Investigation of Sea Water Intake Alternatives at Shores with Low Slope

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Abstract

The presented paper is focused on the seawater intake alternatives for desalination plants with the main aim to introduce the best option at shores with a low slope. Supplying feed water and selecting intake system at site locations with low costal gradient are very important due to providing required water quality and capacity, minimum environmental impact, geotechnical limitations prolongation of intake route and increasing dredging volumes. By attention to the hydrography and topography conditions of this site, it is necessary to investigated all of the intake alternatives. The various seawater intake methods is introduced at this paper and for a case study in Bandar Abbas city, according to their site condition, six alternatives, independent pipeline, existing break water plus pipeline, piled jetty, existing breakwater plus piled jetty, beach wells and tidal sea water, are selected to future investigation. These alternatives are evaluated and compared from the technical, construction, environmental and capital cost aspects, finally by grading and ranking of each alternative, the best intake method, existing break water plus pipeline, is the system that achieved higher scores.

Keywords: Seawater Intake, Low Slope Beach, Desalination Plant

Introduction

Increasing demand for water in the southern cities in Iran has shifted attention to the role of desalination to supply water. Experience in the Persian Gulf demonstrates that desalination technology has developed to a level where it can be as a reliable source of water.

Providing sea water with proper quality is main concern in desalination intake system specially in RO desalination plant. Selection of sea water intake system depends on required water quantity and quality, geotechnical condition and beach morphology. In high capacity desalination plant, beach morphology is very impermissible on intake system. Beaches with low slope has specific characteristic which must be considered in design of sea water intake system therefore in this paper first morphology of low slope beach is described then different intake system and feasible system for this condition is introduced finally proper system for a site in Bandar Abbas is investigated.

Morphology of low slope beach

There are three dominant factors that control the mean grain size of beach sediments:

1. The sediment source,
2. The wave-energy level, and
3. The general offshore slope upon which the beach is constructed.

The importance of the source is obvious. The beach environment will select out the grain sizes that are appropriate for its particular conditions. If it so happens that the sources provide no appropriate material of the right sizes, then there would be no beach. Assuming the sources do provide the proper grain sizes. Then there remains a complex relationship between the energy level of the nearshore waves and currents, the general offshore slope, and the resulting grain sizes of the beach deposit. There is a general tendency for the highest-energy beaches with the largest waves to have the coarsest grains. However, a simple correlation between grain size and wave-energy level cannot be made [1].

Also important is the offshore slope upon which the beaches are formed the slope being considerably steeper off from the headlands. Apparently because of the high slope, as well as greater wave energies, even coarse sand within headland beaches can be maintained in suspension so those particle sizes move offshore leaving only gravel and cobbles. Initially the bedrock slope of the nearshore would govern which grain sizes remain to form a beach. Once the beach is established, however its slope would govern the lower limit of grain sizes that could remain within the nearshore.

Dissipative, intermediate, and reflective beaches a system developed by Wright and Short (1983) to classify beach morphologies and the accompanying patterns of nearshore waves and currents. The classification depends on the angle of the beach slope β and on the wave conditions (Figure 1).

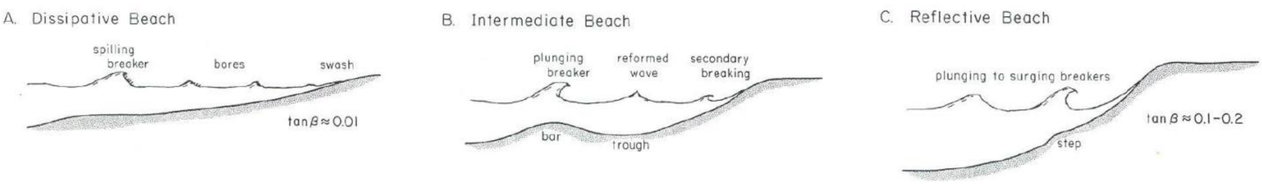


Figure 1: Beach classification based on the angle of the beach slope β and on the wave conditions

