FINAL REPORT
An Environmental and Socioeconomic Cost Benefit Analysis and Pre-design Evaluation of the Proposed Red Sea - Dead Sea Conduit

“Marine Environment Component Study”

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Executive Summary

The present report describes the physical, biological and chemical features and characteristics of the proposed site (including the intake area) for the Red Sea – Dead Sea Conduit project, which is located at the northern tip of the Gulf of Aqaba (at the Aqaba - Eilat border).

Seawater and sediments quality has been studied through generating records of seawater temperature, salinity, transparency, pH, alkalinity, dissolved oxygen, ammonia, nitrate, nitrite, phosphate, silicate and chlorophyll \( a \) as well as total nitrogen, total phosphorous, heavy metals and grain size analysis for bottom sediments. Seawater and sediment samples have been collected and analyzed at different times of the year.

By comparing the obtained data with previous records and offshore samples, taking into accounts the pronounced seasonality, most of the measured parameters reflect in general normal conditions specifically during the period of conducting the study. Phosphate, nitrite and nitrate concentrations did not show significant variation with depth. Although no significant variation in their concentrations among the six sampling station, phosphate concentrations were higher in deeper stations where nitrite and nitrate show higher concentrations in shallower stations.

The sediment in the study area is fine sands and moderately sorted (homogeneous) with low mud contents. Content of mud in the sediments tend to increase with water depth due to calm water conditions and decreasing water activity.

Color and odor of sediments both suggest that they are well oxygenated. The deviation from the white color may indicate localized accumulation of organic matter.

Concentrations of heavy metals in sediments were relatively higher than those recorded by other researches for the same area, but they are still within and close to most of the international environmental standards.

Total phosphorous and total nitrogen in sediments (i.e. 175-590 mg/kg for total nitrogen and 85-560 mg/kg for total phosphate) were relatively higher than some of the previous records.

The biodiversity survey has shown that the area is mainly covered by sea grass meadows and sandy bottoms, although some small colonies of hard corals can be seen at 10 m and 20 m depth. A number of organisms were observed include feather star, sea urchin, sea snails, sea cucumber, various types of algae, sea grass, hard corals, soft corals, ascidians, sea anemone and various types of fishes. Further deep (beyond forty meters depth), the bottom habitat become different from the shallower depths, where more corals can be found.

During the survey, a total of 2823 fishes have been counted representing 40 species that belong to 22 families. The number and diversity of fish species inhabiting the survey site are typical of sea grass beds sandy bottom habitats. The Heniochus diphreutus is the most abundant species, followed by Lethrinus variegates, Parupeneus forsskali and Dascyllus trimaculatus.
The bathymetry of the study area had a smooth gradient and relatively homogenous geometry. The bottom slope within 0-20 m depth range was around 0.097; no significant hills or valleys appeared at the bottom of the study area. The slope decreased with increasing depth and became around 0.045 (1:22) within the 20-60 m depth.

Sea level in the northern part of the gulf fluctuates during the year by up to one meter. The level is high from December through May and low during the period July through October depicting a clear yearly cycle. However, in the study area and reference to the Global mean sea level during the year 2004, the mean was about 16.4 cm, where the lowest value was 1.5 cm, measured in August and the highest was 44.4 cm measured in November.

The maximum sea level range references to global mean sea level during the year 2004 was 142 cm, where the highest value was 94 cm observed on November 15th, and the lowest was -48 cm recorded on August 31st.

Studying temperature, salinity and density showed that the mixing conditions was dominating (on June 12th and 15th) in the upper 50 m, where the temperature, salinity and density were homogenous with mean values of 23.34 ± 0.07 °C, 40.726 ± 0.008 and 28.185 ± 0.020 σt respectively. The stratification conditions began dominating in the study area on July 3rd in the 0-50 m water column. The mean values of temperature, salinity and density were 24.39 ± 0.46 °C, 40.752 ± 0.039 and 27.885 ± 0.111 σt, respectively. It was clear that temperature was the determinative factor of mixing and stratification conditions. However, there was a clear transition from mixing to stratification conditions within 20 days of the study period (June 12th to July 3rd, 2005), which reflected on the water masses characteristics particularly in the study area and generally in the northern Gulf of Aqaba.

Two current regimes were observed in the 2-32 m coastal water column. The first regime was observed in the surface waters at 2 m depth where a constant south-eastward current (157 ± 36°). The current below 2 m depth behaved in another pattern, where anticlockwise rotation in direction and increment of current speed with respect to depth were observed from 4 to 32 m water column. At each layer below 2 m depth there was multi-reverse of current direction between south-eastward and north-westward, i.e. parallel to the shoreline of the study area.

As known the potential impacts of any project/activity on the marine environment depend on the design and the type/nature of the construction and operation activities. Despite of the little available information on the project and its activities which are supposed to take place either during construction or operation, several impacts could be expected as major consequences.

With respect to the construction activities and the associated dredging. It is expected that the benthic habitat at the proposed conduit site will be destructed. The rate of sedimentation in the neighboring marine environment would increase as a result of dumping the dredging material. The water body is expected to carry more fine sediment particles, which takes longer time to settle at the sea bottom, leading to a turbid water body.

As for the physical conditions, it is expected water intake effect on sea level will not be localized and restricted in closed area, whereas the whole Gulf of Aqaba particularly and the Red Sea in general will be affected temporary until it reach stable conditions.
Changes in (increase) water velocity, water turbidity and sedimentation would affect the marine environment. Current velocity also affects the stability of sediments in the sea, water turbidity, light penetration, ability of organisms to capture prey and settlement of juveniles on hard substrates.

The water intake from the northern Gulf of Aqaba will be compensated by increase the inflow of waters from the Red Sea to the Gulf of Aqaba based on conservation of mass theory. It is likely that the surface water temperature will increase gradually and salinity will decrease gradually in the northern tip of the Gulf of Aqaba due to water intake up to reach a stable structure. The maximum expected increase of temperature and decrease of salinity will take one year to be of order +0.5 °C and -0.1 respectively.

However, such slight changes will not cause neither thermal pollution neither affect the natural cycle of mixing and stratification conditions, and consequently the thermohaline circulation will not be affected.

The direction of current will converge near the channel and will be parallel to the channel axis with speed reaches 3 ms⁻¹ in case that the channel width and depth will be 10 m and 2 m, respectively.

It is assumed that the current pattern in the study area far more than 3 km in all directions from the channel will not be affected by the water intake in case that flow speed at the channel entrance will be 3 ms⁻¹, while it will remain just as the existing circulation.
1. Introduction

1.1 Gulf of Aqaba: General Features

The Gulf of Aqaba oriented NNE-SSW is the northernmost sea-flooded part of the Syrian-African rift system. The gulf is a semi-closed basin, separated from the Red Sea by the Straits of Tiran, a narrow passage about 250 m deep. The gulf extends over a length of 180 km and a width of 5 to 26 km, and reaches almost 1800 m depth.

Sea level in the northern part of the gulf fluctuates during the year by up to one meter. The level is high during the period December through May and lowers during the period July through October. The difference is reported due to the influence of monsoon winds in the Indian Ocean (Hulings, 1989).

Tides in the gulf are minimal, with a range of one meter or less. They are semi-diurnal (two high and two low tides every 24 hours).

Currents specifically and circulation generally appear to be largely wind-driven, with additional influence from tides, density gradients, and evaporation. Prevailing winds are from north and thus the predominant wave direction is from the north.

The gulf is characterized by a low rate exchange of water with the Red Sea due to the narrow and shallow passage of Straits of Tiran. The gulf also acts like a closed lake, with summer stratification and biannual turnover. The lower mass of water is colder and nutrient-rich, and has even less exchange with the Red Sea across the shallow Straits of Tiran than surface water. This can lead to algal blooms on the reef following winter storms, which cause upwelling. The residence time of water can exceed two years in the upper depths of the Gulf and three years in the lower depths.

The water of the gulf is exceptionally clear. The high transparency is related in part to the absence of major rivers or streams flowing into the sea.

The relative isolation of this desert-enclosed sea coupled with exposure to an arid, hot climate and high evaporation, cause temperature and salinity to be unusually high as compared to the average range for oceans. Surface water temperature may reach 28 ºC in summer months and falls to just above 20 ºC in the winter. Temperatures within the water mass reflect a degree of stratification versus vertical and lateral mixing by water currents. Vertically, temperature falls with depth in summer although there appears to be an inversion at certain depths in winter months because the deep water mass has a temperature reportedly above 20 ºC.

The lack of regular fresh water input and the high evaporation rate contribute heavily to the particularly saline conditions within the gulf. The salinity is relatively high and ranges between 40 and 45 g/l compared to an ocean’s average salinity of 35 g/l. Vertical salinity differences are very small between 50-150 m. In general, the eastern side of the Gulf is less saline, most likely due to the influx of Red Sea (ICRI, 1995).

Another prominent feature of the gulf is its great depth in proportion to its width. It has an average depth of 800 m increasing to about 1800 m as a maximum depth.

The gulf is a host to more than 1000 species of fish, 110 species of hard coral, 120 species of soft coral in addition to sponges, snails, crabs and sea turtles, (Hulings, 1989).

Twenty percent of mollusks and echinodermata as well as several species of algae occurring in the gulf may be endemic. Of between 300-350 species of fish which have been recorded in Aqaba, 7 species are recognized as endemic, (ICRI, 1995).
These marine creatures live in a complex ecosystem where a very fragile equilibrium maintains all these animals in a necessary co-existence as part of the chain which creates the coral reefs and their surroundings. From almost invisible life-forms to huge fish or mammals, all are equally important and contribute to the food chain, thus creating the conditions for the building and the healthy state of the coral reef.

Despite the fact that the Gulf of Aqaba is one marine unit, there are still differences in relation to its currents, temperature, salinity and coral reef communities that make the northern part different from the southern part and the western part different from the eastern one. Example of such differences is the presence of five species of sea grasses on the western coast while only three have been recorded in the eastern coast (Heiss et al., 1999).

In conclusion, all of the above special combinations of conditions make the gulf especially vulnerable to the effects of pollution low rates of exchange, combined with high rate of evaporation mean that introduced pollutants can affect the gulf for long periods of time. The seasonal minimum of the temperature in the northern part of the Gulf of Eilat is observed during March, when the water column is well mixed to at least 300 m by winter convection. The seasonal maximum within the upper mixed layer (UML) is observed in August. The summer UML is usually at least 10-20 m deep while in winter (from the middle of November until the end of March) it is at least 50 m deep. The seasonal thermocline during summer is extends to 200 m where the maximum temperature is reached in December when the seasonal thermocline is eroded by winter mixing. Winter convection typically reaches 250 – 450 m but the observations also show several cases where the water column on the northern slope of the gulf was mixed to the bottom (about 700 m).

1.2 Objectives of the Study

The main focus of this research study is to detect any potential effects of water intakes on the marine environment of the Gulf of Aqaba.

The overall objective of the research was to identify a range of activities where the potential for adverse effects on marine interest exists as a result of the construction and the operation of the proposed conduit. Specific objectives included:

- Research changes to hydrodynamic regime as a result of the seawater intake
- Research changes of the coastline geomorphology and its impact on the ecology of the system.
- Research sediment movement around the entrance to the water intake canal and likely impact on marine life.
- Identify and collect relevant biological and physical data sets in the study area necessary to conduct biogeographic analyses. Organize the data sets into a Geographic Information System (GIS).
- Assessing the existing seawater and sediment conditions (quality) at the site and research the potential modification might rise as a consequence of the proposed project.
- Evaluating the biodiversity in the study area as well as assessing the impact of the new conditions associated with the new proposed project.
1.3 The Jordanian Coastline

The 26.5 kilometer-long Jordanian shoreline of the Gulf of Aqaba provides the only access to the sea for Jordan for ship transport, fishing, and industrial development that requires large amount of cooling water.

The coast has been divided into zones for development purposes, the city of Aqaba, and the port area, the south tourist area including the marine park and the public beach and the industrial zone area.

The fringing reef along the Jordanian coast is of extreme environmental importance. It is part of the northern most reefs in the northern Hemisphere. This reef system is considered the most diverse within the Northern Hemisphere with many endemic species. The north beach of Aqaba consists primarily of sand and gravel beaches. In the near shore, seabed is sandy with few corals. The slope of the nearshore seabed increases southward, leading to very deep water relatively close to shore.

Further south along the coast, more coral reef areas are evident. These reefs are found scattered nearshore where that of offshore is extending in a more continuous way, although such continuity is interrupted by several bays.

Morphologically, the reef of Aqaba fringes the shoreline, with the area offshore of the reef zone dropping abruptly into deeper water. In most areas, a shallow lagoon separates the shoreline from a shallow, fringing reef flat.

On rare occasions, usually separated by one or more years, extremely low tides occur in the upper gulf during which the reef flat and part of the shallow lagoon may be uncovered for up to 20 minutes each low tide over a period of up to 2 days. Several studies have reported the effects of such extreme low tides (e.g. Fishelson, 1973b, Rawber, 1974 both in Loya, 1988). It has been shown that most of the colonies are able to regenerate after exposure if parts of the living tissue remain intact on the skeleton. It is clearly here that the worst time for any major source of pollution in this area would be during one of these extreme low tides when corals on the reef flat could be exposed directly to such impact.

The Jordanian coast displays a belt of discontinuous fringing reefs that are developed preferentially on small capes and are separated by wide embayment. The position of these bays corresponds to wadi mouths and they are characterized by a sandy sea bed colonized by scattered coral heads and sea grass beds. The fringing reef lining the coast varies in their distribution. In exposed zones, an extensive 2 to 10 m wide reef flat is formed, while in less exposed areas, patch reefs may coalesce to constitute an irregular reef flat (Hulings, 1989).

