Thetis SpA

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Israel Oceanographic & Limnological Research Ltd.

Red Sea - Dead Sea Water Conveyance Study Program

Additional Studies

Red Sea Study

Inception Report

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TABLE OF ABBREVIATIONS

MOCNESS	multiple opening–closing net and environmental sensing system
RDC	Red Sea – Dead Sea Water Conveyance Project
GOAE	Gulf of Aqaba-Eilat
ADCP	Acoustic Doppler Current Profiler
HF	High Frequency
NMP	National Monitoring Program
POM	Princeton Ocean Model
NPZ	Nutrients, Phytoplankton, Zooplankton

1 Introduction

The goal of the proposed Red Sea – Dead Sea Water Conveyance Project (RDC) is to pump sea-water from the northern end of the Gulf of Aqaba and transfer it to the Dead Sea where it will be used for multiple purposes including desalination, generation of electricity, and stabilization and restoration of the water level of the Dead Sea. In some scenarios up to 2 billion cubic meters of water would be pumped from the gulf every year. It is quite likely that removing this amount of water from the northern gulf will have an effect on various aspects of the marine environment. Clearly the most noticeable impact will occur in the immediate vicinity of the intake; however there may also be cumulative effects resulting in slower, long term changes that may be felt at much larger distances. The proposed study aims to critically examine (go-no-go assessments) potential impacts of the RDC project on the marine environment of the northern Gulf of Aqaba/Eilat (GOAE) specifically, as well as the overall, long-term, large-scale impacts. Possible environmental impacts on the Gulf include changes in the circulation, modification of animal distribution and habitats, and possible effects on the dynamics of natural and anthropogenic chemical elements.

Potential changes in the circulation, especially in the nearshore zone, are expected to be a major driving force of all other impacts. There is no doubt that the circulation in the immediate vicinity of the intake will be directly affected in the short-term by the construction activities and over the long-term by the abstraction of large amounts of water during the operational phase. Depending upon the location of the intake, one could expect a synergetic interaction between various effects. For example, for a proposed intake site in the north beach area, internal waves associated with the reflection of the internal tide near the head of the gulf could produce a significant and interesting additional impact on the local flow. The general approach to addressing these issues will consist of a combination of analysis of exiting data, collection of new data as necessary to fill in gaps, and the application of a suite of numerical models designed to simulate the circulation on multiple spatial and temporal scales.

Of greatest concern are the potentially detrimental impacts of the RDC project on the biological connectivity among the coral reefs in Aqaba and Eilat. The lifecycles of most coral reef species involve a larval stage, during which dispersal is achieved and which ultimately defines the demographic and genetic structures of adult populations and communities. Disruption of larval transport by anthropogenic activities has been proven to be an important factor in adversely affecting marine ecosystems in other locations. In the gulf, it is expected that changes that adversely constrain larval transport would quickly cascade to the state of the whole reef. At present very little is known about the pathways of the coral reef species larvae in the northern gulf. In order to assess the potential risk of entrainment of nearshore larvae into the intake, it will be crucial to investigate and understand the present transport patterns through coordinated field measurements.

If approved, construction of the Red Sea – Dead Sea Water Conveyance will take several years and when completed it is expected to operate for many decades. Therefore in addition to the immediate impacts of the construction and pumping it will be necessary to consider the potential effects of anthropogenic climate change as well as anticipated changes in the pollution load and distribution into the northern gulf. These aspects will also be addressed in the proposed study through the combined use of model simulations and the analysis of the best information available concerning these anticipated changes.

The present report represents the Inception report of the project and it aims:

- to briefly present the study team and main scientific, technical and managerial experiences of groups involved (chapter 2);
- to give an introduction on the environmental context of the project (the Gulf of Aqaba/Eilat) (chapter 3);
- to describe the activities foreseen by the project, the technical approach and the methodologies to be applied (chapter 4);
- to present the organization chart of the project (chapter 5);
- to present a list of information which are needed by the study team to achieve the expected results (chapter 6).

Chapter 7 reports a preliminary list of relevant scientific references, concerning several topics of interest for the study.

2 Red Sea Study team

The study will be carried out by **Thetis S.p.A**. (Italy), in collaboration with the following Institutions:

- **Interuniversity Institute for Marine Science in Eilat (IUI)**
  Israel
- **Marine Science Station in Aqaba (MSS)**
  Jordan
- **Israel Oceanographic and Limnological Research (IOLR)**
  Israel
- **Prof. S. Monismith (Stanford University)**
  California USA

Thetis is an **Engineering and Consultancy** company providing management, projects and innovative technologies for environmental remediation and the sustainable development of the territory, mobility management and implementation of knowledge systems.

Thetis expertise in the field of sustainable development has grown within the context of a unique ecosystem, today one of the most complex and fragile of the world: the Venice lagoon.

Thetis business areas are:

- Environmental and Territory engineering;
- Civil engineering and construction supervision;
- Intelligent Transport Systems engineering;
- Knowledge systems engineering.

Thetis originates in the early 90's and the Consorzio Venezia Nuova, concessionary of Ministry of Infrastructures (Venice Water Authority) is the main shareholder; share capital is Euro 11,288,985, while last three years turnover was (millions Euro): 24 in 2008; 19 in 2007; 18 in 2006.

The permanent staff is composed of about 150 people, while long-term consultants are more than 50.

Company's operating methods are directly derived from the procedures and experience that the company has gained from its work on large international engineering projects. This constitutes a guarantee that Thetis will achieve the envisaged results with respect for times and costs and in the context of a highly professional relationship with the Client.

Thetis has the following quality certifications:

- Quality Management System – UNI EN ISO 9001:2000;
- Environmental Management System – UNI EN ISO 14001:2004;
- EMAS II Certification – European regulation (CE) 761/2001;
- SINAL Accreditation – UNI CEI EN ISO/IEC 17025:2000.

Thetis offers a multidisciplinary and systems-engineering approach to environmental problems and provides integrated and sustainable solutions to complex issues. This capability is complemented with specific competences on various environmental topics such as: territorial planning, in particular as far as waters are concerned; remediation of polluted sites; integrated coastal zone management; sediment management; oceanographic and pollution monitoring and modelling.

The Interuniversity Institute for Marine Sciences in Eilat (IUI) originally started in 1968 as the marine station of the Hebrew University of Jerusalem. In 1982 it was officially declared as the Inter-University Institute (IUI) of marine sciences, a national research and teaching institute, directed by all the universities in Israel which directly reports to the Israel Council of Higher Education. The academic activities of the IUI are presently based on a resident faculty of six senior researchers, along with 10-20 non resident scientists from all Israeli Universities. Including graduate students and technical and administrative employees the IUI staff totals about 80 full time and part time workers. Research and teaching areas include marine biology and chemistry, physical and chemical oceanography, marine microbiology, physiology and ecology. Focus is on the open sea, as well as on the coastal coral reef ecosystems. Research is both basic and applied with strong orientation towards global and local (i.e., the unique ecosystems of the Red Sea and the Gulf of Aqaba) ecology. All IUI activities are closely coordinated with the Ministry of the Environment, the National Park Authority (NPA) and the Israel Institute for Limnology and Oceanography (IOLR).

The IUI faculty participated in numerous research programs, both personal and institutional. Some major regional cooperation programs (with Egypt and Jordan) are mentioned below. The IUI is responsible for the Israeli section of the National Monitoring Program of the Gulf of Aqaba sponsored by the Israel Ministry of the Environment.

Over the years, a substantial amount of oceanographic and coral reefs data has accumulated, which is administrated by the IUI database Center.

The Marine Science Station Aqaba (MSS). [in cooperation with Aqaba Special Economic Zone Authority (ASEZA)]. The Jordanian Marine Science Program was initiated by the University of Jordan in 1974. The present MSS campus was established in 1976-1980. The facilities of the MSS were used in 1981 which witnessed the agreement between the university of Jordan and Yarmouk University. Then, the two universities participated in the administration and operation of the station, contributed to its budget and supported its scientific and technical staff.

Among objectives of the MSS are to provide a description of the circulation regime in the northern part of the Gulf of Aqaba and to assess its effects on the spreading of various tracers and pollutants; to conduct field surveys on flora and fauna distribution and diversity of Gulf of Aqaba; to study the effects and impacts of pollutants on the marine environment of the Gulf of Aqaba; to perform field surveys and environmental monitoring programs in the Gulf of Aqaba; to contribute to the undergraduate and postgraduate academic programs of both the university of Jordan and Yarmouk university in the fields of environment and marine sciences.

The MSS activities in the Gulf are closely coordinated with the Aqaba Special Economic Zone Authority (ASEZA), which is in charge of all aspects (economic and ecological) associated with the Jordanian section of the Gulf of Aqaba.

Israel Oceanographic and Limnological Research (IOLR) is a national, government-owned, research institution (non-profit governmental corporation) established in 1967 with the mission of generating knowledge for sustainable use and protection of Israel's marine, coastal and freshwater resources. IOLR conducts scientific research and provides professional services in the fields of oceanography, limnology, mariculture and marine biotechnology.

Much of IOLR's scientific effort is focused on research, monitoring and assessment of the environmental status of Israel's neighboring sea areas (eastern Mediterranean and the Gulf of Aqaba/Red Sea) and inland water bodies (Lake Kinneret and the Dead Sea) and predicting their response to human and natural perturbations. IOLR's diverse program of research includes environmental monitoring and technology, development bridges among many different scientific disciplines including physics, chemistry, geology, biology and ecology, and involves collaboration with academic and research institutions within Israel and world-wide.

IOLR also provides a wide range of professional services to the public and private clients including hydrographic, oceanographic and water quality surveys, analyses and modelling; environmental monitoring and assessment; and, professional consulting. IOLR has a proven track record on conduct of environmental assessments of development projects. Noted recent examples include a feasibility study for the construction of artificial islands off the Israeli Mediterranean coast, environmental impact assessment for the Haifa Port expansion project, and environmental assessments of marine disposal of dredge spoils and industrial effluents.

IOLR has a staff of approximately 170 scientists, engineers, technicians and support personnel. In addition, graduate students and visiting scientists from Israel and abroad are involved in the activities of IOLR's 3 research centers: the National Institute of Oceanography located in Haifa, the Yigal Allon Kinneret Limnological Laboratory located at Tabha (Sea of Gallillee), and the National Center for Mariculture at Eilat. The Headquarters of IOLR is located at the National Institute of Oceanography.

The IOLR maintains advanced research facilities including: research vessels and survey craft; equipment for surveying and sampling the deep sea, coastal waters and inland water bodies; remote data stations; analytical laboratories; and indoor and outdoor experimental facilities. The IOLR has official approval of the Ministry of Environment for performing compliance marine monitoring programs. The Marine Chemistry Department of IOLR is accredited by the Israel Laboratory Accreditation Authority for analyses of water, seawater, sediments and organisms.

The Israel Marine Data Center (ISRAMAR) at IOLR serves as the national repository and dissemination facility for oceanographic data and data products. The ISRAMAR operates within the framework of the International Oceanographic Data and Information Exchange system (IODE).

Within the Red Sea Study the following roles and contributions have been generally agreed:

- Thetis (THE) will act as the team leader and contractual front-end towards the customer, ensuring the necessary effort in terms of project management and coordination. In addition Thetis will be responsible for the quantification of the pollution loads entering the GOAE, for the assessment of environmental and socio-economic effects on the coastal zone and the shoreline, for the reporting and for creation of the project geodatabase;
- The Interuniversity Institute for Marine Sciences in Eilat (IUI) will provide expertise in the fields of physical oceanography and marine biology, taking up the responsibility for most of the modelling and monitoring activities;
- The Marine Science Station Aqaba (MSS) will provide expertise in the fields of chemical oceanography, marine biology and ecology. They will directly take up or participate into the monitoring activities based in Jordan and contribute to many other tasks providing knowledge of the characteristics of the Jordanian side of northern GOAE;
- Israel Oceanographic and Limnological Research (IOLR) will provide expertise in the fields of physical and chemical oceanography and marine biology and ecology, taking up the responsibility or participating to most of the environmental assessment activities;
- Prof. S. Monismith will provide expertise in the field of physical oceanography, participating in the activities involving analysis and exploitation of data from hydrodynamic monitoring and modelling activities.

3 The environmental context

The Gulf of Aqaba/Eilat (GOAE), which is part of the Syrian-African rift valley, is a long (180 km), narrow (5-25 km), and deep (average 800 m, maximum 1800 m) northward extension of the Red Sea. It is connected to the Red Sea through the Straits of Tiran where the sill depth is approximately 250 m. The Gulf is located in an arid region with annual rainfall of less than 30 mm and the surface runoff is practically zero. The best estimate for the annual mean evaporation from the surface is 1.6-1.8 m (Ben-Sasson et al., 2009).