The dissipative beach, "Figure 1-A", is the type having a low-sloping profile, such that the waves first break well offshore and continuously lose energy when they travel as breaking bores across the wide surf zone. If the breaker heights increase during a storm, the waves simply break farther offshore with minimal increase in the incident-wave energy at the shore line. The morphology of the dissipative beach therefore, acts to dissipate the energy of the wind-generated waves. In contrast, on the reflective beach of "Figure 1-C", the incident waves break close to shore with little prior loss of energy. The intermediate beach "Figure 1-B" incorporates a series of morphological types that are more three dimensional in that some involve complex water-circulation patterns and bar-trough systems [2].

So beaches of low slope, those normally composed of fine sand and are characterized by wide surf zones [1].

Introducing different Sea Water Intake Systems

Seawater intake types range from screened wells onshore, to large surface water intakes along the shore and to offshore intake structures. Each type varies in design, power consumption and environmental considerations. Intake types are generally divided into two main groups, which are direct intakes and indirect intakes as shown in "Figure 1" [3].

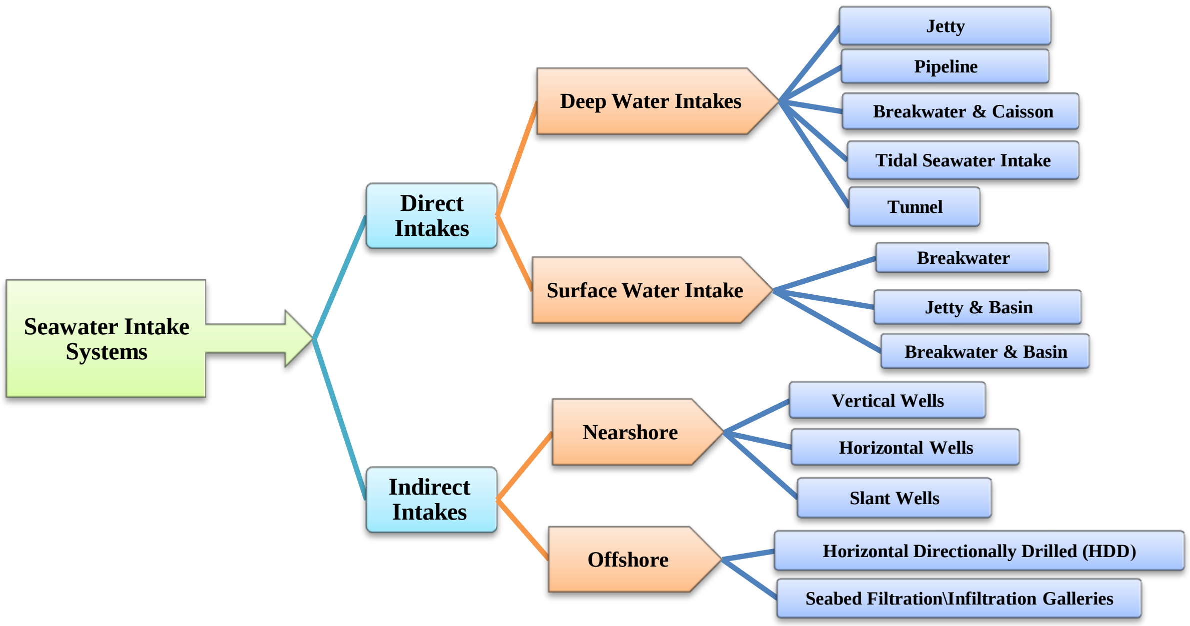


Figure 2: Different possible marine intake types

A direct seawater intake refers to an intake structures which extracts seawater directly from the ocean. This type of structure can either be constructed below the surface (sub-surface) at an offshore location, or as an open channel (surface intake) protected from waves by breakwaters or in a natural bay [3].

Indirect intakes, also referred to as sub-bottom intake structures, extract seawater from a point below the seafloor or beach. Various sub-bottom intake types are available, depending on the local geotechnical conditions and specific project specifications [3]. The indirect intake types include horizontal, vertical and slant wells, horizontal drains and seabed filtration systems.

