EFFECTS OF ENVIRONMENT ON SOURCE WATER FOR DESALINATION PLANTS ON THE EASTERN COAST OF SAUDI ARABIA[1]

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ABSTRACT

A study was carried out in the sea adjacent to a major MSF plant where a new 24MGD SWRO plant is being commissioned. Data were collected on the topographical feature of the marine basin, water quality and plankton of the intake zone. The incidents of planktonic bloom, influx of invasive organisms like jellyfish and macrofouling organisms and ingress of marine algae were monitored regularly. The Intake Bay of the plant is a well designed man-made structure studded to the coast. The marine basin in Al-Jubail, is for geological reasons, a shallow gently sloping shelf while the bay proper is a dredged, deeper basin. The area outside the bay is a vast sea grass bed and the seafloor sediment is sandy. The drag of sea water maintained by the intake pumps facilitates the transport of sediment particles, uprooted algae and floating objects creating fouling problems inside the plant. Seawater temperatures, conductivity, pH, dissolved oxygen and trace metals were found to be very much benign to the trouble free operation of the plant. Influx of jellyfish, noticed during the summer, was not found to be very severe. Data on plankton showed the presence of many phyto and zooplankton organism of biofouling potential in the plant. Total suspended solids indicated the possibility of the intake bay becoming a source of elevated Silt Density Index (SDI) for the new SWRO plant. The paper considers the data in detail and discusses the effects of environment on the desalination plant in Al-Jubail and suggests certain strategies for the protection of seawater intakes and some points useful in the siting and design of coastal seawater intakes in the region.

Keywords: Source water quality, plankton, invasive organisms, macrofouling, desalination.

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1. INTRODUCTION

The establishment of large capacity desalination and power plants in the West Asian countries has necessitated the withdrawal of correspondingly large quantities of seawater from the sea, effectively sending in and out rivers of seawater with varying characteristics [1]. Despite this phenomenal growth of the desalination industry in the Kingdom, information is scanty on the effect of the intake zone environment on plants. The intake system known as once-through cooling system in power plant literature, consists of a seawater intake, an internal part (in-plant), the outfall and a large external part (the receiving sea) [2]. Intake, be it natural surface/subsurface structures or artificial structures studded to the coast, is an important part of the desalination and power plants, and their efficient operation has a significant bearing on the overall efficiency and productivity of the plants. Because inland water is either too scanty or already dedicated to other uses, coastal seawaters offer the best option as source water for desalination and power plants in the region [3]. Appropriate design is a prerequisite for making intakes cost effective and environmentally sustainable and it is emphasized that any once-through intake system should take into account the present and prospective uses of the selected site by the communities of people in a region [4]. Each site demands a separate approach taking into account technical, economic and ecological aspects in a given situation [5].

Environmental effects such as a change in the velocity field of seawater, local current pattern, transport of suspended and bottom sediment and seawater stratification has been reported [3]. Over a larger context, the seawater intakes are at the risk of pollution caused by oil spills, chemical pollutants and city drains and sewers that introduce a potential risk of ingress of such waters to desalination plants. The desalination and power plants in the region are exposed to a variety of operational problems arising from the use of raw seawater. The effects of the marine environment on the plant are recognized primarily as biofouling of the intake structures, pumps and various plant structures by bacterial biofilms caused by microbial attachments and macrofouling caused by a variety of invertebrate organisms and marine algae. Microfouling induced corrosion and macrofouling induced failures have been reported in the literature [6]. Although many instances of severe biofouling in the condenser tubes, water boxes, pipe sections and pump structures have been reported from plants, hitherto no data are available from any of the intakes regarding the biofouling potential of feed seawater posed by planktonic and benthic organisms.

The intakes are further exposed to the periodic ingress of invasive species such as Jellyfish causing clogging of the intake screens and seriously affecting the pumping of seawater needed for the plant. A power plant located on the Arabian Gulf is plagued by Jellyfish influx every year between March and July with a telling impact on the operation of the plant [7]. Jellyfish has smothered the seawater cooling system at a nuclear power plant in Japan forcing the operators to cut output by nearly 30% [8]. The causes of Jellyfish bloom and their control strategies are discussed in a report of the United Nations Environment Programme [9].