The Gulf is a concentration basin in which less saline water enters through the straits in the upper layer and the more saline water, formed in the gulf due to excessive evaporation, flows out near the sill depth (Murray et al., 1984). Estimates of the water exchange through the straits, based on the observed thermohaline structure, vary between 30,000 – 70,000 m^3/s. The volume of surface water loss through evaporation is much smaller than the volume of water exchange through the Straits as in other concentration basins such as the Mediterranean Sea. While this loss is compensated by in-flow through the Straits, it is this small imbalance that drives the overall subtidal circulation.

The surface temperature varies between 21°C in winter and 27°C in summer. Since the deep water is formed locally (in the gulf), the deep water temperature remains at just below 21°C throughout the year (NMP reports 2003-2010). The salinity is among the highest in the world ocean and is around 40.68 ± 0.2 psu. The variations are due mainly to the high surface salinity in summer and the inflow-ing, less saline Red Sea water which appears as a subsurface salinity minimum in spring and sum-mer.

The seasonal dynamics of the GOAE is unique for a warm, sub-tropical water body, as water column stability changes from stably stratified conditions in the summer to unusually deep (350->850 m) mix-ing in the winter. Consequently, the concentrations of nutrients in the upper water column change from extreme depletion during the summer, to nutrient-replete conditions and phytoplankton bloom during winter-spring. Nearly all year a sharp nutricline exists, with relatively high nutrient concentra-tions in the deep water (e.g. reaching 6-7 µM NO_3 at 500-700 m depth).

The water quality of the Gulf changes naturally over an annual cycle due to changes in the density structure of the water column. During the winter cooling at the surface causes convective mixing which can deepen the mixed layer down to >850 m (Genin et al., 1995) transporting nutrient rich deep water to the surface, which supports increased levels of productivity both in the open water and in benthic habitats along the coasts. During the summer warming at the surface causes stratification of the water column (6ºC thermocline from the surface to 250 m depth) leading to nutrient depletion in the surface water and substantially reduced rates of productivity both in the open sea water col-umn and shallow benthic habitats. These changes in density structure influence and are influenced by the general circulation of the Gulf both vertically and horizontally.

The unique morphological characteristics and climate of the Gulf set the stage for a delicate balance between the physical/chemical environment and the species rich ecosystems characteristic of oligotrophic oceanic regions, which have managed to develop and thrive within its boundaries.

Previous studies have shown that ecosystem in the GOAE is strongly dependent on physical and chemical conditions, which have been shown to be perturbed both by short term changes in climate (Genin *et al.*, 1995), naturally occurring extreme phenomenon such as extreme low tides (Loya, 2004) as well as man made perturbations.

A very important component of Gulf ecosystem is represented by coral reefs.

Fringing coral reefs are the overwhelmingly dominant form along the shores of the GOAE. At greater depths, down to at least 65-70 meters, coral carpets covering marginal slopes are abundant. Growth of these deep reefs is facilitated by the clarity of the water that allows light penetration to a depth of ~100m.

The presence of a shallow sill at Bab-el-Mandeb greatly affects the extent and diversity of the coral reefs in the Red Sea, especially those at higher latitudes in the Gulfs of Aqaba and Suez. Unlike “normal” open oceans, where the deep and intermediate water found in the tropics and subtropics is cold, the shallow sill at Bab-el-Mandeb effectively separates the deep waters in the semi-enclosed Red Sea from those in of the Indian Ocean. For example, the water at 1500 m depth in the Gulf of Aden, (the water body connecting the Red Sea to the Indian Ocean), is <10ºC, whereas the deep waters at this and greater depths in the Red Sea including its deepest zone, is always warmer than 20ºC. This characteristic determines the lowest temperature the shallow water can be cooled down to during winter. The ensuing year-round occurrence of warm waters allows coral reef to flourish as far north as the northernmost end of the GOAE.

On the other hand, the occurrence of warm water at depth substantially weakens vertical stratification. For example, below ~300 m, the vertical gradient in temperature in the Gulf of Aqaba is ~0.09ºC / 100 m, compared with more than an order of magnitude steeper gradient in “normal” oceans at a similar latitudes (e.g., 1.07ºC/100 m south of Bermuda, 1.67ºC/100 m at the Central North Pacific).

The weak stratification in the Gulf of Aqaba, together with low air temperature during winter, drives an extraordinarily deep vertical mixing, reaching exceeding >600 m depth, in cold winters. The most striking phenomenon driven by this is the recurrence of immense spring blooms of benthic algae that cover wide sections of the local reefs, sometime causing substantial coral death (Genin et al., 1995). This “intermediate” disturbance, occurring once every 5-20 years, can be one of the processes responsible for the maintenance of the high coral diversity in the Gulf (Connel 1978). Note, however, that the occurrence of deep mixing is limited to the Gulf of Aqaba, at the northern end higher-latitude part of the Red Sea. Air temperature at lower latitudes, south of the Straits of Tiran, is too high to induce deep mixing, even during the winter (Paldor and Anati, 1979; Reiss and Hottinger, 1984).

While its connection with the Indian Ocean places the biogeographic origin of Red Sea fauna and flora within the Indo-Pacific domain, it's setting and geological history make for unique conditions that have direct bearing on the development of reefs along the coasts of this elongated narrow sea. The reefs are dominated by stony, hermatypic corals, consisting of a diverse mixture of branching, foliose and massive species. Most abundant are corals belonging to the genera *Acropora, Stylophora, Montipora, Pocillopora, Porites, Platygyra, Pavona, Echinopora*, and *Favia* (Loya and Slobodkin 1971). The hydrozoan *Millepora* is very abundant in the shallow, sub-tidal zone. Soft corals are also abundant throughout the Red Sea, dominated by *Sinularia, Sarcophyton, Lobophyton*, and Xeniids, with magnificent thickets of nephtheids (mostly *Dendronephthya*) found on elevated substrates and vertical walls exposed to strong currents (Benayahu and Loya 1977). Due to the clear water in the northern Red Sea, zooxanthellate corals reach at least 145 m in depth (Fricke et al. 1987).

The number of coral species found in the Red Sea is approximately 190, belonging to 70 genera (Head, 1987). While the total number of species is generally higher in other tropical Indo Pacific reefs (e.g., ~360 species in the Great Barrier Reef- Veron 1986), the local, within-habitat diversity in the Red Sea is higher than in GBR (Loya 1972).

The fishes in the Red Sea coral reefs, like corals, share an Indo-Pacific origin. Especially abundant and diverse are the guilds of site-attached and mobile zooplanktivorous species, schooling and individual herbivorous fish, including acanthurids, siganids, and scarids, and many benthic predators, including serranids and balistids. Of the 462 reef-associated species that inhabit the Arabian Sea, 69% have crossed successfully into the Red Sea; of these, 55% have crossed into the Gulf of Aqaba. Present-day differences in the species richness of reef associated species among the Arabian Sea, Red Sea and Gulf of Aqaba appear to be the product of external, non-selective constraints on colonization (Kiflawi et al. 2006).

The Red Sea coral reefs are among the most studied reefs in the world. Detailed accounts of their structure and biological composition can be found in numerous publications. Useful references include Loya and Slobodkin (1971), Mergner (1971), Scheer (1971), Fishelson (1971), Benayahu and Loya (1977), and Edwards and Head (1987).

During the last four decades, the coral reefs of Aqaba and Eilat have undergone major changes resulting from increasing impacts due to human activities, coupled with those from natural disasters (e.g., Genin et al., 1995; Meir et al., 2005, Rinkevich, 2005).

Rapid developments in the cities of Eilat and Aqaba during the past few years have intensified the pressure on the coral reefs of the Gulf, including phosphate loading, touristic projects and other anthropogenic activities. The increased diving industry also results in coral damages. Fortunately, stricter rules are being applied on the coastal human activities in both cities to reduce the negative impacts on the neighboring marine environment.

Moreover, the restoration and rehabilitation efforts on the damaged coral reefs have increased in the past years, such as the development of Artificial Reefs on both sides, as well as the establishment of coral nurseries to produce corals for transplantation in damaged reef areas.

4 Overview of project activities

4.1 Schematic identification of work methodology

The study will include the following main activities (see also Figure 4-1):

1. Collection and review of existing data and information. Such activities will start at the commencement date and will be completed by the middle of month 5, in order to timely contribute to the Best Available Data Report, to be delivered by the middle of month 6;
2. Additional monitoring of oceanographic, biological, geochemical and sedimentological parameters to complement the available information where needed. Due to the strong seasonality of phenomena a whole year of monitoring is needed for most parameters. Data processing and analysis will be carried out on a regular basis along with the field activity, in order to provide timely contributions to model set-up and impact assessment activities, and will be completed within month 13, in order to provide due input to the Draft Final Report, to be delivered by the end of month 14;
3. Set-up of numerical modelling tools (circulation model and simplified ecosystem model) for predictive use. Such activities will start at the commencement date and will be completed within 9 months;
4. Predictive use of numerical modelling tools. Such activities will start at the completion of the modelling tools set-up (end of month 9) and be completed within 2 months, in order to supply information to the impact assessment activities;
5. Assessment of relevant oceanographic and environmental impacts through the joint exploitation of existing data, newly monitored data and model outputs. Such activities will start at the beginning of month 12, when all the relevant inputs are made available, and be completed in 2 months time, in order to provide due input to the Draft Final Report, to be delivered by the end of month 14;
6. Production of deliverables: reports and geodatabase of collected and acquired data. Such activities will start at the commencement date and will be carried out through the whole duration of the assignment. The project geodatabase and the Draft Final Report will be delivered by the end of month 14, while the months from 15 to 18 will be dedicated to the review of the Final Report according to the World Bank comments and requirements;
7. Project Management, to be carried out through the whole duration of the assignment.

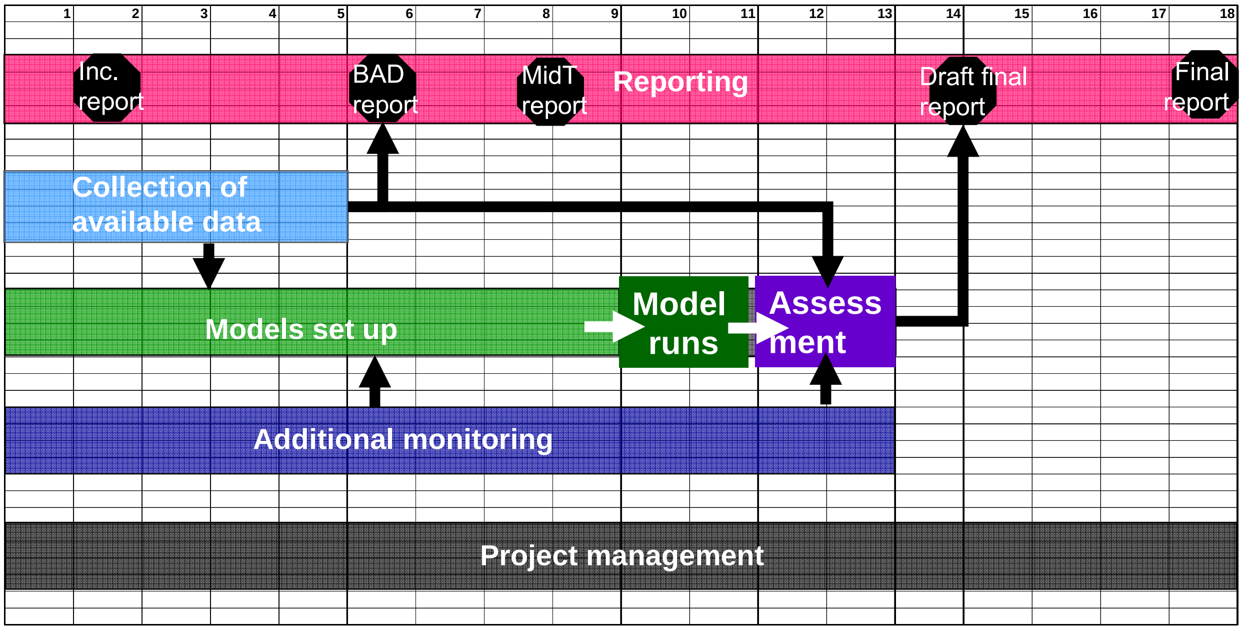

Figure 4-1 Schematic layout of the activities.

4.2 Technical approach and methodology

The study will consist in the following activities:

1. Collection and review of existing data and information;
2. Additional monitoring of oceanographic, biological, geochemical and sedimentological parameters;
3. Numerical modelling.

Methodologies for these activities are described in the following paragraphs (existing data par. 4.2.1, additional monitoring par. 4.2.2, numerical modelling par. 4.2.3).

Methodologies concerning other specific aspects requested by Terms of References are reported in the following paragraphs: climate change effects (par. 4.2.4), effects of development scenarios (par. 4.2.5), description of impacts of construction and operation on the coastal zone and shoreline (par. 4.2.6).

4.2.1 Collection and review of existing data and information

In this study we will provide an overview of the substantial body of scientific and monitoring literature that describes in detail the morphology, climate and salient chemical and biological conditions of the GOAE. This overview will provide a point of reference by which we will be able to assess how anticipated changes in climate and the impact of the RDC on local and general circulation patterns in the GOAE will affect its existing ecosystems.

