nature of their depth and proximity to coastal aquifers, also withdraw shallow groundwater which typically contains a lower salinity (though results are site specific).

Why are so few subsurface intake systems in use supplying raw water to seawater desalination facilities? The answer perhaps resides in the fact that a unique set of conditions must exist for serious consideration of this method as a reliable long-term supply of raw water. A significant amount of data specific to the intake location for a project is necessary. The typical data development process for alternative intake methods is based on the requirement to have a thorough knowledge at the proposed intake location of local subsurface lithology and geological formations, long-term yield and reliability, soil transmissivity, ocean currents, ocean venting velocities, and even historical seismic data. Supplemental work involving hydraulic modeling and test boreholes may also be necessary to further substantiate expected performance and for validation of the models. Development of the necessary supporting information leads to scientifically based and competent decisions about the feasibility of alternative (subsurface) intakes. However, the amount of work necessary to substantiate the use of alternative intakes, and the presumed associated research and testing costs associated with such work, may be unwarranted if operability unknowns are expected to persist through full scale operation. Thus the answer to the first question, can sufficient quantities of source water be sustained over time, is one that in practice is very difficult to determine conclusively prior to full scale operation.

The second question posed above is whether operational challenges associated with the need for adequate pretreatment are sufficiently addressed with an alternative intake system. Raw water quality affects the design of the pretreatment system of a seawater desalination plant. With open intakes, raw seawater conditioning and pretreatment filtration challenges are dealt with through the design of the pretreatment system. Unforeseen or changed conditions, for example an algal bloom, are mitigated by incorporating larger I&E filtration structures in the design process and/or through the integration of supplemental, downstream pretreatment technologies such as dissolved air flotation. On the contrary, since a pretreatment filtration step is a built-in component of an alternative intake system, they require an extended preliminary search, analysis, and proof-testing period due to uncertainty associated with the long-term reliability of the quality and quantity of raw water produced in a subsurface intake configuration. Data collection for subsurface intake systems would be conducted until the results prove that the system can be expected to provide a reliable long-term supply of raw feed water. The importance of the need to study and understand short and long-term changes in potential water quality cannot be overemphasized to design an adequate pretreatment system. Potential water quality changes over time are very difficult if not impossible

[10] Research on the application of alternative intakes in the 1960's-1990's is scant; approximately one to two dozen small wells identified although the author believes many may no longer be in operation.
[11] Schwarz J.: "Beach Well intakes for Small Seawater Reverse Osmosis Plants", MEDRC Project 97-BS015, August 2000.

to precisely predict, resulting in a consistent tendency to "over-design" the intake system out of necessity (increasing cost, complexity and time). Therefore, if the raw feed water is expected to change, the mitigating factor ensuring suitable water quality and long-term reliable operation of the SWRO plant becomes the inclusion of supplemental pretreatment technologies. This approach is typical of drinking water seawater desalination plants in planning and operation.

The status of a number of intake alternatives, either tested at a pilot scale or in service, is summarized below to provide information about installations of subsurface systems with regard to water quality and I&E.

<u>Long Beach (Infiltration Gallery – Pilot Phase)</u>The Long Beach Water Department is conducting a research and development project to study subsurface beach wells in the form of a variable filtration flow ranging from 252 ac-ft/yr to 750 ac-ft/yr (225,000 to 670,000 gallons per day (gpd)) infiltration gallery[12]. The goal of the work was to study hydraulics and filtration, capacity and water quality[13]. Although the upper end of the tested filtration flows were not determined to be sustainable, the Water Department is currently in the process of determining maximum sustainable flow; greater than 476 ac-ft/yr (425,000 gpd) is expected. The total seabed intake area is 3,100 ft^2; with a minimum constructed seabed media depth of 5-feet.The full-scale size of the planned facility is reported to be 10,000 ac-ft/yr (8.9 million gallons per day (mgd)). Therefore the intake would be roughly double in capacity at 20,000 ac-ft/yr or 17.8 mgd.

