SUBSURFACE INTAKES FOR DESALINATION FEED WATER SUPPLY CURRENT LESSONS LEARNED FROM THE ON-GOING MPWSP TEST SLANT WELL LONG-TERM PUMPING TEST CENTRAL COAST OF CALIFORNIA

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Abstract

Along the Central and Southern coast of California, communities are under increasing pressure to provide a reliable source of water for municipal use due to limited ground water supplies, water quality issues, and uncertainties with imported water as a source of supply. Seawater desalination is a viable alternative for diversifying a water supply portfolio and has been made even more attractive through cost effective and efficient subsurface feed water supply systems and water treatment technologies. Properly designed subsurface angled well intake systems reduce or completely eliminate pretreatment requirements for particulate matter thus diminishing impacts to the ocean environment from entrainment or impingement of marine life. Subsurface feed water supply systems near and beneath the ocean floor utilize the natural properties of permeable subsea aquifer sediments to filter out organic matter and suspended sediment rather than relying on expensive pretreatment systems. This results in a significant cost savings to the seawater reverse osmosis (SWRO) plant in the form of reduction in capital expenditure for construction, operation, and maintenance of a pretreatment system. Where permeable materials exist below the ocean floor a slant well system can provide a sustainable feedwater supply of 50 mgd/mi of coastline for typical subsea aquifers found in California. Research over the past 11 years has shown that total yield is a function of scale and field tests show that properly designed and constructed slant wells with engineered artificial filter packs allow production of ground water with low turbidity and silt density indexes less than one. Most importantly, the fact that in California subsurface intakes are the favored feedwater supply method as recommended in the State of California's Water Quality Control Plan for Ocean Waters of California, results in these types of intakes being much easier to get permitted for SWRO desalination plants as compared to open ocean intakes. Subsurface intakes provide a constant water quality source and due to the nearness to the ocean, typically provide 50 mgd per mile of coastline in areas where permeable materials occur beneath the ocean floor. California-American Water Company is utilizing a slant well feedwater supply coupled to a reverse osmosis desalination plant as part of their plan for developing a new water supply along the Central Coast of California. The project is known as the Monterey Peninsula Water Supply Project (MPWSP) and will replace diversion of surface water from the Carmel River. This new innovative project includes constructing a subsurface intake system of seven slant wells to initially provide a 6.4 mgd feedwater supply. As part of this process, a 19 degree 724 ft test slant well was constructed in December of 2014 near Marina California. The test well has been pumping 3 mgd with water quality and inland water level impacts measured for over two years using a 29 monitoring well network. This paper presents a summary of the lessons learned and application of this knowledge to the desalination industry.

I. SUBSURFACE INTAKES FOR DESALINATION PLANT FEED WATER SUPPLY

Subsurface intakes utilize the natural water filtration and pretreatment provided by ocean floor sediments. The number of subsurface intakes throughout the world is relatively small compared to open ocean intakes averaging approximately 12 mgd per facility as compared to approximately 52 mgd per facility for open ocean intakes [1], [2]. Slant well feed water supplies for SWRO desalination plants is an emerging technology. Originating out of the necessity to explore subsea aquifers, the first angled well (slant well) for desalination feed water supply was constructed off the coast of Dana Point in 2006. Since then, a number of subsurface intakes for SWRO have been and are continuing to be evaluated along the California coast ranging in size from small systems (< 10 mgd) to very large systems (> 150 mgd) [3]. The Doheny Beach and Monterey projects are part of this testing and evaluation.

Subsurface feedwater supplies have a number of advantages over open ocean intakes including avoidance of entrainment and impingement impacts to marine life, reduction of costly reverse osmosis pretreatment, absence of ocean construction impacts, and no permanent visual impacts. For desalination plants ranging from approximately 13 mgd to 50 mgd, pre-treatment capital costs range from approximately 15%-18% of the total plant cost and pre-treatment operation and maintenance (O&M) costs are approximately 25% of the total plant O&M costs [3].

Due to the protective environmental atmosphere and stringent permitting process in California, slant well subsurface feedwater supply systems provide an alternative to the traditional open ocean intake for SWRO desalination plants. In fact, the California Ocean Plan (Water Quality Control Plan for Ocean Waters of California) [4] recommends that subsurface intakes are the preferred technology for seawater intakes. In accordance with the Ocean Plan amendment, a number of desalination projects in the planning or testing stage along the Coast of California are considering subsurface intakes for feed water supply. Presently, ten small desalination facilities are in operation along the California coast with 15 more in the feasibility phase with a cumulative fresh water output ranging from 260–367 mgd [3]. Given available coastline and near shore and offshore permeable deposits, slant wells can produce 50 mgd/mile of coastline for typical subsea aquifers.

Since the first phase of the Doheny Ocean Desalination Project was completed (2005-2012), subsequent exploration and analyses are underway for the full-scale project near Dana Point, California. In addition, the Monterey test slant well has completed over two years of long-term pumping and monitoring as part of the initial testing for the Monterey Peninsula Water Supply Project. The background and status of both projects have been summarized extensively in previous documents [5], [6], [7], [8], [9], [10], [11], [12].