The assessments will be based primarily on analysis of the available historical data collected in the Gulf during the past several decades (e.g. Klinker et al., 1978; Reiss and Hottinger, 1984; Krumgalz and Erez, 1984; Gordon et al., 1994; Badran and Foster, 1998; Plahn et al., 2002; Manasrah et al., 2004; Lazar and Erez, 2004; Herut and Cohen, 2004; Badran and Zibdah, 2005; Rasheed et al. 2005; Silverman et al., 2007; Lazar *et al.*, 2008) and from the data collected by the on-going monitoring activities, especially the joint Israeli-Jordanian National Monitoring Program.

<u>Water circulation</u>

The impact of the proposed RDC on the environment in the northern GOAE as well as the entire Gulf cannot be assessed without a sound understanding of water transport in the Gulf.

The water quality of the Gulf changes naturally over an annual cycle due to changes in the density structure of the water column. During the winter cooling at the surface causes convective mixing which can deepen the mixed layer down to >850 m (Genin et al., 1995) transporting nutrient rich deep water to the surface, which supports increased levels of productivity both in the open water and in benthic habitats along the coasts. During the summer warming at the surface causes stratification of the water column (6ºC thermocline from the surface to 250 m depth) leading to nutrient depletion in the surface water and substantially reduced rates of productivity both in the open sea water column and shallow benthic habitats. These changes in density structure influence and are influenced by the general circulation of the Gulf both vertically and horizontally.

Our present knowledge and understanding of water transport in the Gulf is derived from only a few short and long term observational studies consisting of temperature and salinity profiles (Klinker et al., 1976; Wolf et al., 1992; Plähn *et al.*, 2002; Gertman and Brenner, 2004), direct current measurements (Murray et al. 1984; Genin and Paldor 1998; Manasrah et al., 2006; Monismith et al 2006, Manasrah et al 2007), tidal data analysis (Monismith and Genin 2004) and some numerical model simulations (Berman et al., 2000; Berman et al., 2003; Brenner and Paldor, 2004; Biton et al., 2008; Silverman and Gildor, 2008). Supported by NATO, in 2008 and 2009, Genin, Gildor, Manasrah, and Monismith carried out a series of current meter deployments including a nearly year-long deployment near the center of the Gulf. Since August 2005 H. Gildor has been operating a high frequency (HF) radar system that measures the complex surface circulation structure of the northern GOAE with very high spatial and temporal resolution (Gildor et al., 2009). Also with NATO support a second HF radar was installed at MSS in 2008.

In the first stage of this study we shall provide an overview of the salient features of water transport and their relation to water quality in the Gulf by compiling, integrating, and analyzing the above mentioned available data.

The analysis will also include previously collected exclusively by members of our group but unanalyzed data including the HF radar data mentioned above and additional recently collected ADCP data from fixed point moorings and from ship tracks.

This activity will also help define the gaps in the physical which must be filled with additional targeted data collection.

Water quality

In this study we will describe and characterize the current state of water quality both along the shore and in the open water based on data provided by the National Monitoring Programs of both Israel and Jordan.

These programs have been operating since 2003 in their current format and within the framework of Red Sea Marine Peace Park since 2000. Using these data together with publications from the scientific literature describing the water quality in the Gulf intermittently (e.g. Reiss & Hottinger, 1984; Lazar and Erez, 2004; Lazar et al., 2008) we will try and define a base line for water quality parameters and their acceptable ranges of variation considering the well being of coral reefs and sea grass meadows. These ranges will be based upon accepted values from the scientific literature (Kiney & Davies, 1978; Bell, 1992) especially those publications basing their conclusions on measurements conducted on reefs in the GOEA (Silverman et al, 2004; Silverman et al., 2007).

In the near field, the quality of the water supplied at the intake of the RDC is largely determined by the water quality in the open water at the intake depth, which in turn is determined by the density structure of the water column. In addition, the near field water quality may be affected by resuspended sediments due to the force of extraction of water at the intake.

As better detailed below (chapter 4.2.3), depending on the intake design (surface or sub thermocline) and the modelling results, we will make a qualitative assessment of water quality at the intake when the system becomes operational. The effects of various pumping scenarios and intake designs on the nutrient dynamics will be assessed taking into account the results of the physical modelling (water circulation, upwelling/downwelling). This will enable assessment of the potential short and long-term impacts on the water quality transported towards the Dead Sea and the consequent potential down-channel biological impacts.

We recommend that, within the framework of a future monitoring program, a water quality baseline state should be defined for the near field of the eventual intake site and its perimeter by measuring various relevant water quality parameters at high temporal resolution over an annual cycle. These measurements should include: temperature, salinity, total suspended solids, light penetration, turbidity, chlorophyll a, nutrients, trace metals dissolved in water and in suspended matter. An important consideration in deciding the location of the abstraction site is the likelihood of sediment resuspension and the physiochemical characteristics of the potentially re-suspended sediments.

Preliminary brief description of main features of water quality of the Gulf

The Gulf of Aqaba is small, semi-enclosed by land, has warm deep water and low nutrients, but seasonal inputs of nutrients from below (convective mixing). The surface water of the Gulf of Aqaba is mostly oligotrophic (nutrient-poor), except in localized polluted areas (e.g. Badran 2001, Rasheed *et al.,* 2002). As shown in (e.g.) Rasheed et al. (2003), concentrations of inorganic nutrients in the Gulf of Aqaba, particularly nitrogen and phosphate, are low (< 1µM) for most of the year and are especially low during summer (< 0.1 µM). During winter, deep water in Aqaba Gulf is mixed with surface water, resulting in nutrient enhancement in the coastal surface water (Manasrah *et al.* 2005; Rasheed *et al.,* 2002). Badran *et al*. (2001) and Rasheed *et al*. (2002) reported significantly higher nutrient and chlorophyll *a* concentrations in coastal coral reef waters as compared to water column waters just 3 Km offshore. Badran (2001) reported chlorophyll *a* and nutrient concentrations at high temporal resolution for the eastern coast of the Gulf down to 200 m and found relatively high concentrations during winter and low concentrations in the surface water during summer, when a subsurface maximum existed at about 75 m. Richter *et al.* (2001) have shown that coral reefs on the Jordanian side of the Gulf of Aqaba have a large internal regeneration surface dominated by encrusting filter feeders, mainly sponges reaching 3-7 m^2 per projected m^2. Rasheed *et al.* (2003) have also shown rapid recycling in carbonate sediments associated with the coral reef. Most recently Niemann *et al*. (2004) showed that considerable amounts of coastal nutrients and primary production in the Gulf of Aqaba is driven offshore by cross sectional density currents (Monismith et al. 2006).

Overall, biological productivity in the Gulf is poor, and oligotrophy becomes more persistent and stronger towards the north. The lack of anthropogenic nutrient load as well as restricted inflow of nutrients from the Arabian Sea across the narrow and shallow straits of Bab-el-Mandeb, and strong vertical stratification limits the supply of new nutrients from deeper waters, are the major causes for the development of unproductive conditions, except for some reefs along its margins and shelves in the southern part of the Red Sea (Richter and Abu- Hilal, 2006). Furthermore, the lack of regular fresh water inflow and the high evaporation rate contribute significantly to the oligotrophic nature of the Gulf system (Reiss and Hottinger, 1984; Badran, 2001). The deposition of dust transported from nearby sources and subsequent biological fixation of nitrogen acts as source of nutrient in the region (Richter and Abu- Hilal, 2006). In summer, prevailing winds flow down the Red Sea through its entire length, reinforcing the clockwise airflow in the Arabian Sea. This generates strong south-westerly winds, leading to upwelling of cool, nutrient-rich water. Using SeaWIFS and MODIS imagery, Labiosa et al (2003) showed how the interplay between upwelling and deep convective mixing affected seasonal variations in phytoplankton biomass, with the eastern side of the Gulf showing larger than expected productivity during the summer due to upwelling.

In their study in the Gulf of Aqaba, Mansrah *et al.* (2005) described nutrient and temperature variations with depth and by season. They found a clear thermocline in the upper 200 m with weaker stratification at depth. During summer (June) when the stratification strengthened, the difference between the surface and 200 m was about 2.6 °C (sea surface temperature ~23.83 °C), whereas the temperature between 200-400 m of the water column was almost homogenous with values ranging between 21.12-21.23 °C. The authors emphasize the findings of Badran *et al.* (2001), whose measurements show that over the upper 200 m temperature stratification was mirrored in nutrient and dissolved oxygen distributions. Nitrate, phosphate, and silicate increased from the surface to deep water while dissolved oxygen decreased. Low nitrate concentrations with values of 0.2-0.4 µM, persisted in the upper water column (surface to 100 m), while the values reached up to 2 µM in the lower water column (300-400m). Phosphate and silicate also exhibited a similar trend to that of nitrate. Low concentrations in the upper water column were around 0.05 and 1.0 µM for phosphate and silicate respectively). While higher values in the lower water column were recorded (0.15 and 2 µM for phosphate and silicate respectively). Oxygen concentrations decreased gradually with increasing depth in the water column ranging from around 7.0 mg l^{-1} in the surface water to around 5 mg l^{-1} in the 400 m deep water. Nitrite concentrations during summer have a characteristic subsurface nitrite concentration maximum of about 0.5 µM which is found around a depth of 100m. During mixing winter condition, however, homogenize nitrite concentrations of 0.5 µM are found in the entire water column down to 300m depth. Chlorophyll *a* follows the same pattern of nitrite concentrations where subsurface maxima of 0.4 µg l^{-1} are found in summer at about 75 m depth, and homogenize concentrations of about 0.3 µg l^{-1} are recorded in winter down to 300 m.

The data on chemical content and characteristics of the water of the Gulf of Aqaba other than nutrients are summarized in Table 4-1.

Table 4-1 Chemical characteristics of seawater of the Gulf of Aqaba.

Constituent	Mean concentration
pH	8.29
Bicarbonate (HCO3-)	167 mg/l
Bromine	85.0 mg/l
Calcium	0.425 g/kg
Cobalt	1.06 µg/kg
Copper	3.11 µg/kg
Fluoride	1.40mg/kg
Iron	4.07 µg/kg
Magnesium	1.39 g/kg
Manganese	0.026 µg/kg
Nickel	6.95 µg/kg
Potassium	455 mg/l
Sodium	12920 mg/l
Sulfate	3254 mg/l

The shores of the GOAE are lined with well developed fringing coral reefs, which have grown successfully despite the high latitude of the Gulf relative to where coral reefs are typically found. These reefs are likely one of the most important components of the Gulf's ecological system. They provide recycled nutrients that support open water productivity (Erez, 1990), provide a food source and together with sea grass habitats, they function as nurseries for many pelagic species. They provide recycled nutrients that support open water productivity (Erez, 1990), provide a food source and together with sea grass habitats they function as nurseries for many pelagic species. Both coral reefs and sea grass meadows are very susceptible to changes in water quality especially in the GOAE considering that these habitats experience over an annual cycle naturally occurring large variations in environmental conditions such as temperature, light penetration, aragonite saturation and nutrient levels (Silverman et al., 2007b). Seemingly small changes in water column density structure associated with Red Sea water abstraction, external nutrient input, increase in total suspended solids and reduction in light penetration (in the vicinity of the abstraction site) could have detrimental effects on both coral reefs and sea grass meadows. Deterioration of these habitats can conceivably effect the well being of the entire ecological system of the Gulf.

Coral reefs and coral larvae

During the last four decades, the coral reefs of Aqaba and Eilat have undergone major changes resulting from increasing impacts due to human activities (Loya, 1976; Loya, 2004; Rinkevich, 2005), coupled with those from natural disasters (e.g., Loya, 1976; Genin et al., 1995; Meir et al., 2005). Following a first stage of existing data collection, we will integrate and update the available information in the published literature on Aqaba's and Eilat's reef status. Overview of the salient features for the reefs will be performed. Results will reveal trends, reef resilience features, environmental changes and the effects of elevated anthropogenic activities.

As noted above, one of the greatest concerns of the RDC project is the potentially detrimental impacts on the biological connectivity among the coral reefs in Aqaba and Eilat. The lifecycles of most coastal marine organisms involve a dispersive larval stage which ultimately defines the demographic and genetic structures of adult populations and communities. These populations and communities will be adversely affected if the dispersal trajectories are disrupted by changes in the circulation or if the larvae are entrained into the intake. Such disruptions would quickly cascade to the state of the whole reef. At present very little is known about the larval pathways in the northern Gulf and east-west potential connectivity.

The only insight currently available into the dispersal of coral-reef fishes along the coastline of the northern GOAE is based on our micro-chemical analysis of the otoliths of newly settled fish (Ben Tzvi et al 2008). Spatial patterns in the chemical signature in the otoliths of *Chromis viridis* (Pomacentridae) point at two distinct northward dispersal trajectories, one eastern and the other western, which converge at the north-western corner of the Gulf (Ben Tzvi et al 2008). The two trajectories do not appear to continue beyond this point, potentially because of submesoscale barriers to horizontal surface-water mixing (Gildor et al. 2009). However, we do have some indication of interspecific differences (Ben Tzvi et al. in review). For example, *Dascyllus marginatus* (Pomacentridae) does not appear to be affected by the aforementioned barriers; and its eastern trajectory appears to turn southwards, to reach sites along the western coastline.

