INVESTIGATING INTAKE SYSTEM EFFECTIVENESS WITH EMPHASIS ON SELF-JETTING WELL-POINT (SJWP) BEACHWELL SYSTEM[1]

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ABSTRACT

A well-designed subsurface SWRO intake not only yields good quality feed that requires none or minimum of pretreatment, but also when used instead of surface type intake results in a significant saving in plant capital investment and in cost of plant O&M. An SJWP subsurface intake system was tested at SWCC Al-Jubail site, onshore, at high-tide seawater line and mid-tide point at depths of 3.5 m, 3.5 m, and 4.5 m, respectively. The project objective is to investigate the suitability of this relatively new subsurface SJWP as an intake for some SWRO plants. The best SDI values with an average of SDI_{ave} = 2.9, which compares reasonably well with SDI_{ave} = 2.6±0.2 for conventionally pretreated surface seawater feed, were obtained when the well-points were fixed at sea mid-tide point at depth of 4.5 m. The filtrate TDS, total hardness and pH values were lesser than those of seawater indicating mixing of seawater with underground or surface water. At zero incubation time, bacteria count was in the range of 5 x 10^2 to $4x10^3$ colony forming units (CFU), but high aftergrowth rates and short bacteria generation time were observed in the SJWP feed after 24 and 72 hours of incubation. Based on SDI measurements, as well as on other physical and chemical measurements, a good quality SWRO feed can be derived from subsurface well-point beachwells located on a clean non-polluted site, which is expected to diminish the high aftergrowth rate and short

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generation time of bacteria found in the present case. Acurate information on this point can be established by testing the effect on SWRO membrane performance of feed derived from SJWP beachwell located on a clean non-polluted site, which is to be conducted under Part 2 of this program.

1. INTRODUCTION

To avoid membrane fouling, which leads to degradation in SWRO plant performance, feed to SWRO plants is pretreated to remove from it all potential membrane foulants, ideally leaving only the dissolved solids in the feed. To a large extent, the success of SWRO plant operation is dependent on the feed quality and the feed pretreatment. An ideal pretreatment is designed to cause a minimum or no membrane fouling at the lowest possible cost. This not only results in longer membrane life but also improves the overall plant efficiency and reduces the cost of fresh water production. The degree and type of pretreatment required are dependent on the raw seawater quality, in particular its content of suspended solids, debris, biological and organic matters, pollutants, residual heavy metals, etc. However, the water quality, is very much dependent on type of **intake** used in SWRO plants.

The design and selection of seawater intake system are very crucial not only to the optimization of both the pretreatment, and the overall plant performance but also to lowering of cost of water production. A fault in intake design and/or intake site selection could make it difficult, if not impossible, for the pretreatment and the SWRO plant as a whole to function properly. On the other hand, a proper intake system that yields high quality feed requires minimum pretreatment. A good example, **a well-designed seawell or beachwell** type intake produces high quality water that requires no further pretreatment. The natural filtration of feed through the porous subsoil strata cleans the feed from nearly all contaminants normally present in feed taken from an open sea. In addition to low oxygen content, the feed is characterized by its constant physical and chemical properties; also unlike surface feed it is unlikely to be affected by changes in weather or sea conditions. In this case, the seawater intake feed can be supplied directly to the membrane system (only with the addition of the necessary antiscalant), thus avoiding the coagulation filtration step, the addition of coagulant, coagulant-aid and disinfectant or other chemicals to the feed stream. Moreover, many of the SWRO plant problems associated with feed supplied from an open sea intake, some of which are caused by the added chemicals, can be eliminated by drawing the feed from sea subsurface regions. Most obvious example is the elimination of chlorine. Chlorine when present in the feed could react with organic present in the same feed to form the harmful THM compounds. It could also degrade organic, mainly humic acids, to form assemble organics which serve as nutrients to bacteria leading to their fast multiplication and thus membrane biofouling. Moreover, many of SWRO membranes are oxidized and, therefore, are degraded by chlorine. Other well-designed subsurface type intakes could work equally good as seawell and are likely to produce high quality feed.

