DESIGN AND CONSTRUCTION OF SLANT AND VERTICAL WELLS FOR DESALINATION INTAKE

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Abstract

Coastal communities are increasingly considering seawater desalination as a potential source of water for municipal supply due to limited or poor inland ground water quality and a decreasing reliability of imported water supplies. As such, seawater desalination is a viable alternative which has been made even more attractive through more cost effective and efficient subsurface intake systems and water treatment technologies. Desalination intake systems using low angled wells (slant wells) and vertical wells produce ground water from offshore and near shore aquifer systems and provide a number of advantages over open ocean intake systems including avoidance of entrainment and impingement impacts to marine life, reduction of costly reverse osmosis (RO) pretreatment, no ocean construction impacts, and no permanent visual impacts.

Subsea and near shore aquifer systems also provide natural filtration from suspended organic matter and sediment particularly during storm surges and heavy precipitation. Field tests show the engineered artificial filter pack surrounding the screened portion of the intake wells results in low turbidity and silt density indices. A subsurface desalination feed water well supply system typically consists of shallow angle wells (slant wells) or vertical wells in a beach or near-coastal environment. A slant well intake system may consist of a single slant well, an array of slant wells or multiple arrays of slant wells constructed near or beneath the ocean. Environmentally sensitive, slant well systems are buried systems completed below the land surface eliminating undesirable aesthetic impacts (i.e. no visual impacts on the surface). Tried and true well design and construction methods involving an engineered artificial filter pack are employed for both the slant and vertical wells. Drilling and completion challenges of the shallow angled slant wells have been overcome using the dual-rotary method of construction. A telescoping well design allows slant wells to extend to lineal lengths of 1,000 ft or more offshore into subsea aquifer systems. An 18 month pilot test is currently underway as part of the South Orange Coastal Ocean Desalination Project a phased program designed to provide a 30 mgd desalination feed water supply. Located beneath the sands of Doheny Beach near Dana Point in Southern California, a 350 ft long slant well is completed in subsea aquifers to depths of approximately 140 ft. Completed with a 12 in. diameter artificially filter packed well screen the well produces 2,200 gpm. The full scale desalination intake system will consist of seven low angled slant wells (10 deg below horizontal), 1,000 ft long and each well producing 3,000 gpm. In other coastal areas of California and Mexico, vertical and slant well intake systems are viable alternatives to infiltration galleries or open ocean intake systems and where offshore or near shore aquifer systems are favorable.

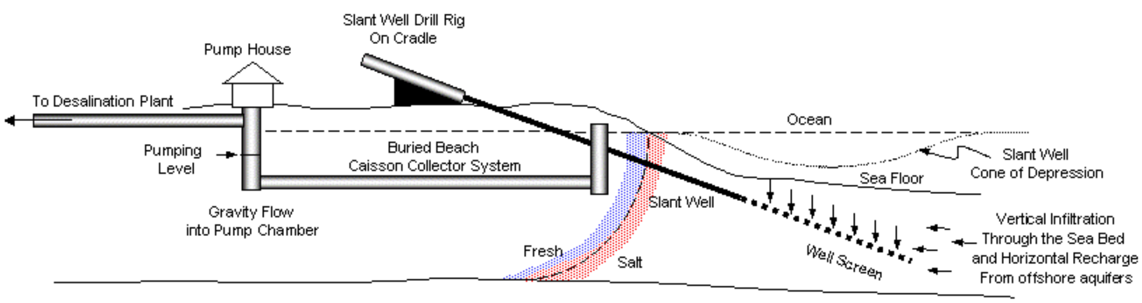
I. GENERAL

1.1 Description of Slant and Vertical Well Desalination Feedwater Supply

A typical water supply well is simply a boring drilled into a geologic formation or group of formations which have some portion of their thickness saturated with water. A pipe placed in the borehole which includes both blank and perforated sections allow inflow of water to the well's pumping system. In order to prevent movement of sand from the aquifer into the well (which clogs the pump), an artificial filter pack is placed between the outside of the perforated pipe and the open borehole. Artificial filter packed well technology has been perfected since the 1940's with excellent success leading to tried and true well designs with sand free water and high productivity. It is this proven technology which is currently being adapted to subsurface intake systems to provide sand and silt free water to desalination plants. As will be seen, one of the design parameters used in reverse osmosis (RO) feedwater supplies is the membrane fouling value as measured by the Silt Density Index (SDI). When Silt Density Indices are less than 3 to 5, costly pre-treatment can be reduced or eliminated entirely. Additional benefits of a subsurface feedwater well supply include no marine life impingement or entrainment issues and minimal to no visual surface impacts.

Slant wells are merely vertical wells drilled on an angle (see Figure 1 below). The same design criteria apply to slant wells and vertical wells alike (e.g. engineered filter packs, well casing and screen design). However, slant wells pose more construction challenges than vertical wells due to shallow construction angles and reduced vertical gravitational forces. Typically slant wells are constructed at angles below horizontal ranging from less than 10 degrees to 30 degrees).

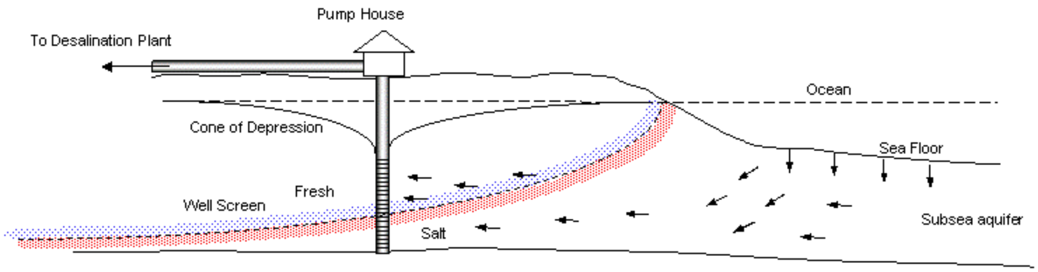
Figure 1 – Slant Well Feedwater Supply



Dana Point CA Slant Well Construction

Figure 2 (below) shows a typical vertical well desalination feedwater supply.

Figure 2 – Vertical Well Feedwater Supply



Gulf of Mexico Vertical Well Construction

Successful desalination feedwater supply wells need to:

- Be completed in suitable aquifer types (i.e. productive with adequate thickness)
- Utilize proven artificial filter pack methodology
- Incorporate proper well construction, completion, development and testing
- Be composed of proper casing and screen materials for a sea-water environment

1.2 Advantages of Using Wells for Subsurface Feedwater Supply

A feedwater well supply system may consist of a single well or a well field. Vertical or slant wells obtain the feedwater supply from permeable aquifer systems near and/or beneath the ocean. Slant wells induce recharge through the sea floor due to the hydraulic head difference between the slant well pumping level and the level of the ocean (see Figure 1). As the supply source is relatively constant, the water supply to a slant well system provides a long-term sustainable water source.