The beaches of the Gulf of Aqaba are narrow and the sand is immature. These beaches are of low relief with a gentle foreshore slope (5-15°) (Abu Jaber, 1991).

The Jordanian shoreline is highly variable. The coast can be classified on the basis of its morphology into three distinct zones which differ considerably in their morphology, sand budget and their surrounding topography. The zones were classified according to several authors (e.g. Abu Jaber, 1991) as: the northern sandy coast, the northern eastern clifed coast, and the southern crenulated coast.
1.4 The Study Site

The study area is located at the northern tip of the Gulf of Aqaba directly at the Aqaba - Eilat border (Fig.1). According to the above mentioned classification of the Jordanian shoreline, the study area lies within the first zone, the northern sandy coast.

The northern shoreline has a cusped/bayed morphology and is lined offshore by an arcuate bar system, where the offshore bar and the cusped/bayed shoreline are out of phase. The longshore currents along the northern coast is an oscillatory motion in which the wave set up erodes an embayment on the coast and accretes an offshore cusp and the wave set down accretes a cusp on the shore. The beach material is composed entirely of fine sand.

However further details on the site characteristics are discussed under the physical oceanography and biodiversity sections.

Fig.: 1 Study site with respect to the Gulf of Aqaba and the Jordanian Coastline.
2. Sea Water and Sediment Quality

Reports dealing generally with water quality of the Jordanian Gulf of Aqaba are basically those of Freemantle et al (1978), Wealker and Ormond (1982), Hulings and Abu Hilal (1983), Wahber and Badran (1991), Badran (1996) and Rashid (1998) in addition of course to the reports of the routine monitoring programs of the Jordan Marine Science Station. It is worthy to refer to a report presented by the World Bank in 1993 which states “during the last 25 years the nutrients levels, turbidity and productivity of the seawater have increased. Recent measurements of phosphate, chlorophyll and water transparency have revealed a reduction in the quality of the water in the northern part of the gulf possibly resulting from man-induced eutrophication”

This report focuses on the seawater and bottom sediments quality determined throughout two surveys conducted during the period October-November and March-End of May 2005. These periods of time in terms of the Gulf of Aqaba is considered as winter and spring transitional to early summer respectively. The seawater and sediment quality component was performed for the following principal objectives:

- Analyzing the available historical data collected in Gulf of Aqaba, mainly those of nutrients.
- Researching and describing of the existing quality of seawater and bottom surface sediments along the proposed site.
- Trying to launch dataset to use later for clarifying the magnitude of the seasonal changes and detection of any potential impacts.

2.1 Analyzing the Historical Data for Seawater in the Northern Gulf of Aqaba

The northern Gulf of Aqaba -as indicated by several reports and researches- is going through an intensive eutrophication process. Several changes indicate that this process has started ten years ago and it is increasing in magnitude. Dissolved oxygen (DO) in the northern Gulf of Aqaba for instant did not change much between the mid 70's and the early 1990's, but since 1991 it decreased. The DO depletion rate increased considerably since the deep mixing event of 2000 and so far, the ecosystem has not reached a steady state. Furthermore, nitrate concentrations in the southern basin of the Gulf of Aqaba during the 70's and 80's were higher than in the northern basin, while the opposite was observed during 1999. This suggests that at present "new" nitrogen originates in the northern Gulf, while in the past the nitrogen was supplied from the Red Sea through the straits of Tiran. Such changes were attributed by the monitoring programs of Inter-university of Eilat (IUI) mainly to the increase in the activity of the fish farms. Since 1998, the fish farms emitted 250-300 ton/year of available N and 40-50 ton/year of dissolved P directly into the marine environment of the Gulf of Aqaba. Another source that has contributed to such high values is the sewage outfall in the northern section of the gulf, where sewage discharge from both Eilat and Aqaba into the gulf used to occur. However, it should be noted here that this discharge from the Jordanian side has completely ceased in 1985.

Chlorophyll-a and phosphate records during the last 10-years were also high in the northern tip (at Eilat and Aqaba) compared to the southern parts.

It is worth mentioning that all hydrographic studies along the Jordanian coastline reported a pronounced summer thermal stratification during the period April-October and mixed waters in winter during the period January-March.
2.2 Sampling and Analytical Methods

The following section describes briefly the sampling and analytical methods for seawater and bottom sediments. However, the methodology of performing the physical oceanography study and biodiversity survey are discussed separately under Section 3 and 4 (Physical Oceanography and Biodiversity).

2.2.1 Seawater

Two different phases of Seawater sampling were carried out. The first included 40 regular samples collected from the surface water along the study site. These samples were used to study any spatial variations in the concentrations of the measured parameters within the site itself. The second phase included samples collected from different depths to study any variation of concentrations with depth. All samples were collected during three different periods of time (winter, spring and summer) in Niskien Bottles from six stations along the site (Fig. 2). Seawater has been tested for temperature, salinity, transparency, pH, dissolved oxygen, ammonia, nitrate, nitrite, phosphate, silicate and chlorophyll a.

Chemical analysis was carried out according to the common protocol at the Marine Science station (MSS), developed mainly from international (IOC) Manuals and Guides (1989). All analytical methods have been verified and tested in research (Badran and Foster, 1998, Rashid, 1998, Badran et al., 1999).

A 10 liter PVC Niskin sampler was used to collect water samples at three different depths (0, 10, 20 and 30 m) at each station. Sub samples were collected and stored in a pre-labeled nalgene or glass bottles as required. They were kept in an ice-box during the sampling and transport period. They were filtered later and stored as frozen for subsequent analysis.

Water temperature and dissolved oxygen were measured in situ by the use of a pre-calibrated dissolved oxygen meter, model YSI58 equipped with 200 ft YSI model. pH of water was measured by the use of a HANNA instrument portable microcomputer pH meter Model HI8424 equipped with a combined electrode.

Color was determined by the use of the Forel scale described in MOOPAM (1989). Transparency was estimated by the use of a white, 30 cm diameter Secchi disc as described in MOOPAM (1989). Annex I includes the data obtained throughout this research for seawater quality.

2.2.2 Bottom Sediments

Bottom surface sediment samples were collected from the same water sampling sites by SCUBA diving. Sampling was confined to the upper 5 cm. Immediately after sampling, a fresh sub sample was fixed for hydrogen sulfide analysis with zinc acetate. For all other analysis, samples were rinsed with distilled water and dried to a constant weight at 60°C in a well ventilated oven.

Organic carbon, ignition loss and grain size analysis were performed according to the methods mainly followed at MSS which described by Holm and Mcentyre (1981).

Total phosphorous and organic nitrogen were measured as reactive phosphorous and ammonia respectively, following Kjeldhal digestion. Heavy metals were measured using atomic absorption spectrophotometer, following nitric-perchloric acid digestion according to the method described by Abu Hilal (1993). All analytical methods have been tested and verified in research.
Fig. 2 Location of sampling stations of seawater and bottom sediments.
2.3 Results

2.3.1 Seawater

Temperature
Surface water temperature along the Jordanian coast has been recorded by the MSS since 1985. Badran and Manasreh (1998) studied the hydrography of the upper 200 m and 400 m water column respectively. All hydrographic studies reported a pronounced thermal stratification during the period April-October and mixed waters in winter during the period January-March.

The recorded temperature at the selected sites during March to end of May was typical of that period of time in the northern section of the gulf (22.2-25.1 °C). During the period of October and November, temperatures records were between 23.2-24.9 °C at water surface, no high variation down to 40 m were recorded (at 40 m = 23.6 °C). The range is similar to those reported at the same period of time in the previous years. In summer, values were within 24.7-25.6 °C.

Dissolved Oxygen (DO)
Dissolved oxygen concentration in the Jordanian coastal waters ranges between 6.0 and 7.5 mg/l (MSS records). According to Klinker et al. (1976), there is a strong relationship between oxygen concentration and both salinity and temperature in the upper 200 m of water of the gulf. No details on such relationship have been explained by the author except concluding that the oxygen saturation, in general is a function of both water temperature and salinity (Hulings, 1989).

Dissolved oxygen was found by several researchers to display clear seasonality (e.g. Badran and foster, 1998). At the study sites and during spring time DO concentrations ranged between 6.2-7.1 mg/l, while during October and November (winter) were 5.86-6.92 mg/l. The lowest values were recorded generally in summer.

Salinity
The results and ranges of salinity show normal values at all sampling sites, depths and different periods of time (40.0-40.8 ᵉ/ₒ). They show that spatial and depth variation of salinity -within the study area- are very small and don’t reflect any unusual trend.

pH
Measurements of pH at the sampling sites in spring were in the range of 8.1-8.4. These values indicate normal conditions at the selected sites and depths. They were also close to values recorded last 5 years by the routine monitoring program of MSS. No significant differences were noticed compared with those of winter (8.21-8.33) and summer (8.21-8.36), (Fig.3).

Ammonia (NH₃)
Mahasneh (1984) has reported relatively high values of ammonia in the surface water along the Jordanian coast. The annual mean ammonia concentration over the entire coastal Jordanian section of the gulf presented by the author was 4.0 μM. According to Mahasneh, a sewage outfall in the northern section of the gulf contributed significantly to this high mean.
Badran (1996, 1998) and Rashid (1998) found higher ammonia concentrations in winter and spring than in summer. The annual concentration range in the Jordanian coastal water according to both authors was from below detection to 0.61 μM. Along the sampling stations during spring, ammonia concentration ranged between 0.09-0.22 μM. These values are higher than those recorded in the past quarter and even relatively higher than those recorded by MSS monitoring programs in the past few years in the same period of time. In winter time concentrations were in the range 0.01-0.14 μM for the surface water, an increase in concentration was recorded with depth. Concentrations in winter and spring were both relatively higher than in summer, (Annex I).

**Nitrate and Nitrite (NO₃, NO₂)**
Badran (1996) and Rashid (1998) reported outstandingly clear seasonality of both nitrate and nitrite concentrations in both coastal and offshore waters. Maximum nitrate concentrations were recorded in deep waters, below 150 m during summer. Nitrite had a summer maximum at about 100 m. In open coastal water, nitrate concentration was minimum at 0.02 μM in summer and reached a maximum of 1.17 μM in winter. Nitrite had a similar pattern, but with about half the concentrations. Nitrite concentration in the collected seawater samples in the period of October-November (winter) has shown a narrow range between 0.25 and 0.36 μM, and they also were higher than those reported during spring and summer where in spring concentrations ranged between 0.02 and 0.1 μM, with concentrations very close to that of the southern coast in the same period of time, and in summer ranged between 0.01 and 0.03 μM. Nitrate concentrations in spring have displayed the same trend similar to nitrite compared with the records obtained during October and November. However, the concentrations were 0.013 and 0.2 μM (Fig. 4). Nitrate concentration in winter ranged 0.36 and 0.58 μM; small variations (lower concentration) were recorded in the offshore samples, (Fig. 4 and 5). The lowest concentrations were found to prevail during summer with values ranged from 0.01 to 0.17 μM.

**Phosphate (P₂O₅)**
According to Badran, (1996) and Rashid, (1998), phosphate concentration in offshore waters had homogeneous values throughout the water column in winter and spring. Minimum values were recorded in the upper 50 m waters during summer. In coastal waters the concentration range was between 0.01 μM to 0.13 μM. No reports have mentioned a clear seasonality of the phosphate concentrations in the upper water (0-400 m) of the Gulf of Aqaba. Hulings and Abu Hilal (1983) identified some short term seasonality patterns which were irregular and unpredictable with respect to the main hydrographic seasons of the gulf. At the sampling sites, phosphate concentrations recorded in spring have shown higher and relatively higher concentration compared with the winter and summer surveys (mean= 0.07 μM) where they ranged between 0.09-0.18 μM, (Fig. 4 and 5).

**Transparency**
The water of the gulf is well known for its high clarity due to the absence of major sources of pollution and fresh water runoff such as rivers or streams. Also, the productivity of water is low compared to other regions which reflected on its high transparency. Consequently, suspended solids and particulate matter level is relatively low and this reflected by the high Secchi disc reading which are considered as useful indicator for estimating the transparency. Secchi readings at the selected sampling sites show ranges of
15-30 m with a relative general trend of decreasing transparency in southernmost and northernmost sites.

**Silicate**
Concentrations of silicate in the upper 400 m of the northern section of the gulf are generally low and they are similar both in summer and winter (1.0-2.0 \( \mu \text{M} \)). The recorded concentrations in the present survey were 0.78-2.1 \( \mu \text{M} \). According to Badran (1998) maximum concentrations were found in the deep water during summer, the only season in which variation with depth was observed. In coastal water, the silicate concentration ranged from 0.92 to 2.5 \( \mu \text{M} \) with the maximum occurring in spring.

**Chlorophyll a**
Several authors have identified two main seasons with respect to productivity measurements and chlorophyll concentrations; low productivity and oligotrophic conditions during the period April to November, and high productivity during the period December to March. Along the Jordanian coast, several authors (i.e. Mahasneh, 1984) reported high values of chlorophyll a, which have been attributed at that time to sewage pollution. However, the reports have shown that the concentrations of chlorophyll a along the Jordanian coast during the last ten years were in the range of 0.01 to 1.2 \( \mu \text{g/l} \) with maximum concentration occurring in winter and spring. Similar concentrations and trend were recorded along the study site where the high values of chlorophyll a were those measured in spring (0.9-1.48 \( \mu \text{g/l} \)) and the lowest were those of summer (0.05-0.8 \( \mu \text{g/l} \)). Winter measurements were in between of these two ranges, but still show values close to those measured by other researchers, they ranged between 0.21 and 0.98 \( \mu \text{g/l} \).

