COASTAL ZONE MANAGEMENT IN DUBAI WITH REFERENCE TO ECOLOGICAL CHARACTERIZATION ALONG DUBAI CREEK

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Coastal Zone Management in Dubai with reference to ecological characterization along Dubai Creek

Ph.D. Thesis

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بسم الله الرحمن الرحيم

قل إن صلاتي ونسكي ومحياي ومماتي

لله رب العالمين لا شريك له

وبذلك أمرت وأنا أول المسلمين

dedicated to environmental management and

sustainable development of Dubai

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Khalid Al Zahed

Declarations

I, Khalid Al Zahed hereby certify that this thesis, which is approximately 46,900 word length, has been written by me, that it is the record of work carried out by me and that it has not been submitted in any previous application for a higher degree.

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I was admitted as a research student in September 2004 and as a candidate for the degree of Ph.D, in September 2005; the higher study for which this is a record was carried out in the University of St Andrews between 2004-2007.

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CONTENTS

ABSTRACT

Integrated Coastal Zone Management (ICZM) is a dynamic process in which a coordinated strategy is developed and implemented for the allocation of environmental, socio-cultural, and institutional resources to achieve the conservation and sustainable multiple use of the coastal zone.

The present study titled "*Coastal Zone Management in Dubai with reference to ecological characterization*" is an effort to consider critical water quality and ecological issues in the current and future coastal zone of Dubai Creek. The work included water quality, ecology and numerical modeling for predicting future conditions. This study is utmost significant due to management of critical coastal environmental issues (fish mortality, bad odour, unaesthetic view, algal bloom etc.) in Dubai Creek besides protection of internationally recognized bird sanctuary (Ras Al Khor Wildlife Sanctuary) and sustainable multibillion dollar of property developments as an extension of Dubai Creek. Comprehensive attempt made to collect primary data on water quality and ecology during 2005 and 2006 from specific monitoring stations spreading along Dubai Creek.

The pragmatic results in Dubai Creek are alarming; the upper region is susceptible to high organic pollution which exhibits 3-122 folds high nutrients levels while biodiversity in the same region at the seabed is almost died and non-existing. The current assessment suggests a policy for the ICZM and an "<u>Immediate Action Plan</u>" for the beneficial and sustainable development of Dubai Creek.

The study recommends the following mitigation as a tool for the management strategies of Dubai Creek lagoon:-

- Dredging in the lagoon of Dubai Creek.

- Tertiary treatment of wastewater from Awir STP prior to discharge into the Creek or divert the discharge from the lagoon of Dubai Creek.
- A new Government Decree for the water quality thresholds in Dubai Creek.

CHAPTER I

Introduction

1.0 Background

The coastal zone, including land and adjacent waters, is among the most heavily developed and exploited regions in the world. Human populations in these areas use the resources from the sea, modify the landscape, and produce large amounts of waste and chemical pollutants, all of which are usually released into the marine environment. This exploitation can be measured by the effect on the fish stocks, water quality, space, and of desirable services such as recreation, waste disposal, and food production (Lindergarth 2004). Marine and terrestrial ecosystems differ in significant ways that suggest that the ocean may respond to human perturbations in a fundamentally different manner from the land (NRC 1995). Production of goods and services in the marine environment is to a large extent based on the biodiversity of the system with its associated ecological processes (Lindergarth 2004). Human existence (and that of most other organisms) is heavily dependent on what biologists call primary producers. 5000 plant species have been used as food by humans, but less than 20 now feed the majority of the world's population (Plotkin 1988 and Reid & Miller 1989). The diversity of life in the ocean is being dramatically altered by the rapidly increasing and potentially irreversible effects of activities associated with human population expansion (NRC 1995). Therefore, to keep continuity of the supply of coastal resources, the diversity of species and their associated functions need to be protected and managed in a sustainable way (Lindergarth 2004).

Historically, coastal zones have been exploited by human beings to initiate their first settlements in many parts of the world. Coastal ecosystems, such as estuaries, marshes, shallow bays and wetlands, mangroves, coral reefs and seagrass beds, play a major role in the life cycle of many marine organisms, including economically important fish species, by providing breeding, nursery and feeding grounds. About 95% of world marine production originates from coastal ecosystems. Marine fisheries are threatened by the accelerated degradation of ecosystems, land reclamation, drainage, coastal construction, sewage and wastewater discharge, and many other competing uses (www.oceansatlas.com). Even using sophisticated knowledge and tools to asses the impacts to the coastal environmental from human interferences, depletion of resources is still continuing in most coastal zones around the globe. Recent environmental issues in the Global Coastal Zone (Shi & Singh 2003) provide an alarming and sobering picture of exploitation of world's coastal resources (Khan et al 2002).

In 1997, 3.8 $x10^9$ people or 60% of the world population lived and worked within the coastal zone. Given the present trend of population growth, an estimated 6.3 $x10^9$ or 75% of world population will reside in coastal areas by 2025 (Khan et al 2002). The common coastal zone problems such as degradation of corals, decline in fish stocks, eutrophication, harmful algal blooms and outbreaks of pathogens are just a few manifestations of the combined effects of coastal anthropogenic activities at local, national, regional and global scale.

Coastal zones are increasingly subjected to high pressure from expanding commercial and industrial fishing and many former productive grounds for fish have been lost to coastal reclamation for industrial, residential and recreational facilities. The Arabian Gulf has lost over 40% of its intertidal areas for such developments. Burgeoning human populations in the Gulf are resulting in considerable pollution from domestic sewage and industrial discharges (Khan et al 2002). Recent events (e.g. the Gulf War) have proved how vulnerable the Gulf coast is to threats such as oil pollution. In addition, the extent of mangroves and seagrass cover in the Arabian Gulf has been declining due to the impacts of unplanned coastal development (Price et al 1993). Natural inland wetlands are also threatened due to over-extraction of water for the expansion of intensive crop growing for the agro-industry and to a lesser extent due to extractions for domestic consumption (Feulner 1996).

The management complexities for the coastal zone are generally associated with the greater diversity of ecosystems and greater resources development opportunities than in purely oceanic marine environments. The fragmented jurisdictions and the lack of adequate understanding of bio-geophysical and socio-economical processes in coastal areas are major constraints in addressing environmental problems and resolving conflicts. In recent years it has been widely recognized that sustainable management of the coastal zone requires an integrated approach aimed at reconciling the conflicting coastal zone interests into a cohesive but dynamic system to ensure its sustainability. The approach is usually referred to as Integrated Coastal Zone Management (ICZM) or Integrated Coastal Area Management (ICAM) (Khan et al 2002).

International environmental organizations recognize two eco-regions in the Arabian Gulf region. Such eco-regions, which can be many thousands of km^2 in extent, have been identified globally on the basis of their unique biological diversity and bio-geographical functioning (Olson & Dinerstein 1997).

The two eco-regions represented in the United Arab Emirates (UAE) - the Arabian Gulf and the Arabian Sea and the Arabian Fog are considered of sufficient ecological and socio-economic importance to warrant concerted action at governmental and inter-governmental level to maintain sustainable levels of resource exploitation (Aspinall 2001).

1.1 Coastal zone management and its benefits

The coastal zone supports a variety of highly productive and economically important ecosystems, such as coral reefs, mangrove forests, seagrass beds, sandy beaches and intertidal mudflats.

Environmental systems (natural capital) have been experiencing intense and sustained environmental pressure and stresses from a range of direct and indirect socio-economic driving forces. Given this context, ecosystem conservation has to be interpreted as efforts to manage the rate of environmental change (Turner et al 2000).

These ecosystem functions generate a coastal resource base in terms of goods (such as commercial fisheries) and services (such as recreation, shipyards and harbours) utilized by various sectors of human activity. These services include shoreline protection (buffering the coastline, protecting it from erosion from storms, winds and waves), storing and cycling nutrients, sustaining biodiversity by maintaining water quality (through filtering and degrading pollutants), and serving as areas for recreation and tourism (Figure 1.1).

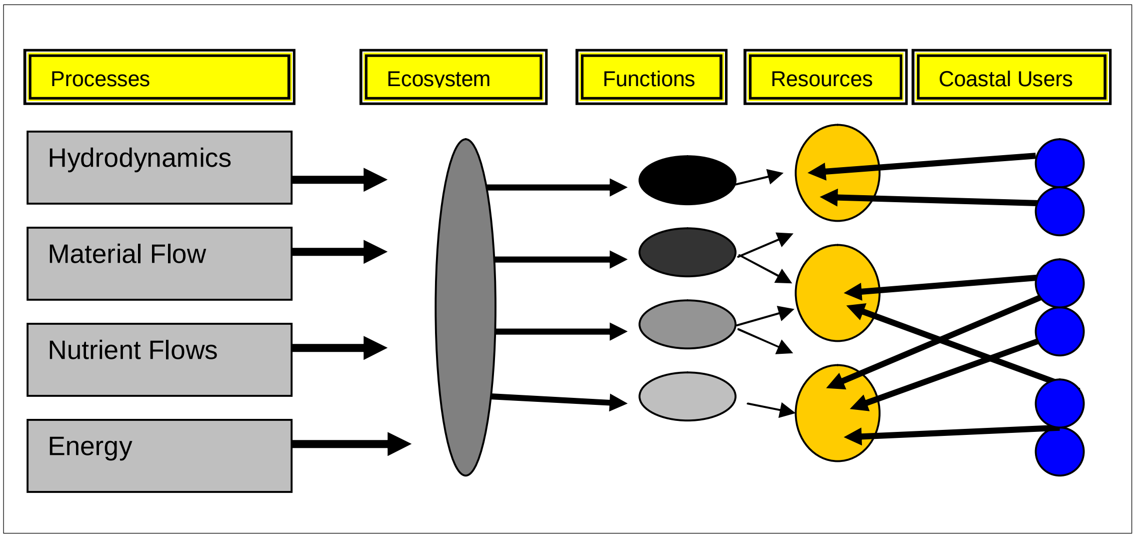


Figure 1.1: Factors of a generalized coastal ecosystem showing the driving processes (left) of the ecosystem providing functional roles in allied resources used by the coastal users

It is important to note that despite their diversity, these ecosystem functions are interdependent and are collectively vital to the sustainability of the coastal zone as a whole (Khan 1997).

1.2 Aspects of ICZM

In the recent literature, ICZM is variously defined, but it is generally understood as "a dynamic process in which a coordinated strategy is developed and implemented for the allocation of environmental, socio-cultural, and institutional resources to achieve the conservation and sustainable multiple use of the coastal zone" (CAMPN 1989).

1.3 Dubai Creek setting

The UAE lies between latitude 22^0-26.5^0 N and longitudes 51^0-55.6^0 E. It has 700 km of coastline and the 77 700 km^2 land area. The landscape is dominated by rolling sand dunes, coastal dunes and gravel plains.

The UAE is a federation of 7 emirates namely Abu Dhabi, Dubai, Sharjah, Ajman, Umm Al Qaiwain, Ras Al Khaimah and Fujairah. The second largest of the federation is Dubai and is the center of trade, commerce and tourism in the UAE. It is also the leading entry port to the region. Dubai's coastline stretches about 72 km along the southern shores of the Arabian Gulf (Figure 1.2).

Dubai Creek, the heart and the focal point of Dubai, has an immense importance for trading as well as great aesthetic value. The water body is also an important landmark of Dubai. It provides an important means of transport, water sports and more than that provides a haven for migratory water birds. The emergence of Dubai as a commercial center is dated back to the beginning of 19^{th} century. The city was a small coastal village, which gradually began to grow. In the 19th century the population of Dubai was approximately 6000 and by the 1930’s approached 18 000 (Wilson & Shukla 1999).

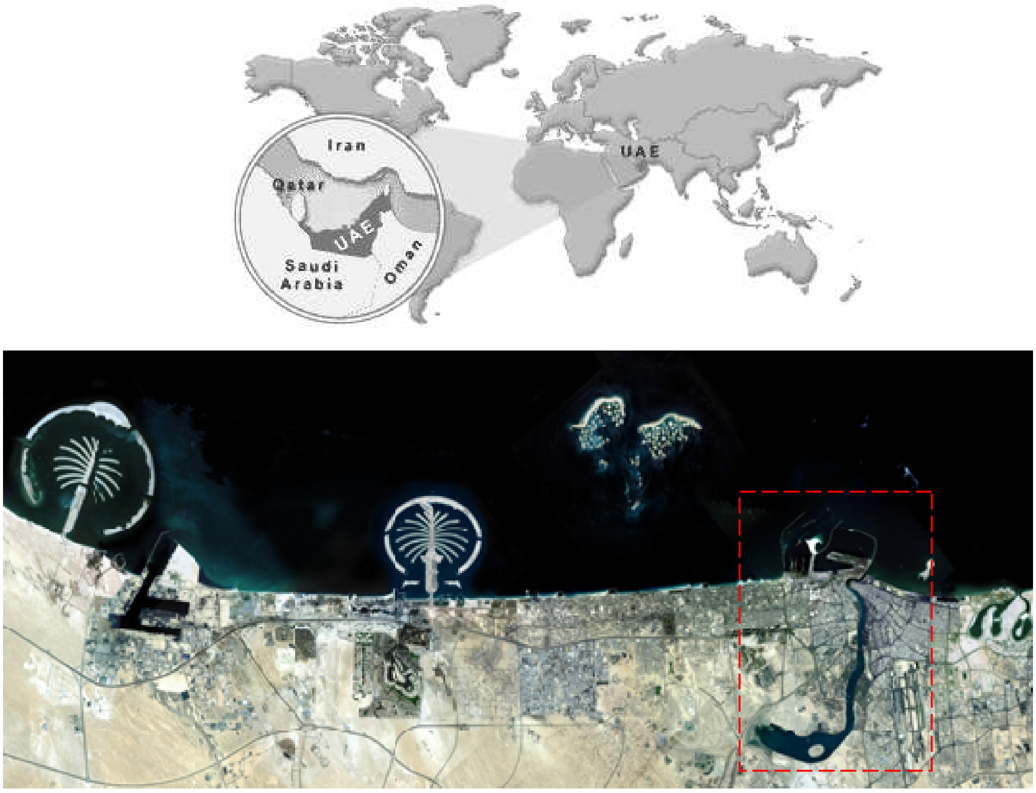


Figure 1.2: UAE above and coastal territory of Dubai showing Dubai Creek (Image courtesy Google earth 2006)

Dubai was the largest town on the Trucial Coast in 1940 with about 25 000 inhabitants. During that period, Dubai Creek divided Dubai town. The length of Dubai Creek was approximately between 8-10 km and many native crafts used to be anchored in Dubai Creek. After the first dredging in Dubai Creek during 1959-60, more ships began to berth in Dubai Creek and opened a new chapter in the commercial life of Dubai (Figure 1.3).

By 1965, a comprehensive plan was made and approved by the Dubai Ruler and amended in 1971 with the help of UNDP (United Nations Development Programme) experts (Wilson & Shukla 1999). Today the population of Dubai is in excess of 1.4×10^6. As a relatively young and progressive city, it has achieved tremendous development in the last two decades. These developments include in particular, Dubai Creek and coastal region (Figures 1.4-1.6).

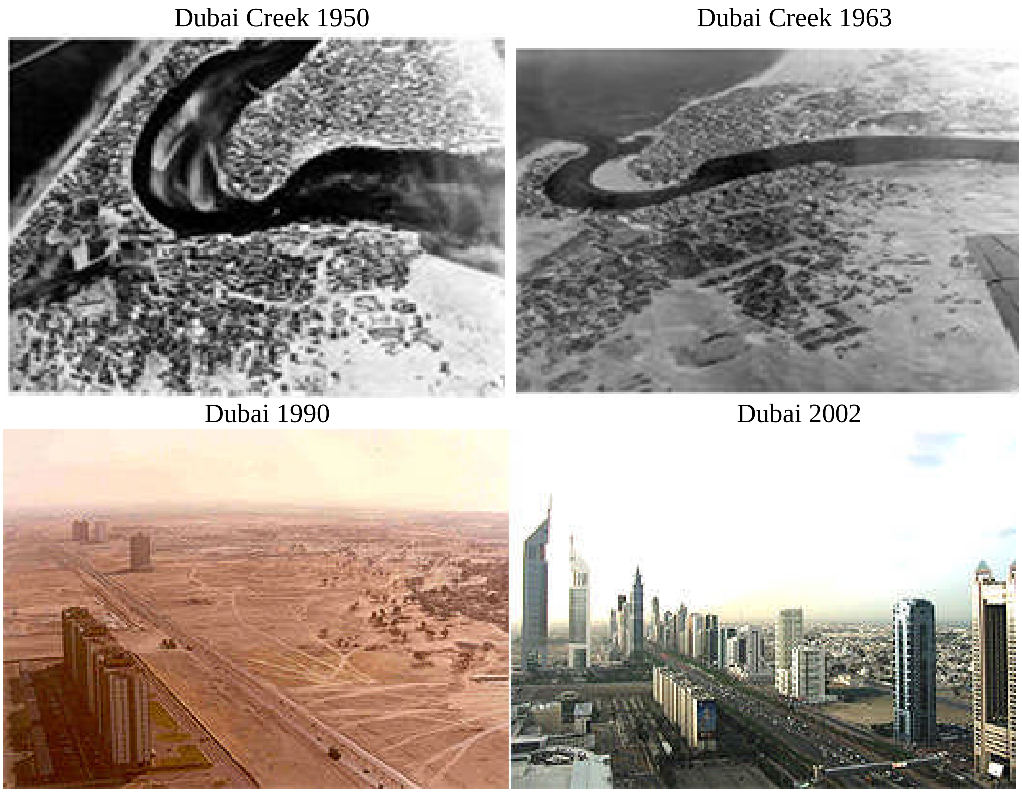


Figure 1.3: Views of Dubai showing historical developments. The pictures taken in 1950 and 1963 are viewing undredged (left) and dredged areas in Dubai Creek respectively (above) and development in Dubai Shaikh Zayed Road (below)

Figure 1.4: Present view of Dubai Creek at night


Figure 1.5: Present view of Dubai Creek showing wooden crafts (Dhows)

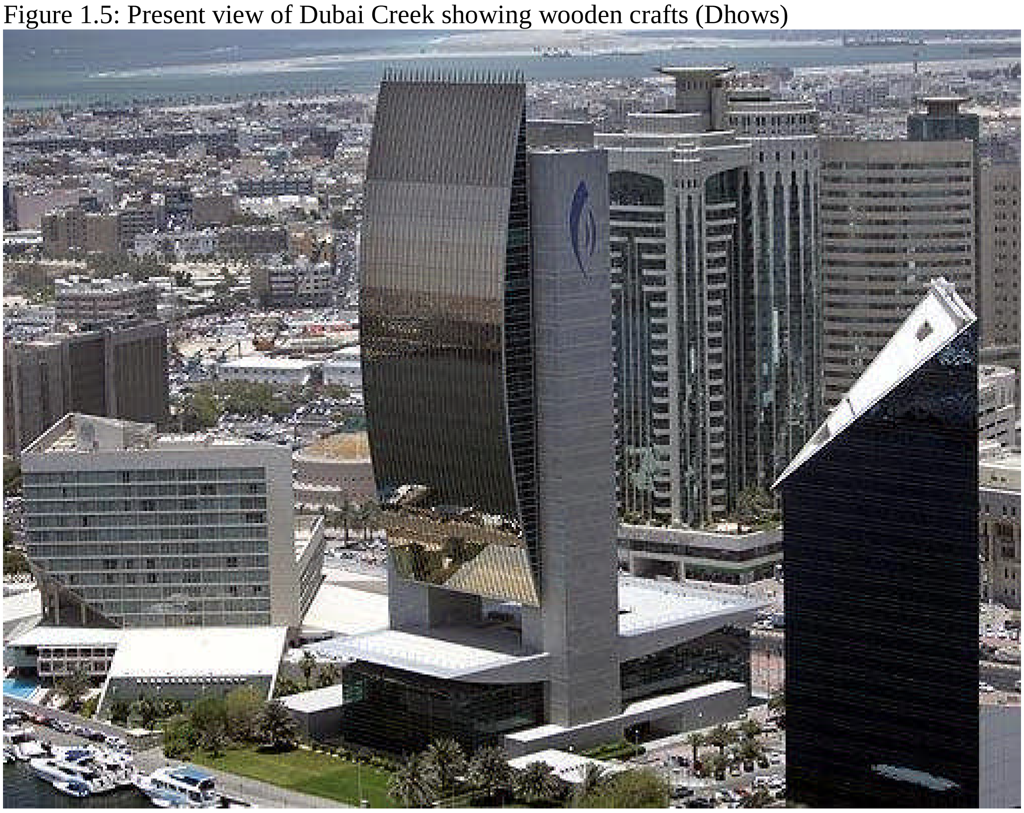


Figure 1.6: Present view of Dubai Creek

In addition to the developments shown, 'the Business Bay Project' a new multi-billion development project has just been initiated in the extension of Dubai Creek from the upstream region (Figures 1.7-1.8).


Figure 1.7: Projected view of Dubai Creek- after Business bay development. Picture courtesy: www.houseofproperty.com


Figure 1.8: Projected view of Dubai Creek- Business Bay Development. Picture courtesy: www.emmar.com

1.4 Climatic and physical conditions of Dubai

The climate of Dubai, like that of the entire Arabian Peninsula, is dominated by the sub-tropical high pressure ridge. The climate in the Arabian Gulf region is arid, resulting in an excess of evaporation over precipitation plus river run-off. Estimates of fresh water flux are quite variable (Hartmann et al 1971, Chao et al 1992 and Reynolds 1993). Precipitation is 0.07-0.1 m/year (Hartmann et al 1971 and Reynolds 1993). The relatively high evaporation combined with restricted exchange with the open ocean leads to the formation of a saline, dense water mass known as Arabian Gulf Water (AGW) and a reverse estuary circulation through the Strait of Hormuz. Within the Strait, flow of AGW out of the Gulf is mostly confined to the southern side of the channel by geostrophy (Emery 1956). Indian Ocean Surface Water (IOSW) normally flows into the Gulf from the open ocean along the northern side of the Strait and continues northward along the Iranian coast (Emery 1956, Brewer et al 1978, Hunter 1983 and Reynolds 1993).

Dubai lies within this subtropical ridge, an area of dry, stable, subsiding air which gives rise to hot, dry and near cloudless conditions. In summer the ridge is weaker than in winter and it is displaced to the north. Occasionally disturbed tropical monsoon weather may reach Dubai, bringing summer rains.

Temperatures are subject to considerable diurnal and seasonal fluctuations. Winters (December to February) are cool to warm. The winter average maximum is about 22 ^{o}C. The coast is warm and humid in summer (June to September) with an average maximum of around 42 ^{o}C. The humidity varies seasonally from about 40% in winter to approximately 70% in summer.

1.5 Characteristics of the Arabian Gulf

Dubai lies within the Arabian Gulf, therefore its geo-physical and oceanographic characteristics are mainly influenced by the Arabian Gulf. The Arabian Peninsula (Arabian platform) consists of a crustal plate divided into the Arabian shield and the Arabian shelf. It is composed of igneous and metamorphic rocks of Pre-Cambrian age dating back 1170×10^6 years. The shield occupies the western side of the peninsula. By Cambrian times, about 550 $\times 10^6$ years ago, the shield was a stable land mass and formed the platform on which the cover rocks of the Arabian shelf were deposited (Chapman 1978).

The Gulf is a very shallow epicontinental sea with an average depth of only about 35 m. The depth of Arabian Gulf overflow water is determined by its source characteristics as it flows through the Strait of Hormuz and by subsequent mixing processes on the continental shelf and slope off Oman and Iran (Figure 1.9) (Bower et al 2000). The evaporation in the Gulf exceeds combined rainfall and freshwater input, and even though there is a substantial flow into the Gulf from the Shatt al Arab delta, there is annually net input of water from the nearby Gulf of Oman. The slope of the floor of the Gulf is a gradual decent through to the north, which runs roughly parallel to the Iranian coast. Most evaporation in both summer and winter occurs in two extensive and mostly very shallow southern embayments along the Saudi Arabian and UAE coast. Usually, the characteristics of the Arabian Gulf are determined by the shallow depth and extreme air temperature, high evaporation rates and the restricted circulation of the Gulf with the Arabian Sea through the straits of Hormuz (Hunter 1982). The resulting offshore environment is harsh, with extremes of salinity. Salinity ranges from 38-42‰ in the region north of Al-Khobar, but increases dramatically to the south. Water enters the Arabian Gulf through the Strait of Hormuz at a salinity of 36.5-37‰. Oceanographic observations show a surface drift of current towards the west along the Iranian shore, consistent with the anticlockwise circulation (Hunter 1983) of the gulf. At all times of the year, the diluting influence of the Shatt al Arab at the northwest corner of the Arabian Gulf is evident. This is especially evident in winter when flow is greatest.

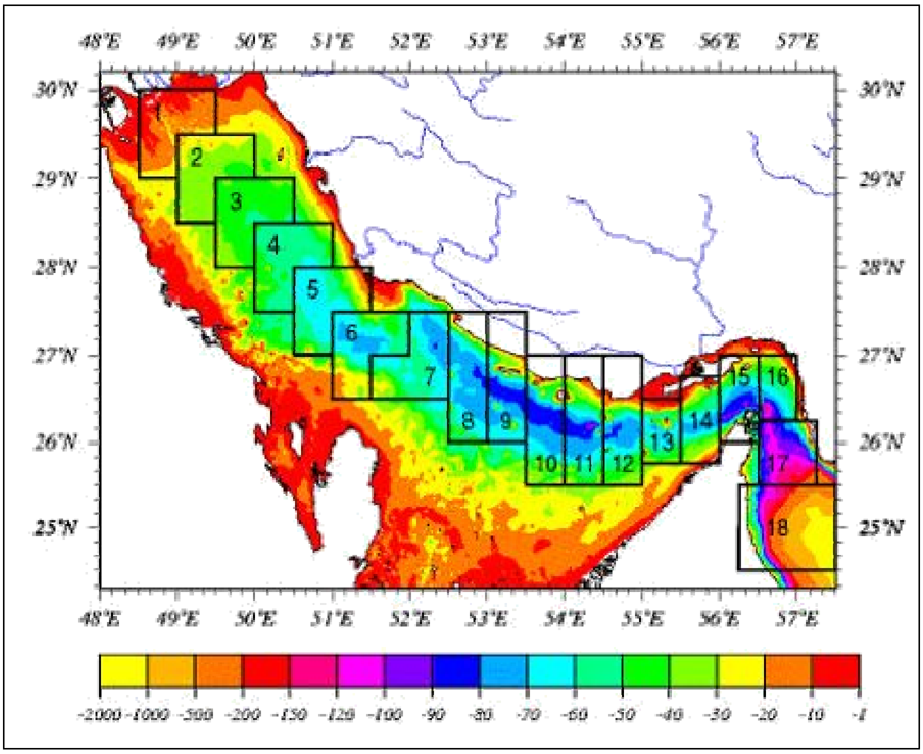


Figure 1.9: Bathymetry of Arabian Gulf compiled from navigation charts shows the elongate Gulf basin narrowing in the western approach to the Strait of Hormuz (Source:www.whoi.edu/science/PO/people/abower/papers/PGulf_circulation_ms.pdf).

The tidal regime is essentially of a semi-diurnal pattern. During neap tides a strong semi-diurnal pattern prevails, with two well-defined high and low water periods during each 24 hour period. However, during the spring tides there is a more mixed system with only a slight difference in height and time between one pair of adjacent high and low peaks each day. During the winter months (November-February) the lowest spring tide of each period occurs during the middle of the day whereas during the summer months the lowest spring tide occurs during the early morning hours. Data on the significant wave heights and directions for the Arabian Gulf were obtained from the Naval Oceanographic Office (Figure 1.10)

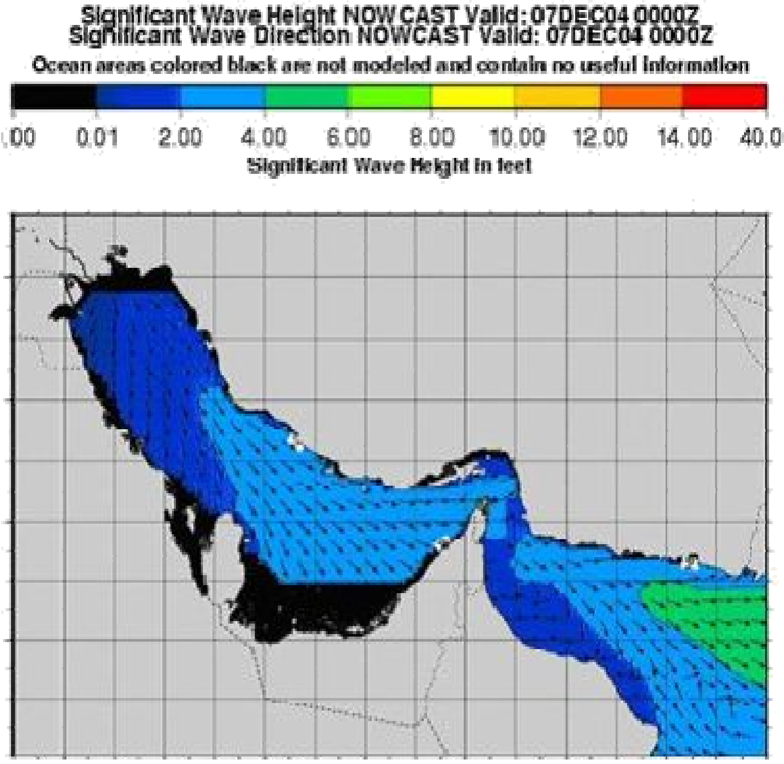


Figure 1.10: Predicted significant wave heights and directions along the Arabian Gulf

1.6 General characteristics of Dubai Creek

Dubai Creek is a tidally influenced water body located in Dubai in the UAE. It forms roughly 14×0.40 km of semi-enclosed waterway in a densely urban setting. At its mouth, the Creek has an opening of about 100 m, before widening to about 1200 m in the upper end of the Creek forming a wide lagoon. The average depth of the Creek is about 6 m throughout the waterway. The maximum tidal difference between neap ebb and spring flood (data provided by Meteorological Office) at Al Maktoum Bridge is -0.04 to 2.08 m.

1.6.1 Current and flushing characteristics

The Creek is a seawater intrusion with no hydrodynamically significant freshwater inputs. The residence time calculated in the upper end region is greater than 90 days (HydroQual 2003). The tidal current, therefore, increases towards the mouth of Creek as the system narrows (known as the downstream channel) (Figure 1.11). For this reason, the peak velocities occur at the channel constriction on the library bend, where cross sectional area is minimum and current reach as the speed of 150 cm/s on the major ebb (Halcrow 1992). The current at the same location during maximum floodwater is slightly lower. Just as current speed increases towards the mouth, so there is a converse reduction towards the head of the lagoon to a level at which secondary process, such as those due to temperature, winds etc. may assume greater significance than tidal effects (Figure 1.11). Thus reduced current means that pollutants from an incident occurring in the Creek would be slow to reach the head of the lagoon (known as the upstream region), but they also mean that any pollution reaching upper reaches of the Creek would be slow to disperse (Figure 1.12). In the upper stream of the seaward end of the customs wharf, the peak current is slow and generally less than 50 cm/s (Halcrow 1992). Assessment by Atkins (1984) indicates that a current of 190 cm/s would be required to initiate a motion of coarse material in the 9 m depth channel seaward of the library bend, and that for the finer sediment at the deep point on the apex of the library bend a current of 70 cm/s would be required (Halcrow 1992).

Figure 1.11: Aerial view of downstream location of Dubai Creek

Figure 1.12: Aerial view of upstream location of Dubai Creek

1.6.2 Sources of inputs (pollutants and nutrients)

In the marine environment of Dubai Creek the sources of pollutants and nutrients are mainly from outlet discharges, discharge of dissolved waste from dhows (wooden cargo vessels), birds droppings (guano), and run-off during rain (mostly in winter).

1.6.2.1 Outlet discharge

A. Discharge inputs into Dubai Creek

There are 34 recognized sources of inputs into Dubai Creek other than dissolved waste (raw sewage) from the dhows, droppings from birds, rain runoff and temporary discharges from dewatering operations. (Table 1.3 and Figure 1.13). However, the principal source of the nutrients in Dubai Creek is secondary treated effluent from outlet No. 18 coming out from Awir Sewage Treatment Plant (STP)

B. Secondary treated effluent

The discharge from Awir STP is a principal source of nutrients entering the system. Sewage effluent from Dubai city is treated at Awir STP, which has been in operation since 5 March 1989. There is a major discharge point from Awir STP to the lagoon of Dubai Creek from which the average current daily effluent discharge is 98000 m^3/day (Table 1.4). This quantity has considerably increased from previous levels due to the expansion in Awir STP in 2000 (Dubai Municipality 2000).

C. Ground water discharge

The major discharges of groundwater enter the Creek from pumping stations or dewatering ground water pumps installed for lowering the ground water level. In addition during construction operations additional dewatering takes place to allow building to take place. There are some other minor discharges from local drainage projects. The ground water drains into pipes which are connected to sumps, which are periodically pumped out. The discharges from these outlets are approximately 3000-5000 m^3/day when in operation. The quality of ground water varies from one location to another. However, they do contain high amounts of minerals and dissolved solids, which lead to high salinity and high amounts of nitrogen (3-6 mg/L). The levels of phosphate discharge from these outlets are comparable with the levels present in seawater. The origins of this groundwater however, are from localities of Al Rashidya, Air port, Al Zabeel area, Palace, Al Jaddaf and Nadd al Sheba etc.

1.6.2.2 Discharge of dissolved waste

Raw human waste, nutrients, coliforms and *Escherichia coli* bacteria, garbage and phosphate-containing detergents are the major constituents discharged by Dhow crews. However, raw human waste, which is also the major source of nitrogen, contributes an average of about 4.4 kg of nitrogen per capita/year (Pffaflin & Ziegler 1993).

D. Industrial effluent

It is the policy of the Dubai Municipality to prevent any industrial liquid wastes entering the drainage systems. This effectively prevents industrial discharge through outfalls to the Creek. No evidence of industrial effluents connected to the Creek has been found, although commercial effluents (heavy metals) and petroleum hydrocarbons are still being discharged from Dubai Ship Docking Yard and Dhows near Al Jaddaf area.

1.6.2.3 Bird droppings

Birds in the Dubai Creek head sanctuary area contribute nutrients through their droppings (guano). It has been estimated that wild ducks contribute 5.8 kg of total nitrogen/acre/year to reservoirs or lakes (Pffafflin & Ziegler 1993). A number of studies have been conducted on waterfowl, but it may be concluded that, although there may be some impact on localized eutrophication, in general, the overall effect is negligible.

1.6.2.4 Run off

Some traceable constituents from the land are washed down into the Creek after rainfall and although rainfall is scarce in Dubai the impact on Creek water quality is substantial particularly during major runoffs (Dubai Municipality 1996a, 1997a).

Table 1.3: Details of wastewater outfalls (numbers, names, locations and quality)

Outlet No.	Outlets opening in Dubai Creek	Discharge quality
1	From fish market area	Ground water
2	SWDR 6, PSTN (near MMI)	Ground water, storm water
3	UPDR 9 (near Middle East Bank)	Ground water
4	SWDR 8 PSTN Deira Post Office	Ground water, storm water
5	SWDR 1 & 2 near Carlton Tower	Ground water
6	SWDR 17 Wharfage Pool No.1	Ground water, storm water
7	SWDR 3 Wharfage Pool No.3	Ground water, storm water
8	From Clock Tower Area	Storm water
9	SWDR 4	Storm water
10	From Airport cargo village area	Storm water
11	From Golf club	Ground water
12	From Airport area	Storm water
13	Ground water pumps 1-4 & 6-7	Ground water, storm water
14	SWDR 9 and 11 from Rashidya area	Ground water, storm water
15	From Airport area Rashidya	Storm water
16	SWDR 14 from Rashidya area	Storm water
17	From Rashidya area	Storm water
18	From Awir STP	Secondary treated effluent
19	From Awir industrial area	Ground water, storm water
20	From Nadd Al Sheba area	Ground water dewatering
21	From Sheikh Mohammed Palace	Ground water dewatering
22	From Zabeel area	Ground water dewatering
23	Abandoned line	-
24	From Dubai Ship Docking Yard	Surface wastewater
25	Old STP I	Strom water during rain
26	Old STP II	Storm water during rain
27	From Creek Side area	Ground water, storm Water
28	From court complex area	Ground water, storm Water
29	SWDB1 From Karama area	Ground water, storm Water
30	From Al Seaf road	Ground water, storm water
31	PSTN B14	Storm water
32	PSTN B15	Storm water
33	GWDB1	Storm water
34	SWDB 5 From Ghubaiba area	Groundwater, storm water

SWDB: Storm Water Dubai, GWDB: Ground Water Dubai
PSTN: Pumping Station, SWDR: Strom Water Deira
UPDR: Underpass Drainage
(Source: Drainage and Irrigation Department, Dubai Municipality)

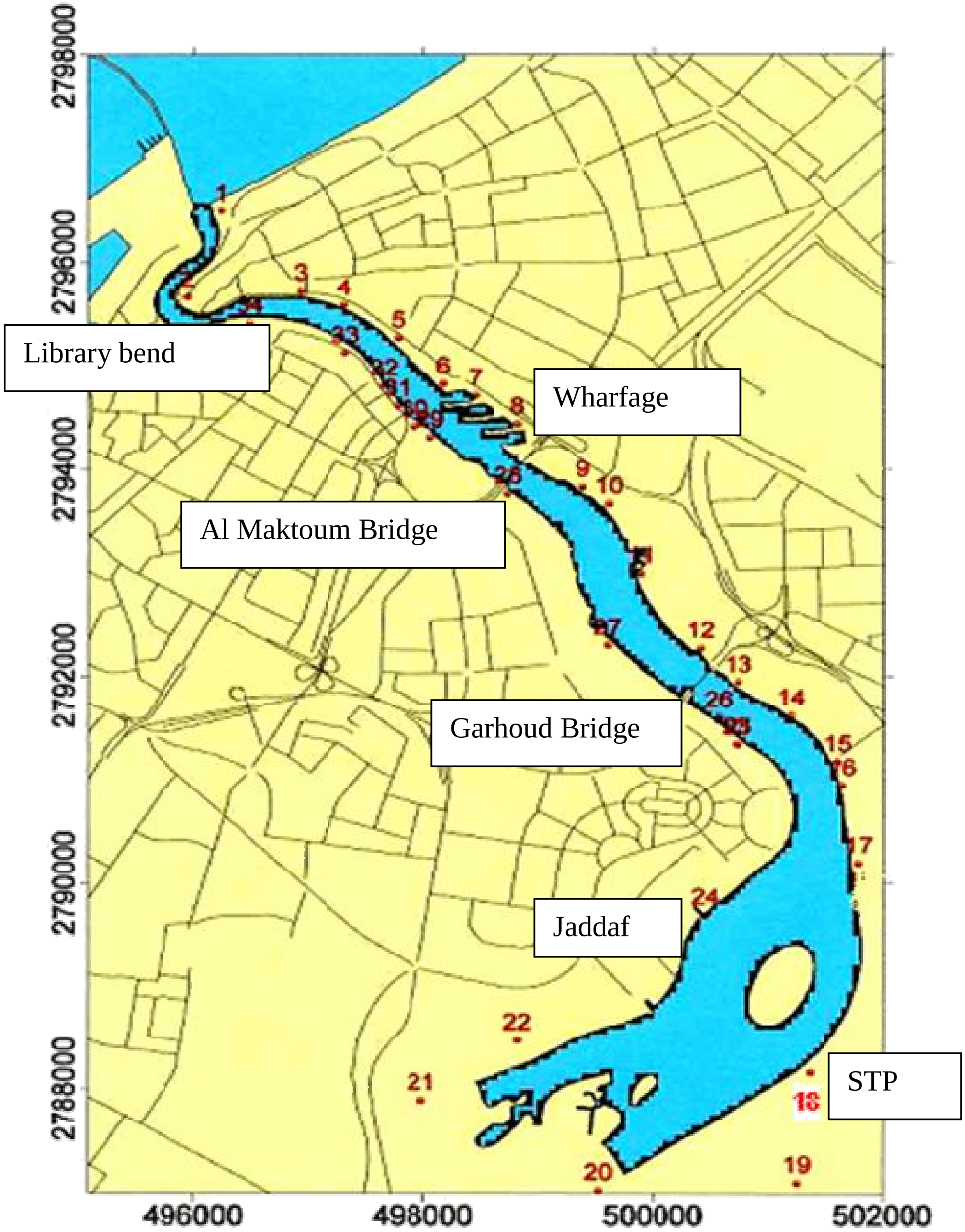


Figure 1.13: Wastewater discharge locations along Dubai Creek

Table 1.4: Secondary treated effluent discharge to Dubai Creek from Awir STP-The statistics of discharge quantity are based on the information obtained from the Drainage Department (Dubai Municipality).

Year	Total discharge from Awir STP (m^3/day)	% of discharge into the Creek	Quantity of discharge (m^3/day) (Approximate Averages)
1991	120 000	50	60 000
1992	120 000	35	42 000
1993	120 000	25	30 000
1994	120 000	15	18 000
1995	120 000	15	18 000
1996	120 000	15	18 000
1997	120 000	15	18 000
1998	120 000	15	18 000
1999	260 000	20	52 000
2000	260 000	20	52 000
2001	260 000	20	52 000
2002	260 000	20	52 000
2003	280 000	30	84 000
2004	280 000	35	98 000
2005	>280 000	35	100 000
2006	>280 000	35	100 000

1.6.3 Ecology of Dubai Creek

Water quality in Dubai Creek is characterized by relatively stable salinity and temperature conditions as controlled by the limited freshwater input to the Creek. Dubai Creek is predominantly an alkaline water body. The salinity of the Creek is 39‰ which is comparable with the salinity of the Gulf water. The water temperature varies from 21^{o}C (winter) to 34^{o}C (summer) with an annual average temperature of 29^{o}C. The channel of the Creek up to the Al Maktoum Bridge represents a well-balanced aquatic system having moderate productivity and biodiversity at both primary and secondary trophic levels. The lagoon part of the Creek (up stream of Al Maktoum Bridge) is nutrient-enriched with a high primary productivity due to Awir STP discharge. The higher content of nutrients leads to continued eutrophication problems in the lagoon. *Nitzschia* and *Rhizosolenia* are the most common genera of phytoplankton in the channel while *Oscillatoria* and *Prorocentrum* are also common in the lagoon (Dubai Municipality 1997b). Copepods, decapod larvae and fish eggs are common groups of zooplankton in the channel as well as in the lagoon. Bivalves, gastropods and polychaetes are common benthic groups in the channel. The level of *Escherichia coli* bacteria at Wharfage is high (Figure 1.11). Sediment samples show high levels of petroleum hydrocarbons and metal contamination at Al Jaddaf and nitrogen and phosphorous at Island stations (Dubai Municipality 2000).

1.7 Significance of ICZM in Dubai Creek

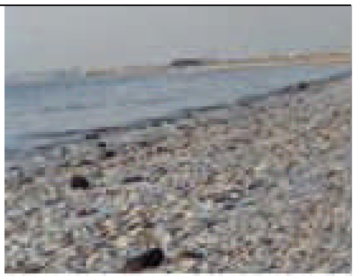
Dubai is developing rapidly and many developmental activities are concentrated around Dubai Creek. As a result, the natural ecosystem is being degraded and there is an increasing threat to its vigor and productivity. Hence there is an urgent need to formulate an ICZM Program to accomplish the following (Khan et al 2002): -

- Preserve, protect, develop, and, where possible, restore and enhance the resources of Dubai's coastal zone for the present and future generations;
- Encourage and develop Dubai's land and water resources, giving full consideration to ecological, cultural, historic, and aesthetic values, as well as the need for compatible economic development;
- Encourage the preparation of special area management plans to provide increased specificity in protecting significant natural resources, reasonable coastal-dependent economic growth, improved protection of life and property in hazardous areas and improved predictability in governmental decision-making; and
- Encourage the participation, cooperation, and coordination of the public, federal, state, local, interstate and regional agencies, and governments affecting Dubai coastal zone.

1.8 Issues and constraints

The major coastal and marine issues concerning the Gulf and some of the problems associated with various environmental pressures are listed in Table 1.2.

Table 1.2: Environmental constraints and coastal issues along Dubai Creek.

Constraints	Issues	Indication
Secondary treated effluent from Al Awir STP drains into the upstream of Dubai Creek. Poor water flushing characteristics in the upstream region and high nutrients content	Eutrophication Eutrophication and dense algal bloom	
Direct discharge of raw human waste from Dhows Groundwater discharge containing high nutrients	Unaesthetic and poor water quality Poor water quality	
Poor water quality, high nutrients, Significant bacteria counts of *Aeromons* and *Vibrio* infection in a single fish *Nametolosa nasus* (long ray bony bream)	Stress in the water quality Phenomenal fish mortality	

1.9 Review of references

1.9.1 Arabian Gulf (physico-chemical and biological) characteristics

The role of the United Nations Educational Scientific and Cultural Organization (UNESCO) and Arab League Educational, Scientific and Cultural Organization (ALESCO) includes environmental matters of mutual concern. UNESCO Man and Biosphere Programme (MAB) are relevant to the region, operating alongside and in tandem with the activities of United Nations Environment Programme (UNEP), United Nations Environment Programme (UNDP) and other organizations. The Regional Organization for the Protection of the Marine Environment (ROPME), with a secretariat in Kuwait, is part of UNEP Regional Seas Programme.

Information on the physico-chemical oceanographic characteristics is outlined in the ROPME Sea Area of the Arabian Gulf (Grasshoff 1976, Brewer et al 1978, Brewer & Dyrssen 1985, Hunter 1983 and Dorgham & El-Gindy 1991).

Studies conducted by various researchers on the Arabian Gulf and the Gulf of Oman provide data on bottom sediments (Ross 1978) and biological characteristics (Grice 1978). Several other studies which were conducted on water quality and biological characteristics have been documented in Kuwait (MNR-Kuwait 1999), Oman (MNR-Oman 1999), Qatar (MNR-Qatar 1999) and Bahrain (MNR-Bahrain 2000).

In the Arabian Gulf, varying degrees of effort have been directed at the national level at ICZM programs. Significant initiatives were undertaken in Oman and Saudi Arabia (Sheppard et al 1992). Several guidelines (Clark 1992) have been published in recent years on ICZM. The recently published guidelines for the integrated coastal area management by ROPME are based on the Omani and Saudi models (ROPME 2000).

There is little published material on environmental modeling from the Arabian Gulf and practically from Dubai Creek. However, some studies are available on oceanographic and mathematical modeling for the Kuwait Action Plan (UNESCO 1984 and UNEP 1985). The extensive assessment on Environment Capacity (GESAMP 1986) and Coastal Modeling (GESAMP 1991) have been reviewed by IMO/FAO/UNESCO/WMO/WHO/IAEA/ UN/UNEP and the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP).

1.9.2 Dubai Creek studies

Substantial amounts of information on water quality during different seasons provide physico-chemical and biological data of the conditions of Dubai Creek water body (Dubai Municipality 2000). Other studies provide data on rainfall and inputs of pollutants during the runoff period in Dubai Creek during 1995-96 (Dubai Municipality 1996b) and 1996-97 (Dubai Municipality 1997a).

Work on the problem of eutrophication in the lagoon of Dubai Creek has defined the eutrophic conditions as well as characteristics of the algal blooms in the lagoon of Dubai Creek during different cycles of the year and the nutrient load in the sediment (Mustafa et al 2001).

The study on macro-benthic communities near the sewer outlets in Dubai Creek provides some information on water quality of Dubai Creek (Ismail 1992). Other work on 24 stations of the UAE coastline (Shriadah & Al-Ghais 1999) gives information on physico-chemical water quality characteristics.

An extensive evaluation of the current environmental situation along various stretches of Dubai Creek and the environmental impacts resulting from proposed developments has been conducted by Halcrow (1992) for Dubai Municipality. The study includes a hydrographic survey of the Creek, an evaluation of discharges into the Creek, marine and terrestrial surveys to identify areas of ecological importance and water quality and sediment analyses. An environmental impact assessment of dredging, increased shipping, commercial and recreational development and land drainage discharges was conducted. Regarding the Ras Al Khor Conservation Area the report proposes maintenance of the area '*as it is*' in order to preserve the delicate ecosystem balance (Figure 1.12). The report also proposes the erection of a floating boom to prevent pleasure crafts from entering the conservation area.

Study and Improvement of Dubai Creek (Halcrow 1992) reviews the previous studies carried out with regard to the improvement of Dubai Creek. As for the Ras Al Khor conservation area, its importance as an ecologically valuable site is recognized and the need for appropriate strategic management of the area is expressed. The future land use of the Creek head area is reviewed and discussed.

Dubai Municipality (1995) reports on a Mass Mortality of Yawafa (*Nematalosa* sp.) in 1995. This incident of fish mortality was not caused by oxygen deficiency nor by toxic flagellate blooms but by Hemorrhagic septicemia. The reason for the outbreak of the disease was suggested as high heavy-metal and oil levels in the water near Al Jaddaf docks (Figure 1.13).

Biological characteristics of the marine environment in Dubai (Dubai Municipality 1996a) provide data on water quality and biological characteristics of several marine areas in Dubai, including the Ras Al Khor Conservation Area. These data include information on the principal structure of the planktonic and benthic communities within the studied areas as well as some water quality parameters such as dissolved oxygen and nutrient levels. High levels of NO_3-N, total nitrogen, phytoplankton and zooplankton biovolume in Dubai Creek lagoon characterize the eutrophic situation in this area. Blooms of phytoplankton genera (*Prorocentrum* and *Oscillatoria*) were also identified in the report. Low macro-benthic populations and biovolume in the same area, however, are an indication of anaerobic conditions limiting the number of species able to survive here.

The Impact of runoff on water quality of Dubai Creek due to rainfall during December 1995 to February 1996 was studied by the Dubai Municipality (1996b). The report gives details on changes in water quality. No increases in hydrocarbons, but increases in heavy metals, inorganic nutrients and turbidity were recorded. A dinoflagellate bloom was observed in December 1995.

Hyland (1996) provides an overview of the importance of Ras Al Khor to wading birds in general and to flamingos in particular. Altogether, 31% of all waders counted in the UAE were found at Khor Dubai, making it the most important site in the country. The number of flamingos varies between roughly 500 and 1500 individuals.

The Annual Water Quality Report provides information on the physical, chemical and biological conditions of the water body at a series of sampling sites inside Khor Dubai and along the coast (Dubai Municipality 2000).

The impact of runoff due to rainfall on water quality of Dubai Creek during the period from December 1996 to April 1997 gives details on rainfall statistics (a total of 193.5 mm versus 354.8 mm during the same period in the previous year). Impacts were enrichment of inorganic nutrients, reduction of surface water salinity and high turbidity near Garhoud Bridge, and input of heavy metals and hydrocarbons from the airport. High levels of chlorophyll *a* were linked to a dinoflagellate bloom (Dubai Municipality 1997a).

A preliminary survey on outlets and their discharges into the marine environment of Dubai (Dubai Municipality 1997e) provides information on discharge flows and details of all outfalls into either the Creek or the open sea in Dubai. In the same year, a study on a bloom of *Dunaliella salina* along the buffer zone near Ras Hisyan (Dubai Municipality 1997d) gives water quality data and describes a bloom in the coastal lagoons near Ras Hisyan near Jebel Ali Dubai. A mass-mortality of fish (*Nematolosa nasus*) in the Ras Al Khor area in August and September 1997 was studied by the Dubai Municipality (1997c). To identify the causes of the event, water quality and biological characteristics were surveyed and a microbiological investigation of fish organs was conducted. Hemorrhagic Septicemia caused by bacteria (*Aeromonas hydrophila*) was diagnosed. It is stressed that the low water quality in the area due to eutrophication and environmental stress resulted in a weakening of the fish immune system and therefore might be responsible for the massive outbreak of the disease.

A report on the problems of 'Eutrophication in the lagoon of Dubai Creek' (Dubai Municipality 1997b) describes a study conducted on the eutrophication problem over the last few years.

Recent studies carried out along Dubai Creek with respect to modeling (DHI 2005), Environmental Impact Assessment (MHW 2006) for development projects (Business Bay and LVC) also indicate the pollution load within the Creek due to Al Awir STP outfall and also define the poor water quality.