By contrast to the minimum or no pretreatment required to treat feed taken from subsurface intakes, an extensive, complex pretreatment with array of equipment, chemicals and chemical dosing systems is required to clean the surface feed from all the contaminants and membrane potential foulants.. The compexity in pretreatment is dependent on type, nature and site of intake as well as on quality of feed required by the different membrane system, i.e., hollow fine fiber, spiral wound or plate and frame. All this is in addition to a higher level of dissolved oxygen, which leads to the higher growth, and multiplication of bacteria and other microorganism attached to the membrane as well as it may lead to a slow membrane oxidation. Moreover, it is well known that both the expected inherent decline in membrane flux and salt passage are significantly greater when the feed is taken from an open sea than that derived from seawell.

In this paper results obtained from the application of a relatively new subsurface self-jetting well-point intake system are discussed. This work, which is done at SWCC RDC, Jubail, is part of a joint R&D program on SWRO between SWCC and USBR.

2. SWRO INTAKE SYSTEM

The various intake systems that are now in use or may be utilized in the future to supply seawater feed to SWRO plants either from an open sea or from subsurface shore sites can be classified into two major intake systems: (a) Surface Intake consisting of: Pipe systems or Open Channel, Canal Lagoon, (b) Subsurface which can be classified into seawell (beachwell), Well-point, seawater gallery with gravel packing, seabed filtration with filter media packing, and Ranney Collector system.

The submerged pipe tends to be the dominant choice when the SWRO plant feed is taken from an open sea. This system is utilized in all SWCC SWRO plants located on the Red Sea shores with capacity (including SWRO plants under construction) of 87 mgd. Depending on coastal line geology and topography, the intake depth varies from one site location to another for SWCC plants on Red Sea shores the intake depth varies from 4 to 19 m [1, 2,3]. This arrangement which places the SWRO intake deep in the sea and away from the coastal line allows for the supply of the SWRO plant with a relatively better quality feed than that obtained from an open channel intake. The open channel intake is rarely used to supply feed to SWRO plants. This type of intake is more suited to deliver feed to MSF plants where, unlike SWRO plants, no extensive feed pretreatment is required.

Seawells are the most used intakes among the subsurface systems. It is employed in many parts of the world to supply feed to a relatively large number of SWRO plants. All the SWRO plants in Malta, capacity 31 mgd, utilize beachwell intake at well depth of about 50 to 60 m [4]. Many of the SWRO plants in Canary Islands [5] as well as in UAE [6,7] and Caribbean Islands are supplied seawater feed from beachwells. Other examples of beachwells and wells with high salinity water TDS > 12000 ppm are described in literature [8, 9, 10]. Another form of seawell is the seawell infiltration system which has been reported only for two cases at the Island of Lanzarote, Canary Islands [13]. Seawells or beachwells are drilled onshore at varying depth below the sea floor. The design and construction of seawells are similar to those of artesian wells of same dimension. Central part of the well double casing is perforated with large number of slots of about 0.3 to 0.5 mm for the interior casing as compared to about 0.7 mm for the exterior one. The depth of the well is determined by the soil geology, soil permeability and the quality of water desired from the well. Water quality tends to vary from one subsoil stratum to another. Seawell water turbidity and SDI are about 1 NTU and less than 2, respectively, as compared to a much higher values for surface feed turbidity of up to 20 NTU and SDI values of up to 6.7 or above. The high quality feed expected from seawell and other subsurface intakes constitutes their major advantage over other surface type intakes. This situation not only eliminates the pretreatment process but also leads, as mentioned earlier to lowering in plant capital cost by up to 25% and plant operation cost by up to 15% [12]. The improvement in the quality of seawater derived from wells has also a great influence on plant availability, which could exceed 95% and product water recovery ratio reaching 45% [5].

