Beach Well Intakes -

Feasibility Considerations For Large Seawater Desalination Plants

A seawater intake must ensure adequate and consistent flow and quality of source water over the entire useful life of a desalination plant. Beach well intakes are an attractive option for small SWRO plants.

Nikolay Voutchkov

The intake is one of the key components of every membrane seawater desalination plant. The purpose of the seawater intake is to ensure adequate and consistent flow and quality of source water over the entire useful life of the desalination plant. The two key types of intakes used for seawater reverse osmosis desalination plants are beach wells (subsurface intakes) and open surface intakes.

Beach wells are typically located on the seashore, in a close vicinity to the ocean. These intake facilities are relatively simple to build and the seawater they collect is pretreated via slow filtration through the subsurface sand/seabed formations in the area of source water extraction. Therefore, raw seawater collected using beach wells is usually of better quality in terms of solids, silt, oil & grease, natural organic contamination and aquatic microorganisms, as compared to open seawater intakes. Sometimes, beach intakes may also yield source water of lower salinity.

Beach wells could be either vertical or horizontal. The most widely used type of horizontal collector beach wells are often referred to as Ranney wells. The vertical beach wells are usually less costly than the horizontal wells but their yield is relatively small (typically, 400 to 4,000 m^3/day (0.1 to 1.0 MGD)) and therefore, the use of vertical wells for large plants is typically less favourable and practical.

Open surface intakes for large seawater desalination plants are often complex structures including intake piping which usually extends several hundred to several thousand metres into the ocean. Source water collected through open intakes usually requires pretreatment prior to reverse osmosis desalination. The cost and time for construction of a new open surface ocean intake could be significant and could reach 10 to 20 percent of the overall desalination plant construction cost. New open ocean intakes could potentially entrain more aquatic organisms than beach wells because they take raw seawater directly from the ocean rather than source water pre-filtered through the coastal sand formations.

Although beach wells have proven to be quite cost-competitive for plants of capacity smaller than 4,000 m^3/day (1 MGD), open surface ocean intakes have found significantly wider application for large seawater reverse osmosis (SWRO) desalination plants. At present, worldwide there are only four operational SWRO facilities with capacity larger than 20,000 m^3/day (5.3 MGD) using beach well intakes. The largest SWRO facility with beach wells is the 54,000 m^3/day (14.3 MGD) Pembroke plant in Malta. This plant has been in operation since 1991. The 42,000 m^3/day (11 MGD) Bay of Palma plant in Mallorca, Spain has 16 vertical wells with capacity of 5,600 m^3/day (1.5 MGD) each. The third largest plant is the 24,000 m^3/day (6.3 MGD) Ghar Lapsi SWRO in Malta. Source water for this facility is supplied by 15 vertical beach wells with unit capacity of 3,800 m^3/day (1.0 MGD).

The largest SWRO plant in North America which obtains source water from beach wells is the 15,000 m^3/day (3.8 MGD) water supply facility for the Pemex Salina Cruz refinery in Mexico. This plant also has the largest existing seawater intake wells – three Ranney-type radial collectors with capacity of 15,000 m^3/day (3.8 MGD), each.

There are a number of key factors that have to be taken into account when assessing the viability of using a beach well intake for a large desalination plant (facility with production capacity over 20,000 m^3/day (5.3 MGD)). These factors are discussed below.

SITE CONDITIONS

Site suitability for the construction of beach well intake is typically determined by the completion of a detailed hydrogeologic investigation. The factors that define to a great extent if the use of beach wells is practical or/and economical are: the transmissivity/productivity of the seashore geological formations; the thickness of the beach deposits; and the existence of nearby fresh water source aquifers, which could be negatively impacted by the beach well operations or have measurable effect on beach well water quality. The geological conditions that favor the construction of beach well intakes are permeable sand formations which transmissivity exceeds 1,000 m^3/day/m, and which depth extends to 15 metres (45 feet) or more.

Beaches of shallow bays that contain significant amount of mud/alluvial deposits and have limited natural flushing do not favour the use of beach wells for SWRO plant intakes. High content of fine solids in the bay seawater in combination with low frequency of bay flushing and low transmissivity of the beach deposits may render shallow bay beaches less desirable or unsuitable for construction of SWRO plant beach well intakes.