Well desalination feedwater supply systems present significant advantages over traditional open ocean intakes including:

- Avoidance of entrainment and impingement impacts to marine life,
- Reduction or elimination of costly reverse osmosis pretreatment,
- No ocean construction impacts, and
- No permanent visual impacts.

1.3 Geohydrologic Considerations

The purpose of a subsurface desalination feedwater supply from either slant or vertical wells is to provide a reliable supply as well as a supply which has a low fouling potential to Reverse Osmosis (RO) membrane systems. Wells should be completed in aquifers having high permeability and sufficient thickness (e.g. high transmissivity), and in hydraulic continuity with the ocean.

1.4 Environmental Considerations

Things to consider in addition to aquifer productivity are:

- Visual Impacts of facilities (during construction and permanent)
- Impacts to off shore water supplies
- Impacts to riparian vegetation
- Impacts to fish and wildlife

Visual impacts may include unsightly facilities on the beach or in near shore areas where recreational or other high use occur. Impacts to inland water supplies are very important if a considerable percentage of the recharge to the well's feedwater supply draws from these sources. Drawdown (i.e. ground water level changes) in areas of sensitive vegetation, fish habitat or other wildlife may also restrict placement of the wells or hinder construction and maintenance.

1.5 Permitting Considerations

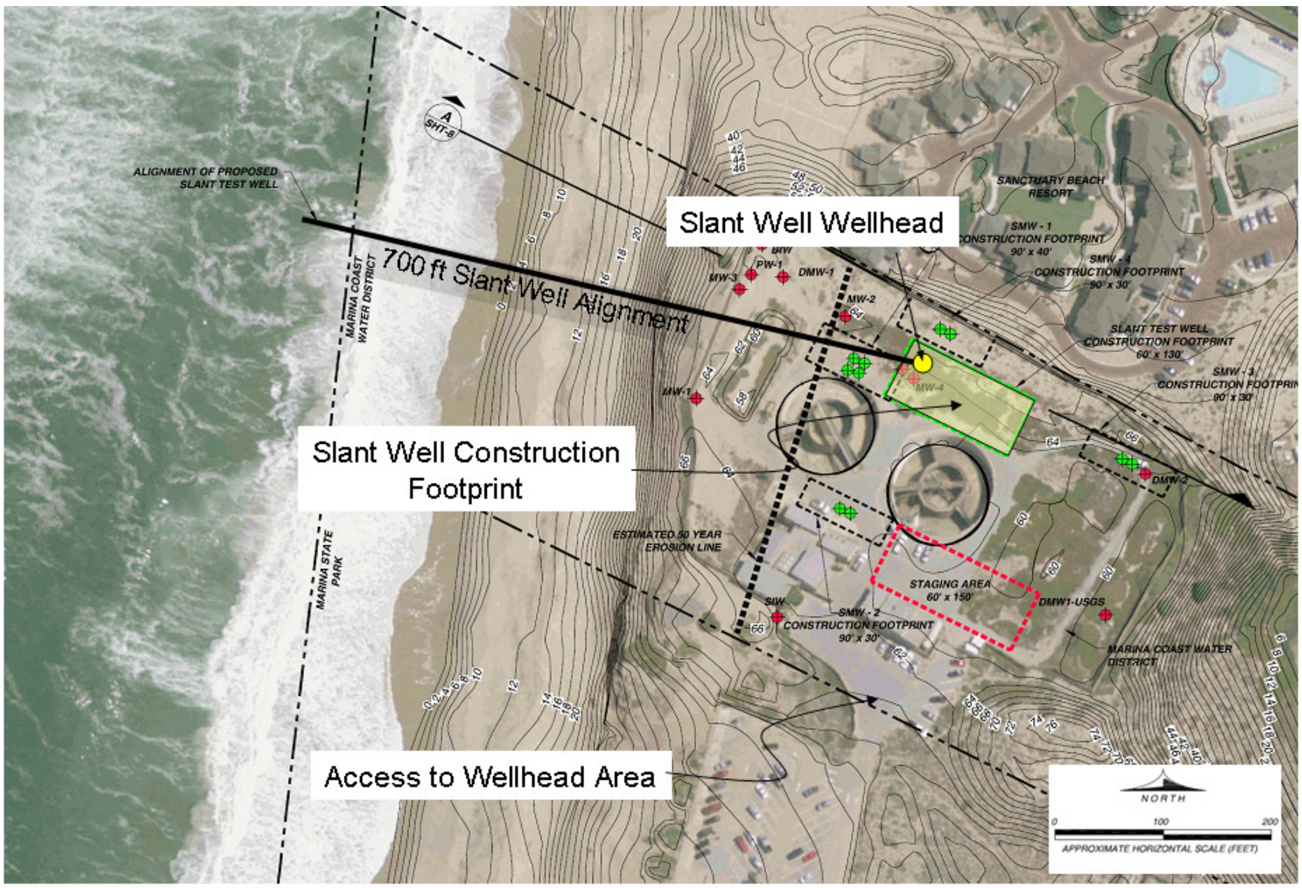
In some coastal areas, obtaining permits is the number one constraint in constructing a near shore or off shore subsurface feedwater supply. For example, in California, permits to construct the Dana Point Test Slant Well on Doheny State Beach required the following permits:

- California Environmental Quality Act (CEQA)
- National Environmental Policy Act (NEPA)
- California Coastal Commission Coastal Development Permit
- California State Lands Commission Lease
- California State Parks Right of Entry Permit
- San Diego Regional Water Quality Control Board
- NPDES Permit No. CAG919002
- United States Army Corps of Engineers Nationwide Permit Number 7
- San Diego Regional Water Quality Control Board Clean Water Act §401
- Orange County Health Care Agency Well Construction Permit
- California Department of Fish and Game Streambed Alteration Agreement

1.6 Access and Maintenance Issues

All wells routinely need to be redeveloped and periodic access to the well head area is necessary. If the well is sited in environmentally sensitive areas, or areas where recreation exists (e.g. on a State Beach), provision must be made to minimize disturbance. Figure 3 (below) shows an example of the construction footprint and access to a slant well feed water supply sited near a State Beach in the Monterey California area. Access is through the parking lot to the south and storage and staging areas are situated in the general vicinity of the wellhead.

Figure 3 Slant Well Layout Near Monterey, California



II. WELL DESIGN PARAMETERS FOR DESALINATION FEEDWATER WELLS

For feedwater supply wells producing from subsea or near shore aquifers, the single most important well design objective is prevention of fine-grained materials (sand and silt) from entering the well. Proper design should maximize aquifer production, stabilize fine-grained materials and maintain as large a screen slot opening as possible.

Proven well design principles and relationships which result in successful wells should include:

- simple and strong,
- high productivity,
- sand and silt free,
- long lasting and suitable for desalination feedwater supply

2.1 Silt Density Index – A Measurement of Membrane Fouling Control

Silt density index (SDI) is one of the major design parameters for a successful desalination feed water supply well. SDI is a non-specific measure of the colloidal fouling potential of water and is the most widely used method for determining feedwater quality for membrane desalting processes. SDI measures the filterability of water by measuring the decrease in flow through a 0.45-um membrane filter over a 15-minute period while operating at a constant 30-psi feed pressure [1]. Dimensionless SDI values are roughly correlated to Reverse Osmosis and Nanofiltration (NF) membrane fouling potential based on empirical experience in membrane desalting operations. As a general guideline, most membrane manufacturers recommend maintaining feedwater SDI less than values of 3 to 5, depending on the membrane type and manufacturer. Waters with SDI values consistently greater than 5 generally require pre-treatment before the membrane desalting process.