Direct intake from Deep Water

Deep-water intakes are the most common intakes for existing RO plants, especially for high capacity ones. The construction of a classic open intake involves submarine pipelines installed on the ocean floor. These may extend from a few hundred meters to over a thousand meters from the shore into the offshore area, or involve intake wells in deeper water with feed water being pumped along pipelines installed on a jetty. Different alternatives for direct deep water intake are described below [4].

- Pipeline

This type of seawater intake will have several components: the head(s), the risers, the pipeline itself, screens, and, if necessary, marine growth control. The head of the intake is where the seawater is drawn in and will be designed to achieve the maximum velocity. The risers connect the intake head(s) to the pipeline. Screens will prevent debris from entering the plant and can be done as a grill or passive technology at the intake itself or an onshore technology (Figure 3) [5].

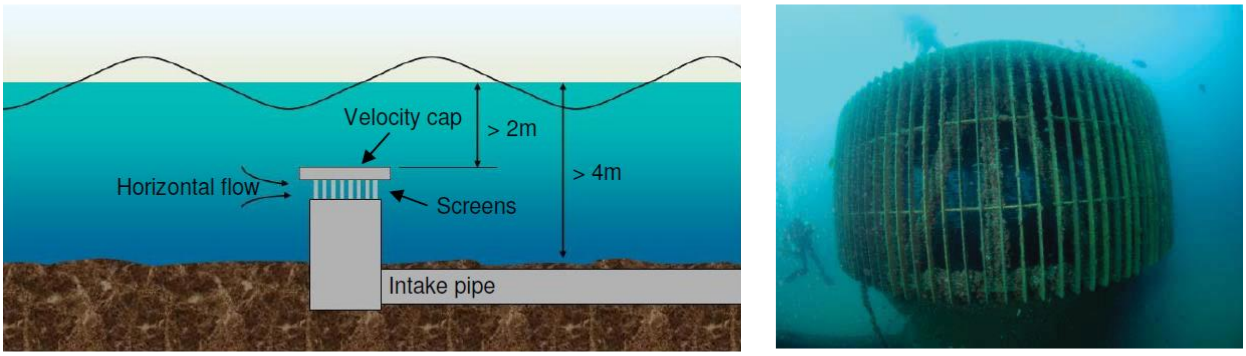


Figure 3: Intake head structure [3, 5]

- Tidal Seawater Intake

In the beaches with low bottom slope, desired intake depth dictate a long conveyance pipeline that raises the project cost. Tidal seawater intake is an alternative to overcome this difficulty by taking the advantages of tide phenomenon. In this method the required pipeline length and dredging volume decrease, since the intake process just works during the flood tide and half of the intake sea water is saved in a reservoir. During the ebb tide the intake pipeline is closed and the desalination feed water is acquired from the reservoir.

- Jetty

One of the common methods to make use of deep water intake is construction of a jetty that extends from the shore into the offshore area. The pipelines are installed on the jetty to convey the feed water to the desalination plant. The jetty can be either a piled jetty or rubble mound structure (Figure 4).

Figure 4: Jetty mounted pipelines

Two approaches of construction can be considered. The outdated one is to make use of pump station which is located at shore side of the jetty. Despite the fact that maintenance of pumps in this method is easier and more accessible, since the experiences have shown that siphon pumps are not completely reliable, this method have been replaced with the new one. The modern system of intake consists of intake wells at offshore side of the jetty with feed water being pumped along pipelines to the desalination plant. Different types of structures to support the offshore pump stations include:

- Piled structures
- Caisson structures
- Artificial island

- Tunnel

This alternative involves the construction of a tunnel over the full distance to the intake structure and diffusers offshore (Figure 5). The full tunnel alternative includes the following key components:

- The construction of a deep shaft adjacent to the proposed Desalination Plant to enable construction of the tunnel(s);
- An intake pumping station located within the deep shaft; and
- Riser structure(s) from the end of the tunnel(s) upwards to the pipelines, located on the seabed, including an excavated cross-connection below the seabed [6].