It should be pointed out that both beach wells and near shore open intakes use the same seawater as a source. In desalination plants with open intakes the solids contained in the source seawater are removed in the desalination plant pretreatment filtration system. In desalination plants with beach well intakes, the same amount of solids is retained on the ocean floor in the area of well source water collection while the filtered water is slowly conveyed through the ocean floor and the beach subterrain formation until it reaches the well collectors. The wave action near the ocean floor is the force that allows the solids separated from the beach well source water to be dissipated in the ocean. If the bay area is not well flushed and the naturally occurring wave movement is inadequate to transport the solids away from the beach well collection area at a rate higher than the rate of solids deposition, than these solids would begin to accumulate on the ocean floor and would ultimately reduce the well capacity and source water quality.

Beach wells for which area of influ-

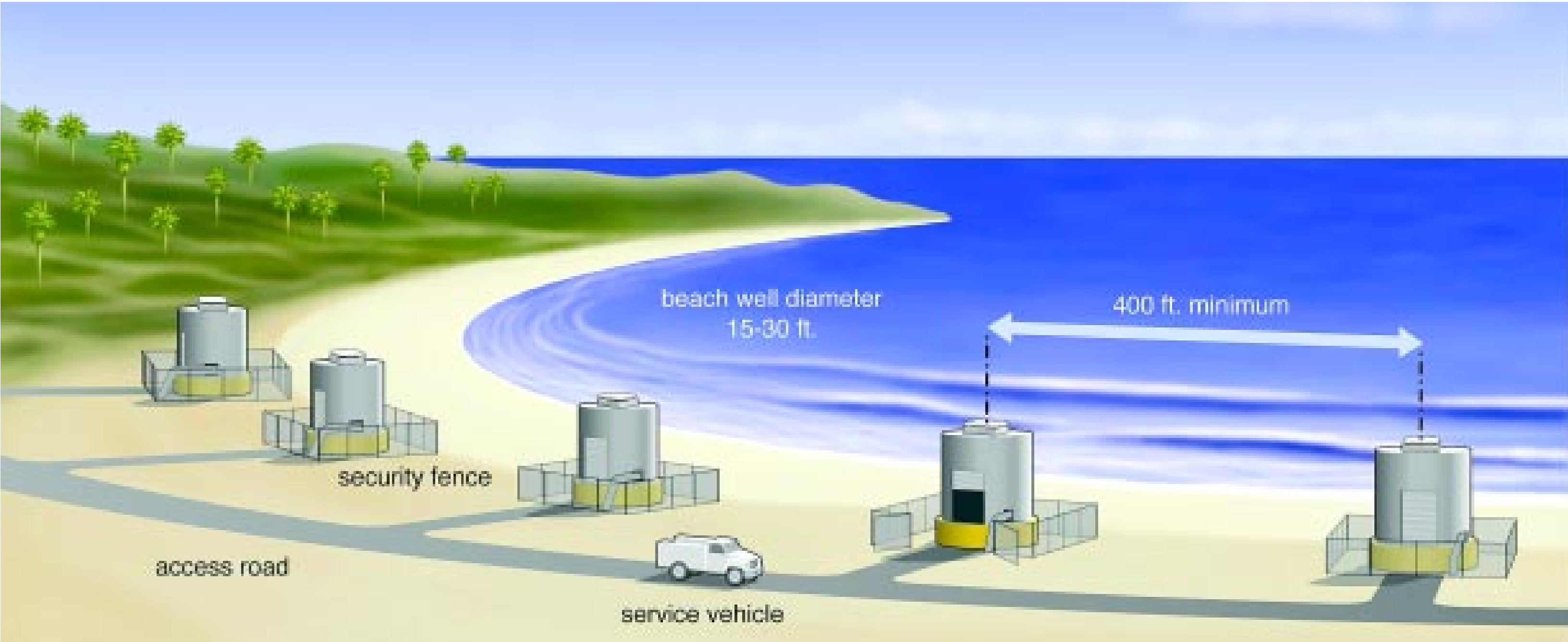

Figure 1 - Beach Well Intake System – Impact on the Seashore

ence/source water collection extends to a nearby fresh/brackish groundwater aquifer may have a negative impact on the aquifer capacity and water quality, and in some cases their operation may result in enhanced seawater intrusion.

On the other hand, if a nearby fresh/brackish groundwater aquifer is contaminated with pollutants, which are typically not present in the seawater in a measurable quantity (such as fuel oil contaminants, endocrine disruptors, heavy metals, arsenic, septic tank leachate, etc.) than the SWRO plant may need to be provided with additional treatment and/or disposal facilities, which would erode the benefits of well intake use.