Because the infiltration gallery tested filtration rates are typically very low, ranging from 0.05 to 0.15 gpm/ft^2, the sand media bed above the collection pipes has the potential to function in-situ as a biofilter. This biological filtration process would be expected to reduce organic and suspended solids loading on the desalination plant pretreatment system or downstream membrane treatment process. Consistent with this effect and also through the natural sand media filtration process, the LBWD proposes that by using an infiltration gallery, "Additional pretreatment is not required, reducing costs, and improving the desalination process[14]".

To a certain extent the testing which has been performed to-date has not revealed any clear operational benefit of utilizing subsurface intake water; although conclusive results are not available because testing has not yet been completed[15].The water quality effects on the downstream cartridge filter and seawater membranes[16]shows the cartridge filters are acting as a pretreatment barrier blocking mass passage of iron and manganese to the SWRO membrane with a change out frequency ranging from every few weeks to over a month. This appears to be more frequent than any other typical SWRO where every 1-2 months or longer is expected from an open intake configuration; although the frequency may also be associated with intermittent operation of the system. According to the test data, the SWRO production (or permeability) losses are not (yet) demonstrated to be recoverable events, and the membranes show decreased service life compared to a typical SWRO facility. Testing continues in order to resolve a number of challenges including seabed movement, pretreatment requirements associated with SWRO permeability losses, and membrane cleaning regimes.

[12] 1 million gallons = 3.07 acre feet; 1 million gallons per day (mgd) = 1,120 acre feet per year
[13] Long Beach Water Department Desal Website referenced Oct 1, 2012 at: http://lbwater.org/under-ocean-floor-seawater-intake-and-discharge-demonstration-system
[14] Ibid.
[15] Presentation "LBWD's Experience with Subsurface Intake as Pretreatment for Seawater Desalination"; 2012 Water Quality Technology Conference, Toronto, Canada, Nov 6, 2012; slides 28 and 32
[16] Ibid.

Future study areas might include potential biomass predation or entrainment effects within the filter bed; tide and current effects on long-term seabed operational and water quality reliability, intake construction costs and time frame, residuals management schemes, permitting, and perhaps additional path(s) forward after current study areas are addressed. The testing program has a timeline through the end of 2016.

The Metropolitan Water District of Orange County South Orange Coastal Ocean Desalination Project(Pilot and Demonstration Phase)The Metropolitan Water District of Orange County (MWDOC) South Orange Coastal Ocean Desalination Project, "SOCOD Project" (previously Dana Point Ocean Desalination Project), began investigating the slant well intake configuration in 2005. After initial, extensive subsurface hydrology investigations (Phase I) followed by construction of a test well (Phase 2), an extended well pumping and pilot test was conducted over a period of nearly 2 years with the extended pumping test starting in early June 2010 and ending in early May 2012.The well was designed to pump a variable rate for testing purposes (350 – 2,050 gpm) of which a partial split-stream (10 gpm) was fed to a SWRO pilot plant. Tested well parameters included well sustainable yield, aquifer response and groundwater model validation, pumped water quality, corrosion characteristics, biofouling rates, microbiological characteristics, and aquifer pretreatment capabilities. Tested SWRO parameters were related to biofouling and membrane performance. Iron and manganese in the raw well water were dissolved (due to the anoxic state of the raw water) thereby temporarily eliminating the need for iron and manganese removal. The iron and manganese removal system testing is expected to remain as a pretreatment component since water quality characteristics are expected to change over time (due to the site-specific aquifer conditions and the location tested).

The full-scale size of the plant is contemplated to be 16,000 ac-ft per year (14.3 mgd). Therefore the intake would be roughly double in capacity at 32,000 ac-ft/yr or 28.5 mgd. Based on present testing results, seven (+ two standby) wells are expected to provide the requisite feed water flow for the planned desalination facility[17].