Hornby et al (1997) conducted a Coastal survey of the UAE. Their study provides detailed descriptions of intertidal habitats and species compositions.

This study contained old data in a scattered format; therefore there is an urgent need to update the environmental conditions of Dubai Creek.

1.9.3 Coastal Zone Management

Several ICZM Guidelines (ROPME 2000, Clark 1992) have been published in recent years, which discuss various aspects of ICZM in details. Most basic requirements of the ICZM are also described by Knecht (1997).

Khan (1997) has reviewed the coastal zone management in the Arbain Gulf region. Coastal users and pressure have been discussed in the Arabian Gulf by Price (1993).

1.10 Aims of the Study

The aim of this work is to incorporate critical ecological considerations in current and future coastal zone management strategies. The work includes conducting an initial characterization of the ecological conditions prevailing in the coastal area. A variety of primary data on water quality and ecological data were collected during 2005 and 2006 from 6 monitoring stations spread along Dubai Creek. The secondary data (bathymetry, currents, waves, winds, air temperature and tides) collected by the Coastal Management Section of the Dubai Municipality during 2002-2005 were used for the setup of numerical modeling, using the HydroQual model that addressed the predicted management scenarios of Dubai Creek based on hydrodynamics and water quality data.

HydroQual's model consists of a 3D hydrodynamic water quality model (ECOM-RCA) that was developed for Dubai Creek with an extension into the Arabian Gulf. The water quality component of the model is an advanced in-house version of the United States Environmental Protection Agency (USEPA) program that was developed originally by HydroQual (Dubai Municipality 2003).

Overall a strategy on ICZM studies in Dubai Creek with reference to ecological characterization is proposed to cover:-

- ecological characterization of Dubai Creek covering selected variables of water quality and biological characteristics
- numerical modeling scenarios of hydrodynamics and water quality characteristics
- identification of biological indicator species during different seasons and
- an authentic document which could be a helpful tool for Government decision makers in preparing management plans for sustainable development, policy formulation, developing ICZM guidelines and formation of a new decree for the management of Dubai Creek.

CHAPTER II

Materials and Methods

Water quality and biological variables measured in the present study were largely dependent on current management priorities and environmental pressures. An overview of sampling methodologies, sampling frequencies and analytical procedures of the variables are given below:

2.1 Sampling Methodology

Sampling of water and sediments was conducted onboard a coastal survey vessel equipped with modern oceanographic sampling equipment, a Global Positioning System (GPS), and 3D Echosounder.

For the purpose of this study, the stations along Dubai Creek were selected based on the earlier observations in Dubai Municipality studies (Halcrow 1992). The lower creek was designated as the area from Creek mouth to Al-Maktoum Bridge whereas the upper Creek was designated as the area south of Al-Maktoum Bridge until Dubai Creek end. These areas have been divided according to the hydrodynamics of the Creek (Halcrow 1992).

According to the hydrodynamics model proposed by Halcrow (1992), Dubai Creek will be divided into the downstream region which includes station numbers 1-3 (in the lower Creek) and the upstream region which includes the station numbers 4-6 (in the upper Creek).

2.2. Sampling Frequency

Water quality, phytoplankton, zooplankton and benthos samples were collected from 6 selected locations along Dubai Creek (Figure 2.1.).

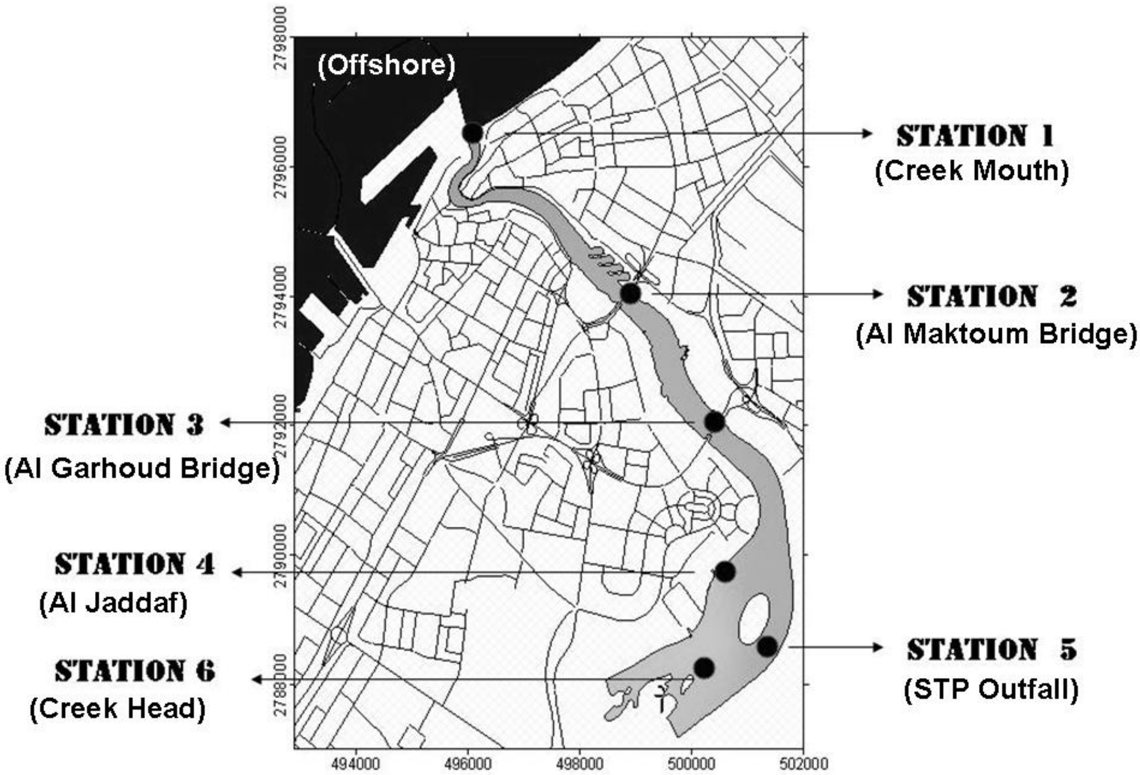


Figure 2.1: Water quality and biological variables sampling stations along Dubai Creek

Bi-weekly monitoring (surface and bottom) of water quality was conducted for the following physico-chemical and biological parameters during summer (April 05, May 05, and July 06) and winter (December 05, January 06, February 05 and March 05):

- Water temperature
- pH
- Dissolved oxygen (DO)
- Salinity
- Suspended solids
- Nitrate-nitrogen (NO_3-N)

- Ammonia-nitrogen (NH_4-N)
- Total nitrogen
- Phosphate-phosphorus (PO_4-N)
- Total phosphorous
- Dissolved Organic Carbon (DOC)
- Particulate Organic Carbon (POC)
- Chlorophyll *a*
- Phytoplankton community analysis
- Zooplankton biovolume
- Zooplankton community analysis
- Macro-benthic biomass
- Macro-benthic community analysis

The existing data on hydrodynamics collected during 2002-2004 from Dubai Municipality were used for review and assessment in chapter V.

2.3 Water Sampling

A plastic Niskin water sampler made by Hydro-bios™ with closing mechanisms at desired water depths was used for the collection of water samples. The samples were collected in glass bottles of 1L capacity, cooled with ice and transferred to the laboratory immediately after the collection.

2.4 Sediment Sampling

A stainless steel Van Veen sediment sampler made by Hydro-bios™ was used for obtaining bottom sediments. The samples were collected in cleaned plastic tubs.

2.5 Methods of Analysis

2.5.1 Water Quality - Physico-chemical Parameters

Water quality monitoring was conducted *in situ* with respect to the following variables measured in the surface, middle and bottom layers of water by using United States Environment Protection Agency (USEPA) approved "Hydrolab H20™" and "YSI™" water quality monitoring equipments. Equipment was pre-calibrated with the specified standards prior to the monitoring of the following variables shown in Table 2.1.

Table 2.1: Accuracy of *in situ* water quality monitoring equipments

Variable	Accuracy
Water temperature	± 0.1 °C
Salinity	± 0.2 ‰
pH	± 0.2 Unit
DO	± 0.2 mg/L

2.5.2 Water quality –suspended solids, nutrients and organic carbon

2.5.2.1 Suspended solids

Suspended solids were designated as the material retained on a tared glass filter pad (0.45 µm) after filtration of a well-mixed sample of water. Results are expressed in mg/L.

2.5.2.2 Total nitrogen

Total nitrogen was measured by the method of Parsons et al (1984). Samples of seawater were oxidized with potassium persulfate under pressure, converting organic nitrogen to nitrate. The nitrate was then analyzed as per the following equation

$$N/L = (E \times F) - A,$$

Where:

E : the corrected sample extinction

F : the response factor concentration of standard

A : the nitrate and nitrite originally present in seawater

2.5.2.3 Nitrate-nitrogen

Nitrate nitrogen was determined by Ion chromatography method (APHA 1998). Only ion chromatography provides a single instrumental technique that may be used for the rapid, sequential measurement of nitrate.

A series of standard nitrate solutions were prepared by weighing 1.3707g of $NaNO_3$ salt dried to a constant weight at 105 ^{o}C and mixed with 1000 ml distilled H_2O. When necessary the sample particulates were removed by filtering through a 0.2 μm membrane filter. Sufficient sample volume was injected to flush sample loop several times. The ion chromatograph was switched from load to inject mode and the peak heights and retention times were recorded on chart recorder.

Concentration of nitrate was calculated according to the following equation in milligram per litre by referring to the appropriate calibration curve.

$$C = H \times F \times D$$

Where:

C : concentration in mg nitrate/L

H : peak height (Concentration)

F : response factor concentration of standard

D : dilution factor for sample

2.5.2.4 Phosphate-phosphorus

Phosphate-phosphorus levels were determined using the Stannous Chloride method (APHA 1998). Molybdophosphoric acid was formed and reduced by Stannous Chloride to intensively coloured molybdenum blue. The concentration was measured photometrically at 690 nm and compared with the calibration curve. The value of Phosphate-phosphorus was calculated by the following equation.

mg P/L = mg P (approximately in 104.5 ml final volume) x 1000/ml sample

2.5.2.5 Dissolved and Particulate Organic Carbon

Samples were combusted in pure oxygen (O_2) under static conditions. Products of combustion were passed over suitable reagents in the combustion tube where complex oxidation occurs. In the reduction tube, oxides of nitrogen (N) were converted to molecular N. The carbon dioxide (CO_2), water vapor and N were mixed and released into the thermal conductivity detector where the concentrations of the sample gases were measured (USEPA 1997).

2.5.2.6 Chlorophyll *a* (Phytoplankton pigment)

For the estimation of chlorophyll *a* from phytoplankton, 500 ml of the water sample was first filtered through a 0.3 mm mesh cloth and then filtered through 0.45μm sartorious membrane filter paper of 47 mm diameter. One drop of magnesium carbonate was added at the time of filtration. Chlorophyll *a* extraction was done in 90% acetone for 24 hr at $4^{o}C$. The final volume was made up to 10 mL, centrifuged and the absorbance was measured at 750 and 665nm and the concentration of chlorophyll *a* calculated adopting the following the formula (Strickland & Parsons 1972)

$$\text{Chlorophyll } a \text{ (mg/m}^3) = 26.7 \text{ (Abs665)b-(Abs665)a x } v_{ext} / V_{samples} \text{ x L}$$

Where:

Abs665 = Absorbance at 665 nm

b = before acidification

a= after acidification

v_{ext} = Volume of 90% Acetone used in the extraction (mL)

V_{Sample} = Volume of water filtered (L)

L = Cuvette path length (cm)

2.5.2.7 Phytoplankton- cell counts and species identification

The phytoplankton sample was mixed by gently inverting the sample bottle for 60 seconds. A predetermined sample volume of 500 mL was loaded into a sedimentation chamber of appropriate volume. Samples should be added to the chamber with a syringe (less than 10 mL) or macropipettor (10 mL or more). Algal taxa were identified to the lowest taxonomic rank possible.

The method consists of a 2 part analysis of phytoplankton (excluding most diatoms) and analysis of diatoms. For operational reasons, the first part of the analysis is also called "soft algal" analysis. The "soft algae" are defined as those that are either naked or have a cellulose cell wall and cannot withstand acid digestion treatment. In contrast, diatoms have relatively "hard" silicious valves and the valves can tolerate harsh acid treatment. Initially a preliminary scan was made of a settled 10 mL sample in order to determine the volume to be used for each of the 2 analyses. For the soft algae analysis, organisms were enumerated in a settling chamber using an inverted microscope at 500x magnification. For diatom analyses, the samples were pretreated with strong oxidants and the cleaned samples were mounted on glass slides and enumerated using a compound microscope at 1250× magnification.

2.5.2.8 Zooplankton- biovolume and species identification

Zooplankton samples were collected using a Heron Trancter net (mouth area 0.5 m^2 and mesh 300 μm) and preserved in 5% buffered formalin. The volume of water filtered through the net was calcuating by an expression using the relative rate of flow (data from flow meter), the area of the net and the time of deployment. The biovolume of zooplankton was estimated by the volume displacement method. A portion of sample (25-50%) was analyzed under the microscope for faunal composition and population abundance. The population was estimated as the number of organisms in 100 m^3 water and biovolume on a volume basis.

2.5.2.9 Macro-benthic-biomass and population

At each sampling station, benthic infaunal samples were taken with a Van Veen grab, 10 cm x 10 cm opening (0.01 m^2) and 10 cm depth. Grab samples were taken at each sampling location on each sampling date. Grabs were retained only if the grab was full in order to standardize volume sampled. Grab samples were taken from a boat at stations specified by GPS coordinates and all sampling locations were in approximately 7-8 m of water. Immediately after collection, the samples were sieved through a 0.5 mm mesh screen, preserved in 10% buffered formalin with added rose bengal dye, and, after 3 days, transferred to 70% ethanol for later sorting and identification. Separation of animals from the remaining sediment was done under a dissecting microscope. All animals were identified to the lowest reliable taxonomic level, with random specimens verified by outside taxonomists. These procedures follow standard formats for benthic sampling outlined by the EPA Environmental Monitoring and Assessment Program (Hyland et al 1991).

Patterns of infaunal community composition were compared among sites for numerically common taxa (those comprising at least 1% or 3% of the total fauna collected at that site), for higher taxonomic groupings. Comparison of higher taxonomic groupings (polychaetes, amphipods, bivalves, oligochaetes) allows observation of overall patterns of distribution.

CHAPTER III

Water Quality

3.1 Introduction

3.1.1. The importance of water quality

Oceans, seas and coastal waters have an important influence on our lifestyle. These ecosystems provide mankind with food, transport and recreation, but also ultimately receive our waste. The major source of marine pollution is from land-based human activities, these anthropogenic sources being responsible for around 77% of the pollutants that enter the oceans and seas (Welling 2001). Shockingly, some 6500 $x10^6$ tonnes of litter find their way into the oceans and seas each year and ocean currents transport pollutants considerable distances (Oceans-98 2001, De Valk 2001). Chemical pollutants entering marine systems are divided into 2 broad groups of compounds: inorganic (phosphates, nitrates, metals etc.) and organic substances (pesticides, hydrocarbons etc.) (Greenpeace1998). These pollutants interact with the other components of seawater, which is a complex conglomeration of animal, vegetable and mineral matter widely dispersed within a saline-water-matrix (Hashim 1992). The full spectrum of organic species is presented from the smallest bacteria, algae, diatoms and plankton through the full diversity of plant and animal life (NASA 2000).

All oceans and seas (especially the Atlantic Ocean, North Sea and Mediterranean Sea) are now experiencing serious threats due to pollution (De Valk 2001). Marine water quality has therefore become a matter of serious concern for mankind because of its effects on human health and aquatic ecosystems, including the rich array of marine life that is often exploited for human use.

Water quality characteristics of an aquatic environment are of great significance for the proper understanding of distribution, growth and physiological function of the biotic community inhabiting the area. Understanding of water quality is also a very important factor in the semi-enclosed systems where nutrients and pollutants may be concentrated and where the growth and proliferation of plankton is largely dependent on the environmental and physico-chemicals variables which can either support or limit their production capacities (Mustafa 2005).

3.1.2 The general characteristics of the Arabian Gulf

The Arabian Gulf covers an area of 226 000 km^2 and has a mean depth of 35 m (Al-Ghadban et al 1998 and Rao & Al-Yamani 1999). The Gulf is nearly 1000 km long, with a maximum width of around 370 km. The coastline along its south-western side is low, whilst the Iranian side is mountainous. Due to its enclosed and shallow nature, the Gulf is particularly subject to the accumulation of anthropogenic contaminants (Randolph et al 1998). There is only a very narrow exchange through the Strait of Hormuz into the Gulf of Oman, which means that the time required for all of the Gulf's water to come within the influence of the open sea is 2.4 years (Hunter 1983); or an actual flushing time of 3 -5.5 years (Sheppard 1993).

The Arabian Gulf is mainly a sedimentary environment with a predominantly soft substrate benthos. Sediments of biogenic carbonates predominate (derived mainly from micro-fauna), but strong terrigenous influences are apparent at the northwest end where the Shatt El-Arab discharges to the Arabian Gulf (Sheppard et al 1992).

3.1.3. Water quality in the Gulf

Limited information is available on the water quality of the Arabian Gulf. The Regional Organization for the Protection of the Marine Environment (ROPME) is currently collecting environmental statistics from the member countries (ROPME 2000). Since 1975, the gathering of data on chemical characteristics of the ROPME sea area has greatly influenced after a consultative meeting on marine sciences in the area was held in Paris (Grasshoff 1976). The damage from the Gulf war of 1991(El-baz & Makharita 1994) and aftermath (Sadiq & McCain 1993) led to some studies of environmental aspects in the Arabian Gulf**.** However, comprehensive data that give a total view of the water chemistry (annual variation from surface and water during ebb and flood conditions) of the area are scarce or absent.

3.1.4. Environmental threats in the Gulf

The Arabian Gulf is a unique biotope, distinct from other tropical and subtropical systems (Rao & Al-Yamani 1999). The Gulf has experienced severe environmental disturbances, most notably the leakage of an estimated 10.8 $x10^6$($1.7x10^6$ m^3) barrels of oil into the marine environment during the 1991 Gulf War and the deposition of an estimated further 8.0 $x10^6$ (1.3 $x10^6$ m^3) barrels of oil fallout from the smoke plumes of the well blowouts and fires in Kuwaiti oil fields (Al-Ghadban et al 1998).

Other environmental threats in the Arabian Gulf are repeatedly noticed, such as those caused by elevated ocean temperature (1996, 1998 and 2002) that resulted in coral loss due to bleaching in the Arabian Gulf (Wilson 2003). Generally the environment of the Arabian Gulf experiences the following on-going disturbances (Rao & Al-Yamani 1999):

- Discharge from cargo vessel ballast waters estimated about 160 $x10^6$ tonnes annually and
- Effluent/discharges from:

- Coastal dredging operations
- Power and desalination plants
- Petrochemical industries
- Slaughterhouses
- Dairy plants
- Sewage treatment plants
- Other industries located on the coast
- Coastal construction and Litter and rubbish dumping

Actions are being taken to assess and mitigate the effects of these disturbances but it seems that many will contiue into the immediate furture

3.1.5 The hydrology of the Creek

A water circulation model has been developed for the Arabian Gulf (Hunter 1983). This model shows that denser water flows outward beneath the inflowing shallow water. More extensive studies on the hydrographic structure of the Arabian Gulf region have been carried out by research vessels Atlantis II from the Woods Hole Oceanographic Institute and National Oceanic and Atmospheric Administration (NOAA) ship (Brewer et al 1978 and Reynolds 1993). The physical oceanographic characteristics of the Arabian Gulf have been elaborated by several authors (Grasshoff 1976, Hunter 1983, Brewer & Dyrssen, 1985 and Dorgham & El-Gindy, 1991).

Water entering Dubai Creek originates from the Arabian Gulf. Therefore the physico-chemical characteristic of Dubai Creek waters are mainly influenced by the conditions in the Arabian Gulf. The topography of the Arabian Gulf is a steady slope to a channel in the north, which runs almost parallel to the Iranian coast. In both the summer and winter months, evaporation is extensive, particularly in the very shallow southern embayment, along the UAE coast. Seawater entering the Arabian Gulf through the Strait of Hormuz has a salinity of 36.5-37.0‰ (Sheppard et al 1992). The Gulf supplies water to the semi enclosed marine intrusion of Dubai Creek. Just as the Gulf is influenced by conditions in the Arabian Sea, the Creek is influenced by the conditions of the Gulf. The Creek however, is more enclosed and its waters respond rapidly to anthropogenic inputs and to external drivers, particularly climatic changes (Halcrow 1992). The tidal current at any point depends upon the geometry of the tidal prism i.e. local cross-sectional area, the water surface area, and the instantaneous rate of changes of tidal elevation. Therefore, the tidal-current velocities increase towards the mouth of Dubai Creek and are greatest where the cross-sectional area is minimal (Halcrow 1992). The upper region of Dubai Creek has a wide cross-sectional area, which slows the rate of tidal elevation and reduces current velocity. The water quality, for that reason, is inextricably linked to the hydrological process. Thus, Dubai Creek does not behave as a simple aquatic system but as a component part of a larger complex system, which is strongly influenced by hydrodynamical process.

3.1.6 Physico-chemical conditions of the Creek

Data on the physico-chemical characteristics of Dubai Creek are either limited or based on spot sampling records. Routine physico-chemical monitoring, based on spot sampling from surface water, has been documented in local annual reports (Dubai Municipality 2005). Some research documents show the vulnerable nature of Dubai Creek in terms of its ecology, such as fish mortality (Dubai Municipality 1995), biological characteristics (Dubai Municipality 1996), impact due to rain runoff (Dubai Municipality 1997a), and eutrophication (Dubai Municipality 1997b). Physico-chemical parameters have been studied during a period of improvement in Dubai Creek (Halcrow 1992) and macro-benthic invertebrate assemblages near sewer outlets (Ismail 1992) have been examined. The record on the environmental characteristics along the UAE coastline has also been recorded from 24 stations (Shriadah & Al-Ghais 1999). Recent studies cover water quality characteristics (Al-Zahed 2005) and organic pollution and macro-benthic studies (Saunders 2007).

Nutrient levels in Arabian Gulf waters are often very low in comparison to other coastal shallow water systems (KFUPM/RI 1986). Seasonal upwelling of nutrients can cause significant algal blooms (ROPME 2000). Some characteristics such as rainfall, which is constantly low, with few exceptions, keep Dubai Creek at the edge of 2 or more global weather systems. The northern 'shamal' winds in winter blow over the shallow water of the UAE region (Arabian Gulf) and cause water temperature to fall to values more usually associated with temperate oceans, sometimes causing massive mortality of the tropical biota.

3.1.7 Current study of Dubai Creek

The present coastal research work is planned to provide a systematic evaluation of the water quality based on the summer and winter conditions together with tide driven vertical variations. Relevant physico-chemical parameters were considered in parallel to ecological data for the first time in a study to help interpret and assess the environmental conditions along Dubai Creek.

As defined earlier, Dubai Creek was divided into 2 sections due to differences in its hydrodynamics condition and water quality. Therefore, hereafter in this thesis station 1-3 will be considered as stations in the channel region while stations 4-6 will refer to the lagoon. (Figure 2.1)

3.2 Results

3.2.1 Water temperature

Water temperature varies in accordance with ambient air temperature. The minimum (20.70 ^{o}C) and maximum (34.20 ^{o}C) water temperature were recorded during winter and summer months respectively, with a mean water temperature of 26.00°C (Tables 3.1-3.18-Appendix I). The seasonal mean values of water temperature during winter and summer were 23.40 and 28.60°C respectively (Figure 3.1). Mean water temperature at the surface and bottom was 26.10 and 25.90°C, respectively. Mean water temperature in the channel and lagoon was 26.05 and 25.97 °C, respectively (Tables 3.19-3.23 and Figure 3.1). Mean water temperature was 25.63°C during ebb and 26.37°C during flood.

3.2.2 pH

Variations in pH were very large during the study period of 2005-2006 along Dubai Creek. The minimum (7.70) and maximum (9.10) pH was recorded during winter and summer months respectively, with a mean pH of 8.16 (Tables 3.1-3.18-Appendix I and 3.23). The mean values of pH during winter and summer were 8.08 and 8.20, respectively (Figure 3.1). Vertical variations in mean pH at the surface and bottom were 8.19 and 8.12, respectively. Mean pH in the channel and lagoon was 8.11 and 8.21, respectively (Table 3.19-3.23 and Figure 3.1). Mean pH was 8.16 during ebb and flood.

3.2.3 DO

Fluctuations in DO were wide along Dubai Creek during winter and summer. The minimum (0.02 mg/L) and maximum (14.0 mg/L) DO was recorded during summer and winter months, respectively, with a mean DO of 5.87 mg/L respectively (Tables 3.1-3.18-Appendix I). The mean values of DO during summer and winter were 6.38 and 5.37 mg/L, respectively. Vertical variations in DO at the surface (7.88 mg/L) and bottom (3.86 mg/L) showed high stratification (Figure 3.2 and Table 3.23). Mean values of DO in Dubai Creek during 2005-2006 were 5.64 and 6.10 mg/L during flood and ebb respectively (Table 3.23). Overall variation in DO along the channel (5.90 mg/L) and lagoon (5.84 mg/L) was not significant.

3.2.4 Salinity

Salinity varied over a narrow range of 34.20-41.50‰. The minimum (34.30‰) and maximum

(41.60‰) salinity was recorded during winter and summer months, respectively with a mean salinity of 39.72‰ (Tables 3.1-3.18-Appendix I). The seasonal mean salinity during winter and summer was 39.20 and 40.24‰, respectively (Figure 3.2 and Table 3.19-3.23). Salinity at the surface and bottom were 39.53 and 39.91‰, respectively. Salinity levels were lower in the lagoon (39.50‰) compared to channel (39.13 ‰). Mean salinity was 39.62‰ during ebb and 39.81‰ during flood (Table 3.23).

3.2.5 Suspended solids

Suspended solids levels varied over wide range of 2.50-332.00 mg/L (Tables 3.1-3.18-Appendix I). The minimum (2.50 mg/L) and maximum (332.00 mg/L) levels was recorded during winter and summer months, respectively, with a mean value of 42.48 mg/L, (Figure 3.3 and Tables 3.19-3.23). The seasonal mean values of suspended solids during winter and summer were 41.54 and 43.42 mg/L, respectively. Vertical variations of suspended solids were significant, the higher mean level was found at surface (47.65 mg/L) compared to bottom (37.13 mg/L). Suspended solids levels show enormous zonal variations in Dubai Creek levels in the lagoon (55.37 mg/L) were double those in the channel (29.59 mg/L). Mean suspended solids during ebb and flood were 44.77 and 40.19 mg/L, respectively (Table 3.23).

3.2.6 NO_3-N

Fluctuation in NO_3-N varied over a wide range of 0.01-3.70 mg/L (Tables 31.-3.18). The minimum (0.04 mg/L) and maximum (3.70 mg/L) NO_3-N were recorded during summer months with a mean NO_3-N of 0.87 mg/L (Tables 3.19-3.23 mg/L). The seasonal mean values of NO_3-N during winter and summer were 1.12 and 0.62 mg/L, respectively (Figure 3.3 and Table 3.23). Variation in NO_3-N was wide in the channel and lagoon; NO_3-N levels were higher (1.29 mg/L) in the lagoon compared to the channel (0.44 mg/L). The mean value of NO_3-N was higher at the surface (1.06 mg/L) than at the bottom (0.67 mg/L) (Table 3.23). Mean variations in NO_3-N during flood and ebb were almost absent (0.86 to 0.88 mg/L) (Table 3.23). Overall mean NO_3-N was 0.87 mg/L.

3.2.7 NH_4-N

Minimum (0.003 mg/L) and maximum (2.57 mg/L) NH_4-N was recorded during summer months with a mean of 0.33 mg/L. (Tables 3.1-3.18-Appendix I and 3.23). The mean values of NH_4-N during winter and summer were 0.33 and 0.32 mg/L, respectively (Figure 3.4 and Table 3.23). NH_4-N levels at the surface and bottom were 0.21 to 0.45 mg/L, respectively. Variations in mean NH_4-N in the channel and lagoon were very large, 0.07 and 0.59 mg/L, respectively (Tables 3.19-3.23 and Figure 3.4).

3.2.8 Total nitrogen

Total nitrogen varied in accordance with NO_3-N. The minimum (0.21 mg/L) and maximum (6.21 mg/L) levels were recorded during summer and winter months, respectively, with a mean value of 1.68 mg/L (Tables 3.1-3.18-Appendix I). Total nitrogen during summer and winter was 1.41 and 1.95 mg/L, respectively (Figure 3.4 and Table 3.23). Surface and bottom levels of total nitrogen were 1.92 and 1.43 mg/L, respectively. Variation in mean nitrogen in the channel and lagoon was 0.97 and 2.38 mg/L, respectively (Tables 3.19-3.23 and Figure 3.4). Mean values of total nitrogen were 1.66 mg/L during ebb and 1.69 mg/L during flood.

3.2.9 PO_4-P

Fluctuations in PO_4-P (mg/L) values were similar to NO_3-N. The minimum (0.01 mg/L) and maximum (1.40 mg/L) PO_4-P levels were observed during summer months with a mean value of 0.36 mg/L (Table 3.1-3.18-Appendix I and 3.23). The seasonal mean values of PO_4-P (mg/L) during winter and summer were 0.40 and 0.32 mg/L, respectively (Figure 3.5 and Tables 3.19-3.23). Vertical variation in mean PO_4-P at the surface and bottom was 0.39 to 0.34 mg/L, respectively. Variation in mean PO_4-P in the channel and lagoon was 0.21 and 0.52 mg/L, respectively (Tables 3.19-3.23 and Figure 3.5). Mean values of PO_4-P were 0.39 mg/L during ebb and 0.33 mg/L during flood.

3.2.10 Total phosphorous

Variations in total phosphorous were very large during the study period. The minimum (0.03 mg/L) and maximum (10.0 mg/L) levels were recorded during summer months with a mean value of 0.78 mg/L. The mean values of total phosphorous during summer and winter were 1.18 and 0.37 mg/L, respectively. Total phosphorous at surface and bottom was 0.91 and 0.65 mg/L, respectively. Variations in mean total phosphorous in the channel and lagoon were 0.54 and 1.02 mg/L, respectively (Table 3.19-3.23 and Figure 3.5). Mean values of total phosphorous were 0.81 mg/L during ebb and 0.75 mg/L during flood.

3.2.11 DOC

DOC levels varied over the range 1.62-12.30 mg/L (Tables 3.1-3.18-Appendix I). The minimum (1.62 mg/L) and maximum (12.30 mg/L) levels were recorded during summer and winter months, respectively, with a mean level of 5.25 mg/L (Table 3.23). The mean values of DOC during summer and winter were 3.87 and 6.64 mg/L, respectively. DOC at the surface and bottom was 5.59 and 4.91 mg/L, respectively. Mean DOC in the channel and lagoon was 4.19 and 6.32 mg/L, respectively (Table 3.19-3.23 and Figure 3.6). Mean values of DOC were higher (6.67 mg/L) during ebb compared to flood (3.83 mg/L).

3.2.12 POC

Fluctuation in POC varied over the range 0.45-11.69 mg/L (Tables 3.1-3.18-Appendix I). The minimum and maximum levels were recorded during winter and summer months, respectively, with a mean value of 3.33 mg/L (Table 3.23). The mean values of POC during winter and summer were 3.15 and 3.51 mg/L, respectively (Figure 3.6). POC at the surface and bottom was 4.25 and 2.41 mg/L, respectively. Variation in mean POC in the channel and lagoon were over the range 2.12 and 4.54 mg/L, respectively (Table 3.19-3.23 and Figure 3.6). Mean POC was 3.39 mg/L during ebb and 3.38 mg/L during flood.

3.3 Correlation matrix and scatter plots

Correlation is one of the most common and useful statistics tools that describe a single metric for the degree of relationship between 2 variables. In probability theory and statistics, correlation, also called the correlation coefficient, indicates the strength and direction of a linear relationship between 2 random variables. In general statistical usage, correlation refers to the departure of 2 variables from independence. In this broad sense there are several coefficients, measuring the degree of correlation, adapted to the nature of data.The correlation coefficient ranges in size from -1 to 1.

3.3.1 Correlation matrix and scatter plots of summer season

Correlation matrices from summer data (Table 3.24) show positive correlations of water temperature with most of the nutrients (NO_3-N, NH_4-N, total nitrogen, PO_4-P and total phosphorous) dissolved (DOC) and particulate organic carbon (POC). Further, pH and DO also show positive correlations with PO_4-P, total phosphorous and POC during summer. Scatter plots of correlations of water temperature (Figures 3.7) and DO (Figure 3.8) during summer indicate the relationship between the 2 variables.

Summer correlations (Table 3.24) also indicate positive correlation among the nutrients and high correlation (r=1.0) between total phosphorous and PO_4-P. Scatter plots (Figure 3.9) show positive correlations of pH Vs POC and PO_4-P and NH_4-N Vs NO_3-N and PO_4-P (Figure 3.9) during summer.

3.3.2 Correlation matrix and scatter plots of winter season

The winter correlation matrix and scatter plots show a reverse trend of water quality as compared to summer in Dubai Creek; the summer season clearly displays negative correlations of nutrients (total nitrogen, PO_4-P and total phosphorous) and DO with salinity (Table 3.25 and Figure 3.10). The correlation matrix from winter indicates highly positive correlations among the nutrients (Table 3.24) and this relationship again displays a similarity in the scatter plots of nutrients during winter and summer (Figures 3.9 and 3.11). A trend in the positive correlation of DO with nutrients in the winter is similar to summer (Table 3.25 and Figure 3.12).

Table 3.19: Averages of water quality variables along Dubai Creek during summer and ebb conditions during 2005-2006.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	27.97	8.12	5.57	40.73	22.17	0.27	0.06	0.71	0.12	0.17	3.54	1.94
	Bottom	27.63	8.12	5.23	40.83	21.40	0.28	0.06	0.68	0.13	0.17	2.94	1.49
2	Surface	27.80	8.20	5.81	39.53	21.40	0.59	0.20	1.27	0.26	0.32	3.56	2.80
	Bottom	27.67	8.20	5.65	39.20	22.87	0.52	0.17	1.03	0.23	0.29	3.21	2.37
3	Surface	27.80	8.16	5.46	39.87	33.23	0.81	0.24	1.62	0.31	0.37	3.92	3.05
	Bottom	27.73	8.15	5.44	39.93	32.07	0.71	0.25	1.43	0.33	0.36	3.63	2.67
4	Surface	27.90	8.23	8.88	40.67	61.60	0.89	0.18	1.65	0.33	0.38	5.28	4.57
	Bottom	27.63	8.21	4.44	40.83	36.00	0.65	0.48	1.41	0.41	0.46	4.15	4.12
5	Surface	28.17	8.33	10.09	39.60	42.80	2.00	1.17	3.53	0.72	0.78	3.99	4.86
	Bottom	27.67	8.22	2.36	40.50	43.27	0.88	0.67	1.92	0.44	0.48	4.54	3.07
6	Surface	27.90	8.50	9.87	40.10	164.00	0.83	0.22	1.77	0.37	0.42	4.43	5.56
	Bottom	27.47	8.32	1.95	40.47	37.33	0.49	1.05	1.60	0.47	0.52	4.24	3.42

Table 3.20: Averages of water quality variables along Dubai Creek during summer and flood conditions during 2005-2006.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	29.10	8.07	5.38	40.40	18.87	0.10	0.01	0.55	0.05	0.08	2.49	1.42
	Bottom	29.20	8.09	5.19	40.30	19.40	0.09	0.01	0.54	0.05	0.08	2.61	1.35
2	Surface	29.70	8.17	5.64	40.30	17.47	0.14	0.01	0.71	0.09	0.13	2.73	1.47
	Bottom	29.23	8.13	5.51	40.33	17.47	0.14	0.02	0.52	0.11	0.14	3.10	1.53
3	Surface	29.93	8.16	5.41	39.47	68.57	0.50	0.06	1.16	0.26	0.28	4.86	3.47
	Bottom	29.40	8.11	4.63	39.73	47.07	0.46	0.09	1.13	0.25	0.27	3.91	2.82
4	Surface	29.80	8.22	7.92	41.10	41.47	0.87	0.10	1.74	0.33	0.41	4.04	6.32
	Bottom	28.70	8.18	1.50	41.27	51.93	0.54	0.87	1.53	0.43	0.57	4.31	3.81
5	Surface	29.83	8.41	7.75	40.27	47.47	1.16	0.41	1.99	0.51	0.58	4.43	6.36
	Bottom	28.67	8.32	0.16	40.17	51.07	0.66	0.58	1.87	0.48	0.53	4.08	3.63
6	Surface	30.00	8.42	8.69	40.00	61.47	0.80	0.05	1.69	0.47	0.54	4.75	8.50
	Bottom	28.52	8.31	0.40	40.20	61.60	0.45	0.80	1.70	0.52	0.55	4.06	3.63

Table 3.21: Averages of water quality variables along Dubai Creek during winter and ebb conditions during 2005-2006.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	23.63	8.02	5.74	40.30	19.05	0.18	0.01	0.54	0.06	0.63	6.17	1.88
	Bottom	23.53	8.00	5.74	40.38	33.00	0.14	0.02	0.49	0.06	0.66	6.29	1.70
2	Surface	23.83	8.01	6.20	38.65	33.93	0.29	0.03	0.72	0.21	0.86	6.90	2.97
	Bottom	23.77	8.02	5.92	40.27	29.97	0.32	0.03	0.71	0.20	1.00	6.32	2.44
3	Surface	20.35	8.20	8.15	39.17	39.15	0.99	0.06	1.87	0.53	1.50	8.64	3.83
	Bottom	23.60	8.18	6.29	39.53	41.92	0.79	0.09	1.32	0.32	1.13	7.66	2.76
4	Surface	24.18	8.18	10.03	38.47	63.35	1.63	0.23	2.45	0.60	1.40	8.49	4.93
	Bottom	23.57	8.09	2.37	39.52	49.43	0.89	0.61	1.36	0.60	1.08	9.92	3.68
5	Surface	24.23	8.12	10.03	38.08	14.92	2.74	0.99	4.42	1.05	2.75	20.51	6.50
	Bottom	23.40	8.07	3.36	38.13	16.07	1.18	1.97	3.12	0.63	1.11	12.13	2.97
6	Surface	24.07	8.11	10.70	38.10	113.35	1.58	0.20	2.65	0.50	1.35	10.09	4.37
	Bottom	23.53	7.98	1.18	38.08	82.17	0.92	0.42	1.59	0.55	1.14	9.62	3.36

Table 3.22: Averages of water quality variables along Dubai Creek during winter and flood conditions during 2005-2006.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	23.35	8.00	5.85	40.17	18.15	0.13	0.01	0.47	0.10	0.39	2.59	1.37
	Bottom	23.37	7.97	5.87	40.28	22.90	0.13	0.01	0.46	0.13	0.48	3.63	0.85
2	Surface	23.53	8.10	6.10	40.35	28.88	0.42	0.02	0.82	0.25	0.79	3.16	1.95
	Bottom	23.55	8.03	5.79	40.38	26.22	0.33	0.03	0.60	0.21	0.68	2.66	1.02
3	Surface	23.32	8.26	8.90	38.85	38.42	1.22	0.03	2.19	0.37	1.17	3.38	2.37
	Bottom	23.38	8.15	6.19	39.47	36.47	1.06	0.04	1.80	0.30	0.89	2.64	1.46
4	Surface	23.37	8.28	11.33	37.78	60.72	2.31	0.12	3.44	0.59	2.61	3.97	4.36
	Bottom	23.25	8.04	3.59	39.70	43.77	1.54	0.33	2.13	0.40	1.08	3.21	1.69
5	Surface	23.60	8.21	9.72	38.27	21.45	3.07	0.50	5.05	0.67	1.89	7.26	12.88
	Bottom	23.13	8.08	2.84	39.05	10.98	1.85	1.49	3.51	0.41	0.93	5.70	0.72
6	Surface	23.58	8.14	9.96	38.42	91.63	2.01	0.08	3.08	0.52	2.00	5.09	4.38
	Bottom	23.27	7.98	1.15	39.28	61.13	1.11	0.63	1.93	0.43	0.88	3.33	1.27

Table 3.23: Vertical, zonal, seasonal and tidal mean values of water quality along Dubai Creek during 2005-2006

Vertical, zonal and seasonal values	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
Ebb summer (average)	27.90	8.23	5.90	40.19	44.85	0.74	0.40	1.55	0.34	0.39	3.95	3.33
Ebb summer channel (average)	27.77	8.16	5.53	40.02	25.52	0.53	0.16	1.12	0.23	0.28	3.47	2.39
Ebb summer lagoon (average)	27.79	8.30	6.27	40.36	64.17	0.96	0.63	1.98	0.46	0.51	4.44	4.27
Flood summer (average)	29.30	8.22	4.85	40.30	41.99	0.49	0.25	1.26	0.30	0.35	3.78	3.69
Flood summer channel (average)	29.43	8.12	5.29	40.09	31.48	0.24	0.03	0.77	0.14	0.16	3.28	2.01
Flood summer lagoon (average)	29.25	8.31	4.40	40.50	52.50	0.75	0.47	1.75	0.46	0.53	4.28	5.38
Ebb winter (average)	23.50	8.08	6.31	39.06	44.69	0.97	0.39	1.77	0.44	1.22	9.40	3.45
Ebb winter channel (average)	23.12	8.07	6.34	39.72	32.84	0.45	0.04	0.94	0.23	0.96	7.00	2.60
Ebb winter lagoon (average)	23.83	8.09	6.28	38.40	56.55	1.49	0.74	2.60	0.66	1.47	11.79	4.30
Flood winter (average)	23.40	8.10	6.44	39.33	38.39	1.27	0.27	2.12	0.37	1.15	3.89	2.86
Flood winter channel (average)	23.42	8.09	6.45	39.92	28.51	0.55	0.02	1.06	0.23	0.73	3.01	1.50
Flood winter lagoon (average)	23.37	8.12	6.43	38.75	48.28	1.98	0.53	3.19	0.50	1.57	4.76	4.22
Surface mean value (Dubai Creek)	26.10	8.19	7.88	39.53	47.65	1.06	0.21	1.92	0.39	0.91	5.59	4.25
Bottom mean value (Dubai Creek)	25.90	8.12	3.86	39.91	37.31	0.67	0.45	1.43	0.34	0.65	4.91	2.41
Summer mean value (Dubai Creek)	28.60	8.22	5.37	40.24	43.42	0.62	0.32	1.41	0.32	0.37	3.87	3.51
Winter mean value (Dubai Creek)	23.40	8.09	6.38	39.20	41.54	1.12	0.33	1.95	0.40	1.18	6.64	3.15
Channel mean value (winter & summer)	25.93	8.11	5.90	39.93	29.59	0.44	0.07	0.97	0.21	0.54	4.19	2.12
Lagoon mean value (winter & summer)	26.06	8.21	5.84	39.50	55.37	1.29	0.59	2.38	0.52	1.02	6.32	4.54
Ebb mean value (Dubai Creek)	25.63	8.16	6.10	39.62	44.77	0.86	0.39	1.66	0.39	0.81	6.67	3.39
Flood mean value (Dubai Creek)	26.37	8.16	5.64	39.81	40.19	0.88	0.26	1.69	0.33	0.75	3.83	3.28
Overall mean value (Dubai Creek)	26.00	8.16	5.87	39.72	42.48	0.87	0.33	1.68	0.36	0.78	5.25	3.33

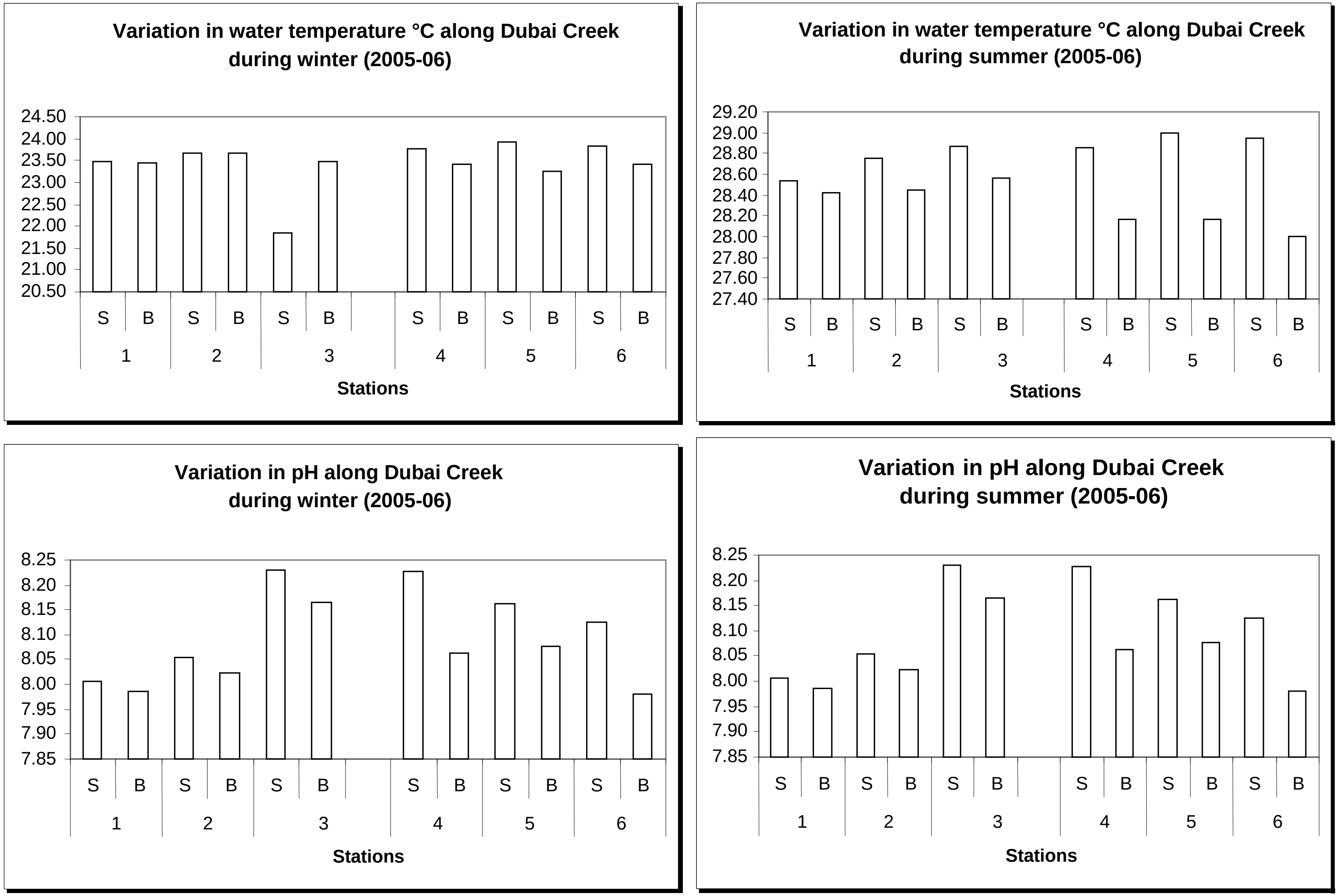


Figure 3.1: Variation in some physico-chemical parameters in Dubai Creek during winter and summer (2005-2006)

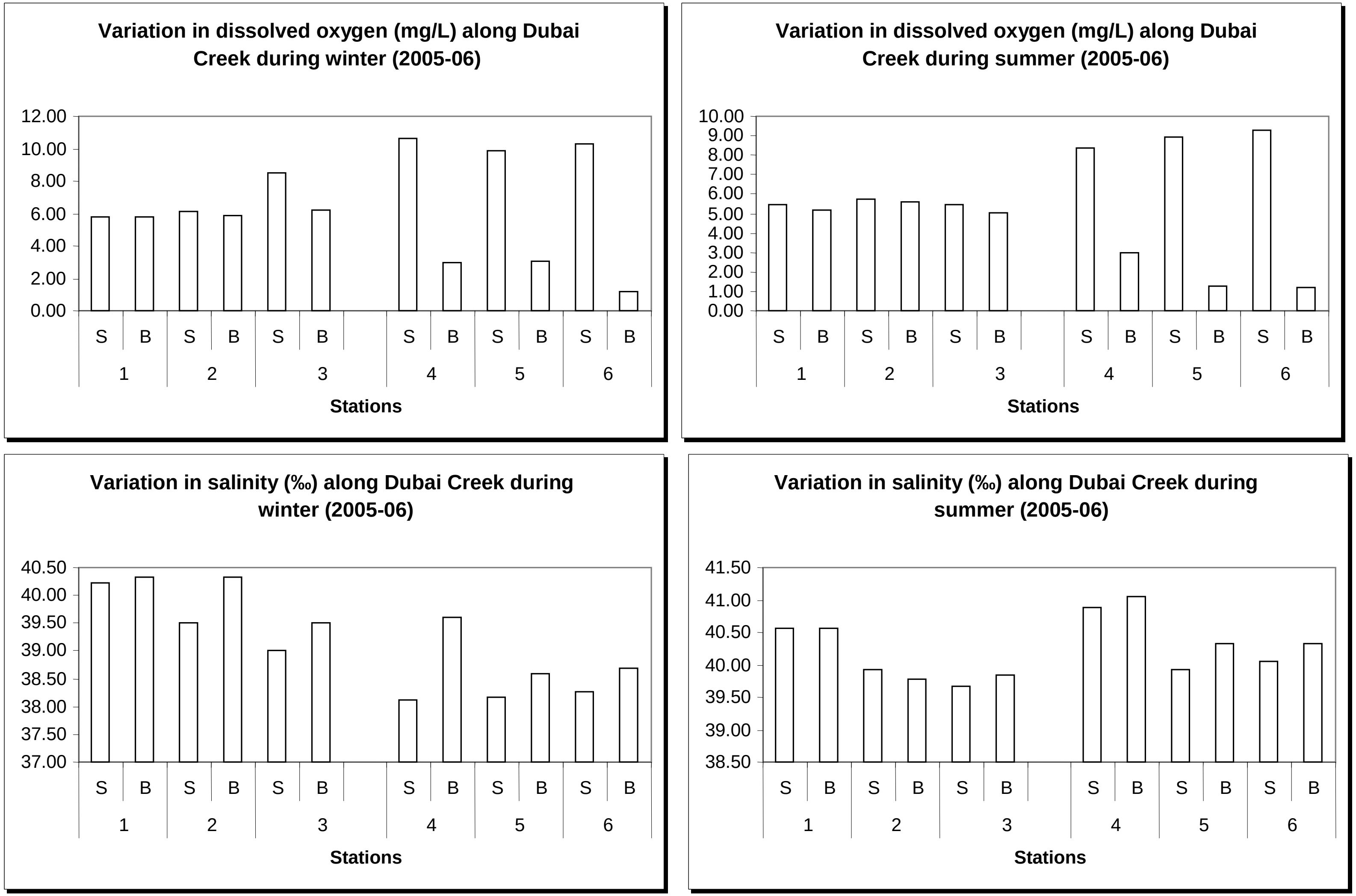


Figure 3.2: Variation in some physico-chemical parameters in Dubai Creek during winter and summer (2005-2006)