In natural water supplies, SDI values are controlled by the type and quantity of colloidal particles, which are comprised of a wide range of constituents including clay, bacteria, colloidal silica, and other particles. In addition to the primary colloidal fraction, which is present in either a surface water supply or ground water supply, a secondary colloidal fraction may occur during the conveyance or treatment of the water supply. Ground water supplies high in dissolved iron and manganese result in formation of an iron and manganese hydroxide precipitate when water is exposed to oxygen or chlorine. These precipitates then further contribute to the colloid quantity and would likely increase SDI levels. In other cases, changes in pH, or addition of pre-treatment chemicals, may result in formation of a secondary colloidal fraction, which may contribute to SDI values.

Section V discusses some case histories of water supply wells, their design parameters and results of SDI measurements. As will be shown, all of the wells which have followed the design criterion recommended in this paper are suitable for desalination feedwater supply systems which do not require pretreatment.

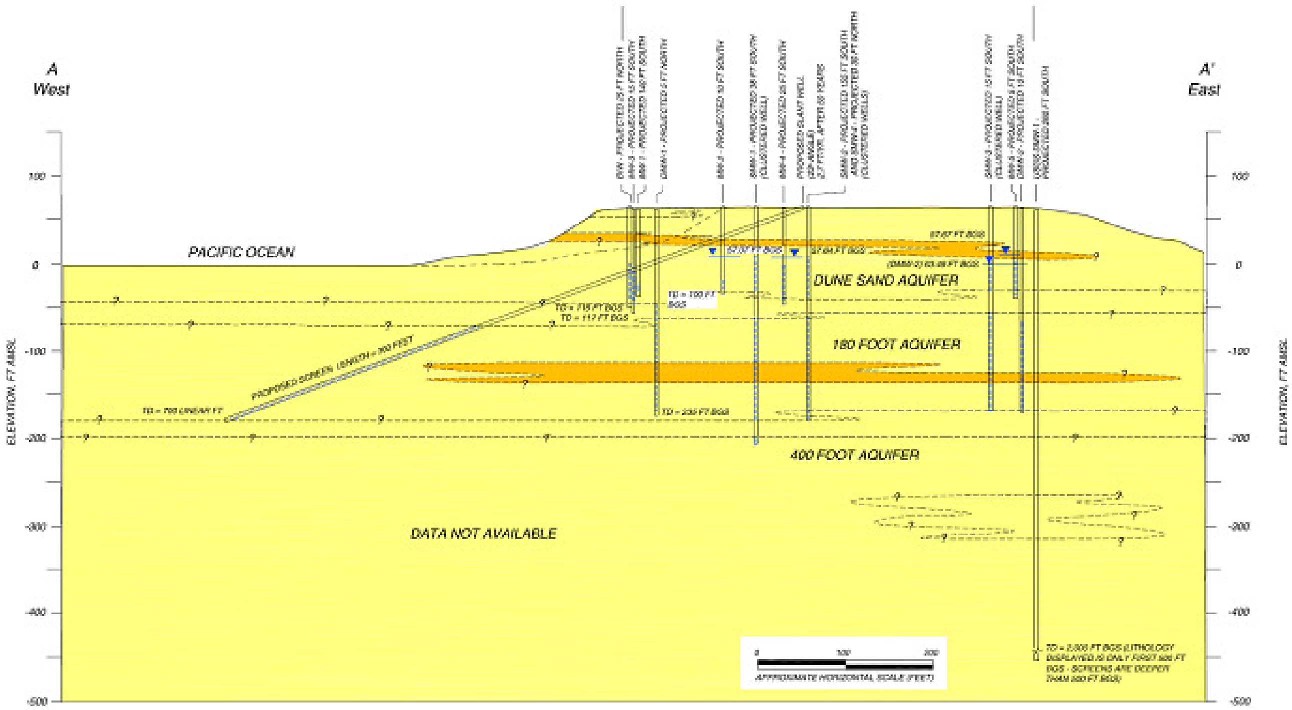
2.2 Design of Well Casing and Screen

2.2.1. Selection of Casing and Screen Lengths

Aquifer transmissivity is the product of hydraulic conductivity and saturated thickness and is directly proportional to the productivity of a well. Proper placement of well screen should maximize aquifer transmissivity in order to obtain the highest production possible from the subsea or near shore aquifer system. Figure 4 (below) shows that the target aquifer for a slant well feedwater supply is the 180 ft aquifer lying at elevations of approximately 50 ft to 200 ft below sea level. A 23 degree 700 ft slant well will be completed entirely within the 180 ft aquifer with a total screen length of 300 ft. The 23 degree angle was dictated by the requirement that the wellhead be located landward of the projected

50-yr coastal erosion line. An important operational issue in this project is to minimize recharge originating from inland water sources. Thus, the design in Figure 4 will result in over 95% of the slant well recharge originating from vertical migration through the sea floor or laterally from off shore subsea aquifers and less than 5% from inland recharge.

Figure 4 – Example of Well Screen Placement in a Slant Well Feedwater Supply



2.2.2. Well Screen Type

Proven well construction technology embraces the principle of "simple and strong". Of the available well screen types, the most desirable for desalination intake systems is horizontal louver shutter screen. In this type of screen, the perforations are slots punched into solid pipe forming horizontal louvers which are small arches around the circumference of the screen. This type of well screen has sufficient open area, necessary yield and tensile strength, and robust enough to withstand the normal abuse during construction and rehabilitation. Figure 5 (below) shows a 12 in. diameter stainless steel horizontal louver shutter screen being installed in the Dana Point Test Slant Well.

2.2.3. Screen Open Area and Entrance Velocity

Field and laboratory tests have shown that when percentage open area of the well screen is within 3-5 percent, there is no significant loss in well efficiency [2]. For properly designed and constructed wells, entrance velocity is not a primary design factor.

Figure 5 below shows installation of horizontal louver shutter screen (Ful Flo pattern). This well screen and design has a sufficient percentage of open area and strength characteristics (yield and tensile) to make it a good choice for desalination intake wells.