Events in the marine environment have a definite bearing on operation and maintenance of desalination and power plants, so that a high quality feed water is a prerequisite for their successful operation. For instance, the degree of biological activity in a feed intake site would indicate the pretreatment regime needed for the successful operation of a seawater desalination plant. Plants are often shut down or put on reduced load due to elevation in the silt density index. The seasonal ingress of algae, sea grass, incidence of planktonic blooms and jellyfish swarms was found to create serious problems at the intake, and inside the plants. SWCC, R&D Center has been devoting its attention to get a clear understanding of various events in the sea that are of significance to the operation of the plant. The intake of feed water and discharge of warm and concentrated brine creates an ecological situation greatly complicated by the topography of the coastal basin, the action of tides, shore currents, sediment movement and salinity [2].

2. MATERIALS AND METHODS

The present study was carried out in the Arabian Gulf, bordering the Al-Jubail desalination and power plants in Saudi Arabia. This is the largest seawater desalination facility in the world producing 246 MGD of water and 1585 MW of power. A 24MGD SWRO plant is also ready for commissioning.

Following were the study sites.

Station I : Intake Bay

This is a man-made structure studded to the coastline. It is protected by two breakwater sea walls. The intake lagoon, with a 330m wide entrance, begins 1.8 kilometers away from the shore and taps the clean open seawaters of the Gulf. The lagoon broadens quickly to 700m for about 1.5 km and then declines to 300m width. The mean depth of the bay is approximately 4.6m. Five intake pumping stations are located on the shore to provide uninterrupted seawater feed supply required for the plants. Feed seawater is taken from a depth of 3m.

Station II : Open Sea

The sea adjacent to the plant is shallow. The coastline is relatively straight and the seaward extension of the continental shelf is a gently slopping one with depths ranging from 1-10m up to a distance of 6 km from the shoreline. The study site is shallow with a depth of around 3m.The area is a major fishing ground and a sea weed bed. A huge industrial city is situated about 20km north to this site.

The materials required for the study were collected during monthly cruises carried out during 1997-98. Data on physico-chemical and biological aspects were collected following procedures given by [10-14].

3. RESULTS AND DISCUSSION

3.1 *General conditions*

The marine basin in the region is very shallow, the depth ranging from 2 to 5m over a long distance from the shore (Fig. 1). The 2m contour is approximately 1-2 km, 5m contour 4 km and 10m contour 6km away from the shore. The continental shelf is a gently sloping one. Whereas the mean depth of the open sea basin is just 3m that of the Intake Bay is 4.6m. The intake lagoon has a surface area of 1.53km^2 with a capacity to hold 7million m^3 of water. The feed water entering the bay from the shallow sea, spreads out to a larger enclosed basin and is withdrawn by a battery of shore based intake pumps at a depth of about 3m. The intake bay has been in operation since commissioning of the plant in 1983 and it has performed well with respect to structural stability of the break water walls [15]. North to this area is situated the Naval Base, a commercial Port and the Jubail Industrial city forming one of the biggest petro-chemical complexes in the world. The area is exposed to the potential threat of pollution from these sources and a desalination plant has to be always on the guard to protect the feed intake locations.

The tide in the region is of a semi-diurnal type. The highest and the lowest tide is at 1.1m above and below the mean sea level. Waves are generally of a moderate nature. The current in the region is predominantly southeast ward along the coast [15]. Because of geological reasons, the sea floor bordering the Saudi Arabian coast is very shallow and has the same geological characteristics as that of the adjacent land masses [16]. The shallow marine basin is covered largely by sandy sediments and sea grass beds. The drag of seawater maintained by the battery of intake pumps facilitates the transport of sediment particles, sea grasses and floating objects into the sheltered bay.

3.2 Physico-chemical features

3.2.1 Temperature and pH

Temperature of seawater showed wide monthly fluctuations. Seasonally, temperature showed highest value during summer and the lowest during winter (Table 1). The variation is not significant on an annual or seasonal scale. The range of variation in temperature was 14^{o}C during the present study. In the Ras Tanura region, further south it was 15.84^{o}C for a 20 year period [17]. The area being relatively shallow, the difference between the surface and bottom water temperatures was less than 1^{o}C and the water body was homogenous throughout the year because of the continuous movement of water towards the plant. Emery [18] has reported a difference of 10^{o}C between the surface and bottom waters at 50m depth and 5^{o}C in shallow regions in the Gulf. The surface temperature in the offshore seas remains stable up to about 25 m and then declines on a depth profile [19]. In coastal shallows like the present area of study, variations seldom occur. The overall temperature profile showed that it has been stable within the general context of the Gulf seawater temperature, and this stability has a profoundly beneficial effect on the successful operation of the desalination plants.