The fact that at present, worldwide only four out of over 50 existing large SWRO plants with production capacity over 20,000 m^3/day (5.3 MGD) use beach wells indicates that finding the right combination of favourable site conditions for large-scale beach-well intakes is a challenging task. Therefore, their viability is very site-specific and has to be evaluated based on a thorough evaluation of a number of factors discussed below.

SIZE OF THE IMPACTED SEASHORE AREA

Beach wells are typically located on the seashore, in close vicinity (typically within hundred metres) of the ocean. Because of the high number of wells required to supply adequate amount of water for a large seawater desalination plant, construction of these facilities would result in disturbance of a significant amount of seashore land and natural habitat.

If the site-specific geological conditions allow, high-productivity horizontal (Ranney) beach wells, infiltration galleries or seabed filtration systems could be used to reduce the number of individual wells needed. These types of beach well intake systems would typically yield 8,000 m^3/day to 20,000 m^3/day (2.1 MGD to 5.3 MGD) of source water per individual well. Under a hypothetical best-case scenario, a 40,000 m^3/day (10.6 MGD) desalination plant (which requires 80,000 m^3/day (21.2 MGD) of intake flow) would necessitate the construction of a minimum of four operational and one standby beach wells of unit capacity of 20,000 m^3/day (5.3 MGD) to provide adequate amount of source water. If horizontal beach wells, infiltration galleries or seabed filtration systems are used, the minimum distance between the individual wells would be 120 m (400 ft), and the footprint of the beach well impacted seashore area would be at least 30 m (100 ft) wide by 610 m (2,000 ft) long. Therefore, the minimum area of seashore impact as a result of construction of a beach well intake system for a 40,000 m^3/day (10.6 MGD) SWRO plant would be 30 m x 610 m = 18300 m^2 (100 ft x 2,000 ft = 200,000 sq ft (4.5 acres)). Figure 1 gives a general representation of the seashore area which would be impacted by the construction of a beach well intake system for a hypothetical 40,000 m^3/day (10.6 MGD) seawater desalination plant.

For comparison, construction of a new open ocean intake would have significantly smaller area of impact on the beach shore. For a 40,000 m^3/day (10.6 MGD) seawater desalination plant this beach area would be less than 2 acres. If the desalination plant is co-located with an existing power plant station, no additional intake structure would be required and therefore, the coastal beach zone and environment would not be disturbed with the installation of additional structures, equipment and associated service infrastructure (access roads, electrical supply equipment, etc.).

Because of the significant size of the impacted seashore area, use of beach wells may result in another site-related implication, i.e. encountering artifacts of historical and archeological significance at the site designated for intake facilities. At many locations worldwide, the probability of discovering remains of ancient habitats along the seashore is much higher than further inland. This probability would increase with increasing the footprint of the disturbed seashore area.

VISUAL AND AESTHETIC IMPACTS

Beach intake well intake structures for large seawater desalination plants are often constructed as large-diameter caissons and are tall above-ground concrete structures that would have a visual and aesthetic impact on the shore line on which they are located. Typically, the pumps and service equipment conveying the water from a large-size beach well are located above the wet-well of the caisson. Taking under consideration that the beach wells are usually located in a close proximity of the ocean, the well intake pumps have to be installed at such an elevation that assures the protection of the well intake pumps and associated auxiliary equipment from flooding. Therefore, the height of the structures of large intake wells with above-grade pump houses may exceed 3 m (10 feet) above the beach ground level (see Figure 2). Figure 2 shows one of the three 15,000 m^3/day (3.8 MGD) horizontal beach wells for the SWRO plant providing water supply for the Pemex Salina Cruz refinery in Mexico.

Figure 2 – Intake Beach Well of Large Seawater Desalination Plant

For a relatively small-size beach wells the caisson/vertical well collector can be build water-tight and located below grade to minimise visual impact. However, the size and servicing of the well pumps, piping, electrical, instrumentation and other auxiliary equipment of large-capacity wells usually dictates the location of their pump house to be above grade. Although the above-grade pump house could be designed in virtually any architectural stile, this facility and its service roads and controlled access provisions may result in a significant change in the visual landscape of the seashore.