Challenges on developing slant well feed water supplies including permitting, siting, design, operation and other factors. These have been identified and resolved during the last five years of planning, design, testing and monitoring of the MPWSP test slant well. This paper identifies important lessons learned and how they have been resolved with regard to development of a subsurface SWRO feed water supply using subsurface slant wells.

II. HISTORY OF THE MONTEREY PENINSULA WATER SUPPLY PROJECT

In 2004, CalAm[1] filed an application for the Coastal Water Project (also referred to as the Moss Landing Project) to replace existing Carmel River water supplies for the CalAm Monterey District service area. The Coastal Water Project and its two alternatives, the North Marina Project and the Regional Project, involved producing desalinated water supplies, increasing the yield from the Seaside Groundwater Basin and building additional storage and conveyance systems to move the replacement supplies to the existing CalAm distribution system. The Coastal Water Project was sized to meet existing water demand and did not include supplemental supplies to accommodate growth. Subsequent to approval of the Regional Project CalAm withdrew its support for the Regional Project and submitted an application for the Monterey Peninsula Water Supply Project (MPWSP). The MPWSP includes many of the same elements of the previous proposed projects, however, key components, including the seawater intake system and desalination plant, have been relocated and/or modified for the MPWSP.

The proposed MPWSP includes construction of a desalination plant located in unincorporated Monterey County northeast of the City of Marina and ten subsurface slant wells at the CEMEX active mining area in the northern area of the City of Marina to produce approximately 10,750 afy. The proposed MPWSP Desalination Plant has a rated capacity of 9.6 million gallons per day (mgd).

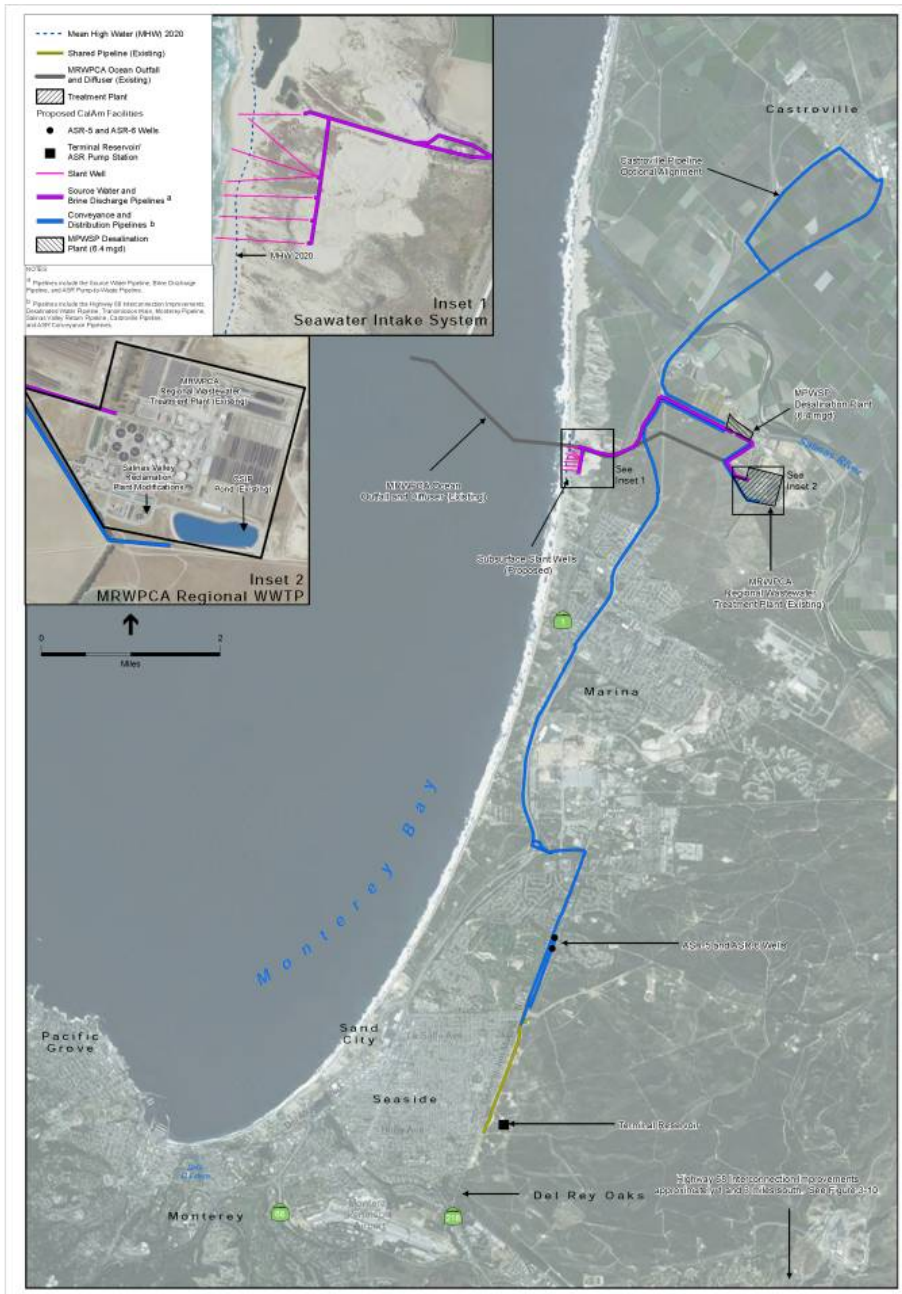


Figure 1. Location of MPWSP (from CalAm EIR/EIS, Jan 2017)

[1] California American Water Company (CalAm) is a privately owned public utility that has served the Monterey Peninsula since 1966.