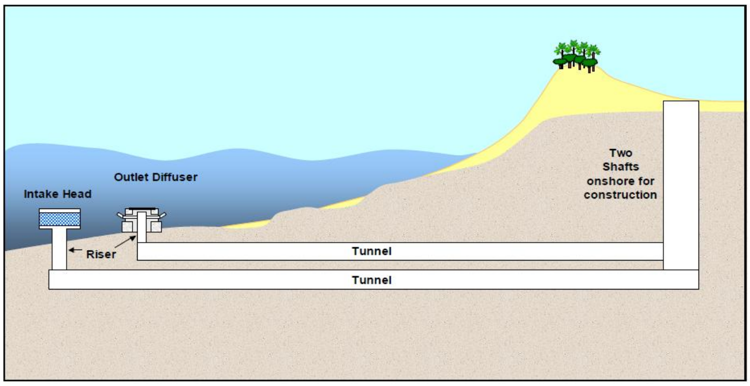


Figure 5: Tunnel seawater intake alternative

Direct intake from Surface

This kind of intake system is usually made of a conveying channel (on low-energy coastlines) and/or a stilling basin protected by a breakwater (on more exposed coastlines) with simple and/or complex mechanical screening systems at the intake. Surface intakes, however, only work with an acceptable degree of performance when small loads of debris are present, as they become ineffective when the water becomes saturated with large loads of debris and sediments (Figure 6) [7].


Figure 6: Examples of open intake basin protected by breakwaters [7]

- Basin Protected by Breakwaters

The first alternative of surface water intake, considering low bottom slope condition, involves construction of two long rubble mound breakwaters and dredging of the long channel to avoid surf zone sediments.

- Jetty & Basin

To minimize the length of the rubble mound breakwaters, an alternative is to construct a jetty as a causeway with a stilling basin at the end of the jetty. The causeway can be either a piled jetty or rubble mound structure.

When construction of a jetty is required, use of deep water intake is more likely to be feasible. Since deep water intake can provide better feed water quality than surface water intake in addition to more construction work of rubble mound structures and periodic dredging that surface water intake requires.

Indirect intake from near Shore

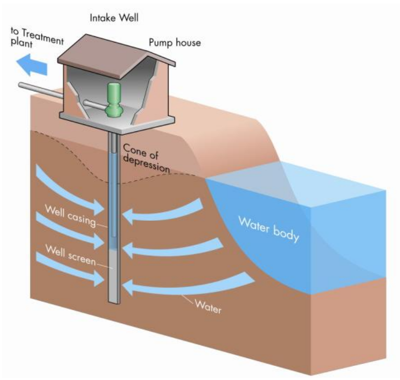
Intake wells are water wells drilled in a coastal aquifer. Horizontal collector wells are most common, but wells can also be drilled vertically or at an angle. The well concept is used where geologic conditions are favorable to develop a water supply by pre-filtering the seawater through natural aquifer deposits to provide low-turbidity, low-SDI water to the desalination system. This process of natural filtration typically eliminates the need for pretreatment to remove suspended particles from the source water [8].

- Vertical Wells

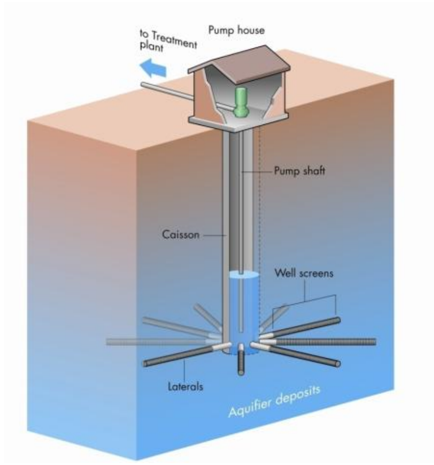
A vertical well, as the name implies, is a well-drilled straight down into the underlying rock or unconsolidated coastal aquifer system. A vertical seawater intake well consists of a non-metallic casing (typically fiberglass or reinforced pipe), a well screen, and a stainless steel submersible or vertical turbine pump. Well diameter and depth is a function of the aquifer characteristics and potential yields (Figure 7-A) [8, 9].