Taking under consideration that the desalination plant source water has to be protected from acts of vandalism and terrorism, the individual beach wells would have to be fenced-off or otherwise protected from unauthorised access. The large and tall fenced-off beach well concrete structures would have a limited visual and aesthetic appeal. Since beaches are visually sensitive areas, the installation of large beach wells may affect the recreational and tourism use and value of the seashore, and may change the beach appearance and character.

For comparison, open coastal intakes are typically lower-profile structures that may blend better with the coastal environment and its surroundings. If the desalination plant is co-located with an existing power plant, construction of new on-shore structures or facilities is typically not required and therefore, is more favourable in terms of additional negative visual and aesthetic impact on the coastal environment and landscape.

USEFUL LIFE OF BEACH WELL INTAKE FACILITIES

Depending on the site specific conditions, often beach wells may have a shorter useful life as compared to open ocean intakes. The useful life of an open ocean intake is at least 30 to 50 years. Without major refurbishment, beach wells would typically operate at a design capacity for a period 10 to 20 years. Over time, the beach well yield may diminish due to naturally occurring scaling of the well collectors caused by chemical precipitates or/and bacterial growth. The rate of decrease of the well yield with time is difficult to predict and requires specialised expertise and detailed studies. Therefore, beach well intakes are usually designed with at least 25 % reserve/standby well capacity, which adds to their capital costs and the size of the impacted beach shore area.

Beach erosion is an additional factor that can significantly impact the useful life of the intake wells. As seen on Figure 3, beach erosion in only several years of operation may result in a loss of soil support on the ocean side of the wells and associated service buildings, which in turn could cause the wells to tilt towards the ocean and ultimately could compromise the structural integrity and performance of the well intake facilities. Therefore, beach erosion may shorten significantly the useful life of the beach wells and increase the overall life-cycle water cost if the well location is not selected appropriately or well construction is completed by a company

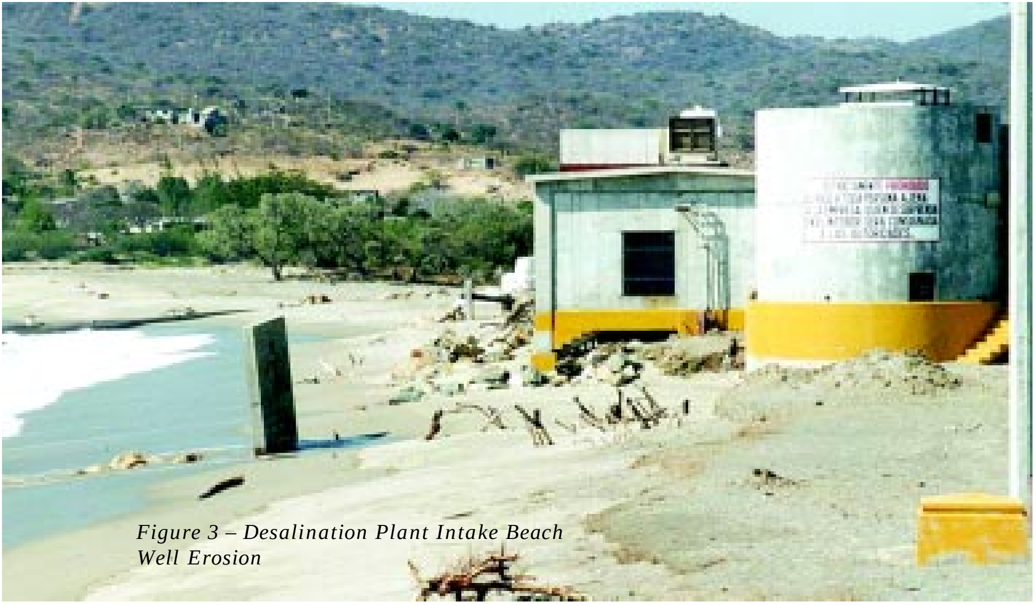

Figure 3 – Desalination Plant Intake Beach Well Erosion

with limited expertise in beach well installation. Beach erosion problems have been observed not only at the Salina Cruz wells shown on Figure 3, but on a number of other locations, such as the vertical intake well for the 2200 m^3/day (0.6 MGD) Marina Coast Water District's SWRO plant.

Due to its significant potential impact on the intake system operation and costs, potential for beach erosion in the vicinity of the targeted intake well location has to be thoroughly evaluated and investigated. If the selected beach site has a high potential for erosion, than the beach wells have to be provided with anti-erosion measures. As can be seen on Figure 3, construction of a single concrete wall on the beach side of the well is not a very effective erosion protection measure.