![Fig.: 3 Concentrations of pH and dissolved oxygen at the six sampling stations (October-November).](image-url)
Fig.: 4 Spatial distribution of nutrients in surface water recorded from 40 surface samples (April – May)
Fig.: 4.Cont.

Marin Environment Component Study / Proposed Red Sea/Dead Sea Conduit Project
Fig.: 5 Variations in nutrient concentration in water column at two different stations (Spring time).
2.3.2 Bottom Sediments

Marine sediments, due to their large storage capacity of organic matter play an important regulatory and buffering function in the ecosystem. The present survey of sediment quality has been designed to include analysis of color, odor, grain size, organic carbon, ignition loss, organic nitrogen and total phosphorous.

Color and Odor

Simple and direct information about the sediment oxygenation state, which is one of the most important parameters in determining the biological productivity and the trophic structure, could be obtained from the color and odor of the bottom sediments.

Sediments at the study area showed similar color properties and it was mainly gray-black (only few samples found to have dark black color (station 2 and 6 at depths of 20 and 30 m respectively). This is expected in this area since it hosts sea grass beds and composed mainly of silicate grains. The sediments at site along south coast (coral reefs area) for example exhibited white color, reflecting the mineralogy of the sediments, where high calcium carbonate content gives whiter sediment color. No distinctive smell was detected for any sample at any station, indicating well oxygenated sediments. However, no serious modification in general was noticed in literature in color and smell of the sediments of the Jordan portion of the gulf.

Grain size distribution and mud content

Surface sediments at the different stations along the study site were quite similar in textural properties and were within the sand grad, and they had low mud contents (<63µm) ranging between 0.3 to 3.6%, (see Annex 1). The values of mud tend to increase with increasing water depth due to calm water conditions and decreasing water activity with depth.

Generally, the variations in textural properties and mud contents could be ascribed to the variety of sediment sources, their response during currents and waves, and the seasonal variability and activity of benthic in fauna. The sediment at the study area is fine sands, moderately sorted (homogeneous), coarsely skewed, this can be explained by the active waves and currents in this opened area due to absence of coral and rock bodies. A calm water condition doesn't exert much effect in sorting improvement of sediments, (Friedman 1968) and thus does not hinder or resist, if not enhances the accumulation of mud. This could be the reason for increasing the mud content in the sediments with increasing depth. The finest mean grain size of the sediments in the study area indicating relatively more dynamic water which leads to cleaning of sediments from very fine materials. These sediments composed mainly of silicate grains derived from land and nearby wadi (Wadi Araba).

Annex II includes the results and methodology of the textural properties of bottom sediments

Total phosphorous

Total phosphorus concentrations during spring time were generally higher than those recorded in winter and the range was wider (185-560 mg/kg). The high concentrations were recorded at all depths of the six stations, (Fig.7). Oppositely, a general decrease in concentration of total phosphorus with increasing depth was noticed in samples examined in winter. Concentrations (in all samples) ranged between 97 to 375 ppm) only 3 samples were found to have concentrations of total phosphorous above 350 ppm (Fig.7&10).
However in general these concentrations were clearly lower and much lower than those recorded in southern coast in similar period of time (MSS records).

**Total nitrogen**

Total nitrogen in coral reef sediments vary quite considerably over the year, but without a well defined pattern (Alrosan, 1998). The values recorded in the present survey are comparable with that recorded by MSS. However, significant differences were observed in concentrations in comparison between the period; October-November, where the values ranged between 137-438 mg/kg with a mean vale of 258 mg/kg and March-end of May, where the range was 135-538 mg/kg and a mean of 356 mg/kg, (Fig. 7 and 10).

**Heavy metals**

Comparison of the heavy metals concentrations of the spring survey with those of winter reveals that cadmium, copper, zinc and nickel are higher where the others are fairly comparable. However, all concentrations of metals recorded in this survey are still within and close to most of the international environmental standards, but it should be considered that any enrichment of certain heavy metals over a reference values in sediments at certain sites suggests events of contamination. Several researchers have attributed the high concentrations of heavy metals along the Jordanian coast (and Eilat coast as well) to pollution from sewage discharge, phosphate loading and discharge of cooling water, (along the southern coast of Aqaba). Figure 6 depicts some of the recorded heavy metals and their variation against the depth.

It is noted here that high levels of metals were recorded by the Israeli monitoring programs along the coast of Eilat mainly by Cu, Pb, Zn and Cd.

Along the study area, the concentration ranges in winter was 1.6-6.4 ppm with mean value 3.8 ppm, while in spring time was 2.8-4.8 ppm with mean value 3.7 ppm, (Fig. 11 and 12).
Fig.: 6 Heavy metal concentrations (ppm) in surface bottom sediments at four different depths (October-November).
Fig.: 7 Total phosphorus and nitrogen concentrations in surface bottom sediments (October-November).
**Fig. 8** Variations in nutrient concentrations in the water column at two different stations; 4 and 6 (October-November).
Fig.: 9 Spatial distribution of nutrients in sea water recorded from 40 samples collected at 20m depth (Nov.-Oct.).
Fig.: 9 Cont.

Marin Environment Component Study / Proposed Red Sea/Dead Sea Conduit Project
Fig.: 10 Total phosphorus and nitrogen concentrations in surface bottom sediments, (March-May).
Fig.: 11 Heavy metal concentrations (ppm) in surface bottom sediments at four different depths (March-May)
Fig.: 12 Comparison of Cd concentrations (ppm) in surface bottom sediments at the sampling stations in both winter and spring.

2.4 Discussions and Conclusions on the Quality of Sediments and Seawater

The surface coastal water of the northern tip of the Gulf of Aqaba is enriched with ammonium and phosphate than the coastal water to the south in this time of the year. The nutrient enrichment is most probably from supply of nutrients and not from upwelling of nutrient-rich deep water. Several anthropogenic sources might have contributed to this enrichment possibly from submarine groundwater discharge, the fish farms and some tourist/port/related activities in Eilat and Aqaba.

Chlorophyll a concentration range in the offshore waters of the Jordanian Gulf of Aqaba is 0.01 to 1.17 μg/l (Badran, 1998) with maximum concentration occurring in winter and spring. In coastal waters, the range was 0.08 to 1.15 μg/l. The range of 0.9-1.48 μg/l recorded for Chlorophyll a in the recent survey represents the transition from winter concentrations (relatively high) to summer low concentrations. These recorded values are remarkably high. This gave rise to a clear spring-early summer bloom at the study sites. However, such high concentrations could be related to the fact that the northern section of the gulf is the only portion that has a real and developed shelf area that dominated in late winter by sea grass.

The gradual die-off of the benthic community following a winter spring peak and subsequent decomposition could be a significant source of nutrients that supported surplus primary productivity during the period March to June (Geninet et al., 1995). In addition, the northern section of the coast (the study area) is protected from the prevailing winds. Consequently, the sea state there is calm, with less wave and current action which leads to a longer residence time of regenerated nutrients and Chlorophyll a.

The study area is very close to the city centers of Aqaba and Eilat and to the recreational facilities in both towns. Although almost all facilities are connected to the main sewerage...
system, the possibility of uncontrolled sewage discharge from either Eilat or Aqaba reaching the sea could not be ruled out. Ammonia concentration which considered as relatively high as compared with the records of the past survey of winter might be attributed not only for anthropogenic sources but also to decomposition and excretion of the plank tonic and benthic communities or even nitrogen fixation by these organisms. Modification of silicate concentrations in comparison with the past survey could be attributed to injection of atmospheric inputs and benthic flux from bottom and re-suspended sediments, (AlFugaha, 1995). Phosphate, nitrite and nitrate concentrations did not show significant variation with depth. Although no significant variation in their concentrations among the six sampling station, phosphate concentrations were higher in deeper stations where nitrite and nitrate show higher concentrations in shallower stations. In sediments, total phosphorous concentrations were higher in stations 2 and 6, where total nitrogen concentrations were higher in stations 1 and 5. Color and odor of sediments both suggest that they are well oxygenated. The deviation from the white color may indicate localized accumulation of organic matter. During the present survey, it was noticed that metal concentrations in the collected sediment samples were slightly higher than that reported by other researchers in 1990 and 1995 for the same area. Such relatively high concentrations of metals although can not be considered chronicle, might be attributed to the increasing human activities in the survey site from both Eilat and Aqaba. Comparing the outputs of this survey with previous records, taking into account the pronounced seasonality for most of the examined parameters, it could be said -although the slight enrichment of some nutrients- that the surveyed area in general is prevailed by normal conditions for this period of time.
3. Physical Oceanography Study

3.1 Methodology

3.1.1 Bathymetric survey
The bathymetry scan was carried out using a fish-finder 50/200 kHz (depth measurement) and Differential Global Positioning System-DGPS (geographic position definer) instrument to cover the study area (Fig.13) with depth resolution of 1 m and maximum depth of about 60 m. The data were arranged, analyzed and charted using Surfer 7.0.

Fig.: 13 Map of study area and sites locations of the physical oceanography study in the northern tip of the Gulf of Aqaba.

3.1.2 Tide records
A pressure sensor was deployed on a base settled on the bottom of coastal water in front of the Marine Science Station. The water pressure variations measurements over the sensor represent the seal level variations or tides. The tides data were sent directly and continuously to the tide gauge with interval of 10 minutes and readjusted reference to the Global Mean Sea Level. Tides at the study site were measured using physical scales on the ground and correlated with the concurrently recorded tides at the MSS in order to generate a long term tidal record at the study site. Horizontal water displacement due to tides at the study site was also recorded.
3.1.3 Temperature, salinity and density $\sigma_t$

A self contained conductivity, temperature and depth meter CTD (Ocean Seven 316/319 Probes) was used to measure temperature, salinity and depth (pressure) profiles on June 12th, 15th and July 3rd, 2005 at five stations (S1, S2, S3, S4 and S5) in the study area (Fig.13). Table (1) summarized the location and profile depths of CTD casts at the stations. The CTD measuring resolution and precision were 0.03% and 0.05% dbar for pressure; 0.001 and 0.003 for salinity; and 0.0005 and 0.003 °C for temperature.

3.1.4 Currents measurements

Currents were recorded continuously with 10 minutes interval in 16 layers (depth cells) of a coastal water column (2-32 m) at the study site using a moored Acoustic Doppler Current Profiler, ADCP WH300 kHz (Fig.14). The operation principle of ADCP 300 is transmission sound bursts into the water. Particles carried by the water currents scatter the sound back to the ADCP 300. As echoes return, the device assigns different water depths to corresponding parts of the echo record, thus forming vertical profiles. Motion of particles in the water relative to the device causes the echo to change in frequency. The ADCP 300 measures this change, the Doppler shift, as a function of depth to obtain water velocity at up to 128 depths through the water column. Duplicating the ADCP 300 current-measuring capability would require a string of 128 conventional current meters. The system setup of the ADCP 300 is summarized in Table (2). The current data was arranged, analyzed and plotted using Surfer 7.0 software.

Table 1 Locations and bottom depths of CTD stations, tidal reference point, and moored ADCP 300 kHz.

<table>
<thead>
<tr>
<th>Station</th>
<th>Longitude E</th>
<th>Latitude N</th>
<th>Bottom (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>34° 58.879</td>
<td>29° 32.353</td>
<td>7</td>
</tr>
<tr>
<td>S2</td>
<td>34° 58.849</td>
<td>29° 32.312</td>
<td>15</td>
</tr>
<tr>
<td>S3</td>
<td>34° 58.820</td>
<td>29° 32.270</td>
<td>20</td>
</tr>
<tr>
<td>S4</td>
<td>34° 58.784</td>
<td>29° 32.211</td>
<td>30</td>
</tr>
<tr>
<td>S5</td>
<td>34° 58.642</td>
<td>29° 32.010</td>
<td>50</td>
</tr>
<tr>
<td>ADCP 300</td>
<td>34° 58.800</td>
<td>29° 32.181</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 2 The system setup of the deployment configuration of the ADCP 300

<table>
<thead>
<tr>
<th>Number of depth cells</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth cell size</td>
<td>2.0 m</td>
</tr>
<tr>
<td>Blank after transmit</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Pings per ensemble</td>
<td>400</td>
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<tr>
<td>Time per ensemble</td>
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</tr>
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<td>Beam angle</td>
<td>20°</td>
</tr>
<tr>
<td>Orientation</td>
<td>Up</td>
</tr>
<tr>
<td>Transducer depth</td>
<td>32 m</td>
</tr>
</tbody>
</table>

$\sigma_t$ = Density(T,S,P) – 1000; where T, S, and P are the temperature, salinity, and pressure (depth) respectively. $\sigma_t$ has the same unit of density (kgm⁻³), but by convention this unit is not written.
3.2 Results

3.2.1 Bathymetry
The bathymetry of the study area in the northern tip of the Gulf of Aqaba had a smooth gradient and relatively homogenous geometry (Fig. 15). The bottom slope within 0-20 m depth range was ~0.097; i.e. depth to horizontal distance ratio was about 1:10. No significant hills or valleys appeared at the bottom of the study area. The slope decreased generally with increasing depth, and became ~0.045 (1:22) within the 20-60 m segment (Fig. 16).

Fig.: 14 The under water vertical deployment of the Acoustic Doppler Current Profiler, ADCP 300 kHz.

Fig.: 15 Bathymetry chart of the study area in the northern tip of the Gulf of Aqaba.
3.2.2 Tides

Mean sea level in the study area in the northern tip of the Gulf of Aqaba reference to the Global mean sea level during the year 2004 was about 16.4 cm and standard deviation of about 23 cm. The seal level anomalies depict a clear yearly cycle, where most of the low anomalies were observed in the summer with the lowest of 1.5 cm, measured in August and the highest mean anomaly occurred in the winter, 44.4 cm recorded in November (Table 3).