Alternative 5a is a variation of the proposed MPSWP with the capacity to produce 6.4 mgd and includes the construction and operation of a reduced-capacity desalination plant capable of producing 6.4 mgd. Project components would be sited at the same locations as the proposed project and the only differences are the number of slant wells and the size of the desalination plant (see Figure 1)

III. LESSONS LEARNED

3.1 Early on Establish a Collaborative Working Group

Development and implementation of any emerging technology project requires a cohesive blend of technical experts, environmental compliance, public perception and regulatory awareness. As such, for a slant well feed water supply in sensitive coastal areas of California, a collaborative effort was necessary which included participation by recognized experts in geology, hydrogeology and modeling. The collaborative group included stakeholders of ground water usage and management in the MPWSP project area and led to development of the Hydrogeologic Working Group (HWG). The HWG first met in 2013 to discuss conceptual models and to form a collaborative plan of investigation to assess the hydrogeologic conditions in the project area. As with any collaborative group, individual opinions need to be evaluated against actual field data and testing to arrive at a conceptual model that reflects a common understanding at the areas of concern. A draft workplan was prepared which provided a phased approach to progressively investigation of the hydrogeology and the potential effects to aquifers from the use of subsurface slant wells for obtaining feed water supply. The final workplan incorporated comments and recommendations by members of the HWG, and covered the investigative steps needed to evaluate the project impacts which became the hydrogeology investigation roadmap.

3.1.1. Hydrogeologic Investigation Workplan

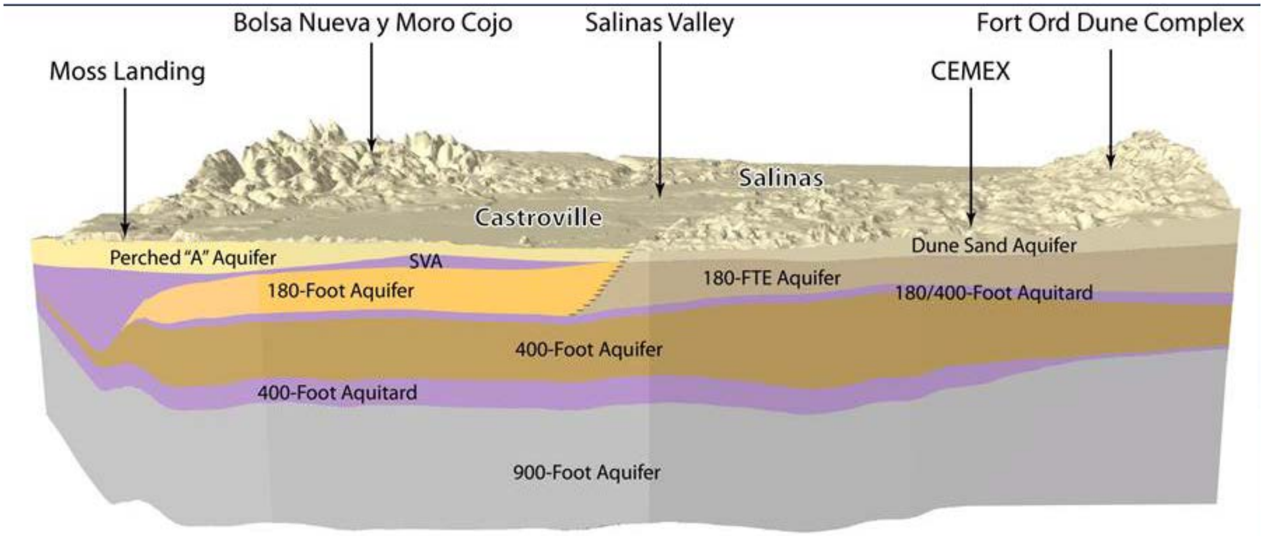
The process adopted by the HWG for the workplan consisted of on-going steps of data collection and analysis. The data collected from this initial phase of investigation was used to construct the various ground water models which became the tools to evaluate the short-and long-term hydrogeologic impacts in the project area from operation of the MPWSP. Each step of data gathering was preceded by an update of the workplan as appropriate, describing the proposed work and desired outcomes. Results were documented by a technical memorandum, the Hydrogeologic Investigation Workplan (HWP), which became the main working document for all exploratory, testing, and modeling work, including: describing the methods of data collection, findings and recommendations.

3.1.2. Hydrogeologic Investigation Report

The companion document to the Workplan was the Hydrogeologic Investigation Report (HIR) and includes technical memorandums documenting all exploratory and testing activities as well as progressive model refinements and impacts, specifically:

- Attachment 1 - Summary of Results – Exploratory Boreholes
- Attachment 2 - Summary of Results – Test Slant Well and Monitoring Wells

- Attachment 3 - Summary of Results – Long Term Pumping Test and Monitoring Well Program
- Attachment 4 - Refined ground water model results following exploratory boreholes, monitoring wells, test slant well and full scale system



Note: 10x Vertical Exaggeration

Figure 2. MPWSP Geologic Setting and Aquifer Systems

3.2 Lessons learned during the siting process

In order to maximize recharge from ocean sources, as well as minimize variations in salinity and impacts to inland resources, slant wells should be located as close as possible to the ocean where permeable materials extend offshore (see Figures 2 and 3).