3.2.2 Conductivity

Although the monthly conductivity values showed wide fluctuations, its variation over a seasonal scale was more stable, in that the values were the highest during summer and the lowest during winter (Table 1). The conductivity values observed now were converted to salinity with a factor of 0.70565. Accordingly, the salinity of the Intake Bay ranged from 37.3 to 40.4 ‰ and that in the open sea ranged from 37.3 to 41.1‰. A salinity range of 38 to 41‰ has been reported from the Saudi Arabian Gulf between Saffaniya in the north and Ras Tanura in the south [17,20]. Compared to the salinity of the most ocean waters which ranges from 34.98 to 36.87‰, the salinity of the Arabian Gulf was always high [19]. The arid nature of the land mass bordering the sea, the poor rainfall and the resultant evaporation being far in excess of the input from rivers, are the reasons for such a high salinity regime in the Arabian Gulf. Surface salinity is generally high in the Arabian Gulf because of excess evaporation in relation to precipitation. The water column was generally devoid of any stratification. The study carried out by the Umitaka Maru Research vessel of Japan corroborates this observation [21]. A disturbing point which might pose potential problems in future is the siting of brine plume in the interior most region of the bay with higher conductivity values than the ambient, during certain months. A subsurface seepage attributable to Outfall Bay is suspected to be the cause.

3.2.3 pH

The pH of seawater in the Intake zone remained always alkaline (Table 1). It ranged from 8.18 to 8.52 in the open sea and from 8.19 to 8.51 in the Intake Bay.

3.2.4 Dissolved Oxygen

The dissolved oxygen concentration in the intake zone seawater showed healthy concentrations throughout the year (Table 1). The concentration of dissolved oxygen during summer was low because of higher temperatures.

3.2.5 Trace Metals

There was no trace metal contamination in the source water zone of the Al-Jubail Plant. The concentration of various metals remained very low (Table 2) and posed no problem for the smooth operation of the MSF and SWRO plant in Al-Jubail.

3.2.6 Total Suspended Solids (TSS)

TSS values in station-I (intake) were lowest during the winter and highest during summer (Table1). Noticeably higher TSS values were seen during the spring and summer. High TSS value is considered as an index of water pollution and it is one of the important water quality criterions for which environmental limits are prescribed by regulatory agencies in many countries. The TSS values in the feed water zone of the Al-Jubail plant were generally high and it was higher in the Intake Bay during Spring and summer. Reason for this elevation can be attributed to an embayment effect caused by the break water walls of the lagoon, the unidirectional flow maintained by the intake pumps , the shallow open sea conditions, the re-suspension of fine grained particles by wave action and the uprooting of sea grass due to powerful winds and consequent turbulence in the sea. This parameter is of great importance to the fouling problems encountered in the MSF plants now, and the fouling problem that it might pose to the new 24 MGD SWRO plant at Al-Jubail.

The sea floor now bordering the Saudi Arabian Coast is very shallow and has the same geological characteristics as that of the adjacent land masses [16]. The suspended particle load in the Arabian gulf is historically greatly influenced by its unique past. The most important contribution to TSS come from marine organisms as decomposable organic matter which is continually falling from the surface to the bottom. Sheltered coastal areas of the Arabian gulf collect organic matter in the form of detritus which in return decomposes and releases nutrients which subsequently become available to the plankton. There is a strong relationship between suspended particles and marine food chain. Arabian Gulf may be among the most productive water bodies in the world [22]. The coarse particles in seawater are colonized by fungi, because of larger surface area offered by them, whereas the finer particles are colonized by bacteria [23].

Along the Arabian peninsula the amount of material transported in the air over the sea is so enormous to form dust clouds and the input, designated as ‘aeolian’ in nature, falls on the sea, get mixed with the water borne debris and organic matter and contributes to the TSS level in the sea for varying periods. Macro algae has been cited as an important source of detritus suspended solids in the Arabian Gulf [20]. Floating sea grass fragments were observed in the Intake Bay during periods of turbulence.