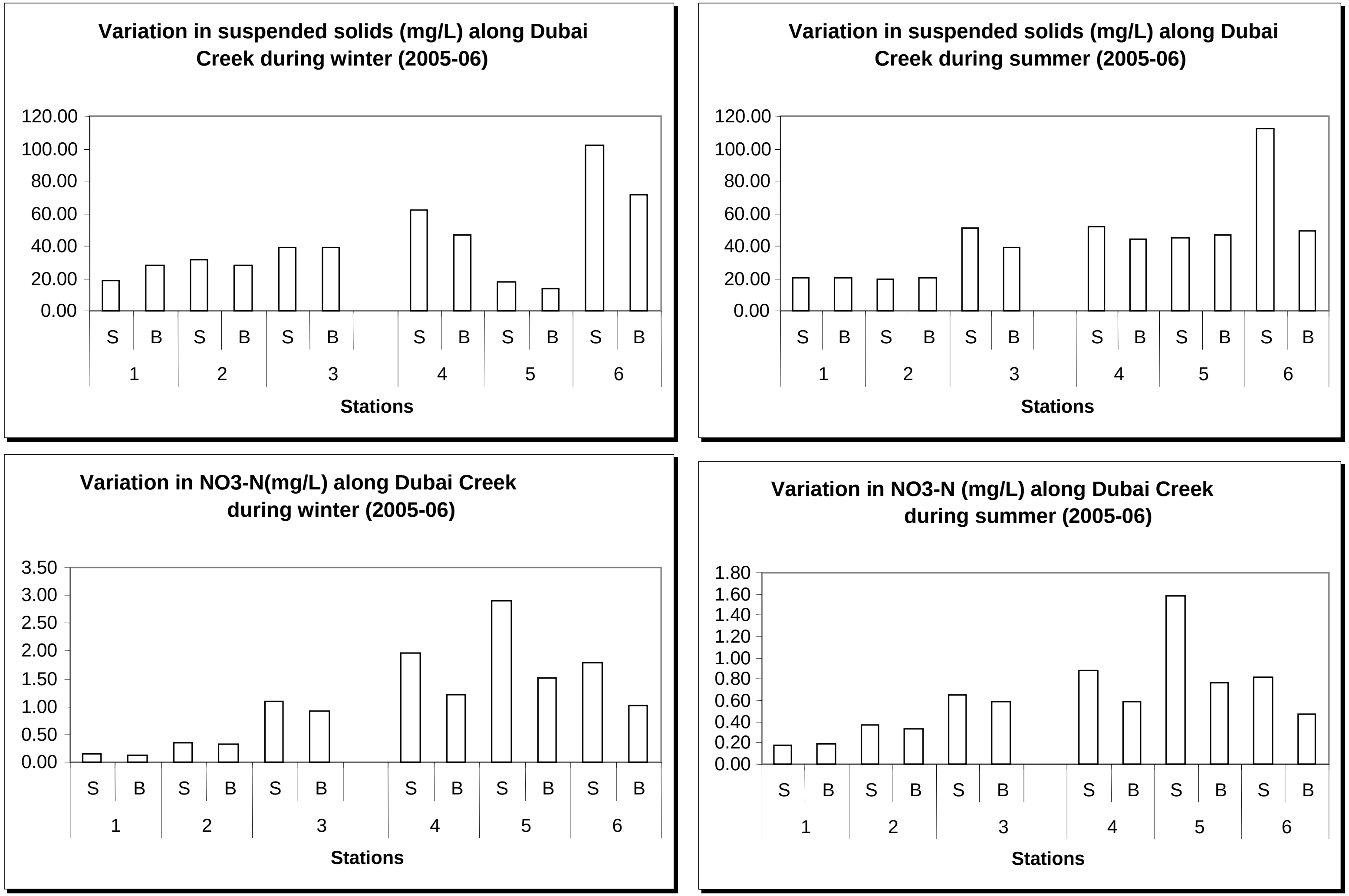


Figure 3.3: Variation in some physico-chemical parameters in Dubai Creek during winter and summer (2005-2006)

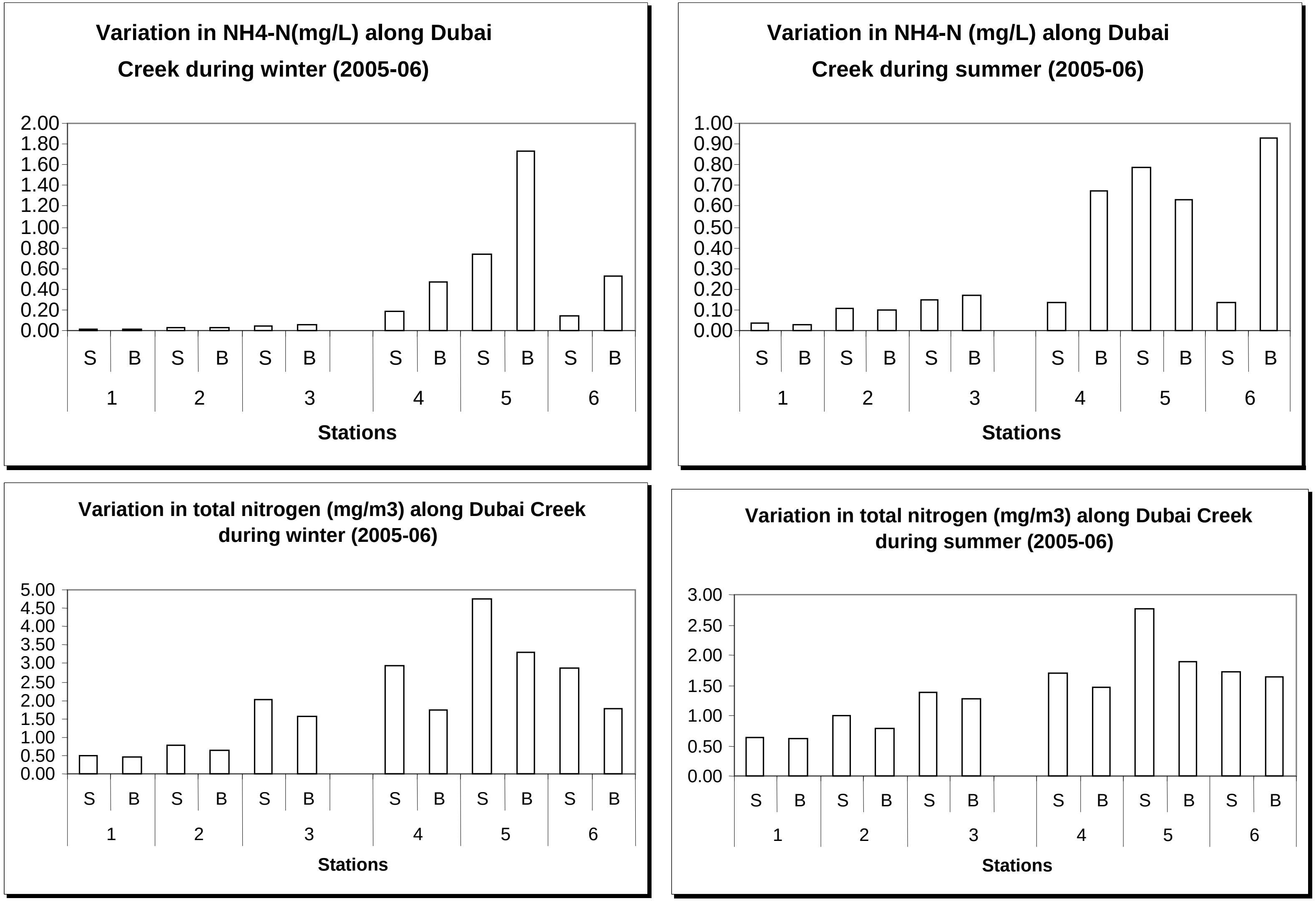


Figure 3.4: Variation in some physico-chemical parameters in Dubai creek during winter and summer(2005-2006)

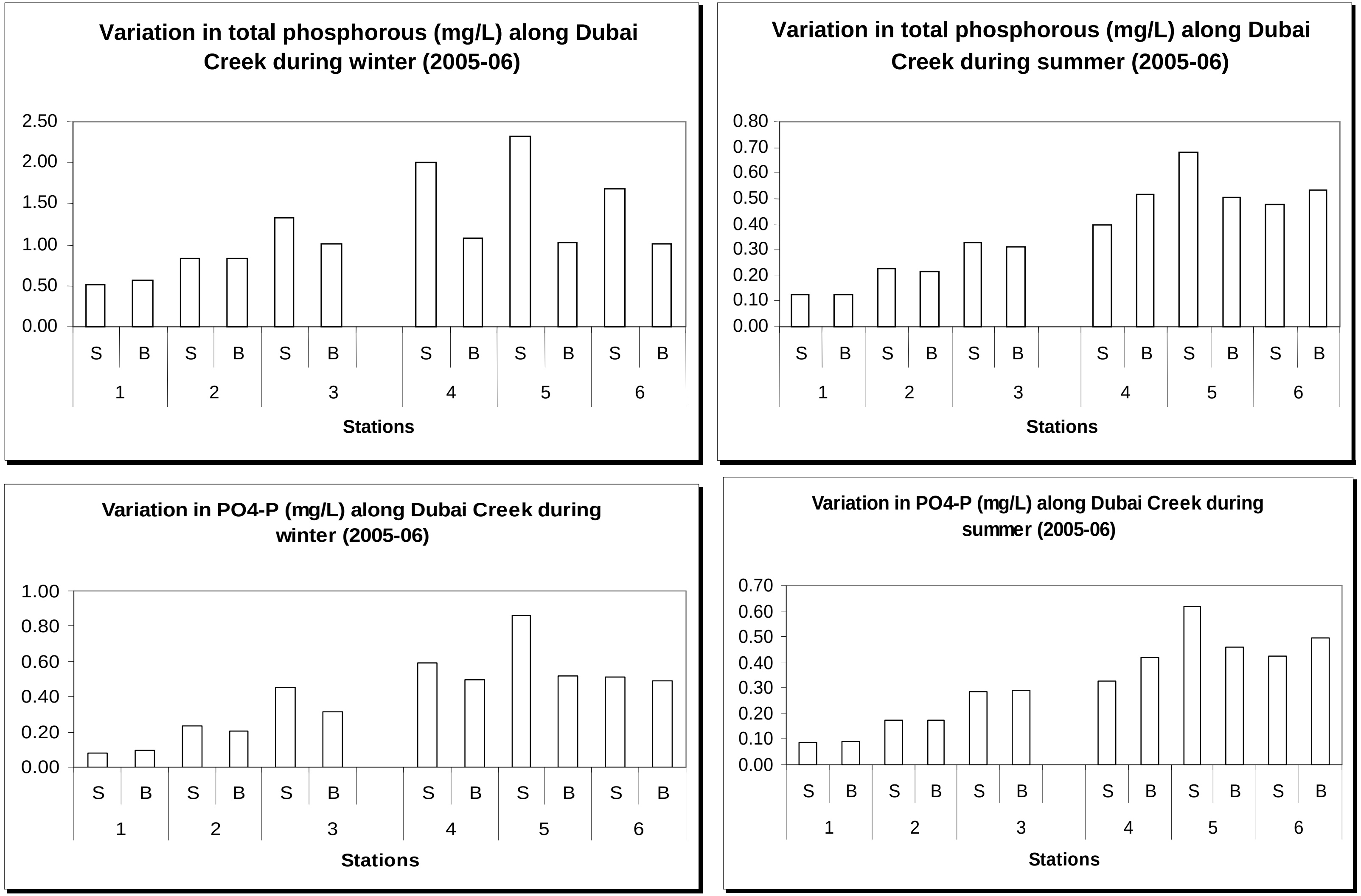


Figure 3.5: Variation in some physico-chemical parameters in Dubai Creek during winter and summer (2005-2006)

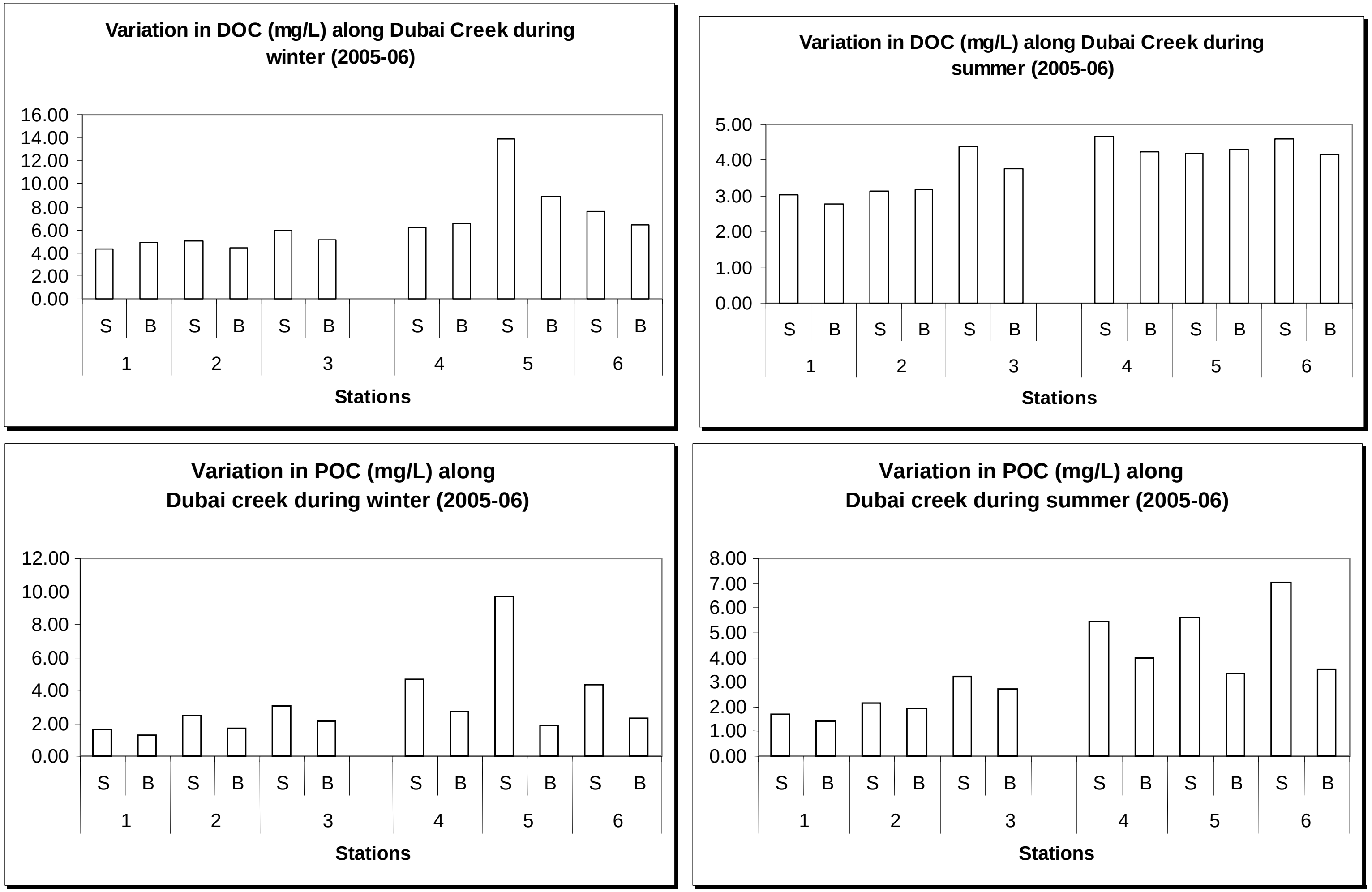


Figure 3.6: Variation in some physico-chemical parameters in Dubai creek during winter and summer (2005-2006)

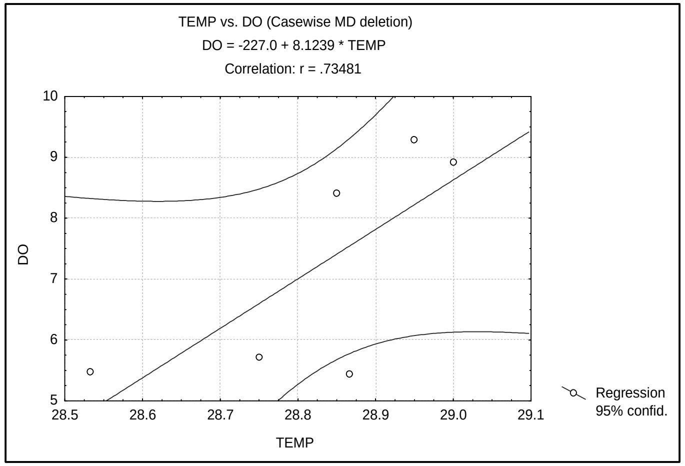
Table 3.24: Correlation matrix between water quality parameters along Dubai Creek during summer

	Water temperature °C	pH	Dissolved Oxygen (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
Water temperature °C	1.00											
pH	0.81	1.00										
DO (mg/L)	0.73	0.89	1.00									
Salinity (‰)	-0.41	-0.23	0.18	1.00								
Suspended Solids (mg/L)	0.63	0.81	0.70	-0.12	1.00							
NO_3-N (mg/L)	0.85	0.70	0.76	-0.17	0.35	1.00						
NH_4-N (mg/L)	0.63	0.51	0.51	-0.30	0.02	0.90	1.00					
Total Nitrogen (mg/L)	0.88	0.74	0.79	-0.21	0.40	1.00	0.88	1.00				
PO_4-P (mg/L)	0.91	0.82	0.82	-0.27	0.51	0.98	0.85	0.99	1.00			
Total Phosphorous (mg/L)	0.91	0.82	0.83	-0.24	0.51	0.98	0.84	0.99	1.00	1.00		
DOC (mg/L)	0.81	0.61	0.69	-0.01	0.74	0.64	0.26	0.66	0.68	0.69	1.00	
POC (mg/L)	0.83	0.90	0.95	0.04	0.85	0.73	0.41	0.76	0.81	0.82	0.85	1.00

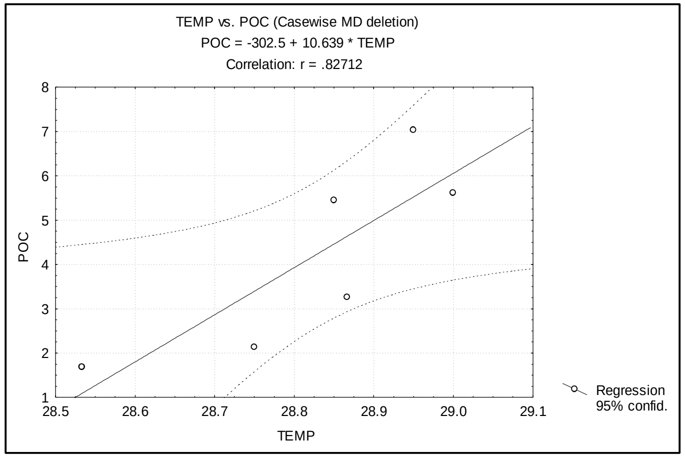
Table 3.25: Correlation matrix between water quality parameters along Dubai Creek during winter

	Water temperature °C	pH	Dissolved Oxygen (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
Water temperature °C	1.00											
pH	-0.39	1.00										
DO (mg/L)	0.16	0.78	1.00									
Salinity (‰)	-0.24	-0.75	-0.97	1.00								
Suspended Solids (mg/L)	0.16	0.28	0.60	-0.54	1.00							
NO_3-N (mg/L)	0.30	0.64	0.88	-0.91	0.24	1.00						
NH_4-N (mg/L)	0.39	0.29	0.51	-0.60	-0.22	0.85	1.00					
Total Nitrogen (mg/L)	0.25	0.63	0.85	-0.89	0.19	1.00	0.88	1.00				
PO_4-P (mg/L)	0.18	0.71	0.85	-0.91	0.17	0.98	0.85	0.99	1.00			
Total Phosphorous (mg/L)	0.25	0.74	0.92	-0.96	0.29	0.98	0.78	0.97	0.98	1.00		
DOC (mg/L)	0.31	0.32	0.55	-0.64	-0.11	0.87	0.98	0.91	0.87	0.79	1.00	
POC (mg/L)	0.36	0.42	0.65	-0.73	-0.07	0.93	0.98	0.95	0.93	0.87	0.98	1.00

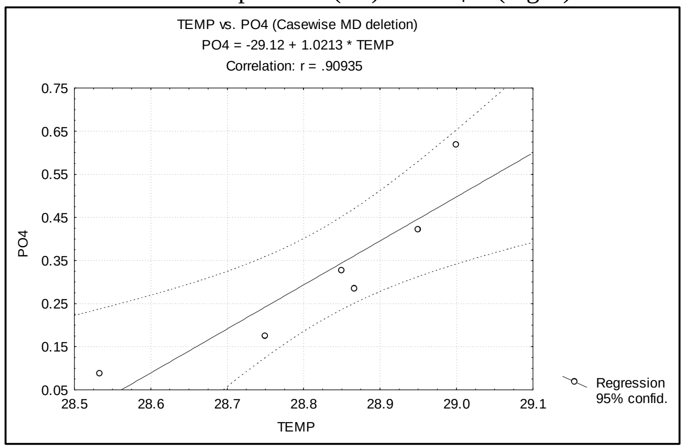
Water temperature (^{O}C) Vs Dissolved Oxygen (mg/L)



Water temperature (^{O}C) Vs POC (mg/L)



Water temperature (^{O}C) Vs PO_4-P (mg/L)



Water temperature (^{O}C) Vs NO_3-N (mg/L)

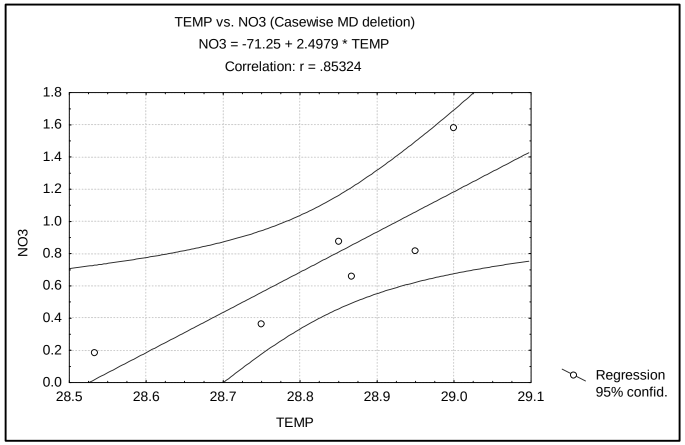
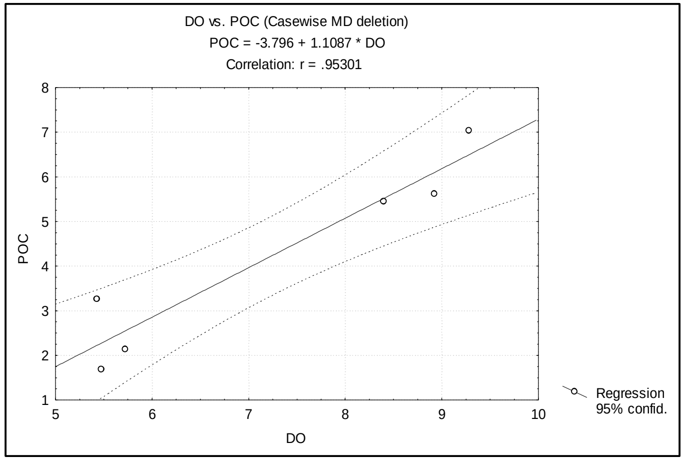
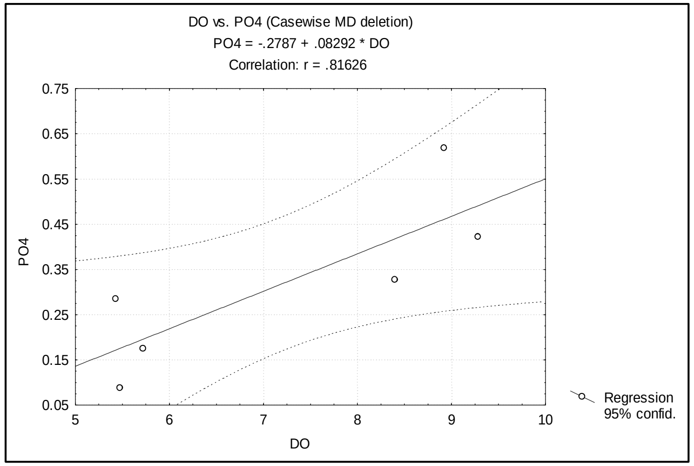


Figure 3.7: Scatter plots showing significant positive correlations ($p>0.05$) of water temperature Vs DO, POC, PO_4-P and NO_3-N along Dubai Creek during summer

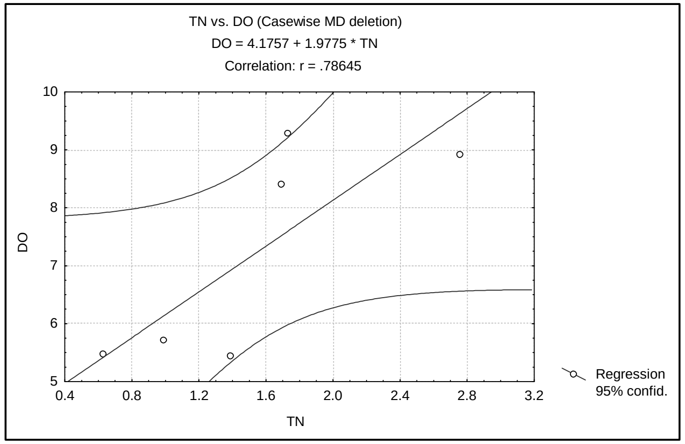
Dissolved Oxygen (mg/L) Vs POC (mg/L)



Dissolved Oxygen (mg/L) Vs PO_4-P (mg/L)



Total Nitrogen (mg/L) Vs Dissolved Oxygen (mg/L)



pH Vs Dissolved Oxygen (mg/L)

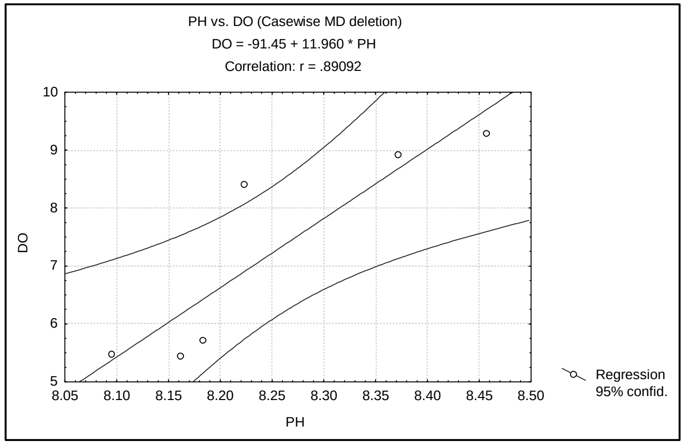
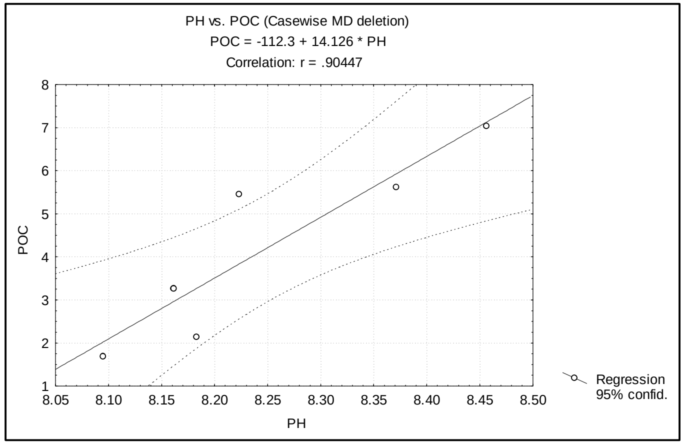
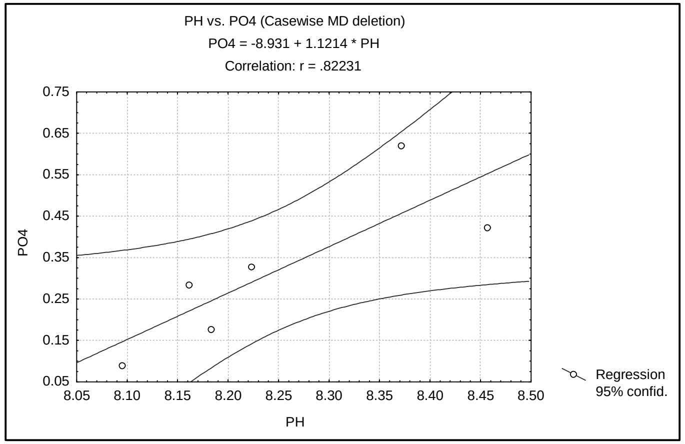


Figure 3.8: Scatter plots showing significant positive correlations ($p>0.05$) of DO Vs POC, PO_4-P, total nitrogen and pH along Dubai Creek during summer

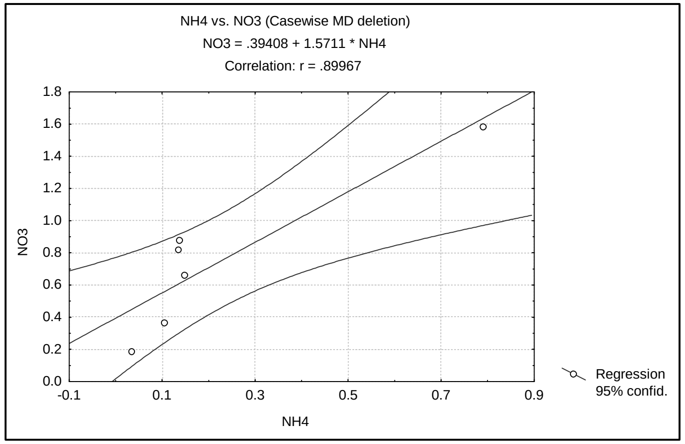
pH Vs POC (mg/L)



pH Vs PO_4-P



NH_4-N (mg/L) Vs NO_3-N (mg/L)



NH_4-N (mg/L) Vs PO_4-P (mg/L)

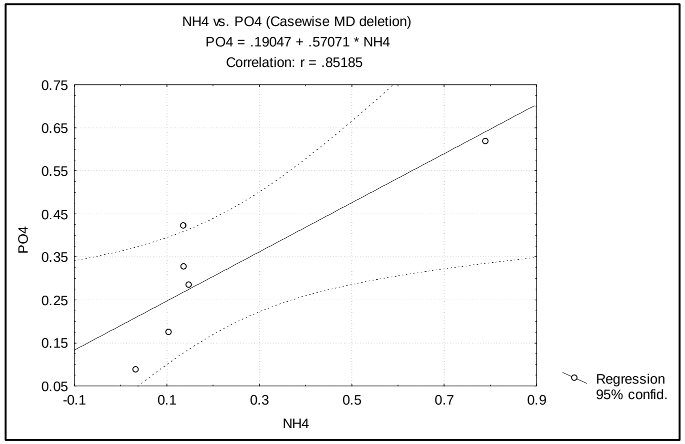


Figure 3.9: Scatter plots showing significant positive correlations ($p>0.05$) of pH and Ammonia-nitrogen NH_4-N (mg/L) with aforementioned physico-chemical parameters during summer

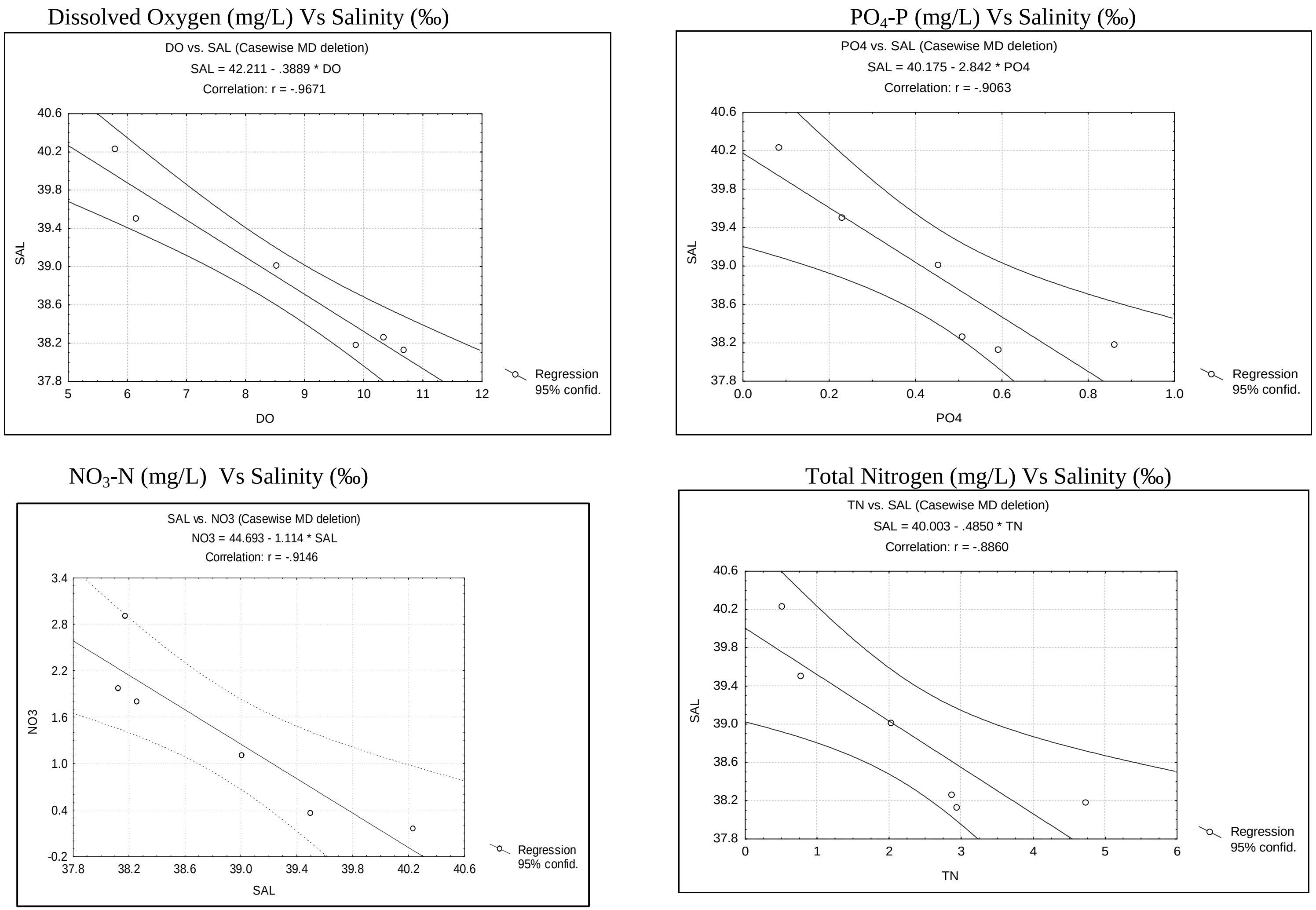
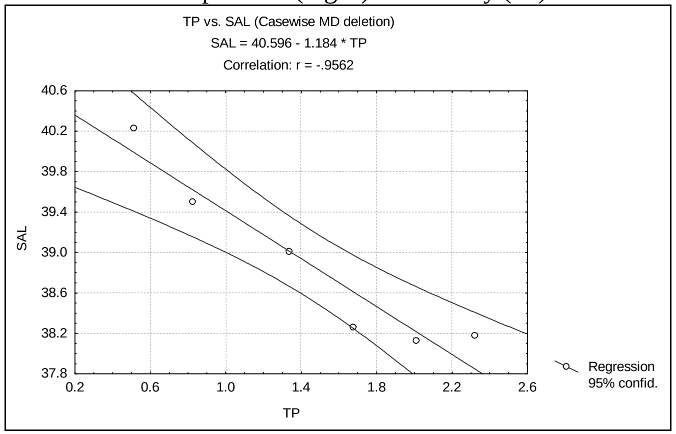
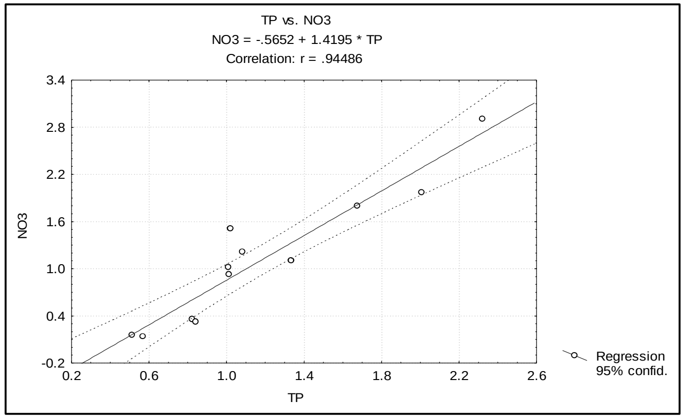


Figure 3.10: Scatter plots showing significant negative correlations ($p>0.05$) of salinity Vs DO, PO_4-P, pH and total nitrogen along Dubai Creek during winter

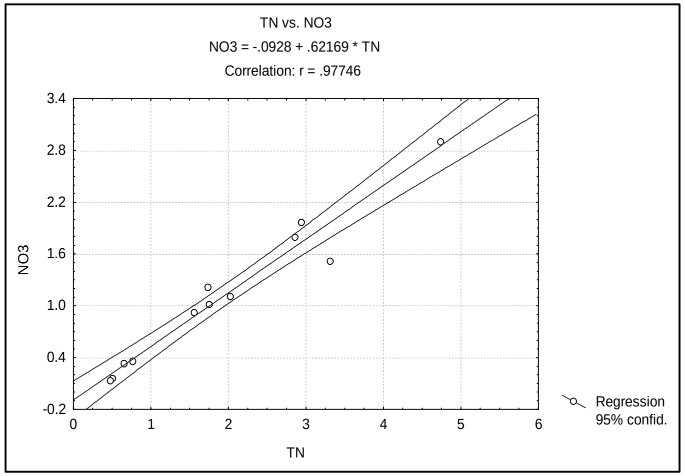
Total Phosphorous (mg/L) Vs Salinity (‰)



Total Phosphorous Vs Nitrate-Nitrogen (mg/L)



Total Nitrogen (mg/L) Vs Nitrate-Nitrogen (mg/L)



Nitrate-Nitrogen (mg/L) Vs Phosphate-Phosphorous (mg/L)

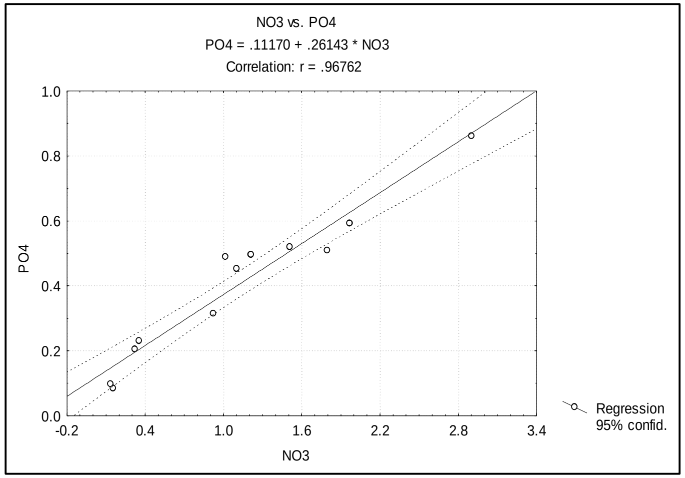
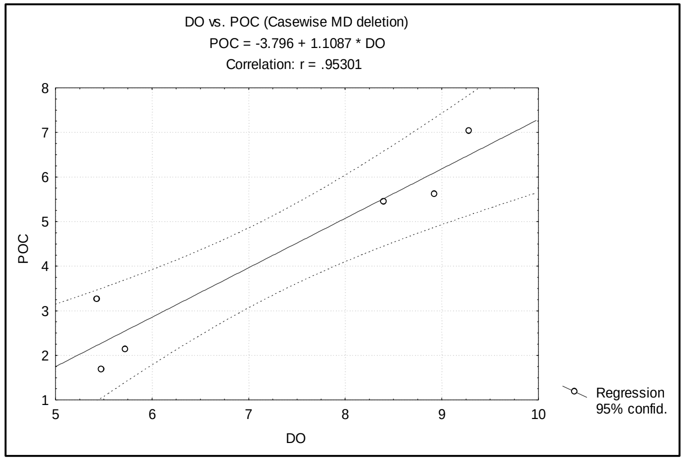


Figure 3.11: Scatter plots showing significant positive (Total Phosphorous Vs Salinity) and negative (Total Phosphorous Vs Nitrate-Nitrogen, Total Nitrogen Vs Nitrate-Nitrogen and Nitrate-Nitrogen Vs Phosphate-Phosphorous) correlations (p.0.05) along Dubai Creek during winter

Dissolved Oxygen (mg/L) Vs POC (mg/L)



Dissolved Oxygen (mg/L) Vs PO_4-P (mg/L)

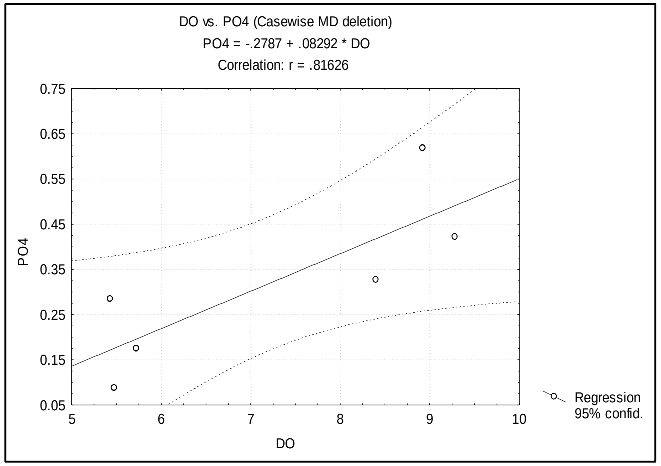


Figure 3.12: Scatter plots showing significant positive (water temperature Vs DO and POC) and negative (DO Vs POC and PO_4-P) correlations ($p>0.05$) along Dubai Creek during winter

3.4 Discussion

Dubai is situated within the coastal zone of the Arabian Gulf, which covers Iran, Iraq and 6 GCC (Gulf Cooperation Council) countries (Kuwait, Saudi Arabia, Bahrain, Qatar, the UAE and Oman). These countries are connected to the Gulf of Oman and the Arabian Sea through the Strait of Hormuz. These countries are arid to semi-arid owing to limited conventional sources of water in addition to a scarcity of rainfall and a high rate of evaporation (Al-Awadhi 2002). Rapidly expanding human populations in these countries together with increasing water demand per-capita, which are required to meet the huge socio-economic developments since the 1970's, have recently magnified the problem (Hashim & Hajjaj 2005). This chapter aims to highlight the problems of water quality in Dubai Creek associated with anthropogenic activities. The potential solutions for the management of water quality in Dubai Creek are described in Chapters V and VI.

Management of water resources constitutes the biggest challenge facing humanity today. The World Water Council (WWC 2000) reported that there is a current water crisis, which is not concerned with having little water to satisfy the needs, but is a crisis of managing water so poorly that billions of people and the environment suffer so badly. In arid zones of the Arabian Gulf, water management is the focal point for sustaining economic development. It is estimated that by the year 2010, the Arabian Gulf region will demand $96x10^6$ m^3 /day of water (Dabbagh 1996) and $137x10^9$ m^3/year will be needed by the year 2025 (Al-Awadhi 2002). Such a huge requirement necessitates water management at the top of the agenda.

Dubai creek falls within the north-temperate tropical margin that encompasses most of the earth's deserts and displays limited variation in water temperature. The range of water temperature in the present study is comparable with the earlier records of Dubai Creek (Deshgooni 2002) indicating that the marine water quality in Dubai Creek is unaffected by the thermal discharge or desalination activities. However, the ambient values of water temperature play a significant role in controlling the water quality characteristics. For example: the significant positive correlations of water temperature with DO ($p>0.05$, $r=0.74$), PO_4-P ($p>0.05$ $r=0.90$), NO_3-N ($p>0.05$ $r=0.86$), and POC ($p>0.05$ $r=0.82$) during summer (Figure 3.7) in contrast with the significant negative correlations of the water temperature with DO ($p>0.05$, $r= - 0.97$) and POC ($p>0.05$, $r= - 0.73$) during winter (Figures 3.10 and 3.11) clearly defines the critical role of temperature controlling the water chemistry that increases and decreases DO and POC levels in summer and winter seasons, respectively. This is exemplified by conditions during summer when small bubbles, which are always present in the sea associated with organic matter, grow in the presence of high oxygen saturations (Ramsey 1962).

Very large variations in pH (7.7-9.1) specifically during winter (7.7-8.4) and summer (8.0-9.1) indicate that Dubai Creek is often alkaline. The acidic character of CO_2 respiration and photosynthesis cause a decrease and an increase of sea water pH, respectively (Naqwi & Jayakumar 2000). The values of pH during summer are relatively higher than the recorded levels closest to Dubai [Abu Dhabi creek (Abu-Hilal & Adam 1995) and the UAE coastal waters (Shriadah & Al-Ghais 1999)] but are nevertheless comparable with the earlier records for Dubai Creek (Dubai Municipality 2000 and Al-Zahed 2005)

Low pH in the channel with insignificant vertical variation showed the well-mixed nature of the water body. The high pH in the lagoon, with significant vertical variations, is mainly influenced by high and low photosynthetic activities respectively at the surface and bottom layers, respectively, that contributes to an elevation of the level of pH at the surface and reduces the pH levels at the bottom. The significant difference of pH in the channel (8.11) and lagoon (8.21) is attributed to low and high primary productivity zones, respectively. Usually the horizontal variation in the waters of the UAE is insignificant due to shallowness and vertical turbulence (Shriadah & Al-Ghais 1999) whereas vertical stratification is due to a high rate of photosynthesis at the surface which leads to the production of more oxygen and consumption of CO_2.

Lower levels of pH at the bottom (8.12), as compared to the surface (8.19), are induced by the decomposition of organic matter that results in oxygen uptake and CO_2 generation. Thus, combinations of factors such as photosynthetic activity as identified by positive correlation between pH and DO ($p>0.05$ $r=0.78$ during winter and $p>0.05$ $r= 0.85$ during summer), detrital accumulation due to high algal growth at the surface, disposal of sewage wastewater and decomposition of organic matter in the Creek waters are the factors controlling the pH in the creeks water of the UAE (Shriadah & Al-Ghais 1999)

A positive correlation between pH and DO ($p>0.05$ $r=0.89$) and PO_4-P ($p>0.05$ $r=0.82$) reflects an increase in pH where the DO is elevated due to high primary production (Al-Zahed 2005). Such high values are also evident in Dubai Creek in response to significant anthropogenic inputs from outfalls located on the banks of Dubai Creek (Abu-Hilal & Adam 1995). The exceptionally high pH values (>9) in Dubai Creek are indicative of high primary productivity, which fully utilizes the available CO_2. Biological activity plays an important role in regulating the speciation of dissolved inorganic carbon or ΣCO_2, which is strongly dependent on pH. In the pH range normally encountered in oceanic surface waters, HCO_3- is the predominant species (90%); only about 1% of SCO_2 is present in the aqueous or hydrated form CO_2 (aqueous) and H_2CO_3 with the rest occurring as CO_3^{2}- It is only the ‘free’ (unionized) form which can be exchanged with the atmosphere; its concentration is represented as pCO_2, the equilibrium partial pressure of CO_2 (Naqwi & Jayakumar 2000). The relationship of high pH and high primary productivity has been defined as the phenomenon of stagnant aquatic environments with examples such as lake (Chilka lake) and saline reservoirs (Salt pans- Mumbai) in India (Mustafa 2005 and Nayak et al 2004).

DO content in an aquatic system is an essential factor influencing factor for aquatic life. The available DO is derived from the atmosphere and photosynthesis. Organic matter oxidation contributes to the depletion of oxygen in the water body. Changing the balance between the oxygen supply and consumption leads to a characteristic DO profile. Therefore, under aerobic conditions the oxygen content is one of the most suitable measures related to the state of the water body.

Current results for DO based on the vertical, zonal and seasonal variation gives a comprehensive picture of the oxygen behavior in Dubai Creek (Table 3.23). DO values indicate a well mixed zone in the channel with balanced levels during winter and summer seasons. A trend of vertical stratification is evident in Dubai Creek in surface (7.78 mg/L) and bottom (3.86 mg/L) waters. The low values at the bottom compared to the surface were expected due to sediment respiration, high sediment oxygen demand and chemical reactions, whereas the high DO values at the surface in the lagoon are due to air diffusion at the air-water interface, high photosynthetic activity and less mixing due to low surface turbulence. The observed stratification in DO levels correspond to the earlier records of Dubai Creek that show a high variation (0.02-10.30 mg/L) that is a clear indicative of high stratification at the surface and bottom layers (Al-Zahed 2005)

Negative correlation of DO with salinity ($p>0.05$, $r = -0.97$) during winter indicates its close association with freshwater influx in Dubai Creek. Further, positive correlation between DO and total nitrogen [$p>0.05$, $r=0.85$ (winter), $p>0.05$ $r=0.79$ (summer)], PO_4-P [$p>0.05$, $r=0.85$ (winter), $p>0.05$ $r=0.82$ (summer)], and total phosphorous [$p>0.05$, $r=0.92$ (winter), $p>0.05$ $r=0.83$ (summer)] verifies that DO levels are associated with anthropogenic inputs that are enhancing the photosynthesis and primary productivity in the water.

Seasonally, DO values are higher during the winter (6.38 mg/L) compared to the summer (5.37 mg/L) seasons. Increasing DO values during winter are due to high solubility of oxygen in lower water temperatures and increasing turbulence, while the falling DO values during summer are attributed to high water temperature that is increasing the rate of organic matter decomposition in the coastal and creek waters of the UAE (Shriadah & Al-Ghais 1999).

Salinity levels (39.72 ‰) in Dubai Creek are higher than the oceanic waters (~35 ‰), but comparable with the typical salinity regime of the Arabian Gulf region (Hunter 1982) that increases upto ~45 ‰ as a consequence of the flow restriction caused by the Straits of Hormuz, shallow depth and the high evaporation rates (Hashim & Hajjaj 2005).

Vertical distribution of salinity in Dubai Creek indicates higher values at the bottom (39.91‰) compared to the surface (39.53‰). Oceans and seas are in reality one single body of water; yet, their waters are not homogeneous (Fitzsimons 2001). The density of ocean seawater varies with depth and temperature, where it increases with ocean depth (Nelson 2001) and becomes denser as seawater becomes colder. Salinity variation in Dubai Creek is mainly influenced by anthropogenic fresh water influx rather than prevailing regime of the Arabian Gulf (Grasshoff 1976).

The horizontal distributions of salinity are more prominent along Dubai Creek. The channel (39.93‰) is highly saline compared to the lagoon (39.50‰). Low salinity levels are associated with the anthropogenic freshwater inputs (Saunders et al 2007) from STP outfall (Figure 3.13) located in the lagoon region of Dubai Creek.

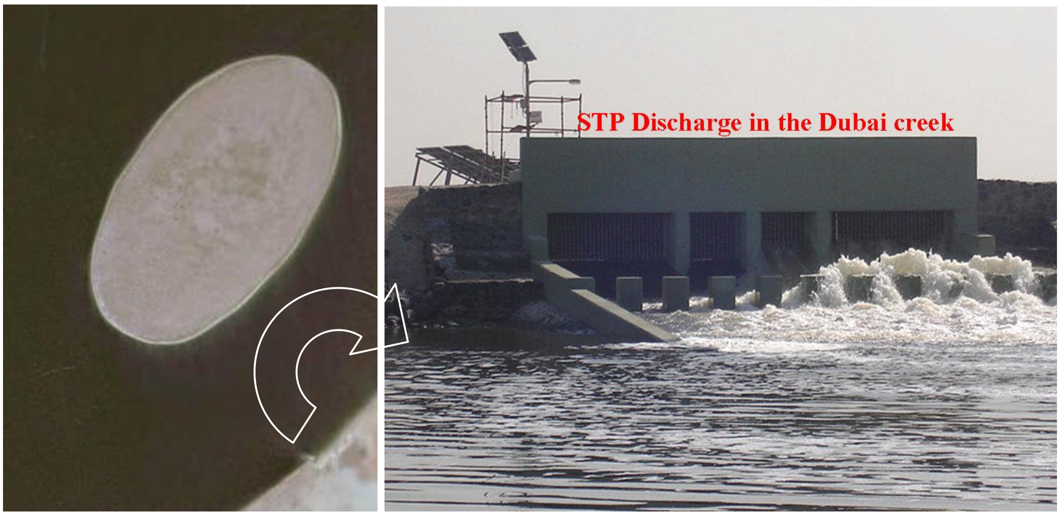


Figure 3.13: Awir STP outfall in Dubai Creek (right picture courtesy: Google earth)

Significant negative correlations between salinity and NO_3-N, total nitrogen, PO_4-P and total phosphorous indicate that excess pollutant (nutrients) in Dubai Creek originates from the freshwater source from STP and continues to organic pollution in the lagoon (Saunders et al 2007). The STP treatment means the effluent will have been through several stages of filtration and settlement and is therefore expected to have low suspended solids. That the salinity is lowest at this station is probably due to the huge volume of fresh water produced by the STP, but also an indication that within a saline system the input of considerable freshwater could be considered a pollutant (Saunders et al 2007). Currently the STP discharges more than 100,000 m^3 a day into the lagoon with average levels of 22.6 mg/L, 11.6 mg/L, and 1.0‰ of NO_3-N, PO_4-P and salinity respectively (Dubai Municipality 1997b) STP outfall. Such characteristics are common in Indian Estuaries where nutrient levels are controlled by anthropogenic discharge (De-Sousa 1999)

The salinity profile in the channel of Dubai Creek is comparable with the Gulf of Oman (Basson et al 1977 and Abu-Hilal et al 1990). Salinity levels are high during summer (40.24‰) compared to winter (39.20‰). The high level of salinity during winter is attributed to a greater quantity of discharge as a result of lower consumption for irrigation (secondary treated discharge from STP used for land irrigation and partially amount discharge into Dubai Creek) (Dubai Municipality 2007).