Currently the Project is in the process of compiling and evaluating a significant amount of test data for compilation in a "Phase 3"Report. The Report is expected to contain operations, testing and evaluation of[18] the following studies: corrosion, microbial biofouling, tracer(s), iron/manganese pretreatment, and a step drawdown test. In addition, groundwater modeling results will be presented including sustainable yield, SOCOD impact/mitigation, and coastal modeling. Other potential content for the Report may include impact on downstream RO, intake costs and time frame, residuals management scheme, permitting, potential biomass predation or entrainment effects in the well zone of influence (if necessary); and perhaps paths forward for additional testing or analyses if warranted. The Report is expected to be released in early 2013 and a decision to move forward with the Program in spring or summer of 2013[19].

Sur (Oman) – Commercial Operation – Beach Wells, 2011The Sur facility represents an example of successful technical implementation of a beach well system and is the largest of its kind. The system is located in a region of the world generally more suitable to the technology[20] due to the proliferation of sand having the attributes of high transmissivity located in an area with a low risk of tidal erosion. Although the

[17] Written communication with Richard Bell, Principal Engineer / Project Manager at MWDOC, October 31, 2012.
[18] SOCOD Participants meeting Executive Overview of September 26, 2012 retrieved Oct 1, 2012 at: http://www.mwdoc.com/cms2/ckfinder/files/files/Agenda%20and%20Packet%20for%20September%2026%202012%20SOCOD%20Participants%20Meeting%20FINAL.pdf
[19] Ibid.
[20] Schwarz J.: "Beach Well intakes for Small Seawater Reverse Osmosis Plants", MEDRC Project 97-BS015, August 2000.

geology in the region was known to possibly meet many conditions suitable for a subsurface intake, a significant degree of testing and modeling (as associated with any alternative intake) was necessary over about 3 years, to support the determination to build full-scale and to rely completely on wells. A radial collector system was also evaluated but determined to be unfeasible due to the site-specific geology.

The plant commercially produces 23,500 ac-ft/yr (21 mgd). The conceptual design initially started with 21 wells planned to produce 33,800 ac-ft/yr (30.2) mgd, supplemented by the balance of raw feed water from an open intake system[21]. However, as studies progressed over an approximately 2-year period, and pilot well testing data was gathered, the determination was made that additional beach wells could be drilled to fully supply the plant[22]. Ultimately, 32 wells were drilled over approximately 12.5 acres[23] producing 64,900 ac-ft/yr (58 mgd).

The plant also uses pretreatment media filters following the beach wells as a precaution; although they may be bypassed if a determination is made that the raw water is of sufficient quality to bypass them. Media filter pretreatment is a pretreatment step that would normally be employed in an open intake system as well.

Sur is an example of a facility taking advantage of suitable subsurface geology, meeting all site-specific requirements supporting beach wells.

<u>Fukuoka (Japan)Infiltration Gallery – Commercial Operation, 2007</u>The Uminonakamichi Nata in Fukouka uses a constructed intake system (infiltration gallery). Although the precise reason why a constructed intake was built in lieu of beach wells or other types is not in the available literature, the plant is located inland in a highly populated District with significant vessel and port traffic, and there are no apparent open coastal areas available for an open intake or beach wells[24]. Additional, regional process treatment challenges for the plant included water quality transients created by a busy commercial shipping port and organic mass associated with a treated wastewater discharge point in an adjacent bay.

The Fukuoka plant capacity is 14,800 ac-ft/yr (13.2 mgd)[25] with a constructed intake capacity of 30.5 ac-ft/yr (27.2 mgd) and a total seabed area consuming approximately 5 acres (215,000 ft^2). The location of the constructed seabed area is an important element of the design of the intake system. Due to the benefits of the wave currents in this particular spot, the surface of the sand bottom receives continual gentle washing by wave action, resulting in a sand bed which does not plug but also does not erode. The seawater intake supply is filtered by an ultrafiltration membrane pretreatment system downstream of the infiltration gallery and prior to the reverse osmosis process. The ultrafiltration step is similar to what would also be a design component of an open intake system.

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[21] Choules, Paul;"Design & Operations Considerations for Seawater Reverse Osmosis Desalination Facilities", CA-NV American Water Works Association (Desalination Committee), Monterey, CA, July 23, 2009

[22] David Boris, et al: Beach Wells for Large-Scale Reverse Osmosis Plants: The Sur Case Study, IDA World Congress, Dubai, UAE, November 7-12 2009. IDAWC/DB09-106

[23] National Centre of Excellence in Desalination (NCEDA) International Workshop on Desalination Intakes and Outfalls, Adelaide Australia, 16/17 May 2012.