o Horizontal Wells

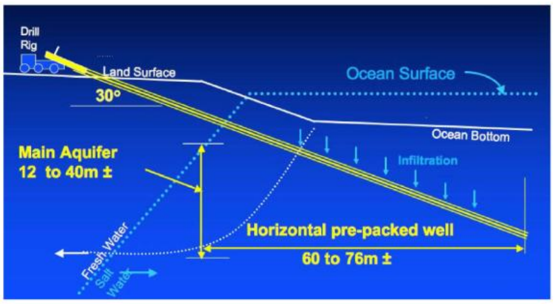
Often referred to as radial or “Ranney” collector wells after their inventor, a horizontal well consists of a reinforced concrete caisson sunk down into the coastal aquifer and well screens that extend out laterally into the formation from inside the caisson (Figure 7-B).



(A) Vertical Well



(B) Horizontal Well



(C) Slant Well

Figure 7: Indirect Near Shore Alternatives [9]

o Slant Wells

Slant wells and HDD (Horizontal Directionally Drilled) wells are drilled at an angle so that the pump house and access roads can be built some distance from the shore, minimizing loss of shoreline habitat, recreation access, and aesthetic value. Furthermore, with the use of extensive piping, multiple slant wells and HDD wells can be connected together to branch out and cover a large area of shoreline from a single pumping facility.

As shown in "Figure 7-C", to optimize the well screen distance from shore these wells are typically drilled using rotary drilling equipment set at an angle of up to 25° from horizontal. The primary intent of using this design is to extend the screened area of the well away from the wellhead/pump location out toward the sea. Because the well casing and screens are installed at an angle, the well screens will likely transect multiple geologic layers within the coastal aquifer, drawing water of different qualities from different layers/levels. Few slant wells have been installed for seawater desalination applications so very little data are available regarding these wells construction, performance and maintenance [8].

Indirect intake from offshore seabed

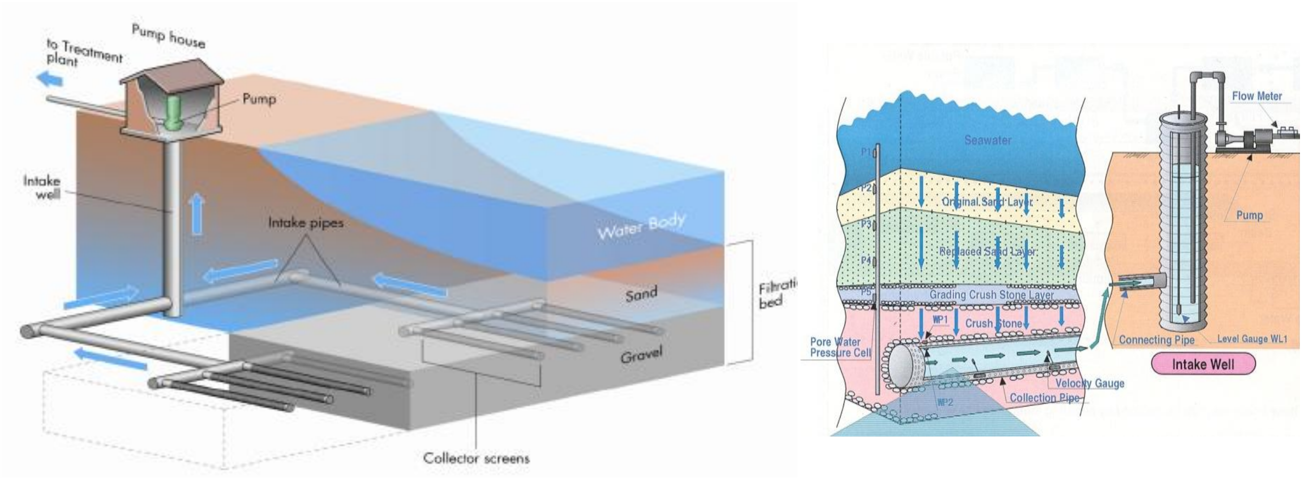
o Horizontal Directionally Drilled (HDD)

HDD wells are non-linear slant wells that are installed using a specialized drilling technology that has been used extensively in the petroleum and power industries. As shown in "Figure 8", drilling begins with a pilot hole drilled at a low angle from the horizontal from an on-shore location [8].