The useful life of a well designed and operated seawater desalination plant is 25 to 30 years. Because the beach wells may often have a shorter useful life span than that of the desalination plant, in the worst-case scenario, two sets of beach wells may need to be constructed over the useful life of the SWRO plant. The need for replacement of some or all of the original beach wells after the first 10 to 20 years of the desalination plant operation would magnify the shoreline impacts of the beach wells and would increase the overall cost of water production. Therefore, the potential difference between the useful life of beach wells and open intakes has to be reflected in the life-cycle cost comparison associated with the selection of the most viable type of desalination plant intake.

NEED FOR PRETREATMENT SYSTEM

As mentioned previously, beach wells typically yield better intake water quality than open seawater intakes in terms of seawater turbidity and silt density index, which are two of the key parameters associated with the selection, sizing and costs of the desalination plant pretreatment system. Therefore, often it is assumed that the use of beach wells would eliminate the need for seawater pretreatment prior to reverse osmosis desalination.

However, the existing experience with the use of beach wells for seawater desalination in California and at the largest beach-well seawater desalination plant on the West Coast in Salina Cruz, Mexico indicate that some desalination plants using beach wells may face a costly problem – high concentrations of manganese and/or iron in the intake water. Unless removed ahead of the reverse osmosis membrane system, iron and manganese may quickly foul the cartridge filters and SWRO membranes and render the desalination plant inoperable. The treatment of beach well water which naturally contains high concentrations of iron and/or manganese requires chemical conditioning and installation of conservatively designed "greensand" pretreatment filters ahead of the SWRO system. This costly pretreatment requirement may significantly reduce the benefits of the use of beach wells as compared to an open seawater intake. Open seawater intakes typically do not have iron and manganese source water quality related problems because open ocean water does not contain these compounds in significant quantities to cause RO treatment problems.

Example of beach well desalination plant which faced an elevated source water iron problem is the 4,500 m^3/day (1.2 MGD) Morro Bay SWRO facility located in Northern California, USA. The plant source water is supplied by five beach wells with a production capacity of 1,100 m^3/day to 1,900 m^3/day (0.3 to 0.5 MGD) each. The beach well intake water has iron concentration of 5 to 17 mg/L. For comparison, open intake seawater typically, has several orders of magnitude lower iron concentration.

The Morro Bay facility was originally designed without pretreatment filters, which resulted in plugging of the RO cartridge filters within half-an-hour of starting operations during an attempt to run the plant in 1996. The high-iron concentration problem was resolved by the installation of pretreatment filter designed for a loading rate of 6.1 m^3/m^2.h (2.5 gpm/sq ft). For comparison, a typical open-intake desalination plant is designed for pretreatment loading rates of 10 to 13.5 m^3/ m^2.h (4.0 to 5.5 gpm/sf ft) – and, therefore would require less pretreatment filtration capacity. As indicated previously, the largest existing Pacific-coast seawater desalination plant in Salina Cruz, Mexico has also faced an iron and manganese problem, which was resolved by the installation of pretreatment filters and chemical conditioning of the beach well water. The existing experience shows that, the costs for a pretreatment of seawater with high iron/manganese content collected by a beach well intake are typically comparable or higher than these for pretreatment of seawater collected using an open-ocean intake.

SOURCE WATER QUALITY VARIATION

Open ocean intakes provide relatively consistent seawater quality in terms of total dissolved solids (TDS) concentration. The intake source water TDS concentration data collected for the development of the Huntington Beach seawater desalination project in Southern California, USA indicate that the open intake salinity varied within 10 percent of its average value of 33.5 ppt. Although in general beach wells produce source water of consistent salinity, they could also yield water of unpredictably variable TDS concentration with swings exceeding over 30 % of the average. For example, the TDS concentration of the two operational wells at the Salina Cruz water treatment plant vary in a wide range – for well No. 2 between 16.8 and 21.8 ppt, and for well No. 3 between 17.8 and 19.8 ppt. The wide range of source salinity concentration in this case is explained by fresh groundwater influence.

A similar trend was observed at the Moro Bay SWRO plant in California. During the plant's initial operation in 1992, the well water TDS was approximately 26,000 mg/L. In December 2001, the TDS of the intake water was 6,300 mg/L. The December 2002 data for the same plant indicate intake salinity of 22,000 mg/L.