[24] Shimokawa, Akira; "Desalination plant with Unique Methods in Fukuoka"; Report produced by the Fukuoka District Waterworks Agency, (undated)

[25] National Centre of Excellence in Desalination (NCEDA) International Workshop on Desalination Intakes and Outfalls, Adelaide Australia, 16/17 May 2012.

The Uminonakamichi Nata plant is an example of a drought-proof facility that was purposefully built in a confined area with the right combination of wave and area subsurface conditions allowing successful implementation of a constructed seabed system. There are no known published articles containing information describing larval destruction associated with sand washing above the bed or potential entrainment and/or predation of larvae populations above the intake pipelines.

Cartagena (Spain) – Commercial Operation, 2005The Cartagena Sea Water Reverse Osmosis Desalination Plant is located at Murcia in the southeast of Spain, on the Mediterranean coast. Preliminary investigations and pilot testing concluded that a vertical beach well system would be ideally suited for this facility. Therefore, vertical wells were constructed to supply raw water to the facility, followed by pretreatment media filtration as a supplemental treatment step. Unfortunately, pilot testing of the vertical well configuration did not capture the production limitations and reliability of the full-scale system that were experienced once it was constructed. Because the vertical wells could not supply the required flow rate for plant production, horizontal direction drilling (HDD) was employed to try to supplement the raw water capacity[26]. While the HDD performed adequately for the initial 17 MGD project phase, site specific hydrogeological constraints have limited their use for the plant expansion to 34 MGD and a new 17 MGD open water intake system was constructed instead[27].

The Cartagena plant had an initial production capacity of 19,200 ac-ft/yr (17.2 mgd) and was subsequently expanded to 38,100 ac-ft/yr (34mgd). There are no known published articles containing information describing the potential entrainment or predation effects of larvae populations above the HDD pipelines.

Other Plants

Marina, California (2003, decommissioned).The Marina Coast Water District (MCWD), near Monterey, California, operated a desalination facility with a vertical beach well intake. The system was operated full-time in the late 1990's and intermittently through either 2001 or 2003, when the water treatment plant was shut down[28] ; although the intake and well pumping system was operated routinely until 2010.The intake system withdrew a mixture of seawater and freshwater, and consisted of a 95-foot deep vertical well drilled down into the deep sand layers beneath Marina State Beach. The raw water TDS was highly brackish, at about 21,000 mg/L. The aquifer sand in this locale is "well sorted and coarse to very coarse grained and has a saturated thickness (saline groundwater depth) more than double that near Santa Cruz"[29].

The intake system provided up to approximately 784 ac-ft/yr (0.7 mgd) of feed water to the plant in order to produce approximately 336 ac-ft/yr (0.3 mgd) of product water; although the plant permitted volume was no greater than 300 ac-ft/yr.

The well and pump access was provided through a concrete vault buried beneath the sand on the beach. However, erosion advanced to the extent that the vault became exposed in 2006 and again in 2008

[26] National Centre of Excellence in Desalination (NCEDA) International Workshop on Desalination Intakes and Outfalls, Adelaide Australia, 16/17 May 2012.
[27] California Coastal Commission CDP application E-06-013 November 15, 2007, hearing transcript pages 170-171
[28]Telephone and email correspondence with Brian True, PE, Capital Projects Manager, Monterey County Water District, November/December 2012
[29]Hopkins, 2001 as-referenced in Kennedy/Jenks, *Review of Subsurface Intake Approach, scwd² Seawater Desalination Program,* 50868005, September 2008

(approximately). MCWD purchased replacement sand to prevent the concrete vault from jutting out over the beach. The sand continued to erode and eventually the well cap and some pipe segments were removed in 2010. The well can be re-activated in the future if needed.