Interspecific difference in dispersal trajectories can arise from differential vertical positioning in the water column. Vertical positioning of fish larvae (and of zooplankton, in general) is thought to balance several factors, including: the probability of encountering prey and visual predators; the exploitation of shears to affect transport; and potential phylogenetic constraints (e.g. Irisson et al. 2010). With the exception of a descriptive study based on light-trap sample (Froukh 2001. MSc thesis), essentially no information exists of the spatial distribution of coral-reef fish larva in the Gulf of Aqaba. Our own data (Kimmerling & Kiflawi unpublished), which is based on vertically discrete MOCNESS samples of the upper 100m, is currently insufficient for robust inferences; but work is continuing and will supplement that to be collected as part of the RDC impact study.

Other important marine habitats (seagrasses habitat, sandy habitat, etc)

The main habitats at the northern coast of the Gulf of Aqaba include coral reef, seagrass, and sandy bottoms. Seagrasses are the only group of higher plants that have adapted to life submerged under the sea. They inhabit soft-bottom, shallow-water areas of temperate, subtropical, and tropical seas where they may form large meadows (Edwards & Head (1987), Kirkman & Kuo 1990). Seagrass habitats have recently been considered to be of fundamental ecological importance as primary producers in the sea. Seven species have been reported in the Gulf of Aqaba and at the extreme northern end only *H. stipulacea*, *H. ovalis* and *Halodule uninervis* have been found. *H. stipulacea* has been proven to grow on the range of sediment types found in the area. They serve as important nursery grounds for many commercially important fishes and crustaceans. In general, the community is structurally and functionally complex. In the northern Gulf of Aqaba found more than 49 species of invertebrates (mostly molluscs) were found living in seagrass beds, either attached to the plant (gastropods) or buried in the sediment (bivalves) (Wahbeh 1980).

The Red Sea Ichtyofauna is quite well known compared with other parts of the tropical Indo-Pacific Ocean. About 500 fish species have been recorded in the Gulf of Aqaba (Khalaf & Disi 1997; Khalaf 2004; Khalaf M.A and M. Kochzius 2002), but new records are being made continuously. The number and diversity of fish species inhabiting the north coast are typical of seagrass beds and sandy bottom habitats (Al-Rousan et al., 2005). Some of the fish species observed are characteristic of this site and not abundant elsewhere on the Jordanian coast. The abundance of fishes in the Royal Yacht Club port includes several coral fish species that appear to have succeeded in colonizing this originally sandy bottom enclosed habitat. These well-developed seagrass beds serve also as important nursery grounds for the fish larvae. These can settle down in the seagrass and find protection against predators until they grow up (Al-Rousan et al., 2005).

The well-developed seagrass beds at the northern Jordanian coast cover about 70–98% of the bottom (Al-Rousan et al., 2005). These seagrass beds have a highly significant ecological value as they serve as nursery grounds for the larvae of several fish species. Other important species in the area are sea urchin and sea cucumbers. The relatively limited Jordanian and Eilat coasts of the Gulf of Aqaba has to serve all conflicting uses of the coastal areas, i.e. tourism, ports, industry, military, education and marine conservation. Swimming, fishing and boating activities in shallow areas found to affect the development and growth of these beds, and disturb their natural distribution.

Sediments

Bottom surface sediments at the northern Jordanian coast are clastic in nature derived from existing metamorphic rocks, by weathering and erosion. They are characterized by high contents of terrigenous materials (quartz, feldspare, mica, and other minerals) and low carbonate (some shells of foraminiferans, gastropods, and bivalves) and organic carbon contents; this is mainly due to the absence of coral cover (Al-Rousan et al., 2005).

Biogenic sediments are generally remains of organisms, mainly calcium carbonate (calcite, aragonite), opal (hydrated silica), and calcium phosphate (teeth, bones, crustacean carapaces). They arrive at the site of deposition either by *in situ* precipitation or through settling via the water column.

Clastic sediments on the other hand are composed of fragments or grains derived from existing rocks, by weathering, erosion, transportation, and deposition. They include clays, silts, sands, and gravels. Both sediment types are present in varying proportions at different parts of the Jordanian coast of the Gulf of Aqaba.

The surface structure of the unconsolidated bottom sediments along the northern coast is undisturbed, animal tracks are rare, but bioturbated holes and mounds are abundant. Most of the mounds have their tops rounded off; some of them exhibit small depressions (Al-Rousan et al., 2005).

Quantification of pollution entering the marine environment

The present pollution loads entering the marine environment of GOAE and those that may arise due to future development will be quantified based on available data and information, to be retrieved both from technical reports/scientific publications and from the relevant managing and planning authorities and/or ministries.

In particular the following pollution sources will be considered:

- *Urban pollution from the cities of Eilat and Aqaba*: discharge of treated and untreated effluents from septic tanks, sewage networks and municipal wastewater treatment plants, taking account for the re-use of treated wastewater for irrigation, for the present state of efficiency of the WWTPs and for their planned upgrade/improvements.

  The current Eilat sewage disposal system, based on treatment in sand ponds and on a seasonal reservoir, was originally designed to guarantee "zero flow to the sea", but recent growth in population has subjected the municipal sewage system to loads that were unanticipated at the time of its construction: the quantity of sewage water currently surpasses the treatment and recycling facilities so that system overload has led to periodic breakdowns, resulting in sewage spill to the sea. At present the city is faced with the need to restructure and augment its sewage system in order to safely handle current loads and facilitate ongoing new construction in the area.

  The previous Aqaba wastewater treatment plant also recently reached its full treatment capacity too due to population growth and was upgraded with support from USAID in order to ensure no discharge to the sea thanks to water re-use. The areas in Aqaba that are not connected to the central wastewater network are served by septic tanks, which are sealed and pumped out to tankers.

  Quantification of present pollution loads from the two WWTPs will be conducted considering the recorded/predictable events of sewage overflow from the municipal networks.

- *Fish farming*: In the past two commercial fish farms (floating fish cages) were located close to the Jordanian-Israeli border at the northern tip of GOAE, with an annual production of about 2000 tons. In 2008 the fish farms on the Eilat side of the Gulf were completely removed from the sea. Alternative land based solutions are now being developed so the fish farms are no longer a major source of pollution. If any other fish farms remain in the Gulf, total nutrient loads to the sea can be calculated based on feed conversion rate and food consumption.

- *Sewage discharge from the main touristic settlements*: according to the characteristics of the wastewater collection, treatment and disposal facilities of the main touristic settlements and their accommodation capabilities. Wastewater discharge from marinas moored boats will be included in the calculations. Beside the Eilat and Aqaba site, the overall pollution loads discharged from the Taba, Nuweiba and Dahab resorts areas will be roughly estimated.

- *Port operations*: atmospheric deposition of airborne pollutants from ship engines and loss of anti-fowling substances from ship keels during navigation in the GOAE and port operations. Loads calculation will be based on published standards, according to ship type and size, and ship traffic data.
- *Fertilizer loading terminals*: accidental discharge of phosphate, potash and bromides to the GOAE during ship loading operations. The Port of Eilat presently exports about 0.25 millions tons/year of phosphate ore and 1.2 millions tons/year of potash, while the Port of Aqaba exports about 3 millions tons/year of phosphate ore. Port traffic projections from Aqaba Development Corporation predict a relevant growth of phosphate ore export for the next future, to be handled through the expanded South Port.

  Phosphate dust has been considered a major source of nutrient loading to the GOAE, so that many engineering improvements have been applied to limit the airborne dust in the Port of Eilat and in the Port of Aqaba.

  Estimates of nutrient loads to the GOAE can be based on available direct measurements in dust from Eilat Port and direct scaling to Aqaba.
- Possible *pollution loads from existing industrial settlement*s will be investigated and quantified according to size, typology and water treatment/disposal facilities, although it is expected that according to the “zero flow” policy little to no wastewater is discharged from industries to the GOAE. In particular ASEZA reports no permitted or known industrial wastewater discharge from the Jordan side, even from the Aqaba Southern Industrial Zone.
- Seven main catchments drain through the urban areas of Aqaba: the runoff from Wadi Yutum flows down towards the north of Aqaba to the gulf. Runoff from Wadi T and Wadi Shallalah passes through the urban center of Aqaba. Wadi Jeishiek drains towards the main port while the runoff from Wadi Mabruk passes through the Container Port. Further south of these wadis, Wadi 9 passes through the tourist areas of the ‘Coral Coast’ and Tala Bay. Run off from Wadi 2 passes through the northern end of the industrial area.
- Submarine groundwater discharge into the Gulf is substantial and continuous and is a significant source of nutrients (Shellenbarger et al 2006; Paytan et al., 2006). It is likely that fertilizers (nutrients) and other man made pollutants have seeped into the groundwater system upstream in the urban centres of Eilat and Aqaba as well as the agricultural field of the Araba/Arava Valley (Bein et al, 2004). In this study we will assess the contribution of the groundwater discharge to the GOEA’s nutrient budget by generalizing and integrating the findings reported in Shellenbarger et al (2006) and Bein et al. (2004). We will also take into consideration future increases in the pollutant loads in the northern region of the GOEA due to foreseen accelerated urban development in both Eilat and Aqaba.

Tourist activities in the Gulf will be considered both for the evaluation of pollution loads and for the analysis of coral population dynamics. In addition to the numbers of tourists in both sides, hotels beds and other tourist related impacts (water consumption, sewage, etc) published materials will be considered as well (Zakai, D., Chadwick-Furman, N.E., 2002; Riegl, B., Verlimirov, B., 1991. Meshi, N., Ortal, R., 1995. Hawkins, J.P., Roberts, C.M., 1992. Hawkins, J.P., Roberts, C.M., 1993. Hawkins, J.P., Roberts, C.M., 1994.).

Contributions from wadi runoff will be estimated according to the available data concerning discharge volumes and measured pollutant concentrations in runoff water. Pollutant concentrations from literature, depending on catchment characteristics, will be adopted in case of missing site-specific measured data.

In general it is anticipated that *non-point pollution loads from agriculture* will be considered negligible due to the limited extension of the farmed areas, their distance from the sea and the very high local evapotranspiration rates, except for the occasional flood (once per year) from the Araba/Arava Valley which can introduce pollutants and sediments into the northern Gulf. It will be difficult to quantify this so that at this stage it is unlikely that any specific calculation will be made. The same applies to *livestock breeding*, due to its very limited presence in the area.

A historical water quality analysis on the sea water (and groundwater, including data from the monitoring programme operated by ASEZA's Water Resources Management Division, if made available) will be conducted on existing data from previous and ongoing monitoring programs, to identify and give evidence to the recent trends, with particular reference to nutrient (nitrogen, phosphorus) concentrations and to the other parameters relevant to the trophic state of GOAE. The identified trends will be compared with the changes in the above pollution loads.

4.2.2 Additional monitoring of oceanographic, biological, geochemical and sedimentological parameters

CURRENTS AND HYDROGRAPHIC DATA

According to the feasibility study (Coyne et Bellier, 2009, Options Screening and Evaluation Report. Executive Summary) one of the two proposed locations for the RDC intake is on the Jordanian north coast of the GOAE, between the Jordanian/Israeli border and the boundary of the Ayala Project development in Aqaba.

One of the key gaps in understanding of the Gulf circulation is the cross-isobath structure of the near shore flow along the northern coast of the gulf, information that will be crucial for assessing the larval trajectories and thus the potential risk of entrainment into the intake.

To address this issue, we will deploy two moorings with acoustic Doppler current meters (ADCP) near the border. One will contain a 600 kHz ADCPs in the near shore zone at a depth of 30-40 m. The second mooring will be at ~200 m bottom depth and will include a downward looking 150 kHz ADCP to sample the water column from 40 m to near the bottom, and an upward looking 600 kHz ADCP to sample the water column from 40 m to near the surface. A third mooring with a 600 kHz

ADCP will be deployed at 30-40 m depth along the eastern Jordanian shore near the second proposed intake site.

These current meters will be deployed for three two-month periods in January/February, April/May, and July/August in order to observe the different seasons. Data will be retrieved on a bi-monthly basis to ensure a high rate of return and to facilitate making the data available for further analysis on a regular basis.

These data will be used to help assess and understand the larval trajectories and to calibrate the numerical model. These data will be supplemented with data from other ongoing projects which will be kindly made available to this project, such as the surface currents provided by the HF radar system deployed as part of a NATO project. The proposed locations are shown in Figure 4-2.