High suspended solids (42.48 mg/L) in Dubai Creek are mainly associated with POC levels as defined by a significant positive correlation ($p>0.05$, $r=0.85$). The suspended solids show a clear demarcation between a higher level in the lagoon (55.37 mg/L) compared to the channel (29.59 mg/L).

Dissolved nitrogen and phosphorus compounds are present in low concentrations in seawater. Nitrogen is mainly present as NO_3-N with low concentrations of (nitrite) NO_2-N and NH_4-N, while the major inorganic species of phosphorus is PO_4-P. High concentrations of these nutrients in water however can lead to excessive growth of algae resulting in eutrophication (Lundberg 2005).

Existing NO_3-N (0.87 mg/L), NH_4-N (0.33 mg/L), total nitrogen (1.68 mg/L) PO_4-P (0.36 mg/L) and total phosphorous (0.78 mg/L) are extremely high in Dubai Creek but comparable with recent data from Dubai Creek (Al-Zahed 2005, Saunders et al 2007). These nutrients levels are more elevated than the historic data from Dubai Creek (Abu-Hilal & Adam 1995) and significantly higher than the regional [Kuwait, Saudi Arabia, Qatar (Dorgham et al 1987)] and UAE water quality levels (Shriadah & Al-Ghais 1999) including Abu Dhabi Creek (Abu-Hilal & Adam 1995) (Table 3.26).

Wide variations of these nutrients (NO_3-N, NH_4-N, total nitrogen PO_4-P and total phosphorous) exist in the channel and lagoon, during summer and winter, at the surface and bottom (Table 3.23). Generally nutrients are stable and comparatively low in the channel whereas these levels are fluctuating and high in the lagoon.

Table: 3.26: Nutrients levels of Dubai Creek in comparison with region water quality.

Variables Region	NO_3-N (mg/L) (Minimum)	NO_3-N (mg/L) (Maximum)	PO_4-P mg/L) (Minimum)	PO_4-P (mg/L) (Maximum)	Reference
Kuwait*	0.002	0.01	0.004	0.01	Dorgham et al (1987)
Saudi Arabia*	0.001	0.02	0.0001	0.01	Dorgham et al (1987)
Qatar*	0.004	0.01	0.006	0.03	Dorgham et al (1987)
Dubai Creek (1989-90)	0.007	0.33	0.024	0.88	Abu-Hilal & Adam (1995)
Abu Dhabi Creek (1989-90)	0.001	0.26	0.001	0.14	Abu-Hilal & Adam (1995)
Abu Dhabi UAE (Mangrove Area)*	0.008	0.11	0.003	0.09	Shriadah (2000)
Abu Dhabi UAE (Nearshore waters)*	0.001	0.10	0.0001	0.04	Shriadah (2000)
Umm al Quwain UAE (Mangrove Area)*	0.003	0.17	0.003	0.10	Shriadah (2000)
Umm al Quwain UAE (Nearshore waters)*	0.002	0.10	0.001	0.09	Shriadah (2000)
Ras Al Khaimah UAE (Mangrove Area)*	0.003	0.01	0.002	0.09	Shriadah (2000)
Ras Al Khaimah UAE (Nearshore waters)*	0.001	0.11	0.001	0.18	Shriadah (2000)
Khor al Khuwair UAE (Mangrove Area)*	0.017	0.19	0.004	0.09	Shriadah (2000)
Khor al Khuwair UAE (Nearshore waters)*	0.002	0.10	0.0001	0.15	Shriadah (2000)
Abu Dhabi Creek UAE (Mangrove Area)*	0.008	0.11	0.003	0.09	Shriadah (2000)
Abu Dhabi Creek UAE (Nearshore waters)	0.001	0.10	0.0001	0.04	Shriadah (2000)
Dubai Creek (1999-2000)	0.28	0.36	0.20	0.42	Deshgooni (2002)
Dubai Coastal Waters (2002)	0.04	0.14	0.02	0.03	Mustafa & Deshgooni (2006)
Dubai Creek (2005-2006)	0.44**	1.29**	0.21**	0.52**	Al Zahed (2007) Present Study
Dubai Creek (2006) No. of fold higher than Dubai coastal waters	**11**	**9**	**11**	**17**	(Averages) Mustafa & Deshgooni (2006)
Dubai Creek (2006) No. of fold higher than UAE waters	**103**	**10**	**126**	**5**	(Averages) Shriadah (2000)
Dubai creek (2006) No. of times higher than regional waters	**220**	**99**	**70**	**31**	(Averages) Dorgham et al (1987)

*(Values converted from µg/l to mg/L) ** Min and max values are taken as average of channel and lagoon, respectively

The rate of nutrient enhancement has continued in Dubai Creek for the last 2 decades, Current levels of NO_3-N and PO_4-P are 2.5 fold higher than the levels in 2000 (Figure 3.14).

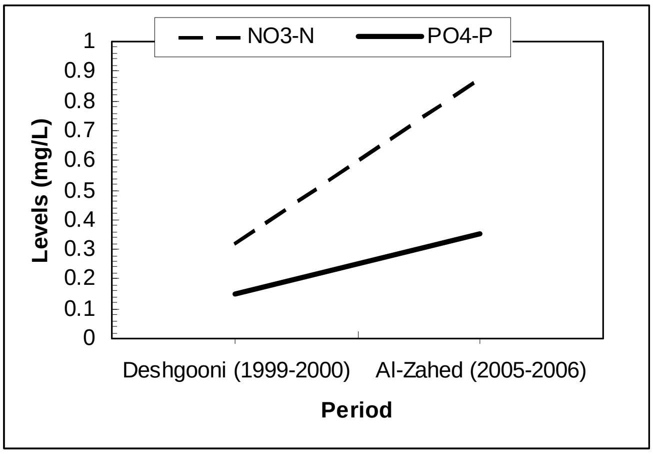


Figure 3.14: Comparison in nutrient levels in Dubai Creek from 1999 to 2006

Present status indicates that NO_3-N, NH_4-N, total nitrogen, PO_4-P and total phosphorous in the lagoon are respectively 2.9, 8.4, 2.5, 2.5 and 1.9 fold higher than in the channel (Table 3.26).

Nutrients (NO_3-N, total nitrogen, PO_4-P and total phosphorous) levels are high during winter (Figures 3.17-3.18). These high levels could be attributed to the low rate of photosynthesis during winter that requires less nutrient supply. Further, the quantity of nutrient discharge from STP is greater during winter (Dubai Municipality 1997).

Table 3.27: Nutrients levels in Dubai Creek during winter and summer

Nutrients	Channel	Lagoon	Difference No. of folds
NO_3-N (mg/L)	0.44	1.29	2.9
NH_4-N (mg/L)	0.07	0.59	8.4
Total nitrogen (mg/L)	0.97	2.38	2.5
PO_4-P (mg/L)	0.21	0.52	2.5
Total phosphorous	0.54	1.02	1.9

Generally, the nutrient increase from the channel to the lagoon indicates that the lagoon area is heavily vulnerable to eutrophication. This pattern of organic pollution has been found before by Hassan et al (1995), while El-Sammak (2001) also divided the Creek into similar zones.

PO_4-P concentration of 0.3 μg/L will support plankton growth, while concentrations of 1.0-3.2 μg/L PO_4-P will trigger blooms (USEPA 1986 and Dunne & Leopard 1978). The N: P ratio in the lagoon region of Dubai Creek is lower than the global oceanic ratio of 16:1 (Redfield 1934). Algal production is correlated to the levels of nitrogen (N) and phosphorus (P) in the water. Above a 16:1 N: P ratio in coastal areas, the system is likely to experience an algal bloom, the severity of which will be in relation to the excess phosphorus available (Schindler 1978 and Jaworski 1981). In those systems, where N: P is below 10:1, nitrogen is the limiting nutrient and the estuarine or coastal system will experience an algal bloom if excessive nitrogen becomes available (Jaworski 1981).

The N (2.18 mg/L) to P (0.95 mg/L) ratio in Dubai Creek is 2.3:1, which is much lower than the global ratio of nearby areas [Ras Al-Khaima (9.8:1), Abu Dhabi (9.5:1) and Umm Al-Quwain (8.9:1) (Shriadha & Al-Ghais 1999)] indicates highly eutrophic effects in the lagoon of Dubai Creek. The principal reason for the eutrophication in the lagoon is attributed to high total nitrogen. Adverse impacts due to eutrophication are visible and quite apparent in Dubai Creek lagoon and indicated by some of the environmental issues such as fish mortality (Dubai Municipality 1995), unappealing colours caused by the dense algal blooms and a bad odour (Dubai Municipality 1997b).

Eutrophication is often caused by a combination of high anthropogenic organic input combined with hydrodynamic conditions where nutrients are not removed and there is little fresh input of oxygen to compensate for the high demand (Gray et al 2002, Painting et al 2007). It has been suggested that the input from the STP is largely responsible for the eutrophication in the lagoon (Dubai Municipality 1997b) and our study supports that high nitrogen is the principal nutrient from the STP responsible for the eutrophication in the lagoon of Dubai Creek.

Overall, Dubai Creek exhibits 3-120 and 4-122 fold higher levels of NO_3-N and PO_4-P respectively compared to the levels of the Arabian Gulf (Table 3.26)

DOC and POC show high levels in the lagoon (DOC-5.95 mg/L and POC-4.11 mg/L) compared to the channel (DOC-4.19 mg/L and POC-2.12 mg/L). Positive correlationbetween POC and DOC with total phosphorous and NO_3-N indicates its association with nutrients (pollutant) and other biological detritus. Particulate matter in the upper surface layer of marine waters consists mainly in the form of NO_3-N (Rabitti et al 1992). High levels of DOC and POC may also be due to other biological factors such as phytoplankton excretion or exudation and zooplankton feeding and excretion.

3.5 Conclusion

Overall, this chapter provides the following findings on water quality parameters in Dubai Creek: -

- The first systematic records of 12 water quality variables that cover summer and winters levels covering ebb and flood tides as well as surface and bottom values.
- Water temperatures are related to increases and decreases in the levels of DO and POC in summer and winter, respectively.
- The pH increases with DO due to high photosynthesis and primary production.
- DO levels shows high stratification in the lagoon of Dubai Creek, mean surface levels are 2 fold high than mean bottom levels.
- Dubai Creek is susceptible to organic pollution, excess of pollutant originates from the freshwater source from STP.

- Suspended solids clearly demarcate the lagoon (high levels) from the channel (low levels).
- Nutrients in the channel are 2 to 8 fold higher than in the lagoon. The levels of NO_{3}-N and PO_4-P in Dubai Creek have increased almost 2.5 fold over the past 5 years.
- POC and DOC indicate its association with pollutant and other detrital biological matters.
- Dubai Creek shows levels of NO_{3}-N and PO_4-P that are 5-126 fold higher than in the UAE, which is an alarming indication of the need for an immediate management plan for the improvement of water quality.
- High nutrients and organic pollution in the lagoon region have a severe adverse impact on the water quality, biodiversity and the aesthetic value of Dubai Creek.
- The winter season exhibits high nutrients and DO compared to summer.
- The summer season shows low nutrients and DO compared to winter.
- Levels of total nitrogen, total phosphorous, NO_{3}-N and PO_4-P were high at the surface compared to the bottom.

CHAPTER IV

Ecological Characterization of Aquatic Systems

4.1 Introduction

Characterisation of the ecological status of an aquatic ecosystem, especially if targeted at the quantification of human impact, requires the assessment of several biological “quality” elements. These quality elements may, however, react in different ways to disturbances but have been selected over many years to represent the best possible indicators of system health. In the present study, a baseline assessment of the biological status of Dubai Creek has been based on the diversity and of organisms representative of different trophic levels in the system. The elements selected in this study were phytoplankton and zooplankton, that represented ecological impacts at primary and secondary levels, respectively, while the macro-benthos was used to assessing benthic conditions.

4.1.1 Phytoplankton

All heterotrophic organisms need a supply of energy and food to grow and reproduce. Phytoplankton (autotrophs) are the primary producers providing autochthonous carbon that can be used by higher level (heterotrophs) consumers. Autotrophs form the base of the food chain, which then supports further trophic levels (consumers). Primary producers are deemed to be the first level, herbivores are the secondary level, small carnivores the third and larger carnivores that consume smaller carnivores the next, and so on. On average, ten percent of energy is transmitted across each trophic level (www.ideo.colombia.edu). However, this figure varies greatly depending on the efficiency of the producer/consumer/carnivore system.

The efficiency is often greater between producers and primary consumer than between consumer and carnivores (Ricklef & Miller 1999).

Phytoplankton community assemblages are determined in part by their environment, exhibiting a complex response to this influence. Predicting changes in species composition for a phytoplankton community as an indicator of the variability of coastal water quality characteristics has promoted analysis of this community using different strategies, such as long-term monitoring of dominant species and their relationships with seasonal changes of environmental conditions (Jones et al 2001 and Roelke et al 2003). Communities of phytoplankton changes due to species succession, which occurs in response to new conditions encountered in the environment (Huisman et al 2001). Two important factors are recognized as controlling the community structure of phytoplankton. The first is related to physical processes such as mixing of water masses, light, temperature, turbulence, and salinity, and the second is associated with nutrients. The study of the phytoplankton community response to these variables is considered useful for interpreting hydrological variations in coastal areas (Troccoli et al 2004). Different human activities in coastal areas generate wastes that cause changes in the natural hydrological conditions of the coastal system, inducing eutrophication and chemical pollution. Phytoplankton community structural changes are a good indicator of eutrophication effects, as it is recognized that phytoplankton composition is a natural bioindicator because of its complex and rapid responses to fluctuations of environmental conditions (Livingston 2001).

Information with regards to the phytoplankton assemblages or species associated with eutrophication are almost negligible in the Arabian Gulf. Eutrophication in the lagoon of Dubai Creek has defined algal blooms associated with nutrient loading (Mustafa et al 2001). Some studies cover nutrient limitation for primary productivity (Kimor 1987) and describe four hundred species of phytoplankton (Dorgham & Muftah 1986) in the Arabian Gulf. Other studies suggest that the coastal zone throughout the Arabian Gulf coast is already exposed to major impacts as a result of local resource utilization (MEPA 1992). Phytoplankton assessments adjacent to the desalination outfalls in Jubail, Arabian Gulf show seasonal changes in the community structure and population abundance in the phytoplankton during summer (Abdul-Aziz 1998) associated with blooms (Abdul-Aziz 2000). More recent studies from the same area indicate that seawater temperature and salinity did not impact on the abundance of phytoplankton (Abdul-Aziz 2003). Phytoplankton blooms and harmful algal blooms of red tide are quite common in the Arabian Gulf (Rao et al 1999) and have resulted in harmful environmental impacts such as in fish kill (Glibert et al 2001).

4.1.2 Zooplankton

Zooplankton dynamics, their seasonal variability and driving mechanisms is a central issue of oceanographic research (Mackas et al 1985, GLOBEC Science Plan 1997). The identification of changes in species composition related to long-term trends in the ocean is a strategy used to monitor the influence of global changes on marine communities.

The knowledge of target species representing the evolution of an ecosystem is of paramount importance. In polar and temperate waters this task is relatively simple due to the predominance of well-studied species. In oligotrophic seas, environmental changes and phytoplankton abundance may vary rapidly and irregularly over short time periods (Bustillos-Guzman et al 1995) with a concomitant influence on zooplankton.

Zooplankton in the Arabian Gulf is described by Michel et al (1986a, 1986b). Leveau and Szekielda (1968) particularly studied the zooplankton in the Strait of Hormuz of the Arabian Gulf, and theorized that Gulf population may be restricted because deeper living organisms would either not pass over the shallow entrance or else would not survive the high salinities and temperatures. Other significant works on the zooplankton are reported from the Kuwait, Arabian Gulf by Al Yamani et al (1998).

4.1.3 Macro-benthos

Oceans cover about 70% of the surface area of the earth, and sedimentary habitats ranging from gravel to fine mud cover most of the sea-bottom (Snelgrove et al 1997). Soft-sediment habitats are common in coastal areas throughout the world, but only a small fraction of the macro-benthos that reside on or are buried in sediments has been described (Snelgrove 1999). Human activities, directly or indirectly, are now the primary cause of changes to marine biological diversity (biodiversity), especially in coastal areas. The present rate of habitat degradation in marine ecosystems is alarming (Gray 1997 and Snelgrove et al 1997), and conservation of marine biodiversity is of critical importance. Biodiversity covers the range of variation in and variability among systems and organisms at the levels of ecological community, organism, and genetic diversity (Harper & Hawksworth 1994 and Heywood & Watson 1995).

Studies on the macro-benthic communities near the sewer outlets in Dubai Creek provided some information on water quality of the Creek (Ismail 1992) and more recent work has confimed environmental impacts (Saunders et al 2007). Benthic biomass has been studied in the Arabian Gulf region by Sheppard et al (1992). Studies on seagrasses along the coast from Iraq, through Iran and Kuwait to beyond Bahrain and UAE (WCMC, 1991) and animals in the seagrass beds along the Arabian Gulf are well documented (Basson et al 1977, Coles and McCain, 1990).

Other important contributions to benthic studies in the Arabian Gulf are based on salinity and sediment particle effects (Stephens and McCain 1990) and infaunal abundance (Clark & Keij 1973 and Evans et al 1973).

This work describes the current status of the phytoplankton, zooplankton and macro-benthos of Dubai Creek in order to assess ecological conditions and provide a baseline for future studies.

4.2 Results

4.2.1 Chlorophyll *a*

Chlorophyll *a* varied over a wide range of 1.2 -190.0 mg/m^3. The minimum (1.2 mg/m^3) and maximum (190.0 mg/m^3) was recorded at station 1 (bottom) on 7 July 2006 and 27 December 2005 and station 4 (surface) with a mean chlorophyll *a* of 30.70 mg/m^3 (Tables 4.1-4.18-Appendix II) respectively. The seasonal mean values of chlorophyll *a* during winter and summer were 27.75 mg/m^3 and 36.65 mg/m^3 respectively (Table 4.51-52). Mean chlorophyll *a* in the channel and lagoon was 16.1 and 45.53 mg/m^3, respectively (Table 4.53).

Phytoplankton population in terms of cell counts varied in a range of 154.0-192763.4 with an average cell count of 6662.9 x 10^3/L. The minimum and maximum cell counts were observed at station 1 (bottom) and station 6 (surface) on 11 April and 26 May 2005 respectively. The minimum number of species (6) was encountered at station 4 on 27 December 2005 whereas the maximum number of species (23) was recorded from station 1 during July 2006 (Tables 4.19- 4.32-Appendix II). The seasonal mean values of the phytoplankton population during winter and summer were 2374.93 x 10^3/L and 12656.0 x 10^3/L, respectively (Tables 4.51-4.53). Mean values of the phytoplankton population in the channel and lagoon were 2671.5x10^3/L and 10654.28 x10^3/L, respectively (Table 4.53).

Thirty-three species of phytoplankton were observed in Dubai Creek comprising bacillariophycaea (21), cyanophyceae (3), dinophyceae (6) euglenophyceae (2) and chlorophyceae (1).

Chaetocerose sp, *Coscinodiscus* sp, *Guinardia delicatula, Navicula* sp, *Nitzschia closterium, Nitzschia sigma, Nitzschia sp, Rhizosolenia habitata Rhizosolenia* sp, *Thalassionema nitzschioides* were the most common diatoms (bacillariophycea). *Prorocentrum* sp. and *Peridinium* sp. were common species of dinophyceae. *Euglena* sp. and *Tetraselmis* sp. were the major species from the class eugenophyceae and chlorophyceae respectively whereas *Pseudoanabeana* sp. and *Limnothrix* sp. were the most common species cyanophyceae (Tables 4.21-4.32-Appendix II).

4.2.2 Zooplankton

Zooplankton biovolume and population density fluctuated over the range of 0.01-1.41 ml/m^3 (average 0.18 ml/m^3 and 52-37692 no./m^3 (average 2452 no./m^3), respectively. The minimum and maximum biovolume and population were recorded from station 4 (28 April 2005) and station 5 (28 April 2005) and station 5 (26 May 2005) and station 2 (5 May 2005), respectively, (Tables 4.33-4.44-Appendix II). The seasonal mean values of zooplankton biovolume and population during winter and summer were 0.19 ml/m^3 and 1730 no./m^3 and 0.21 ml/m^3 and 4063 no./m^3, respectively (Tables 4.51- 4.52). Mean values of zooplankton biovolume and population in the channel and lagoon were 0.21 ml/m^3 and 2842 no./m^3 and 0.17 ml/m^3 and 2062 no./m^3 , respectively (Table 4.53).

The minimum and maximum number of species (6) was encountered at station 5 on 11 April 2005 whereas the maximum number of species (19) was recorded from station 1 during 27 December 2005. Species diversity were poor in summer. *Acartia tropica* and *Pseudodaiptomus arjuna* were the most common species. Zooplankton species showed good diversity in winter. *Acartia tropica, Bestiola similis, Pseudodaiptomus arjuna,* Pagurids, Ostracods, Fish eggs and Fish larvae were the most common zooplankton species/groups during summer (Tables 4.33-4.44- Appendix II).

4.2.3 Macro-benthos

Macro-benthos biomass and population varied over the range of 0.02-22 gm/m^2 (average 6.38 gm/m^2) and 42-15830 no./m^2 (average 2650 no./m^2), respectively. The minimum and maximum biovolume and population were recorded from station 6 (22 January 2006), and station 2 (27 December 2005) and station 3 (5 January 2006) and station 6 (22 January 2006), respectively (Tables 4.45-4.50-Appendix II). The seasonal mean values of macro-benthos biomass and population during winter and summer were 6.86 gm/m^2 and 3258 no./m^2 and 5.91 gm/m^2 and 2043 no./m^2, respectively (Table 4.53). Mean variations in macro-benthos biomass and population in the channel and lagoon were 13.0 gm/m^2 and 5518 no./m^2 and 0.06 gm/m^2 and 187 no./m^2 ,respectively (Tables 4.51-4.53).

The minimum number of species (1) was encountered at station 6 on 22 January 2006 whereas the maximum number of species (20) was recorded from station 1 on 15 January 2006.

High species diversity in the channel was represented by many species belonging to class Crustacea (*Anthurid* sp., *Grandidierella exilis*, *Diogenes c.f. avarus*,*Ilyoplax frater*,*Apseudes latreille*, *Thalamita poissoni*, *Pilumnus savignyi*, Cumaceans, Ostracods) and Polychaetes (*Nephthys* sp., *Capittalidae* sp., *Serpuliidae* sp., *Nereis* sp., *Nereis c.f. falcaria, Nereis lamellose*, *Glyceridae* sp., *Spionidae* sp., *Chaetopteridae* sp., *Ammotrypans* sp., *Syllis* sp., *Gonadia* sp., *Eunice antennata, Eunice* sp., *Loimia medusa, Lumbriconereis* sp.) (Tables 4.45-4.50).

Capitallidae was dominant in the lagoon with a small number of other species (*Grandidierella exilis, Neries lamellose* and spoinidae were the major species)

4.3 Correlation matrix and Scatter plots

4.3.1 Scatter plots for the summer season

Scatter plots of biological variables during the summer season shows negative correlation with most of the water quality variable (Figures 4.1-4.3).

Phytoplankton species and macro-benthos population were negatively correlated with water temperature at $r = -0.97$, $p>0.05$ and $r = -0.82$, $p>0.05$, respectively. DO negatively correlated with phytoplankton species ($r= -0.82$, $p>0.05$) and zooplankton population ($r= -0.82$, $p>0.05$). Other negative correlations were observed between phytoplankton species with pH ($r= -0.80$, $p>0.05$), DO ($r = -0.82$, $p>0.05$), and NO_3-N ($r = -0.83$, $p>0.05$). The only positive correlation was found between salinity Vs zooplankton population ($r= 0.82$, $p>0.05$).

3.3.2 Scatter plots for the winter season

The winter scatter plots showed negative correlation of phytoplankton species with pH ($r= -0.86$, $p>0.05$), phytoplankton species with DO ($r= -0.77$, $p>0.05$), salinity with chlorophyll *a* ($r= -0.95$, $p>0.05$). Chlorophyll *a* showed positive correlation with NO_3-N($r= 0.85$, $p>0.05$) (Figure 4.3).

Table 4.51: Averages of biological characteristics variables along Dubai Creek during winter.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton Biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	5.76	500.42	19	0.29	17	2301.50			
	Bottom	4.46	349.83	13				8.50	16	3143.00
2	Surface	15.73	1514.87	12	0.23	13	1895.50			
	Bottom	8.57	508.06	10				18.50	9	5776.75
3	Surface	36.75	3529.67	11	0.15	10	1834.75			
	Bottom	11.59	732.64	10				14.00	12	10121.75
4	Surface	68.64	3944.02	10	0.16	8	1467.75			
	Bottom	12.45	676.40	9				0.09	2	197.50
5	Surface	61.62	4940.91	10	0.16	8	1778.25			
	Bottom	12.25	728.61	9				0.05	2	217.50
6	Surface	81.38	6496.48	11	0.13	8	1105.00			
	Bottom	13.80	1045.30	10				0.02	1	90.00

Table 4.52: Averages of biological characteristics variables along Dubai Creek during summer.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton Biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	7.09	387.77	18	0.09	10	690.88			
	Bottom	4.61	297.18	17				5.03	12	1286.50
2	Surface	20.32	4970.29	15	0.29	10	11004.80			
	Bottom	15.38	4370.30	13				15.04	12	4147.50
3	Surface	42.13	9873.88	14	0.20	9	2503.94			
	Bottom	30.96	5678.41	13				15.13	11	6148.50
4	Surface	48.70	13632.05	13	0.40	9	4760.06			
	Bottom	33.68	7268.88	12				0.08	4	131.50
5	Surface	67.83	32907.58	12	0.08	8	3597.69			
	Bottom	30.29	6722.20	13				0.08	4	330.50
6	Surface	113.74	48562.75	12	0.17	9	1819.70			
	Bottom	25.03	17208.47	13				0.08	5	212.00

- Data on zooplankton from bottom and macro-benthos from bottom were not required to collect * data could not be collected

Table 4.53: Zonal, seasonal, and annual averages of biological variables along Dubai Creek during 2005-2006.

Zonal, Seasonal and Annual averages	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton Biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
Average Winter	27.75	2374.93	11	0.19	11	1730	6.86	7.00	3257.75
Average Summer	36.65	12656.65	14	0.21	9	4063	5.91	7.75	2042.75
Ebb Summer	20.08	4262.97	15	0.19	10	4733	-	-	-
Flood summer	53.21	21050.32	12	0.22	9	3392	-	-	-
Ebb Winter	21.64	1824.80	12	0.21	12	1875	-	-	-
Flood Winter	37.31	2883.62	10	0.15	9	1546	-	-	-
Channel Average	16.1	2671.5	14	0.20	12	2841.7	13.0	11.9	5518.4
Lagoon Average	45.53	10654.28	11	0.17	8	2062.08	0.06	2.61	187.11
Overall average	30.7	6662.9	12.3	0.2	10.1	2451.9	6.5	7.3	2852.8

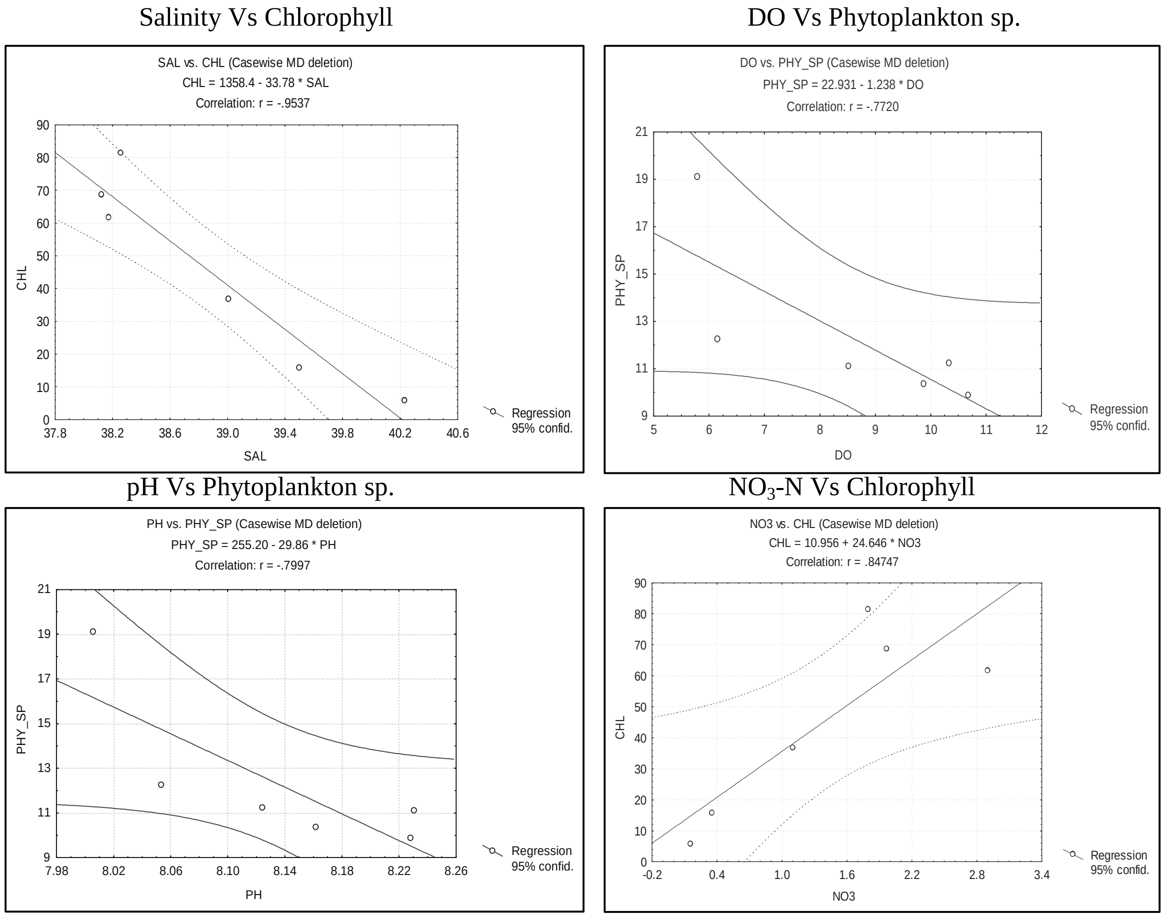
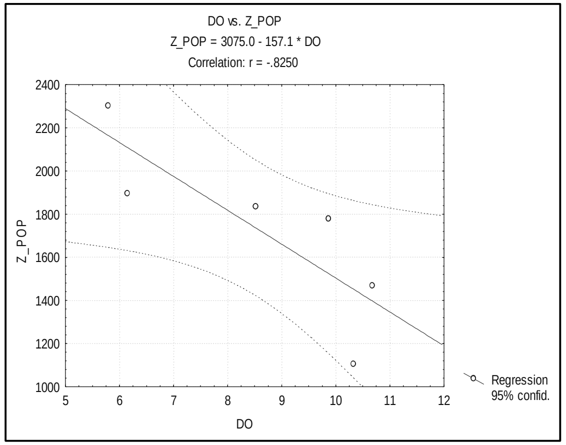
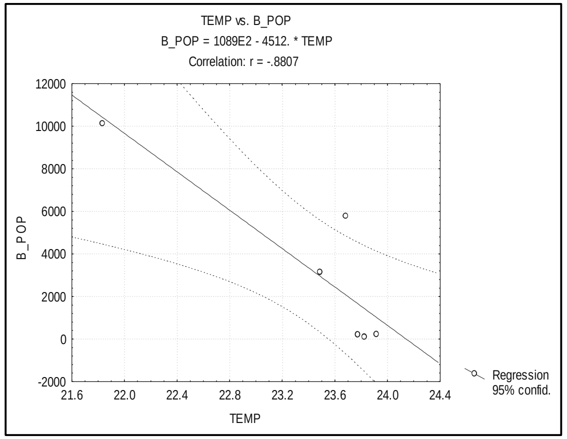


Figure 4.1: Scatter plots showing significant negative and positive correlation between selected variables ($p>0.05$) during winter

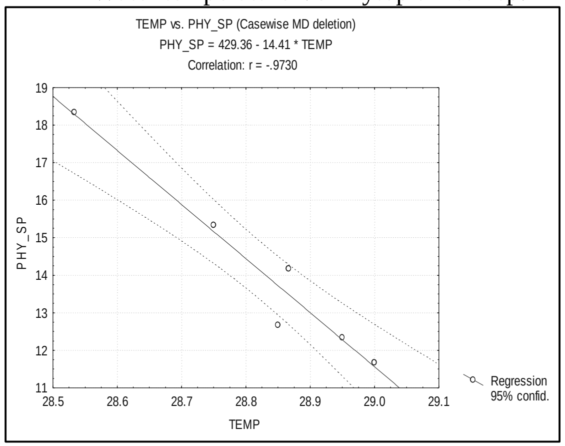
DO Vs Zooplankton population



Water temperature Vs Macro-benthos population



Water temperature Vs Phytoplankton sp.



Salinity Vs Zooplankton population

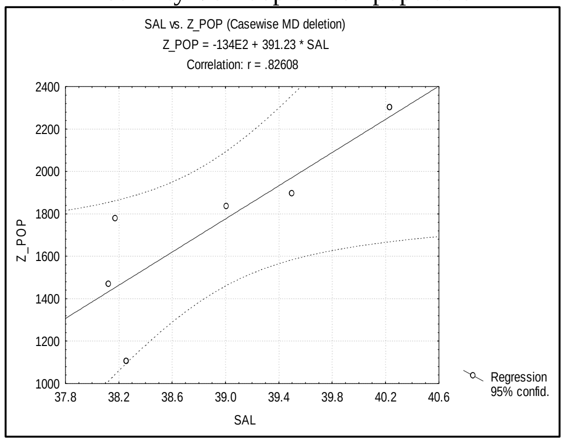
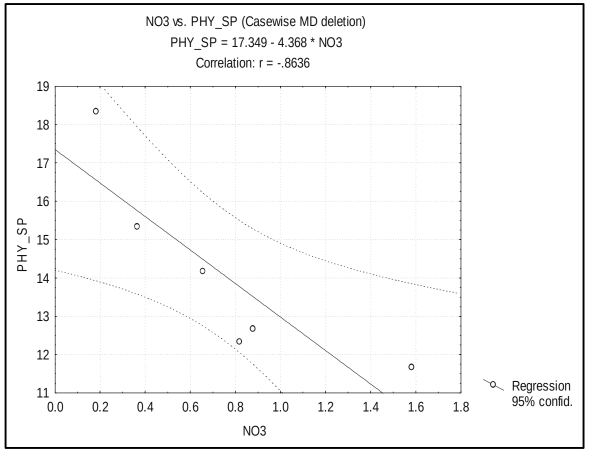
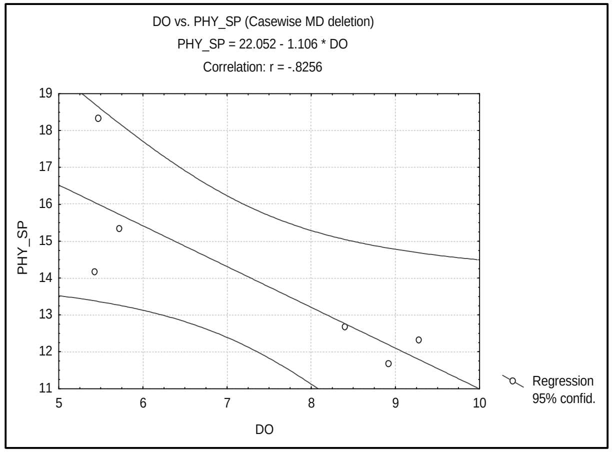


Figure 4.2: Scatter plots showing significant negative and positive correlations between selected variables ($p>0.05$) during summer

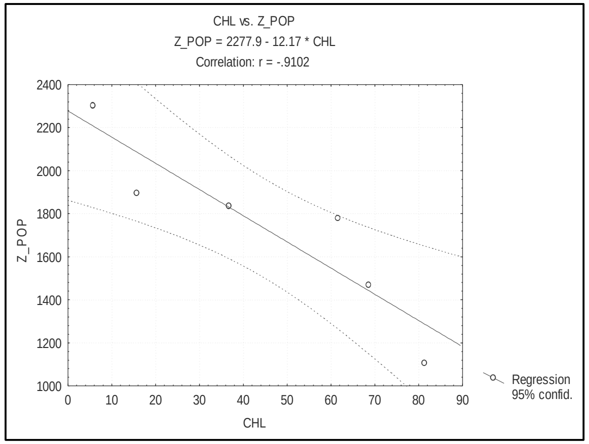
NO_3-N Vs Phytoplankton sp.



DO Vs Phytoplankton sp.



Chlorophyll Vs Zooplankton population



pH Vs Phytoplankton sp.

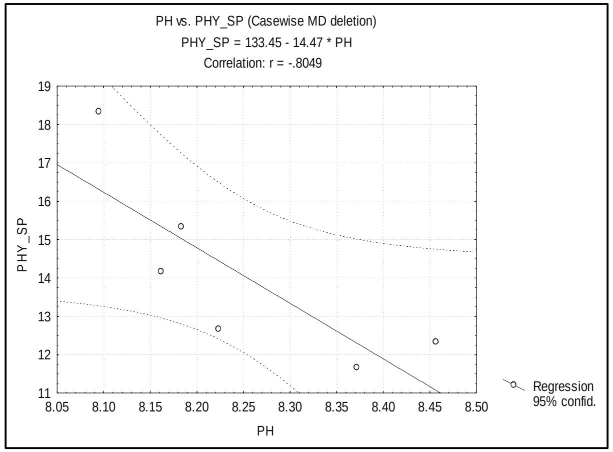


Figure 4.3: Scatter plots showing significant negative correlations between selected variables ($p>0.05$) during summer

4.4 Discussion

4.4.1 Phytoplankton

Ecological features in Dubai Creek are influenced by marine organisms of the Arabian Gulf that is characterized by its shallow depth, extreme air temperature, high evaporation rates, and restricted circulation. These combined factors create harsh environmental conditions, with salinity extremes exceeding most other areas of the world (Hunter 1982) due to evaporation during 2 prominent seasons the summer and winter; the evaporation is extensive in both the seasons, particularly in the very shallow southern embayment, along the UAE coast. Water enters into the Gulf through the Strait of Hormuz at a salinity of 36.5-37.0‰ (Sheppard et al 1992), which reaches 42‰ in Bahrain (MNR 2000), and as high as 70‰ in the Gulf of Salwah at its extreme southern extremity (Basson et al 1977).

Phytoplankton assessment can be used as a tool for assessing the quality of aquatic ecosystems since some genera and species of algae are indicative of organic pollution (Palmer 1969). Variability in phytoplankton cell counts from 6 monitoring stations within Dubai Creek during summer and winter follows the same trends as revealed in the nutrients with 2 distinct regions found in the aquatic ecosystem of Dubai Creek, the channel and the lagoon. Phytoplankton population and species are higher in the channel compared to the lagoon.

Very high variability was found in the phytoplankton pigments in terms of chlorophyll *a* (1.2-280 mg/m^3) and phytoplankton abundance in terms of cell counts (154.02-192763.4 x $10^3/L$) showing respective differential ratios of 1~233 and 1~1252. This extensive disparity in lower and higher phytoplankton pigment (chlorophyll *a*) and abundance (phytoplankton population) is mainly due to excessive inputs of nutrients from STP outfalls and hydrodynamic conditions in Dubai Creek (Mustafa et al 2001, Deshgooni 2002, Al Zahed 2005 and Saunders et al 2007).

Chlorophyll *a* concentration in water can be used to determine phytoplankton-standing stock, an important indicator of primary productivity. The measurement of chlorophyll *a* concentration is an alternative approach to cell counts taking account of the fact that the phytoplankton are the primary producers and the estimation of the concentration of photosynthetic pigment in the algae is a common measure of their abundance.

The average level of chlorophyll *a* (30.7 mg/m^3) in Dubai Creek is 36 to 154 fold higher than the average level (0.2 to 0.86 mg/m^3) of the Arabian Gulf environment (Sheppard et al 1993).

Two distinct regions- the channel and the lagoon in Dubai Creek, are defined by their own characteristic due to flushing conditions (Halcrow 1992) and eutrophication (Mustafa et al 2001 and Saunders et al). The channel of Dubai Creek denotes high diversity and moderate assemblage of phytoplankton whereas the lagoon shows poor diversity and high phytoplankton assemblage (Figures 4.4 and 4.5) during winter and summer seasons. This confirms the greater impact of anthropogenic effects in the lagoon.

The seasonal variability indicates clear effects of temperature on primary productivity during winter and summer along the channel and lagoon respectively. The lagoon and channel sustain a 4 times higher phytoplankton count during summer compared to winter (Figure 4.5). High primary productivity in Dubai Creek during summer is attributed to high sunlight associated photosynthesis. Such a phenomenon is common in the Arabian Gulf that shows seasonal changes in the phytoplankton community and their population abundance during summer (Abdul-Aziz 1998) associated with phytoplankton blooms (Abdul-Aziz 2000).

The atomic ratio of nutrients, nitrogen and phosphorous (N: P), is an indicator which can define the conditions of the aquatic system. Average N: P ratio in Dubai Creek was calculated as 1.5:1, which is much lower than global oceanic waters (16:1) (Redfield 1934) and regions closer to Dubai such as Ras Al-Khaima (9.8:1), Abu Dhabi (9.5:1) and Umm Al-Quwain

(8.9:1) (Shriadha & Al-Ghais 1999). With a ratio of greater than 16:1 in an estuarine or coastal area, the system will likely experience an algal bloom, the severity of which will be in relation to the excess phosphorus available (Schindler 1978 and Jaworski 1981), whereas when N: P ratios are below 10:1, nitrogen is the limiting nutrient and the estuarine or coastal system will only experience an algal bloom if excessive nitrogen becomes available (Jaworski 1981) or cells capable of nitrogen fixation (some cyanobacteria) are present. The present assessment based on a low N:P ratio indicates that nitrogen is a limiting nutrient for the high primary productivity and algal bloom formation in Dubai Creek. This explains why *Pseudoanabeana* (cyanobacteria) was one of the bloom forming species in the channel during summer. *Euglena* and *Tetraselmis* were the dominant algae in the lagoon of Dubai Creek causing a greenish colored bloom during the summer whereas *Prorocentrum* was the genera causing a reddish bloom in the lagoon of Dubai Creek. *Pseudoanabeana, Euglena, Tetraselmis, Prorocentrum* are genera which are indicators of high organic pollution in fresh water systems (Hosmani & Bharati 1980). *Euglena* alone indicates as a pollution indicator species found near the sewage outfall (Stonik & Selina 2001) whereas *Pseudanabeana* indicates eutrophication (Toming 2006).

Eutrophication of coastal marine environments is a widespread and transboundary problem necessitating consideration of measures to conserve and restore the marine environments that have been adversely affected (Gurel et al 2005). Blooms of pollution species cause discoloration and unaesthetic water quality. A negative correlation between phytoplankton species diversity and pH, DO and NO_3-N during summer is indicative that these species are influenced by the physico-chemical characteristics of water quality in Dubai Creek. Biological communities integrate the environmental effects of water chemistry (Gafri & Gunale 2005) and phytoplankton could be used in the monitoring as an indicator to detect water-quality changes (Willen 2001).

4.4.2 Zooplankton

Zooplankton biovolume (0.01-1.41 average 0.18 ml/m^3) shows high variation in Dubai Creek; however the average density indicates that the productivity at secondary pelagic level is comparable with the other region (140-407 mg/m^3) in the Arabian Gulf (Michel et al 1986a, 1986b). Zooplankton biovolume varies in Dubai Creek in accordance with the season; summer season represents high biovolume and population compared to winter, and similar variations are reported in other areas (4.8 and 288 mg/m^3 -inner part of Kuwait bay and southern area of the Kuwaiti Territorial waters) of the Arabian Gulf (MNR 1999).

The variability in zooplankton numbers and biovolume between the channel (average biovolume 0.31 ml/ m^3 and density 4377 no./ m^3) and the lagoon (average biovolume 0.25 ml/m^3 and density 3146 no./ m^3) were significant. The channel of Dubai Creek sustains high biovolume and density during both the seasons. High biovolume and density during winter and summer mainly reflected the copepods *Acartia tropica*, *Pseudodiaptomus ardjuna* and *Bestiola similes*. Undoubtedly these species indicate the availability of food for grazing during both seasons (Tables 4.35-4.46 and Figure 4.6-4.7). A negative correlation between zooplankton density and chlorophyll *a* indicates the effect of grazing by the phytoplankton.

Zooplankton biovolume, density and diversity clearly defined the variability in the channel and lagoon. The low diversity (12) of zooplankton in the lagoon compared to the channel (18) indicates stress in the lagoon of Dubai Creek.

4.4.3 Macro-benthos

Ecological health in the coastal region is an issue of coastal zone protection and management, specifically when 40% of intertidal areas in the Arabian Gulf has been lost due to urban and industrial development (Khan et al 2002). The present rate of habitat degradation in marine ecosystems is alarming (Gray 1997 and Snelgrove et al. 1997) and conservation of marine biodiversity is of critical importance. One of the important measures to define the coastal zone is benthic macro-fauna that provide an integrative measure of the system health (Pearson & Rosenberg 1978).

The present assessment from Dubai Creek indicated drastic variations in the biomass, density and diversity of the macro-benthic community. The macro-benthic assessment indicated the severity of the stressed environment. The channel of Dubai Creek sustains a healthy biomass (19.5 gm/m^2), density (8278 no./m^2) and diversity (18) whereas the lagoon of the Creek region indicates stress given the comparative values of biomass(0.09 gm/m^2), density (280 no./m^2) and diversity (4). Current assessment indicates that there is a high level of organic pollution within the lagoon and that eutrophication is already a significant problem in the area (Mustafa et al 2001, Saunders et al 2007) (Tables 4.47-4.50 and Figure 4.8-4.9). Although organic pollution has been found previously in the Creek (Abu-Hilal et al 1994, Hassan et al 1995 and El-Sammak 2001) with related changes in the benthic macro-fauna community (Ismail 1992) the present assessment clearly defined zones of high and low pollution impact on the macro-benthic infauna.

Organic pollution of the lagoon was the major problem near the sewerage outfall in the Dubai (Ismail 1992) with a change in community associated with organic pollution (Pearson & Rosenberg 1978) compared to samples taken away from the outlets. However, the present assessment indicates the almost complete disappearance of the macro-benthic community especially during the summer. Dubai Creek has become susceptible to seasonal algal blooms and high stratification of DO in the lagoon (Dubai Municipality 2000 and Mustafa et al 2001) Macro-benthic studies are highly significant in the aquatic environment where stratification develops for several days during summer (Wetzel 1983 and Rabalais et al 1994). Under such conditions, bottom-water hypoxia (DO <2 mg/L) commonly develops (Ryther & Dunstan, 1971 and Officer et al 1984) and sulphate-reducing bacteria cause accumulation of sulphide, toxic to many aerobic organisms (Nilsson & Rosenberg, 1994, Gray et al 2002 and Karlson et al 2002). If hypoxic and sulphidic conditions persist for longer than 7 days, extensive mortality of sessile benthic invertebrates occurs (Josefson & Widbom 1988, Pihl et al 1991, Diaz & Rosenberg 1995 and Rabalais et al 2001).

Generally, organic pollution increases from the mouth of the Creek into the lagoon, with the opposite pattern for DO, which has led to an increase of algae in the upper Creek. A combination of all these conditions in the upper Creek leaves it heavily vulnerable to eutrophication. Hassan et al (1995) found higher levels of organic pollution in a sample from the lagoon compared to the lower Creek while El-Sammak (2001) divided the Creek into high and low pollution zones based on organic content of the sediment, including the area around station 3 within the heavily polluted upper Creek.

The lagoon area benthos was strongly represented by Capitellidae sp. including *Capitella capitata*, again indicating a community influenced by organic pollution.

The most prevalent use of the term 'biodiversity' is as a synonym for the 'variety of life' (Gaston 1996). Biodiversity covers the range of variation in and variability among systems and organisms at the levels of ecological or community, organismal, and genetic diversity (Harper & Hawksworth 1994 and Heywood & Watson 1995). Many benthic species have pelagic larvae that remain in the water for days or months, and marine systems are more 'open' and barriers to dispersal are relatively weak. Macro-faunal communities are comparatively slow to respond to changing water conditions and are therefore a good indication of the state of a system over a prolonged time period (Bilyard 1987). The results of this baseline macro-fauna survey therefore display signs that sections of Dubai Creek, especially in the lagoon, are already heavily affected by organic pollution. Given the rapidly increasing population of Dubai and the expected growth around the Creek, especially the proposed development around the lagoon, the results from our study highlight the need for a more comprehensive survey over a prolonged period. A requirement of such work should include studying the pollution tolerance and behavior of many species within this area as this is largely unknown, a situation that currently hinders a more detailed assessment of the effects of pollution on the macro-fauna community.