Although feed with constant chemical composition and physical properties is derived from seawells its composition is not necessarily the same as that of seawater. The composition of feed derived from a well or subsurface intake is always influenced by the composition of the subsoil strata from which the seawater flows into the well. Thus, the selection of both site and depth of subsurface intakes are to be thoroughly investigated in advance of well construction by drilling of bore holes at various locations to establish the site suitability for subsurface intake construction and to make sure that the intake can supply high quality feed to SWRO plants at constant feed flow without water depletion.

Directional drilling now allows for drilling of seawells in a horizontal position, which has the advantage of increasing the flow from such seawells. A new porous polyethylene well pipe that is now available since 1995 is reported to require no additional external media packing for long-term operation as that required with conventional seawells. The polyethylene pipe porous structure acts as both well screen and packing media. This product is claimed to make the horizontal drilling of wells under the seafloor feasible and economical for the first time [13].

The subsurface intake systems of : seawater gallery with gravel packing, seabed filtration with filter media packing and the Ranney Collectors have one feature in common in that in these cases feed water is collected through a number of horizontally laid PVC screen pipes at certain depth in the subsoil strata. Seabed and gallery filtration systems are similar in design and construction except for their packing system. Instead of crushed stone packing used in the seawater gallery, filter media packing material is used in the seabed filtration system. This way the seabed filtration system functions as both seawater gallery and sand filter giving it the advantage for use in SWRO intakes over the seawater gallery intake system. The three subsurface intake systems of seawater gallery, seabed filtration and Ranney Collectors appear to be promising, and good candidates for SWRO plant intakes with the advantage of possibly supplying greater quantity of feed than that taken from a single seawell, nevertheless, they have not been reported in literature as a feed source to SWRO plants. They are discussed in literature only as a possibility for SWRO intakes. For more information on those subsurface intakes see reference [14].

The well-point beachwell system tested here as a SWRO intake is shown in Figure 1. The well point itself is similar in design to the well-point system used in ground dewatering, mainly in the coastal areas where water table is high (Figure 2). However, this system offers a finer degree of water filtration than that delivered by the well-points ground dewatering. The well points are constructed in a fashion similar to that of seawell construction although the well points are much smaller in diameter. Central part of the double casing is perforated with large number of very fine slots (less than 0.5 mm) in the interior casing. Outer casing consists of a screen normally with media packing in-between the two screens.

The well-point intake system combines features from both the beachwell and the other subsurface intake systems. Like the beachwell intake, the well points are vertically jetted but at several points on or off shore at shallower depth than that of seawells. Like the subsurface intake of seawater gallery, seabed filtration and Ranney Collector, the well-point system collects the feed from many screen pipes, which are vertically laid in the subsoil as opposed to their horizontal burial in the latter three systems. The well-point system, however, differs from all other subsurfaces intake systems in that it can be easily self-jetted at site without major construction as required by other subsurface intake systems. The system, as the name indicates, is self-jetting, the one and same pump used to pump feed to SWRO plant is also used to jet the well-points to the desired underground depth. Unlike other intake systems, which once constructed remain fixed to the site, the well points can be easily moved for use at other sites.

The well-point intake system has been used by the US Army as a quick SWRO intake system for providing water for mobile SWRO plants in remote areas. The system has been in continuous operation in Port Hueneme, California and San Nicholas Island, USA, since 1993 [13, 15].

3. EXPERIMENTAL

3.1 Site Selection and Bore Holes Drilling

Because of its proximity to SWCC R&D Center, a coastal area about 100 m north of Al-Jubail MSF plant intake was selected as project site. A local company [16] was contracted to drill three onshore test bore holes at about 30 m away from the sealine, 30 m apart and each at depth of about 10 to 11 m. Subsoil samples were collected from the surface (i.e., depth of zero) also from 3, 6 and 9 m below ground level. The contractor at his laboratories analyzed the samples.