Algal litter was seen on the sea shore and breakwater walls inside the bay. It was also seen in abundance on the intake screens and heaps of grass litter were disposed from trash racks of the intake structures during such periods. The data point to the need of adequate protection for the new 24MGD SWRO plant in Al-Jubail.

3.3 Biological Issues

3.3.1 Planktonic Blooms

Planktonic blooms were observed first in May and later in August,1998. Water appeared to be a greenish broth with lot of suspended particles noticed in the water, particularly during spring and summer months. The bloom noticed in August, lasted for a few weeks. Dead and dying fishes were observed in August during the frequent survey of the phenomenon in the Intake Bay. One such planktonic bloom noticed on August 17, 1998 was found to cover about 20km^2 area adjacent to the Jubail shore. Reddish particles of algae were seen floating over the sea like a scum. By the end of the month, the sea became clear of this bloom. Planktonic blooms, induced by change in temperature and nutrients have the potential of creating increased colloidal and biofouling problems in the plant. Special disinfection strategies have to be adopted to combat the situation. This natural phenomenon occurs periodically and would disappear within a few days or a few weeks. If the phenomenon lasts, it may lead to mortality of plankton, fish and shellfish resources of the region.

3.3.2 Ingress of Sea grass

The open sea near the plant witnessed extensive sea grass growth during the spring and summer periods. Floating sea grass fragments were observed in the Intake Bay during the turbulent winter months. Algal litter was seen on the sea shore and break water walls inside the bay. They were also seen in abundance on the intake screens, and heaps of grass litter was found disposed from the trash racks of the intake structures during the winter. This is in agreement with previous reports from the Gulf [20]. The present observation indicates that the plant structures would indeed be exposed to serious problems of clogging during this period.

3.3.3 Influx of Jellyfish

Monitoring on Jellyfish influx during 1997-98 showed that they were present in the area during February-May, 1998. Their peak incidence occurred during March-April. In April, a particularly noticeable ingress was witnessed in the intake bay, wherein large number of adult Jellyfish were brought in by strong tidal currents. This large-scale influx lasted only for a day. Jellyfish influx did not cause any serious problem at the intake during this period. Jellyfish ingress has been reported to swarm the intake bays of numerous power and desalination plants in the world [7-9]. The incidence of Jellyfish was reported to be about100 tons/h during its peak incidence in a power plant intake on the Arabian Gulf coast. The control measures adopted now are the methods of physical removal from the travelling screens and scavenging from the bar screens.

3.3.4 Ingress of Biofouling Organisms

Seawater intakes concentrate the drifting and floating plankton near to the site of pumping and creates situations of great biofouling potential. The cost of fouling has been found to be enormous and despite worldwide efforts on biofouling control, the solution remains still elusive. Occasional biofouling has been reported from the Jubail Plant Phase-I units. Condenser tubes were seen to be choked with marine shells. Bacteria and diatoms were two of the most significant groups entering the plant structures through the feed seawater. Once attached to a surface, they divide very rapidly and form a slimy film of great importance to the fouling community. A wide variety of phytoplankton and zooplankton (Table 3) are involved in biofouling. Organisms from Protozoa to Chordata were seen in the zooplankton. Protozoans are commonly found associated with bacterial and diatomaceous slime. Observation of some pipe sections in the plant and wire ropes in the sea showed that the main constituents of biofouling community in the region belongs to Coelenterate (sea anemones, corals, etc.), Annelida (serpulid worms), Arthropoda (barnacles, amphipods, isopods, etc.), Echinodermata (starfishes, sea lilies, etc.), Chordata (appendicularia) and a variety of helminth worms.

The Arabian Gulf is a very productive ecosystem [24-26] and the numerical abundance of phytoplankton indicative of planktonic blooms highlights the biofouling potential of the feed seawater. The groups of plankton encountered now are similar to those reported earlier from Kuwaiti and Saudi Arabian waters [27]. The data on the biological components in the Intake Bay reflected an entrainment effect caused by the unidirectional, plant-ward flow of a subsurface current sustained by the intake pumping activity (Table 4). This stream brings in an extra load of the passively floating plankton into the bay. The entrainment noticed here has been found to be benign with respect to planktonic abundance and production.