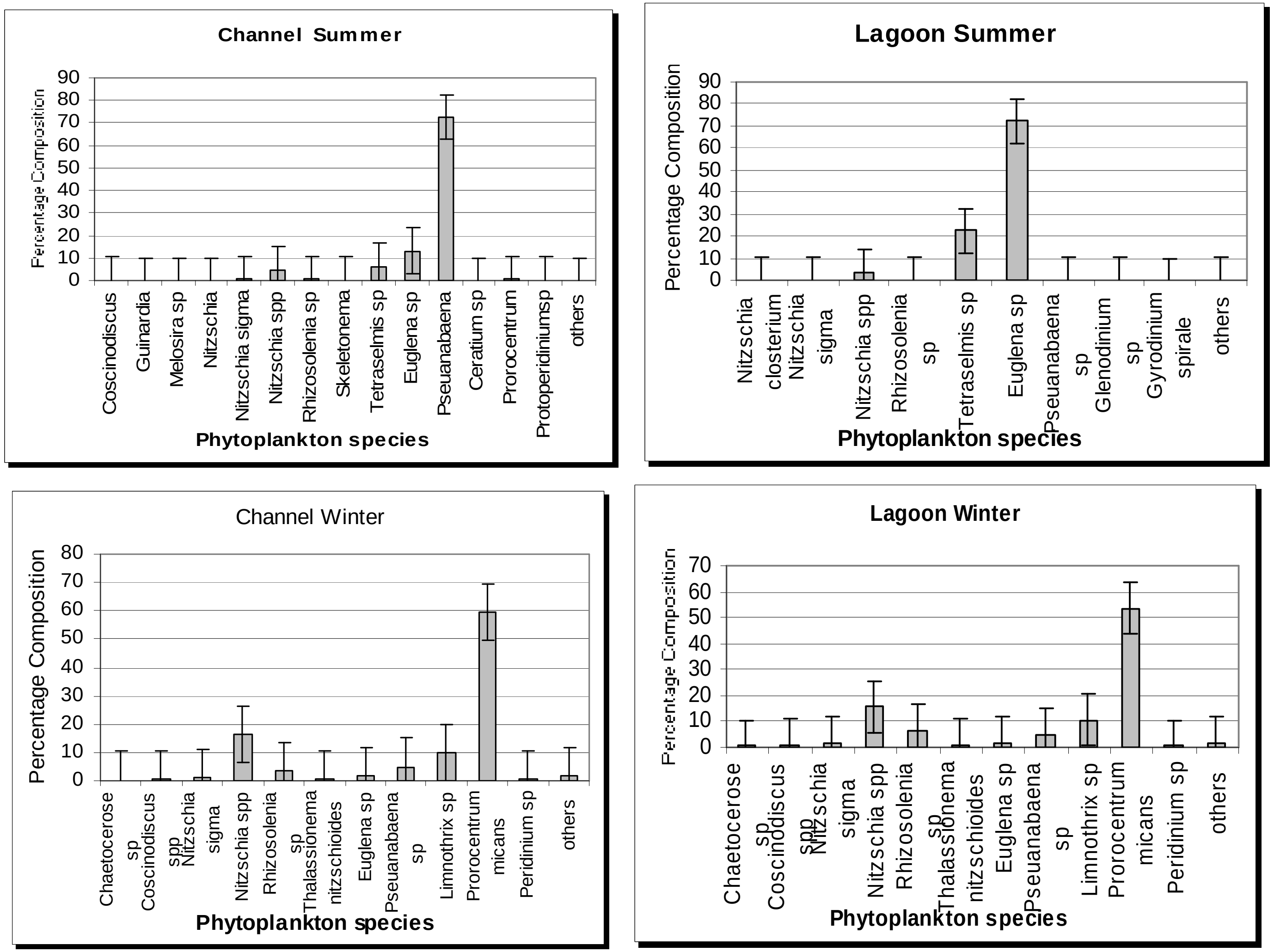


Figure 4.4: Percentage species composition of phytoplankton assemblages along Dubai Creek during winter and summer of 2005-2006

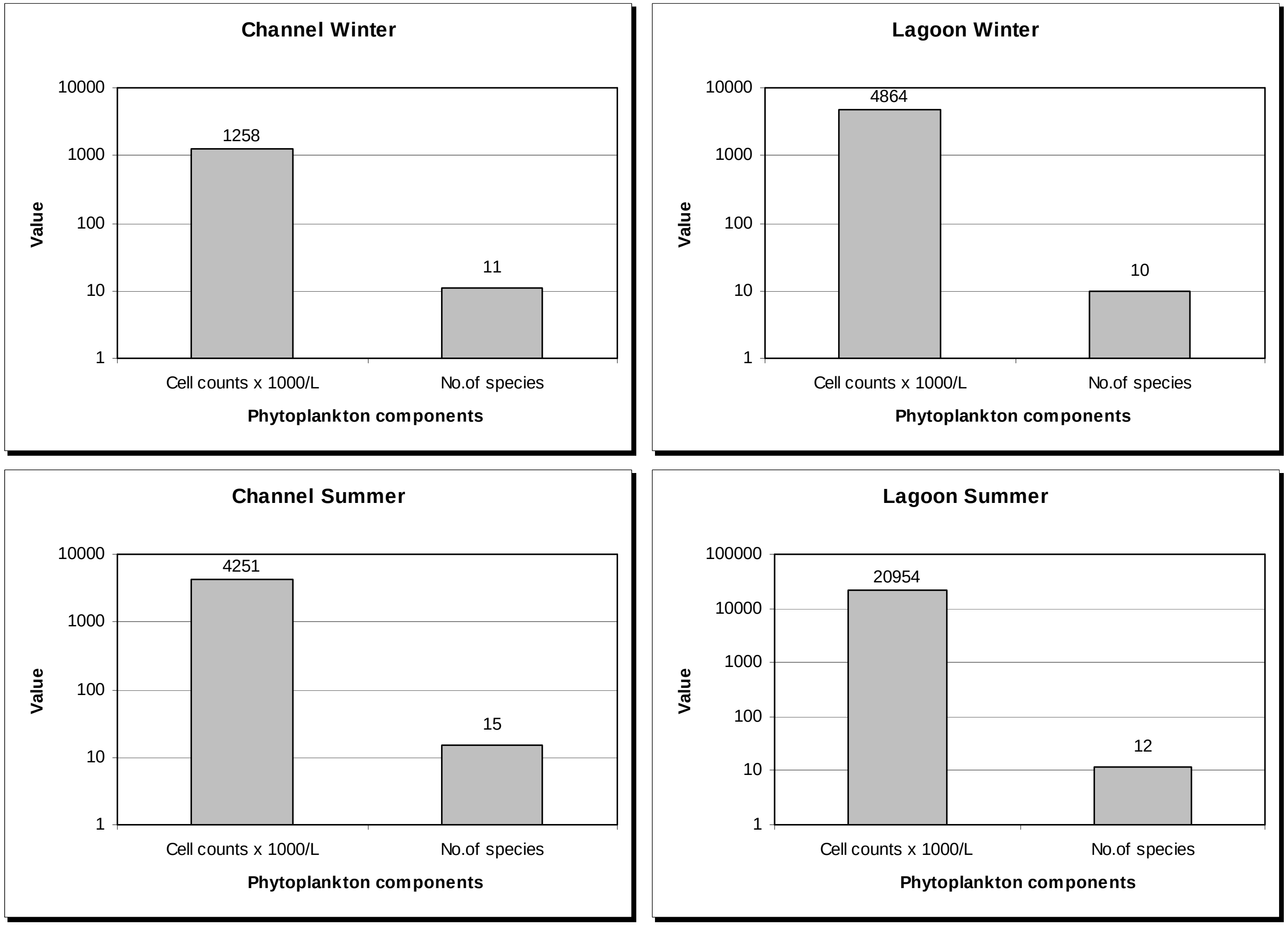


Figure4.5: Composition of phytoplankton density (no.x10^3/m^3) and diversity along Dubai Creek during winter and summer of 2005-2006

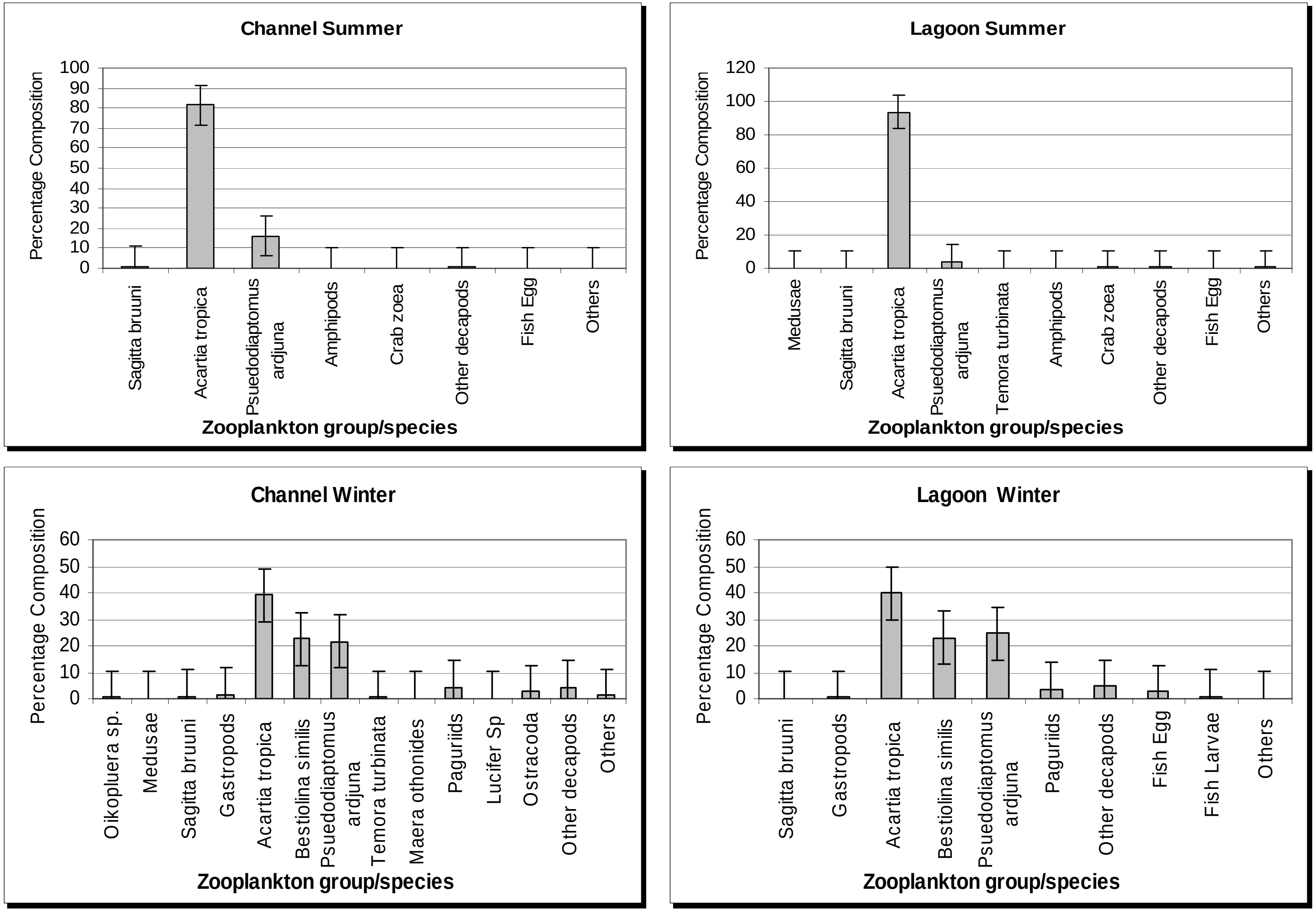


Figure 4.6 : Percentage species composition of zooplankton assemblages along Dubai Creek during winter and summer of 2005-2006

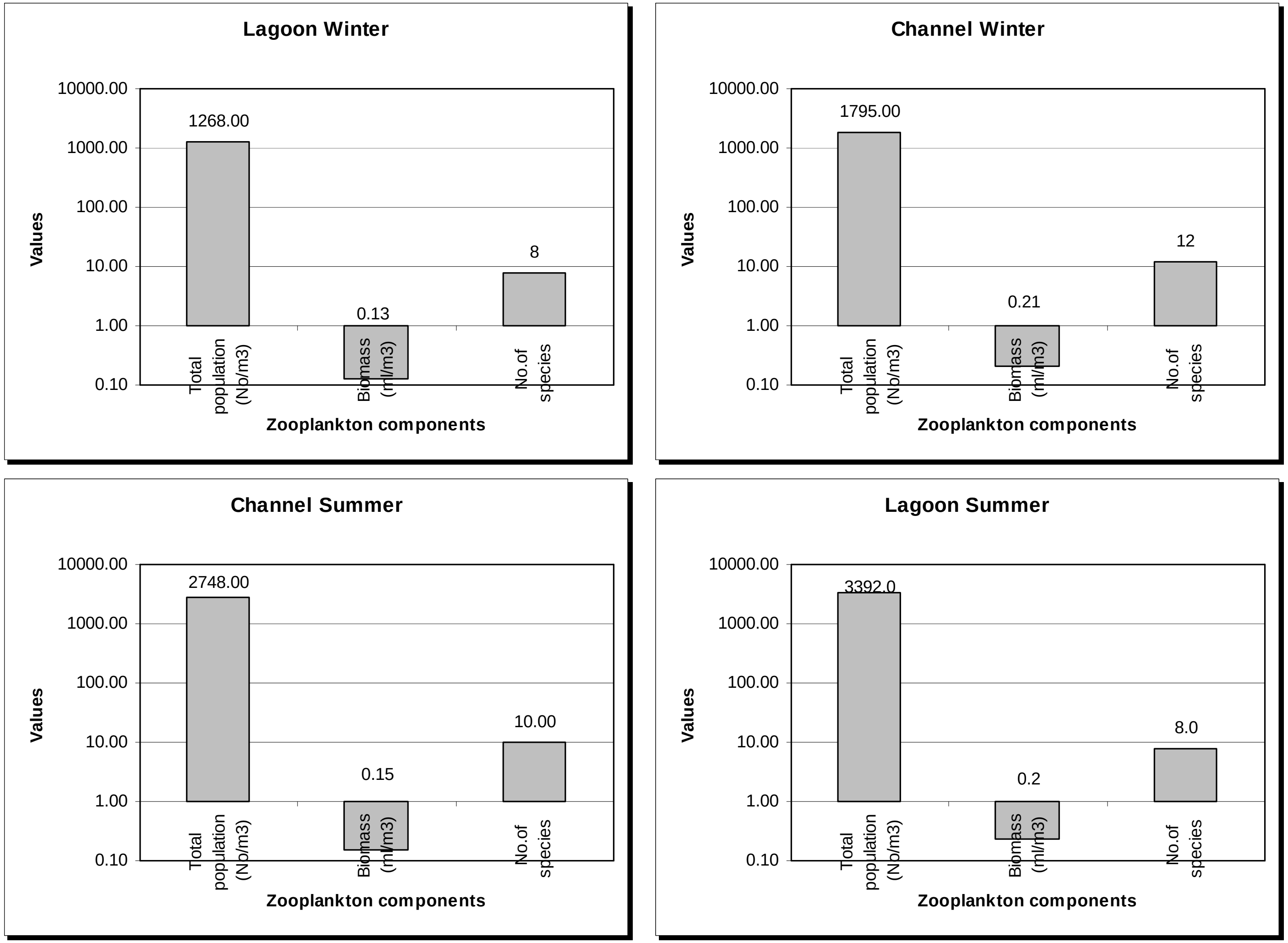


Figure 4.7: Composition of zooplankton biovolume (ml/m^3) density (no/m^3) and species diversity (no.) along Dubai Creek during winter and summer of 2005-2006

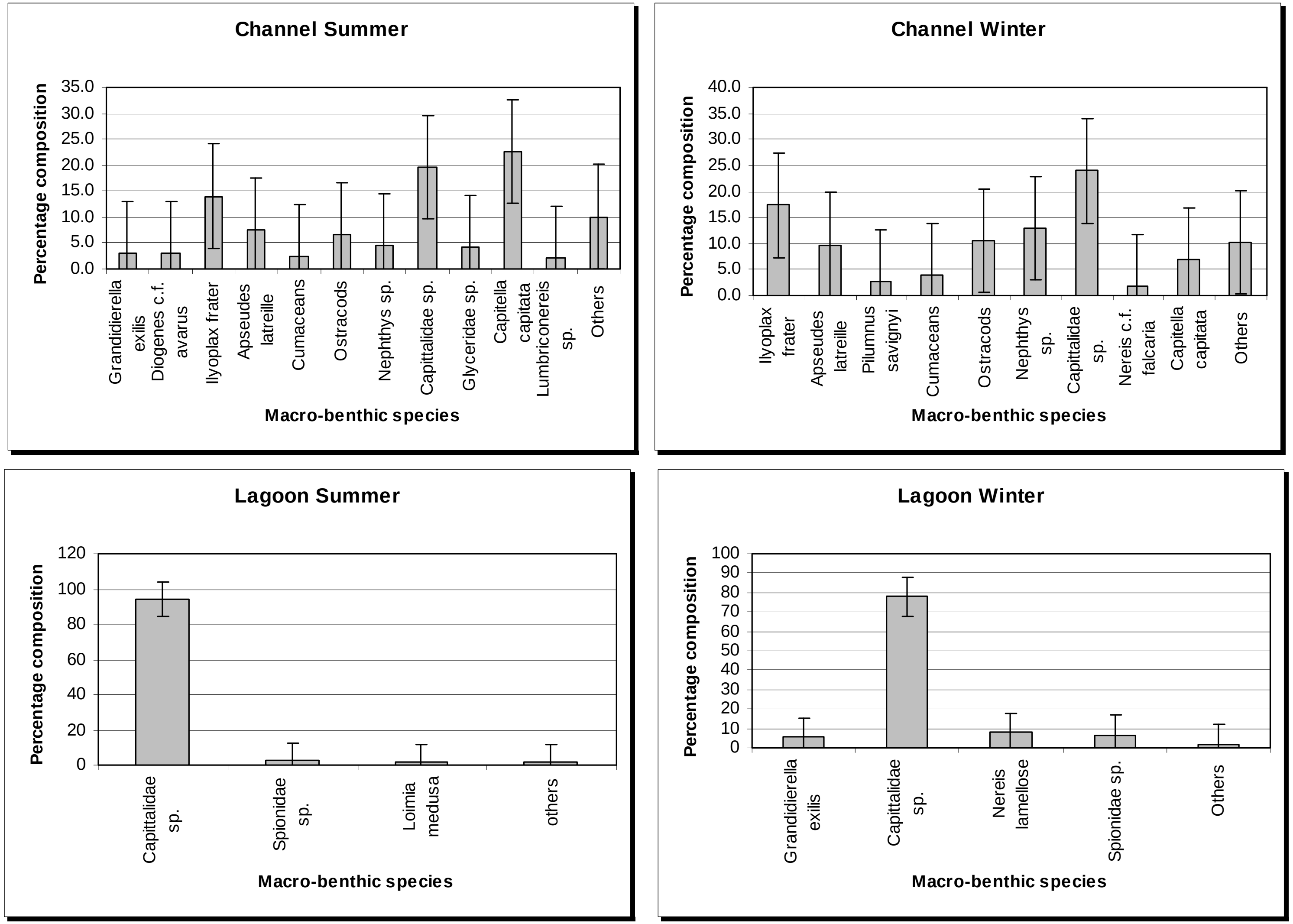


Figure4.8: Percentage species composition of macro-benthic assemblages along Dubai Creek during winter and summer of 2005-2006

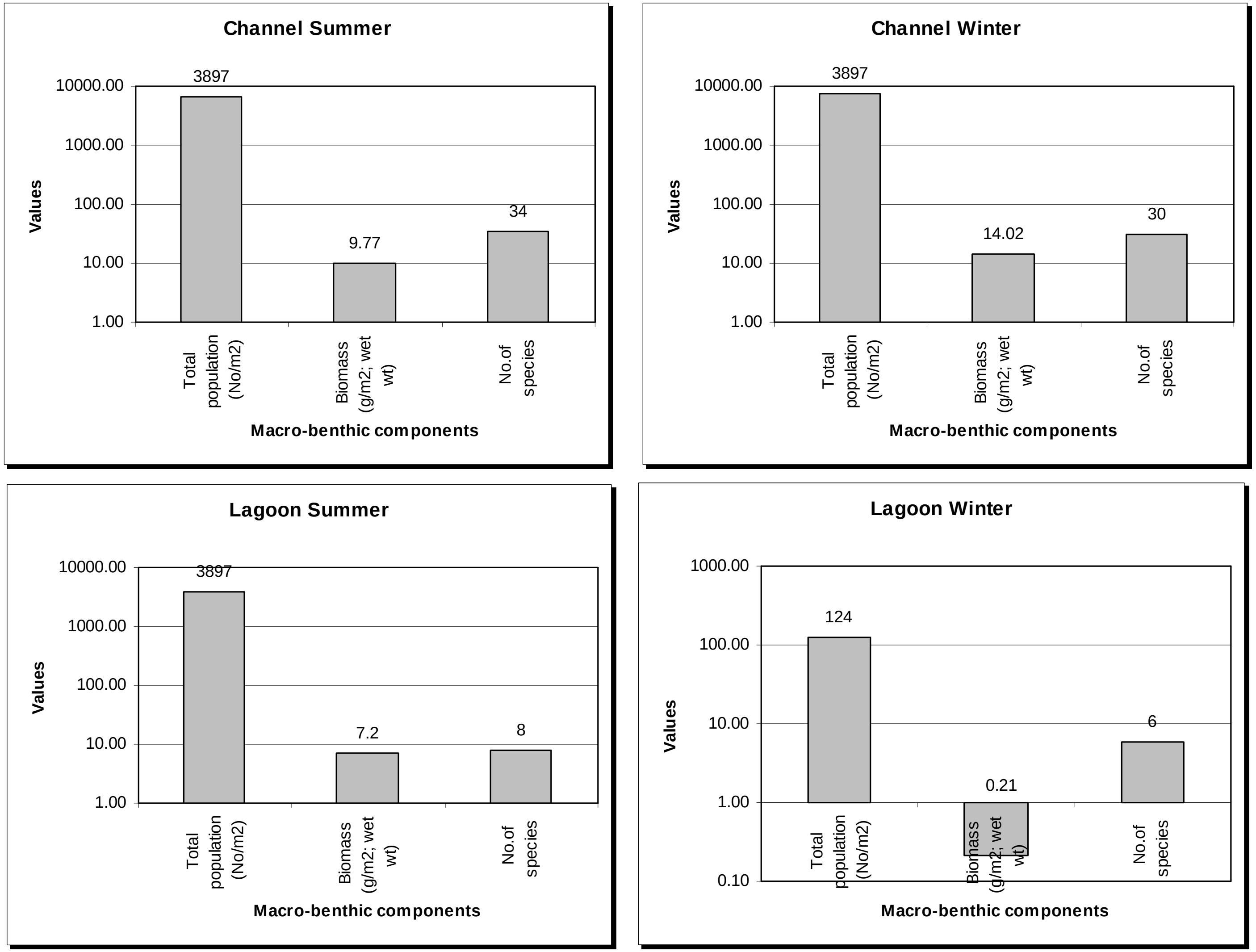


Figure 4.9: Composition of macro-benthic biomass (gm/m^2) density (no/m^2) and diversity along Dubai Creek during winter and summer of 2005-2006

4.5 Conclusion

The ecological characterization of Dubai Creek was defined by:

- Two distinct zones in Dubai Creek, the channel and lagoon
- The channel of Dubai Creek was moderately stressed whereas the lagoon of Dubai Creek indicates that it is a zone of significant organic pollution
- The lagoon of Dubai Creek shows a zone of high productivity in the surface water associated with bloom forming species of phytoplankton associated with an organic pollution load.
- Species occur that can change the coloration of the water, produce an unaesthetic view of the environment and odour throughout the year
- The lagoon of Dubai Creek contains a dead zone for benthic productivity and diversity due to the extreme load of organic pollution
- Although, Dubai Creek lagoon nutrient load is enough to produce algal blooms, daily inputs of secondary effluent from the STP worsen these conditions.

CHAPTER V

Hydrodynamics and Water Quality Modeling

5.1 Introduction

Coastal zones are very attractive regions for human settlement, but anthropogenic activities may have significant environmental impacts on these sensitive natural systems. The usual approach to water management is dictated by a combination of public safety issues, economics and other environmental considerations. Hydroinformatics is a new scientific branch linking informatics tools with natural hydraulics and environmental concepts and models, providing both operational information and insights into long-term trends (Abbott 1996). The rapidly growing computational resources, as well as the user friendly processing of spatial information and graphical presentation, has the potential to provide novel and improved tools to support the planning and management of coastal zones. The mathematical model is a tool that can be designed to predict the water quality results based on the simulation of circulation patterns and biogeochemical processes, and which can enhance decision-support for water resources management (Pinho *et al* 2004).

In order to prepare a tool for the specific water quality management of Dubai Creek, a pre-calibrated model developed in the HydroQual framework (www.hydroqual.com) was used to conduct the hydrodynamics and water quality modeling (Dubai Municipality 2003). This model is available free of cost on web. A simplified schematic view of the kinetics of this model is provided in Figure 5.1 whereas the model description from the manual is given the Annex at the end of this chapter. More information of the model can obtained from the following link http://www.hydroqual.com/Temp/RCA_Release_3.0_13Oct04.pdf

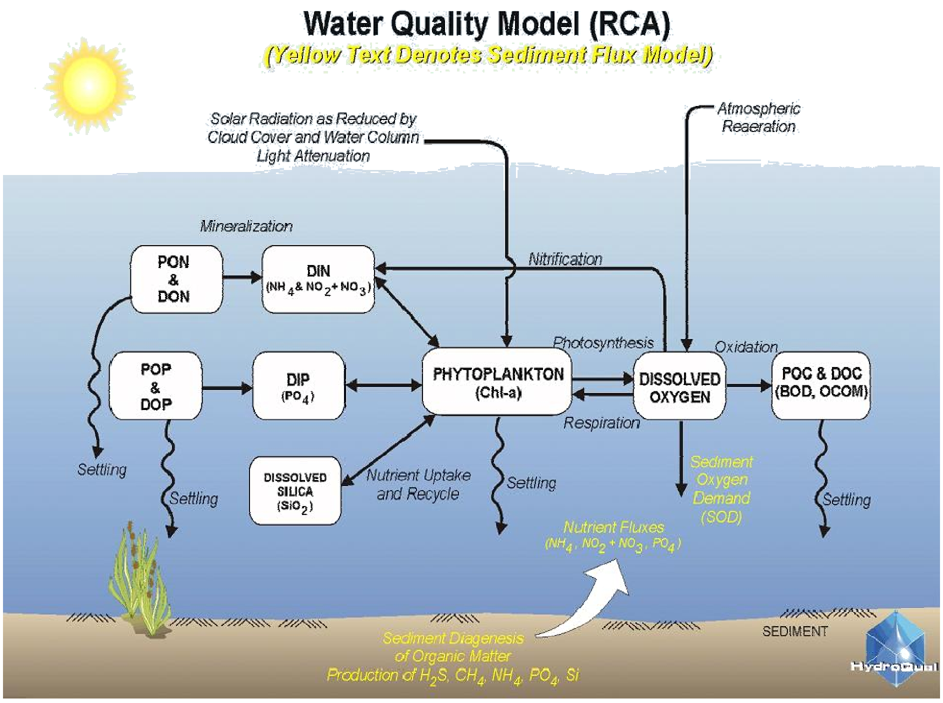


Figure 5.1: Schematic of HydroQual's water quality model RCA (Source: www.hydroqual.com)

5.2 Modeling Objectives

The purpose of the modeling was to:-

- improve understanding of hydrodynamics and water quality processes in Dubai Creek
- test the efficacy of 3 management scenarios to reduce the degradation of water quality in Dubai Creek.

5.3Materials and Methods

5.3.1 Grid design for the modeling

A computational numerical grid was developed for the study area including the entire reach of Dubai Creek and the offshore areas (Figures 5.2 and 5.3.). The grid is an orthogonal curvilinear grid comprised of 21 x 74 horizontal segments with 11 equally spaced vertical (sigma) levels. The grid extends to the upstream reach of tide and salinity effects in Dubai Creek and extends out to the Arabian Gulf. The transformed sigma coordinate system in the vertical plane allows the model to have equal numbers of vertical computational segment in all grids. Horizontal grid sizes vary from 70 m in the vicinity of the STP outfall to 1500 m in the Arabian Gulf. Inside Dubai Creek, the grid has a much higher resolution than out in the Gulf in order to better resolve the physics in the region of the sewage treatment plant outfall. The depth of each grid is configured with high resolution 11 layers (1 m each) gridded bathymetric data. This grid is taken from the earlier used 3 dimension modeling of HydroQual in Dubai Creek (Dubai Municipality 2003). The same grid was used to run the management scenario in the present work.

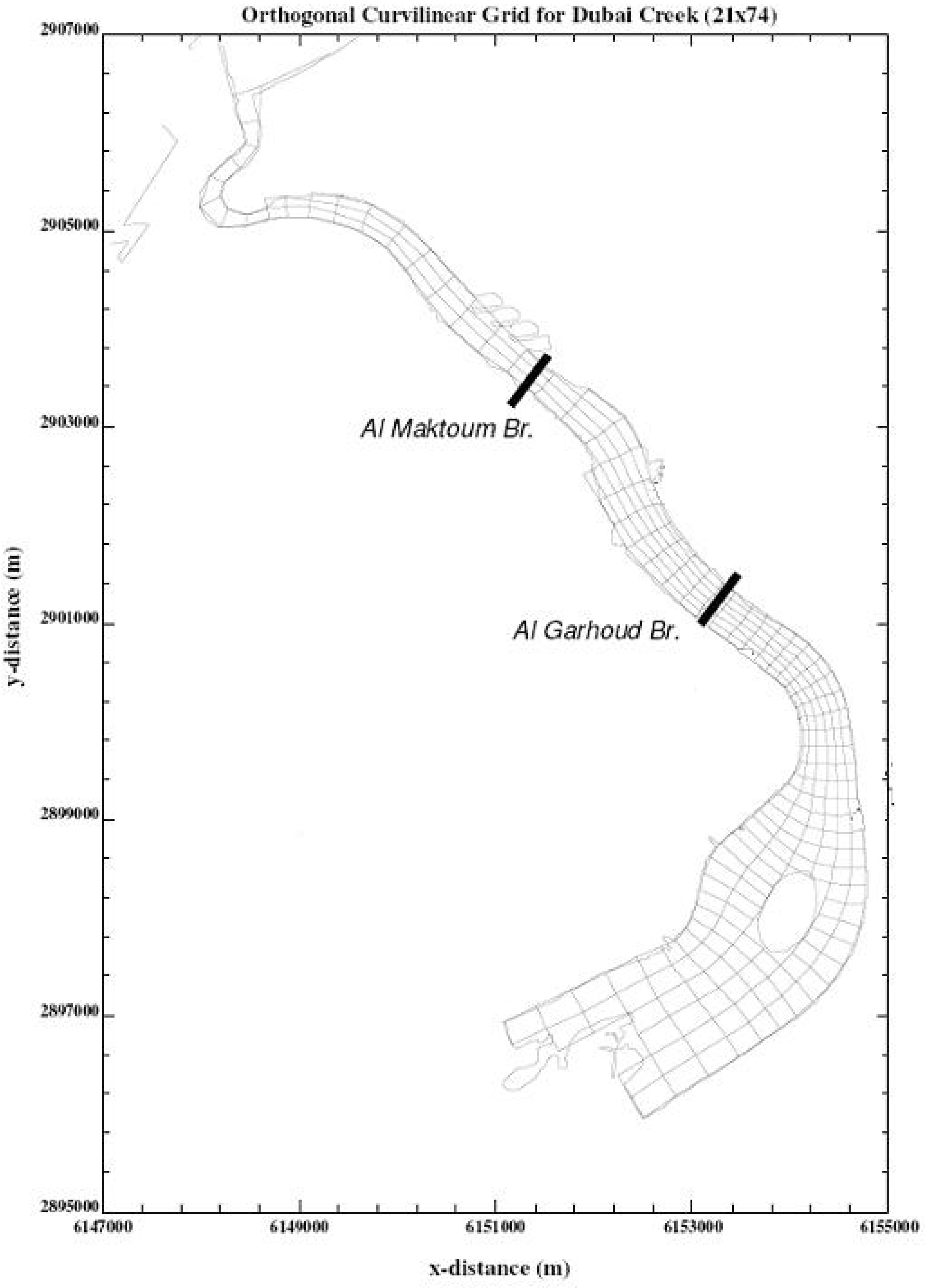


Figure 5.2: Dubai Creek modeling grid at different locations

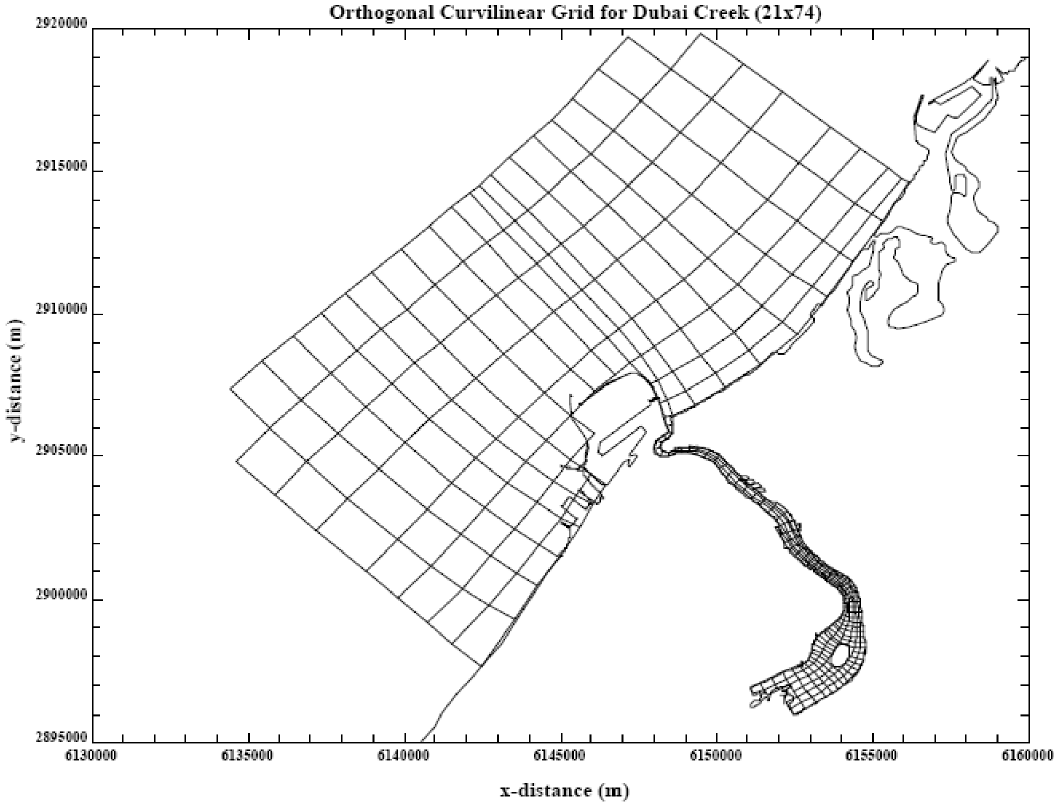


Figure 5.3: General view of Dubai Creek modeling grid extending into the Arabian Gulf

5.3.2 Model Calibration

Model calibration was taken from the earlier study of the same model (Dubai Municipality 2003) in Dubai Creek. However, because the model was at the basis of the management scenarios developed in this work, a brief description of the calibration process and calibration results are given in following subsections 5.3.2.1 and 5.3.2.2.

5.3.2.1 Hydrodynamic Model

The calibration of the hydrodynamic model was based on various sensitivity tests and model parameters aimed at producing reasonable model predictions. Throughout the simulation, a time step of 50 seconds was used. The minimum bottom friction coefficient (C_D) was set as 0.0030 with a bottom roughness scale of 1 mm. The horizontal eddy diffusion coefficient based on a Smagorinsky (1963) formulation, C_S, was chosen as 0.01. The Cs is a dimension coefficient which relates the horizontal eddy coefficients to the horizontal deformation of the flow field as suggested by Smagorinky (1963). Typical values applied in coastal waters range from 0.001 to 1.0. For this study, a Cs of 0.01 was selected after conducting several sensitivity analyses for Dubai Creek. That selection produced the most accurate vertical and horizontal temperature and salinity distributions, when compared with field observed density fields.

The friction in HydroQual model (ECOM) is based on Z_0 the roughness height (m). Z_0 is characterized by the type of bottom sediment. This value is used in conjunction with the model's vertical turbulence closure submodel to produce velocity and K_m in the water column. When the vertical resolution is not sufficient to produce a good bottom boundary layer (KB < 8) the model will switch from using Z_0 to using Cd. The actual algorithm is to set Cd to the larger of the 2 values computed by the equation of the logarithmic law of the wall or the value given in input file. Both were determined via data or calibration. Because the bottom sediment of Dubai Creek is predominantly fine silt/mud in the lagoon of Dubai Creek, the chosen value of Z_0 was 1 mm.

Water temperature and salinity data from monitoring stations along with several bottom mounted temperature sensors were used for calibration and validation of the model computation. Water temperature and salinity data were both compared to time series from the model obtained at grid cell locations corresponding to the location of the measured data.

For convention purposes and to aid understanding, the actual location names were used in Dubai Creek instead of station numbers. Therefore hereafter the figures in this chapter will refer to station 2, station 4 and station 6 as Al Maktoum, Al Jaddaf and Creek Head respectively (Figure 5.4).

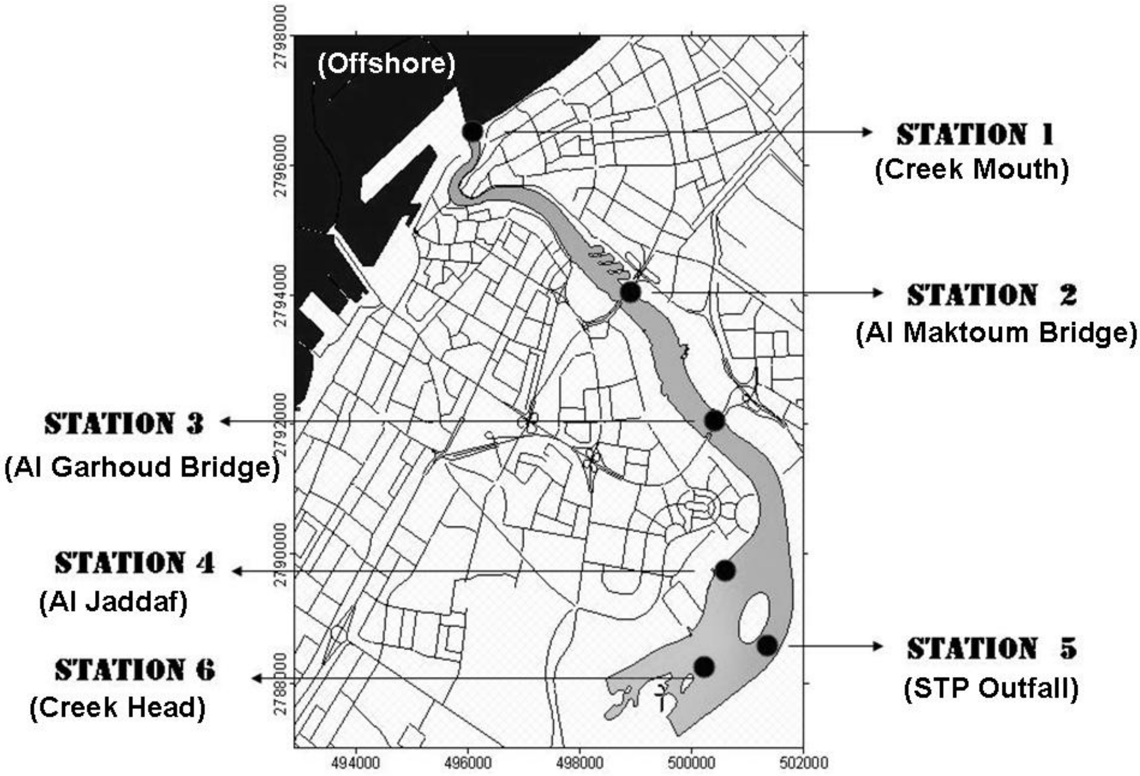


Figure 5.4: Dubai Creek and offshore showing station numbers (used in the text) and actual station name (used in the figure) for the convention purpose

Comparison of model computed sea surface elevations at station 4 and station 2 is shown in Figure 5.5. This shows a 30-day portion of the 1 year simulation and displays very good agreements of model computed elevations with data (Figure 5.5). The phase of the tidal waves varies at different reaches of Dubai Creek but remains within a few minutes of difference. As the tidal forcing data suggest, the tides in Dubai Creek exhibit the characteristics of mixed tides with a relatively strong influence of semi-diurnal components. The result also indicates that the model reproduced both the spring and neap tidal elevation cycles in Dubai Creek very well (Figure 5.5).

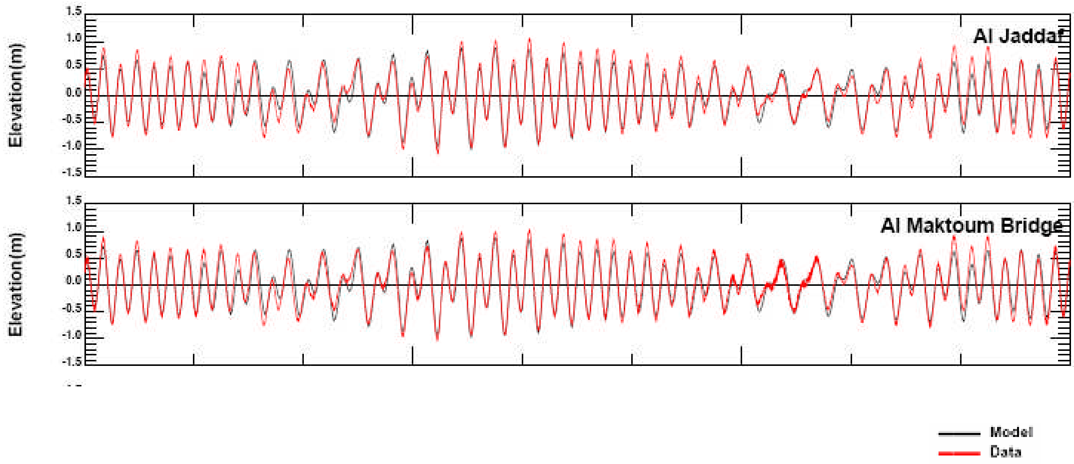


Figure 5.5: Hourly sea surface elevations: computed (black lines) vs. observed (red lines).

The tidal current velocity at station 2 was around 0.5 m/sec at the surface and about 0.4 m/sec at the bottom. The currents in the lagoon of Dubai Creek are less than 0.1 m/sec. The model reproduced the tidal current patterns very accurately (Figure 5.6), for both amplitude and phase, at different parts and depth of Dubai Creek. The measured and computed vertical salinity profiles at water quality monitoring stations also matched (Figure 5.6). The plots show very good agreements between observed and computed salinity at different locations as well as at depths. The results indicate that there is not much vertical stratification in the channel and moderate stratification in lagoon of Dubai Creek.

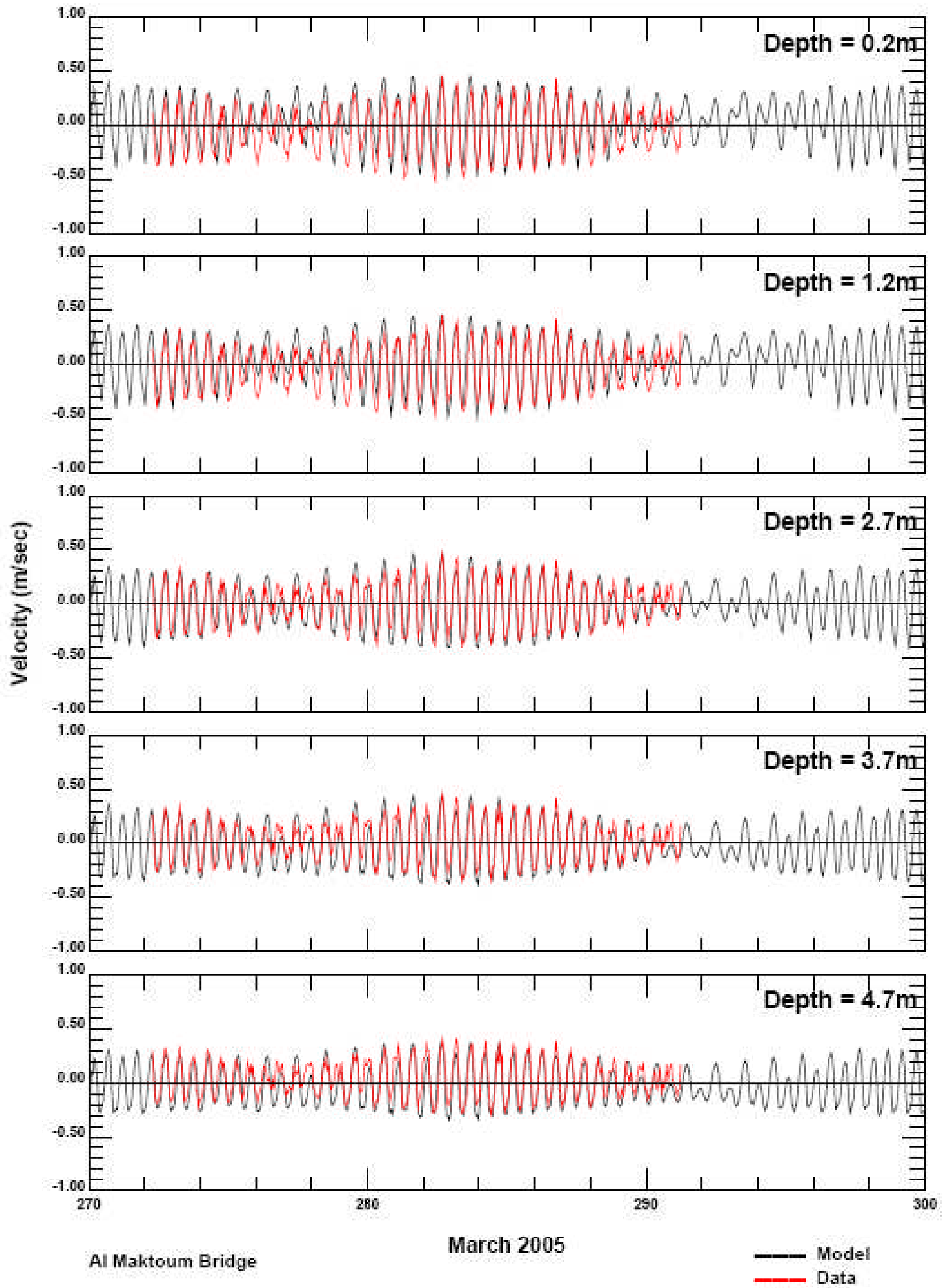


Figure 5.6: Hourly current velocities at station 2 (Al Maktoum Bridge) on surface and bottom during March 2005: computed (black lines) and observed (red lines)

Measured and computed vertical temperature and salinity profiles in the plots again show very good agreement of observed and computed levels at different zones of Dubai Creek (Figures 5.7 and 5.8).

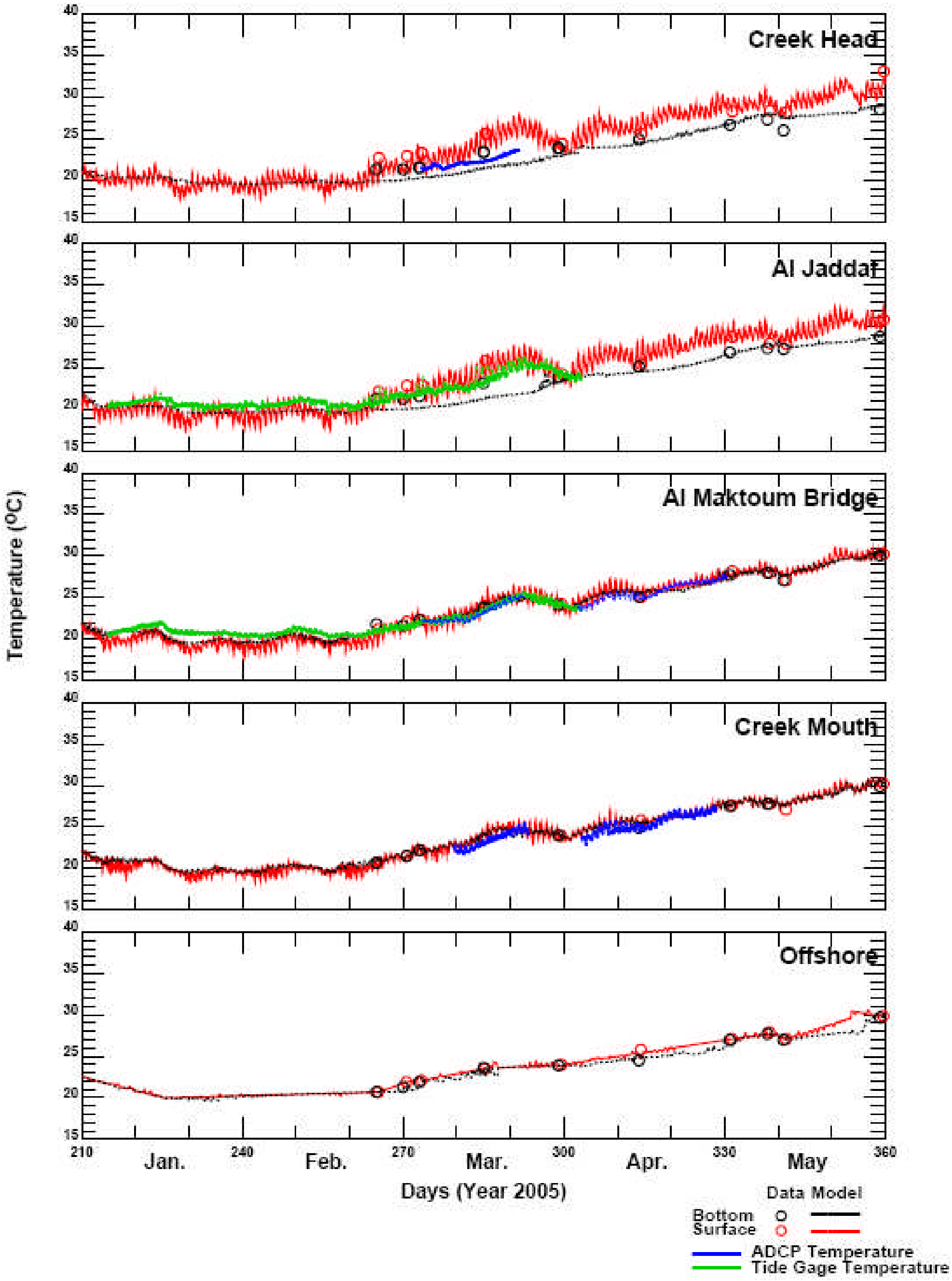


Figure 5.7: Comparison of computed and observed temperature for a one year simulation period (Dubai Municipality 2003)

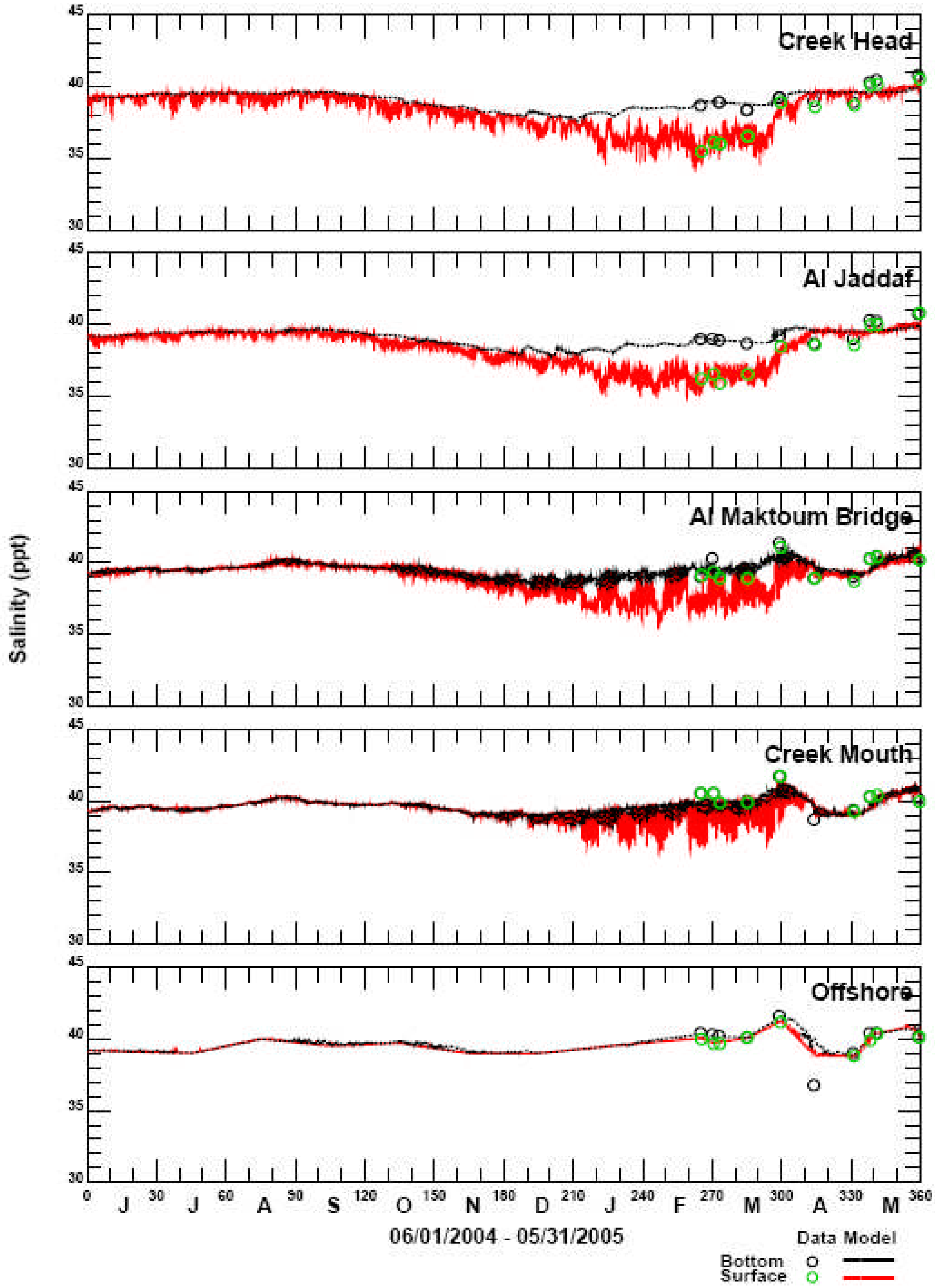


Figure 5.8: Comparison of model computed salinity with observed data for a 1 year simulation period

5.3.2.2 Water Quality Model

Physico-chemical and biological variables are important to the eutrophication and DO processes that affect Dubai Creek. Water temperature, salinity, nitrogen and phosphorus (as described in chapters III and IV) are the most important physical and chemical variables that directly affect phytoplankton growth in Dubai Creek.