3.2 The Self-Jetting Well-Point Beachwell Intake

The SJWP system used in this investigation (Figure 1) consists of two well-points of 1.5″ diameter and 3′ in length, followed by three 316 stainless steel risers, each of 1.5″ in diameter and 3′ in length. The risers are connected to a common header of PVC pipe terminating at the pump. A control valve controls the water flowing through the system.

The beachwells were constructed at the selected site by using the same pump in jetting the well points slowly through the subsoil to the desired depth, 3-5m, without encountering any difficulties. The well points were slowly driven in the porous ground by pumping the water at low pressure through its central pipe. The water flowing out (from inside the well-point) fluidize the porous soil around it and allows for the drilling of a shallow beachwell to the desired depth below the sea floor. Based on core sample analytical results, (see section 4.1) it was possible to drive the well point to a depth of 4.5 m without difficulty. Once the well was drilled the system was put into service (using the same pump in reverse). This way, naturally filtered water through the sand layers starts to flow into the beachwell and well-points from which it was continuously pumped. To allow for good formation of the beachwells 15 to 20 minutes were required per jetting of each well-point. Trial tests were made at three location at the selected site where test bore holes were made: onshore at well-point depth of 3.5 m, at high-tide seawater line at depth of 3.5 m and at mid-tide seawater line at well-point depth of 4.5 m.

3.3 Water Quality Analyses

Various chemical, physical and biological analyses were made according to standard procedures for various samples collected at each of the three site locations. Main emphasis was on the measurement of beachwell filtrate : temperature, pH, conductivity and SDI. Complete chemical and biological analyses were carried out on selected samples. Analyses of residue collected on SDI filter paper were also performed by the scanning electron microscope (SEM) and the energy dispersive X-ray (EDX) method. Prior to bacteria count in CFU/ml each of the samples was incubated at 30 °C for different periods of 0, 24, 72 and 96 hours, after culturing on marine agar by the pour plate method for 96 hours, at 30 °C.

4. RESULTS AND DISCUSSION

4.1 Soil Structure Analysis

Results of soil analysis done by the contractor at his laboratories showed that the upper subsoil layer at a depth of about 7 m consists of sand with silt and in some cases extends to a depth of 9 m [16]. Below the sand-silt layer, there was a layer of a very weak limestone moderately weathered and closely fractured.

4.2 Water Quality Criteria for Well-point Beachwells

When the saline water is intended for use as feed to a SWRO plant it must meet certain quality requirements. The feed with the highest possible quality standard is a seawater that does not contain any impurities e.g., bacteria and other microorganisms and suspended solids including colloidal matter, organic carbon, that may cause harm to the membrane or other SWRO process components. For certain membranes the case of no chlorine or no oxygen in the feed is also a rigid requirement. Use of the disinfectant and coagulant chemicals which are essential to the pretreatment of surface seawater feed may have an adverse, damaging side effect on the membrane. Dissolved oxygen when present in the feed is also a process variable. It may lead to a slow but progressive damage to the membrane in addition to its influence on speeding up bacteria growth and multiplication which may give rise to membrane biofouling. The ideal feed case is rarely realized in practice, especially if the feed is derived from surface type intake, although quality of feed from a well-designed seawell or subsurface intakes or membrane treated feed could approach this idealized situation. In this investigation the quality of feed derived from the well-point beachwell at Al-Jubail site was evaluated as a possible feed for a SWRO plant mainly by measuring the feed SDI, pH, TDS, biocount and measurements of other relevant chemical and physical parameters.

Tables 1 and 2 list, respectively, the chemical and biological analyses parameters measured for samples collected at the same site. For reasons of comparison the chemical composition of surface seawater is also included in Table 1. Depths are measured below ground level at the location. The SDI values for the filtrate collected at different sites are plotted versus operation time in Figure 3.