Not much is publicly known regarding the operability of the plant, how much time the conceptual and preliminary design took in order to validate the well approach; or the quality or variability of the raw water feeding the facility. However, the water drawn through the intake was reported to contain periodic high turbidity, which stressed the treatment process (to what extent is currently not known)[30].

Morro Bay (1992 – Commercial Operation).Morro Bay is an example of an alternative intake (beach well) that was operated in California in 1992 and then in 1995 as a drought relief measure[31]; however raw water quality problems have caused the plant to shut down. However, the plant may be used as a regular non-emergency water source if necessary. The plant source water is supplied by five beach wells with a production capacity of 336 ac-ft/yr to 560 ac-ft/yr (0.3 to 0.5 mgd) each with intake water having a very high concentration of iron. The facility production is rated at 1,350 ac-ft/yr (1.2 mgd).

The facility was originally designed without a pretreatment filtration system because the beach wells were expected to produce very high quality raw feedwater. However, iron in the feedwater caused an excessive rate of SWRO membrane fouling and a pretreatment system was installed to remove the iron[32].

The plant has had its' challenges; in particular the raw water was found to have an unanticipated high iron content coupled with contamination (from MTBE in local groundwater from a local gas station). Beach well systems or constructed intake source waters withdrawing a fraction of groundwater will, by definition, present a potential risk for contamination of the raw water if such contamination is present in the aquifer from which the source water is withdrawn[33].

Sand City (2010 – Commercial Operation). Sand City is actually not a seawater desalination plant because the raw feed water is brackish: a mixture of seawater and fresh groundwater. However, the plant bears discussion because the feed water source comes from beach wells and there are few reference points to add to the list of installed projects in the USA.

Sand City benefits geologically by being near a "seawater wedge" that keeps part of the city's coastal area brackish, meaning the water is saltier than freshwater but not as briny as seawater[34]. The plant recovery is quite low (33% feed water recovery) because the concentrate discharge permit required the salinity of concentrate match the receiving water salinity.

Three wells (plus one spare for rotation) provide up to 300 ac-ft/year (approximately 98 million gallons) over a 300 day time period to the facility. Air bubbles at the well extraction point(s) have interfered with the

[30] Confirmed with B. True and also referenced in Kennedy/Jenks, *Review of Subsurface Intake Approach, scwd² Seawater Desalination Program,* 50868005, September 2008.
[31] City of Morro Bay 2010 Urban Water Management Plan, Final Report, June 2011.
[32] WateReuse and Desalination Association White Paper: "Overview of Desalination Plant Intake Alternatives"; referenced on October 18, 2012 at: http://www.watereuse.org/sites/default/files/u8/Intake_White_Paper.pdf
[33] Similar problems were observed at the Santa Catalina Island (California) 0.132 MGD beach wells (feeding SWRO); per ref. above – WateReuse Association.
[34] Scientific American, "Coastal California City Turns to Desalination to Quench Its Thirst", April 7, 2012. Web reference dated October 22, 2012 at: http://www.scientificamerican.com/article.cfm?id=california-desalination-reverse-osmosis.

capability of each well to meet design capacities and the City is contemplating adding additional beach well capacity to alleviate the concern[35]. The plant does not employ supplemental pretreatment ahead of the RO elements, with the exception of cartridge "guard" filtration. The pretreatment cartridge filters require replacement every 3-4 weeks; which is more frequent than any other typical BWRO where cartridge replacement every 3-4 months (or longer) which would normally be contemplated from an inland brackish well source. For comparison, 1-2 months or longer would be expected from an open intake SWRO configuration. The RO elements have been cleaned once over a 20+ month period of operation compared with a typical 4 times per year for open intakes with conventional pretreatment; which should greatly increase the useful life of the RO membranes[36]. It is not known if, during conceptual planning, the cartridge filter change-out frequency and RO cleaning frequency was anticipated compared to the actual field performance results.