The spatial variability of the water quality parameters in Dubai Creek is mainly due to the effect of the STP outfall, as the highest DO stratification and nutrients levels are found in the lagoon of Dubai Creek. There is also a marked temporal variability in the levels of water temperature, DO and nutrients. This variability is not only related to changes in the loads of nutrients from STP, but also reflect the variability of other environmental factors, including water temperature, incident solar radiation, light transparency, and grazing pressure from higher trophic levels. Flow estimates were therefore made on the basis of information collected from the Drainage Department of Dubai Municipality.

The spatial distributions of observed data and model output are presented (Figure 5.9). The filled red circles represent the average surface concentration and the open blue circles the bottom concentration and the range is indicated by the horizontal bars. Because DO was measured at 5 or 6 points over depth, the surface and bottom concentrations were defined by the average of the top 2 and bottom 2 measurements, respectively, to better represent the top and bottom water layers. The model output is represented by the shaded area on each figure. The model output is presented with the upper and lower boundaries of the shaded area representing ± 1 standard deviation of the model results.

Both model and data indicate excessive algal growth in the lagoon. Average surface chlorophyll *a* levels approach 60 mg/m^3 near station 6 with average bottom chlorophyll *a* levels between 20 and 30 mg/m^3. The nutrient levels are highest at station 5 near STP wastewater discharge indicating that the STP is a significant source of nutrients to Dubai Creek. The model reproduces the NH_4-N and NO_3-N spatial and vertical patterns reasonably well, however, an additional undefined groundwater nutrient load was added to the model as part of the calibration analysis and will be discussed subsequently. In the lagoon surface, NH_4-N levels are low due to algal uptake and bottom NH_4-N levels are elevated due to sediment release of NH_4-N. NO_3-N bottom concentrations are lower than surface values as a consequence of denitrification in the sediment where NO_3-N is transformed by bacteria to nitrogen gas. Computed PO_4-P levels are less than measured values despite sensitivity analyses to add a reasonable estimate of a potential groundwater load.

Figure 5.9 indicates significant DO vertical stratification in the lagoon of Dubai Creek with average surface and bottom DO levels of 10 mg/L and 2 mg/L, respectively.

Figure 5.9a and Fig 5.9b shows the calibration results.

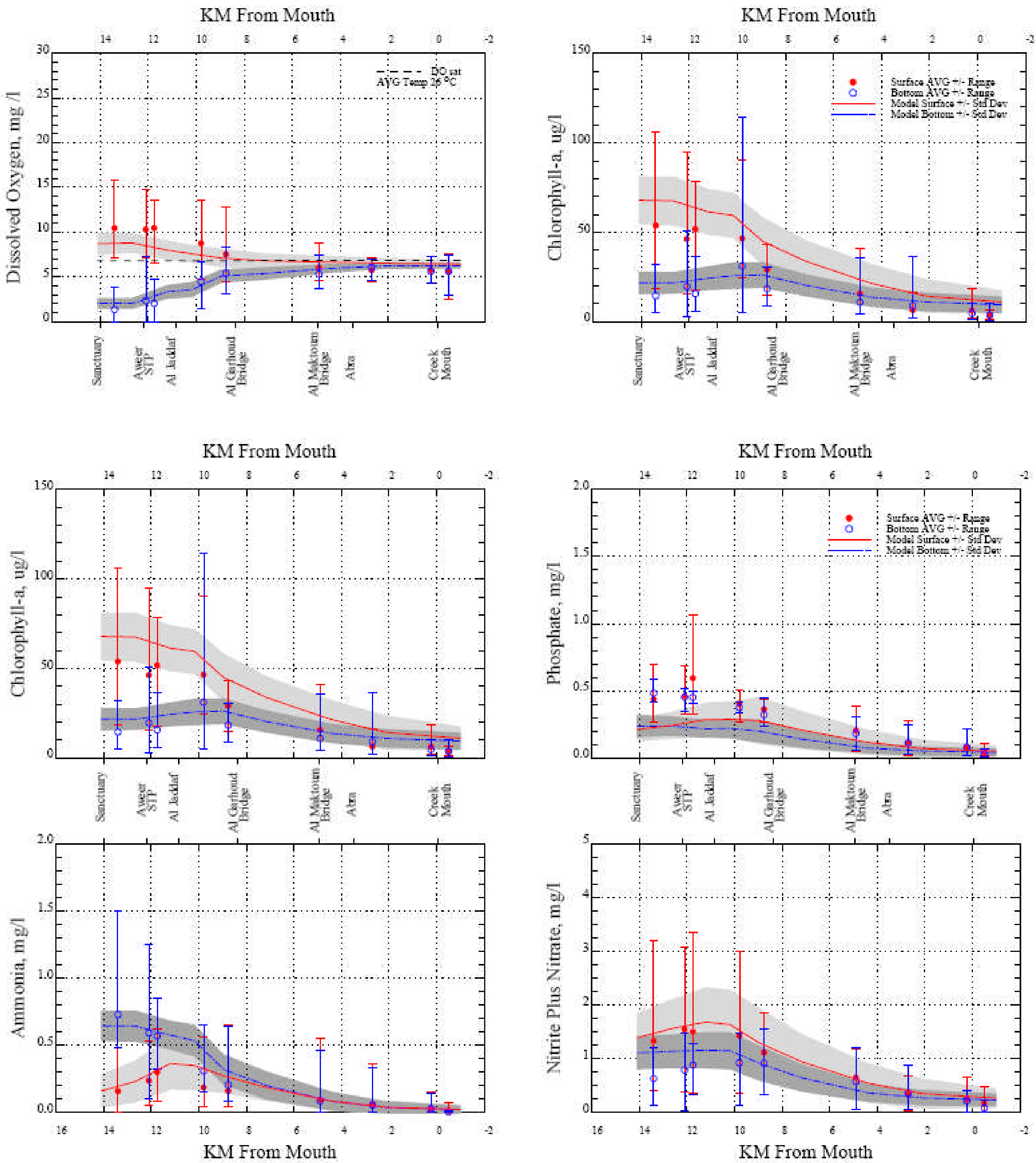


Figure 5.9: Spatial plots of model computation versus data for DO, chlorophyll a, PO_4-P, NH_4-N and NO_2-N plus NO_3-N

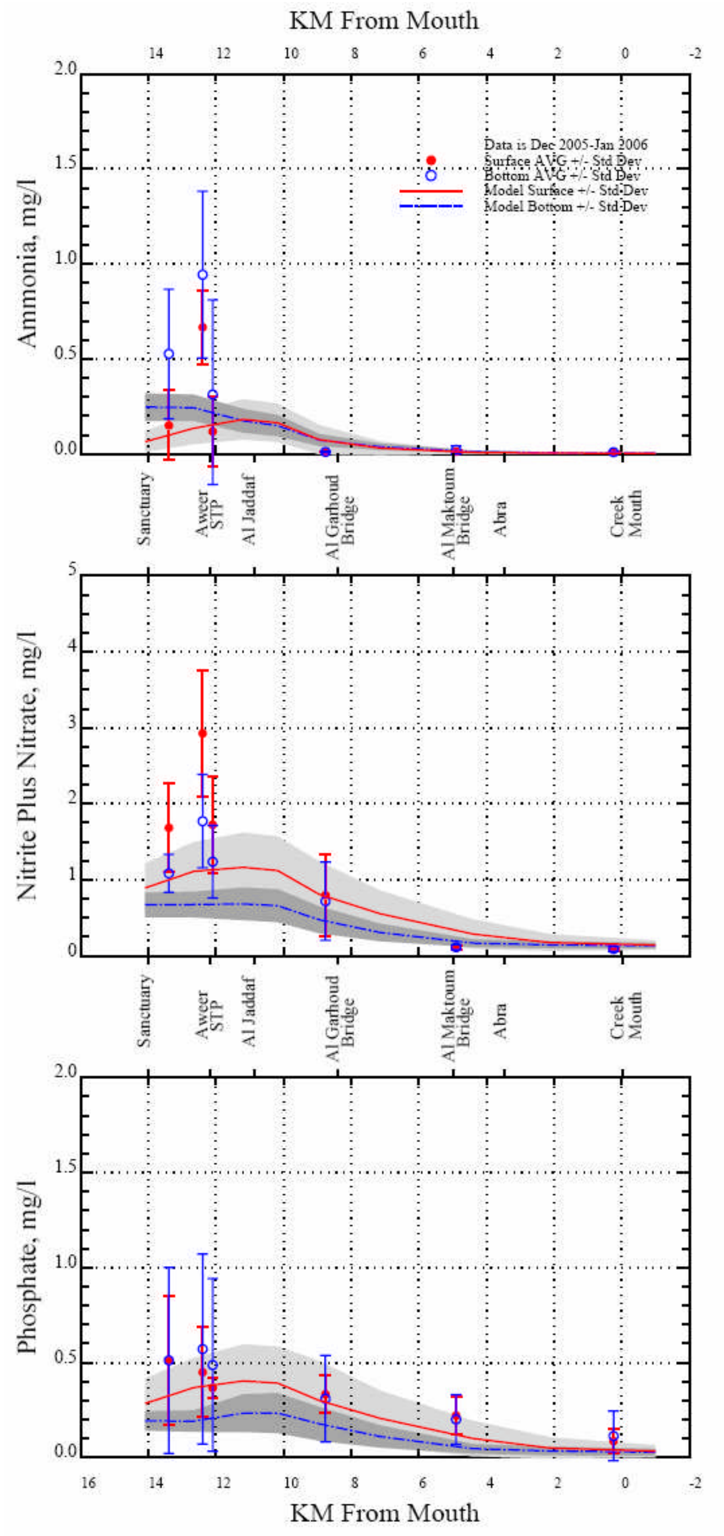


Figure 5.9b: Model calibration results from Dubai Creek during December 2005-January 2006

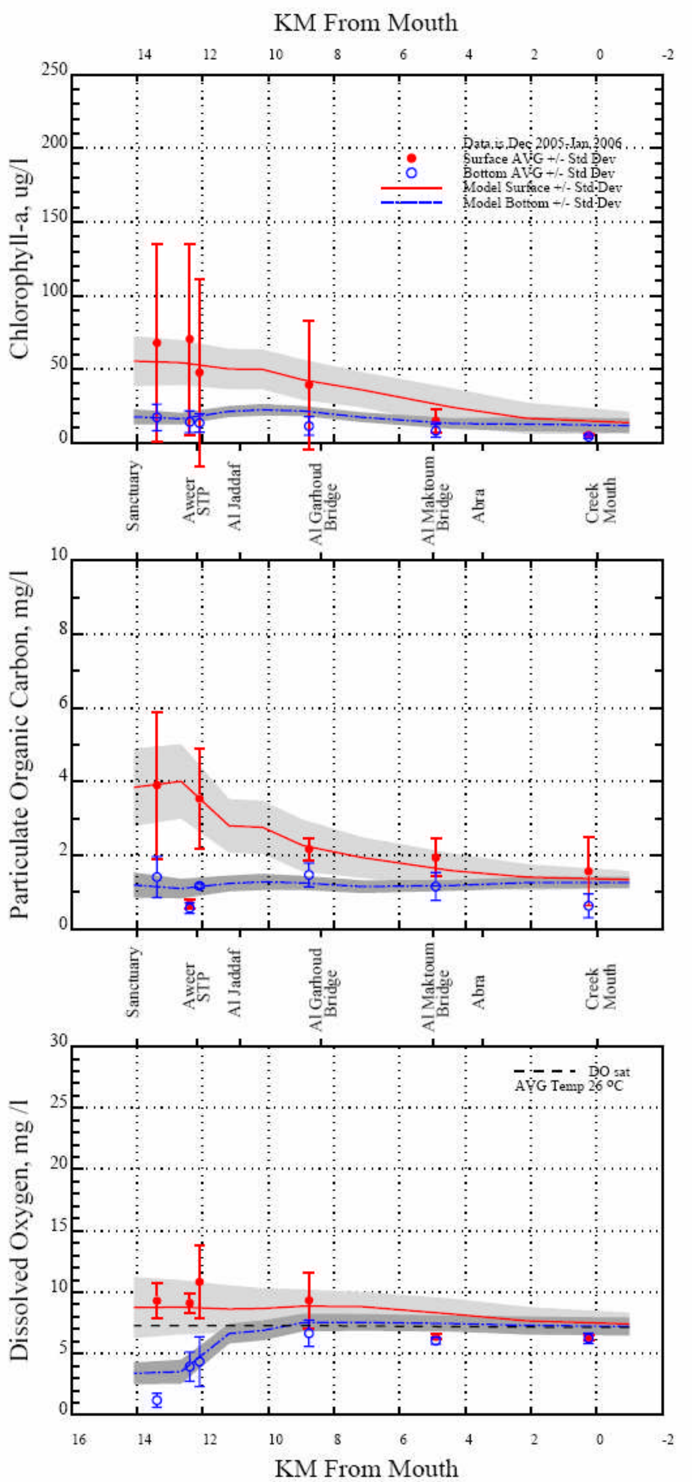


Figure 5.9b: Model calibration results from Dubai Creek during December 2005-January 2006

5.4 Scenarios for the management of the water quality

Following calibration, the model can be used to inform decision making options to improve water quality in Dubai Creek. Management strategies were constructed to examine the impact of various remediation scenarios. This section details 4 scenarios, which are run using the earlier calibration as the base run or “no action scenario”. All the boundary conditions and model coefficients were the same as those used for the base calibration.

The management scenarios tested are:

- **Scenario 1**: Behavior and characterization of water quality after 6 months, 1, 2, 5, 10, 15, 20 and 25 years if the flow of treated sewage effluent from the outfall located in the lagoon of Dubai Creek was completely eradicated.
- **Scenario 2**: Behavior and characterization of water quality after 6 months, 1, 2, 5, 10, 15, 20 and 25 years following a tertiary upgrade of the STP- reduction of nitrogen and phosphorus – prior to effluent discharge into Dubai Creek.
- **Scenario 3**: Behavior and characterization of water quality condition if remedial sediment dredging (-0.5 m from the existing bed level) was implemented in the lagoon of Dubai Creek
- **Scenario 4**: Behavior and characterization of water quality condition if remedial sediment dredging (-0.5 meter from the exiting bed level) and complete cessation of the STP outfall were implemented.
- **Scenario 5**: Behavior and characterization of water quality condition if remedial sediment dredging (-0.5 meter from the exiting bed level) and tertiary treatment of STP outfall prior to discharge into Dubai Creek were implemented.

For each of the above scenarios, a new loading was estimated. A comparison of the daily average organic carbon and nutrient loadings used for the scenarios versus those used for the calibration are given (Table 5.1). The numbers are based on a wetlands study conducted on the marshes of the sanctuary zone that shows that the wetland is a source of carbon and sink for nutrients. Wetlands loading pattern was constructed to simulate periods of high growth during the warmer months and lower growth during the cooler months. These assumptions produced the organic carbon, nitrogen and phosphorus loads contained in Table 5.1. Although it is minor, an inorganic nutrient uptake (i.e., negative load of NH_4-N and PO_4-P) was assigned to balance the organic nitrogen and phosphorus export to the Creek. Tertiary treated effluent nutrient loads were based on widely accepted nitrogen and phosphorus nutrient removal efficiency (Thomman & Muller 1987). Running the projections for long-periods - up to 25 years by cycling the hydrodynamic and water quality forcings (i.e., temperature, winds, solar radiation, boundary conditions, and nutrient loadings) was necessary for scenarios 1 and 2 to assure that the model computations achieved a new equilibrium position.

Table 5.1: Daily average organic carbon and nutrient loadings (kg/day) for the base calibration and the projection runs (Dubai Municipality 2003).

Scenario Number	Total phosphorus	Total nitrogen	NH_4-N	NO_2-N+ NO_3-N	Total Organic Carbon (TOC)	Dissolved Oxygen (DO)	PO_4-P
1	27	138	-138	-	5500	55	-27
2	27	138	-62	75	6200	430	48
3	27	138	926	1805	6454	430	491
4	27	138	-138	-	5500	55	-27
Base	27	138	926	1804	6454	430	491

5.4.1 Scenario 1 (Discontinuation of STP discharge into Dubai Creek)

The objective of this scenario was to determine the short-term and long-term effects on water quality resulting from a complete discontinuation of the discharge of wastewater from the STP outfall. This management scenario represents a shift towards soil injection or full re-use of the wastewater in irrigation. The rationale of a long-term run stems from the following: ending the discharge of wastewater, and hence of nutrients into Dubai Creek will reduce the severity of eutrophication processes by directly affecting the ability of the algal populations to grow. In the absence of any other source of nutrients, one would expect Dubai Creek's water quality to fully recover. However, it is also true that historical phosphorus stored in the sediment as a consequence of years of wastewater discharge into the system, will continue to be a slow but sustained source of phosphorus to the water column: PO_4-P is produced via the mineralization of particulate organic matter that ultimately results in the diffusion of PO_4-P into the overlying water (Di-Toro 2000). As a consequence, bottom DO levels in the lagoon of Dubai Creek will likely remain low until sediment PO_4-P begins to be exhausted, and chlorophyll *a* has declined. The operational question is the time it will take for all the sediment-bound phosphorus to be exhausted before water quality returns to an oligotrophic condition. The objective of this scenario was therefore to determine how long it will take for the Creek to recover. It is noteworthy that this computation should be interpreted more as an indication of a “long” recovery period, than the exact years for the recovery to occur.

Water quality computations were run by cycling the hydrodynamic run for the length of the 25 year simulation. The comparisons between the base case (*i.e.*, *present situation*) and the projections for chlorophyll *a*, DO, PO_4-N, NH_4-N and NO_3-N daily average concentrations in the surface and bottom water at 3 locations along Dubai Creek- Lagoon area near station 3, station 2 and station 1 are presented (Figures 5.10-5.12). In general, the model computes greatly reduced concentrations of nutrients in Dubai Creek. A relatively rapid decline of chlorophyll *a* concentrations in the water column would be observed at all locations, but the most downstream location would reach steady-state concentrations faster (i.e., 2-3 years after cessation of the discharge) than the upstream locations (i.e., up to 5 years after cessation of the discharge).

The rapid response of the system to eliminating the STP discharge is in part due to the nitrogen removal, which reflects the dynamics of nitrogen behavior. As nitrogen input into Dubai Creek is reduced, mineralization of organic nitrogen in the sediment produces NH_4-N that is nitrified to NO_3-N, which in turn escapes as a flux to the overlying water or is denitrified to nitrogen gas. In addition, the flux of NO_3-N from the overlying water to the sediment adds to the NO_3-N that is available for denitrification. As algal settling is reduced as a consequence of reduced phytoplankton production, the stored organic nitrogen in the sediment is ultimately depleted and the flux of NO_3-N to the water column is reduced.

In the lagoon area, except for PO_4-P that declines at a much slower rate, NH_4-N and chlorophyll *a* levels decline rapidly less than a year after cessation of the discharge, and reach steady-state concentrations in about 5 years. The slow rate of phosphorus decline is due to the sustained source of phosphorus to the water column from the flux of historical PO_4-P stored in the sediment as a consequence of years of wastewater discharge into the system and the absence of any reactions that deplete sediment PO_4-P comparable to the denitrification of sediment NO_3-N to nitrogen gas. The production of PO_4-P is via the digenetic mineralization of particulate organic matter that ultimately results in the diffusion of PO_4-P into the overlying water. As a consequence, according to this model, it might take about 20 years before the phosphorus in the overlying water reaches levels comparable to concentrations after only 5 years near station 2.

In summary, scenario 1 shows that the discontinuation of the STP discharge into Dubai Creek will cause a marked improvement in the water quality of Dubai Creek. The impact on water quality is pronounced: concentrations of nitrogen and chlorophyll *a* decline relatively quickly and the rate of decline is higher in areas far from the STP site.

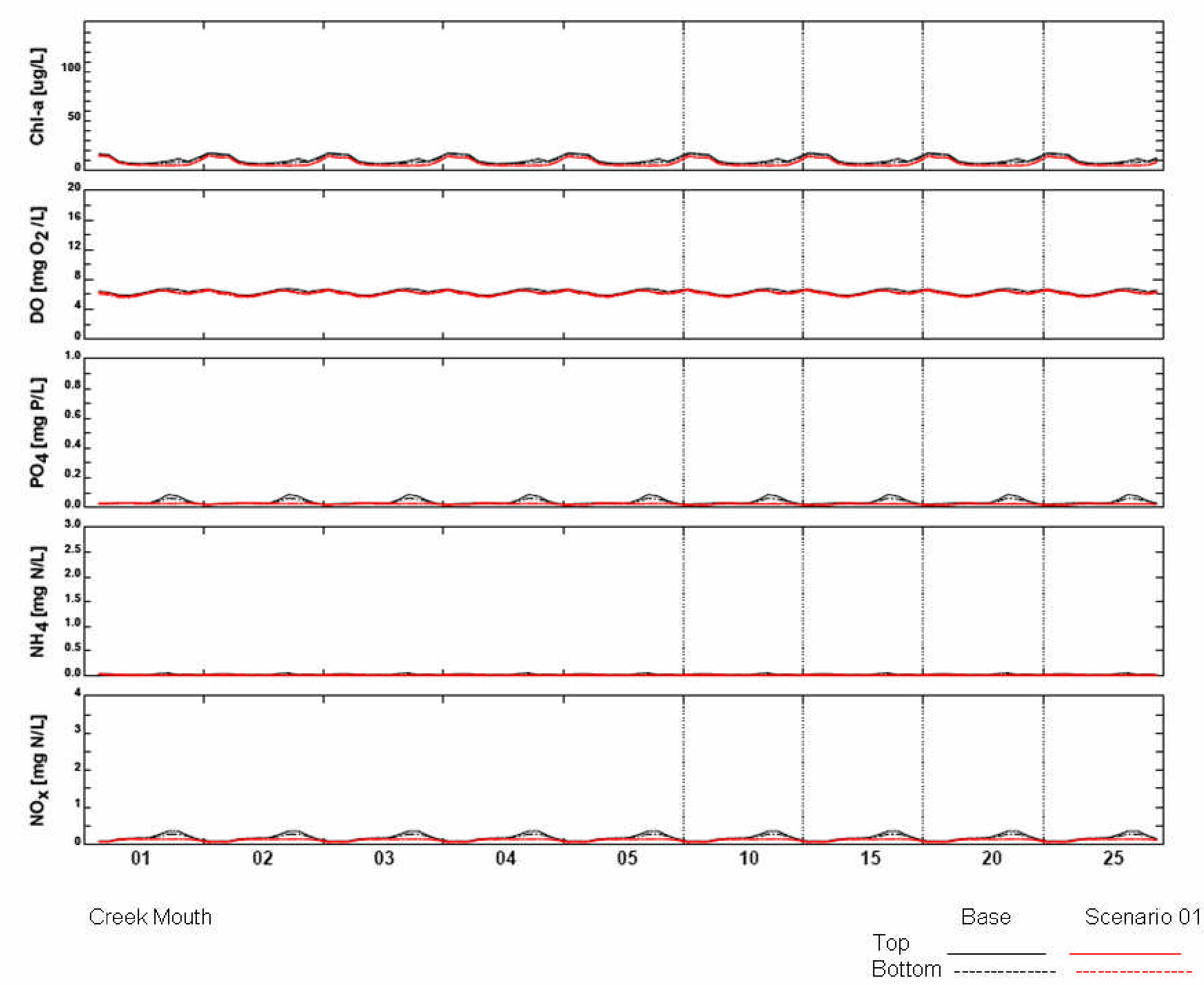


Figure 5.10: Comparisons of base calibration and scenario 1 at station 1 along Dubai Creek

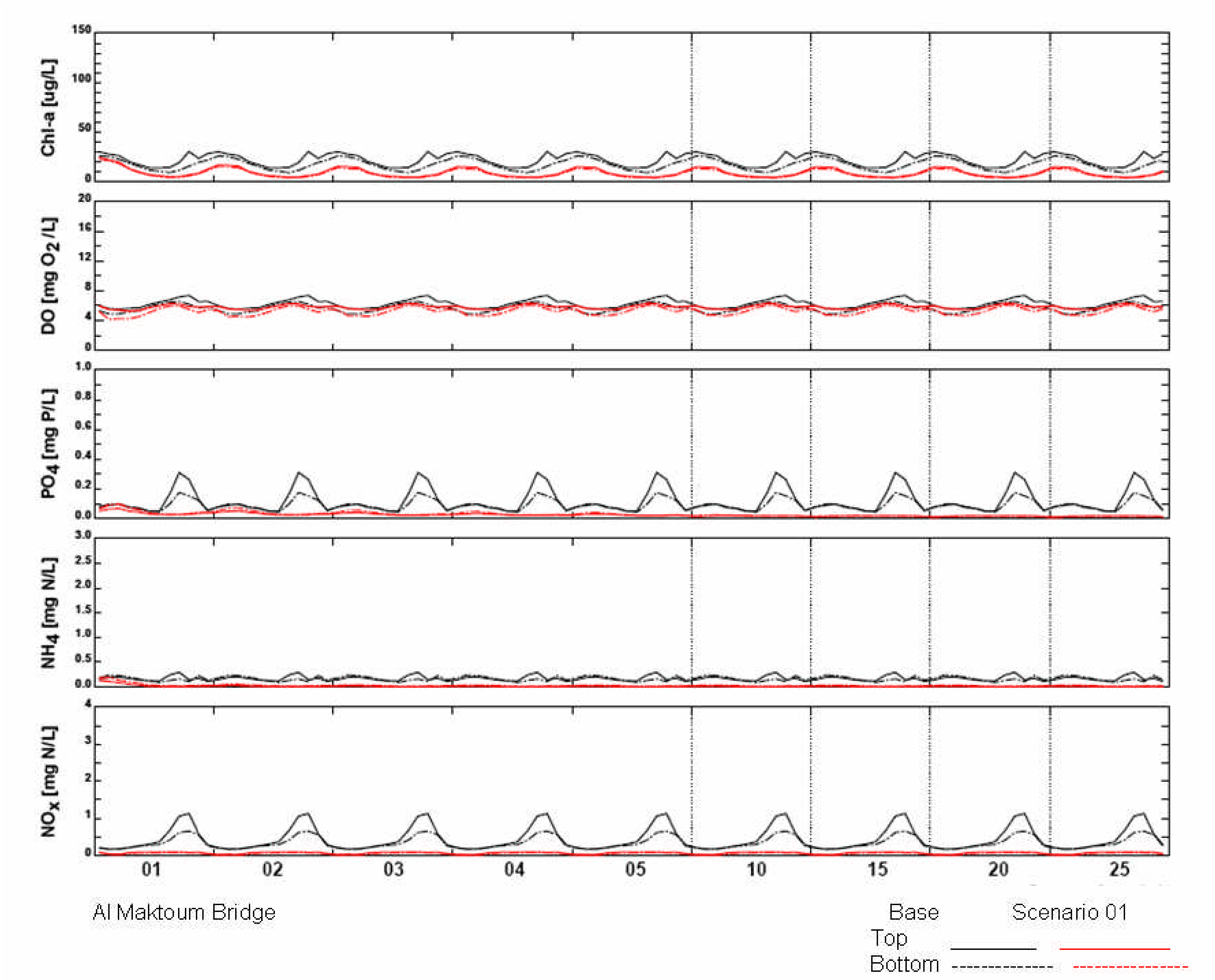


Figure 5.11: Comparisons of base calibration and scenario1 station 2 along Dubai Creek

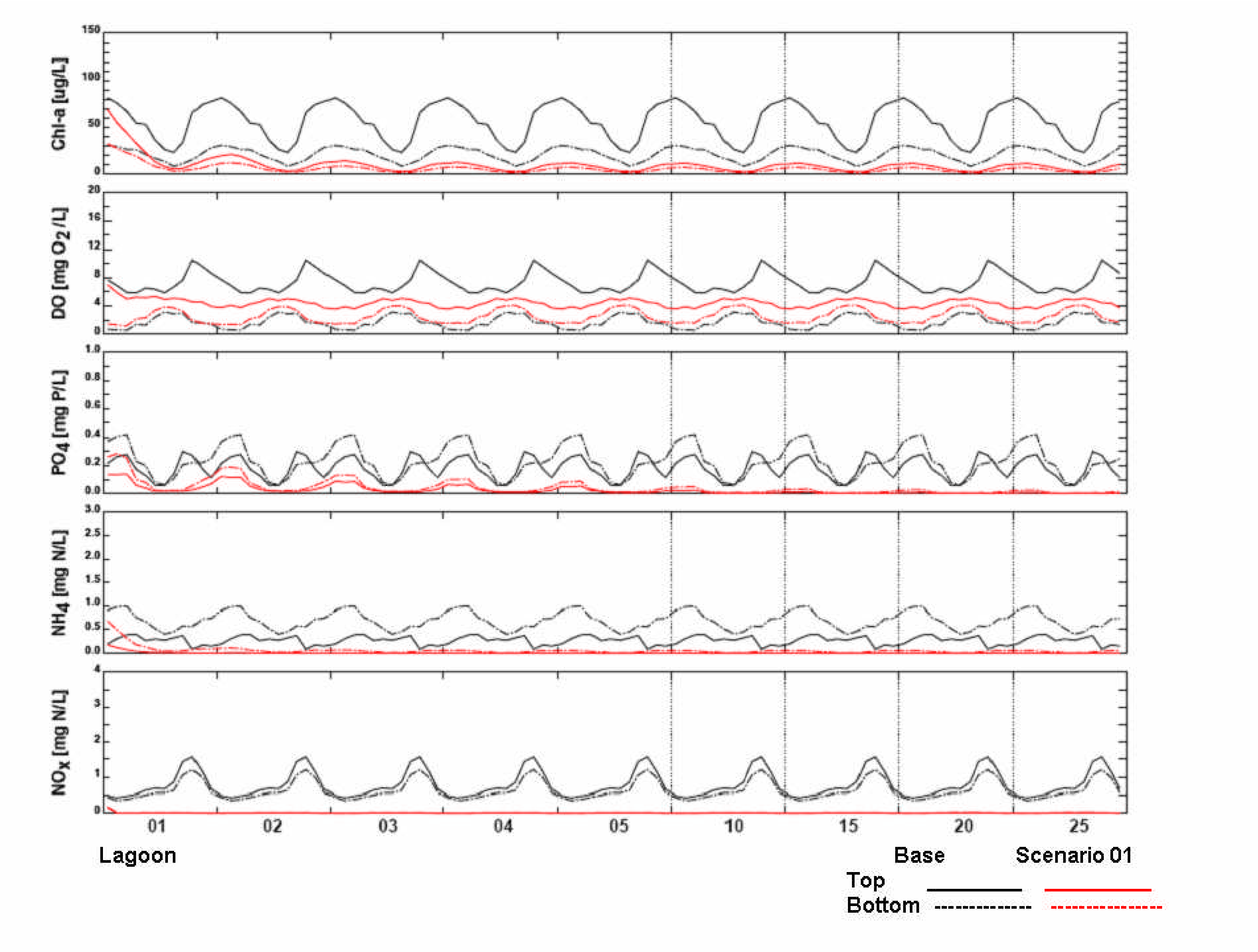


Figure 5.12: Comparisons of base calibration and scenario 1 in the lagoon along Dubai Creek

5.4.2 Scenario 2 (STP upgrade to tertiary treatment before discharge into Dubai Creek)

The objective of this scenario was to determine the short-term and long-term effects of a reduction in the effluent nutrients concentrations on water quality prior to the discharge of the treated wastewater into Dubai Creek. Since tertiary treatment is usually designed to reduce the nutrient concentrations in the effluent, a reduction in the nutrient levels of the receiving waters would be expected.

This scenario is a variation of scenario 1 (i.e., elimination of the STP discharge) whereby the flow of wastewater remains the same but with a significant reduction of the nutrient loads as a result of the tertiary treatment. NH_4-N, NO_3-N and phosphorus levels in the effluent water were all reduced to 1.0 mg/L, with a resultant decrease in the loadings as shown (Table 5.1). The comparisons between the base case and the projections for chlorophyll *a*, DO, PO_4, NH_4, and NO_3 daily average concentrations in the surface and bottom water at three locations along Dubai Creek - the lagoon, downstream of station 3, Al-Maktoum Bridge, near Abra, and at Dubai station 1 - are presented (Figures 5.13-5.15). Relative to the base case, this scenario would achieve an improvement in the quality of the receiving water, but of a lesser magnitude than achieved in scenario 1 (i.e., discontinuation of the STP discharge). Nutrients levels, nitrogen in particular, decline to algal growth limiting concentrations (Thomman & Mueller, 1987). Because the tertiary treatment will leave residual levels of nutrients in the effluent wastewater, Dubai Creek will contain slightly higher levels of nitrogen and phosphorus than under scenario 1. The most noticeable differences are in the lagoon area where the DO levels will remain relatively depressed until the PO_4-P has been exhausted from the sediment and chlorophyll *a* declines. In addition, both chlorophyll *a* and DO stratification is maintained.

As in scenario 1, the channel of Dubai Creek will reach steady-state conditions faster than the lagoon, mainly as a result of the low current velocities in the lagoon area, the slow decline in chlorophyll *a* and the slow release of PO_4-P from the sediments. Scenario 2, however, might cause undesirable consequences on the quality of the wastewater destined for irrigation: the reduction of nutrient levels from the effluent deprives the irrigation water of its essential minerals. Although one would expect that nutrient reduction will be applied on the effluent destined for Dubai Creek's discharge, the variability in the demand for irrigation water might pose operational problems in a tertiary treatment unit, which is usually designed for a narrow range of flow regimes

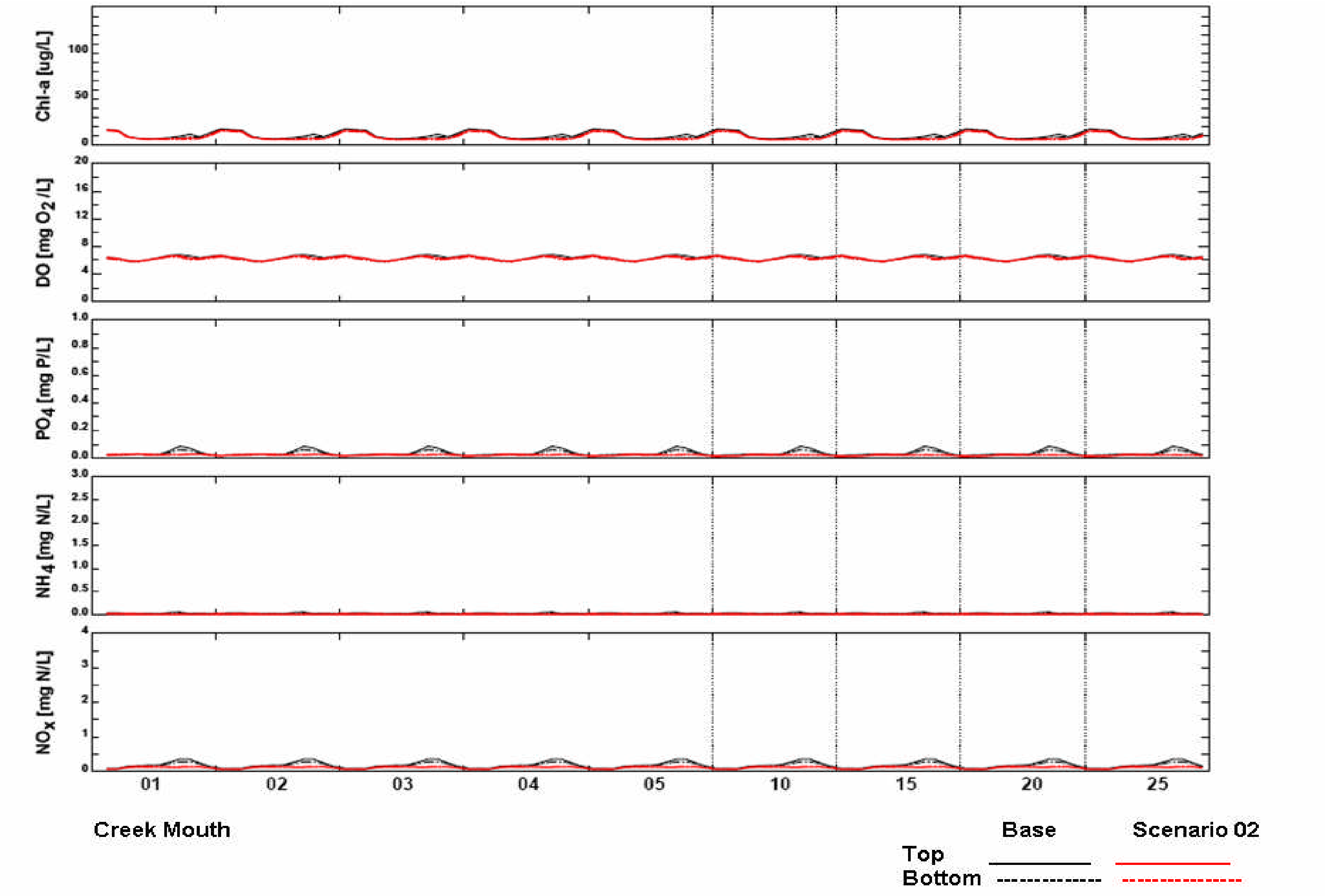


Figure 5.13: Comparisons of base calibration and scenario results at Station 1 along Dubai Creek

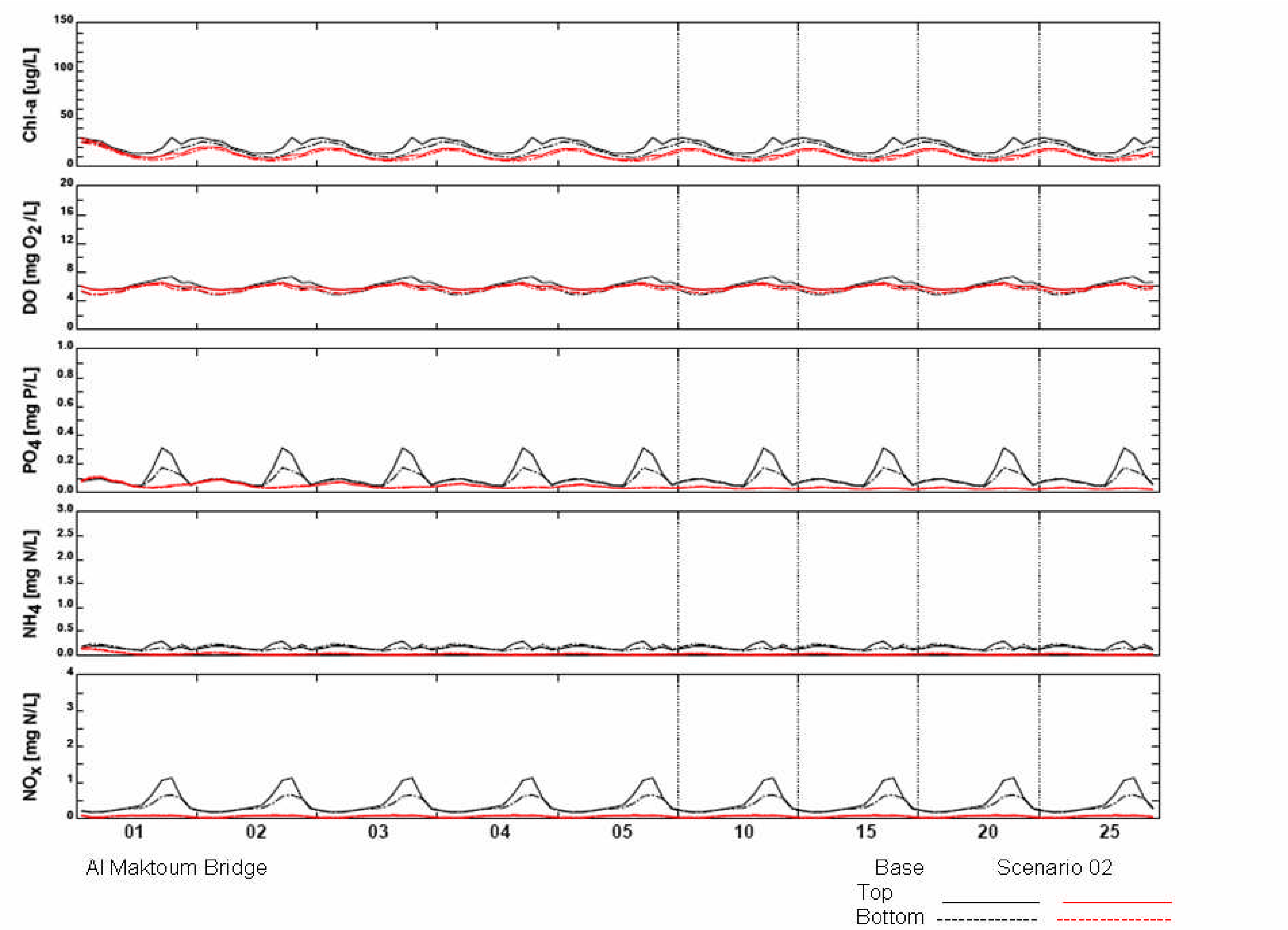


Figure 5.14: Comparisons of base calibration and scenario results at Station 2 along Dubai Creek

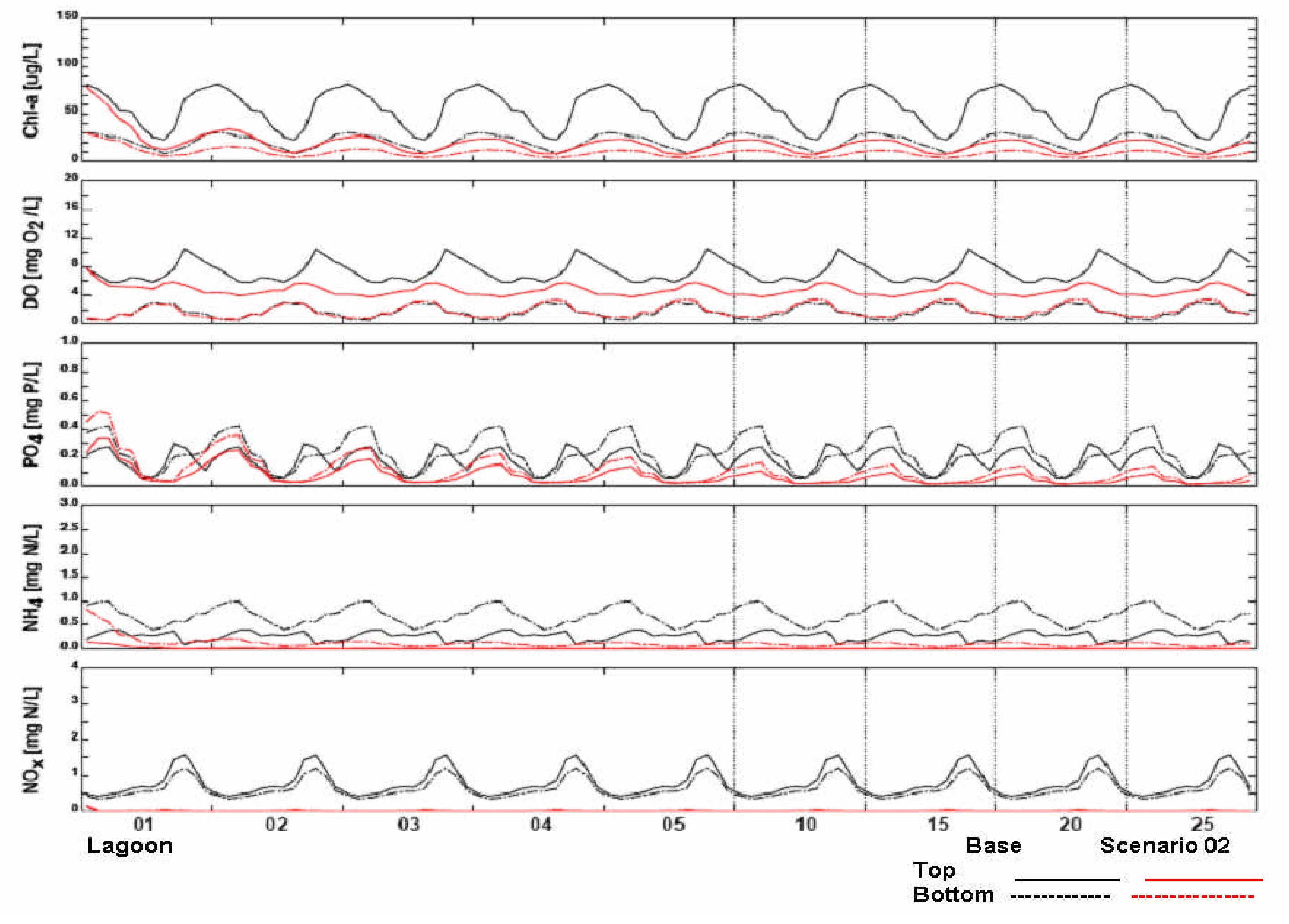


Figure 5.15 Comparisons of base calibration and scenario results in the lagoon along Dubai Creek

5.4.3 Management Scenario 3 (Dredging with No Other Action)

This scenario is an attempt to predict the effect of eliminating the flux of nutrients from the sediment, by dredging a 0.5 m sediment layer between the boundary of station 6 (*anti-pollution boom*) and the station 3 site. The rationale for this is based on the assumption that by removing the reservoir of nutrients (*i.e., sediment layer*) from the bottom of Dubai Creek, the flux of nutrients to the water column will cease and Dubai Creek will ultimately improve. This removes an element of latency from the system. To ensure that the hydrodynamic model properly captured the effect of deepening a section of Dubai Creek, water depth in the lagoon of Dubai Creek from station 3 to station 6 was deepened by 0.5 m and the model re-run with the other model forcing conditions used in the base calibration run retained. This re-running of the hydrodynamic model was necessary to ensure that no sharp vertical or horizontal gradient in salinity, temperature or current velocity would occur as a result of dredging.

The rationale of cycling is to assure that the model computations achieve a long-term equilibrium response. Also, since this scenario assumes a continuous discharge from the STP outfall, a one-year run could not capture the potential build-up of a new sediment layer and its impact on the overall water quality.

The comparisons between the base case and the projections for Chlorophyll *a*, DO, PO_4, NH_4-N, and NO_3-N daily average concentrations in the surface and bottom water at 3 locations along Dubai Creek- the lagoon, downstream of station 3, station 2 and at station 1 - are presented (Figures.5.16-5.18). In general, the model computations indicate that dredging will make little difference to the water quality in Dubai Creek under current conditions (i.e., continuous discharge of the STP effluent in Dubai Creek). In spite of a temporary reduction in nutrients concentrations in the water column, the cycle of phytoplankton production, deposition and decay will re-build an active sediment layer that will re-exert sediment oxygen demand on the water column and increase PO_4-P in the lagoon.

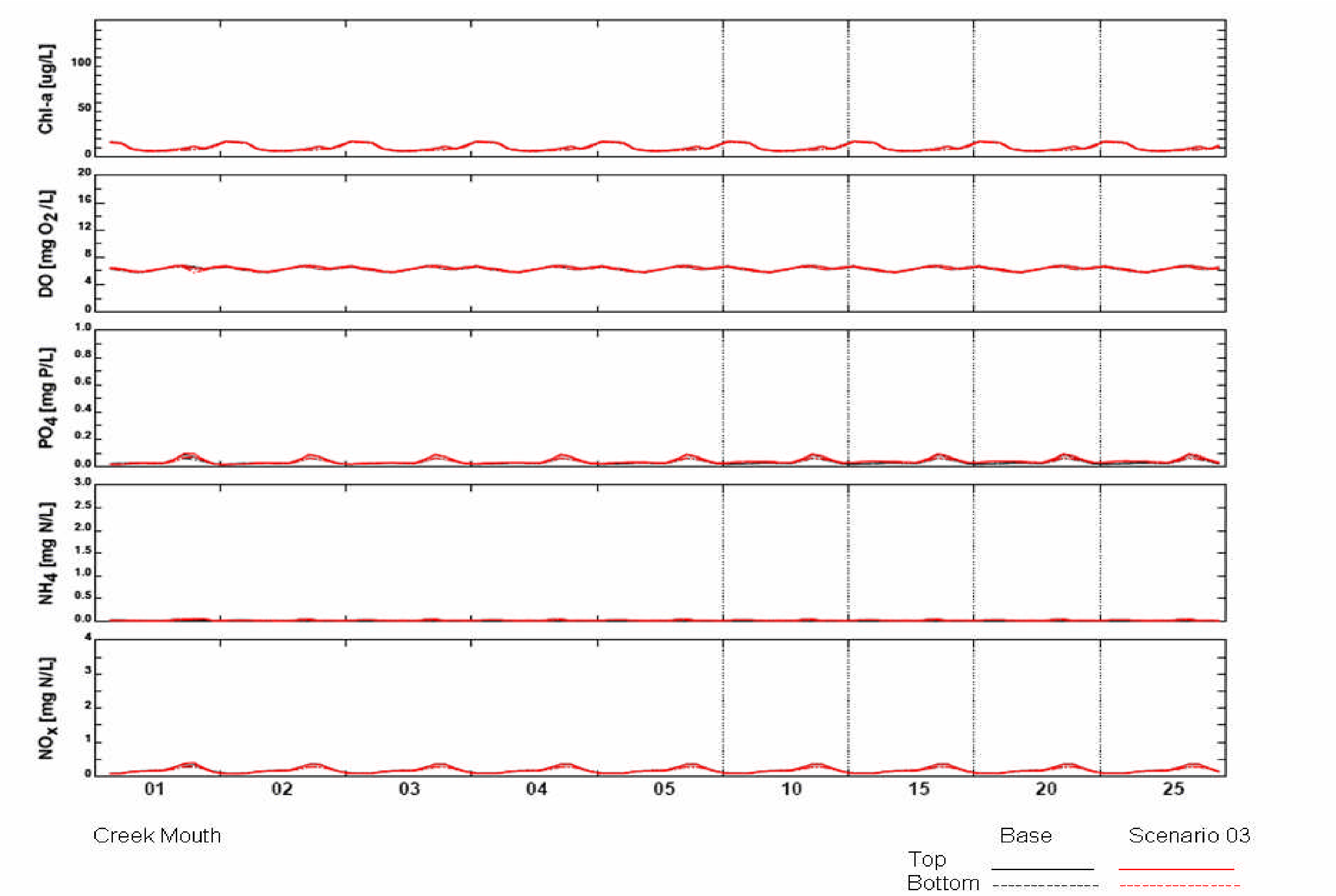


Figure 5.16: Comparisons of base calibration and scenario results at station 1 along Dubai Creek.