The wide range of intake salinity in systems using beach wells over time would require the installation of variable frequency drives for efficient power use control, which would ultimately increase the construction cost of such system and complicate its operation.

One important issue to be taken under consideration when assessing the viability of using beach wells is the fact that the intake well salinity can change unpredictably over time when influenced by fresh water inflow to the aquifer. This uncertainty of intake water quality increases the risk of uncontrollable increase in unit cost of water production over time and has to be taken in consideration when comparing the overall life-cycle costs of the desalination plant operations. Therefore, the beach well intake water quality has to be thoroughly characterised by installing a set of test wells and collecting water quality samples under variety of operational conditions. Thorough year-around water quality characterisation is of high importance for beach wells whose source water may be influenced by fresh groundwater aquifers with seasonal fluctuation of water quality.

DIFFICULT TO TREAT CONTAMINANTS

Usually open ocean intakes are considered less viable source of water for desalination plants in areas located in close proximity to wastewater discharges or industrial and port activities. However, the open intake seawater is typically free of endocrine-disruptor or carcinogenic type of compounds such as: MTBE, NDMA and 1,4-dioxane. Long-term water quality data collected for the development of the Huntington Beach and Carlsbad SWRO projects in Southern California and a number of other desalination plants worldwide, confirm this observation. Beach well water however, may contain difficult to treat compounds especially when they are under influence of contaminated groundwater. Example is the Morro Bay SWRO plant, where beach well intake water was contaminated by MTBE caused by contamination from an underground gasoline tank spill. MTBE is a gasoline additive. Similar problems were observed at the California's Santa Catalina Island 500 m^3/day (0.132 MGD) seawater desalination plant that uses beach well intake.

The compounds of concern could be treated by a number of available technologies, including activated carbon filtration, UV irradiation, hydrogen peroxide oxidation, ozonation, etc. However, because these treatment systems will need to be constructed in addition to the SWRO system, this additional treatment may increase the overall desalinated water production cost measurably.

OXYGEN CONCENTRATION OF DESALINATION PLANT DISCHARGE

Beach well water typically has a very low dissolved oxygen (DO) concentration. The DO concentration of this water is usually less than 2 mg/l, often it varies between 0.2 and 1.5 mg/L. The SWRO treatment process does not add appreciable amount of DO to the intake water. Therefore, the SWRO system product water and concentrate have the same or lower DO concentration. Low DO concentration of the product water will require either product water reaeration or will result in significant use of chlorine.

If the low DO concentrate from a well intake desalination plant is to be discharged to an open water body – the ocean or a river, this discharge typically would not be in compliance with the United States Environmental Protection Agency's daily average and minimum DO concentration discharge requirements of 4 mg/L and 5 mg/L, respectively. Because large desalination plants using intake wells would discharge a significant volume of low-DO concentrate, this discharge could cause oxygen depletion and stress to aquatic life. Therefore, this beach well desalination plant concentrate has to be re-aerated before surface water discharge. For a large SWRO plant, the amount of air and energy to increase the DO concentration of the discharge from 1 mg/L to 4 mg/L is significant and would have a measurable effect on the potable water production costs. Discharge of this low DO concentrate to a wastewater treatment plant outfall would also result in a significant additional power use to aerate this concentrate prior to discharge.

For comparison the concentrate from SWRO plants with open intakes would typically have DO concentration of 5 to 8 mg/L, which is adequate for disposal to the ocean, without re-aeration.

SUMMARY AND CONCLUSIONS

Beach well intakes are an attractive option for small SWRO plants. However, a number of their advantages over open ocean intakes typically diminish for desalination plants with capacity over 20,000 m^3/day (5.3 MGD). Large above-grade beach well intakes may have a measurable impact on the visual appearance and aesthetics of the coastal shoreline and environment. Uncertainties related to beach well productivity, capacity, useful life and intake water quality could significantly elevate the risk of uncontrollable increase in the cost of water production over the useful life of the desalination plant. Therefore, these factors have to be taken in consideration and studied thoroughly prior to selecting the most viable intake system for large membrane seawater desalination plants. ***AW***

Nikolay Voutchkov *is Senior Vice President – Technical Services, Poseidon Resources Corporation. For his contact details, please email the editor of Asian Water at vikass@singnet.com.sg.*