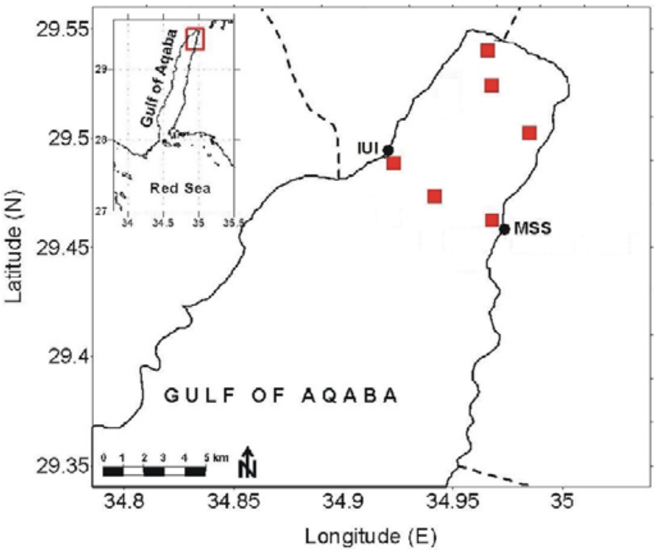

Figure 4-2 Current meters locations.

Another important piece of knowledge that is missing is information on the cross-gulf variability in the low frequency flow from near the surface and down to ~250 m depth. In order to evaluate this variability, we will obtain data from the routine current measurements conducted near IUI and MSS as part of the respective National Monitoring Programs. At these two locations ongoing data are collected with 600 kHz ADCPs.

To complete the picture of the cross-gulf variability, based on the experience gained in a previous NATO project, we propose three two-month periods of deployment of a deep mooring near the center of the gulf at a depth of ~500 m. This mooring will be configure with a 150 kHz ADCP and a 600 kHz ADCP as on the 200 m mooring described above.

In addition we will deploy CTD loggers and thermistor chains at various depths to provide information on the vertical and temporal structure of the water stratification. The location of the deep mooring is also shown in Figure 4-2. These data will provide an important benchmark for the calibration/validation of the circulation model.

To complement the fixed point measurements described above we will carry out four seasonal CTD surveys in the northern GOEA over an annual cycle (every 3 months) that will describe the current state of key hydrographic fields (temperature, salinity, fluorescence and PAR). These measurements will extend existing time series of thermohaline structure parameters and increase the spatial resolution of existing measurements substantially. The collected will be employed in the calibration and validation of the GOEA general circulation model.

The measurements will be carried out along two sections (latitudinal and longitudinal, Figure 4-3) that intersect at the location of station A where hydrocasts have been carried out over the last 20 years. Each section will consist of vertical CTD profiles at 7 stations from the sea surface to the bottom. Each CTD cruise will require 1-1.5 days. The observation results will be presented in form of plots and charts as well as in digital format accepted by the project database.

A summary of additional monitoring activities for currents and hydrographic data is reported in the following Table 4-2.

Table 4-2 Currents and hydrographic monitoring activities.

TYPE OF DATA TO BE COLLECTED	**a) Subsurface currents**: we will deploy two moorings with acoustic Doppler current meters (ADCP) along the Israel-Jordan border over water depth of 200 m and 500 m. Each will contains a downward looking 150 kHz ADCP to sample the water column from 40 m to near the bottom, and an upward looking 600 kHz ADCP to sample the water column from 40 m to near the surface. A 600 kHz ADCPs will be deployed in the near shore zone along the Israel-Jordan border at a depth of 30-40 m. An additional 600 kHz ADCP will be deployed at 30-40 m depth along the eastern Jordanian shore near the second proposed intake site. In addition, we will obtain data from the routine current measurements conducted near IUI and MS S as part of the respective National Monitoring Programs. At these two locations ongoing data are collected with 600 kHz ADCPs.
	b) Surface currents: will be measured by existing HF radar network.
	c) Hydrographic data: Each of the mooring at 200 and 500 m will contain at least five temperature loggers and two conductivity (salinity) loggers distributed between the surface and bottom. In addition, CTD transects will be carried out over the northern part of the Gulf every season. Both sections (latitudinal and longitudinal) will intersect at the location of station A where hydrocasts have been carried out over the last 20 years. Each section will consist of vertical profiles at 7 stations that will include observations of temperature, salinity, dissolved oxygen, fluorescence, PAR vertical profiles. Each CTD cruise will require 1-1.5 days.

NEED AND MOTIVATION TO COLLECT THE DATA	**a)** and **b) currents**: The synoptic spatial variability of the circulation below the surface is largely unknown due to lack of measurements. The above mentioned measurements are needed in order to properly calibrate and validate the numerical model. According to the feasibility study (Coyne et Bellier, 2009, Options Screening and Evaluation Report. Executive Summary) one of the two proposed locations for the RDC intake is on the Jordanian north coast of the GOAE, between the Jordanian/Israeli border and the boundary of the Ayla Project development in Aqaba. One of the key gaps in understanding of the Gulf circulation is the cross-isobath structure of the near shore flow along the northern coast of the gulf, information that will be crucial for assessing the larval trajectories and thus the potential risk of entrainment into the intake.
	c) hydrographic data. These measurements will extend existing time series of thermohaline structure parameters and increase the spatial resolution of existing measurements substantially. The collected will be employed in the calibration and validation of the GOEA general circulation model.
DETAILS ON DATA COLLECTION	**a) currents.** The moorings (for both currents and hydrographic measurements) will be deployed for three two-month periods in January/February, April/May, and July/August in order to observe the different seasons (we aim at getting at least 4 weeks of data in each season). Data will be retrieved on a bi-monthly basis to ensure a high rate of return and to facilitate making the data available for further analysis on a regular basis. **c) hydrographic data**. The measurements will be carried out along two sections (latitudinal and longitudinal, Figure 4-3) that intersect at the location of station A where hydrocasts have been carried out over the last 20 years. Each section will consist of vertical CTD profiles (including Fluorescence and PAR) at 7 stations from the sea surface to the bottom. Each CTD cruise will require 1-1.5 days. The observation results will be presented in form of plots and charts as well as in digital format accepted by the project database.
PLANNED DATES	**a) currents**. See above. **c) hydrographic data**. Cruises are planned 4 times over an annual cycle every 3 months; 3-4/5/2010, 15-16/8/2010, 15-16/11/2010, 15-16/2/2011.

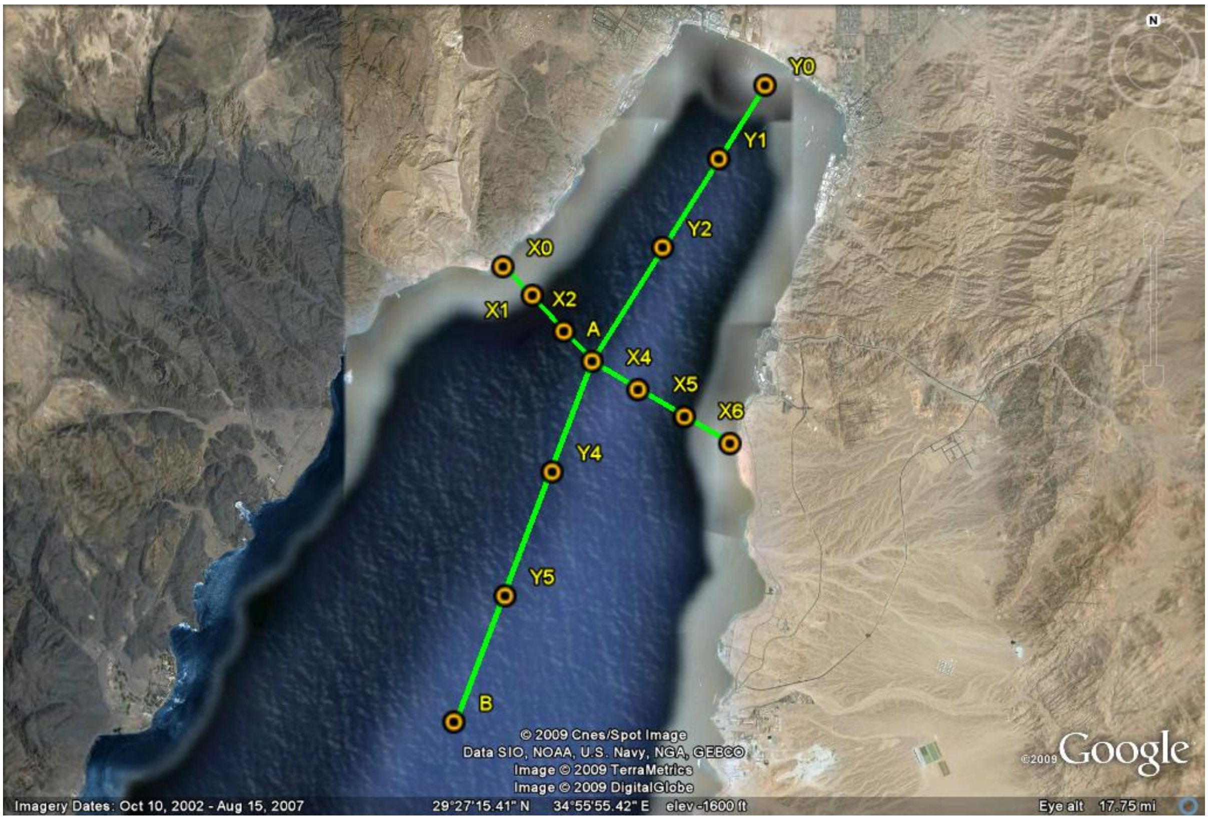

Figure 4-3 CTD vertical profiles will be measured every three months over an annual cycle at the locations indicated on the map over a 24 hour period per survey.

<u>BIOLOGICAL DATA</u>

New acquisition of biological data will consist of:

- sampling of planktonic larvae;
- study of population genetics profiles of major reef organisms;
- study of biodiversity by a visual census survey of the corals and fish, identification of algae and other fauna on the Jordanian side of the coast.

The objectives of this investigation are: (1) to establish the temporal and spatial distribution of larvae (invertebrates and fish) along the northern tip of the gulf, especially along the north shore; (2) to infer the main larval-transport trajectories along the northern tip of the GOAE; (3) to quantify the extent of biological connectivity between the Israeli and Jordanian coasts of the GOAE; and (4) to assess the sensitivity of these larval-transport trajectories to possible RDC-driven changes in the circulation.

Sampling of planktonic larvae

Data collection will consist of vertically discrete plankton samples collected along 9 transects, covering the northern tip of the GOAE (Figure 4-4). At each transect, samples of planktonic larvae will be taken using a 1-m^2 multiple opening–closing net and environmental sensing system (MOCNESS), fitted with 4 or 6 nets of 600μm mesh (for fish larvae) and 4 nets of 100 μm mesh (for invertebrate larvae). Samples will span the upper 40 to 100 meters, depending on bottom depth and distance from shore. Individual nets will sample depth increments of 20-25 m, while being towed at 2 knots for 5 minutes. Coverage of all nine transects (Figure 4-4) will require 2 days of ship time. Sampling will cover a period of one full year for invertebrate larvae, and the period of July-November for fish larvae; at a rate of once and twice a month, respectively. Coincident with the plankton samples, the MOCNESS provides accurate measurements of depth, temperature, salinity, and the volume of water filtered for each sample.

The collected samples will be preserved in ethanol for subsequent analyses by an expert technician at the IUI, including gross taxonomic identification (general group, class, family, or genus level depending on taxonomic characteristics). For fish larvae the developmental stage (e.g. pre- and post-flexion larval fish) will also be recorded. The analyses will provide information on the horizontal and vertical distribution (density) of the different taxa (and developmental stage of fish larvae) during different times of the year.

The ensuing spatial data (i.e. vertical and horizontal larval distribution) will be reviewed in the context of biophysical models (e.g. Werner et al. 2007). As a fist approximation, we will use the passive-particle tracking capability of the hydrodynamic models to interpret the observed distribution patterns- i.e. to back calculate the trajectories that led to the observed pattern, and predict where these trajectories may lead. Then, by incorporating the different pumping scenarios into the model, it would be possible to predict how these inferred trajectories will be affected.

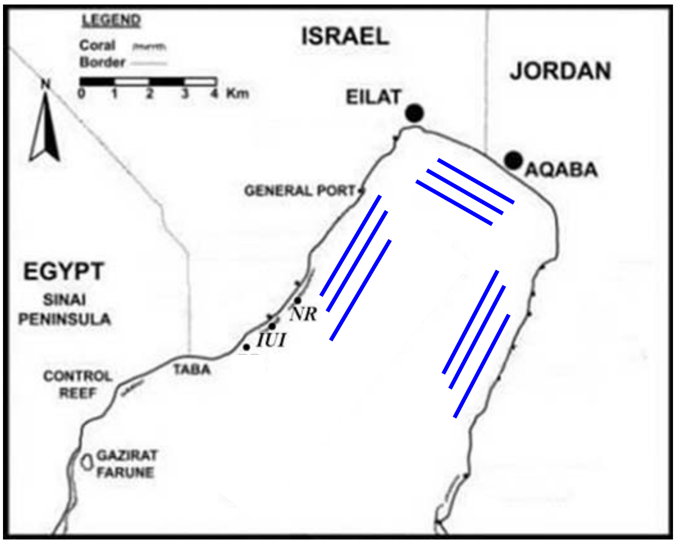

Figure 4-4 Approximate location of the 9 MOCNESS sampling stations (Blue lines).