3.4 Intake Issues and Management strategies

3.4.1 The unpredictability of intakes

Many of the issues of source water characteristics identified above constitute the effect of environment on the plant. The marine environment being a unique ecosystem and the sea water being in a state of perpetual motion, the feed sea water quality and marine life are prone to frequent changes and are unpredictable. Desalination plants require a through understanding of their intakes for evolving suitable management strategies. Whereas the MSF plants have shown greater resilience with respect to many of the issues cited above, the Sea Water Reverse Osmosis plants are susceptible to fouling caused by bacteria and colloidal particles. Intake system effectiveness has become a matter of greater interest recently because of the fouling related problems increasingly being noticed in many desalination plants. Pollution of intake from other sources and from the plant's own discharges are suspected to reduce the effectiveness of intakes. During the present study, no pollution threat was discernable from the Al-Jubail industrial city zone.

The Al-Jubail experience with a segregated Intake Bay has been a great success story. A redeeming feature observed was that the water quality did not show any deviation from that of the Open Sea. In contrast to the Open Sea site (Station-II) characterized by turbulent waves and shallow depths the Intake Bay was calmer and deeper. The Intake Bay mouth, situated about 1.7 km from the seashore accords the plant, the benefit of a clear offshore sea water. The intake pumps withdraw water from a depth of 2-4m making it typically a coastal subsurface intake.

Besides the entrainment effect, the enclosed nature of the intake system unavoidably has created an embayment effect also in the form of elevated TSS values and planktonic abundance. The intake bay serves as a shelter for the phytoplankton and zooplankton providing greater residence time and increased biofouling potential. The intake water chlorination and subsequent in-plant chlorination has been found to be quite effective. The intake zone is free from contamination from the disposed brine. Desalination plants in the Middle East, where the intake zone is not segregated from the discharge zone has experienced contamination of the feed by the discharged brine [28]. In such plants, the intake zones were found to be impacted by the elevated temperature and salinity of the receiving waters, apparently due to spreading and recirculation of the effluent - mixed layer. This underlines the need for a carefully segregated intake and discharge bays for all desalination plants located in the region. The Jubail experience in this regard has been found to be most successful in keeping the feed water free from discharged brine.

3.4.2 Prevention of intake contamination and biofouling

Certain points regarding the intake structures of desalination and power plants in Saudi Arabia are worth reviewing in this context. There are primarily two types of intakes, the slightly offshore subsurface intakes seen in majority of plants and the protected and segregated coastal subsurface intakes seen at Al-Jubail and Assir plants. Prevention of source water contamination has been by far the principal benefit derived from protected intake bays. In plants having offshore subsurface intakes, the outfalls are all coastal surface. The intakes of plants in Jeddah and Al-Birk are suspected to be contaminated by biologically rich and polluted waters. Severe biofouling has been reported from these plants [29, 30]. While highlighting the benefit of intakes in the context of a new RO technology without continuous chlorination, intakes of 4-10m depth are reported to be ideal [31]. According to another report [32], intakes for RO plants should be located at a depth of 8-10m on the assumption that sun light penetration beyond 5m is significantly reduced. In fact biological activity is vigorous throughout the lighted zone, and coastal waters being very productive this assumption does not hold good for Saudi Arabia. How ever, a thorough oceanographic study is needed in desalination sites to understand the problem and suggest the best available option for preventing contamination.

In Jubail, the Intake for the new SWRO Plant will be at about 2-4m depth in the Intake Bay at Intakes 13 and 14. The intake 14 has been observed already as having high biological potential and suspended solids. The width of intake basin at Intake 14 is only about 150m whereas in other areas it is greater than 300m. The sensitive nature of Intake 14 is due to its interior most position in the lagoon. The area being relatively shallow, the problem of biofouling and colloidal fouling could be significant to the new SWRO plant in Al-Jubail and preventive measures are needed for the same.

4. CONCLUSIONS

(1) The Al-Jubail experience with a segregated and protected coastal intake bay has been found to be a great success. The source water quality remained impressively good through out the period of study and did not show any sign of contamination either from the discharge area or from the region of the Al-Jubail industrial city.

(2) At Al-Jubail, the sea adjacent to the plant is shallower than the intake basin. The drag of seawater maintained by intake pumps and the break water walls of the bay creates an entrainment and embayment effect.

(3) Whereas elevated total suspended solid load, incidence of planktonic blooms and ingress of biofouling organisms have the potential of creating serious colloidal and biofouling situations in the seawater RO plant, the ingress of jellyfish and sea grass could render the intake bar/travelling screens ineffective and decrease the efficiency and increase the cost of operation and maintenance of plants.