Figure 5 – Horizontal Louver Shutter Screen Being Installed in the Dana Point Slant Well

2.2.4. Casing and Screen Materials for Sea-Water Environment

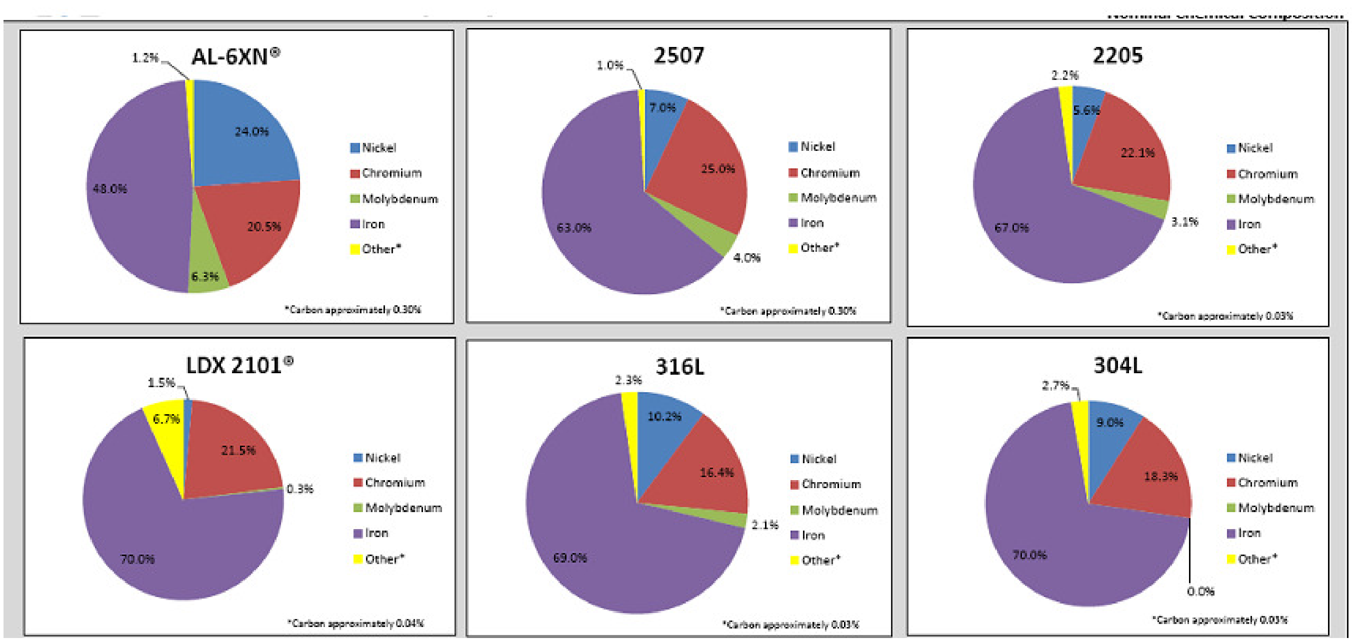
All down hole well materials (casing, screen, centralizers, and tremie guides) should be manufactured using Super Duplex stainless steel (SS) material or other suitable material. It is important that the material chosen can withstand both the corrosion environment of sea water and tensile and yield forces during well construction and maintenance.

Corrosion resistance as measured by the pitting resistance equivalent formula[1] is provided by the British Stainless Steel Association [3] namely:

$$PREN = Cr + 3.3Mo + 16N$$

The pitting resistance equivalent is 44 for AL-6XN and 42 for Type 2507 Super Duplex SS. When the PREN is greater than 40, the materials are generally considered immune to pitting and suitable for use in a seawater environment. Chemical compositions of AL6-XN, 2507 Super Duplex SS as well as other stainless steels are shown in Figure 6 below:

Figure 6 – Chemical Composition of Stainless Steels



2.3 Artificial Filter Pack

2.3.1. Fundamental Principle of Well Design

The underlying principle guiding successful well design is:

> "***The purpose of the filter pack is to stabilize the aquifer.***
> ***The purpose of the well screen is to stabilize the filter pack***"

[1] Pitting resistance equivalent numbers (PREN) are a theoretical way of comparing the pitting corrosion resistance of various types of stainless steels, based on their chemical compositions. Some formulas weigh nitrogen more, with factors of 27 or 30, but as the actual nitrogen levels are quite modest in most stainless steels, this does not have a dramatic effect on ranking.

The single most important design parameter for desalination plant feedwater supply wells is proper design and placement of an artificial filter pack between the well screen and the borehole. "Tried and true" design criteria developed over many decades and successfully demonstrated on vertical wells can be applied with equal success to slant wells.

2.3.2. Filter Pack Composition

Materials suitable for an artificial filter pack should be well-rounded water worn rock composed primarily of silica with little silt, clay or organic matter. Calcareous gravels must be avoided or should not comprise more than 3%-5% of the total volume [4].

2.3.3. Filter Pack Thickness

The annular space between the outside of the well screen and the borehole should be adequate for the filter pack to be installed without any "bridges" or voids. Because of this, the annular space for the filter pack is typically 4 in. to 6 in. [4]. Too large an annular filter will inhibit proper development (e.g. > 8 in.) and too small a space may result in an inadequate filter thickness.

2.3.4. Terzaghi Design Criterion

Relationships between the aquifer materials and filter pack are determined using Terzaghi's critera [5] namely:

$$D_{15} \text{ (filter)} \;/\; d_{85} \text{ (formation)} \;<\; 4 \;<\; D_{15} \text{ (filter)} \;/\; d_{15} \text{ (formation)}$$

The left hand side of the above equation is known as the Terzaghi migration factor and prevents migration of fine sands through the filter pack. Simply put, the 15% passing of the filter pack should be less than 4 times the 85% passing size of the finest aquifer:

$$D_{15} \text{ (filter)} \;<\; 4 \times d_{85} \text{ (formation)}$$

The right hand side of the equation is called the Terzaghi permeability factor and ensures that the filter pack material is of such a size as to provide a significant increase in permeability. This increased filter pack permeability reduces fluid pressure in the filter pack and near-well zone lowering entrance velocities and potential for sand migration. The Terzaghi permeability factor can be written:

$$D_{15} \text{ (filter)} \;>\; 4 \times d_{15} \text{ (formation)}$$

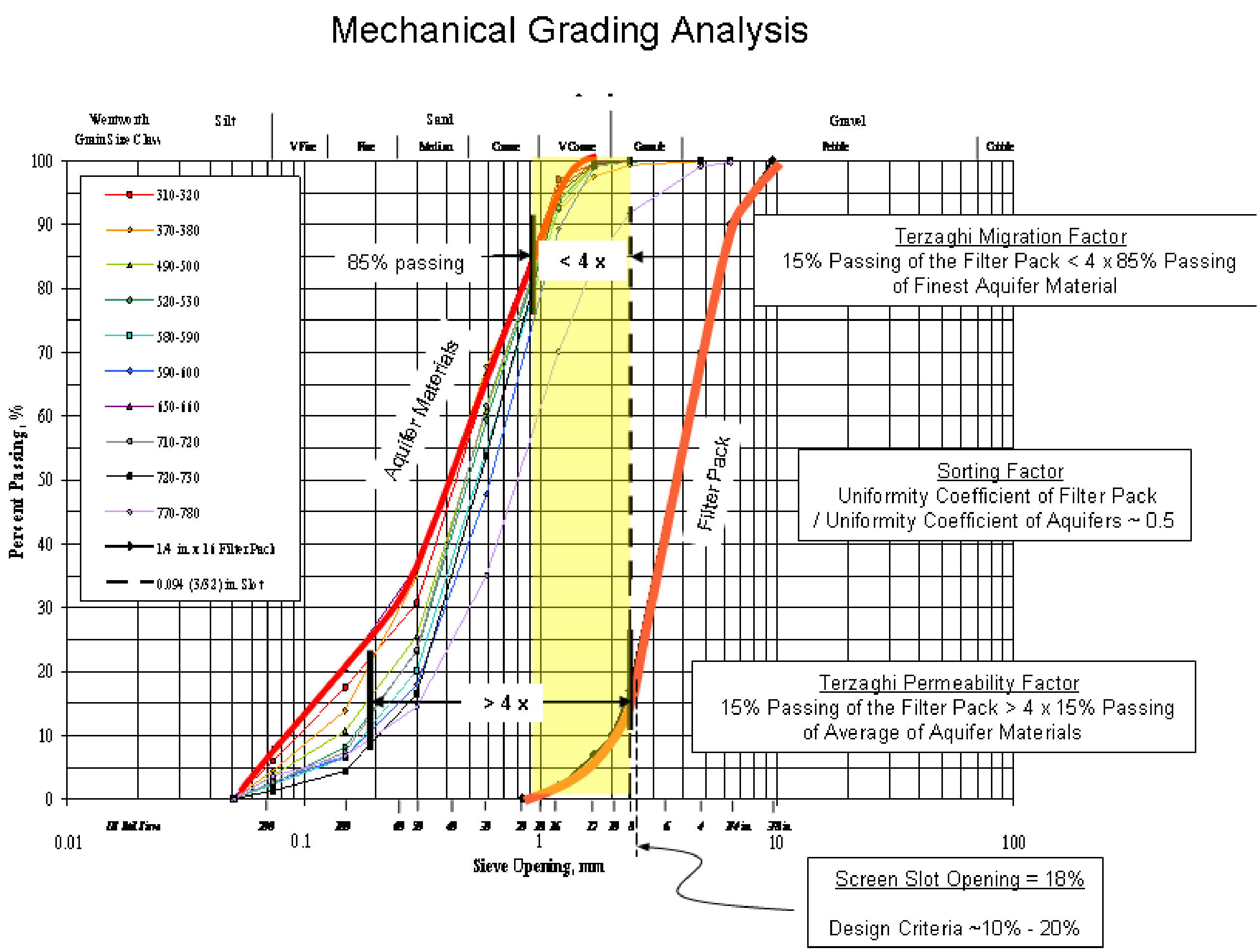
2.3.5. Uniformity Coefficients and Sorting Factor

The uniformity coefficient is the ratio of the 60 percent passing size to the 10 percent passing size ($CU = d_{60} / d_{10}$). For materials of uniform size the CU = 1 and materials would plot as a vertical line on the mechanical grading analysis (see Figure 7 below). Experience has shown that it is good well design practice to slightly "slope" the filter pack (i.e. slightly increase the uniformity coefficient) by including a slight fraction of fine grained materials in the filter material. This helps stabilize fine-grained aquifers preventing the movement of sand. The sorting factor (SF) is a measure of the slope of the filter material (i.e. mechanical grading analysis plot) and is the ratio of the uniformity coefficient of the filter pack to the average uniformity coefficients for aquifer materials within the screened portion of the well. The sorting factor should be approximately 0.5 for fine grained aquifers and less important in coarser grained aquifers.

2.3.6. Well Screen Slot Size

The percentage of filter pack material passing the well screen slot opening should range from approximately 10% to 20% [4]. The slot opening should be as high as possible in order to allow the well to "breathe" while at the same time stabilizing fine-grained materials. Figure 7 below shows filter pack design criteria.

Figure 7 – Terzaghi Filter Pack Design Criteria



III. WELL CONSTRUCTION

3.1 Vertical Wells

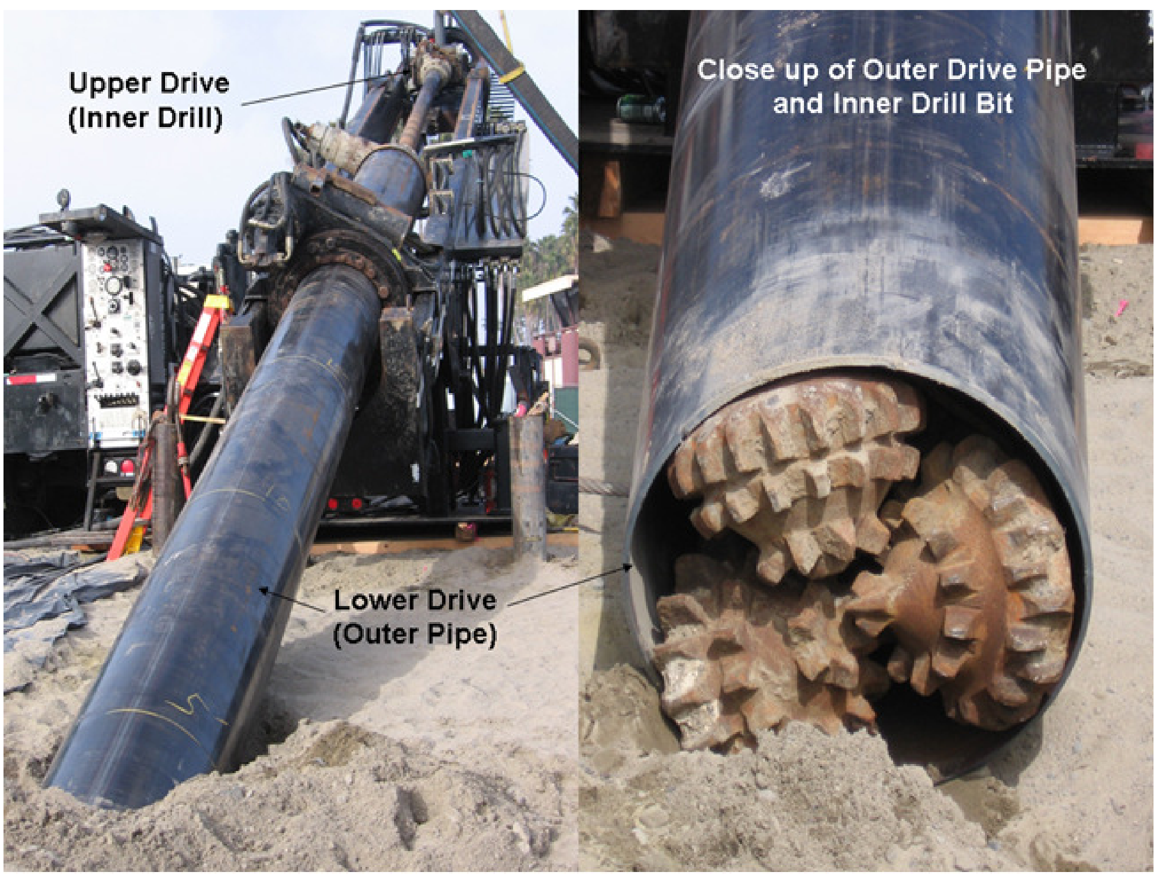
Construction of vertical wells in a near-shore environment should use the industry standard reverse circulation method of construction. In addition, the dual rotary method of construction may also be used as discussed in the following section. In vertical wells, as with slant wells, special attention should be paid to the design criteria relating to casing, screen and filter pack.