The maximum sea level range references to Global mean sea level during the year 2004 was 142 cm. The highest value was 94 cm observed on November 15th, and the lowest was -48 cm recorded on August 31st (Table 3).

The seal level variation for the period February-June 2005 (Fig. 17) revealed that the mean value was 23 cm and maximum range was about 138 cm with highest and lowest values of about 94 cm recorded on March 11th and -43 cm observed on May 6th, respectively.

The daily anomalies of tide during February-June 2005 (Fig. 18) exhibited that the maximum value (spring tide) was 99 cm on February 11th and minimum (neap tide) value was 28 cm on April 17th.

The horizontal displacement due to the tide at the study area was evaluated from the tide range following this relation:

\[ X_H = 9.03 \times X_{SL}, \]

where \( SL \) and \( H \) are the sea level in the study area reference to the Global mean sea level and the horizontal displacement (all in meters), respectively. As example, the maximum \( X_{SL} \) during the year 2004 was 1.42 m; therefore the maximum \( X_H \) was 12.8 m.

### Table 3

<table>
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<tr>
<th>Month</th>
<th>Readings</th>
<th>Mean</th>
<th>Min.</th>
<th>Max.</th>
<th>Range</th>
<th>Std. Dev.</th>
<th>Std. Err.</th>
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<td>25.23</td>
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<tr>
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<td>107.2</td>
<td>22.23</td>
<td>0.34</td>
</tr>
<tr>
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<td>-29.3</td>
<td>66.4</td>
<td>95.7</td>
<td>23.35</td>
<td>0.35</td>
</tr>
<tr>
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<td>4316</td>
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<td>-43.9</td>
<td>49.9</td>
<td>93.8</td>
<td>22.62</td>
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</tr>
<tr>
<td>Jul</td>
<td>4457</td>
<td>8.3</td>
<td>-45.8</td>
<td>59.0</td>
<td>104.8</td>
<td>22.49</td>
<td>0.34</td>
</tr>
<tr>
<td>Aug</td>
<td>4451</td>
<td>1.5</td>
<td>-48.2</td>
<td>55.2</td>
<td>103.4</td>
<td>23.54</td>
<td>0.35</td>
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<tr>
<td>Sep</td>
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<td>59.8</td>
<td>104.8</td>
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<td>0.36</td>
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<tr>
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<td>-29.3</td>
<td>80.5</td>
<td>109.8</td>
<td>24.54</td>
<td>0.37</td>
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<tr>
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<td>44.4</td>
<td>-20.7</td>
<td>93.6</td>
<td>114.3</td>
<td>22.82</td>
<td>0.39</td>
</tr>
<tr>
<td>Dec</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
Fig.: 17  Tidal records (cm) in the northern tip of the Gulf of Aqaba reference to Global mean sea level during February-June 2005.
Fig.: 18 Time series distribution of daily anomalies of tides in the northern tip of the Gulf of Aqaba during the period February 1st to June 30th, 2005.

### 3.2.3 Temperature salinity and density

Temperature (°C), salinity and density (σt) casts were measured three times on June 12th, 15th and July 3rd, 2005 at five stations (S1-S5) in order to clarify the water masses characteristics in the study area. The mixing conditions on June 12th and 15th still dominated in the upper 50 m where the temperature, salinity and density were homogenous with mean values of 23.34 ± 0.07 °C, 40.726 ± 0.008 and 28.185 ± 0.020 σt, respectively (Fig's. 19 and 20).

The stratification conditions began dominating in the study area on July 3rd in the 0-50 m water column. The mean values of temperature, salinity and density were 24.39 ± 0.46 °C, 40.752 ± 0.039 and 27.885 ± 0.111 σt respectively (Fig. 21). It is clear that temperature was the determinative factor of mixing and stratification conditions, i.e. salinity played a minor role in density calculation. The surface waters near shoreline had the same water mass characteristics (temperature ~24.55 °C and salinity 40.76) with deeper waters of 20-25 m water column that far more than 200 m from the shoreline (Fig. 21).

There was a clear transition from mixing to stratification conditions within 20 days of the study period (June 12th to July 3rd, 2005), which reflected on the water masses characteristics particularly in the study area and generally in the northern Gulf of Aqaba.
Fig.: 19 Vertical distribution of seawater temperature (°C), salinity and density (σ_t) along a perpendicular section of the shoreline on June 12th, 2005 in the study area in the northern tip of the Gulf of Aqaba.
Fig.: 20 Vertical distribution of seawater temperature (°C), salinity and density (σ₁) along a perpendicular section of the shoreline on June 15th, 2005 in the study area in the northern tip of the Gulf of Aqaba.
Fig. 21 Vertical distribution of seawater temperature (°C), salinity and density (σ) along a perpendicular section of the shoreline on July 3rd, 2005 in the study area in the northern tip of the Gulf of Aqaba
3.2.4 Circulation

Circulation pattern during summer in the study area was clarified using the current data during the period June 8th to July 2nd, 2005. Two current regimes were observed in the 2-32 m coastal water column. The first regime was observed in the surface waters at 2 m depth where a constant south-eastward current (157 ± 36°) dominated with relatively strong magnitude of about 35 ± 18 cms-1 and daily average displacement of about 22 km day-1 (Figs. 22a, 22b and Fig. 24). The current below 2 m depth behaved in another pattern, where anticlockwise rotation in direction and increment of current speed with respect to depth were observed from 4 to 32 m water column (Fig's. 23a, 23b and Fig. 24). At each layer below 2 m depth there was multi-reverse of current direction between south-eastward and north-westward, i.e. parallel to the shoreline of the study area. The daily average displacement of waters in the 4-12 m and 14-32 m water columns were about 0.7 ± 0.22 km and 1.5 ± 0.13 km, respectively (Fig. 24).

The distribution of the vertical current in the surface waters revealed a sinusoidal variation with average amplitude of -4.2 ± 4.12 cms-1, whereas most of vertical current direction was downward until June 27th, after that the direction became upward with average magnitude of 1.6 ± 2.67 cms-1 (Fig. 22c). The deeper waters (4-32 m) showed a fluctuation of vertical current direction from up- to downward and relatively weaker magnitude with average value of -0.2 ± 0.41 cms-1 comparing to surface current (Fig. 23c).

The profile of the average values of current speed and direction (Fig. 25) throughout the period of records (20 days) revealed and supported the current pattern that resulted from the raw data itself. The current in the surface waters was strong and directed to south-southeast while a weaker magnitude with anticlockwise rotation in direction with respect to depth dominated in the deeper layers (4-32 m).

The current pattern during winter resembles that of current during summer below the surface (<2m) in term of direction (Fig. 26), i.e., anticlockwise rotation in direction from north-northwestward (340°) at 6 m depth to west-southwestward (245°) at 34 m depth was observed (Fig. 26). The average value of current speed and direction at all selected depth levels (4, 6, 12, 18, 20, 28, 32 and 34 m) during winter were 6.3 ± 4.50 cms-1 and 264 ± 100.1°, respectively. Moreover, the average value of displacement rate during winter for all selected depth levels (2.1 ± 5.90 km day-1) approached of that during summer below surface (>2m). The vertical current distribution mostly behaved similar of that during summer below surface (>2m), where an alteration of vertical current direction from up- to downward and relatively weak magnitude with average value of -0.1 ± 0.70 cms-1 dominated during winter (Fig. 27).
Fig.: 22 Time series records of (a) east current component (b) north current component and (c) vertical current (all in cm/s) during the period June 8th to July 2nd, 2005 in the 2-6 m water column in the study area in the northern tip of the Gulf of Aqaba.
**Fig.: 23** Time series records of (a) east current component (b) north current component and (c) vertical current (all in cm/s) during the period June 8th to July 2nd, 2005 in the 6-32 m water column in the study area in the northern tip of the Gulf of Aqaba.
**Fig.: 24** Progressive vector diagram of water displacement (km) caused by currents at different depth layers during the period June 8th to July 2nd, 2005 in the 2-32 m water column in the study area in the northern tip of the Gulf of Aqaba.
Fig.: 25 Profiles of temporal average of current speed (cms⁻¹) and direction (°) during the period June 8th to July 2nd, 2005 in the 2-32 m water column in the study area in the northern tip of the Gulf of Aqaba.

Fig.: 26 Progressive vector diagram of water displacement (km) caused by currents at different depth layers during the period January 11th-28th, 2004 in the 4-34 m water column in the study area in the northern tip of the Gulf of Aqaba.
Fig.: 27 Distribution of vertical current at selected depth levels (6, 18 and 34 m) during the period January 11th-28th, 2004 in the study area in the northern tip of the Gulf of Aqaba.
3.3 Discussions and Conclusions

3.3.1 Existing Conditions

3.3.1.1 Tides

The yearly cycle of the sea level anomalies at the northern Gulf of Aqaba follows the corresponding sea level variations in the Red Sea. The sea level changes of the Gulf of Aqaba are determined by the water balance of the Red Sea. The Red Sea and Gulf of Aden depends on the following factors: (i) real decrease of the water volume due to intensive evaporation from sea surface (ii) the variation of a positive component of water exchange through Bab el Mandeb and Suez Canal and (iii) the water redistribution in the sea due to the wind (Table 4). The seal level anomalies in the northern Gulf of Aqaba are represented an annual cycle, whereas the lowest sea level occurs during summer and the highest arise during winter. The significant factors that control the annual cycle of sea level variations in the northern Gulf of Aqaba are the evaporation and winds, i.e. factors (i) and (ii) that mentioned above. Both factors during summer are significantly more effective than in winter, therefore evaporation and winds are causing lower sea level during summer than in winter. Daily average anomalies depict the natural monthly cycle of tides in the northern Gulf of Aqaba. Semidiurnal and diurnal tide signals, as well as biweekly neap and spring tide signal are likely to be detected in tide records.

In general, during the period December-May, wind induced water movement driven by the north-east monsoon, has a net flow from the Indian Ocean to the Red Sea, which results in elevating the water level in the Red Sea and the Gulf of Aqaba (Table 4). During the period July-October, the wind induced water movement, due to the south-west monsoon, has a net flow from the Red Sea to the Indian Ocean, which results in a lower water level in the Red Sea and consequently in the Gulf of Aqaba (Table 4).

<p>| Table 4: Annual sea level (cm) variation in the Red Sea relative to the long term mean between central, northern and southern parts. |
|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|                             |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |</p>
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<th><strong>Set of observations</strong></th>
<th><strong>Month</strong></th>
<th><strong>Level differ (cm)</strong></th>
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<td>12</td>
<td>I II III IV V VI VII VIII IX X XI XII Amp.</td>
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<tr>
<td>Sudan(2)</td>
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<td>13 9 6 7 5 -5 -16 -22 -14 4 11 11 35</td>
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<tr>
<td>Perim(3)</td>
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<td>6 6 5 3 9 3 -6 -12 -15 9 -3 3 21</td>
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<tr>
<td>Aden(4)</td>
<td>25</td>
<td>5 7 7 10 10 4 -6 -14 -12 -10 -3 1 25</td>
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(2)-(1) 3 0 -3 -5 -1 -5 -4 -1 4 8 8 1 13
(2)-(4) 8 2 -1 -2 -5 -9 -10 -8 -2 14 10 24
(2)-(3) 7 3 1 4 -4 -8 -10 -10 1 5 14 8 24
(3)-(4) -1 -1 -2 -7 -1 -1 0 2 -3 1 0 2 9
3.3.1.2 Thermohaline structure

The water masses in the northern Gulf of Aqaba characterized by mixing during winter and stratification in summer. The Gulf is distinguished based on the fact that mixing is complete in entire of the Gulf, because it receives virtually no fresh water and consequently exhibits no salinity stratification in winter. The high evaporation during summer, negligible runoff or rivers, negative heat flux to the air during winter and positive heat flux to the air during summer, all are considered as main factors for determination of mixing and stratification period and depth. Day to day changes of the water column characteristics, especially during the transition period, March to June can be great. It is therefore important to emphasize that the recorded ambient conditions are more pertinent to the sampling day than to the entire month.

The significant change of water mass characteristics in the northern tip of the Gulf of Aqaba in the study area was an evidence of transition between mixing and stratification, and therefore a change in density/gravity current, upwelling and downwelling phenomena. Upwelling is the transport of subsurface water to the surface. A consequence of wind patterns, upwelling occurs where surface waters diverge (divergences are where surface water is pushed away by wind and subsurface water rises to replace it.) Upwelling regions develop in response to prevailing winds along coasts and at sea (Fig. 28).

Upwelled waters are cooler and more nutrient rich than the surface waters they replace. Because of their high nutrients, upwelling regions support high levels of primary production. Important fisheries are the result of upwelling. Seasonal or longer variations in wind patterns (such as El Niño) lead to changes in upwelling that can soon impact fisheries.

![Fig.: 28 Upwelling dynamics sketch. Modified by D. Reed from image by J. Wallace and S. Vogel, El Niño and Climate Prediction](image)

It was clear in the first two CTD casts (June 12th and 15th, 2005) that the homogenous distribution (mixing) of temperature and salinity dominated in the study area. In general, the water remains mixed since it still losing heat to the air, therefore constant loss of buoyancy of the surface water due to heat loss cause the density to pass a critical threshold after which vertical convection occurs, i.e. permanent downward movement of waters. This status will be changed when satisfaction condition begin dominating, i.e., as the air losing heat to the sea, the downward waters will be no more presented. This agrees with
the distribution of temperature and salinity on July 3rd when stratification appeared clear in the study area, therefore a behavior of upwelling was existed (Fig. 21).