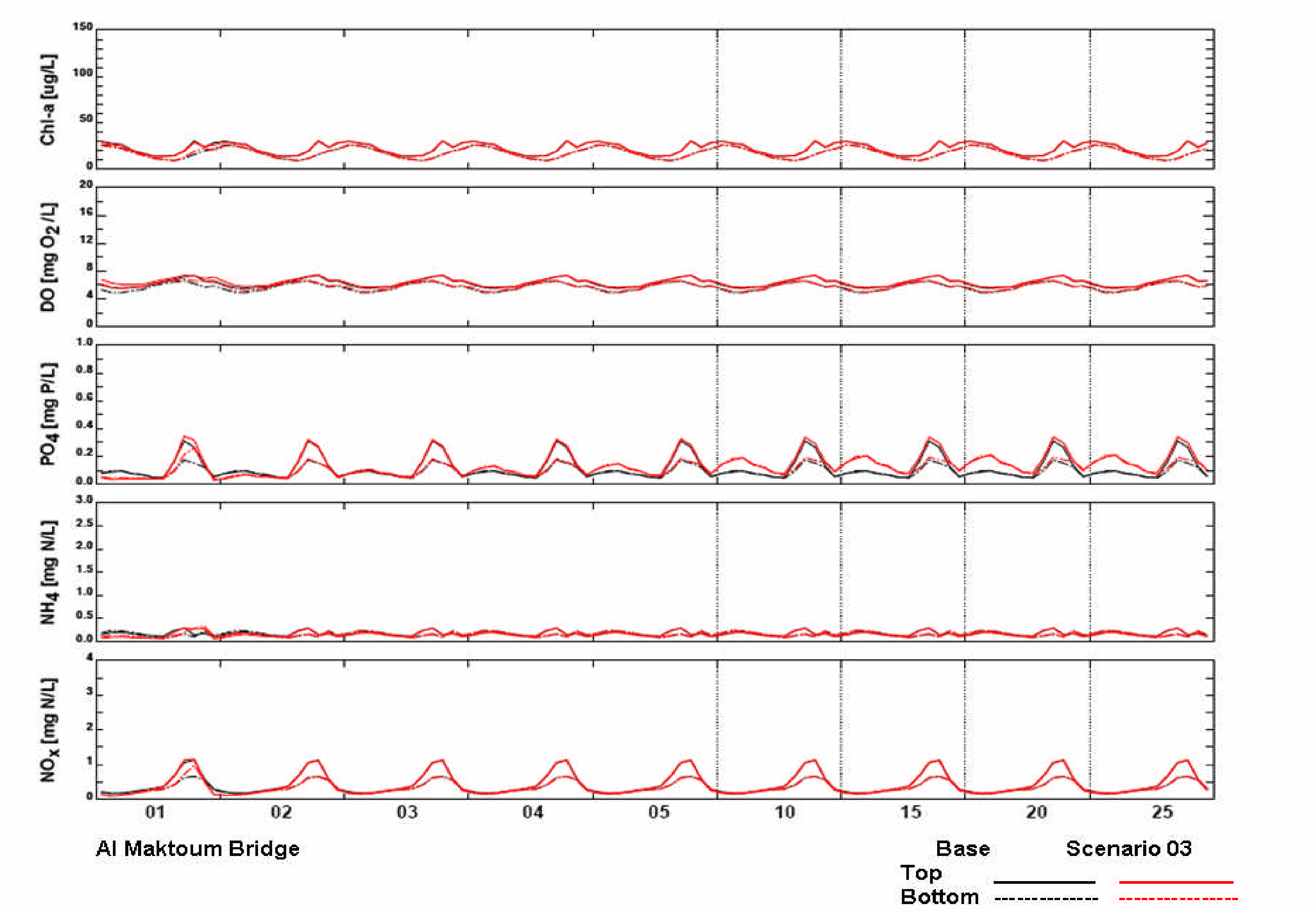


Figure 5.17: Comparisons of base calibration and scenario results at station 2 along Dubai Creek

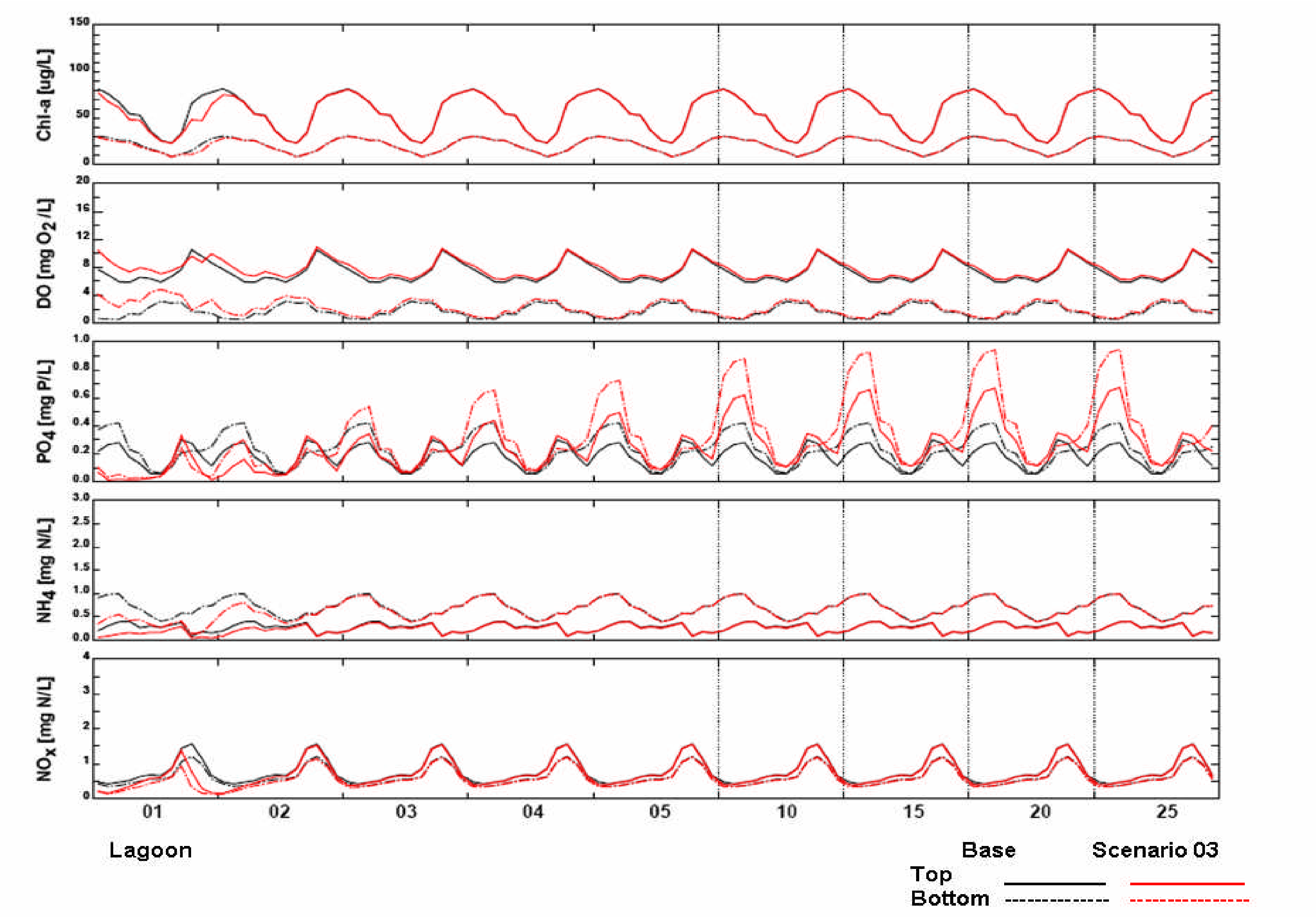


Figure 5.18: Comparisons of base calibration and scenario results in the lagoon along Dubai Creek

5.4.4 **Management Scenario 4** (Dredging and Discontinuation of STP Discharge)

This scenario is a combination of the dredging (scenario 3) and the discontinuation of the STP discharge (scenario 1) scenarios. The rationale of combining both measures is that while the model computations showed that eliminating the STP discharge is likely to improve the quality of the receiving waters, the sustained release of the buried phosphorus will slow that improvement. In addition, removing the active sediment layer by dredging, without ceasing the input of nutrients from the sediment will result in the re-building of an active layer and the return to the status quo. Combining both measures was predicted to hasten the recovery process by eliminating the point source (i.e., STP discharge) and the long-term diffuse source from Dubai Creek bed (i.e., sediment layer).

The comparisons between the base case and the projections of chlorophyll *a*, DO, PO_4, NH_4, and NOx daily average concentrations in the surface and bottom water at 4 locations along Dubai Creek- the lagoon, downstream of station 3, station 2 and station 1- are presented (Figures 5.19-5-21). As expected, the combined measures of dredging and discontinuing the STP discharge would achieve an immediate improvement in Dubai Creek water quality. At the end of the annual cycle, the model computes greatly reduced concentrations of chlorophyll *a* in the lagoon area approaching 10 mg/m^3 compared to 50 mg/m^3 in the base case. During the summer months, the DO levels in the bottom waters increase relative to the base case, while in the surface layers, the DO drops as expected as a result of the decreased primary productivity (i.e., less nutrients, less chlorophyll *a* production, less photosynthesis, less DO production). One can also note a small depression in DO level during the spring between the calibration run and this scenario. This slight depression may be the result of mixing between a super-saturated surface (because of high chlorophyll *a* levels) and a depressed DO in the bottom during the calibration run, versus mixing between a lower DO at the surface (because of decreased productivity in the absence of enough nutrients to promote phytoplankton growth) and a depressed DO in the model.

Because the dredged zone in this scenario is confined between by the anti-pollution booms and station 3 site, sediments in the un-dredged areas (e.g., wetlands and downstream of station 3) would continue to exert an oxygen demand and release nutrients in the water column. However, the model computations under scenario 1 (discontinuation of the STP discharge) suggest a rapid decrease in NH_4-N and chlorophyll *a* – within a year - without any partial dredging. It is consequently expected that the combination of the partial dredging and cessation of the STP discharge would further shorten that recovery period. The model computations also predict a marked improvement at the downstream locations, in particular near the vicinity of the station 3 site, where a significant decline in chlorophyll *a* and an increase in the bottom DO would be expected.

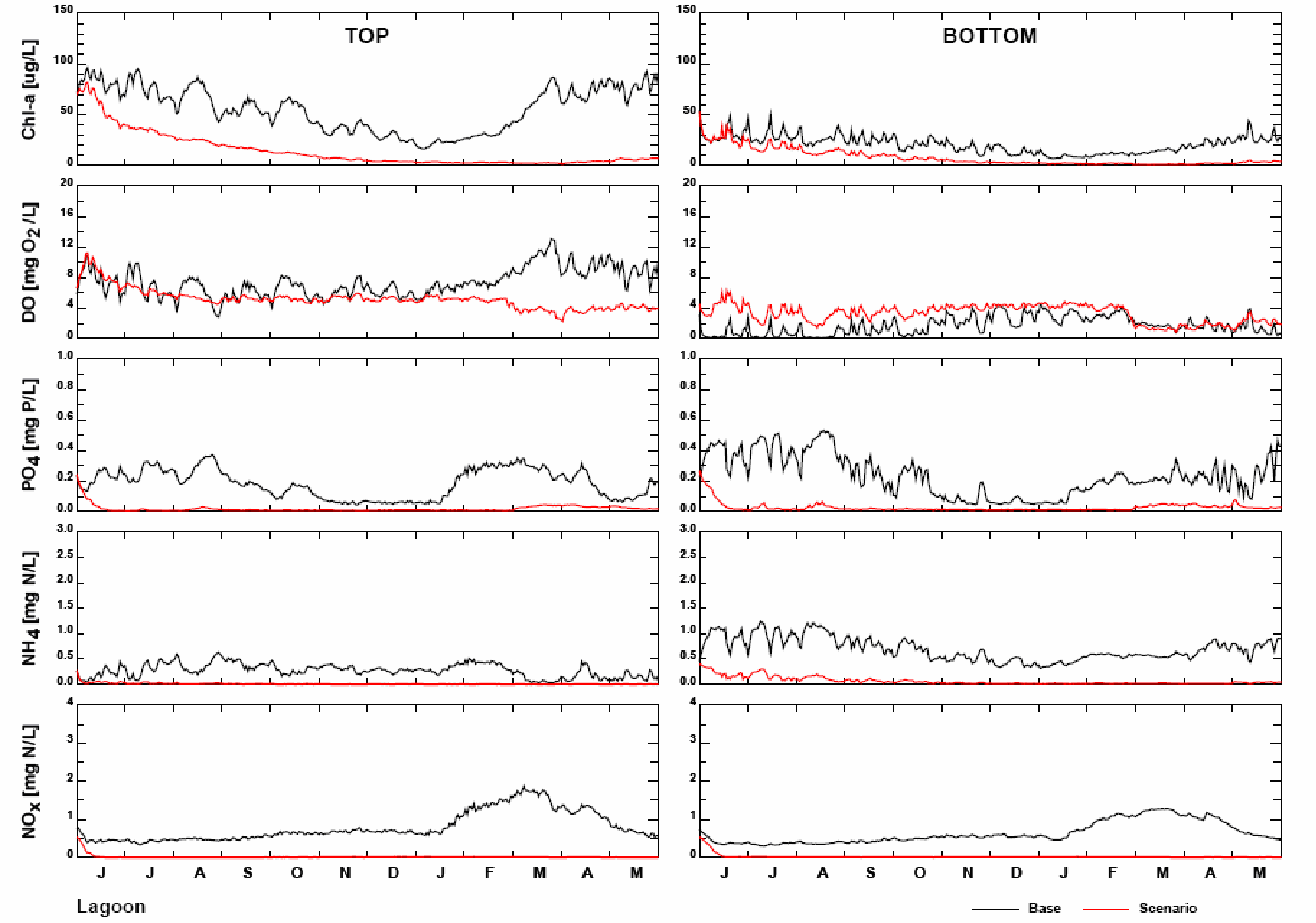


Figure 5.19: Comparisons of base calibration and scenario results (scenario 4) in the lagoon along Dubai Creek

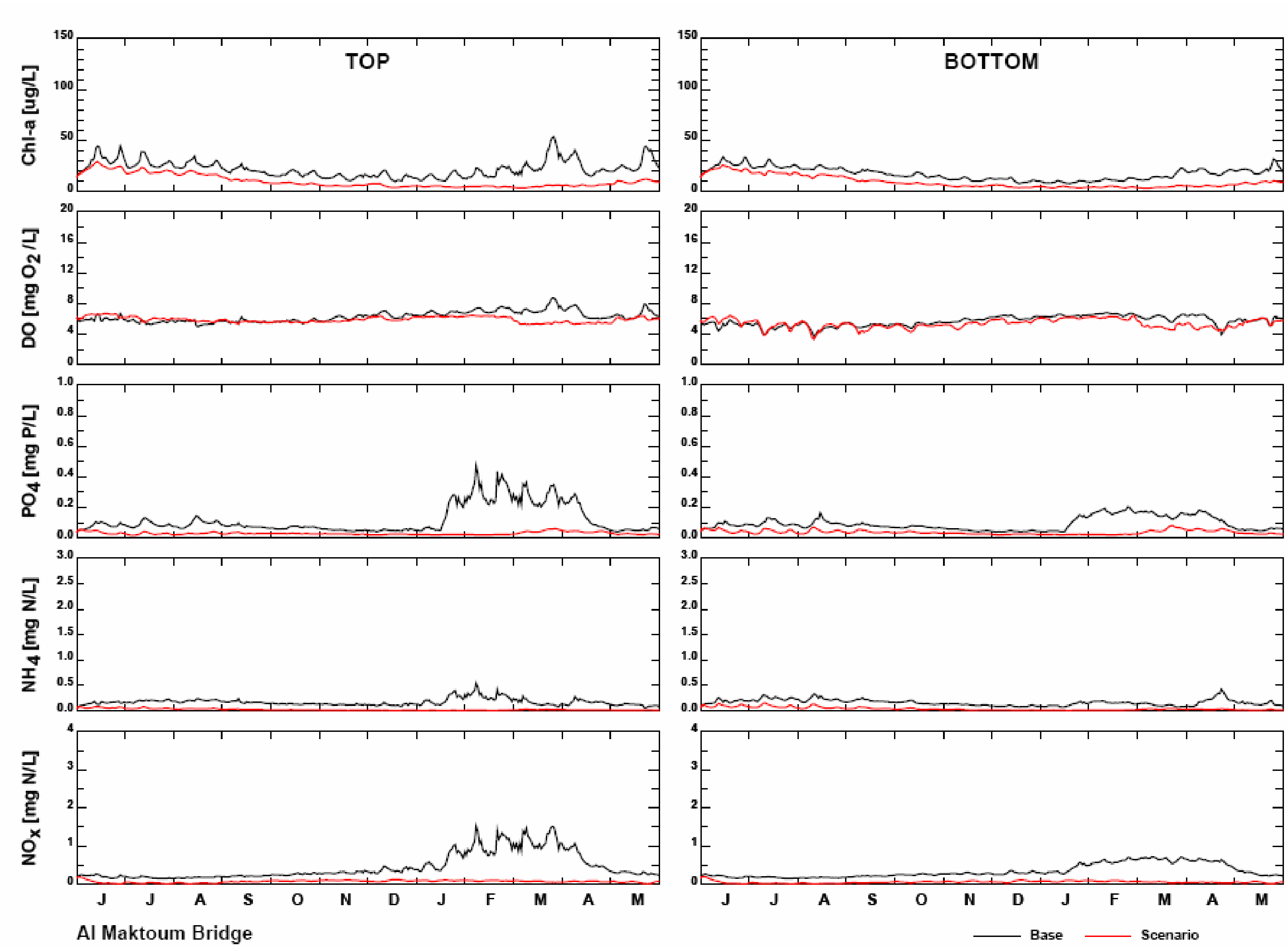


Figure 5.20: Comparisons of base calibration and scenario results (scenario 4) at station 2 along Dubai Creek

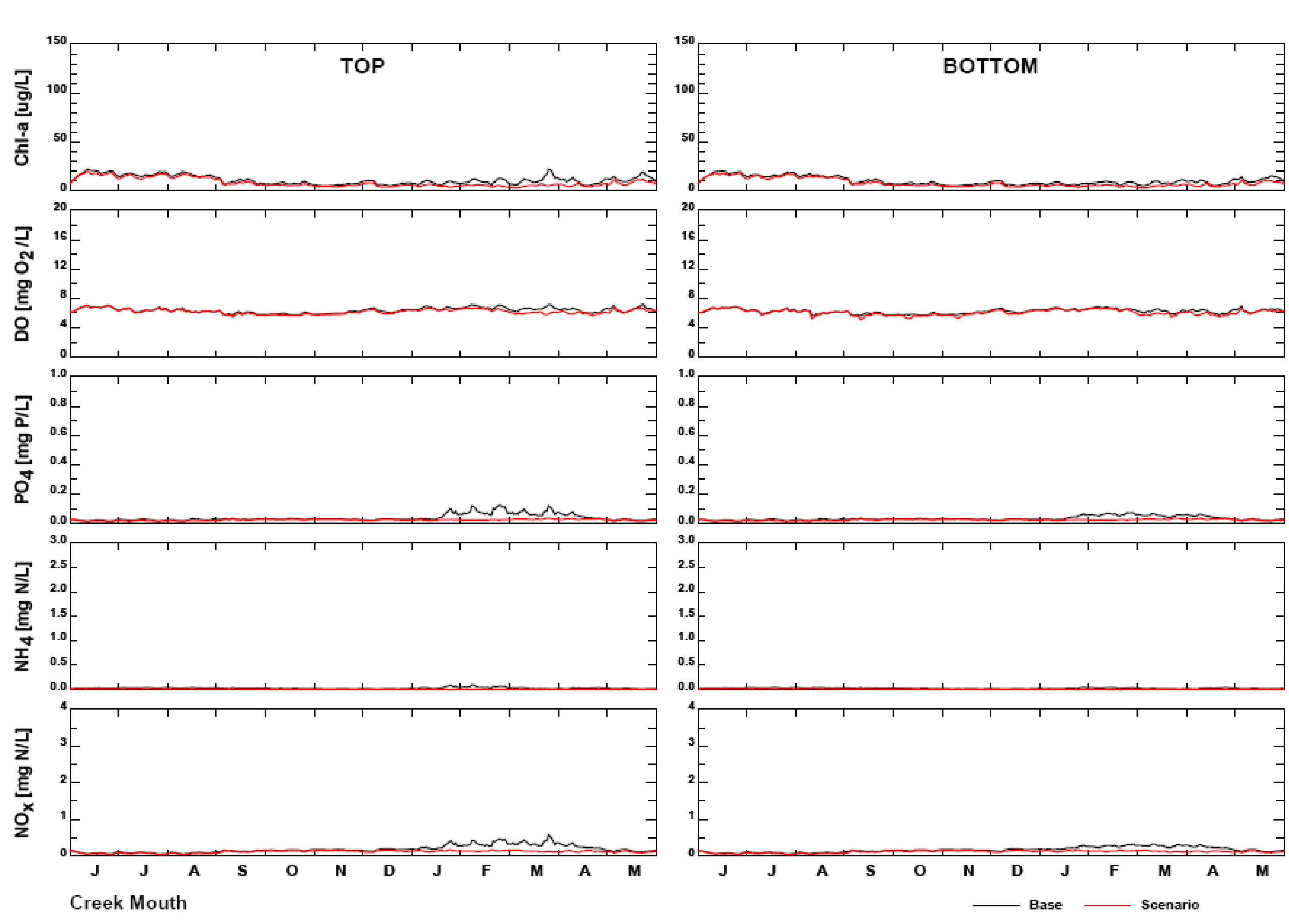


Figure 5.21: Comparisons of base calibration and scenario results (scenario 4) at station 1 along Dubai Creek

5.4.5 Management Scenario 5 (Dredging and Tertiary Treatment before of STP Discharge)

This scenario is a variation of scenarios 2 and 3, whereby in addition to dredging, the flow of wastewater remains the same but with a significant reduction of the nutrient loads as a result of the tertiary treatment. Again, because deepening might affect transport, the one-year water quality computations used the transport from the hydrodynamic model with the re-configured bathymetry in the dredged zone while all other forcing functions remained the same.

The comparisons between the base case and the projections for Chlorophyll-a, DO, PO_4, NH_4, and NOx daily average concentrations in the surface and bottom water at three locations along the Creek – the lagoon, downstream of station 3, Al-Maktoum Bridge, and at the Creek mouth station 1, are presented in Figure 5.22-24. As expected the model computations predict a marked improvement in water quality in the Creek as a result of the combined tertiary treatment and dredging measures. However, because of the residual nutrients concentrations in the effluent, at the end of the annual cycle, the model computes chlorophyll-*a* levels in the lagoon area approaching 15 µg/L compared to 20 µg/L if the STP discharge was completely discontinued without dredging (scenario 1). In August, the DO levels in the bottom waters increase relative to the base case from zero mg/L to about 2 mg/L (versus 3 mg/L without the STP discharge). Because the dredged zone in this scenario is limited to the area between by the anti-pollution booms and DFC site, sediments in the un-dredged areas (e.g., Sanctuary and downstream of DFC) would continue to exert an oxygen demand and release nutrients in the water column. However, the model computations under scenario 1 (discontinuation of the STP discharge) suggest a recovery time of 5 to 7 years without any partial dredging. It is consequently expected that the combination of the latter measure with a reduction of nutrients levels in the STP discharge would further shorten that recovery period.

The model computation also shows that chlorophyll-a and nutrient concentrations decrease with distance from the upper Creek toward the lower sections. In the vicinity of Al-Maktoum

Bridge, the model predicts an obvious improvement in the Creek's water quality. As mentioned under scenario 2, the reduction of nutrient levels from the effluent through tertiary treatment would deprive the irrigation water of its essential minerals. If this mitigation measure were to be adopted, one would expect that nutrient reduction would be exclusively applied on the effluent destined for the Creek's discharge. However, the variability in the demand for irrigation water might pose operational problems in a tertiary treatment unit, which is usually designed for a narrow range of flow regimes.

In summary, the model computations in this scenario predict a significant improvement in the quality of the water, in particular, in the upper section of the Creek. Residual nutrients in the discharge are not high enough to promote any significant algal growth beyond the ambient concentrations resulting from nutrient release from sediments in the un-dredged areas.

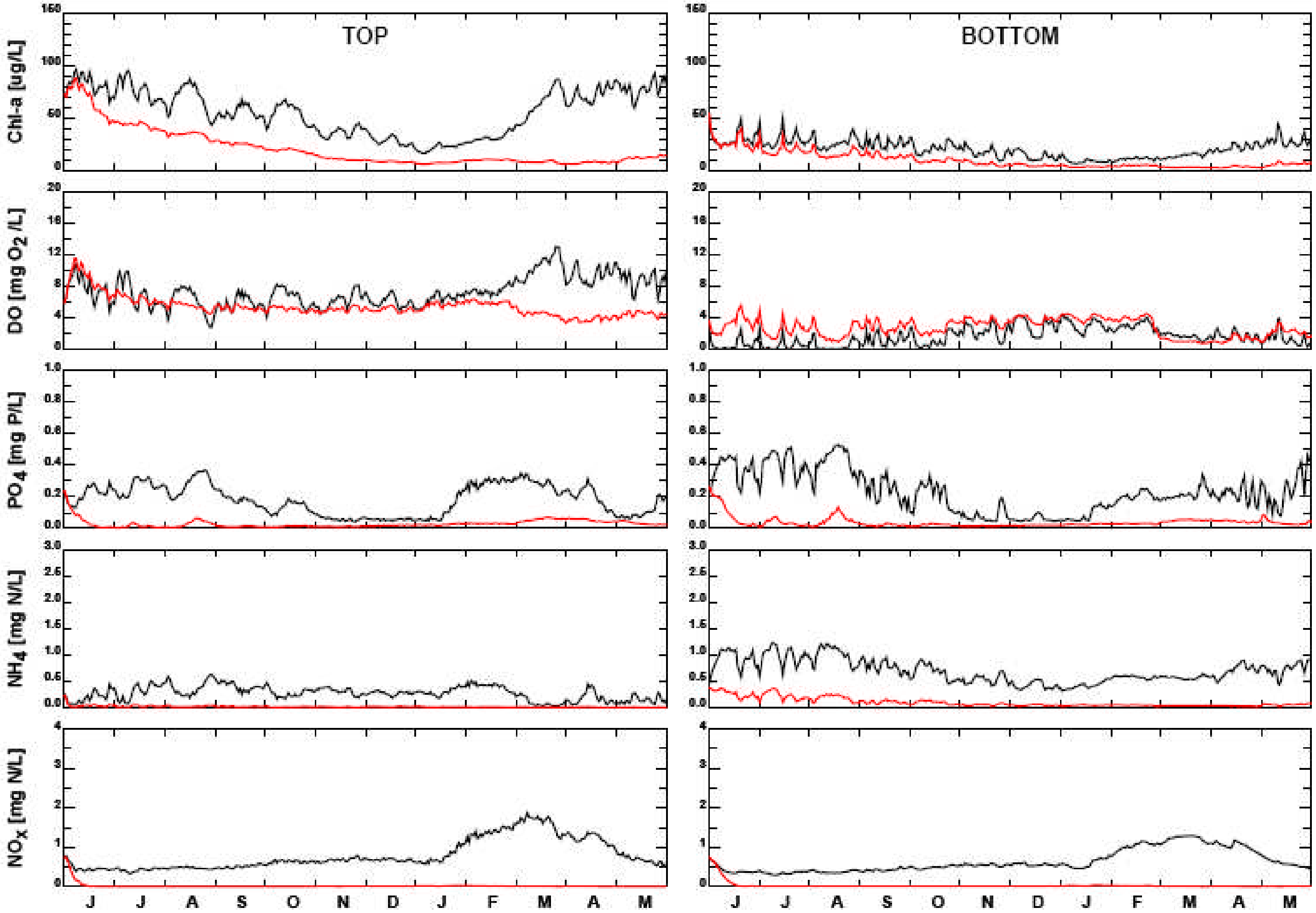


Figure 5.22: Comparisons of base calibration and scenario results (scenario 5) in the lagoon along Dubai Creek

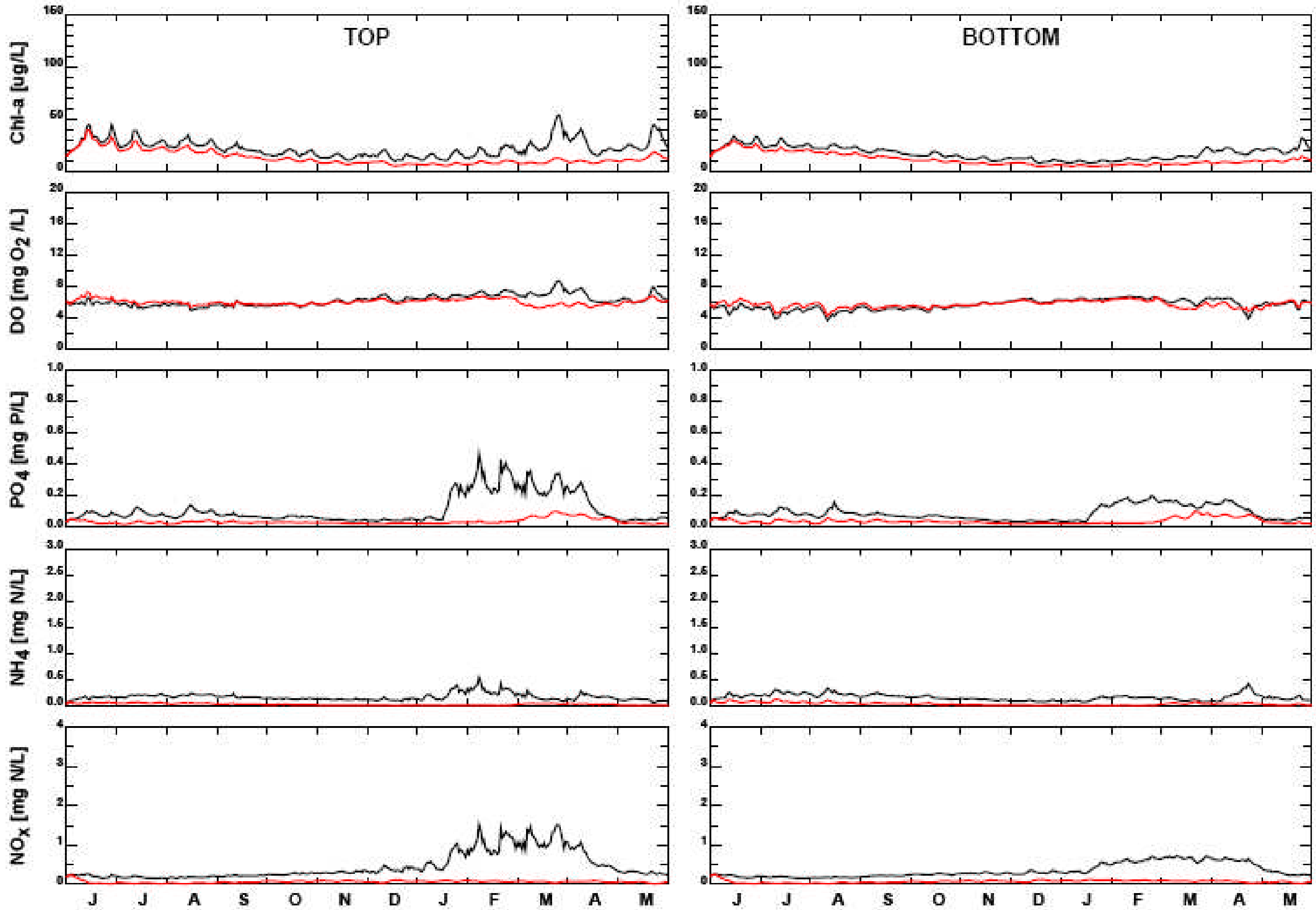


Figure 5.23: Comparisons of base calibration and scenario results (scenario 5) at Station 2 (Al Maktoum Bridge) along Dubai Creek

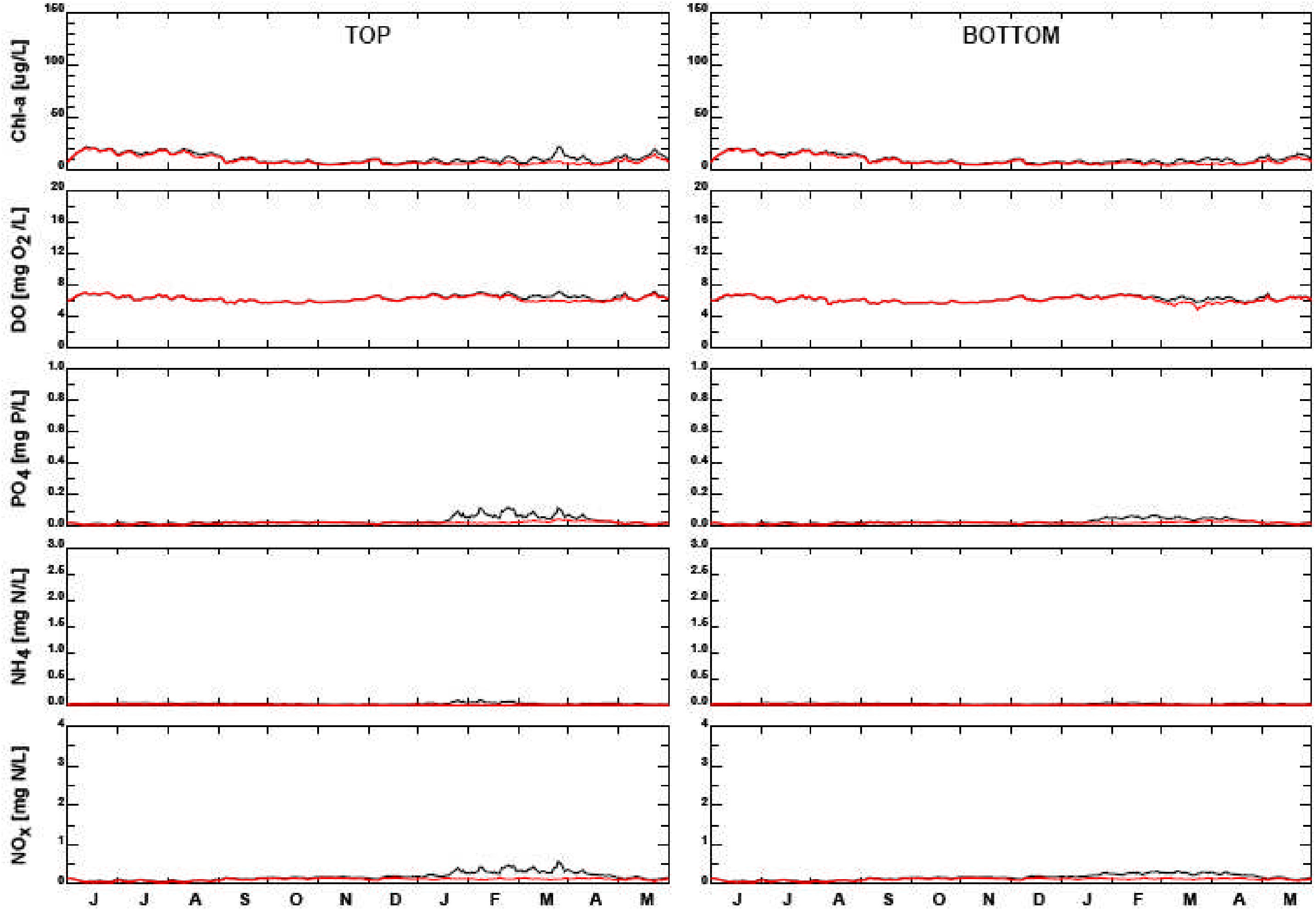


Figure 5.24: Comparisons of base calibration and scenario results (scenario 5) at Station 1 (Creek Mouth) along Dubai Creek

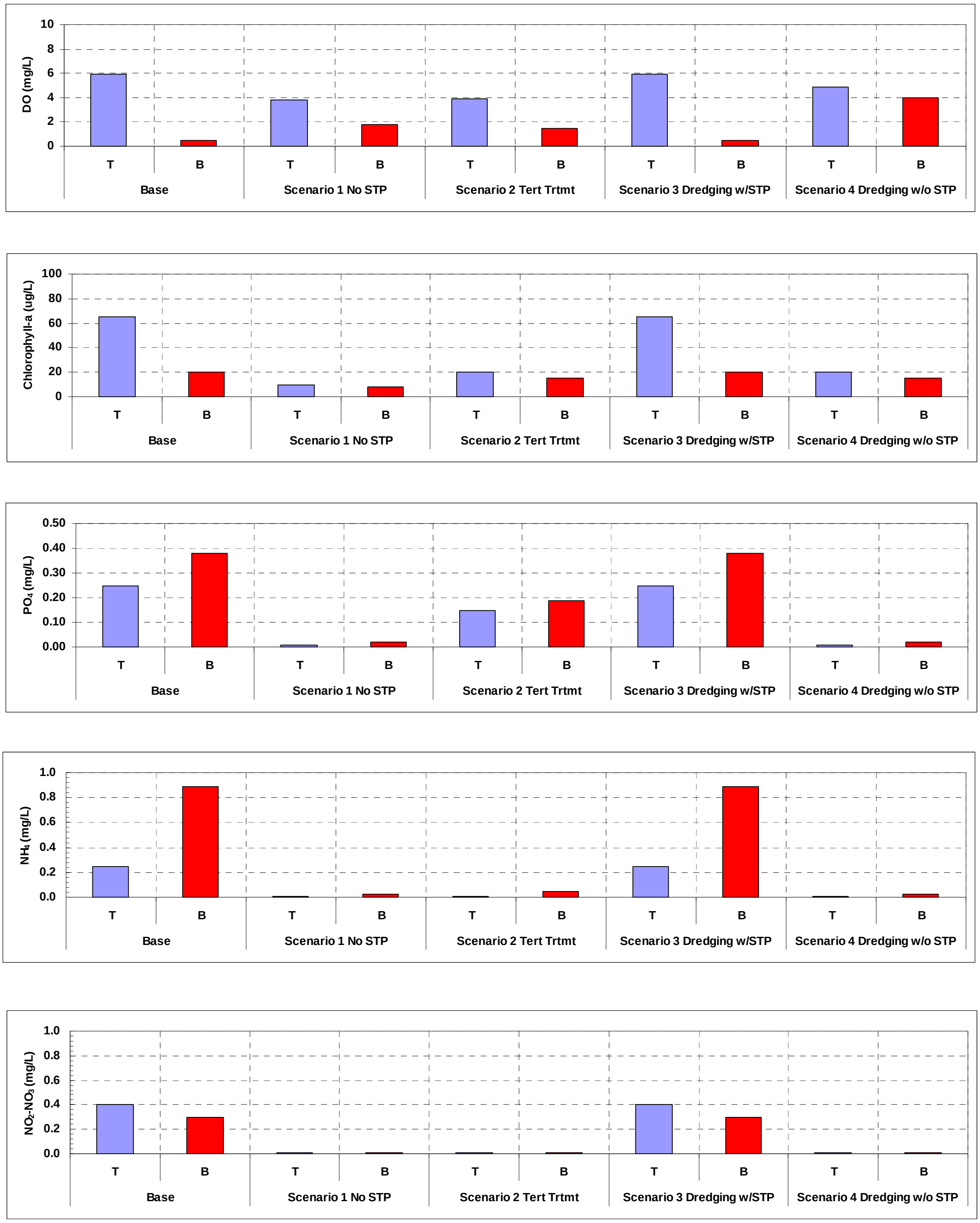


Figure 5.25:Comparison of base vs. projected DO, chlorophyll a and nutrients concentrations during the month of August for scenarios 1, 2, 3 and 4 in the lagoon area for surface (blue columns) and bottom (red columns) waters.

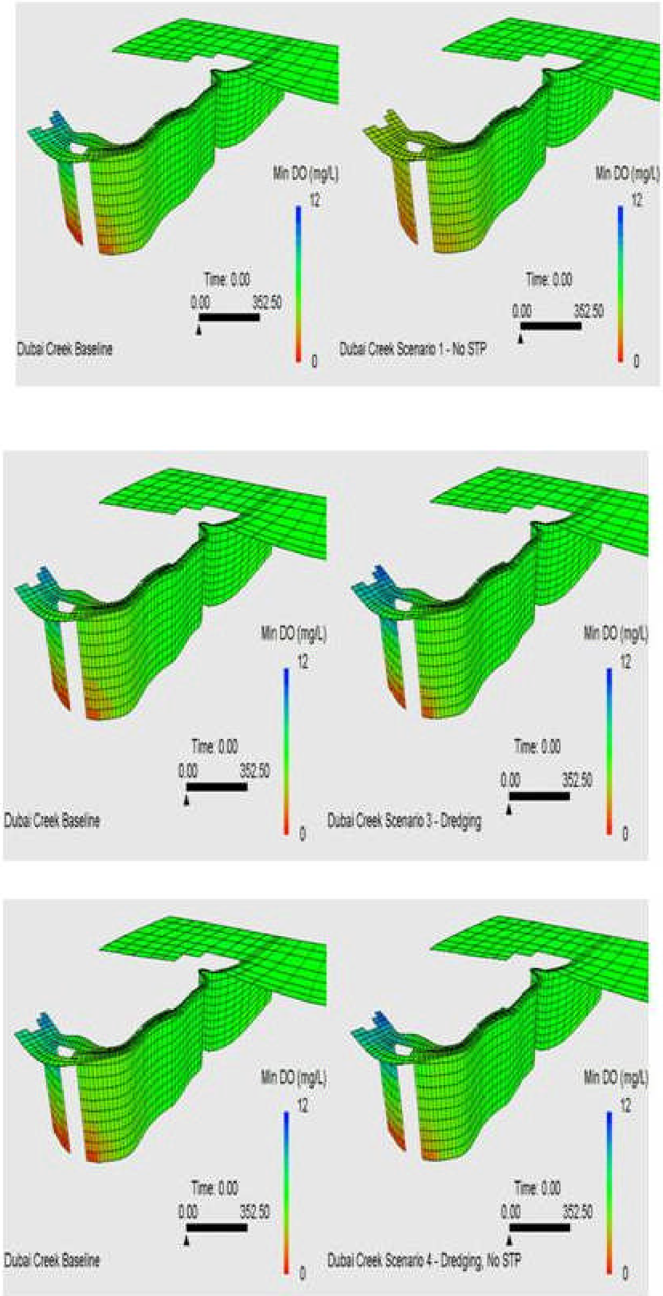


Figure 5.26: Model simulation DO for scenario 1, 3 and 4 for Dubai Creek. No simulation made for scenario 2. or 5.

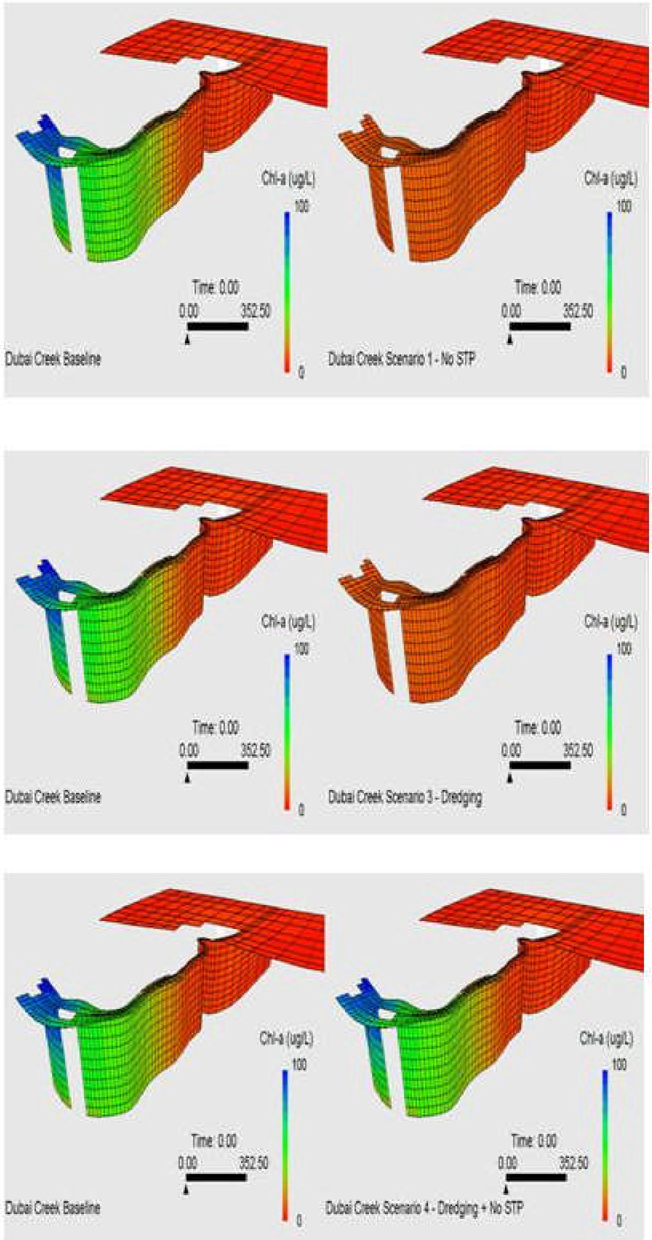


Figure 5.27: Model simulation chlorophyll a for scenario 1, 3 and 4 for Dubai Creek. No simulation made for scenario 2 or 5.

Conclusion

The modeling run for management scenario indicates:

- Scenario 1 (No STP): The Concentrations of nitrogen and chlorophyll a decline relatively quickly and the rate of decline is higher in areas far removed from the STP site (Figures 5.25-5.27).
- Scenario 2 (Tertiary treatment of STP): Tertiary treatment is designed to reduce the nutrient concentrations in the effluent; a reduction in the nutrient levels of the receiving waters would improve the water quality (Figure 5.25).
- Scenario 3 (Dredging): The rationale is based on the assumption that by removing the reservoir of nutrients (i.e., sediment layer) from the bottom of Dubai Creek, the flux of nutrients to the water column will cease and Dubai Creek water will ultimately improve. This removes an element of latency from the system (Figures 5.25-5.27).
- Scenario 4: (No STP + Dredging): The rationale of combining both measures is showed that eliminating the STP discharge is likely to improve the quality of the receiving waters, the sustained release of the buried phosphorus will slow that improvement. In addition, removing the active sediment layer by dredging, without ceasing the input of nutrients from the sediment will result in the re-building of an active layer and the return to the status quo (Figures 5.25-5.27).
- Scenario 5 (Tertiary treatment of STP + Dredging) model computations predict a marked improvement in water quality in the Creek as a result of the combined tertiary treatment and dredging measures.
- Scenario 5 provides the best management option for the improvement of Dubai Creek water quality with rapid declines in nutrient and improvement in environmental variables.

ANNEX

Introduction

RCA is a Row-Column version of AESOP, HydroQual's general purpose water quality modeling computer code. RCA was developed to directly interface with HydroQual's general circulation model, ECOMSED. As such, it will eliminate the need to use ECOSOP, the hydrodynamic to water quality model interface program that is required to link ECOMSED and AESOP.

Both RCA and AESOP solve general mass balance equations for water quality variables of interest. The principle difference between RCA and AESOP is that RCA obtains it advective and dispersive transport fields from a hydrodynamic model, whereas in AESOP the transport fields are specified by the user, based on kinematic box analysis or via calibration to a conservative tracer variable such as salinity.

A second difference between the two computer codes is that RCA has been written to take advantage of the parallel processing capabilities of CRAY or SGI computer systems and, therefore, should be faster than an equivalent AESOP model with the same number of segments.

Characteristics of the Model

Generality

RCA (as is AESOP) is a general purpose code developed to be used to evaluate a myriad of water quality problem settings. The user is able, via the development of a FORTRAN subroutine, to tailor RCA to address the specific water quality issues of the water body under investigation. The FORTRAN subroutine (called TUNER) prescribes the biological, chemical and/or physical kinetics or interrelationships between the relevant water quality variables of interest.

Mass Balance

RCA formulates mass balance equations for each model segment for each water quality constituent or state-variable of interest. These mass balance equations include all horizontal, lateral and vertical components of advective flow and dispersive mixing between model segments; physical, chemical and biological transformations between the water quality variables within a model segment; and point, nonpoint, fall-line and atmospheric inputs of the various water quality variables of interest.

Finite Difference

The partial differential equations, which form the water quality model, together with their boundary conditions, are solved using mass conserving finite difference techniques, Equation 1.

$$\frac{dM_i}{dt} = C_i \frac{dV_i}{dt} + V_i \frac{dC_i}{dt} \quad (1a)$$

$$\frac{dV_i}{dt} = \sum Q_{in} - \sum Q_{out} \quad (1b)$$

$$\frac{dC_i}{dt} = \sum \frac{Q_{in}}{V_i} \left(\alpha \, C_{up} + (1-\alpha) \, C_i \right) - \sum \frac{Q_{out}}{V_i} \left(\alpha \, C_i + (1-\alpha) \, C_{dwn} \right) + \sum \frac{R_{ij}}{V_i} \left(C_j - C_i \right) + \frac{W_i}{V_i} \pm k_i \, C_i \quad (1c)$$

where

M_i = mass of substance in segment i (kg),
C_i = concentration of substance in segment i (mg/L),
V_i = volume of segment i (m^3),
t = time,
Q_{in} = flow(s) entering segment i (m^3/sec),
Q_{out} = flow(s) leaving segment i (m^3/sec),
α = weighting or differencing factor,
= 1 for upwind scheme,
= 0.5 for central differencing scheme,
C_{up} = concentration of substance entering segment i due to Q_{in}, i.e., the concentration in the "upstream" segment (mg/L),
C_{dwn} = concentration of substance in the "downstream" segments associated with Q_{out} (mg/L),
R_{ij} = bulk exchange coefficient between segments i and j (m^3/sec),
C_j = concentration of substance in segment j (mg/L),
W_i = load or source input of substance i (kg/day),
k_i = reaction of substance in segment i (day^{-1}).

Each water quality segment or grid cell is assumed to be completely mixed, i.e., the concentrations of each water quality variable are uniform within the model segment or grid cell. Two finite difference approximations are available for the space derivatives: central difference, which introduces little or no artificial diffusion; and backward or upwind difference, which introduces an artificial diffusion that is proportional to the advective velocity and the grid size, as per Equation 2:

$$E_{num} = \frac{u\Delta x}{2} \quad (2)$$

where

E_{num} is the artificial or numerical diffusion (m^2/sec),
u is the advective velocity (m/sec),

Δx is the grid spacing (m).

Ideally, one would want to utilize central difference approximations in water quality modes, since no artificial diffusion is introduced into the model solution. However, the use of central differences can introduce other "problems" (but not errors) into the solution of the model equations. In particular, the use of central differences does not guarantee positivity, i.e. "negative" concentrations can be computed, although mass is conserved. Nor do central differences resolve step functions or delta functions, as might be introduced by point source inputs or intermittent CSO inputs, in a desirable fashion. The specification of these "abrupt" inputs can result in the generation of "saw-toothed" solutions, i.e. small oscillations about the mean concentration profile, along a spatial gradient, or "in a purely advective system" the apparent propagation of concentration upstream of a pollutant discharge. Again, these characteristics are not "errors" in the solution, but rather undesirable features resulting from the use of central differences in an attempt to eliminate numerical dispersion. While the central difference algorithm is available for use in RCA applications, it is recommended that it not be used because of the aforementioned problems.

As noted above, backward or upwind finite difference approximations to the continuous partial differential mass balance equation are also included as an option in RCA. While upwind differences do maintain positivity and do not generate "saw-toothed" solutions, they do introduce numerical dispersion into the finite difference equations. For certain problems, the magnitude of this numerical dispersion might be sufficient to eliminate or significantly reduce concentration gradients in the vertical or horizontal planes. To partially alleviate this problem, RCA has been coded with an additional user selectable option that permits the use of an upwind corrector scheme, based on Smolarkiewicz's antidiffusive velocity algorithm, which reduces the magnitude of the numerical dispersion in the finite difference solution. While this option can significantly improve the resolution of vertical and horizontal concentration gradients by RCA, it does so at the cost of additional computational overhead (20 to 50 percent increases in run-time).

<u>Solution Options</u>

RCA provides the user with a number of numerical schemes for solving the water quality mass balance equations. In time-variable mode, the user may utilize one of five explicit time-stepping algorithms, all of which require that the time-step (Δt) obey Equation 3:

$$\Delta t \leq \mathrm{Min}\left(\frac{V}{\sum Q + \sum R + kV}\right) \tag{3}$$

where

Δt is the maximum time-step or integration interval (secs),

V is the segment volume (m^3),

$\sum Q$ is the sum of the advective fluxes leaving the segment (m^3/sec),

$\sum R$ is the sum of the dispersive fluxes leaving the segment (m^3/sec),
kV is the loss rate of material due to kinetic reactions (m^3/sec).

The five algorithms include: (1) a centered-in-time Smolarkiewicz-corrected upwind scheme; (2) forward-in-time (first order Euler) with and (3) without Smolarkiewicz correction upwind schemes; (4) and split-timestep with and (5) without Smolarkiewicz correction upwind schemes.