3.2 Slant Wells

3.2.1. Dual Rotary Method of Construction

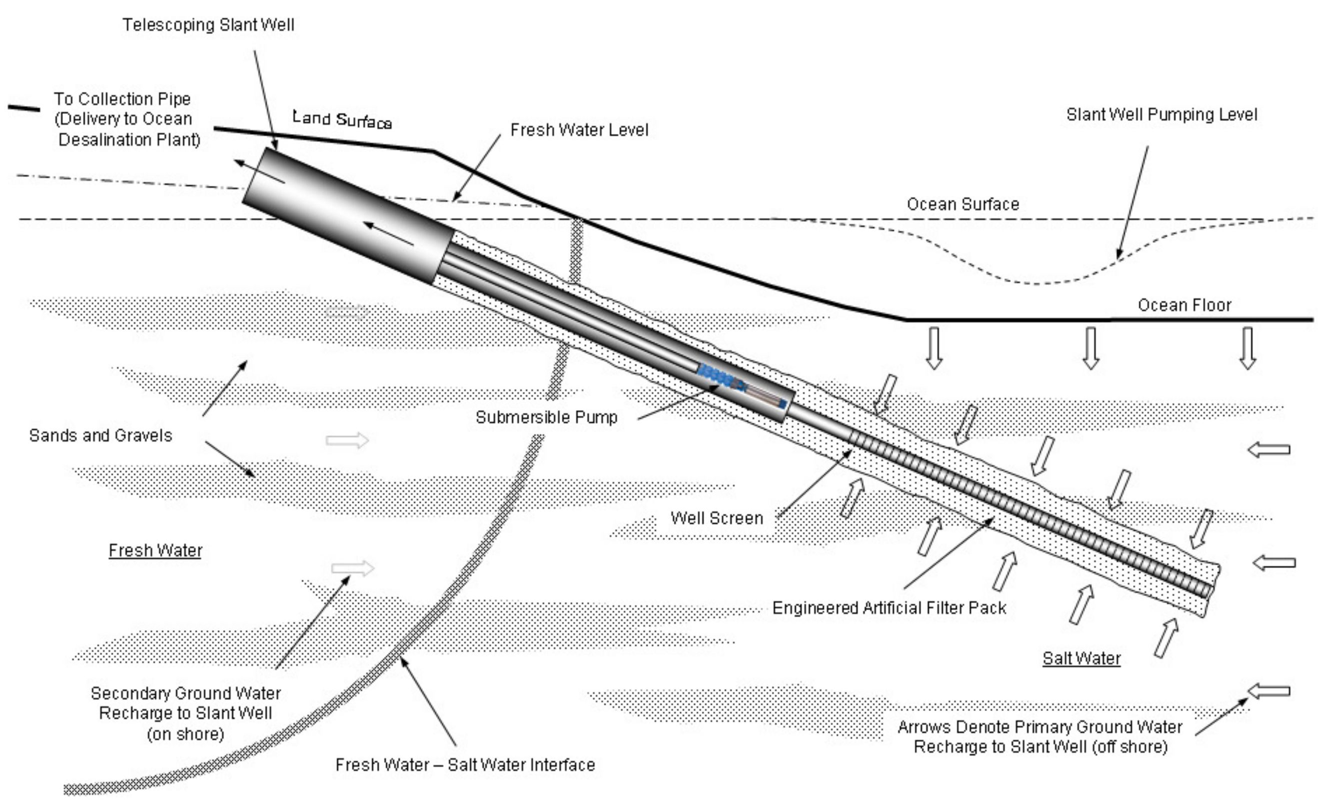
Construction of slant wells beneath the ocean creates special challenges in placing casings, screens and artificial filter packs. In vertical wells, borehole stability is maintained by pressure of the drilling fluid acting on the borehole sides. However in a low angled well (slant well), the vertical depths are generally much less than a vertical well and as such, borehole stability cannot be maintained with drilling fluid unless heavy mud additives are used. Addition of heavy mud additives would compromise the ability to properly develop the well due to a heavy mud cake on the borehole walls. This impermeable mud cake is very difficult to remove and would most likely result in a sufficient loss in production. The dual rotary method of construction solves this problem for subsea slant wells by placing a temporary solid casing extending to the total length of the slant well allowing an unrestricted access to placement of an engineered filter pack between the well casing and screen and the temporary casing. Placement of the artificial filter pack is accomplished using a pressurized system of single or multiple tremie pipes, while at the same time, withdrawing the temporary casing. Figure 8 below shows the dual rotary method of well construction.

Figure 8 – Dual Rotary Well Construction



During the temporary casing withdrawal, the filter pack is settled by fluidizing the annular space between the well screen and borehole wall. The result is an artificially filter packed well completed below the ocean. This technique can be used for slant wells with very low angles. The dual rotary method uses a lower rotational driving unit that is used to advance casing up to 40 inches in diameter through unconsolidated overburden such as sand, gravel and boulders. In addition, an upper or top rotary head is used to simultaneously drive a "dual-wall" drill string. The drill string consists of two sizes of pipe that are rotated and advanced simultaneously when drilling (see Figure 8 above). The dual wall drill string typically measures 10 ¾ inches outside diameter and has a 6 inch inner diameter pipe. At the bottom of the dual wall drill string is a roller cone rock bit used to break up large diameter formation materials while advancing the borehole. Compressed air is forced between the 10 ¾ inch outer drill string and the 6-inch inner drill string. Jets, or vents, placed within the 6 inch inner drill string just above the drill bit cause the formation materials (drill cuttings) and fluid to return to the surface by way of the inside of the 6 inch inner drill string. Cuttings are then discharged at the surface through a swivel located at the top of the drill string and casing. Figure 9 (below) shows a schematic of an artificially filter packed slant well feedwater supply completed beneath the ocean.