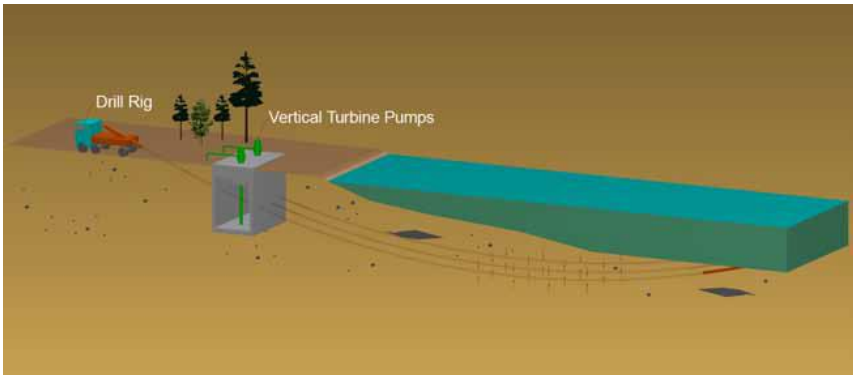
o Seabed Filtration\ Infiltration Galleries

These systems are typically constructed by excavating native soils or rock, placing a screen or network of screens within the excavated area, and then backfilling with a porous media (of a size and depth similar to that of granular media filters used for conventional water treatment plants) to form an artificial filter around the screens. Heavy armor stone is sometimes required for erosion protection. These excavations need to be located beyond surf zones, in areas with sufficient water depth and at an appropriate burial depth to protect the integrity of the structure. The intake screens are typically connected to a pump station/sump by a pipe. By pumping the system, water is drawn into the excavation and filtered through the media, undergoing some pretreatment in the process (large particle removal). As wave action, currents, and sedimentation occur with time, impacts on this type of intake will likely require periodic removal of surficial silts and debris and ultimately replacement of the entire filter media to maintain performance [8].

Infiltration galleries tend to be used where seawater intake wells are not feasible due to geologic conditions and where very low capacity is desired.



(A) Seabed filtration



(B) HDD Seawater Intake Well

Figure 8: Indirect offshore alternatives [8, 9]

Feasible Intake Systems for Low slope beach

Sea water intake alternatives originate from two main concepts that are direct and indirect water intakes. In each concept several different systems as shown in "Figure 2" were elaborated. All of the direct deep water intake alternatives are feasible for low slope beach. But it must be considered the tunnel alternative needs high technology equipment.

Direct surface water intake alternatives in general have worse water quality in comparison with deep water intake alternatives. Since the RO desalination plants are sensitive to water turbidity, it may be required to go to deeper water to exit the surf zone and provide better water quality therefore require relatively long rubble mound breakwaters or jetty in low slope beach in order to pass surf zone. Therefore surface water intake alternatives were rejected.

Indirect near shore intake methods, it is clear that due to morphology of low slope beach, are not feasible. Also the seabed filtration/seabed galleries method is rejected due to large dimensions of required galleries and consequently large volume of dredging.

According to the above descriptions, feasible alternatives can be proposed for low slope beach are as follow:

- Pipeline sea water intake
- Tidal sea water intake
- Jetty sea water intake
- Tunnel sea water intake

Case Study: Intake Systems for Bandar Abbas desalination plant

Site condition

The site of the project is located on the Persian Gulf seashore in Hormozgan province of Iran. The location of the site is shown in "Figure 9". The project is located in the U.T.M. projection zone of 40N and the approximate U.T.M. geographic coordinates are: E = 438365.5, N = 3007360.