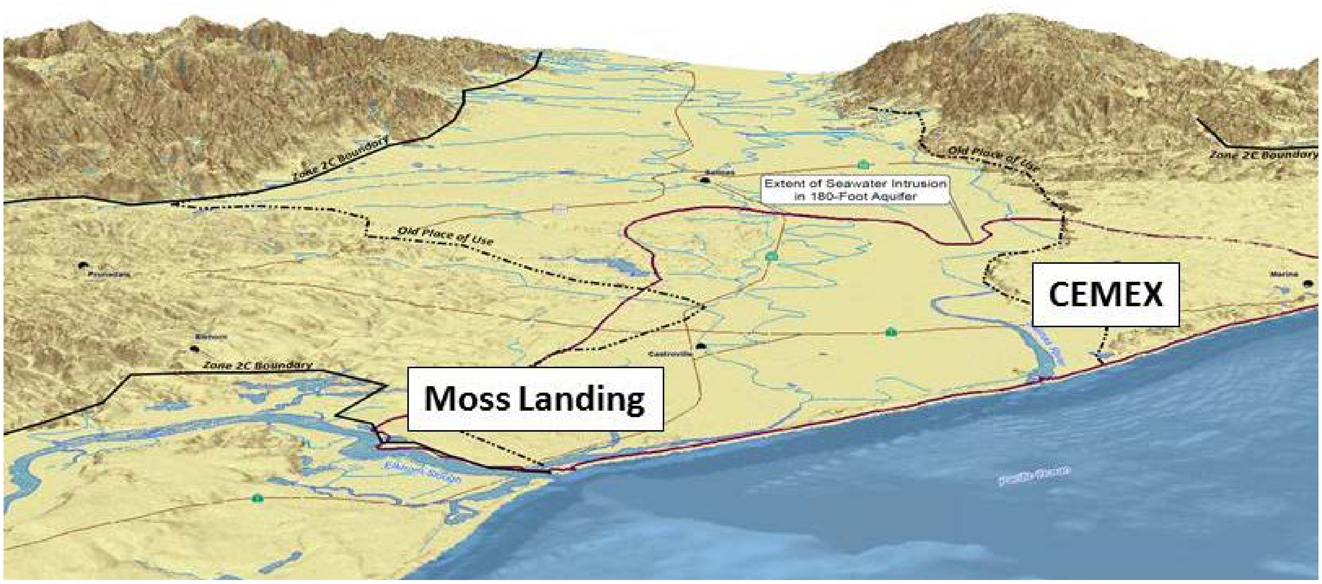


Figure 3. Location of the MPWSP (Along the Coast Near CEMEX)

Locating subsurface intakes near and offshore maximizes both vertical leakage through the seabed and horizontal recharge from offshore aquifers. Other considerations include coastal erosion, 100-year flood zone, sea level rise and proximity to sensitive habitat, well construction footprint, access to the drilling site and equipment staging area, and periodic access for monitoring and maintenance [13], [14], [15], For example, in the Doheny project, the test well was located on a State Beach and subjected to strict compliance with recreational uses. For the Monterey project, siting considerations were within a strict footprint to comply with all of the factors listed above.

Proximity to existing surface water bodies should also be considered during the siting process as infiltration from either seasonal or perennial surface water bodies may impact the water quality from the initial well testing phase used for long-term treatment planning. The location of wells should consider constraints (environmental and others) to site access as well as the appropriate footprint for well construction and staging.

3.3 Lessons learned during the permitting process

Construction in sensitive coastal areas of California involves numerous permits obtained from many different agencies. As local and regional stakeholders should be included in all preliminary discussion therefore, public outreach is as important to the project as is collecting accurate data and developing a technically sound project design. The development of a collaborative technical advisory committee is an important tool in ensuring that project plans, data, and communication are shared and discussed among stakeholders to move the project efficiently through the various technical phases. The Hydrogeologic Working Group (HWG) composed of highly qualified technical experts representing major stakeholders was developed during the planning and permitting stages of the MPWSP project. The HWG has worked closely to plan investigations and understand and interpret project data.

“Half Moon” screen design

Figure 4. MPWSP Test Slant Well

3.4 Lessons learned during design and construction

Prior to the construction process a close collaboration with the drilling contractor is essential. Reviewing well designs and step by step methods to be used at every phase of well drilling and construction should be prioritized before equipment is mobilized. The Geohydrologist should satisfy themselves that appropriate equipment is selected and set apart for the project. Equipment should be inspected prior to mobilization, and the contractor should ensure that timely replacement of high quality parts which inevitably require replacement during the operation will occur. Figures 4 and 5 show the design of the MPWSP test slant well.