Study of population genetics profiles

Quantification of marine connectivity and evaluating the magnitudes and patterns of genetic exchange between populations of marine organisms is hindered by the available methodologies that try to track trajectory and monitor the fate of propagules. A recent meta-analysis (Weersing and Toonen, 2009) further elucidated that even the conventional evaluation through pelagic larval duration is not a good predictor of the magnitude of gene flow and geographic scales of population structures in marine systems. The tasks of ascertaining connectivity routes, dispersal ability of free swimming/floating larvae, actual dispersal, magnitude and genetic differentiation of populations at multiple scales have been successfully answered by the use of a myriad of molecular tools. These tools have become more efficient, powerful and flexible, and thus more widespread, allowing difficult research questions about connectivity in marine organisms to be efficiently addressed. These and other direct marking techniques revealed unexpected differences in connectivity and rates of self-seeding between adjacent coastline segments as well as between congeneric species developing in the same waters at the same time (i.e., Becker et al., 2007), differences that can not be elucidated by the use of direct larval sampling or oceanographic modelling.

To fill in gaps in knowledge on biological connectivity in the northern Gulf, population genetics profiles of major reef organisms will be evaluated and studied by using two types of molecular markers (microsatellite loci and AFLP). As several sets of microsatellite loci have already been developed for selected coral species that are found in the Red Sea (such as for *Pocillopora* and *Seriatopora*), we'll use the already available tools. We shall also use AFLP markers for selected reef organisms in populations residing along the Jordanian and the Israeli coasts (the coral-pest snail *Drupella*). Using these molecular markers, we shall sample DNA from organisms belonging to several populations of each selected species and elucidate the population genetics properties of selected northern Gulf's residing species.

Biodiversity study

Finally, the Jordanian coast is characterized by a high diversity, and this high diversity is attributed to the variable habitats exist along the coast such as coral reef, seagrass meadows, sandy habitats and deep sea fish fauna. Therefore our description will focus on the biodiversity and will include: (1) a review of the existing data and information of the coral reef habitat, the seagrass habitat, and the sandy bottoms at the two suggested intake locations; (2) a visual census technique survey of the corals and fish by divers; (3) a description of the seagrass meadows based on existing data; (4) collection and classification of algae; and (5) collection and identification of other fauna up to family or genera levels.

A summary of additional monitoring activities for biological data acquisition is reported in the following Table 4-3.

Table 4-3 Biological monitoring activities.

TYPE OF DATA TO BE COLLECTED	**a) sampling of planktonic larvae**. Spatial and temporal distribution of coral reef larvae, focusing on larvae of key invertebrates and fishes inhabiting the local coral reefs. Sampling will cover the entire photic layer (0-100 m depth) during one full year.
	b) population genetics profiles of major reef organisms. **IOLR:** Small tissue samples will be collected from *Pocillopora damicornis* and *Seriatopora hystrix* colonies. Whole *Drupella* snails will be collected from infected areas in the gulf. Sites along the Jordanian and the Israeli sides will be sampled.
	c) biodiversity. Along Jordanian coasts, a visual census survey of the corals and fish by divers will be carried out at shallow depths between 2 and 18 m at the old Thermal Power Station because of the lack of information at this site. Other fauna also will be collected and identified at the suggested intake site (the old Thermal Power Station). Three times survey will be performed with triplicate transects parallel to the seashore during May to December 2010 at 2 m, 8 m, and 18 m depths.
NEED AND MOTIVATION TO COLLECT THE DATA	**a) sampling of planktonic larvae**. Data collection is aimed to establish the temporal and spatial distribution of larvae (invertebrates and fish) along the northern tip of the gulf, especially along the north shore; data will allow to infer the main larval-transport trajectories along the northern tip of the GOAE.
	b) population genetics study. Data collection is aimed to quantify the extent of biological connectivity between the Israeli and Jordanian coasts of the GOAE and to assess the sensitivity of these larval-transport trajectories to possible RDC-driven changes in the circulation.
	c) biodiversity. The data will be needed to establish a data base about the preconstruction history. It is also important for determining the suitable mitigation measures to reduce the negative impacts. A detailed quantitative and qualitative description for the study site will result from the benthic habitat survey. This should constitute the data base for the biological diversity in the study area. Depending on the results, the mitigation measures can be designed to avoid and/or reduce the expected negative impacts of the project.
DETAILS ON DATA COLLECTION	**a) sampling of planktonic larvae**. 9 stations will be sampled, covering the northern tip of the GOAE (Figure 4-4). Sampling will cover a period of one full year for invertebrate larvae, and the period of July-November for fish larvae; at a rate of once and twice a month, respectively.
	b) population genetics study. At least 3 reef sites along the Jordanian coast and 4 reef sites along the Israeli coast will be sampled, covering the northern tip of the GOAE. From each species at least 25-30 tissue samples/sites will be collected. Partial DNA extraction will be performed in the field to ensure the quality of the results. Complete DNA extractions, PCR amplifications, sequencing for AFLP markers (for *Drupella*) and microsatellites (*Pocillopora damicornis* and *Seriatopora hystrix*) and data analyses will be performed in the laboratory at Haifa.
	c) biodiversity. The study site can be divided into zones according to the area. Each zone will be subdivided into survey transects for the benthic habitat study. A 50m long transects will be used according to the point intercept method, where all common habitat features can be studied. The same transects will be used to study the fish community structure. The transects can be separated according to depth or distance (i.e. at each 5m depth contours until the 30m depth is reached or each 10m distance from the shoreline until the 30m depth is reached).

PLANNED DATES	**a) sampling of planktonic larvae.** Sampling will commence as soon as the 600 and 100 μm mesh nets are received from the manufacturre (expected by June 1st, 2010). Monthly sampling expeditions, each covering all 9 transect (Figure 3), will be carried out for a period of one full year, with an additional expedition per month (for fish larvae only) to be carried out during the summer (the peak period of fish reproduction and recruitment).
	b) population genetics. Sampling of biological material will be performed during March –May 2010 months. The work on fingerprinting AFLP markers and microsatellites including the population genetics analyses will take about one year for completion.
	c) biodiversity. Three times survey will be carried out during May – December 2010.

Geochemical and sedimentological parameters

The expected impacts of the construction works on sediments and bottom dwelling organisms will be analyzed using the existing database of physiochemical properties of sediment (Erez & Nishri, 2004; Herut & Halicz, 2004) and by further monitoring at the two suggested intake sites. This will include monitoring the sedimentation rates at both intake sites. All these data will be important and represent baseline records of the existing sediment environment.

Sediments will be collected by diving teams from the two suggested intake sites – one near the border and one near the old thermal power station in Aqaba. From each site sediments will be collected at three depths (5 m, 15 m, and 30 m) using the core method (8 cm diameter). The cores will be 15 cm long. After fixation they will be transported to the laboratory and sliced into three sections representing the layers 0-5 cm, 5-10 cm, and 10-15 cm. The cores will be analyzed as follows:

- Calcium carbonate content ($CaCO_3$) will be measured by complex metric titration of calcium carbonate with 0.1N of hydrochloric acid as suggested by Muller (1967).
- The redox potential for the water above the sediment surface will be measured using a Mettler Toledo electrode.
- Grain size distributions will be assessed by a set of calibrated analytical sieves (from 2 mm to 63 µm). The grain size is presented in Q which is equal to $-\log_2$ of the grain size diameter in mm. Mud content will also be calculated (<63 µm).
- Organic carbon content in the sediments will be measured following the method of Gaudette and Flight (1974), where 0.2 g of the sediment is treated with H_2SO_4 (12 M) and potassium dichromate then titrated with ferrous ammonium sulphate solution. The samples are then treated with 1 N HCL first to remove any inorganic carbon in the samples as suggested by Muller et al. (1994).
- Ignition loss will be determined by weight difference before and after combusting over 24 h in a furnace at 500 °C.
- Total organic nitrogen will be determined by Kjeldahl digestion. Organic nitrogen is then converted to inorganic nitrogen by concentrated H_2SO_4 (12 M), which is measured as ammonium following the standard method of Strickland and Parson (1972).

- Total phosphorus (TP) will be determined using the ignition method for particulate phosphate analysis, where 0.2 g of the sample is combusted in a furnace at 450 °C, and the ash is boiled in 1N HCL for 15 min. The sample is then diluted to 100 ml with distilled water, and phosphate is measured spectrophotometrically following the method of Strickland and Parson (1972).
- Heavy metals – a portion of each sediment layer will be mixed and dried at 105°C. The dried samples (0.2 g) will be digested following the method of Wade et al., (1993). The resulting solutions will then be analyzed using a Flam atomic absorption spectrophotometer.
- Sedimentation rates will be monitored through deploying sediment traps at both intake sites. The sediment jars will be collected twice during May-June 2010 and sedimentation rates will be calculated.

A summary of additional monitoring activities for sediment data acquisition is reported in the following table.

Table 4-4 Sediment monitoring activities.

TYPE OF DATA TO BE COLLECTED	a) Physical properties sediment; b) Chemical properties sediment; c) Sedimentation rates.
NEED AND MOTIVATION TO COLLECT THE DATA	The physical and chemical properties of the sediments at the intake sites as well as the sedimentation rates will help to quantify the expected impacts of the construction works on sediments and bottom dwelling organisms.
DETAILS ON DATA COLLECTION	Sediments will be collected once during May 2010 by diving teams from the both intake sites at three depths (5 m, 15 m, and 30 m) using the core method (8 cm diameter). The cores will be 15 cm long. After fixation they will be transported to the laboratory and sliced into three sections representing the layers 0-5 cm, 5-10 cm, and 10-15 cm. The cores will be analyzed as follows: a) Sediment physical properties: Colour, odour, and grain size analysis (mud content); b) Sediment chemical properties: Calcium carbonate, organic carbon, ignition loss, redox potential, total phosphorus, total organic nitrogen, heavy metals. Sedimentation rates will be monitored through deploying sediment traps at both intake sites. The sediment jars will be collected twice during May-June 2010 and sedimentation rates will be calculated.
PLANNED DATES	Sampling of sediments and sedimentation rates will be performed during May-June 2010.

4.2.3 Numerical modelling

By necessity, field data collection is limited in both time and space. In order to obtain a complete four dimensional description (three space dimension plus time) of the circulation, it is necessary to use a numerical circulation model. Due to the multiple scales of interest in this project, we propose to use a hierarchy of nested three dimensional numerical models ranging from a full gulf model with a nominal grid resolution of 500-600 m, an intermediate resolution model of the northernmost 12 km of the Gulf with a resolution of ~100 m, and a small, very high resolution model (~20 m grid size) in the vicinity of the proposed intakes. The models will be used to reconstruct the present circulation as well as to evaluate the potential effects future changes in environmental conditions and the effects of the abstraction of water from the northern Gulf. All of the models require bathymetry, initial conditions, surface (atmospheric) forcing, and forcing at any open lateral boundaries. All three models will be based on versions of the Princeton Ocean Model (POM; Blumberg and Mellor, 1987), which is a three dimensional, time dependent, free surface model. POM is one of the most widely used ocean circulation models. For example, POM is currently being used as part of an operational ocean forecasting system in the Mediterranean Sea (Brenner et al, 2007).The full gulf model and the intermediate resolution northern gulf model will be based on the latest version of POM, which is hydrostatic. Due to the very small scales to be simulated, we will explore the possibility of using a non hydrostatic version (Brovchenko et al., 2007) for the very high resolution model near the intakes. An example of the near surface currents simulated with a model comparable to the proposed intermediate northern gulf model is shown is Figure 4-5.

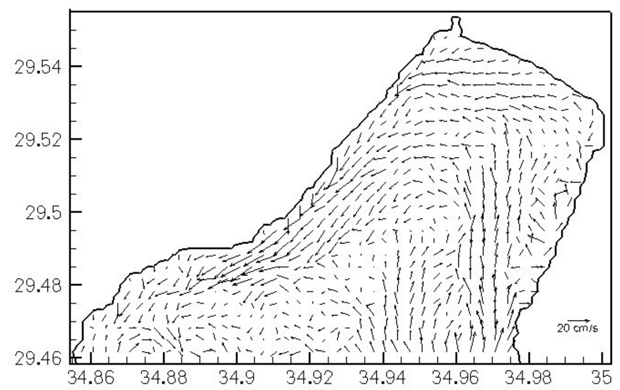

Figure 4-5 Example of near surface currents on 3 Jan 2008 from a previous model simulation with a horizontal grid resolution of 160-185 m which is slightly larger than the grid of the proposed intermediate model.