### 3.3.1.3 Water exchange between the Red Sea and Gulf of Aqaba

Three-layer circulation system characterizes the water exchange between the Gulf of Aqaba and Red Sea through the Strait of Tiran, particularly in summer when the thermohaline controlled inflow forms a water parcel (q1) that enters the Gulf and travels northward. There, when the water has cooled and become more saline it loses buoyancy and starts to sink and travel southward (q2) beneath the in-flowing water. These two opposite water movements take place in the upper 150 m and have a stationary layer between them below 50 m. In deeper water below 150 m a third water parcel (q3) moves from the Red Sea into the Gulf of Aqaba (Fig. 29b).

The extent of the northward travel of these waters has not been identified. However, the deep water below 150 m was uniform in temperature and salinity in the entire Gulf of Aqaba while the upper water differed significantly from south to north. This can lead to the conclusion that the deep water inflow or a part of it at least does reach the northern end of the Gulf.

The three quantities q1, q2 and q3 were estimated by two different computational techniques; the conservation of mass and the critical Richardson conditions across the Strait of Tiran. The two techniques resulted in similar values for q1 but quite different values for q3.

The conservation of mass calculation gave:
- \( q_0 = -280 \text{ m}^3\text{s}^{-1} \) (evaporation from)
- \( q_1 = 23,780 \text{ m}^3\text{s}^{-1} \) (subsurface inflow)
- \( q_2 = -45,500 \text{ m}^3\text{s}^{-1} \) (subsurface outflow)
- \( q_3 = 22,000 \text{ m}^3\text{s}^{-1} \) (deep water inflow)

Calculations based on critical Richardson conditions across the Strait of Tiran gave:
- \( q_1 = 21,000 \text{ m}^3\text{s}^{-1} \)
- \( q_2 = -34,000 \text{ m}^3\text{s}^{-1} \)
- \( q_3 = 11,000 \text{ m}^3\text{s}^{-1} \)

In winter, a two-layer water exchange system in the upper 150 m was existed. Both the Strait method for calculating the water exchange as well as the mass balance method gave similar estimates of the quantities q1 (inflow) and q2 (outflow); about 70,000 \text{ m}^3\text{s}^{-1} \) (Fig. 29b).

The suggested flow rate form the intake waters from the northern tip of the Gulf of Aqaba to the Dead Sea is -60 m³s⁻¹, which is represented about 20% of evaporation rate and 0.2% of subsurface inflow from the Red Sea. This indicates that the rate of intake waters will not affect the water exchange system between the Red Sea and the Gulf of Aqaba in general since it is not comparable with that huge rate values from the Red Sea to the Gulf.
3.3.1.4 Current pattern

Two main external forces controlled the current pattern in the study area in the northern tip of the Gulf of Aqaba during summer and winter seasons. Winds were considered as a main external force that governed surface waters to flow in the same direction. In details, more than 90% of the winds blow to south-eastward (north-westerly winds) with average wind speed of 4.2 ms$^{-1}$, therefore, the main surface current direction was south-eastward (Figs. 22 and 24). The other force that affected in circulation in the study area was tidal currents that caused clockwise semidiurnal (12.25 h) and diurnal signals (23.81 h). Besides, a periodic signal of one cycle per 3.47 days was observed in the current resulting in the multi-reverse of current direction between south-eastward and north-westward (Figs. 23 and 24).

The upwelling phenomenon in the upper 6 m during summer was observed clearly in the vertical current profiles (Fig 23c) after June 27th when the transition from mixing to stratification condition occurred (Figs. 19-21). It is likely that the upwelling phenomenon disappears during winter (mixing) and dominates during summer (stratification) in the study area.

3.3.2 Expected Future impacts

3.3.2.1 Sea level

Sea level is not affected by a stable water exchange system, i.e. no external intake or flow is available. On the other hand, sea level is influenced temporally by any external intake or flow until it reaches a stable condition.
If we assume that waters will be pumped from a closed area $A$ ($\text{km}^2$) by a flow rate $\varphi$ ($\text{m}^3\text{s}^{-1}$), then the sea level difference $\Delta SL$ (m) after passing time $T$ (hours) of pumping waters from the area will be:

$$\Delta SL = -\frac{T \times \varphi}{A}$$  \hspace{1cm} (Eq. 1)

Where, the negative sign means fall off in sea level.

In the RDC project, the suggested rate of water intake, which will take place in the northern tip of the Gulf of Aqaba between Jordanian and Israeli borders is $-60 \text{ m}^3\text{s}^{-1}$. Therefore, the rate of sea level falling based on Eq. (1) will be $-5.2$ and $-1.0$ m day$^{-1}$ in an area of 1 and 5 km$^2$, respectively, comparing to the normal conditions (without water intake). Considering the whole Gulf of Aqaba is closed water body, therefore the falling rate of sea level due to the suggested water intake will be $0.53$ m year$^{-1}$ or $1.45 \times 10^{-3}$ m day$^{-1}$ (Fig. 30).

The oceanic motions are governed by the fundamental principles of fluid continuum theory and of thermodynamics, i.e., by the conservation of mass and momentum, therefore the water intake effect on sea level will not be locally and restricted in closed area, whereas the whole Gulf of Aqaba particularly and the Red Sea in general will be affected temporally until it reach stable conditions.

The response time for compensating the sucked waters from the Red Sea depends on the surface area and length of the Gulf of Aqaba, rate of water intake, and the tunnel or channel design of water intake. This water intake will be compensated by increase the inflow of waters from the Red Sea to the Gulf of Aqaba based on conservation of mass theory, i.e. rebalanced the sea level difference.

**Fig.: 30** The falling rate of sea level (m day$^{-1}$) in the Gulf of Aqaba -as closed water body- due to the suggested water intake from the northern tip of the Gulf.
3.3.2.2 Thermohaline structure

The thermohaline structure in the northern tip of the Gulf of Aqaba will be influenced by the water intake in term of temperature and salinity variations. The surface water temperature in southern Gulf of Aqaba is higher than the northern part and visa versa regarding salinity. Therefore, it is likely that the surface waters temperature will increase gradually and salinity will decrease gradually in the study area and northern tip of the Gulf of Aqaba due to water intake up to reach a stable structure. The average temperature and salinity of seawater surface in southern and northern parts of the Gulf of Aqaba during winter are 23.2 °C; 40.1 and 21.6 °C; 40.6, respectively, and 27.5 °C; 40.2 and 25.6 °C; 40.7, respectively during summer. The expected maximum increase of temperature and maximum decrease of salinity due to water intake could be derived based on the thermal equilibrium theory as following:

\[ T_n'(t) = \frac{q_o t T_{n-1}' + T_n V_n}{q_o t + V_n} \]  \hspace{1cm} (Eq. 2)

\[ S_n'(t) = \frac{q_o t S_{n-1}' + T_n V_n}{q_o t + V_n} \]  \hspace{1cm} (Eq. 3)

Where, \( T_n' \) (°C) and \( S_n' \) are the temperature and salinity after equilibrium in the nth sector of the Gulf of Aqaba (Fig. 31), \( q_o \) is daily volume of the intake water (m³day⁻¹), \( V_n \) (m³) is the volume of the nth sector of the Gulf of Aqaba, and \( t \) is the Julian days after operating water intake. Theoretically, and based on Eqs. (1) and (2), the expected maximum increase of temperature and maximum decrease of salinity are 0.5 °C and 0.1, respectively, where the expected time of reaching these values is more than 3 years (Fig. 32). Thereafter, no expected increase and decrease of temperature and salinity, respectively, due to water intake will be detected, i.e. the stable conditions will dominate in the northern tip of the Gulf of Aqaba after 3 year of water intake.

Fig.: 31 Schematic map of the Gulf of Aqaba showing the \( n^{th} \) sectors and its temperature, salinity and volume that used for calculations in Eqs. (1) and (2). Where, \( T_n' \) (°C) and \( S_n' \) are the temperature and salinity after equilibrium in the \( n^{th} \) sector of the Gulf of Aqaba, \( q_o \) is daily volume of the intake water (m³day⁻¹), \( V_n \) is the volume (m³) of the \( n^{th} \) sector of the Gulf of Aqaba.
Fig.: 32 Time series of seawater temperature and salinity anomalies in the $n^{th}$ sector of the Gulf of Aqaba after operating water intake.

This expected change will not cause any kind of thermal pollution and will not affect the natural cycle of mixing and stratification conditions. Therefore the thermohaline circulation will not be affected.

On the other hand, some changes may occur locally in vicinity to the study area in term of upwelling/downwelling phenomena. A successive of water intake may cause volume of waters that will be gathered near shoreline which will increase the capacity of mass in the area and cause a downwelling phenomenon. This will affect on nutrient source in the area, i.e. the nutrient will decrease slightly. There is a probability to avoid occurring downwelling and so far avoiding nutrients decrease in the area by making the flow before the channel totally equivalent to the water intake thought it, i.e. a homogenous water flow before and through the channel.

### 3.3.2.3 Circulation pattern

The water circulation in the study area and in the vicinity waters will be changed depend on the channel or tunnel design. The flow speed of water intake through the suggested channel or tunnel can be calculated using the following formula:

$$v = \frac{\varphi}{A} \quad (\text{Eq. 4})$$

Where, $v$ (m/s) is the flow speed of intake waters, $A$ (m$^2$) is the area of cross section of the channel or tunnel and $\varphi$ is the flow rate (m$^3$/s). Assuming that waters will be pumped at a rate of 60 m$^3$/s through a rectangular channel of 2 m depth and 10 m width ($\text{Area} = 2 \times 10 = 20 \text{ m}^2$), then the flow speed will be 3 m/s, but if we use a cylindrical tunnel of 2 m
radius \( (\text{Area} = \pi r^2 = 12.57 \text{ m}^2) \) then the flow speed will be 4.77 ms\(^{-1}\). Based on that, using a wider and deeper channel or larger tunnel diameter is better to reduce the flow speed and then reduce the effect of water intake on the existing circulation. In case of using a tunnel, the depth source of waters that will be pumped is important to be selected carefully to avoid development of turbulence and/or strong eddies in the area and to eschew unexpected increase of nutrients in the pumped waters through the tunnel. The suggested depth of the tunnel entrance in the sea should be deeper than the active and liveliness layers and above the seabed. Basically, these layers extend down to the thermocline depth (max. 250 m). Therefore, it is recommended to lay the tunnel below 200 m depth from the surface and above 50 m from the seabed.

The channel is a better solution to be used for pumping waters from the northern tip of the Gulf of Aqaba to the Red Sea instead of using tunnel for the following reasons:

i) Water intake will be pumped from surface waters less (<3 m depth), therefore the effect on circulation will be limited.

ii) Channel width could be determined easily to control flow speed of water intake; this will also limit any change on the existing circulation.

iii) Deep and offshore waters will not be influenced significantly rather than pump waters by a tunnel from there.

iv) Low flow speed through the channel will allow the sea level to be rebalanced by increase the inflow rate from the Red Sea through the Strait of Tiran with shorter time.

The expected change in water circulation in the region in vicinity of water intake in case of using a channel will be a change in current direction and increase of current speed. The direction of current will converge near the channel and will be parallel to the channel axis with speed reaches 3 ms\(^{-1}\) in case that the channel width and depth will be 10 m and 2 m, respectively. This current convergence begins vanishing whenever the distance of any direction from the channel entrance increase (Fig. 33). The flow rate of the water intake at the channel assumed to be 3 ms\(^{-1}\), and this speed decreases with increasing distance from the channel entrance in all directions with a dispersion rate of -0.1% per meter, i.e. the flow speed of water intake will be 2.9 ms\(^{-1}\) and 0.0 ms\(^{-1}\) at distance of 100 m and 3000 m from channel, respectively (Fig. 34). It is assumed that the current pattern in an area that far more than 3 km in all direction from the channel will not be affected by the water intake and it will remains just as the existing condition.

**Fig.: 33** Scheme diagram of current pattern in vicinity of the channel of water intake in the northern Gulf of Aqaba
The major outputs in case of using a channel for water intake from the northern Gulf of Aqaba to the Red Sea are:
1. Water intake effect on sea level will not be locally and restricted in closed area, whereas the whole Gulf of Aqaba particularly and the Red Sea in general will be affected temporally until it reach stable conditions.
2. The water intake from the northern Gulf of Aqaba will be compensated by increase the inflow of waters from the Red Sea to the Gulf of Aqaba based on conservation of mass theory.
3. It is likely that the surface waters temperature will increase gradually and salinity will decrease gradually in the northern tip of the Gulf of Aqaba due to water intake up to reach a stable structure.
4. The maximum expected increase of temperature and decrease of salinity will take three year to be of order +0.5 °C and -0.1, respectively. Thereafter, no expected increase and decrease of temperature and salinity, respectively, due to water intake will be detected.
5. The expected change in temperature and salinity in northern tip of the Gulf of Aqaba will not cause any kind of thermal pollution and will not affect the natural cycle of mixing and stratification conditions, therefore the thermohaline circulation will not be affected.
6. The direction of current will converge near the channel and will be parallel to the channel axis with speed reaches 3 ms\(^{-1}\) in case that the channel width and depth will be 10 m and 2 m, respectively.
7. The current convergence will begin vanishing whenever the distance of all directions from the channel entrance increase.
8. It is assumed that the current pattern in the study area far more than 3 km in all directions from the channel will not be affected by the water intake in case that flow speed at the channel entrance will be 3 ms\(^{-1}\), while it will remain just as the existing circulation.
9. To avoid occurring downwelling and so far avoiding nutrients decrease in the area that will be caused by gathering volume of waters near shoreline by making the flow before the channel totally equivalent to the water intake thought it, i.e. a homogenous water flow before and through the channel.