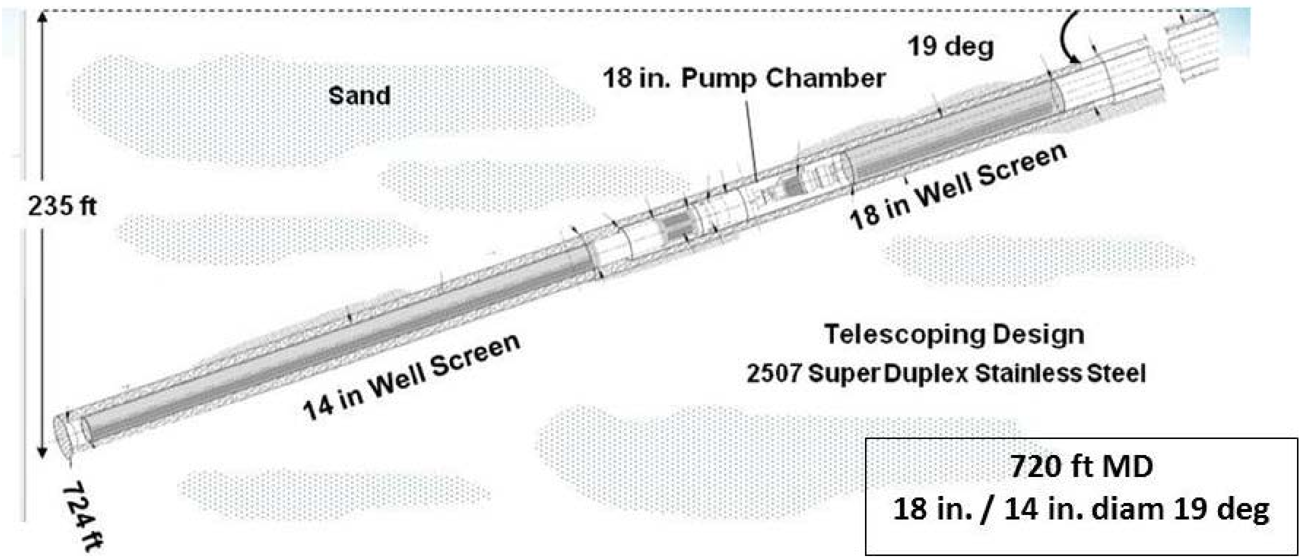


Figure 5. MPWSP Test Slant Well Showing Telescoping Design

3.4.1. Partial Well Screen around casing circumference – Half Moon Design

During the lifetime of artificially filter packed vertical wells, the filter material placed in the annular space between the borehole wall and the well screen tends to lose volume due to compaction and settlement over time. To refill the filter pack, gravel feed pipes are placed in the annular space between the well screen and borehole wall. This allows for periodic topping up the filter pack preventing migration of fine-grained aquifer materials into the well during pumping. In vertical wells the gravitational forces acting downward are parallel to the vertical axis of the well and the filter pack