The slope of the ground and seabed is very smooth and the site area is almost flat. Based on the available onshore geotechnical data, Muddy silt is the predominant material observed.

The site of the project is in the vicinity of Nakhle-Nakhoda breakwater and an abandoned jetty constructed for another project. There is a cove in about 2 km far away of the site location. An inlet which is locally called the “Khour Abi (Abi inlet)” stands to the east of the site and a river named “Rudkhane-ye Shur” is connected to the inlet and should be considered as a source of sediments. A shrimp farm is located in the east of the inlet [10].

Figure 9- Location of Bandar Abbas seawater desalination plant [10]

Feasible Intake Systems for desired project

Based on the site condition the feasible intake systems are modified for this project. The pipeline, tidal and jetty sea water Intake are possible but the tunnel alternative is rejected at this project because of geotechnical limitations, technology requirements and lack of construction experience.

As mentioned before, in order to provide desired water quality for RO desalination plants the pipeline and jetty will be very long. One alternative that is considered to overcome this difficulty and take the advantages of employing the existing breakwater is extending the existing breakwater to desired water depth. Therefore constructing a new jetty from the end of existing breakwater to the favorable point of intake is considered.

To extend the existing breakwater to desired water depth, there is one more alternative which is utilization of pipelines. So instead of constructing a new jetty, it can be possible to lay pipes from the end of existing breakwater to the desired point of intake. Note that despite the pipeline alternative, it is not possible to convey the seawater under gravity from the intake point to the desalination plant. Therefore offshore pump station is required at the end of existing breakwater.

According to the above description, feasible alternatives can be proposed for more investigation is as follow:

- Independent Pipeline
- Tidal sea water
- Piled jetty
- Existing breakwater plus piled jetty water
- Existing breakwater plus pipeline

Investigation of Feasible Alternatives for desired project

The above mentioned alternatives are more investigated to select more promising methods, considering various aspects including: technical, environmental, construction and capital cost. The feed water flow rate & quality, reliability, flexibility and development feasibility of intake system are investigated at technical item and the alternative with best performance gets the higher score. At the construction investigation, it is mentioned to the local experience, needed special equipment and the time to build of each alternative. The best alternative is the one that have a higher construction experience in Iran, not need so special equipment and minimum time for the construction.

All of the suggested methods create a similar of negative environmental impacts on the coastal and marine ecosystem but intensity and extent are different. Negative impacts on the coastal and marine ecosystem may be damage to marine and costal ecology such as aquatic fauna and flora, damage to natural aquatic plant growth, damage to littoral zone, displacement of fishery resources and other mobile bottom biota due to construction work and form new habitats which may introduce undesirable species.

The other important factor that will directly affect the selection of the best alternatives is the cost of construction and operation. The cost of construction, operation and maintenance and land ownership for each alternative are estimated by considering their main components. It must be notice that tidal seawater alternative is required extra land to build reservoir basin at onshore, so the land ownership is estimated only for this alternative. The relative construction costs of each alternative are presented at "Figure 10".