**Fig.: 34** Relationship between waters flow speed (ms\(^{-1}\)) and distance (m) from the channel entrance.
4. Assessment of Existing Benthic and Pelagic Marine Environment

4.1 Site seeing and Dive Description

The target area was divided into two zones separated by 200 m. Each zone was then divided according to depth into 4 depth categories: 5 m, 10 m, 20 m and 30 m. Underwater photos were taken to visually describe the depth categories and record the main biological components observable to the divers before conducting the survey study. At 5 m depth the area was found to be covered mainly by sea grass meadows and sandy bottoms, although some small colonies of hard corals can be seen. Many coral reef organisms were recorded at this depth were photographed and presented in Fig. 35. The included feather star, sea urchin, sea snails, sea cucumber, algae, sea grass, hard corals and various types of fishes (Fig. 35). The 10 m depth was mainly covered by sea grass meadows with some scattered small organisms and small batches of sandy areas (Fig. 36). The 20 m depth in the study area is characterized by having equal distribution of sandy bottoms and sea grass meadows with some small batches of corals. At this depth, a big batch of corals that can be called micro-atoll was found with about 2 m high and 3 m width and 3 m length. This micro-atoll has many coral reef species that live together forming a small coral reef ecosystem among the sandy and sea grass habitat. The types of organisms that were found include various types of fishes, various types of hard corals, soft corals, ascidians, sponges, sea anemone, sea grass, various types of algae and jelly fish (Fig. 37). The 30 m depth is mainly sandy bottoms with small batches of sea grass and algae distributed in the area (Fig. 38). At depths below 40 m, the bottom habitat become different from the shallower depths, where more corals can be found and also the topography details of the bottom are quite different from the first 40 m. A more detailed study is needed to characterize this depth for any future predictions of the project on the deeper bottom habitat.

4.2 Benthic Community Structures

To study the benthic cover at the proposed RDC project site, the target area was divided into two zones, designated A and B (Fig. 39). The area which was covered in this survey extends to 600 m starting from the boarder and heading east parallel to the shoreline and to 30 m depth towards the sea direction. Each one of the two zones was subdivided into 4 depth categories (5 m, 10 m, 20 m and 30 m). At each depth, 3 transect lines, each with 50 m long, were laid separated by 20 m distance (Fig. 39) and the major reef components were surveyed according to the method of English et al. (1994). Fourteen coral reef components were surveyed in the study area (Table 5). The items were selected in accordance with their importance in the Gulf of Aqaba coral reef's ecosystem. The results of benthic cover survey have shown that sea bottom at the RDC project site is mainly sea grass meadows and sandy bottom habitats, although corals are present as small batches or aggregates of mixed coral reef components. The coverage rate of the sea grass meadows ranged between ca. 10% at 30 m depth in zone A to ca. 95% at 10 m depth in zones A and B. This habitat form an important nursery grounds for the fish larvae and host many types of organisms like the various types of fishes, sea slugs, crustaceans, sea urchins, sea cucumbers, feather star and many other faunal organisms. The corals are not
Fig.: 35 Digital photos of the various organisms that were encountered at 5 m depth in the study area. A. feather star, B. algae, C. hard coral, D. sea grass meadows, E & F. two types of sea snails, G. sea urchin, H, I & J are batches of hard corals with various types of fishes, K & L are two types of sea cucumber.

Fig.: 36 Digital photos of the benthic cover at 10 m depth in the study area. A sand dunes and sea grass batches, B sea grass meadows.
Fig.: 37 Digital photos of the features characterizing the 20 m depth in the study area. A. micro-atoll composed of many coral reef organisms with 2m high and 3x3m surface area, B. hard coral, C. scorpion fish, D. hard coral, E. algae, F. sponge, G. jelly fish, H. sea grass meadows, I. sea anemone, J. soft coral and morey eel, K. algae, L. ascidians and soft corals.

Fig.: 38 Digital photos of the features characterizing the 30 m depth in the study area. A. small batches of Seagrasses and algae distributed among the sandy bottoms, B. sandy bottoms at 30 m depth.
Three lines were laid at 5 m, 10 m, 20 m and 30 m depths and the benthic cover component was surveyed according to the method of English et al. (1994).

### Table 5: Coral reef components used in the survey study with their abbreviations.

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<td>Sea grass</td>
<td>SG</td>
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<tr>
<td>Soft coral</td>
<td>SC</td>
<td>Sand</td>
<td>SD</td>
</tr>
<tr>
<td>Sea Anemone</td>
<td>SA</td>
<td>Rock</td>
<td>RC</td>
</tr>
<tr>
<td>Sponges</td>
<td>SP</td>
<td>Rubble</td>
<td>RB</td>
</tr>
<tr>
<td>Ascidians</td>
<td>AS</td>
<td>Others</td>
<td>OT</td>
</tr>
<tr>
<td>Clams</td>
<td>CL</td>
<td>Man Made Objects</td>
<td>MM</td>
</tr>
<tr>
<td>Algae</td>
<td>AG</td>
<td>Recently died coral</td>
<td>RC</td>
</tr>
</tbody>
</table>

considered major component of the benthic cover in the study area. However, coral batches and small colonies are present in the area. One considerably big coral aggregate (i.e. micro-atoll) was found at 20 m depth in zone A, with dimensions of 3x3 m for the surface area of the base of the atoll and 2m high (Fig. 37). The results obtained for benthic cover components are presented below, where the mean values of 3 transects at each depth (as illustrated in Fig. 39) are plotted with the standard deviation of each set.

### 4.2.1 Five meters depth

In zone A, the 5 m depth had about 93% coverage rate of sea grass meadows, while much smaller rate was covered by sand, algae and soft corals, respectively (Fig. 40). In zone B, the 5 m depth was nearly divided between sea grass and sandy bottoms, with far too low percent cover of hard coral and algae (Fig. 40).
4.2.2 Ten meters depth

The 10 m deep transects were characterized by homogeneous and heavy distribution of sea grass meadows, which had about 90% and 94% coverage rate in zone A and B, respectively (Fig. 41). The rest of the transects was occupied by sand in both cases.

4.2.3 Twenty meters depth

In zone A, about 77% of the bottom habitat was covered by sand and 19% by sea grass, while much less percentage was covered by algae, soft corals and hard corals (Fig. 42). In zone B, the situation is quiet similar with more soft corals present in the site (ca. 3%), (Fig. 42).

4.2.4 Thirty meters depth

The 30 m depth was more characterized by having sandy bottoms with little sea grass and algae present among the sandy bottom. In zone A, about 77% was occupied by sand, while 20% and about 3% was covered by sea grass and algae, respectively (Fig. 43). Zone B had about 80% coverage rate for sand and about 11% and 8% covered by algae and sea grass, respectively (Fig. 43).
Fig.: 41 Percent cover of the benthic components at 10 m depth in zones A and B in the study area. For components abbreviations, see Table (5).

Fig.: 42: Percent cover of the benthic components at 20 m depth in zones A and B in the study area. For components abbreviations, see Table (5).
4.3 Faunal components in sediments

After conduction of the benthic survey, a sediment core from the middle of each transect was taken to the laboratory for analysis of faunal organisms living within the sediment of the study area. The sediment samples were kept at -20°C until it was analyzed. For analysis, 1 g sediment was sieved in a 300 um sieve and where microscopically analyzed for the major faunal organisms. The faunal composition of the sediment cores includes shells of many species of the foraminiferans and ostracoda (crustaceans) in addition to the small bivalves and snails. The density of foraminiferans was way too much compared with the other components at all depths surveyed.

4.3.1 Five meters depth
The 5 m depth had about 88 and 73 individuals/g sediment of foraminiferans in zone A and B respectively. Much less number of snails (about 5 and 8 individuals/g sediment in zone A and B respectively), bivalves (about 3 and 6 individuals/g sediment in zone A and B respectively) and ostracoda (about 9 and 4 individuals/g sediment in zone A and B respectively) (Fig. 44).

4.3.2 Ten meters depth
The 10 m deep transects had slightly higher number of foraminiferans compared with the 5 m depth, with about 90 and 117 individuals/g sediment in zone A and B respectively (Fig. 45). The number of the other faunal groups remained small, although they were increased (Fig. 45).

4.3.3 Twenty meters depth
At 20 m depth, the number of foraminiferans increased to about 150 individuals/g sediment in both zones, with the other groups also increasing by increasing depth (Fig. 46).
4.3.4 Thirty meters depth

At this depth, the number of foraminiferans has exceeded 235 individuals/g sediment in zone A and about 145 individuals/g sediment in zone B (Fig. 47). The other faunal groups remained in the same level like the 20 m deep transects (Fig. 47).

**Fig.: 44** Faunal composition at 5 m depth in zone A and B.

**Fig.: 45** Faunal composition at 10 m depth in zone A and B.
Fig.: 46 Faunal composition at 20 m depth in zone A and B.

Fig.: 47 Faunal composition at 30 m depth in zone A and B.
4.4 Fish fauna assemblages

About 350 fish species have been recorded in the Gulf of Aqaba (Khalaf and Disi, 1997). A detailed survey at the RDC project site was carried out aiming at describing the distribution of fish species and assemblages in the target area.

Fish communities in shallow water habitats (5-30 m depth) were surveyed by visual census technique following English et al. (1994). Line transects of 50 m in length and 3 m width were deployed at each of the 2 selected survey sites zone A and zone B in front of the proposed project site (Fig. 39). At each zone visual census were conducted along three transects to cover a total area of 450 m² at 5 m, 10 m, 20 m and 30 m depths. During the survey and after lying the transect line, the observers waited for about 10 minutes to allow the fish to resume their normal behavior. Subsequently, the divers recorded the number of individuals of all fishes encountered within a distance of 1.5 m on each side of the line and 3 m above it. All fishes exhibited a total length of 30 mm or more were identified to the species level and recorded on a plastic slate. The duration of count for each transect lasted about 20-30 minutes.

Abundance of fishes was described using the following parameters: relative abundance (RA) = (the pooled average abundance of species i from each depth and site/ the pooled average abundance of all species from each depth and site) X 100, number of species.

Frequency of appearance (FA) = (number of transects in which species i was present /total number of all transects) X 100. Species richness, species diversity and evenness were calculated using PRIMER-5 software (Primer-E 2000).

4.4.1 Fish assemblages and community indices

In the present survey study, a total of 2823 fishes were counted representing 40 species that belong to 22 families. All inhabiting the shallow water with an average of 117.6 fish per transect. In terms of relative abundance per family the ichthyofauna showed the following rank: Chaetodontidae (23.2%), Mullidae (15.8%), Lethrinidae (15.7%), Labridae (9.0%), Serranidae (8.1%) and Pomacentridae (6.9%) of the total population. These 6 families account for 78.7% of the total population.

The most abundant species were Heniochus diphreutus (23.0%), Lethrinus variegatus (15.7%), Parupeneus forsskali (6.6%), and Dascyllus trimaculatus (5.8%) Pseudanthias squamipinnis (5.5%), and Upeneus pori (5.0%). These six species made up 61.6% of the total population. Frequency of appearance suggest that the most common species were Dendrochirus brachypterus (79.2%), Synodus variegates (75.0%), Coris caudimaculatus (70.8%), Epinephelus fasciatus (66.7%), and Sidera grisea and Arothron hispidus (62.5%, each).

Number of species ranged from 6 species per transect in 5 m deep transects to 22 species within the same depth with an average of 13.3 species per transect. Number of species ranged from 7 species per transect in 10 m deep transects to 16 species within the same depth with an average of 12.3 species per transect. Number of species ranged from 8 species per transect in 20 m deep transects to 25 species within the same depth with an average of 15.5 species per transect. Number of species ranged from 5 species per transect in 30 m deep transects to 11 species within the same depth with an average of 8.3 species per transect (Fig. 48).
Table 6 List of fish species in the studied area with total number, average abundance (AA), relative abundance (RA), and frequency of appearance (FA) at all depths. Bold letters indicate fish families.