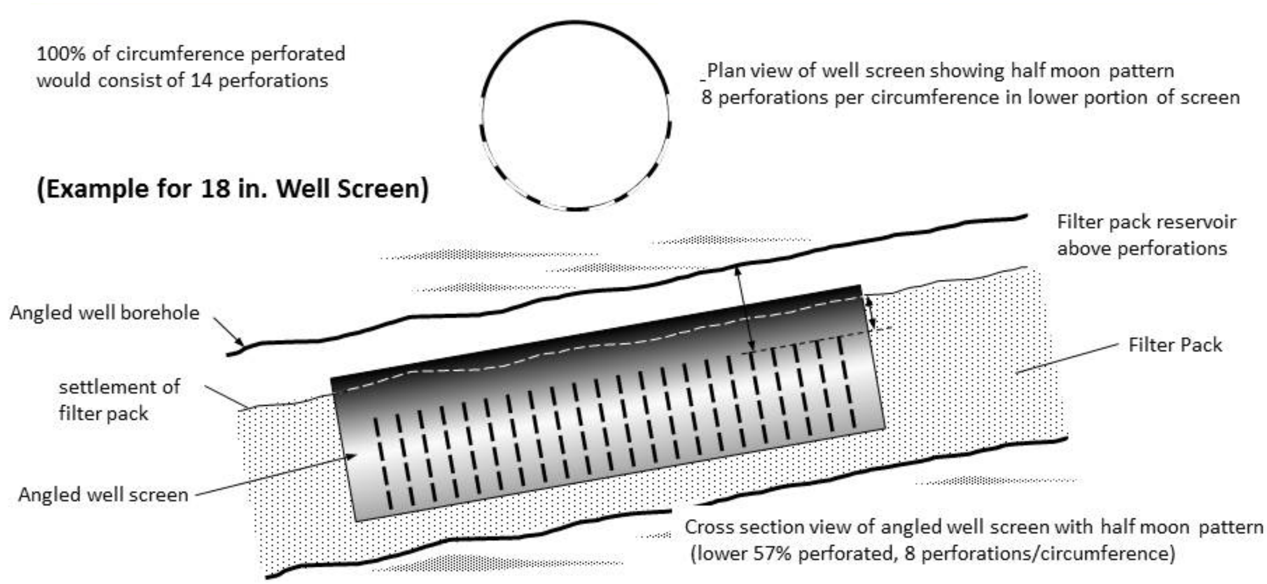


Figure 6. Half Moon Well Screen Perforation Design

completely surrounds the well screen. However, in angled wells (which vary from a few degrees to a few tens of degrees below horizontal), gravitational forces also act vertically but do so throughout the entire well screen length. Due to the angled well's unique method of construction, there is no filter pack reservoir other than the volume of filter material resting above the top of the well screen pipe. Over time, consolidation of this overlying filter material may result in the pack settling to the point that the top of the well screen is exposed directly to fine-grained aquifer materials. If the angled well screen is perforated throughout the entire circumference of the well screen pipe, settlement of the pack will expose well perforations directly to aquifer materials which could result in catastrophic well failure. To prevent this from happening in the MPWSP test slant well, the well screen was perforated only in the lower portion allowing some filter pack material to remain above the perforations (in the annular space between the top of the perforations and the borehole wall) acting as a reservoir. This partial perforation method (i.e., half-moon pattern) allows for some vertical settlement of the filter pack over time but still provides a reservoir to prevent the well screen from directly contacting the aquifer (see Figures 5 and 6). In other words, the half-moon design creates a built in filter pack reservoir for every lineal foot of well screen length which allows for filter pack settlement without compromising the well's ability to stabilize the aquifer.

3.4.2. Drilling Issues

In coastal settings which may primarily be underlain by beach or dune sand, considerations should be given as to drilling method used to construct the wells. The dual-rotary method is suited best for drilling in all types of saturated sediments. Using a telescoping drill casing allows penetration of over a thousand feet of material. However, in the surface dry sand, the dual rotary method will require the use of mud to advance the larger diameter conductor casing. Alternatively, the starter (conductor) casing can be pre-installed by trenching and placed at the design angle prior to mobilizing the drilling rig. Telescoping the drill casing as the boring advances is essential for efficient penetration of the drill casing. Due to frictional forces acting between the drill casings and surrounding soil, the length of each telescoped drill casing length should be planned ahead with knowledge of the specific sediments depths and types from exploratory borings. It is essential to minimize the frictional forces especially in the upper larger diameter drill casings which remain static the longest, and which will receive well screen during well construction. The overall time at which each drill casing is left immobile should be minimized through efficient well construction. Due to the absence of gravity from the low angle of the well, placing the filter pack material, tremie methods and tagging filter pack are much more challenging but can be accomplished by placing multiple tremie pipes over the well casing. Filter pack tagging may be done using a solid PVC tagging tool or potentially using geophysical methods from within the well casing.

3.5 Lessons learned during the pumping test

The MPWSP long-term pumping test has been operating for over two years. During that time, the availability of a reliable power supply has been important for minimizing or eliminating unplanned shut downs. Although, important data can be collected when a well is shut down and started up (such as changes in specific capacity as the well continues to develop), reducing shut downs more reliably demonstrates that well can and will function over long- periods and that water quality is consistent with time. Coastal wells are influenced by normal tidal changes as well as seasonal water level changes from precipitation and storm surges. Tidal correction of water level data is required to normalize data for analysis. In addition, as the test slant well is producing from two main aquifer systems (Dune Sand and