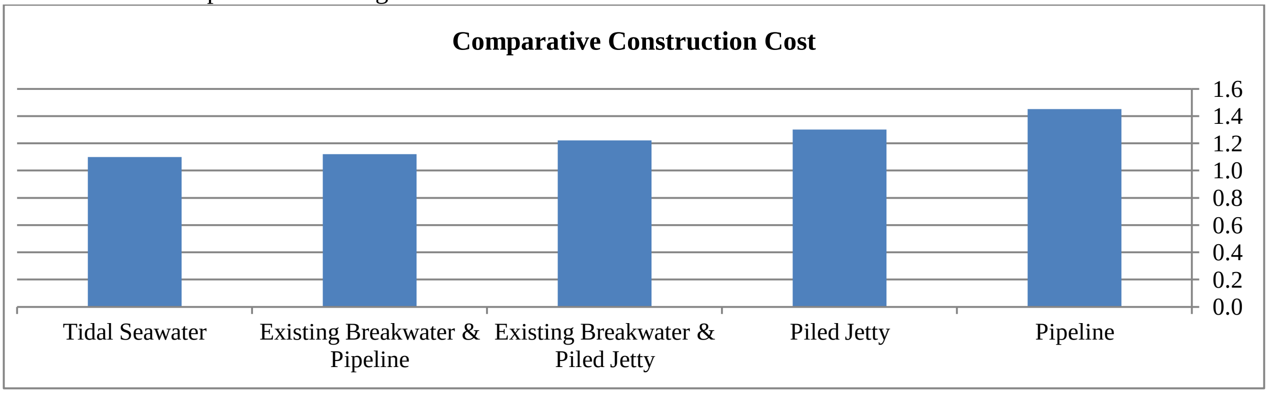


Figure 10: Comparing capital costs of five alternatives for desired low slope beach

"Table 1" presents an overall comparison between five alternatives. It is concluded that the piled jetty, independent pipeline, and existing breakwater plus pipeline are the best alternatives from the technical aspect. According to the above grading, best alternatives considering constructional aspects are the existing breakwater plus piled jetty, existing breakwater plus pipeline, and piled jetty alternatives. It is also clear that the existing breakwater and piled jetty and piled jetty alternatives have minimum environmental damages. By considering all of the technical, constructional and environmental items, the existing breakwater plus piled jetty, piled jetty, and existing breakwater plus pipeline have higher score than other alternatives. The existing breakwater plus pipeline and existing breakwater plus piled jetty alternatives are cheaper by comparing their total economic aspects. Finally, by comparison of the final weighted score of five alternatives that considered technical, construction, environmental and economic aspects, the existing breakwater plus pipeline and existing breakwater plus piled jetty are two best alternatives for suggestion seawater intake system at this site location.

Table 1: Comparison of alternatives for desired low slope beach

Aspects		Weight factor	Pipeline	Existing Breakwater & pipeline	Piled jetty	Existing Breakwater & Piled jetty	Tidal sea water
Technical	Feed water Quality	2	80	80	80	80	60
	Reliability	2	100	80	90	80	60
	Flexibility	2	100	100	70	60	100
	Development feasibility	2	50	60	100	80	60
Construction	Local Experience	2	90	70	80	80	90
	Equipment	2	100	100	80	80	100
	Time	2	50	90	60	70	60
Environmental	Coastal	1	70	80	100	100	80
	Littoral Zone	1	30	50	50	60	30
	Aquatic fauna and flora	1	50	70	65	90	50
	Aquatic plants	1	55	80	90	100	60
Economic	Capital Cost	5	68	91	76	82	92
	Operation & Maintenance Cost	5	68	91	76	82	92
	Land Ownership	5	100	100	100	100	60
Weighted Score			2528	2848	2688	2726	2700

Conclusions

Taking into account the growing strain on the natural fresh water resources and restrictions of picking water from groundwater sources, it is expected that Iranian southern cities fresh water resources for domestic, industrial drinking uses will have to be supplemented by desalinated seawater in the near future. The practical experience and technology of various desalination plants at the Persian Gulf is also growing at recent years, but selecting the alternative for seawater intake system at the site condition with low costal gradient are so complex. At this paper, all of the various methods are investigated for a case study at Bandar Abbas city. Five possible alternatives were compared and the best alternatives were proposed to present a typical case study. However the following general conclusion could be presented for beach with a mild slope [11].

- A framework, used in a case study, was presented in the paper. The presented framework can be used by design engineers in similar projects which need the selection of the best alternative for seawater intake when the beach is flat.
- When the desired beach is flat, the construction of a jetty using rock materials is very promising, because it is usually the cheapest alternatives. However it may create some environmental restrictions.
- The use of pipeline is acceptable for a flat beach but it requires large amount of dredging and the design engineers should take into account the cost and time of construction for dredging. It means dredging is the main concern for pipeline alternatives when the desired beach is flat.
- If the desired beach is environmentally sensitive then it highly recommended the existing structures to be used to reduce the extent of any type of new construction. Such a case is presented and discussed in this paper.

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