<table>
<thead>
<tr>
<th>Species</th>
<th>Total</th>
<th>AA</th>
<th>RA</th>
<th>FA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dasyatidae</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Himantura uarnak</td>
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<td>0.0</td>
<td>4.2</td>
</tr>
<tr>
<td>Gymnothorax flavimarginatus</td>
<td>3</td>
<td>0.1</td>
<td>0.1</td>
<td>8.3</td>
</tr>
<tr>
<td>Sidorae grisea</td>
<td>55</td>
<td>2.3</td>
<td>1.9</td>
<td>62.5</td>
</tr>
<tr>
<td>Synodontidae</td>
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<td></td>
<td></td>
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<tr>
<td>Synodus variegatus</td>
<td>58</td>
<td>2.4</td>
<td>2.1</td>
<td>75.0</td>
</tr>
<tr>
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<td>0.3</td>
<td>20.8</td>
</tr>
<tr>
<td>Antennaridae</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antennarius coccineus</td>
<td>2</td>
<td>0.1</td>
<td>0.1</td>
<td>8.3</td>
</tr>
<tr>
<td>Scorpaenidae</td>
<td>5.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epinephelus areolatus</td>
<td>12</td>
<td>0.5</td>
<td>0.4</td>
<td>16.7</td>
</tr>
<tr>
<td>Epinephelus fasciatus</td>
<td>62</td>
<td>2.6</td>
<td>2.2</td>
<td>66.7</td>
</tr>
<tr>
<td>Pseudanthias squamipinnis</td>
<td>154</td>
<td>6.4</td>
<td>5.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Apogonidae</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Apogon aureus</td>
<td>29</td>
<td>1.2</td>
<td>1.0</td>
<td>4.2</td>
</tr>
<tr>
<td>Nemipteridae</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scolopsis ghanam</td>
<td>43</td>
<td>1.8</td>
<td>1.5</td>
<td>29.2</td>
</tr>
<tr>
<td>Haemulidae</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Diagramma pictum</td>
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<td>1.8</td>
<td>1.5</td>
<td>25.0</td>
</tr>
<tr>
<td>Lethrinidae</td>
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<td></td>
<td></td>
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<tr>
<td>Lethrinus variegatus</td>
<td>444</td>
<td>18.5</td>
<td>15.7</td>
<td>50.0</td>
</tr>
<tr>
<td>Mullidae</td>
<td>15.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parupeneus forsskali</td>
<td>187</td>
<td>7.8</td>
<td>6.6</td>
<td>58.3</td>
</tr>
<tr>
<td>Parupeneus macronema</td>
<td>118</td>
<td>4.9</td>
<td>4.2</td>
<td>54.2</td>
</tr>
<tr>
<td>Upeneus pori</td>
<td>140</td>
<td>5.8</td>
<td>5.0</td>
<td>33.3</td>
</tr>
<tr>
<td>Chaetodontidae</td>
<td>23.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heniochus diphreatus</td>
<td>650</td>
<td>27.1</td>
<td>23.0</td>
<td>8.3</td>
</tr>
<tr>
<td>Heniochus intermedius</td>
<td>6</td>
<td>0.3</td>
<td>0.2</td>
<td>8.3</td>
</tr>
<tr>
<td>Pomacentridae</td>
<td>6.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amphiprion bicinctus</td>
<td>6</td>
<td>0.3</td>
<td>0.2</td>
<td>8.3</td>
</tr>
<tr>
<td>Dascyllus marginatus</td>
<td>7</td>
<td>0.3</td>
<td>0.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Dascyllus trimaculatus</td>
<td>163</td>
<td>6.8</td>
<td>5.8</td>
<td>37.5</td>
</tr>
<tr>
<td>Teixeirichthys jordani</td>
<td>20</td>
<td>0.8</td>
<td>0.7</td>
<td>12.5</td>
</tr>
<tr>
<td>Labridae</td>
<td>9.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coris caudimaculatus</td>
<td>122</td>
<td>5.1</td>
<td>4.3</td>
<td>70.8</td>
</tr>
<tr>
<td>Oxyechelinos orientalis</td>
<td>56</td>
<td>2.3</td>
<td>2.0</td>
<td>45.8</td>
</tr>
<tr>
<td>Pteragogenus polyclus</td>
<td>46</td>
<td>1.9</td>
<td>1.6</td>
<td>54.2</td>
</tr>
<tr>
<td>Thalassoma ruppellii</td>
<td>6</td>
<td>0.3</td>
<td>0.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Species Total</td>
<td>23</td>
<td>1.0</td>
<td>0.8</td>
<td>16.7</td>
</tr>
</tbody>
</table>
The number of fish individuals ranged from 26 individuals per transect in 5 m depth to 139 individuals within the same depth with an average of 103.5 fish per transect. The number of fish individuals ranged from 44 individuals per transect in 10 m depth to 175 individuals within the same depth with an average of 97.7 fish per transect. The number of fish individuals ranged from 46 individuals per transect in 5 m depth to 763 individuals within the same depth with an average of 218.0 fish per transect. The number of fish individuals ranged from 18 individuals per transect in 30 m depth to 79 individuals within the same depth with an average of 51.3 fish per transect (Fig. 49).

The average species richness ranged from 1.4 per transect in 5 m depth to 4.3 within the same depth with an average of 2.7. The average species richness ranged from 1.6 per transect in 10 m depth to 3.1 within the same depth with an average of 2.5. The average species richness ranged from 1.7 per transect in 20 m depth to 3.6 within the same depth with an average of 3.0. The average species richness ranged from 1.1 per transect in 30 m depth to 2.4 within the same depth with an average of 1.9 (Fig. 50).
4.4.2 Dominant Taxa and Fish Community parameters

Heniochus diphreutus is the most abundant species on the surveyed area, followed by Lethrinus variegates, Parupeneus forsskali and Dascyllus trimaculatus. The coral reef fish assemblages along the Jordanian coast showed completely different picture. The most abundant fish species among the Jordanian reef were Pseudanthias squamipinnis, Pomacentrus tichorous, Chromis dimidiate and Dascyllus marginatus (Khalaf and Kochzius, 2002).

In terms of relative abundance of families, the coral reef fishes along the Jordanian coast are dominated by non-commercial coral reef fish families such as Pomacentridae, followed by Anthininae (subfamily of Serranidae) and Labridae (Khalaf and Kochzius, 2002). Visual censuses of fish assemblages in this study revealed that dominance of the non-commercial important fish families such as Chaetodontidae, followed by commercial families such as Mullidae and Lethrinidae.

The sea grass beds play significant role in harboring juveniles of various commercial fish (e.g. Lethrinids, Siganids and Mullids). Availability of food, shelter and protection from...
predators within the sea grass lattice contribute to the nursery functions of these habitats. Hence, understand well the contribution of grass beds to coastal fisheries in terms of fish distribution, species composition and spawning seasons. The present survey revealed an average of 117.6 fish per 50 m transects line and average Shannon-Wiener diversity ranged from 0.8 to 2.6.

A total of 40 fish species belonging to 22 families were reported during this study. The number and diversity of fish species inhabiting the survey site are typical of sea grass beds sandy bottom habitats. The percent number of species per family showed the following rank: Labridae (12.5%), Pomacentridae and Scorpaenidae (10.0%, each), Mullidae and Serranidae (7.3%, each). These five families account for 47.3% of the total population. Some of the fish species observed can be characteristic of this site and not abundant elsewhere on the Jordanian coast.

### 4.4.3 Composition of fish species in the study area

The following is a list of some fishes that characterizes inhabits or utilizes the sea grass habitat at the northern most tip of Gulf of Aqaba:

1. *Heniochus diphreutes* (Pennantfish): This species is found in large aggregations in the water column above sandy flats or sea grass beds. It is the most abundant species and it forms 23% of the total population. In the studied area, juveniles were seen to live among the spines of the sea urchins or having shelters of solid substrates such as rocks, tires…etc.

2. *Lethrinus variegates* (variegated emperor): *It is the second abundant fish species. It forms 15.7% of the total population. Similar to L. borbonicus, this fish utilizes the sea grass beds.*

3. *Parupeneus forsskali* (Red Sea goatfish): This fish species is distributed along the Jordanian coast. Juveniles of this species live in mixed schools with other goatfishes (*P. macronema*) in sea grass beds and forms 6.6% of the total population within the studied area. Adult fish may stay in sea grass or may migrate to the sandy bottoms around the reefs. It feeds on a wide variety of small animals particularly crustaceans and worms.

4. *Dascyllus trimaculatus* (the Domino): This is a coral reef species found in the surveyed area. In their primary habitat, coral reef, the juveniles used to live in association with sea anemones. However, in the present studied area, it was seen hiding among the spines of the sea urchins with size range between 10 to 20 mm.

5. *Pseudanthias sqamipinnis* (the sea goldi): This is a common species inhabits the coral reef areas. It lives in aggregations. It is found in the area over solid substrates (such as rocks, containers and tires).

6. *Upeneus pori*: This is a common species and can only be seen at the northern part of the Jordanian coast. It inhabits shallow coastal waters off sandy flats and the sea grass beds. This species lives at depth range of 1 to 20 m. It feeds on benthic invertebrates.

7. *Scolopsis ghanam* (Arabian threadfin bream): This is a common species of inshore water usually found over sand flats. It forms about 1.5% of the total population in the studied area. Most of the recorded individuals of this species in the area are juveniles and with size range of 20 to 40 mm. The fish was seen hiding among the leaves of the sea grass beds and utilizes it for shelter as well as for feeding on the epiphytic invertebrates.
8. *Siganus rivulatus* (Rivulated rabbitfish): The species live in schools and inhabit shallow water around sandy and sea grass meadows. It forms 4.3% of the total population of the studied area. Most of the recorded individuals are juveniles observed to live among sea grass beds and use it for shelter and for feeding on the benthic algae.

9. *Teixeirichthys jordani* (Jordan’s damselfish): This species lives in aggregations over sea grass areas and sandy beaches. Juveniles are often found among the spines of the sea urchins in the studied area. This is the first report about its assemblages and their habitat along the Jordanian coast during a long term monitoring program carried out by the first author.
5. General Impacts and Mitigation Measures

5.1 Evidence of Existing Pollution or Environmental Degradation

Nearby the channel front of RDC project site the fish cages are located to the eastern direction in Eilat’s water. This is known to produce high amounts of nutrients leading to eutrophication, which was attributed to be the cause of coral degradation at Eilat’s reef (Loya et al., 2004). Previous results obtained at the project’s site have shown increased concentrations for ammonium and nitrate during summer time compared with other sites, which may indicate a slight contamination due to the fish farms in Eilat where some wastes may be released. During winter, the concentration difference may disappear because of vertical and horizontal mixing which increase nutrient concentration to high levels. It is also noticed that zooplankton is lower at the project site. In the near future, another project close to the RDC site, Saraya Al-Aqaba resort will be constructed and will have various effects on the neighboring marine environment, therefore any future Environmental Impact Assessment study (EIA) should take into consideration the cumulative effects of both projects on the marine environment.

5.2 Impact on the Existing Environment

This project is unique in terms of the amount of water that is going to be pumped from the sea and was not implemented before at this level. Therefore, no data exist on similar projects regarding the effects on the marine environment that might arise upon construction and operation of the project.

The effects of the RDC project on the marine environment are dependant on the way that the canal will be designed and constructed and the method that will be used to intake seawater from the water body of the Gulf of Aqaba. The amount of water pumping is very high (60 m³s⁻¹) and its effect on the velocity of water currents depends on the dimensions of the exit channel and/or the pipes that will be used to intake seawater. A small diameter outlet would lead to a significant increase of water currents around the outlet, while a wide and deep channel will have smaller effects on water velocity. In the later case, a 10 m wide with 2 m deep channel will lead to >10 folds increase in current velocity at the vicinity of the channel opening. The smaller in the outlet dimensions, the more increase in water velocity and vice versa. The increase in water velocity will lead to an increasing turbidity of seawater at the project site, which in turn will reduce light penetration in the water column. Furthermore, the water pumped is going to be replaced from neighboring water body of the gulf, and due to the presence of fish farms close to the project site, which is considered as a source of nutrients, eutrophication is also expected to happen at the project site.

The results of the benthic cover survey have shown that the project site is mainly characterized by sea grass habitat with some scattered coral cover and other benthic invertebrates. The sediment has also many types of foraminiferans, crustaceans, bivalves, mollusks and algae, which live on and within the bottom sediment. Seagrasses are the only group of higher plants that have adapted to life submerged under the sea. They are considered as the most productive of the global ecosystems (Klumpp et al., 1989). They have a fundamental role in primary production and main tendencies as feeding and breeding grounds for fish, shrimps and other invertebrates (den Hartog, 1977; Haywood et
Sea grass meadows influence benthic biogeochemical processes through their growth and metabolism (Marba and Duarte, 2001). Seagrasses reduce current velocity and increase sedimentation rates of finer sediment sizes (Heiss et al., 2000; Peterson et al., 2004) and act as a sink for nutrients (Connell and Walker, 2001). On the other hand, foraminiferans are important in the biogeochemical cycle of the sea and act as a sink for calcium carbonate in the sea bottom. The macroalgae, which live at the sea bottom reduce water movement, increase sedimentation and reduce turbidity, thereby increase light penetration of the water column (Madsen et al., 2001). Macrophytes beds provide important services to the ecosystem; improve water quality, reducing sediment re-suspension, erosion and turbidity (Madsen et al., 2001). Furthermore, bivalves, such as oysters and clams, as a direct result of their suspension-feeding activity, serve to reduce concentrations of phytoplankton and suspended inorganic particles, reduce turbidity and help re-store sea grass, which in turn reduce sediment re-suspension and improve light condition (Newell and Koch, 2004).

The forthcoming are some of the potential detrimental effects expected to come about during construction and operation processes of the project. They are mainly based on literature information on similar or close situations and the personal experience and represent at the time being a pure expectations rather than being facts.

5.2.1 Destruction upon dredging

Upon construction of the opening water channel, the benthic habitat at the channel front will be destructed as a result of dredging. This is unavoidable destruction as the way for the channel must be dredged. Dumping of materials dredged has other detrimental effects on the marine environments. Dredging will also result in increasing the rate of sedimentation in the neighboring marine environment. The water body is expected to carry more fine sediment particles, which takes longer time to settle at the sea bottom, leading to a turbid water body. Once this fine sediment settles down, the bottom will turn into muddy rather than being sandy. This muddy sea bottom is known to decrease growth rate of benthic marine organisms, such as bivalves (Grizzle and Morin, 1989), which plays a vital role in the marine ecosystem.

5.2.2 Effects of increased water velocity, water turbidity and sedimentation on the marine environment

The effects of currents velocity on the marine environment depend on the extent to which water currents are increased or decreased. Water motion has a profound effect on the physiological ecology of organisms living in fluid environments, through its effect on the diffusive boundary layers of organisms that use their body surface for exchange of metabolites (Gardella and Edmunds, 2001). Current velocity also affects the stability of sediments in the sea, water turbidity, light penetration, ability of organisms to capture prey and settlement of juveniles on hard substrates.