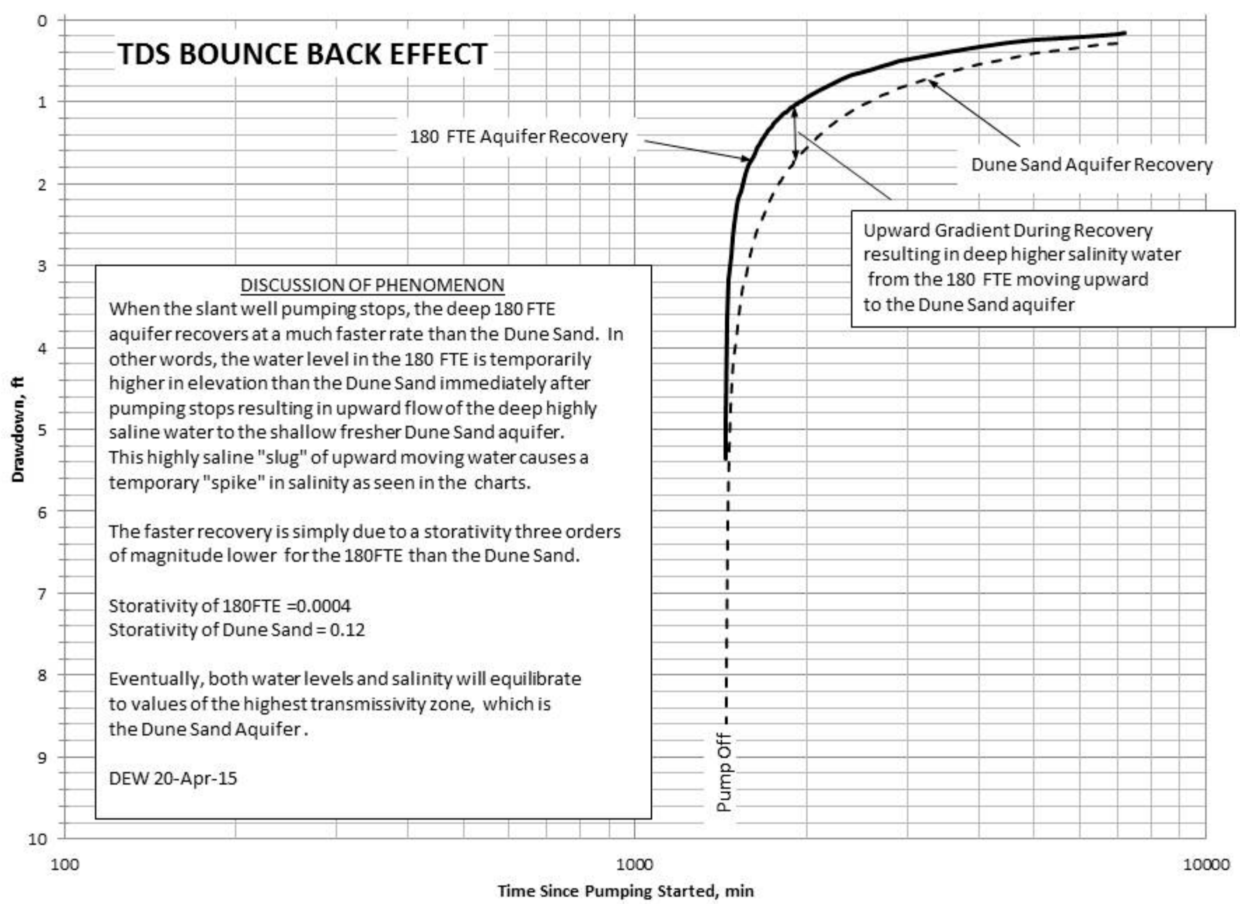


Figure 7 MPWSP Test Slant Well Showing Water Quality Variation During Recovery

180 FTE), differing hydraulic properties result in different water quality during start up and shutdown (see Figure 7). Although these differences are fairly minor, they should be considered in the full scale system operation.

3.6 Lessons learned during monitoring

Observation wells should be sited to ensure that on-going data collection will not only allow detailed analysis of the near-well conditions but also measure any changes in groundwater level further afield, especially where the presence of existing wells may potentially be influenced by pumping. The locations of observations wells should be determined through the technical committee to ensure that stakeholder concerns will be addressed through collection and analysis of data. Observation well networks should include monitoring of all aquifers that could potentially be impacted by pumping. Baseline data should be collected as far in advance as possible from observation wells to document seasonal trends in groundwater level changes not associated with test well pumping (see Figure 8).