5. RECOMMENDATIONS

(1) As the sea adjacent to the plant is very shallow, a detailed physical oceanographic modeling of the region is needed before extra load is placed on the existing intake bay.

(2) In order to reduce the potential of colloidal and biological fouling in the new SWRO plant in Al-Jubail from the presently used intake 14, a suitable alternate intake may be identified for drawing the needed feed seawater. An effective filtration and pre-treatment system taking into account the uncertainties

regarding suspended solids and planktonic blooms also may be incorporated in the plant.

(3) The Al-Jubail plant has to be in a state of preparedness to meet the ingress of jellyfish into the intake bay. Fixing of jellyfish scooping device in front of the bar screen, putting up a jellyfish prevention boom and fixing of electronic repeller at the bay entrance are some proposed measures to control ingress of jellyfish.

(4) The northern break water wall of the intake bay needs a modification at its entrance to prevent a direct access of invasive species into the intake bay.

Table 1. Physico-chemical parameters in the intake zone during 1997-98

Seasons	Months	Temperature ^oC		Conductivity (ms/cm)		pH		Dissolved oxygen (mg/L)		Total suspended solids (mg/L)	
		Intake bay (St-I)	Open sea (feed source) (St-II)	Intake bay (St-I)	Open sea (feed source) (St-II)	Intake bay (St-I)	Open sea (feed source) (St-II)	Intake bay (St-I)	Open sea (feed source) (St-II)	Intake bay (St-I)	Open sea (feed source) (St-II)
Fall	Sept.	33.50	32.75	55.10	54.60	8.20	8.20	6.69	6.37	11.0	4.00
	Oct.	30.00	30.00	56.45	55.80	8.16	8.14	5.44	5.10	2.50	3.50
	Nov.	24.75	25.00	55.20	55.05	8.22	8.22	5.27	5.10	7.00	6.00
Winter	Dec.	18.00	18.50	55.50	55.60	8.44	8.40	6.29	6.46	5.00	8.70
	Jan.	18.58	19.00	52.80	52.90	8.42	8.40	5.95	5.95	4.50	6.85
	Feb.	19.15	19.50	50.10	50.20	8.40	8.40	5.61	5.44	4.00	5.00
Spring	Mar.	20.50	20.50	54.45	53.70	8.60	8.60	5.18	5.03	8.00	4.00
	Apr.	24.00	28.40	53.10	56.70	8.33	8.30	4.76	4.59	1.20	0.90
	May	26.35	26.30	55.50	55.20	8.60	8.66	4.93	5.15	8.00	7.50
Summer	Jun	31.80	30.30	57.70	58.80	8.24	8.23	5.57	6.17	13.00	12.00
	Jul	31.10	31.00	58.90	60.50	8.10	8.20	6.22	4.33	12.00	10.00
	Aug.	35.00	35.00	55.35	55.50	8.20	8.20	5.36	6.37	16.00	15.00

Table 2. Trace metal concentration (μg/l) in the source water

Metals	Study	
	Intake bay (station –1) 1997-98	**Open sea (station-II) 1997-98**
Chromium	0.06- 0.20	0.08- 0.18
Copper	0.00- 5.40	1.00-13.10
Iron	0.28-10.40	0.30-10.50
Nickel	0.50- 3.90	0.36- 3.70
Lead	0.10- 3.90	0.10- 4.20
Cobalt	0.37- 1.60	0.40- 1.10
Arsenic	2.80- 3.20	2.80- 3.20
Cadmium	0.02- 0.10	0.02- 0.18