The project site is mainly covered by seagrasses. The distribution of seagrasses is controlled by a range of environmental conditions including light availability, nutrient availability, water motion and grazing (Longstaff and Dennison, 1999). Seagrasses decline as a result of eutrophication-induced lower light levels reaching sea grass as a consequence of phytoplankton in water column and decreased water clarity (turbidity) by sediment re-suspension (Newell and Koch, 2004). If seagrasses start to decline, more sediment may be re-suspended and water clarity will decline even further (Newell and Koch, 2004). Moderate increased of flow speed in addition to nutrients enhance the growth rate, morphology and composition in aquatic plants (Crossley et al., 2002). The leaf biomass, width, and canopy height increase with moderate increase in current velocity. It is
important for pollination and reduces boundary layer and thereby increases photosynthesis (Ackerman, 1986; Short and Neckles, 1999). It also enhances the ability of seagrasses and the associated epiphytes to remove nutrients from the water body (Cornelissen and Thomas, 2002). The low water movement also enhances growth and production of macroalgae, while high water movement reduces their growth (Hurd, 2000; Madsen et al., 2001). The increased current velocity will produce greater re-suspension of sediments, an increase in turbidity, and an overall reduction in the amount of light reaching sea grass beds, thus having a negative impact on habitat (Short and Neckles, 1999). Water turbidity is also caused by factors such as sediment during dredging activities, strong winds, flooding (Longstaff and Dennison, 1999). Over time, turbidity will lead to a decrease in shoot density, biomass and canopy height and eventually death of seagrasses (Longstaff et al., 1999; Longstaff and Dennison, 1999). The increase in current velocity may also lead to erosion of sea grass (Short and Neckles, 1999) and other benthic organisms.

Sedimentation, hydrodynamics, and recruitment processes are important determinants of coral reef’s structure (Rajasuriys et al., 1997). A moderate increase of flow speed will lead to increased energy intake by increasing zooplankton capture and thereby increasing growth rates in corals (Sebens, 1984). Such flow rate also leads to increased rates of net photosynthesis, dark and light calcification in corals (Dennison and Barnes, 1988). While, high flow speed lead to reduced growth rate and increased mortality rate in corals (Sebens et al., 2003). The corals produce larvae during their sexual reproduction. These larvae are released in the water column until they settle down (i.e. recruitment) on a hard substrate and develop into a small coral colony. Larval dispersal and recruitment are important factors that determine the distribution and species composition of adult corals (Wallace, 1985; Harii and kayanne, 2003). The dispersal distance of larvae is determined by their position in the water column, the currents that deliver the larvae, and the competency period of the larvae (Harii and kayanne, 2003; Miller and Mundy, 2003). At moderate flow rate, the larvae are dispersed and find suitable hard substrate, where they settle and form colony (Ben-Yosef and Benayahu, 1999). But at high current velocity and high sedimentation rates, the time passes without being able to settle on a hard substrate and therefore the larvae die leading to a decreased reef development capacity (Wallace, 1985; Gilmour, 1999). Likewise, low sedimentation rate (Sato, 1985) and moderate flow rate are important for the survival of juvenile corals. The long term exposure of hard and soft corals to high rates of sedimentation lead to tissue necroses and death of colony, although hard corals have the ability to clear their body from sediment until certain limit (Riegl, 1995). Furthermore, the presence of unstable substrates due to water movement will increase death of coral transplants (Lindahl, 2003). In order to mitigate the negative impacts that were mentioned above, the water intake method should be taken into consideration. Using an open water channel instead of any other alternative methods (such as a pipeline) is one of the important mitigation measures that can be done. This channel should be designed wide and shallow as much as possible with the needed pumps being installed a way from the channel entrance and not in the sea, which will have little influence on the water turbulence and current speed near the channel entrance and thereby will have little effect on the nearby open sea.

### 5.2.3 Effects of eutrophication on the marine environment

As mentioned above, the RDC project site is located close to the fish farms in Eilat. The fish farms produce high amounts of nutrients in the seawater. At present, the distribution of nutrients is governed by natural water currents and mostly produces local influence on the marine environment at Eilat. It is possible, that pumping of water from the northern part of the Gulf of Aqaba will produce a temporary decrease of sea level at the vicinity of the
outlet channel. This water level decrease must be replaced from neighboring water body. Since the fish are very close to the project site, then water replacement will be in part from the water around the fish farms. In this case, the water replaced is going to bring more nutrients to the project site in the flow direction. Such assumption needs further investigation and must be taken into consideration for any future modeling of the impacts of the RDC on the marine environment.

5.3 Mitigation Measures to Reduce Expected Negative Impacts on the Marine Environment

Some of the above mentioned potential effects of the RDC project on the marine environment can be avoided and/or minimized if suitable precaution measures are used during the construction and operation of the project. Followings are suggested mitigation measures that can be applied;

5.3.1 Destruction upon dredging

Destruction of the benthic cover upon dredging of the channel is unavoidable in essence. The only way by which this effect can be mitigated is through transplantation of the valuable benthic habitat to another area. Re-transplantation in the same area is possible after the end of construction process. Dumping of dredging material into the sea must be strictly prohibited. Upon dredging, the sedimentation rate is going to be increased drastically, but using water to spray the dredged sand will reduce its transport to the sea.

5.3.2 Water movement, sedimentation and eutrophication

The speed of water movement can be reduced by having the exit channel with dimensions that favor minimized increase of water currents. For example, a channel with 10 m width and 2 m depth would have a water flow rate of about 3 m/s based on a pumping rate of 60 m$^3$s$^{-1}$. The bigger channel dimensions the smaller water flow rate that will be produced. The presence of big rocks will reduce speed of water currents at a localized scale. This in particular important when small naturally existing micro-environment, such as coral micro-atolls found in the project site is needed to be protected. Special measures to reduce sedimentation rate can be taken during the construction and the operation processes. These include: spreading of water to trap dust during dredging and add borders such as rocks inside the water body to trap the sediment at the sea bottom. The sea grass meadows can naturally trap sediments as well as decreasing the water movement and thereby increasing sedimentation rates. Therefore, once finished with the construction process, a mass transplantation process of seagrasses in the project site is highly recommended. If an eutrophication problem arises from replacement of the pumped water by water from the neighboring fish farms, a solution is needed to mitigate this problem. A significant reduction of suspended particulate matter and nutrients can be achieved by treatment with the suspension feeders, like bivalves and macroalgae, which reduce suspended particulate matter, phytoplankton, bacteria and the associated nutrients (Jones et al., 2001). Such treatment is durable if these organisms are cultured and then implemented in the waters at the project site.

The project site is mainly covered by sea grass meadows and sandy areas. The restoration of sea grass is quick compared with the benthic community, which is considered more accurate indicator for the ecosystem health (Craft and Sacco, 2003). The benthic species might take much longer time for restoration. These organisms feed upon and regulate populations of smaller organisms, such as microalgae and meiofauna, provide food
resources for fish species and play an important role in the decomposition of organic matter. Finally, this project is very big and the outputs promised are huge, therefore it would be wise to implement it. But a more intense and careful study is still needed. Once operated, it is highly recommended to consider having a continuous monitoring program especially made for the project and the close neighboring marine environment.

In general, the site selected in this study is considered best compared with other sites along the Jordanian coast of the Gulf of Aqaba for conducting the RDC project. Though, further analysis and studies are still needed.
6. Bibliography


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Marin Environment Component Study / Proposed Red Sea/Dead Sea Conduit Project


Annex I

Chemical characteristics of surface water

Table I.1 Chemical characteristics of surface water at the study site (mean values obtained from 40 surface samples along the site during winter)

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<th>Chlorophyll a μg l⁻¹</th>
<th>Ammonia μM</th>
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Annex II

Textural Properties of Bottom Sediments

General

One representative sediment sample was taken per transect using cylindrical plastic tubes from the upper 5 centimeters of the sediment surface, by SCUBA diving. The plastic tubes were quickly punched in situ with rubber stoppers to prevent any contact with sea water or atmosphere, and then transferred to an ice box upon arrival to the laboratory. The color and odor of the sediments were recorded and the samples were dried to a constant weight in the sun (for 24 hours), desegregated, homogenized and the coarse material ($\geq 2$ mm shells of gastropods, bivalve, coral fragments.....etc.) were discarded at this stage. Representative sub-samples (100 g) were taken from the dried ones by quartering. Sub-samples were then subjected to grain size analysis using U.S standard sieves of size interval of 1 phi.

Grain-size statistics and parameters

The grain size statistical parameters were given in phi ($\Phi$) units. The phi unit ($\Phi$) is a logarithmic transformation of millimeters into whole integers, according to the formula:
\[ \Phi = -\log_2 d \]
Where $d$=grain diameter in millimeters. The parameters calculated from these analyses were carried out on the cumulative curve according to formulas given by Folk (1966, 1968, and 1974), and Friedman et al. (1992) and include:

- "mean grain size" is the average grain size and equals:
\[ Mgz = \frac{\Phi_{16} + \Phi_{50} + \Phi_{84}}{3} \]
Where $\Phi_{16}$, $\Phi_{50}$ and $\Phi_{84}$ represent the size at 16, 50, and 84 percent of the sample by weight.

- "sorting" is the grain-size variation of a sample by encompassing the largest parts of the size distribution.
\[ \sigma = \frac{\Phi_{84} - \Phi_{16}}{4} + \frac{\Phi_{95} - \Phi_{5}}{6.6} \]
Where $\Phi_{84}$, $\Phi_{16}$, $\Phi_{5}$, and $\Phi_{95}$ represent the phi ($\phi$) values at 84, 16, 5, and 95 percentiles.

- "skewness" measure the degree to which a cumulative curve approaches symmetry and equals:
\[ Sk = \frac{\Phi_{16} + \Phi_{84} - 2\Phi_{50}}{2(\Phi_{84} - \Phi_{16})} + \frac{\Phi_{5} + \Phi_{95} - 2\Phi_{50}}{2(\Phi_{95} - \Phi_{5})} \]
Where phi ($\phi$) values represent the same percentile as those for sorting. The verbal classification for sorting and skewness scales were taken from Folk (1968).

Color and odor

Simple and direct information about the sediment oxygenation state, which is one of the most important parameters in determining the biological productivity and the trophic structure, could be obtained from the color and odor of the bottom sediments.

The color scale of bottom sediments collected from the study area is shown in Fig (I.1). The figure was constructed depending on transforming the subjective colors to objective criteria by giving weights to the different sediment colors. The naturally white/brown...
Sediment has been given 1, naturally white/brown-gray 1.5, gray 2, gray-black 2.5 and black 3.

Fig. I.1 Color code of bottom surface sediment from the eight stations along study area at different depths. Data represent the average of three values (T1, T2 and T3) at each depth.

Sediments at the study area showed similar color properties and it was mainly gray/black (Fig. I.1). This is expected in this area since it hosts sea grass beds and composed mainly of silicate grains. The sediments at the Marine Science Station site (coral reefs area) for example exhibited white color, reflecting the mineralogy of the sediments, where high calcium carbonate content gives whiter sediment color. No distinctive smell was detected for any sample at any station, indicating well oxygenated sediments.

Grain size distribution and mud content

The results of grain size analysis were expressed as weight percentage of each of the classes separated. Graphical method was used to calculate the physical parameter of the sediments with the formula given by Folk & Award (1957) and Wentworth size classification was used to classify the sediment. Results for textural analysis for the studied sediment are shown in Table (I.1) and Fig's (I.2) and (I.3).

Surface sediments at the different stations along the study site were quite similar in textural properties and were within the sand grad. Both zones (A and B) and at all depths showed similar mean grain size (Table I.2). The median grain size diameters calculated were ranged between 2.22 to 2.33 phi (0.18-0.25 mm) for stations at zone A and from 2.06 to 2.51 phi (0.18-0.25 mm) for stations at zone B. These sediments are classified as fine sand.

On the basis of size analysis, the sorting coefficient of the studied sediments ranged from 0.68 to 1.0 and the sediments were classified as moderately sorted (Table I.2).
Fig. I.2 Cumulative curve distribution of the surface sediments within the investigated sites. Data represent the average of three values (T1, T2 and T3) at each depth.

Table I.1 Summary statistics and interpretation of the textural characteristics (mean grain size, sorting, skewness and mud content) based on cumulative curves for the studied sediment. Data represent the average of three values (T1, T2 and T3) at each depth.

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<th>Sorting (σ)</th>
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Fig. I.3 Percentage mass (% mass) against grain size (mm) values for sediments collected from study area. Data represent the average of three values (T1, T2 and T3) at each depth.

The average skewness values of the studied sediments were in the range between -0.09 and -0.3 and it can be stated that all sediments were coarsely skewed (Table I.1). At the study site, sediments had low mud contents (<63 µm) ranging between 1.16 to 3.6% at zone A and between 0.3 to 2.93% at zone B (Table I.1). The values of mud tend to increase with increasing water depth (Fig. I.4) due to calm water conditions and decreasing water activity with depth.
Fig. I.4 Mud content (%) of sediments collected from the study area. Data represent the average of three values (T1, T2 and T3) at each depth.

Generally, the variations in textural properties and mud contents could be ascribed to the variety of sediment sources, their response during currents and waves, and the seasonal variability and activity of benthic infauna. The sediment at the study area is fine sands, moderately sorted (homogeneous), coarsely skewed, this can be explained by the active waves and currents in this opened area due to absence of coral and rock bodies. A calm water condition doesn't exert much effect in sorting improvement of sediments, (Friedman 1968) and thus does not hinder or resist, if not enhances the accumulation of mud. This could be the reason for increasing the mud content in the sediments with increasing depth (Fig. I.4). The finest mean grain size of the sediments in the study area indicating relatively more dynamic water which leads to cleaning of sediments from very fine materials. These sediments composed mainly of silicate grains derived from land and nearby wadi (Wadi Araba)