<u>Aruba "SWRO-2" (2012 – Commercial Operation).</u> The Aruba seawater desalination plant capacity is 7,059 ac-ft/yr (6.3 mgd). Fourteen (14) vertical beach wells supply feed water to the plant, which was designed with 5-micron cartridge filtration as the single pretreatment component. High concentrations of suspended material and precipitants have caused excessive plugging of the cartridge filters requiring changeout every four days[37] (compared to a more appropriate 1-2 month or longer change-out cycle expected with adequate pretreatment). Additional pretreatment components are currently under investigation to effectively deal with the issue, including incorporation of bag filters.

<u>Cuevas de Almanzora (Spain).</u>The Bajo Almanzora desalination plant is located near the Almanzora River creek in Almeria, Spain. The plant capacity is 8,875 ac-ft/yr (7.9 mgd).This SWRO plant, commissioned in September 2011, is fed by 14 beach wells[38]. The pretreatment process of the raw water involves chemical dosing to disinfect the raw water, flocculation, the use of pressurized sand filters and then cartridge filtration to achieve microfiltration[39]. According to the Bajo Almanzora SWDP Project Director, Acuamed, beach wells were "chosen among other reasons because of the better seawater quality that provided to the process, reducing, therefore, the requirements for an optimal pre-treatment process which will be less complex, than under other circumstances (for example in case of raw water open intake)"[40]. The raw water quality is reported to exhibit biomass associated with marine intrusion, variable salinity associated with aquifer withdrawal, and fouling tendencies from sulfate content[41]. There are no known published articles containing information describing the potential entrainment or predation effects of larvae populations above the wells.

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[35] Written communication with Richard Simonitch, who referenced the conclusion gathered from CalAm documents; Sand City Desal Program Engineer at Creegan+D'Angelo, November 5, 2012.
[36]Membrane life expectancy is typically 5-years; decreasing the cleaning frequency could extend the life several more years (results are site-specific)
[37] Water Desalination Report, Volume 49 Number 12, March 25, 2013.
[38]Alcantara, Javier et al. 2007, "Engineering Design of Bajo Almanzora Seawater Desalination Plant" presented at the IDA World Congress – Maspalomas, Gran Canaria- Spain, October 21-26, 2007. Referenced December 12, 2012 at http://www.aqualia-infraestructuras.es/media/docs/Pnencia%20bajo%20almanzora.pdf
[39]Ibid.
[40]Ibid.
[41]Presentation given by Mr. Domingo Zarzo, NCEDA Workshop (prev. referenced) - Adelaide Australia, 16/17 May 2012.http://desalination.edu.au/2012/05/report-on-the-nceda-international-desalination-intakes-and-outfalls-workshop/

SUMMARY

<u>Impingement and Entrainment (I&E)</u>

A reference search on species-specific I&E vulnerability with alternative intakes, and cumulative sources of mortality based on each alternative intake type has not been found in the literature. Perhaps this is due to the lack of a regulatory or permitting requirement to study such impacts. It is the author's opinion that, in addition, the lack of information could be a result of a generalized, (apparently) unsubstantiated conclusion that open intakes by default impose greater I&E mortality impacts compared to alternative intake methods. It is particularly concerning that literature is virtually nonexistent on this subject, as well as guidance regarding the proper assessment pathway to ascertain relative, comparative impacts of one intake method versus another at any one site.

A lack of published information documenting the potential or actual entrainment and/or organism predation of larvae populations above the intake and within the seabed may be due to the idea that the depth of the wells or intake pipelines extend far beneath the apparent impact of subsurface withdrawal rates. This appears to be categorically debatable. The thought process and decision whether to measure potential impacts is not discussed in available technical papers; and documentation supporting negligible I&E impacts using various applicable alternative intake methods in lieu of open ocean intakes is lacking. Clearly this issue should be further vetted in the industry before any conclusive decisions can be made regarding the potential benefits of an alternative intake method versus open-ocean.