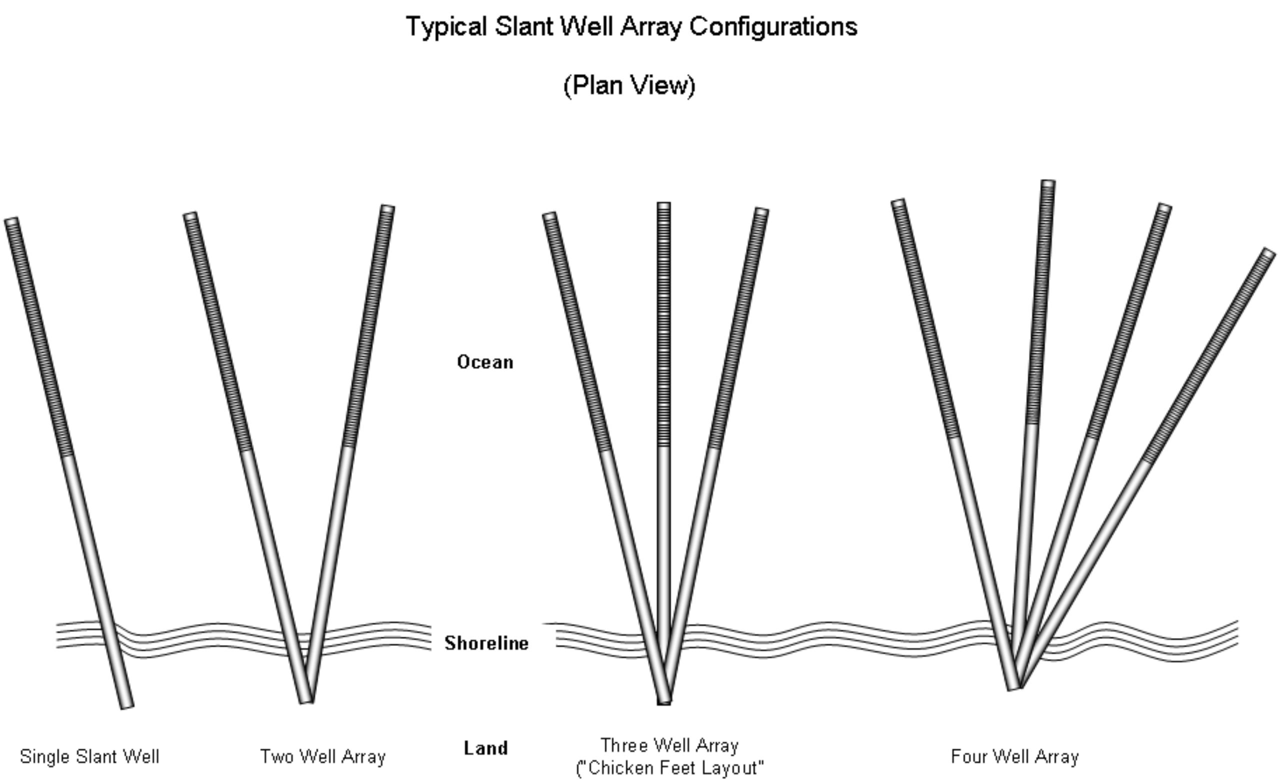
Figure 9 – Artificially Filter Packed Slant Well Beneath the Ocean



IV. WELLFIELD DESIGN AND SALINITY MANAGEMENT

Once all necessary geohydrologic and geotechnical investigations and pilot testing are complete, well production and feed water quality variations can be designed using a variety of geometric layouts. These layouts depend upon the quantity of supply and the variation in feed water salinity. Figure 10 below shows typical slant well array configurations.

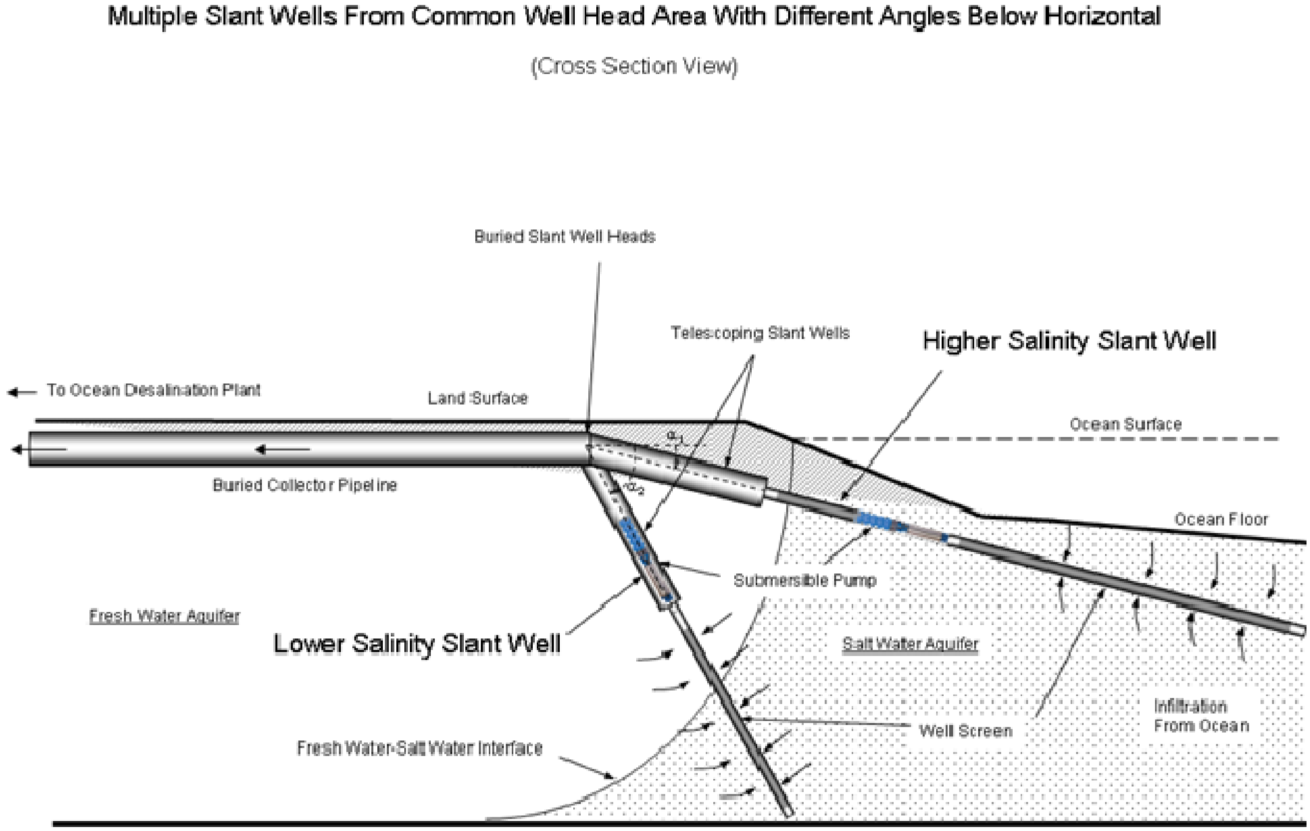
Figure 10 - Slant Well Desalination Feedwater Supply System



4.1 Management of Intake Salinity

A system of slant wells can also minimize variation in feedwater salinity (due to hydrologic variations of the fresh-salt water interface), by varying the physical layout and vertical angles (below horizontal) of individual slant wells or groups of slant wells (e.g. arrays). Shallow angle slant well arrays can produce water with higher salinity to stabilize the feedwater quality during wet hydrologic cycles (i.e. by mixing with the more saline portions of the subsurface aquifer). Steeper angled slant well arrays can produce water with lower salinity to stabilize the feedwater quality during dry hydrologic cycles (i.e. by mixing with the less saline portions of the subsurface aquifer). Figure 11 (below) illustrates the concept of feedwater salinity management.