4.2.1 Well-Point Filtrate Chemical and Physical Properties

The best SDI values with an average SDI_{ave} of 2.9 were obtained when the well-points were fixed at mid-tide seawater site at a depth of 4.5 m. This value compares reasonably well with the average SDI_{ave} values of about 2.6±0.2 obtained from SDI measurements made on conventionally pretreated feed derived from an open sea at Al-Jubail. The pretreatment consisted of coagulation with $FeCl_3$ and dual media filtration [17]. Filtrate water conductivity ranged between 18,880 to 26,800 µs/cm at the onshore site and rose to over 40,000 to 49,000 µs/cm at the other two site locations at the hightide and mid-tide water lines. In all cases the conductivity of filtrate from the well-point beachwells is lower than that of surface seawater of about 60,000 µs/cm. Total hardness, is also less in beachwell water than that in seawater. Variation in pH with site location was noticed and in all cases it ranged between 7.1 to 7.9 and was less than the seawater pH of 8.2. Total organic carbon (TOC) of 1.2 to 2 ppm is of the same order as in seawater of TOC ≤ 2 ppm. Temperature of filtrate collected from the well-point beachwell also differs from one site location to another. The lower pH, hardness and conductivity values of filtrate samples than those of seawater indicate seepage of surface water or the mixing of ground water with seawater at these three site locations, with a greater mixing ratio of surface water to seawater at the onshore site. This also tends to be true for seawell water from Kuwait beachwell drilled to a depth of 30m where the water TDS and pH are about 38,850 ppm and 7.7, respectively [18].

The H_2S water smell, which was noticeable when the water samples were taken from onshore site, disappeared when the well-points site was shifted toward the sea and was fixed at lower subsoil level of about 1 m and 2 m at the high-tide line site and mid-tide site, respectively. The presence of H_2S smell in the well-point beachwell filtrate indicates the presence of unaerobic sulfur reducing bacteria in the water at onshore underground at depth of 3.5m. It also indicates lack of sufficient oxygen in that water.

As was established from EDX spectrum the main residues collected on the SDI filter paper are dried seawater salts and ions, mainly Na^+, Cl^-, Mg^{++}, Ca^{++}, S^+ and K^+, most of which disappeared from the EDX spectrum upon washing gently the filter paper with deionized water. From the EDX analysis it appears that no major residue or total suspended solids (TSS) matter are present in the water derived from well-point beachwell at depth of 4.5 m below mid-tide sea floor. This, however, does not rule out the presence in the well-point beachwell filtrate of soluble elements such as humic acid and other soluble organics which serve as nutrients to bacteria.

4.2.2 Well-Point Filtrate - Biological Properties

At zero hour of incubation, bacterial count in CFU/ml in filtrate from well-point beachwell and surface seawater are similar in number. At the zero hour, the bacteria count was about $1.8x10^3$ CFU/ml to $4.04x10^3$ CFU/ml in surface seawater and about $5.0x10^2$ CFU/ml to $3.79x10^3$ CFU/ml in subsurface water (Table 2). (Strangely enough and unexpectedly, these numbers compare favorably well with $1.2x10^3$ to $1.3x10^3$ T. count (CFU/ml) in water derived from two beachwells drilled at depth of 30 m near the beach in Doha, Kuwait [18]! However, they (bacteria) are not necessarily the same type or possess the same properties, mainly in their ability to attach themselves to membrane surfaces. At 24 and 72 hour aftergrowth, however, the bacteria aftergrowth were faster in filtrate from beachwell than their aftergrowth in surface seawater. This is evidenced by the time in hours required for the bacteria generation (gt) to double in number, Table 2.