<u>Water Quality and Operational Benefits</u>

Through considerable research, planning, studying, testing, and post-startup operational adjustments, a handful of subsurface alternative seawater intake systems appear to be a suitable solution for the local region in which they have been installed,[42] producing a sufficient quantity and quality of source water. The operational benefits are not clear compared to open intakes because these successfully operating plants largely operate with a supplemental pretreatment component that many have argued are unnecessary with alternative intake systems. Some alternative subsurface seawater intake systems have not produced the quantity of water expected and necessary; or the raw water quality has been lower (worse) than anticipated. Source water did meet the capacities expected by system planners at Sur, Fukuoka, and Cuevas de Almanzora; however volumes fell short at Sand City, Cartagena, and Marina. Results are evidently site specific, suggesting that even with extensive preparation and testing, an alternative intake system must be built with the requisite knowledge that supplemental capacity may be required once the subsurface intake configuration is actually operating.

Furthermore, the installed alternative subsurface intake systems have in some cases shown that there are operational challenges associated with the need for adequate pretreatment depending on the location. From the plants discussed in this memo, although the system designers expected better quality seawater from subsurface intakes (Morro Bay, Aruba, Cuevas de Almanzora), pretreatment processes remained necessary to adequately treat the raw water quality from the wells. There does not appear to be any clear or broad-based raw water quality benefit, based on the research and operational data published to date, to the employment of alternative intake systems in lieu of open intakes for seawater desalination. Additional operational risks can also include unknowns from the aquifer's raw water quality over time or from tidal

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[42] Small capacity beach wells have been periodically employed for various non-municipal uses for decades throughout the Middle East; though current information on the operational status and long term viability of the overwhelming majority of these systems is not available in published literature.

erosion for certain types of intake alternatives. Benefits include the potential for decreased chemical usage[43] associated with fewer RO membrane cleaning events or potentially longer membrane life. All risks should be thoughtfully considered for a plant that must reliably produce drinking water.

Similar to conventional media pretreatment systems at dozens of seawater desalination facilities around the globe, vertical beach wells, horizontal radial type wells, and constructed infiltration galleries also use a physical barrier of sand media to pre-filter the seawater (albeit directly through a natural soil or an engineered ocean floor). Pretreatment is unavoidable for all SWRO facilities[44]; an alternative intake system filtering seawater through the ocean floor functions to an SWRO plant in the same way as a media filter located at the treatment plant. However, a review of desalination plants using alternative intake methods reveals that virtually all successfully operating plants integrate an additional pretreatment measure, including membrane filtration or conventional sand media filtration, as an operating risk reduction measure to protect the downstream RO membranes. Such pretreatment is routinely incorporated into open intake SWRO facilities; although an open intake facility may also integrate additional pretreatment steps – such as dissolved air flotation - to reduce algal biomass or oil and grease content. In other words, the same pretreatment steps in practice are considered and usually integrated into alternative intake systems as a mitigation measure (or as a necessity) in case raw feed water quality is not as predicted or changes over time. Unforeseen impacts that could either degrade the efficiency of the SWRO system or cause plant shutdown require such measures in order for a plant to reliably produce drinking water.

From a technical perspective, the projects currently undergoing testing or employing alternative intake methods have invested significant time and money in the process of investigating the technical viability of these methods. In the authors opinion, those projects undergoing testing still appear to have much ground to cover before any decision is made regarding the applicability of subsurface intakes as a preferred alternative to open ocean for each tested location.

One of the impacts observed in several locations where alternative intake systems are utilized is raw water containing the naturally occurring or undesirable constituents in the aquifer from which the source water is withdrawn. For example, as observed in the LBWD pilot infiltration gallery, Morro Bay, and Aruba beach well systems, an alternative intake system may withdraw feed water containing high levels of iron, manganese, low or no dissolved oxygen, or radioactivity naturally residing in geological formations. Such characteristics are typically not a major concern for open intake systems. Iron and manganese pose particular fouling problems for seawater RO membranes and must be dealt with in the pretreatment process otherwise a loss in efficiency of the membranes will result. If the feed water contains low levels of dissolved oxygen and radioactivity, quantities present in the SWRO concentrate stream may not be within discharge limitations which are set by local, state, and the Federal Government. The significance of raw water quality on the processes downstream of the pretreatment is of equal concern to planners and engineers because the characteristics of the raw water quality are of critical importance regardless of intake type. Because of this, in several systems, identical pretreatment methods were selected for “alternative” intakes as those that would be also employed in open ocean intake facilities (Fukuoka’s ultrafiltration pretreatment, Cartagena, Sur (Oman) media filtration.)