The bathymetry for the models will be taken from the best available data. For the full Gulf model, we will use the data from Hall and Ben-Avraham (1978). For the intermediate and the high resolution models we will use the data of Sade et al. (2008) or the data digitized from the maps provided by Coyne et Belliers. The initial conditions will be constructed based on a combination of exiting data and any of the new data collected in this project. The main information required consists of temperature and salinity profiles at all model grid points. These will be generated through an objective analysis and interpolation of the existing data.

Surface forcing will be based on available meteorological observations. Wind speed and direction, solar radiation, relative humidity, air temperature, and cloud cover are routinely measured at IUI and MSS. Both historical and ongoing measurements will be available to this project. Data from additional stations such as the airports in Aqaba, Eilat, and Sharam (at the southern tip of the Sinai Peninsula) will be requested from the local weather services. Wind speeds will be converted to wind stress and the other parameters will be used to compute the heat flux components and evaporation following the standard bulk aerodynamic formulae (Ben-Sasson et al., 2009).

Specification of the lateral boundary conditions at open boundaries depends upon the particular model. For the full gulf model, the open southern boundary will be located near the tip of the Sinai Peninsula which is about 50 km (at least 50 grid points) from the Straits of Tiran. Here the temperature and salinity at inflow points will be specified from climatology and/or from model simulations of the Red Sea (Biton et al., 2007). The normal velocity component will be specified by an Orlanski type Sommerfield radiation boundary condition. Finally the free surface height will be specified from a global sea level model combined with available tide gauge records. The latter is important for properly simulating the tidal variability of the currents (e.g., Berman et al., 2003).

Due to the very tight schedule of this project, the model development will commence immediately and preliminary calibration and validation will be carried out with existing, historical data. As data from the field measurements become available, they will be used to further refine the calibration and assess the models' skill in reconstructing the present circulation.

In order to assess the effects of present and future conditions on the marine ecosystem, we will couple a water quality/ecosystem model to the hydrodynamic models. The ecosystem of the warm, temperate Gulf is quite unique so that adapting and applying a properly calibrated marine ecosystem model is far beyond the scope of this project, mainly due to the very short time schedule. Based on our experience from other marine environments, proper and rigorous tuning and calibration of a marine ecosystem model would require several years of intensive research. Thus we propose to use an existing, simplified model which has a limited number of state variables. The model that we will use is the NPZ (nutrients, phytoplankton, zooplankton) model that was developed by Labiosa (2007) for a preliminary study of the ecosystem of the GOAE. The model was coupled to POM and was tuned for the GOAE based on existing data at the time. In view of our comments regarding the intensive work that would be required to properly tune and calibrate an ecosystem model, we will use the same values for the tuning parameters that were specified by Labiosa (2007). The first simulation will be of the present conditions in order to establish the baseline. Subsequent simulations will then be run to assess the impact of future changes (pollution loads and climate change) for the "no action" (i.e., no RDC abstraction) case.

Models runs and simulation scenarios

Identification of the areas and depths affected by the abstraction will be accomplished through a series of simulations with the intermediate (northern Gulf) and the high resolution (vicinity of intake) hydrodynamic models. The control runs will establish the present or baseline conditions as well as the "no action" future conditions. All of the simulations to be conducted in this task, in which we will identify the potential impacts of the RDC abstraction, will be compared to the baseline and the no action cases. The assessments will be based mainly on statistical analyses of the difference fields computed between the various scenarios and the baseline. The high resolution model will resolve the very fine structure and small scale features in the vicinity of the intakes, where we expect the impact to be most noticeable. The intermediate model will help identify far field effects that may occur in other parts of the northern Gulf. These simulations will form the basis for the assessment of the potential impact of abstraction on the larval transport trajectories.

Based on the information supplied by the Feasibility Study Consultant we will run a series of around 16 scenarios with the intermediate and high resolution hydrodynamic models, the particle tracking module, and the water quality/ecosystem model. The scenarios will focus on the two most likely intake locations (one along the north shore near the border and one on the Jordanian east shore of the Gulf, ~ 5-6 km south of the north shore). Based on the recent discussions with the Feasibility Study Consultant, the simulations will be run for a submerged bellmouth. We will consider various depths for the intake and four abstraction amounts (0.5, 1.0, 1.5, and 2.0 billion cubic meters/year). The scenario simulations will also include the expected future changes in the Gulf as described above in Section 4.1.2.3.

The **particle tracking module** will use the hydrodynamic model results to assess potential impacts of RDC induced small and intermediate circulation changes on the larval transport trajectories.

A series of simulations will be run with the particle tracking module forced with the observed currents as well as coupled to the intermediate and high resolution hydrodynamic models with the various intake configurations. For different flow conditions (winter, spring, and summer) we will assess the probabilities of a particle released at a given location being entrained into the RDC intake.

These simulations will assume that the particles are inertia-less, passive tracers, and will neglect their physical characteristics, the interaction between particles, and their settling velocity. These simulations are designed mainly to assess the impacts of the abstraction on the larvae, although we note that larvae swimming behaviour will not be considered. They are not intended to simulate sediment transport since the model does not include any representation of sediment characteristics or dynamics.

The scenario simulations with the **hydrodynamic and water quality/ecosystem models** will give an indication of the potential impacts on the stratification and the nutrient availability in the northern Gulf. This will provide the basis for the assessment of potential impacts on the water quality. The model results together with the water quality assessment will be used to assess the potential impact on the various components of the ecosystem.

The quality of the water supplied at the intake of the RDC will be determined mainly by the water quality in the open water at the intake depth, which in turn is determined by the density structure of the water column. The extent of influence on the density structure of the open sea water column will be determined using the hydrodynamic models to simulate the large-scale full Gulf circulation, the intermediate scale northern Gulf circulation, and the small circulation in the vicinity of the suggested intakes. In the near field water quality may be affected by resuspended sediments due to the force of extraction of water at the intake. Depending on the intake design (surface or sub thermocline) and the modelling results we will make a qualitative assessment of water quality at the intake when the system becomes operational. The effects of various pumping scenarios and intake designs on the nutrient dynamics will be assessed taking into account the results of the physical modelling (water circulation, upwelling/downwelling). This will enable assessment of the potential short and long-term impacts on the water quality transported towards the Dead Sea and the consequent potential down-channel biological dynamics. Based on anticipated changes in the density structure of the open sea water column, we will assess the changes in water quality in the open water, which in essence are representative of the water at the intake. The near field simulation will be used to qualitatively assess the potential for sediment resuspension and water quality degradation at the intake. It should be noted that the hydrodynamic models do not explicitly consider very small scale plume processes such as entrainment in the immediate vicinity of the intake, and therefore are not intended to address issues related to the specific engineering details of the intake. The objective of this study is to assess the potential impacts of abstraction on the Gulf and its ecosystems and therefore consideration will be given to the configuration, overall shape, and location (depth below the surface, height above the bottom, and distance from the shore) as well as to the rate of the abstraction of water.

4.2.4 Climate change effects

The Gulf of Aqaba/Eilat is not exempt from global climate change processes specifically, global warming and ocean acidification. The latter is due to increased levels of dissolved CO_2 in sea water (Caldeira & Wickett, 2003; Orr et al., 2005). Both processes are considered to have a profound affect on the health and functioning of coral reefs and in fact are expected to cause severe decline in coral reefs world wide within the 21^{st} century (Hoegh-Guldberg *et al.*, 2007; Silverman *et al.*, 2009). In the GOAE, preliminary data analysis has revealed a steady increase in Gulf's seawater temperature (positive linear trend of 0.02 ^{0}C/year calculated for the data obtained during 1975-2003; Gertman, I. and Brenner, S. 2004. Analysis of water variability in the Gulf of Eilat. (http://isramar.ocean.org.il/Report1.pdf). While, the abundant shallow and deep water carbonate res-ervoir in the Gulf of Eilat/Aqaba may be able to buffer the increase in atmospheric CO_2 locally by in-creasing carbonate dissolution as proposed by Andersson *et al.* (2003) it has not been demonstrated yet.

Available trends in warming and acidification from the literature will be used to examine their effect on the $CaCO_3$ budget of coral reefs near the canal intake and the Gulf of Eilat/Aqaba in general.

Concerning the effects on corals, some experimental data are available in the literature. In a recent study (2004-2006; Amar et al., 2007), reproductive seasonality in *Stylophora pistillata* peaked during April to June and surprisingly, planulae were also collected in August months, compared to a previ-ous decade-long survey (1974-1983; Rinkevich and Loya 1987) in which reproductive seasonality peaked during March to May without any planulation in August. Similarly, in four out of ten years of a previous survey (1974-1983), none of the examined colonies released any planulae in July, whereas during the recent survey planulae were obtained in all 3 July months. Another significant difference between this 3-year study (Amar et al., 2007) and the former 10-year works (Rinkevich and Loya 1987) is the average number of colonies that were reproductive. Whereas two to three decades ago, 100% of colonies in the wild released planulae during March months, in the more recent study less than 88% of colonies released planulae. Planulae were always obtained during the months of April to June in both surveys (1974-1983 survey and 2004-2006 survey) and an additional survey (1998 and 2003; Amar and Rinkevich, 2007). While the reef in Eilat have gone many changes during the last four decades that may influence coral reproductive activities, one possible explanation for this research outcomes is the steady increase in Eilat's seawater temperature (positive linear trend of 0.02 0C/year calculated for the data obtained during 1975-2003; Gaterman and Brenner 2004).

These results therefore indicate a probable shift in the sexual reproductive seasonality of *S. pistillata* during the last three decades, potentially connected to global changes.

This matter will be elaborated in the study, based on available literature data.

4.2.5 Development scenarios

Changes in the environmental conditions of the GOAE over the next twenty years can be expected through two anthropogenic effects. First, the pollution loads and distributions are likely to change as part of the continuing development and expansion of the cities of Aqaba and Eilat. To accomplish this task best available information from the relevant planning authorities and government ministries are needed regarding expected developments of both cities and assess the potential changes in the pollution loading accordingly.

The Red Sea Study team already asked at the Kick-off meeting in Amman the WB to help in providing such information.

The cities of Aqaba and Eilat have undergone significant expansion and development in recent years. Both cities are major tourist attractions and both cities have ports, although the port of Aqaba is significantly more active than the port of Eilat since Aqaba is Jordan's only outlet to the sea. As the cities expand, the population increases and infrastructure is further developed.

It is possible that future development of the region will include other major abstractions of water from the northern Gulf for purposes such as water projects, additional desalination facilities, and thermal cooling facilities (e.g., power plants).

Identification of major projects / developments that are under construction or have been approved and will start in the next years and description, to the best of available knowledge, of water abstractions and, if any information about, of pollution generation will be provided.

To better respond to this point, Thetis will have a specific meeting with Coyne and Bellier and ERM, in order to acquire to RDS the information already available from the Feasibility Study and the ESA.

The second expected change in environmental conditions will be felt in terms of climate change. As noted previously, the Gulf is located in an arid region where the annual rainfall is less than 30 mm. This amount of precipitation is negligible in terms of affecting the sea. The main climate change effect that is anticipated in this region is an increase in temperature and a possible accompanying slight increase in evaporation. These effects will be assessed through additional hydrodynamic model simulations in which the predicted atmospheric temperature increase is added to the surface forcing terms. We do not expect a significant change in the wind regime since the Gulf is an extension of the Araba/Arava Valley and is bounded on both sides by mountains that rise to at least 400-500 m above sea level. These mountains have a very strong channelling effect on the winds which consequently blow from the north nearly 90% of the time. An additional climate change induced effect is ocean acidification. This process has only recently been studied and is poorly understood. An in depth analysis of the carbon cycle of the Gulf is beyond the scope of this study.

4.2.6 Description of impacts of construction and operation on the coastal zone and shoreline

Two possible intake locations have been preliminarily selected within the feasibility study by now (Coyne et Bellier, 2009. Options Screening and Evaluation Report. Executive Summary). One is located on the Jordanian north coast of GOAE, between the Jordanian/Israeli border and the boundary of the Ayla Project development, and one on the Jordanian east coast of GoA, approximately 5.5 km south of Aqaba.

The first one is in the area of the Eilat marina and touristic resorts, of the hotel zone of Aqaba and of the floating fish farms, while the second one is located between the Main Port and the Container Port of Aqaba.

The intake construction works are likely to affect the fragile marine coastal environment, which represents a valuable element and a fundamental resource for the economic activities related to tourism and fishery in the upper GOAE. Impacts are expected for example in terms of possible direct destruction of habitat but also due to increased turbidity and possible resuspension of contaminated sediments from the bottom.

Moreover, direct impacts on shipping, navigation, tourism and fishing activities are expected, both during construction and operation, due to restrictions (temporary or not) in the access to coastal marine and shoreline areas and because of noise and vibrations produced by the construction works.

The environmental and socio-economic impacts of intake construction works and operation will be identified and described (intensity, size of affected area, duration) according to the predictable characteristics of the intake and of the related building activities (to be identified in cooperation with the Feasibility Study Consultant), to the knowledge of the local ecosystem and on the characteristics of the main activities of socio-economic significance in the coastal marine and shoreline areas next to the intake location (to be obtained from the relevant authorities and/or ministries: ASEZA, Aqaba Development Corporation, Port of Eilat Authority, …).