In the case of subsurface water where samples were collected from onshore beachwell it is noticed that only 0.207 hour is required for the bacteria to double its population after 72 hours of incubation as compared to more than twice this time of 0.484 hours when the sample is collected from surface seawater and 0.226 hours for subsurface water samples collected from beachwells located at the mid-tide point. The latter value increased to 0.235 hours after 96 hours of incubation indicating the possibility of decreasing nutrients in the sample, as shown in Table 2. This situation, indicates that bacteria aftergrowth is proceeding at a faster rate in subsurface water obtain from this site than in open seawater. Moreover, it indicates the availability of sufficient nutrients in the present subsurface water which partially originates from the accumulated organic seawater residues, e.g., humic acid and is partially due to the residues present in the surface water seeping from the surrounding areas. The data suggest the possibility of a polluted site, which was established to be the case after through survey of the site. Surface and some waste water was seeping to the site from neighboring grounds. A better quality feed with SDI ≤ 2, containing low bacterial count and presumably having low level of nutrients can be obtained by the selection of a non-polluted site.

5. CONCLUSION

From the above discussion it can be concluded that based on SDI, as well as on other physical, chemical and biological measurements (Tables 1 and 2, also Figure 3) a good SWRO quality water with low TSS content can be derived from subsurface well-point beachwell. The high aftergrowth rate and short generation time of bacteria found in the feed may be attributed to the site itself, which was found to be polluted by the seepage of surface and waste water. Changing the site to a clean non-polluted site could alleviate this effect and may result in good quality feed to SWRO plants and in consequence to good plant performance. To a certain degree, however, this should depend on type of bacteria and nutrients found in SJWP beachwell feed and the bacteria ability to condition and to attach themselves to membrane surface. These conditions are essential for the formation of biofilm [19]. Accurate information on this point can be established by testing the effect on SWRO plant performance of feed derived from SJWP beach-well located on a properly selected clean non-polluted site. This work is to be conducted soon.

6. RECOMMENDATION

From the trial tests made with this subsurface SJWP beachwell intake good quality water with an $SDI_{ave} = 2.9$ was obtained but high aftergrowth rates and short generation time of bacteria may be expected to give rise to a decline in SWRO plant performance. This latter factor can be corrected by the selection of a clean non-polluted site. Moreover, the experiment done so far was exploratory in nature and it is, therefore, recommended: (1) to conduct further experiments on a clean non-polluted site; (2) to work on optimization of the SJWP beachwell intake by improvement of yield and filtrate quality; (3) to determine design criteria for small to medium size SWRO plants; and (4) to perform process technoeconomic analysis. These recommendation were accepted by SWCC and a future evaluation of the system is under way.

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Table 1. Beach Well Water Sample Chemical analysis

				24.03.93	***7.04.93***
S.NO	**Prameters**		**Seawater**	**Sample-1**	**Sample-2**
1	Tempreture °C			24	23.5
2	pH		8.2	7.62	7.3
3	Conductivity at 25 °C	(μS/Cm)	60000	40100	41000
4	T.D.S at 105 °C	(ppm)	46900	31289	31430
5	Total Hadness (as CaCO3)	(ppm)	6738	5250	5850
6	Calcium as Ca^{++}	(ppm)	519	480	480
7	Magneisum as Mg^{++}	(ppm)	1326	984	1130
8	Sodium as Na^{+}	(ppm)	12860	7888	9000
9	Potassium as K^{+}	(ppm)	450	344	392
10	Sulfate as SO4^{--}	(ppm)	3265	5400	5514
11	Chlorides as CL^{-}	(ppm)	23000	13650	16661
12	TOC	(ppm)	2	1.2	2

Table 2. Bacterial Count (CFU/ml) and generation time in hours/double generation, (hrs/2g) in Well point water at two different locations: on-shore and at mid-tide seawater line