Open intakes have parallel challenges, in particular and more commonly related to algal biomass and turbidity and suspended solids, which are dealt with in the pretreatment step by incorporating additional

[43] Results are entirely site specific and cannot be accurately predicted without significant testing
[44] Minimum pretreatment consists of cartridge filtration.

treatment steps or by modifying existing treatment processes. Open intakes also have challenges that are not shared with alternative intakes, i.e. open intakes located in an industrial or commercial port have the potential to be exposed to an oil spill, which would cause a SWRO plant to be shut down until the spill is gone.

CONCLUSIONS

Each alternative intake method carries its own specific set of challenges and risks, with an unclear advantage to the use of alternative intakes in lieu of open intake systems. In summary, a number of conclusions can be made from the subsurface intake systems reviewed.

1. The success of all alternative subsurface intake types is uniquely site specific.
2. A handful[45] of subsurface seawater desalination intakes for the production of municipal drinking water are in service and each are purpose-built for the locale. Those currently undergoing testing in the US are in varying stages of multi-year testing efforts; of which no project appears to have any advantage or disadvantage as an intake method compared to open ocean due to continued testing.
3. Alternative intakes are fixed in-place and may not be insulated from operational risks. For example, beach well intakes, depending on the river and/or tidal influences at the site, may be vulnerable to: potential sediment movement that could affect the productivity of the intake system (for example, in some cases, erosion of sand has damaged beach well intake systems[46]); changes in water quality (based on location and depth); or the impact of uncontrolled events (such as an earthquake). Although open intakes do not have the ability to buffer or eliminate feed water quality changes or uncontrolled events; they do incorporate supplemental, site-specific pretreatment steps and contingencies resulting in lesser risks for reliable operation.
4. Similar to pretreatment systems for open intakes, successful alternative intake method designs also incorporate the same supplemental pretreatment step(s) as an operational mitigation measure to prevent poor source water quality from reducing the efficiency of the SWRO membranes.
5. Considering all required, site-specific knowledge supporting an alternative intake system is on hand, additional capital improvements may be needed due to the inability to accurately predict all water quality variables. Some examples of factors that have affected reliable production include: variability in water quality; pipe material degradation; influences of nearby fresh water aquifers[47]; and contaminants (such as radioactivity and metals) that negatively impact membrane concentrate quality (for disposal) and carry potential permitting and long-term performance implications.
6. There is no research or site-specific test results available today allowing one to conclude potential, comparative, or actual entrainment and/or organism predation of larvae populations above the intake and within the seabed (based on intake type).

The conclusions do not support moving forward with employment of alternative intake methods unless the appropriate and necessary technical research and assessment takes place. In the author's opinion, unless there will be anticipated cost savings directly as a result of employing an alternative intake method, pursuit of an alternative intake method is risky unless it can be backed-up with solid field results and thoughtful

[45] Estimated less than 10, based on literature search and knowledge of the industry.
[46] Kennedy/Jenks, prev. referenced technical memorandum, 2008.
[47] More specifically, the EPA Final Groundwater Rule and the occurrence and monitoring of contaminants of concern as well as fresh water aquifer analytes affecting pretreatment efficacy.

consideration of the pretreatment components needed to ensure reliable operation. If initial technical assessment and results appear promising, testing should follow; ultimately followed by implementation if the testing results solidly support the use of an alternative intake. However, it is difficult for a project to move forward if any step is not properly and conclusively vetted. This process was vetted at Santa Cruz[48].

Construction of a subsurface intake system does not appear to be justified solely based on an anticipated reduction in I&E compared with an open intake, in particular, since there is a lack of evidence that such is the case (based on alternative intake type). There is no known association between implementation of alternative intake methods and quantifying, or lessening the impacts of impingement and entrainment or biomass predation associated with water withdrawals for drinking water facilities.

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[48] Kennedy/Jenks, prev. referenced technical memorandum, 2008.