As it is expected that turbidity generated during the construction works will be a major source of impact, plume dispersion of the resuspended sediments will be analyzed using particle-tracking within the high resolution hydrodynamic model set up for areas closer to the inlets.

The evaluation of impacts of construction and operation will be given at a qualitative and general level, coherently with the overall scope of the Study and accordingly with the time and resource constraints. The evaluation will be based on a simplified analysis and it will not take into consideration many details which are needed in the framework of an Environmental Impact Analysis procedure.

4.3 Production of output

4.3.1 Reporting

The study output will be presented in report format, with the key elements summarized, and in power point presentation format.

The reports will describe the progress of the project activities and address all the questions identified in each of the tasks described in the TOR based on the information available so far.

4.3.2 Data management

Raw or elaborated data acquired by automatic recording systems such as current profilers, CTDs, thermistors or resulting from analyses of field samples will be organized in order to be easily accessed by a GIS system.

The most appropriate format and data classification will be designed after a coordination meeting held with ESA consultants and/or GIS system provider.

All geo-data will be however stored and organised in a geodatabase (e.g. Access, SQL, Oracle or ESRI File Geodatabase, etc.) in order to ensure easy accessibility to GIS platform. Acquired data will be therefore readily available to generate thematic maps and perform standard and spatial queries, by means of GIS functionalities.

Moreover, each data set will be classified and organised at least by means of data source and sampling period. Data will be provided with metadata, at least including:

- geographic coordinates;
- depth;
- sampling date and time;
- Sampling activity short description;
- type of data (e.g. scalar or vector);
- sample name.

The coordination meeting with ESA consultants will define specific metadata to be considered, in case integrating the above preliminary list. Particular attention will be given to the selection of coordinate typology and projection system.

4.4 Milestones and deliverables

The following table defines the list of the expected project milestones, where the quality and the time schedule of the project will be continuously assessed.

Project milestones include key meetings, delivery of project reports and the completion of the main groups of project activities.

Table 4-5 Project milestones.

	Milestone description	Planned date
M1	Award of Contract (effective date)	February 19th, 2010
M2	Kick off workshop	March 7th, 2010
M3	Submission of Inception Report	April 2nd, 2010
M4	Completion of collection and review of existing data and information	July 1st-15th, 2010
M5	Submission of Best Available Data Report	July 15th, 2010
M6	Submission of Mid-Term Report	October 15th-30th, 2010
M7	Completion of models set up and calibration	November 15th-30th, 2010
M8	Completion of additional monitoring activities	March 15th-30th, 2011
M9	Submission of Draft Final Report	April 15th-30th, 2011
M10	Submission of Final Report	August, 2011
M11	Closure meeting	August, 2011

4.4.1 Best Available Data Report

According to WB request, the Best Available Data Report (BAD Report) will be available by July 15th, in order to provide information for the preparation of Draft Final Report of the Feasibility Study under preparation by Coyne & Bellier.

The Report will include baseline description according to TORs, <u>on the basis of already available data and information</u>.

The baseline will consist in the detailed description of the currently prevailing oceanographic conditions and environmental quality of the whole Gulf of Aqaba/Eilat in general and in greater detail for the northern tip of the Gulf. The description will address the following parameters:

- topography and bathymetry;
- climate and weather patterns;
- currents, tides, circulation, upwelling and down welling;

- water quality and chemistry;
- sources, nature and extend of pollution from both dispersed and point sources;
- types and location of bottom sediments;
- types, variety and extent of marine habitats and their importance and sensitivities;
- marine ecology, zoology, biology and biodiversity;
- coral reefs and distribution and flow patterns of coral larvae;
- presence, location and pumping rates of other sea water intakes in the Gulf of Aqaba/Eilat, based to the best available knowledge.

A range of realistic climate change scenarios will be considered to evaluate long term impact on oceanographic conditions (impacts will be addressed primarily in terms of the circulation and physical conditions).

The BAD Report will also contain some very preliminary anticipation of the project results, based on:

- the limited understanding available at the stage;
- the lack of modeling tools, presently under development;
- the uncertainties on location and depth of the intakes, that should be supplied by the Feasibility Study according to the ToR (Task 2.1).

Preliminary description of effects of water abstraction will be formulated by comparison of Pros & Cons of different project options.

The different options will be considered with respect to the following aspects:

- <u>abstraction rate</u>: comments and recommendations will be given on effects of minimum and maximum abstraction rates;
- <u>intake depth</u>: pros & cons of different options will be discussed; a “surface” option (intake depth of about 25 m) and a “deep” option will be considered;
- <u>intake location</u>: pros & cons of different options will be discussed; the northern and the eastern intake options will be considered.

For the different options, the following environmental aspects will be discussed:

- effects on water circulation;
- effects on water quality;
- effects on ecology, focused on coral reefs.

On the base of such preliminary analysis, preliminary recommendations will be given on best options to address the Feasibility Study.

Such anticipations of project results could be subjected to change and modification in the later stages of the project, when the outcomes of monitoring and modeling activities will become available.

Analysis of effects and recommendations given in the BAD report will necessarily be very preliminary and general, due the lack, at that stage of the project, of some important elements, to be filled by results of field work and modeling activities that will become available during the further phases of the study.

Particularly, the following elements will be still uncertain and are expected to be clarified by the new data and modeling results:

- patterns of water circulation in the Gulf (new evidences from monitoring activities and modelling);
- spatial distribution of coral larvae – invertebrates and fish larvae – and their seasonal dynamics (new evidences from monitoring activities);
- effects of changes in circulation on coral larvae distribution (new evidences from particle tracking model);
- effects of changes in circulation on water quality in the Gulf (new evidences from ecological model);
- genetic connectivity evidences between coral population in the Gulf (new evidences from monitoring activities).

In addition to that, some issues concerning project options (e.g. intake locations) will be still not exactly defined, causing additional uncertainty. This factor is going to be another reason for BAD report analysis of effects and recommendations to be preliminary and general.

After the submission of BAD report the Consultants will keep the Word Bank informed about new outcomes of the project by means of the other expected reports (Mid Term Report, Draft Final report, see Table 4-5 for time schedule), planned meetings and other information exchanges (e.g. conference calls).

The model set up and calibration will begin with the hydrodynamic models, proceeding in the order of the model resolution hierarchy beginning with the full gulf model, followed by the intermediate resolution model, and ending with the high resolution model. The particle tracking module and the ecological model will be run only after the hydrodynamic models have been calibrated.

By the end of September we expect to have the full gulf and intermediate resolution models ready based on existing data any new data that may be available.

Results from preliminary simulations of the present and future conditions without the RDC should be completed by the end of October.

The completion of models set up and calibration is expected by the end of November, 2010, in the next 1-2 months results from modeling simulations are expected to become available, providing, by beginning of 2011, significant additional information for the preparation of final analysis and evaluations of the project.

The completion of additional monitoring activities (field work and laboratory analysis) is foreseen by the end of March, 2011, and they will be incorporated in the Draft final report, to be submitted by the end of April, 2011.

4.4.2 Mid term and Final Reports

Mid term and Final Reports will address all project issues requested in the Terms of Reference.

Preliminary outline for the **Mid term report** is the following:

1. Description of the existing and predicted future environmental conditions in the no action case;
2. Description of the effects of abstraction on the upper gulf;
3. Identification of the resulting impacts on the environment of the head of the Gulf;
4. Identification of the effects of abstraction at the gulf-wide scale.

Preliminary outline for the **Final report** is the following:

1. Description of results of filed;
2. Description of the existing and predicted future environmental conditions in the no action case;
3. Description of the effects of abstraction on the upper gulf;
4. Identification of the resulting impacts on the environment of the head of the Gulf;
5. Identification of the effects of abstraction at the gulf-wide scale.

Contents and outline of both reports could be modified during the study. The Word Bank will be informed of proposed modifications to the contents and structure of the reports.

5 Project organization

The scheme reported in Figure 5-1 summarizes project organization.

Responsibilities of different Institutions involved are pointed out in Table 5-1.

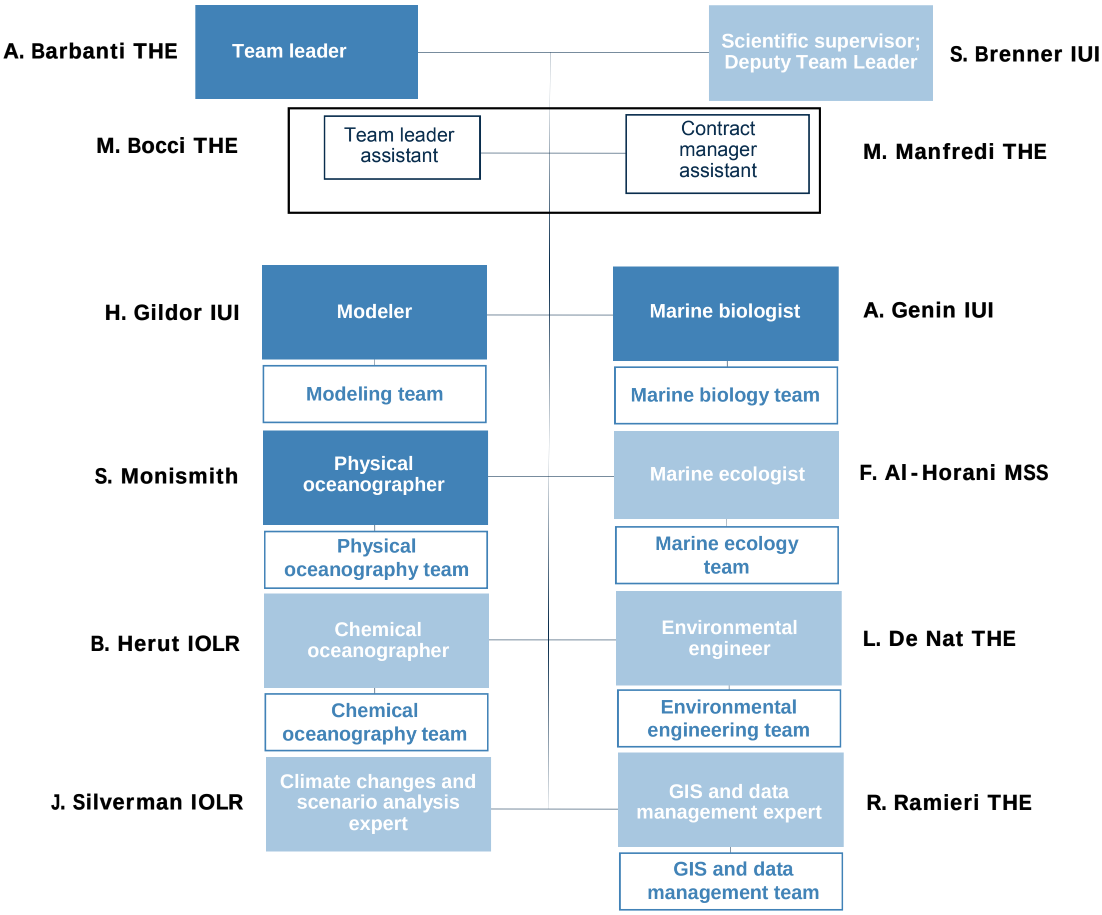

Figure 5-1 Project organisation.

Table 5-1 Main project activities and responsibilities.

Main activities	Responsible	Supporting	Key staff	Reference person
PROJECT MANAGEMENT AND REPORTING	THETIS	-	TEAM LEADER	A. Barbanti *(Thetis)*
			DEP.TEAM LEADER	S. Brenner *(IUI - Bar-Ilan)*
MODELLING	IUI *(Weizmann Institute + Bar-Ilan University)*	-	MODELER	H. Gildor *(IUI -Weizmann)*
PYHSICAL OCEANOGRAPHY	IUI *(Weizmann Institute + Bar-Ilan University)*	MSS	PHYSICAL OCEANOGRAPHER	S. Monismith *(Stanford U.)*
CHEMICAL OCEANOGRAPHY	IOLR	MSS, IUI	-	B. Herut *(IOLR)*
MARINE BIOLOGY	IUI *(IUI-Eilat + Hebrew University of Jerusalem)*	MSS	MARINE BIOLOGIST	Genin *(IUI - Eilat)*
MARINE ECOLOGY	MSS	IUI	-	F. Al-Horani *(MSS)*
POLLUTION LOADS ESTIMATION	THETIS	IUI, IOLR, MSS	-	L. De Nat *(Thetis)*
DATA MANAGEMENT	THETIS	-	-	E. Ramieri *(Thetis)*

6 Information from the Word Bank and Coyne et. Bellier

The following information will be provided by the Word Bank and Coyne et. Bellier to the Red Sea Study Team. Such information is essential for the executions of the activities.

- Depth and location of intakes;
- Proposals of modification of modelling scenarios (considering eventually preferred options);
- Project study database format.

Such information needs to be provided not later than June 30th, 2010.

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