Figure 11 – Management of Feedwater Salinity With Different Angled Slant Wells



V. CASE HISTORIES OF WELL DESIGN PARAMETERS AND SDI MEASUREMENTS

5.1 Dana Point Test Slant Well

The Municipal Water District of Orange County (MWDOC) identified a favorable site for evaluating the feasibility of using a subsurface intake system for a 30 mgd ocean desalination supply at Doheny State Beach near the mouth of San Juan Creek, in Dana Point, California [6]. The subsurface deposits of sand and gravel associated with the San Juan Creek channel extend off shore beneath the ocean, with favorable aquifer properties. A 350 ft long 12 in. diameter (casing and screen) test slant well was constructed on Doheny beach in 2006 in order to obtain actual measurements of subsurface intake discharge rates and aquifer properties through performance. An 18 month pilot pumping test began in June 2010 and will extend through the end of 2011. Data obtained from the Dana Point test well is validating model predictions regarding feedwater salinity and SDI values have been averaging in the 0.1 range well below the initial 2006 value of 0.6.

Once pilot testing is complete, the full-scale system design will be finalized which will include seven 1,000 ft long slant wells, 10 degrees below horizontal with each well producing 3,000 gpm. Figure 12 shows the location of the Dana Point Test Slant Well.

Figure 12 – Dana Point Test Slant Well

5.2 Results of SDI Field Testing and Well Design Parameters

The following table summarizes actual well design and performance results from a selected number of vertical and slant wells. Discharge rates range from 31 to over 4,000 gpm. Silt Density Index measurements were taken after the well was developed and under normal operating conditions. As can be seen in Table 1 below, SDI ranged from less than 0.1 to 2.0 reflecting values well below the recommended 3 -5 design limit for reverse osmosis desalination plants.

Table 1 – Case Histories of Well Design Parameters and Silt Density Indices

Location	Type of Well	Total Depth (ft bgs)	Screened Interval (ft bgs)	Screen ID (in.)	Production (gpm)	Filter Pack	Slot Size (in)	Terzaghi Migration Factor	Terzaghi Permeability Factor	Sorting Factor	Turbidity (NTU)	SDI 15
Dana Point SL-1	Slant Well	350	130-350	12	2,100	4 x 16	0.094	3.2	3.6	0.5	-	0.1
City of Oceanside TW-1	Vertical Well	180	70-130 140-170	6	31	6 x 20	0.050	3.6	6.1	0.4	0.4	0.5
Cab San Lucas Mexico PW-1	Vertical Well	75	30-65	8.35	175	1/4 x 16	0.094	1.6	4.7	0.7	<1	-
San Pasqual 4B	Vertical Well	89	25-41 45-81	8.25	150	4 x 16	0.080	3.6	7.2	0.7	0.3	1.6
Hesperia RW-4	Vertical Well	466	202-270 280-446	18	4,041	1/4 x 16	0.094	0.3	1.9	0.4	0.4	0.9
Hesperia RW-5A	Vertical Well	532	200-258 268-512	18	4,052	1/4 x 16	0.094	1.4	6.0	0.5	0.1	0.4
Hesperia RW-3	Vertical Well	548	200-254 264-528	18	4,045	1/4 x 16	0.094	1.2	4.6	0.4	0.2	0.2
San Bernardino 9th Street South	Vertical Well	1,020	448-480 510-1000	20	3,517	1/4 x 16	0.094	2.3	1.6	0.4	1.1	2.0
San Bernardino 9th Street North	Vertical Well	1,000	440-490 500-980	20	3,445	4 x 14	0.070	3.1	3.4	0.4	0.5	0.9
Chino Desalter II-1	Vertical Well	410	155-288 308-390	16	2,600	1/4 x 16	0.094	2.1	5.9	0.4	<0.20	< 0.1
Chino Desalter II-2	Vertical Well	342	156-312	18	3,000	1/4 x 16	0.094	2.8	11.8	0.3	<0.20	0.3
Chino Desalter II-3	Vertical Well	355	160-325	16	3,000	1/4 x 16	0.094	2.1	7.9	0.5	<0.20	< 0.1
Chino Desalter II-4	Vertical Well	370	156-340	18	2,000	1/4 x 16	0.094	2.5	12.8	0.6	<0.20	0.2
Chino Desalter II-6	Vertical Well	315	150-295	16	2,000	1/4 x 16	0.094	2.3	7.6	0.6	0.4	< 0.1
Chino Desalter II-7	Vertical Well	275	140-245	16	1,500	1/4 x 16	0.094	2.9	8.8	0.5	0.3	< 0.1
Chino Desalter II-8	Vertical Well	260	130-230	16	1,500	1/4 x 16	0.094	1.6	4.4	0.6	0.6	0.2
Chino Desalter II-9A	Vertical Well	315	180-195 206-295	18	2,000	1/4 x 16	0.094	0.6	2.9	0.3	<0.20	0.2
Chino Desalter I-16	Vertical Well	170	100-140	18	252	1/4 x 16	0.094	1.1	5.3	0.6	1.1	1.8

VI. SUSTAINABILITY

In order to maintain the feedwater production, planned rehabilitation of the slant or vertical well subsurface supply will be necessary. The frequency between rehabilitation depends on both site specific conditions and operational schedules. The same rehabilitation techniques from over 60 yrs of experience with maintaining sustainability in vertical water supply wells can be successfully applied to slant and vertical well feedwater supplies, including both mechanical and chemical rehabilitation. Based on data from the Dana Point Test Slant Well, it is expected that the frequency between well rehabilitation would be on the order of five to ten years.

VII. SUMMARY AND CONCLUSIONS

Proven design practices and procedures developed in the water well industry for the past seven decades, and routinely applied to high capacity municipal water supply wells, are equally applicable to desalination feedwater supply wells. Near shore and offshore permeable aquifer systems provide the sustainable supplies with low silt density indexes eliminating the need for pre-treatment. Subsurface intake systems also eliminate impingement and entrainment issues and other environmental impacts associated with conventional intake systems. Silt density indices are well below the RO design standard for wells which have applied Terzaghi's migration and permeability design standards. The dual rotary method of drilling allows construction of artificially filter packed slant wells beneath the ocean floor to lengths of 1,000 ft or more. Variation of feedwater salinity can be accomplished by varying the location and/or angle of slant wells to adapt to a changing fresh water-salt water interface. Sustainability of feedwater production can be accomplished using standard well rehabilitation methods.

The main conclusions are:

- Proven well design methods developed for vertical water supply wells may be applied to desalination feed water supply wells.

- Slant wells constructed using the Dual Rotary method enable placement of artificial filter packs in subsea and near shore aquifers.

- The RO design SDI range of 3-5 is achievable using an artificial filter pack and the Terzaghi filter pack design principles.

- Both offshore slant wells and near shore vertical wells can provide sustainable desalination feed water supplies in permeable near shore and offshore subsea aquifer systems.

- Sustainability would include mechanical and chemical rehabilitation with an expected frequency ranging between five to ten years depending on site conditions and operation.

VIII. REFERENCES

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