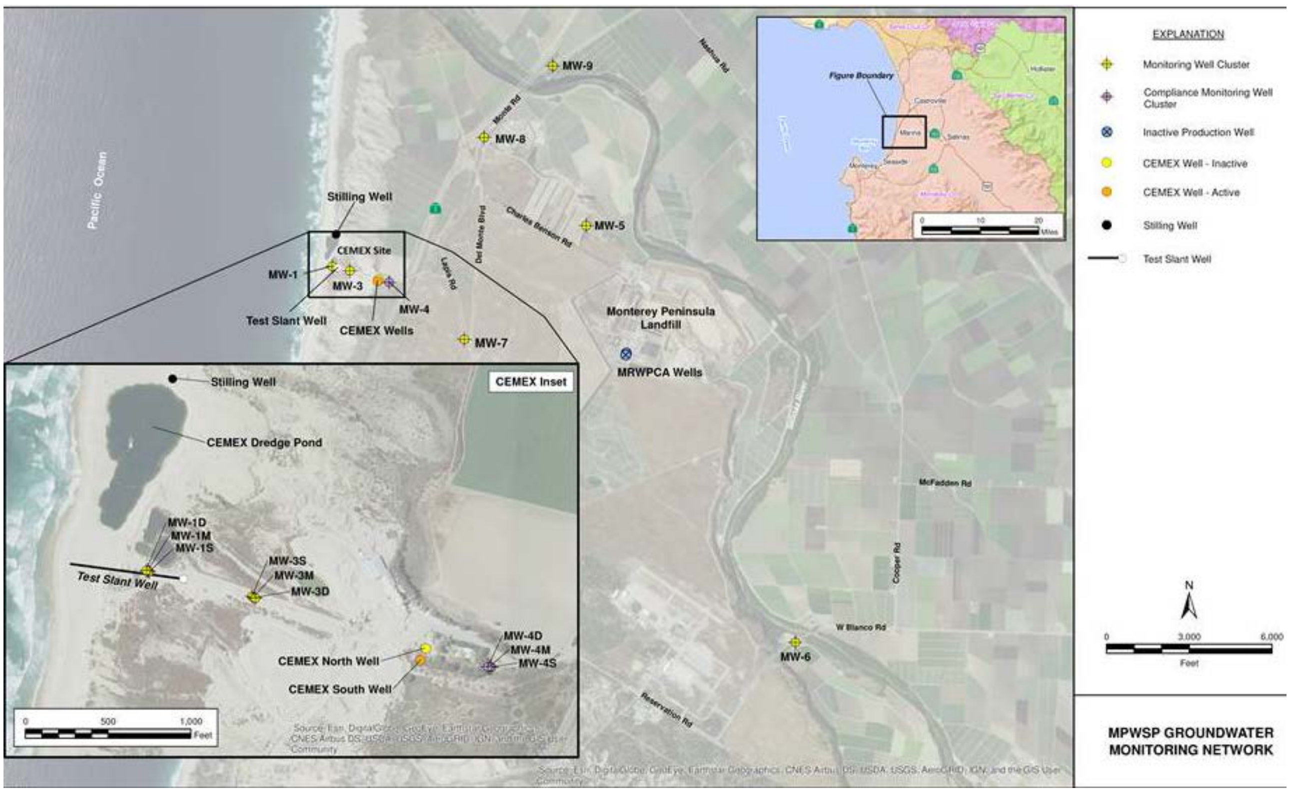


Figure 8. MPWSP Monitoring Well Network

In coastal aquifers, the normal interface between freshwater and saltwater described by Ghyben-Herzberg relation results in the salinity stratification with one or multiple aquifers. With the addition of seawater intrusion in some coastal areas, salinity stratification may occur over short vertical distances and can result in an erroneous characterization of baseline water quality and changes in water quality within the target aquifers. Salinity profiling should be conducted during initial site investigations and accounted for in the observation well design, placement of monitoring devices, and groundwater sampling to result in accurate determination of water quality in the aquifers.

The MPWSP project emphasized the importance of an on-going monitoring program to measure water level and salinity changes and provide on-going data that can be used to assess potential adverse impacts. As with any project located near sensitive habitat or on-shore uses of groundwater, monitoring is essential to ensure that the projects are not significantly impacted. A 29 well monitoring has been on-going in the MPWSP since the end of 2014. During this period, the wells have been monitored for water levels and water quality. The distance of the wells from the test slant well vary from approximately 200 ft to over four miles. The monitoring network includes eight monitoring well clusters where each cluster consists of three monitoring wells at different depth intervals. The monitoring wells are continuously monitored for water level and salinity (TDS) changes. Data are being used to refine ground water models and improve prediction of potential impacts associated with the full scale project. Monitoring is required in most cases to comply with regulatory requirements and in the case of the Monterey project to comply with a California Coastal Commission development permit.

3.6.1. Water Quality

During the long term pumping test, water quality showed a high percentage of ocean water in the test slant well discharge. In addition, high concentrations of iron and manganese found in the old marine ground water in the Doheny test slant well was absent in the Monterey test slant well. This suggests that the Doheny project was initially pumping old (ancient) marine groundwater in the subsea aquifers associated with the geology and hydrology of subsurface alluvial materials of the nearby creek. Iron and manganese concentrations from the MPWSP test slant well are very low, suggesting that the subsea environment containing old marine ground does not occur off the Monterey coast and may be associated exclusively with subsea paleochannels such as in the Dana Point area. This is significant in that precautions in the feedwater supply that may need to be taken in the Doheny project (due to iron and manganese) do not have to be considered for the Monterey project.

3.7 Lessons learned during the environmental review process

Close, accurate, timely, and consistent communication with project regulators will ensure that the project progresses efficiently and that project data is available for review and independent comment by regulators. Data should be presented in a format that is easily understood and legible to communicate the project conditions timely and accurately. Involvement of the technical committee (e.g., HWG) is crucial for regulator confidence that the data collection methods and analysis are appropriate and defendable throughout the review process. The consistent and transparent availability of on-going data collection and analysis will also provide regulator confidence in the process.

3.8 Lessons learned – public perception

In California, the environmental process associated with any new project planning necessarily and appropriately provides a consistent opportunity for the public to provide input into the planning process. Publicly available project updates as well as community meetings aid the process of providing the public with a correct understanding of the project and the data collection and analysis which is being accumulated for on-going project planning. The MPWSP provides publically available weekly progress reports documenting the data collection. The primary regulator is issued a monthly report signed by the technical advisory group documenting project activities and providing data and data interpretation in strict accordance with project permits. In addition, when questions arise outside of permit considerations, the technical advisory group meets to address questions through technical collaboration.

IV. SUMMARY AND CONCLUSIONS

Subsurface alluvial materials extending beneath the ocean floor can be developed through a network of low angled wells (slant wells) producing from near shore and offshore subsea aquifer systems. The slant wells provide a sustainable feed water supply to sea water reverse osmosis (SWRO) desalination plants. Favored by the California Ocean Plan, these types of subsurface intakes eliminate impingement and entrainment issues and other environmental impacts associated with conventional open ocean intakes. This paper summarizes lessons learned from a test slant well completed off the coast near Monterey which is currently in the final stages of the permitting and testing process as part of the Monterey Peninsula Water Supply Project (MPWSP). The project has taken five years to reach the current stage which includes over two years of long term testing at 3 mgd. The first phase of the project will consist of seven 1,000 ft slant wells screened near and beneath the ocean floor. Lessons been learned during the course of the MPWSP development include:

- Development of a collaborative working group
- Consideration of Coastal Erosion, Sea level rise, 100 yr flood and environmental sensitivity during the siting process
- Permitting is the number one constraint to project development and needs to begin early in the process
- Drilling wells on an angle result in a number of challenges due to the absence of gravity and completion beneath the ocean floor
- Screening the completion section by only partially perforating the well screen pipe circumference ensures a built in filter pack reservoir.
- Drilling using the dual-rotary method requires a careful blend of lithologic knowledge as well as circumference of the temporary casing and maximum extension of each telescoping section
- Monitoring of water levels and quality need to start as soon as possible to establish a defendable baseline to measure project impacts against.
- Close collaboration with the stakeholders, environmental groups and water producers in the area need to be initiated early on in the project.
- Like any new and innovative project, there is a natural reaction to change by the public. Public awareness workshops and transparency are paramount in advancing the project forward.

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