Sample	**0 h**	**24h**		**72h**		**Locations**
	CFU/ml	**CFU/ml**	**hrs/2g**	**CFU/ml**	**hrs/2g**	
Raw seawater	1.8x 10^{3}	1.1x10^{5}	0.404406	5.6x10^{4}	0.483831	Onshore
Well water	1.3x10^{3}	3.3x10^{5}	0.300394	4.0x10^{6}	0.20708	
Raw seawater	4.04x10^{3}					Mid-tide point
Well water	3.79x10^{3}					
Raw seawater						
Well water	5.9x10^{2}	4.86x10^{5}	0.247727	9.3x10^{5}	0.225892	Mid-tide point

Generation time = t x 0.693/ (Ln Nt - LnNo) : Where: t = time; Nt = Bacterial count at time t hrs; No = Bacterial count at zero hrs

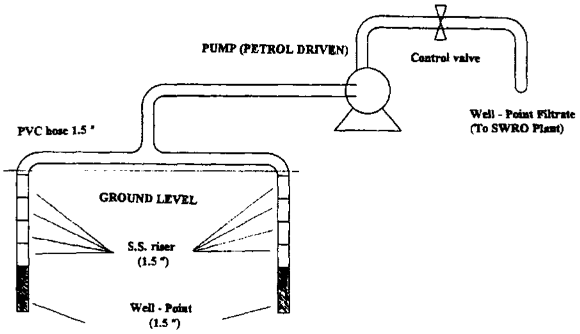
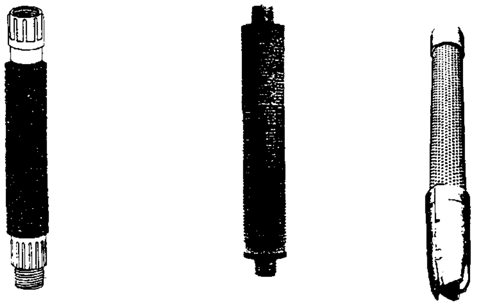


Figure 1. Two Well-Point Beach Well Layout



Sand Packed
For SWRO Intake

Gravel Packed
For SWRO Intake

C- Dewatering
For Underground Waters

Figure 2. Fine Water Filtering Well-Points

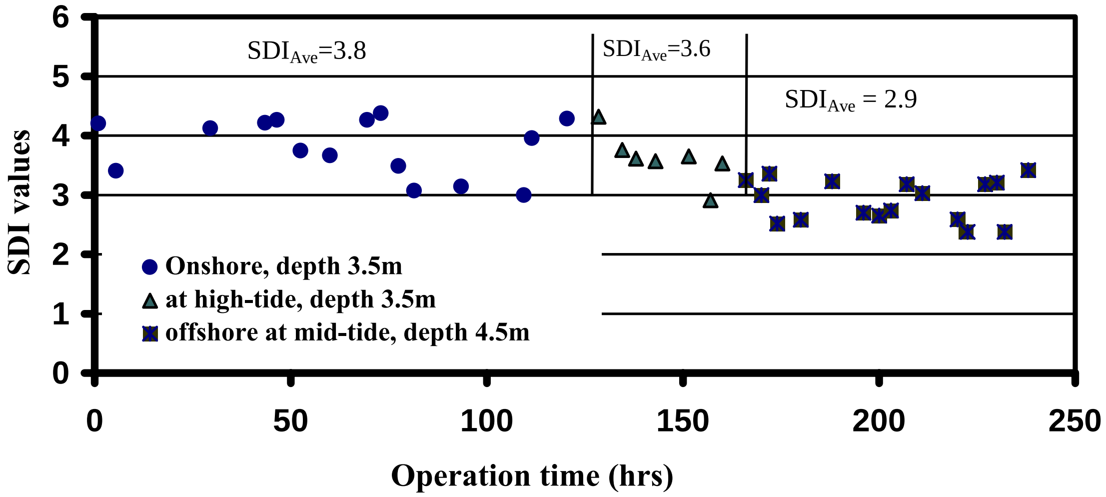


Figure 3. Quality of water at different well-point depth as well as different locations onshore and offshore