Table 3. Distribution of plankton in the intake zone during 1997-98

Parameters	Stations	Seasons			
		Fall	Winter	Spring	Summer
Setting volume (ml/m^3)	I	0.88	0.42	0.68	5.73
	II	1.85	0.52	3.36	3.92
Dry-weight (mg/m^3)	I	27.00	0.02	140.07	162.16
	II	35.00	0.02	289.82	234.73
Phytoplankton density (cell No/m^3)					
Diatoms (yellow-green Algae)	I	1.53 E+ 07	1.01 E+ 05	3.26 E+ 05	4.25 E+ 07
	II	2.18 E+ 07	2.86 E+ 05	3.98 E+ 06	2.81 E+ 07
Dinoflagellates	I	3.25 E+ 05	2.45 E+ 04	5.95 E+ 04	1.66 E+ 05
	II	7.30 E+ 05	3.11 E+ 05	5.46 E+ 04	1.77 E+ 05
Blue green algae	I	5.70 E+ 04	2.93 E+ 04	2.47 E+ 05	1.70 E+ 05
	II	1.40 E+ 04	1.72 E+ 04	1.35 E+ 06	5.49 E+ 05
Zooplankton density (No/m^3)					
Protozoa	I	9580	3400	8460	56080
	II	6520	3000	6860	6800
Coelenterata	I	-	-	3700	24860
	II	-	-	3180	9080
Aschelminthes	I	540	-	2110	5780
	II	360	200	4180	15560
Annelida	I	190	-	-	-
	II	180	-	-	-
Mollusca	I	360	-	1100	140
	II	720	4000	1500	-
Arthropoda	I	12080	78200	72380	107660
	II	13240	56130	32040	80960
Echinodermata	I	-	-	-	-
	II	-	2000	500	-
Chordata	I	5050	141320	33680	141340
	II	5190	36030	45800	102280

Table 4 : Biological effects of intake bay in relation to open sea

S.No.	Parameters	Seasons	Intake bay : EE* compared to open sea Increase (%)
1	**Chlorophyll a**	Fall	-
		Winter	10
		Spring	5
		Summer	-
2	**Plankton Biomass** (dry-weight, mg/m^3)	Fall	30
		Winter	-
		Spring	-
		Summer	18
3	**Zooplankton**		
	Total population		55
	Protozoa		382
	Coelenterata		-
	Aschelminthes		-
	Annelida		6
	Arthropoda		37
	Mollusca		-
	Chordata		68
	Appendicularia		9
	Fish Eggs		10

*EE: entertainment effect

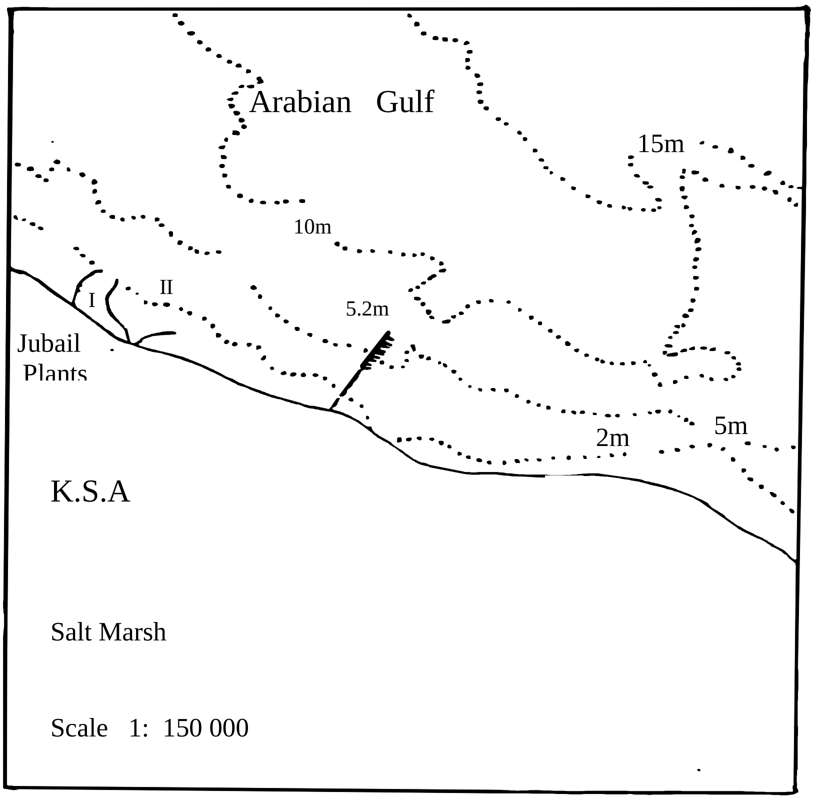

Figure 1. Arabian Gulf between Lat.26° 52′ and 26° 55′ N and between Long. 49°45′ and 49° 52′ E. Study sites and depth contours (Map adapted from Admiralty Chart No.3788 (1986))

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