Two modifications have been implemented within RCA to reduce run times for computationally-intensive applications. First, an option to evaluate the kinetic portion of the mass balance equation on a less frequent basis than the transport portion of the equation is evaluated and, second, a split-timestep integration procedure. The first modification assumes that the kinetics or reaction rates of the problem have much lower time constants than do the transport, i.e., the biological or chemical reaction rates on the order of 0.01 to 0.2/day versus equivalent transport rates of 1 to 10/day or greater (equivalent to detention times of 1 to 0.1 days or less). If, for example, a model investigation of eutrophication requires a timestep of 0.01 day (about a quarter hour) to meet the stability criteria of Equation 3, a user might wish to select the option in RCA which permits the kinetic subroutine (TUNER) to be evaluated every 0.10 days, rather the 0.01 day required for the transport. Selecting this option might permit a savings of 20 to 30 percent of the runtime. However, it is recommended that all final calibration runs and all projection runs be performed with the kinetic routine called every transport timestep. This ensures that no "errors" are introduced into the model solution. One way to determine the maximum stepsize for evaluating the kinetic subroutine is to perform a number of simulations, wherein the stepsize for evaluating the kinetics is increased each time and the computational results are compared against a run wherein the kinetic and transport stepsizes are the same, i.e., the base case. The user could then pick a stepsize value for evaluating the kinetics, which minimizes computer runtime, but does not significantly affect the computational results relative to the base case.

The second modification (available in the "in-house" version of RCA), split time-step integration, permits the integration of the "critical detention time" segments using a small timestep to maintain stability for the critical segments, while integrating the remaining (majority) of the water quality segments using a larger (factor of 5 to 10) timestep than is required for the critical segments. One of the options available in RCA is to have RCA step through the entire simulation period (or hydrodynamic transport file) to determine the critical integration timesteps for each averaging period within the hydrodynamic record. This diagnostic analysis provides the absolute "critical" timestep required to maintain stability (as defined by Equation 3) and, in addition the critical timestep for 1, 5, 10, 15 and 20 percent of the computational water quality grid. For example, a water quality grid with 5,000 segments might have the following "average" critical timestep characteristics: an absolute critical timestep of 0.0057 days; 1 percent (50 segments) with a critical timestep of 0.0091 days or less; 5 percent (250 segments) with a critical timestep of 0.012 days or less; 10 percent (500 segments) with a critical timestep of 0.021 days or less; 15 percent (750 segments) with a critical timestep of 0.026 days or less; and 20 percent (1000 segments) with a critical timestep of 0.031 days or less. The user could, then, using the appropriate RCA input options, select a critical or split timestep of 0.005 days and a full timestep of 0.025 days (and possibly further select a kinetic subroutine timestep of 0.10 days). This could result in an overall 50 to 75 percent reduction in total computational time over the base case, where all segments are integrated using a timestep of 0.005 days and a kinetic timestep of 0.005 days. Once again the user is urged to perform a number of runs in order to evaluate the sensitivity of the model solution to the split time-step integration stepsize.

Variable Grid Size and Sigma-Level and Z-Level Coordinates

Since RCA depends upon the hydrodynamic model, ECOMSED, for its model geometry and transport fields, it employs the same variable horizontal grid and vertical (either sigma- or Z-level) coordinate system as does ECOMSED. (For further information on sigma coordinates and the HydroQual general circulation model the user is referred to the ECOMSED Primer.) While the user may run RCA using a sigma-level coordinate system, RCA will still permit the user to specify boundary condition and initial conditon inputs using standard (or fixed depth) levels. RCA then transforms the standard level inputs to the sigma-level grid using linear interpolation.

Flexible Specification of Pollutant Inputs

RCA permits the user to specify pollutant inputs using any or all of four categories: point source (WWTPs/CSOs/SSOs), nonpoint source (urban/agricultural/ watershed runoff), fall-line or riverine sources, and atmospheric source (wetfall/dryfall). Although all pollutant inputs could be organized and input into the model as one loading group, as is done in AESOP, it was thought that permitting these four groupings in RCA would provide the user with greater flexibility in structuring his/her input deck. By splitting the inputs into four groups, the user can perform sensitivity or component analysis much easier by just setting the scale factor for the appropriate group to the desired value rather than be forced to edit the input file and modify a large group of numbers that correspond to the loading group to be analyzed. An example of this would be to reduce all STP and CSO inputs by fifty percent but keep all non-point source, riverine and atmospheric loadings the same. To do this the user would need only to set the scale factor of the point source loading group to 0.5, leaving all other inputs to the model the same.

Flexible Disk Storage of Computational Results

RCA permits the user two types of storage for computational results: (1) domain-wide or "global" dumps of all state-variables at "coarse" time intervals; and/or (2) detailed dumps for selected segments at "fine" time intervals. In the first instance a user could save concentrations for all state-variables over the entire model domain for a period of a year using 10 day intervals. This would permit the user using the HydroQual post-processing tool H4D to generate contour plots or time-variable movies for any plane within the model. When using detailed dumps a user can generate more detailed information concerning model performance by saving secondary variables, such as total extinction coefficients, nutrient limitation terms, etc., as well as the state-variable concentrations for selected segments within the model, at one day intervals. The user could then generate detailed time-series plots using HydroQual post-processing tool GDP. (Note: the information contained in the detailed dumps is determined in the TUNER subroutine via a series of CALLs to the subroute RCAWBUF. A more complete description of the structure of the RCA output files is contained in Appendix D.)

Enhancements to RCA Version 3.0

A number of enhancements have been made between this release of RCA (Version 3.0) and previous versions of the code. These include:

- implementation of an integer "clock" to control the overall numerical simulation and the updating of hydrodynamic, load, and boundary condition inputs,
- a revised input structure for specifying point, nonpoint, and fall line loads that includes provision for specifying a load identification table,
- implementation of piece-wise linear interpolation of load inputs,
- greater checking for input errors, and
- use of comment or header records for input records to facilitate editing or modification of required input information.

In previous versions of RCA a real-time clock (in days) was used by RCA to keep track of the simulation time and coordinate with updating of time-variable models inputs such as generated by the hydrodynamic model ECOMSED or loadings and/or boundary conditions. Unfortunately, the use of REAL variables can result in numerical round-off errors after repeated addition of fractions. This can result in synchronization errors when updating the hydrodynamic model inputs. Therefore, RCA has been modified to use INTEGER variables to specify the numerical time-step for integration and to keep track of the simulation time. These internal variables will operate in units of seconds.

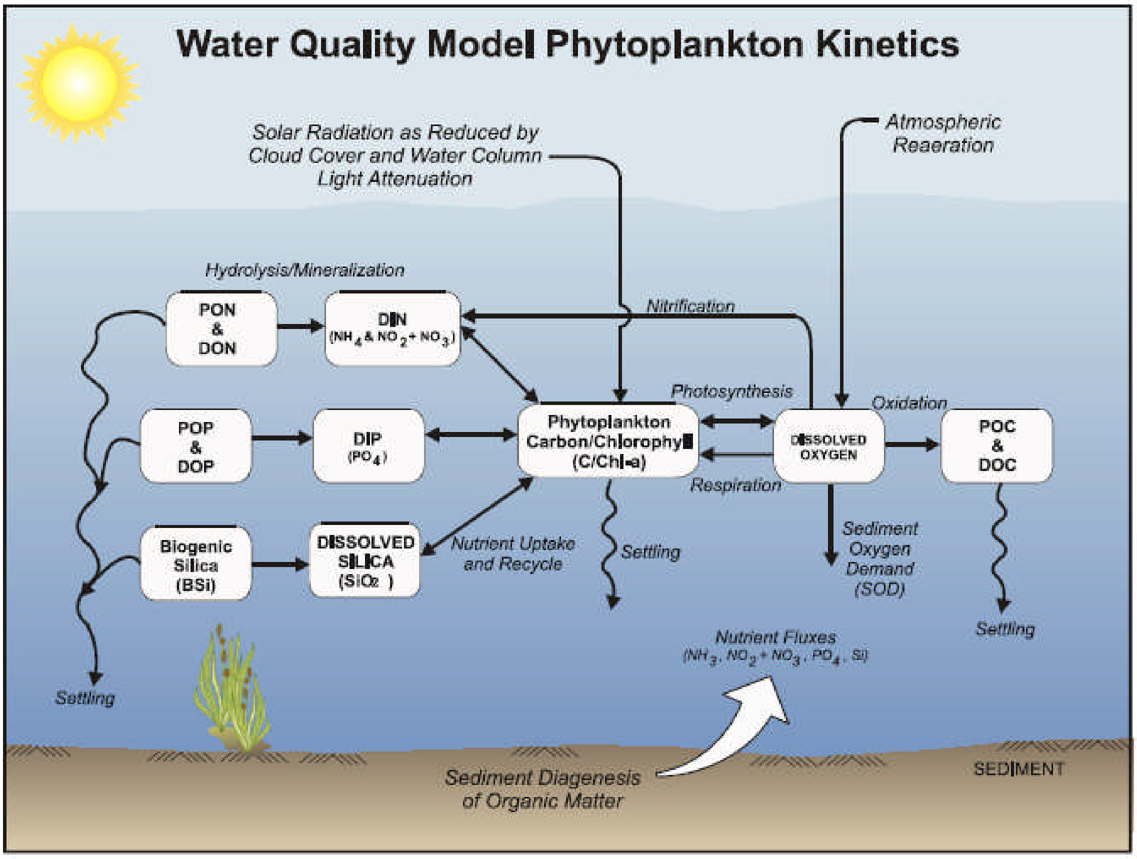
RCA has also been modified so that pollutant loads can be specified using piece-wise linear interpolation rather than just step function changes. As an example suppose a user specifies the following time-series input for a pollutant load:

value	time	value	time	value	time
10.0	0.0	20.0	50.0	40.0	100.

If the user selected the step-function option, the value of the pollutant load at time = 25 would be 10.0. If, however, the user selected piece-wise linear interpolation the value at time = 25 would be 15.

Version 3.0 of RCA has also been improved to provide greater checking of model inputs. For example, RCA will check to make sure that the model segment to which a pollutant load is assigned is a valid water cell.

Finally, for normal Ascii (or card-image) files, RCA has been modified to include a "comment" or "header" record to be read before every major input record. Although the user may leave these records "blank" without any consequence, use of these comment records to list or describe the input data to follow may facilitate subsequent editing or modification of the input data required to run the model. It should be noted, however, that comment or header records SHOULD NOT be included in binary files.



Principal Kinetic Interactions for Nutrient Cycles and Dissolved Oxygen

CHAPTER VI

Coastal Zone Management Strategies for Dubai Creek

6.1 Introduction

Chapters III, IV and V summarize the water quality conditions, the ecological status and provide water quality modeling respectively. From these chapters it is evident that:

- Dubai Creek is demarcated into 2 zones of related water quality and ecological characteristics- These regions being the channel and the lagoon
- The channel is characterized as a high flushing zone and with unpolluted water quality and balanced ecological characteristics
- There is a severe eutrophication in the lagoon of Dubai Creek
- Levels of nutrients in the lagoon are elevated due to continuous discharge from the STP outfall located in Dubai Creek
- Dark green and red colored blooms of phytoplankton are regular in the lagoon of Dubai Creek during summer and winter seasons
- Benthic life is almost entirely absent in the lagoon specifically during summer
- Phytoplankton and macro-benthos indicates heavy organic pollution in the lagoon of Dubai Creek

The conditions described above produce unaesthetic environmental condition in the lagoon, with fish mortality and unpleasant odor examples of existing water quality issues (Figure 1.1).

Figure 6.1: Water quality and ecological problems in the lagoon of Dubai Creek

6.2 Water Quality and ecological thresholds

Selected indicator water quality and ecological variables were interpreted against local and international, marine water quality criteria (Table 6.1) in order of priority (Dubai Municipality 2004, USEPA 2006 and ANZECC 2000).

Table 6.1: Water quality and ecological thresholds levels from local and international references.

Selected Variables	Mean levels (Dubai Creek lagoon)	Exiting Thresholds*	USEPA (2006) Thresholds**	ANZECC (2000) Thresholds***	Recommended Thresholds****
pH	8.21	Not available	6 – 8.5 (USEPA Class III Marine Recreation 2006)	-	7.8-8.2
DO mg/L	5.84	Not less than 5	-	-	Same as exiting
Suspended Solids mg/L	55.37	25	-	-	Same as exiting
NO_3-N mg/L	1.29	0.5	-	0.03-0.1	0.1
NH_4-N mg/L	0.59	0.1	-	0.004-0.05	0.05
Total Nitrogen mg/L	2.38	2	-	0.3-1.0	0.5
PO_4-P mg/L	0.52	0.05	-	-	0.05
Chlorophyll a mg/m^3	45.5	Not available	≤1.1 (USEPA Ambient WQ Rec. 2002)	-	Not more than 5
Macro-benthos biomass gm/m^2	0.1	Not available	Not available	Not available	Not less than 20

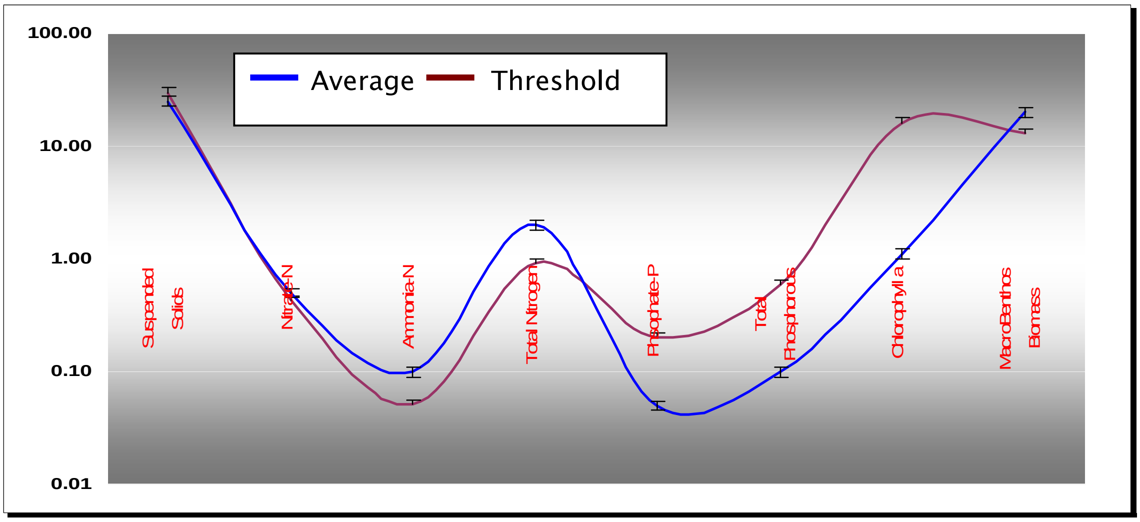
*Exiting thresholds levels Dubai Municipality (2004) - Marine Water Quality Objectives for Sea and Coastal Zone www.dm.gov.ae
**USEPA (2006) Used where DM do not address the variables- United States Environment Protection Agency www.epa.gov
***ANZECC (2000) Australian and New Zeeland Guidelines for water quality www.epa.qld.gov.au
**** Recommended thresholds for Dubai Creek based on the baseline values and regional references described in Table 1.2 kmzahed@rta.ae

6.3 Existing problem in the lagoon

Annual data collected from 6 monitoring stations covering ebb and flood tides from surface and bottom waters indicate high variation in water quality and ecological characteristics against threshold levels. These variations are more prominent in the lagoon and it is apparent from the present study that the lagoon needs an immediate action plan for the coastal zone management.

Overall, the annual average data(Figure 6.2 and Table 6.2) indicate that: except for NH_4-N and total nitrogen, indicator parameters of water quality (suspended solids, NO_3-N, PO_4-P, total phosphorous) and ecology (chlorophyll *a* and macro-benthos) in the channel are comparable with thresholds levels; and indicator parameters of water quality (suspended solids, NH_4-N and total nitrogen NO_3-N, PO_4-P, total phosphorous) and ecology (chlorophyll *a*) are much higher than thresholds in the lagoon. Levels of macro-benthos are much lower than the threshold in the lagoon.

Dubai Creek channel



Dubai Creek lagoon

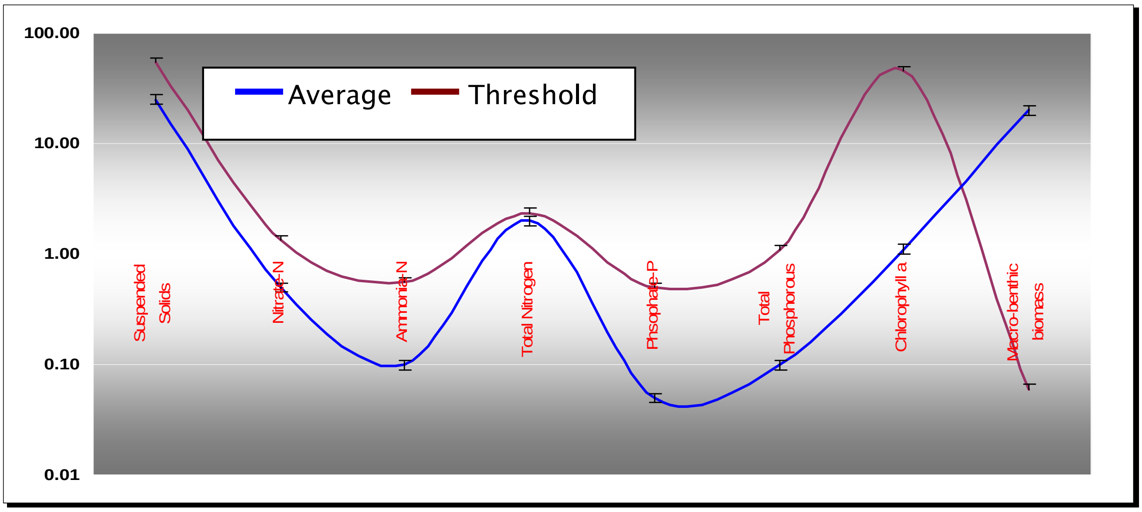


Figure 6.2: Comparisons in the levels of different variables against accepted threshold which should be established for Dubai Creek channel and Dubai Creek lagoon

Table 6.2: Options for the management of Dubai Creek environmental conditions based on the numerical simulations and reference values obtained from the regional published data

Variables	Management Strategies							
	Dubai Creek and reference value				Impact and management option			
	Channel value (average)	Lagoon values (average)	Reference value	Lagoon levels- number of fold higher/ lower than ref. value	Reference	Impact due to Higher/lower Value (Lagoon)	Management Option for the lagoon	Recommended water quality and ecological Objectives
Water temperature (°C)	25.93	26.06	-	-	-	-	-	-
pH	8.11	8.21*	7.9-8.2	-	Mustafa & Deshgooni (2002)	-	-	7.8-8.5
DO (mg/L)	6.1	6*	-	-	-	Fish Kill	Dredging Lagoon	Existing as given in table 6.1
Salinity ‰	39.93	39.50	-	-	-	-	-	-
Suspended Solids (mg/L)	29.59	55.37	-	-	-	Unaesthetic	Dredging Lagoon	Existing as given in table 6.1
NO_3-N mg/L	0.44	1.29	0.04-0.07	**18-32** ↑	Mustafa & Deshgooni (2002)	Odour	Stop STP	0.1
NH_4-N mg/L	0.07	0.59	-	-	-	Unhealthy	Stop STP	Existing as given in table 6.1
Total Nitrogen (mg/L)	0.97	2.38	-	-	-	Eutrophication	Stop STP	0.5
PO_4-P mg/L	0.21	0.52	0.02-0.03	**16-25** ↑	Mustafa & Deshgooni (2002)	Eutrophication	Stop STP	0.05
Total Phosphorous (mg/L)	0.54	1.02	-	-	-	Eutrophication	Stop STP	-
DOC (mg/L)	4.19	6.32	-	-	-	Organic Pollution	Stop STP	-
POC (mg/L)	2.12	4.54	-	-	-	Organic Pollution	Stop STP	-
Chlorophyll *a* (mg/m3)	16.1	45.5	0.9-1.4	**33-51** ↑	Mustafa & Deshgooni (2002)	Algal Bloom	Dredging lagoon	1.1
Phytoplankton counts (Nox10^3/L)	2672	10654	19.7-44.1	**241-549** ↑	Mustafa & Deshgooni (2002)	Discoloration	Dredging lagoon	-
Phytoplankton sp.	14	11	20-26	**2** ↑	Mustafa & Deshgooni (2002)	Unhealthy	Dredging lagoon	-
Zooplankton biovolume (No.m^3)	0.2	0.2	-	-	-	-	-	-
Zooplankton sp.	12	8	10-12	-	-	-	-	-
Zooplankton Population (No./m^3)	2842	2062	2200-8600	-	-	-	-	-
Macro-Benthos Biomass (gm/m^2)	13	0.1	26.5-130	**265-1300**↓	Sheppard et al 1992	Severe Impact	Dredging lagoon	Not less than 20
Macro-benthos sp.	12	3	-	-	-	Organic Pollution	Dredging lagoon	-

*Variation in surface and bottom are enormous

Abbreviation

↓ Low

↑ High

6.4 Solutions and Recommendations

Current assessment based on the data collected during 2005-06 suggests the following management strategies for Dubai Creek lagoon (Figure 6.3)

- Dredging in the lagoon of Dubai Creek (Figure 6.4)
- Treat waste from the STP or divert the outfall from the lagoon
- A new Government Decree should be made to achieve the water quality thresholds as suggested in Table 6.1 and Table 6.2

The above mitigation is of utmost urgency as the head of the lagoon has highly significant ecological and social value due to the internationally recognized bird sanctuary (Ras Al Khor Wildlife Sanctuary) and multibillions of dollars of waterfront property projects planned in the lagoon of Dubai Creek and its extension – Business Bay (Figure 6.5). Overall, Dubai Creek management should fall into an **"Immediate Action Plan"** for the beneficial and sustainable development of the Emirate of Dubai.

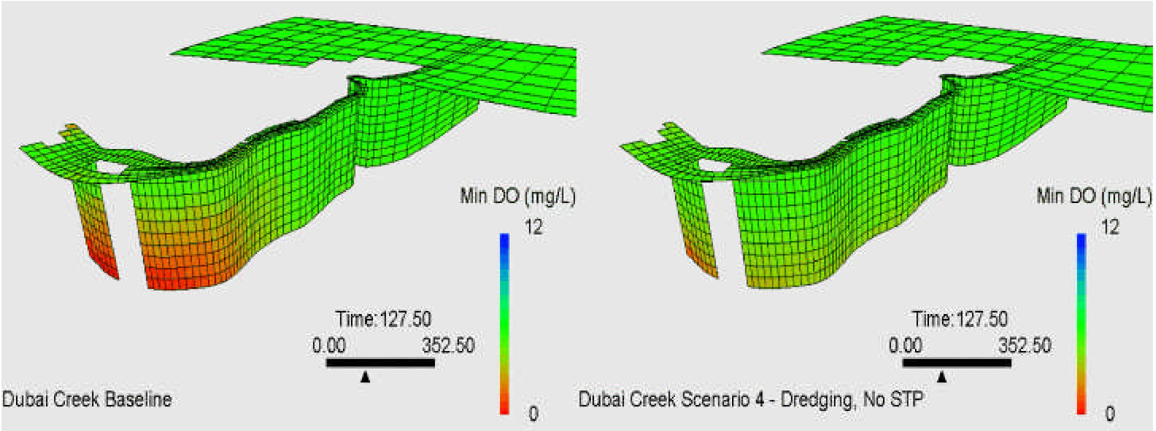


Figure 6.3: Recommended management scenario of Dubai Creek lagoon

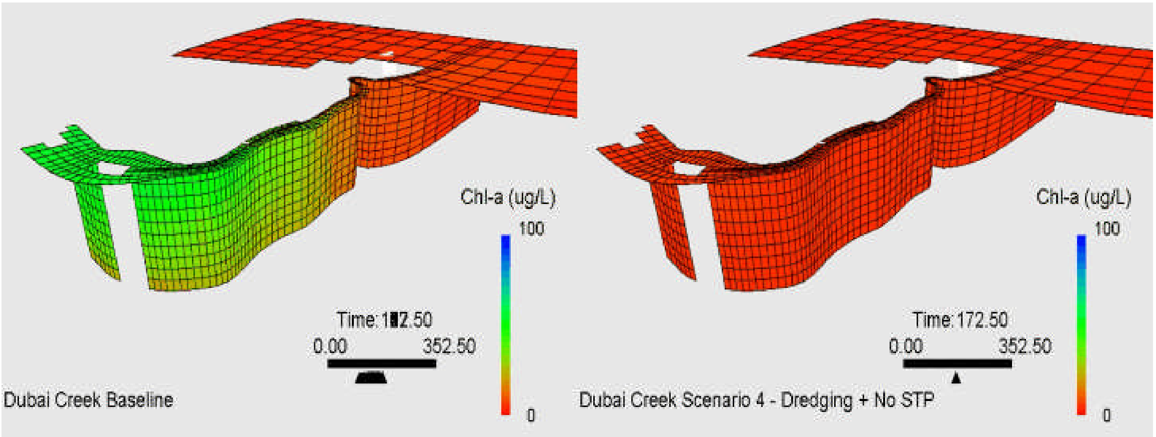


Figure 6.4: Recommended management scenario of Dubai Creek lagoon

Figure 6.5: Multibillion dollar developments are underway in the lagoon of Dubai Creek (Photo courtesy: Ten Real Estate)

6.5 Conclusion

The results obtained in Dubai Creek are alarming; the lagoon is susceptible to high organic pollution which exhibits 3-122 fold high nutrients levels while biodiversity in the same region at the seabed has almost died and ceased to exist.

Assessment suggests the formation of ICZM policy, with the following elements:

- New decree for water quality and ecological objectives or standards;
- Mitigation measures to achieve the goal for the management of water quality and biological variables; such mitigation are remedial dredging in the lagoon and treatment of STP discharge up to tertiary level before discharging into the Creek.

The suggested mitigation, dredging in the lagoon of Dubai Creek and tertiary treatment of wastewater from STP beside new thresholds indicator variables, will certainly improve the condition in Dubai Creek for coming multibillion waterfront projects, or else this may worsen the problem and devastate the attraction of water edge.

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Appendix I

Table 3.1: Variation in water quality variables along Dubai Creek during summer on the ebb conditions of 11 April 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	23.90	8.17	5.22	41.50	31.00	0.34	0.003	0.59	0.08	0.14	5.09	2.02
	Bottom	24.00	8.10	5.04	41.50	23.20	0.37	0.01	0.63	0.09	0.14	3.14	1.34
2	Surface	24.00	8.20	5.86	41.30	31.20	0.79	0.01	1.19	0.26	0.30	3.12	3.31
	Bottom	24.00	8.19	5.73	41.30	31.80	0.79	0.01	1.21	0.25	0.31	2.66	3.24
3	Surface	24.20	8.19	5.80	40.20	52.40	1.00	0.05	1.47	0.32	0.37	4.94	3.77
	Bottom	24.10	8.20	5.50	40.50	45.60	0.96	0.09	1.51	0.33	0.36	3.03	3.35
4	Surface	24.30	8.15	10.39	40.80	94.80	0.92	0.07	1.50	0.33	0.37	5.70	5.21
	Bottom	23.90	8.19	1.96	41.50	51.20	0.90	0.11	1.45	0.35	0.39	3.66	4.52
5	Surface	24.60	8.20	12.01	39.50	47.60	1.14	0.29	1.83	0.39	0.44	4.24	5.17
	Bottom	24.20	8.14	1.87	40.50	56.00	0.73	0.46	1.50	0.40	0.43	4.31	3.20
6	Surface	24.40	8.19	10.74	40.20	50.00	0.83	0.08	1.33	0.33	0.38	3.84	5.81
	Bottom	23.90	8.20	2.62	40.50	56.00	0.53	0.48	1.33	0.43	0.45	3.16	2.95

Table 3.2: Variation in water quality variables along Dubai Creek during summer on the ebb conditions of 28 April 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	25.80	8.20	5.86	39.90	17.50	0.39	0.16	1.09	0.21	0.23	2.53	1.61
	Bottom	24.90	8.15	5.19	40.00	20.00	0.40	0.15	1.06	0.21	0.23	2.47	1.33
2	Surface	25.60	8.20	5.70	36.10	19.00	0.85	0.56	2.03	0.39	0.47	3.55	2.68
	Bottom	25.00	8.20	5.49	36.10	18.80	0.66	0.47	1.54	0.31	0.36	2.78	2.08
3	Surface	25.10	8.10	5.29	39.20	23.30	0.84	0.66	2.20	0.42	0.48	3.59	2.97
	Bottom	25.10	8.14	5.21	39.20	25.60	0.76	0.64	2.07	0.45	0.46	3.99	2.46
4	Surface	25.50	8.13	7.83	40.90	26.00	0.85	0.44	2.00	0.40	0.47	3.94	3.11
	Bottom	25.20	8.14	7.32	41.00	30.80	0.18	1.25	1.84	0.52	0.56	3.48	2.65
5	Surface	26.10	8.19	8.59	39.80	32.80	3.47	2.55	6.37	1.07	1.10	2.93	3.23
	Bottom	25.10	8.13	4.19	41.20	30.80	0.80	0.85	2.39	0.48	0.53	4.71	2.80
6	Surface	25.60	8.20	8.64	40.90	332.00	0.77	0.48	2.01	0.42	0.47	4.04	3.07
	Bottom	24.90	8.16	2.70	41.30	32.00	0.14	1.38	2.03	0.54	0.61	3.96	2.70

Table 3.3: Variation in water quality variables along Dubai Creek during summer on the flood conditions of 5 May 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	27.60	8.10	4.97	40.50	23.40	0.12	0.02	0.57	0.05	0.07	2.05	1.39
	Bottom	27.50	8.09	4.83	40.60	23.60	0.10	0.01	0.51	0.05	0.07	1.82	1.72
2	Surface	27.60	8.15	5.40	40.40	21.20	0.13	0.02	0.63	0.06	0.09	1.62	1.37
	Bottom	27.50	8.15	5.31	40.50	17.40	0.19	0.04	0.68	0.10	0.13	1.76	1.48
3	Surface	28.20	8.14	5.12	39.00	32.00	0.65	0.10	1.43	0.31	0.33	2.27	3.50
	Bottom	27.70	8.12	4.14	39.30	35.60	0.57	0.12	1.36	0.24	0.31	2.90	2.46
4	Surface	28.80	8.13	7.67	40.90	31.20	0.81	0.06	1.65	0.41	0.47	3.21	7.61
	Bottom	26.90	8.17	0.02	41.30	31.20	0.68	0.34	1.79	0.43	0.46	3.92	4.47
5	Surface	28.50	8.17	7.20	40.10	16.80	0.94	0.10	1.93	0.45	0.51	4.26	8.03
	Bottom	26.80	8.18	0.04	40.00	42.80	0.44	0.48	1.79	0.49	0.49	3.84	3.83
6	Surface	28.30	8.21	6.89	40.00	38.80	0.80	0.08	1.66	0.41	0.46	4.21	7.62
	Bottom	26.70	8.18	0.02	40.20	37.60	0.39	0.60	1.86	0.51	0.50	3.94	3.67

Table 3.4: Variation in water quality variables along Dubai Creek during summer on the flood conditions of 26 May 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	28.50	8.10	4.97	40.60	18.80	0.02	0.00	0.26	0.01	0.03	1.92	1.08
	Bottom	27.90	8.09	4.83	40.30	16.40	0.01	0.00	0.21	0.01	0.03	1.72	0.72
2	Surface	28.60	8.15	5.40	40.30	11.00	0.07	0.00	0.35	0.05	0.07	2.36	1.24
	Bottom	27.60	8.15	5.31	40.20	16.80	0.07	0.01	0.37	0.05	0.08	2.35	1.32
3	Surface	28.80	8.14	5.12	39.20	153.50	0.34	0.07	1.03	0.26	0.32	3.61	5.11
	Bottom	27.90	8.12	4.14	39.40	91.00	0.33	0.14	1.18	0.27	0.34	3.22	3.89
4	Surface	28.20	8.13	7.67	40.90	65.00	0.39	0.18	1.33	0.35	0.41	3.91	6.04
	Bottom	26.60	8.17	0.02	41.30	100.00	0.04	0.77	1.75	0.47	0.52	4.22	3.18
5	Surface	28.10	8.17	7.20	40.10	83.00	0.35	0.25	1.39	0.33	0.38	3.82	5.76
	Bottom	26.60	8.18	0.04	40.00	76.00	0.34	0.48	1.67	0.40	0.47	3.79	2.77
6	Surface	28.80	8.14	9.95	40.00	61.00	0.41	0.00	1.02	0.27	0.35	4.35	11.69
	Bottom	26.47	8.14	0.95	40.20	93.00	0.17	0.72	1.79	0.48	0.51	4.03	3.20

Table 3.5: Variation in water quality variables along Dubai Creek during summer on the ebb conditions of 7 July 2006.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	34.20	8.00	5.64	40.80	18.00	0.08	0.01	0.44	0.07	0.13	3.00	2.20
	Bottom	34.00	8.10	5.45	41.00	21.00	0.07	0.01	0.36	0.07	0.13	3.20	1.80
2	Surface	33.80	8.20	5.86	41.20	14.00	0.12	0.03	0.60	0.13	0.19	4.00	2.40
	Bottom	34.00	8.20	5.72	40.20	18.00	0.11	0.04	0.35	0.13	0.20	4.20	1.80
3	Surface	34.10	8.20	5.28	40.20	24.00	0.60	0.01	1.20	0.20	0.27	3.24	2.40
	Bottom	34.00	8.10	5.62	40.10	25.00	0.40	0.01	0.72	0.22	0.26	4.22	2.20
4	Surface	33.90	8.40	8.42	40.30	64.00	0.90	0.02	1.44	0.25	0.31	6.20	5.40
	Bottom	33.80	8.30	4.05	40.00	26.00	0.86	0.08	0.93	0.37	0.43	5.30	5.20
5	Surface	33.80	8.60	9.68	39.50	48.00	1.40	0.68	2.38	0.71	0.80	4.80	6.20
	Bottom	33.70	8.40	1.02	39.80	43.00	1.10	0.70	1.87	0.43	0.49	4.60	3.20
6	Surface	33.70	9.10	10.24	39.20	110.00	0.90	0.09	1.98	0.37	0.40	5.40	7.80
	Bottom	33.60	8.60	0.54	39.60	24.00	0.80	1.30	1.44	0.45	0.49	5.60	4.60

Table 3.6: Variation in water quality variables along Dubai Creek during summer on the flood conditions of 7 July 2006.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	32.10	8.00	6.20	40.10	14.40	0.15	0.01	0.83	0.10	0.14	3.50	1.80
	Bottom	32.20	8.10	5.90	40.00	18.20	0.17	0.01	0.89	0.10	0.13	4.30	1.60
2	Surface	32.90	8.20	6.12	40.20	20.20	0.23	0.01	1.15	0.16	0.24	4.20	1.80
	Bottom	32.60	8.10	5.92	40.30	18.20	0.16	0.01	0.51	0.19	0.21	5.20	1.80
3	Surface	32.80	8.20	5.98	40.20	20.20	0.51	0.01	1.02	0.20	0.20	8.70	1.80
	Bottom	32.60	8.10	5.62	40.50	14.60	0.48	0.01	0.86	0.25	0.14	5.60	2.10
4	Surface	32.40	8.40	8.42	41.50	28.20	1.40	0.05	2.24	0.22	0.37	5.00	5.30
	Bottom	32.60	8.20	4.46	41.20	24.60	0.90	1.50	1.05	0.38	0.74	4.80	3.80
5	Surface	32.90	8.90	8.86	40.60	42.60	2.20	0.87	2.64	0.76	0.87	5.20	5.30
	Bottom	32.60	8.60	0.40	40.50	34.40	1.20	0.80	2.16	0.56	0.62	4.60	4.30
6	Surface	32.90	8.90	9.24	40.00	84.60	1.20	0.08	2.40	0.74	0.80	5.70	6.20
	Bottom	32.40	8.60	0.24	40.20	54.20	0.80	1.10	1.44	0.56	0.63	4.20	4.00

Table 3.7: Variation in water quality variables along Dubai Creek during winter on the flood conditions of 21February 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	20.70	8.10	5.16	40.70	14.80	0.05	0.00	0.27	0.02	0.04	2.42	0.62
	Bottom	20.70	8.10	5.27	40.70	14.40	0.04	0.00	0.22	0.02	0.03	6.55	0.46
2	Surface	21.10	8.15	5.65	41.20	17.80	0.91	0.03	1.37	0.22	0.24	2.50	1.21
	Bottom	21.50	8.16	5.42	41.10	18.40	0.71	0.03	1.05	0.18	0.18	2.08	0.90
3	Surface	21.20	8.15	5.74	39.40	36.00	1.65	0.08	2.22	0.38	0.42		2.85
	Bottom	21.80	8.19	4.92	39.30	34.80	1.33	0.10	1.84	0.33	0.34	2.61	1.38
4	Surface	22.20	8.10	12.30	39.70	73.00	2.95	0.06	3.55	0.56	0.61	3.68	6.79
	Bottom	21.30	8.15	4.06	40.80	30.00	1.49	0.35	2.23	0.42	0.43	3.07	1.32
5	Surface	22.40	8.11	12.86	38.90	72.00	3.35	0.37	4.41	0.67	0.72	4.14	5.38
	Bottom	21.40	8.17	3.44	39.80	38.00	1.09	0.62	2.01	0.45	0.46	2.88	1.15
6	Surface	22.70	8.11	12.82	39.00	59.00	3.21	0.15	4.20	0.62	0.70	5.35	6.87
	Bottom	21.30	8.14	1.78	39.70	30.40	0.90	0.81	2.04	0.50	0.51	2.72	1.10

Table 3.8: Variation in water quality variables along Dubai Creek during winter on the ebb conditions of 1 March 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	SS (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	21.50	8.09	4.48	40.70	18.60	0.66	0.04	1.01	0.15	0.20	2.43	0.82
	Bottom	21.50	8.10	4.80	40.70	34.20	0.37	0.06	0.59	0.13	0.16	2.06	0.77
2	Surface	21.80	8.12	5.66	41.20	46.00	1.01	0.12	1.32	0.29	0.32	3.19	1.98
	Bottom	21.50	8.12	5.86	41.30	31.40	1.22	0.12	1.70	0.29	0.34	2.93	1.17
3	Surface	22.10	8.15	5.27	39.90	44.00	1.86	0.17	2.52	0.44	0.46	3.59	2.20
	Bottom	21.60	8.19	4.97	40.50	47.20	1.55	0.35	2.29	0.38	0.43	3.06	1.50
4	Surface	22.90	8.15	12.17	39.00	65.60	3.07	0.53	4.03	0.69	0.71	3.90	3.39
	Bottom	21.30	8.12	1.19	40.30	71.60	1.14	0.72	2.24	0.50	0.52	3.88	1.24
5	Surface	22.90	8.14	12.20	39.60	34.40	3.46	0.63	4.54	0.73	0.78	3.70	3.10
	Bottom	21.30	8.16	0.08	38.30	49.60	1.21	0.67	2.29	0.50	0.53	3.36	1.04
6	Surface	22.90	8.18	12.92	38.90	180.40	2.86	0.41	3.74	0.69	0.70	4.10	2.90
	Bottom	21.30	8.16	0.08	34.30	135.60	1.17	0.71	2.25	0.50	0.51	2.49	1.45

Table 3.9: Variation in water quality variables along Dubai Creek during winter on the ebb conditions of 13 March 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	22.20	8.08	4.51	40.10	18.00	0.40	0.00	0.72	0.09	0.12	2.51	2.52
	Bottom	22.20	8.11	4.42	40.10	18.60	0.41	0.00	0.79	0.08	0.12	2.44	2.48
2	Surface	22.20	8.12	5.54	40.90	21.40	1.18	0.00	1.52	0.26	0.31	3.73	3.73
	Bottom	22.20	8.10	5.43	40.87	14.80	0.84	0.00	1.23	0.19	0.21	2.95	0.99
3	Surface	22.30	8.13	5.17	39.20	29.20	1.56	0.05	2.20	0.36	0.40	3.90	2.35
	Bottom	22.30	8.13	4.83	39.50	17.60	1.19	0.10	1.71	0.30	0.32	2.95	1.40
4	Surface	23.00	8.25	9.56	38.40	26.00	2.08	0.28	3.06	0.47	0.57	5.34	3.19
	Bottom	21.60	8.10	1.68	38.20	22.20	1.14	0.57	2.10	0.46	0.47	3.07	3.04
5	Surface	23.30	8.32	9.03	39.00	40.40	1.76	0.08	2.67	0.45	0.54	5.93	4.71
	Bottom	21.60	8.10	0.07	41.20	13.80	1.28	0.33	2.02	0.40	0.42	3.90	0.82
6	Surface	23.30	8.40	8.61	39.50	35.20	1.77	0.01	2.62	0.37	0.49		1.98
	Bottom	21.50	8.14	0.09	40.20	18.40	1.16	0.53	2.24	0.46	0.49	3.46	1.40

Table 3.10: Variation in water quality variables along Dubai Creek during winter on the flood conditions of 27 March 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	23.60	8.20	5.32	40.10	24.0	0.0647	0.003	0.27	0.0248	0.0431	3.91	1.9630
	Bottom	23.60	8.20	5.11	40.20	61.2	0.0691	0.003	0.28	0.0267	0.0439	1.71	1.2400
2	Surface	23.70	8.15	5.34	40.00	30.8	0.3040	0.031	0.64	0.1136	0.1405	2.85	1.1110
	Bottom	23.70	8.18	5.24	40.00	22.4	0.1750	0.019	0.46	0.0754	0.1043	1.68	0.6780
3	Surface	24.00	8.14	6.00	39.20	25.6	1.0600	0.139	1.79	0.4060	0.4408	3.58	1.8670
	Bottom	23.80	8.16	4.56	39.70	40.0	0.6860	0.128	1.14	0.2860	0.3080	2.59	1.1520
4	Surface	25.90	8.14	11.40	39.00	43.6	1.3300	0.279	2.03	0.4820	0.5099	3.32	4.1370
	Bottom	23.20	8.19	0.80	40.10	13.2	0.7790	0.641	1.76	0.4690	0.7336	3.20	1.4720
5	Surface	26.20	8.07	11.60	39.70	38.0	3.5700	2.570	6.21	1.2870	1.2326	3.43	4.1440
	Bottom	23.30	8.18	1.20	38.50	30.8	0.9400	0.617	1.98	0.4840	0.5246	3.10	1.7190
6	Surface	25.60	8.10	10.40	39.00	32.0	1.1200	0.046	1.66	0.4250	0.4622	2.89	2.7580
	Bottom	23.40	8.11	1.20	38.90	19.2	0.6790	0.490	1.51	0.4230	0.4435	2.91	1.8900

Table 3.11: Variation in water quality variables along Dubai Creek during winter on the ebb conditions of 15 December 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	24.00	7.90	6.30	40.30	17.60	0.10	0.01	0.55	0.100	1.10	2.40	2.10
	Bottom	24.00	7.80	6.70	40.30	23.60	0.12	0.01	0.62	0.100	1.10	5.30	0.99
2	Surface	24.60	8.00	6.20	40.10	18.40	0.12	0.01	0.60	0.300	1.70	2.50	1.80
	Bottom	24.50	8.00	6.10	40.00	19.60	0.13	0.01	0.41	0.200	1.40	2.00	1.50
3	Surface	24.40	8.30	8.30	40.00	36.20	1.90	0.01	3.80	0.400	2.30	2.40	1.90
	Bottom	24.20	8.20	6.80	40.10	35.00	1.80	0.01	3.60	0.300	1.50	2.20	1.10
4	Surface	23.90	8.30	12.20	37.40	72.40	2.60	0.07	3.60	1.300	10.00	3.60	2.70
	Bottom	24.00	8.00	4.80	39.50	40.80	1.80	0.10	3.24	0.400	2.00	2.90	1.10
5	Surface	24.40	8.00	8.70	38.20	3.00	3.70	0.68	7.77	0.400	2.00	12.30	0.60
	Bottom	24.20	8.10	5.20	38.00	3.50	2.40	0.70	5.70	0.400	1.30	9.40	0.45
6	Surface	23.30	8.10	8.70	37.90	59.10	2.80	0.12	3.40	1.100	7.10	7.80	2.80
	Bottom	23.50	8.10	0.90	39.00	38.90	1.20	0.38	2.16	0.400	1.30	3.90	1.32

Table 3.12: Variation in water quality variables along Dubai Creek during winter on the flood conditions of 15 December 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	23.80	7.80	6.20	40.20	15.40	0.08	0.01	0.44	0.05	0.10	2.40	0.66
	Bottom	23.70	7.80	6.10	40.30	16.80	0.09	0.01	0.47	0.05	0.10	3.30	0.67
2	Surface	24.50	7.90	6.50	39.80	16.30	0.12	0.01	0.70	0.20	0.20	2.70	1.60
	Bottom	24.40	7.90	5.90	40.00	17.20	0.14	0.02	0.90	0.05	0.10	2.10	1.20
3	Surface	24.30	8.20	7.90	39.90	35.40	0.90	0.01	2.70	1.40	1.40	2.50	2.00
	Bottom	24.30	8.10	6.40	40.10	34.20	0.80	0.02	1.44	0.05	0.10	2.10	1.30
4	Surface	24.50	8.20	7.20	37.90	75.20	1.40	0.01	2.24	0.40	0.30	3.20	2.30
	Bottom	24.50	8.10	3.50	38.30	33.80	0.80	0.04	0.86	0.30	0.40	3.00	1.40
5	Surface	24.30	8.10	8.60	37.50	2.80	1.90	0.80	3.80	0.30	0.40	10.40	0.80
	Bottom	24.30	7.90	4.90	38.30	3.50	0.80	0.92	4.20	0.30	0.40	8.70	0.70
6	Surface	23.80	8.20	9.30	36.70	50.20	1.60	0.56	3.20	0.30	0.30	6.60	2.50
	Bottom	23.70	8.00	1.80	38.30	32.30	0.80	0.50	1.44	0.01	0.40	4.50	1.20

Table 3.13: Variation in water quality variables along Dubai Creek during winter on the ebb conditions of 27 December 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	24.30	7.90	6.20	39.80	20.30	0.1	0.01	0.55	0.10	0.40	3.30	2.10
	Bottom	24.50	7.83	5.60	40.30	17.90	0.11	0.01	0.57	0.10	0.30	2.10	0.50
2	Surface	24.50	8.30	6.50	40.00	21.40	0.12	0.01	0.6	0.20	1.00	3.50	2.50
	Bottom	24.50	7.90	5.60	40.30	18.40	0.15	0.01	0.48	0.20	0.90	3.00	1.20
3	Surface	24.20	8.40	14.00	37.80	39.60	1.10	0.01	2.75	0.30	1.40	3.60	2.10
	Bottom	24.50	8.00	5.80	39.80	34.80	0.90	0.01	1.62	0.30	1.20	1.90	1.70
4	Surface	23.50	8.40	13.50	36.10	70.20	1.60	0.01	3.04	0.40	2.10	3.20	2.80
	Bottom	24.50	7.90	5.10	40.50	31.80	1.40	0.04	1.51	0.30	1.20	2.70	1.20
5	Surface	24.20	8.20	8.90	37.90	4.00	2.45	0.49	5.00	0.30	1.40	8.30	0.76
	Bottom	24.50	7.90	2.00	39.10	2.50	1.70	0.8	1.87	0.40	1.10	7.10	0.52
6	Surface	24.50	8.10	8.50	38.20	59.00	1.90	0.12	4.18	0.30	1.20	3.80	2.70
	Bottom	24.70	7.70	0.70	38.90	28.30	1.20	0.25	1.80	0.40	0.70	3.00	2.00

Table 3.14: Variation in water quality variables along Dubai Creek during winter on the flood conditions of 27 December 2005.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	24.45	7.90	5.96	40.30	18.40	0.09	0.01	0.50	0.06	0.10	2.50	0.70
	Bottom	24.30	7.90	5.81	40.60	16.80	0.08	0.01	0.42	0.05	0.10	5.50	0.50
2	Surface	24.30	7.90	6.20	39.80	20.30	0.13	0.01	0.65	0.10	0.40	3.30	2.10
	Bottom	24.30	7.90	5.80	40.00	19.00	0.12	0.01	0.38	0.10	0.40	2.10	0.87
3	Surface	24.00	8.00	7.70	38.90	40.20	0.80	0.01	1.60	0.20	0.70	2.00	1.80
	Bottom	24.30	8.00	4.90	39.10	35.60	0.60	0.01	1.08	0.20	0.70	2.10	1.25
4	Surface	24.20	8.10	6.90	38.20	65.80	1.10	0.03	1.76	0.30	1.00	3.60	3.60
	Bottom	24.60	7.90	2.30	39.20	35.20	0.70	0.07	0.76	0.30	0.90	3.00	2.75
5	Surface	24.50	8.00	8.25	36.10	3.60	1.90	0.36	3.23	1.40	4.20	7.50	0.57
	Bottom	24.30	8.00	4.50	37.50	2.80	1.20	0.60	1.80	0.40	1.30	6.70	0.46
6	Surface	24.00	8.10	8.20	37.90	61.20	1.20	0.07	2.40	0.30	1.00	6.40	2.50
	Bottom	24.80	7.70	0.60	38.90	30.30	0.80	0.16	1.44	0.40	1.10	5.30	1.20

Table 3.15: Variation in water quality variables along Dubai Creek during winter on the ebb conditions of 15 January 2006.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	24.10	8.00	6.40	40.20	18.30	0.10	0.01	0.55	0.00	3.27	22.95	-
	Bottom	23.90	8.00	6.30	40.20	33.80	0.13	0.01	0.68	0.00	3.49	22.95	-
2	Surface	24.50	7.90	6.70	40.20	41.90	0.12	0.01	0.60	0.37	3.49	26.23	-
	Bottom	24.50	8.00	6.40	40.10	37.70	0.14	0.01	0.45	0.46	4.58	26.23	-
3	Surface	24.00	8.20	9.70	38.90	44.50	0.50	0.01	1.00	0.44	5.01	36.07	-
	Bottom	23.80	8.30	8.20	39.40	47.20	0.40	0.01	0.72	0.83	4.58	32.79	-
4	Surface	23.80	8.30	14.20	37.50	64.30	1.70	0.50	2.72	1.30	4.79	32.79	-
	Bottom	24.10	8.10	4.50	39.20	71.30	1.10	1.30	1.65	1.60	2.83	42.62	-
5	Surface	24.00	8.20	10.60	38.20	4.80	3.40	0.96	5.44	1.40	6.20	91.80	-
	Bottom	23.80	8.20	4.70	38.00	5.10	1.70	-	2.72	1.70	2.83	45.90	-
6	Surface	24.30	8.00	9.30	38.00	175.90	1.90	0.08	3.80	0.89	4.36	36.07	-
	Bottom	24.50	7.90	1.00	39.20	140.00	1.40	0.60	1.80	1.57	3.27	39.34	-

Table 3.16: Variation in water quality variables along Dubai Creek during winter on the flood conditions of 15 January 2006.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	24.50	8.00	6.30	40.10	17.50	0.06	0.01	0.33	0.20	0.60	2.40	0.38
	Bottom	24.40	8.00	6.70	40.20	32.50	0.05	0.01	0.26	0.40	1.20	3.00	0.29
2	Surface	24.30	8.10	6.30	39.90	43.70	0.09	0.03	0.45	0.30	0.80	3.40	0.93
	Bottom	24.30	8.00	6.20	40.00	31.60	0.08	0.06	0.26	0.30	0.90	2.80	0.75
3	Surface	23.80	8.30	10.80	38.70	42.30	0.40	0.01	0.80	0.40	1.10	3.50	2.50
	Bottom	23.80	8.20	7.90	39.80	46.50	0.34	0.01	0.61	0.30	1.00	3.00	1.60
4	Surface	24.10	8.10	7.80	37.60	62.60	2.20	0.02	3.52	0.40	1.10	3.50	5.60
	Bottom	24.50	8.00	3.30	39.20	71.50	1.60	0.05	1.73	0.40	1.30	3.60	2.30
5	Surface	23.80	8.30	9.10	37.80	5.30	3.20	0.68	3.84	0.80	2.40	6.10	0.82
	Bottom	23.70	8.10	3.20	37.90	4.60	2.40	-	2.64	0.40	1.20	5.60	0.65
6	Surface	24.00	8.10	12.30	37.60	160.20	1.20	0.09	1.90	0.30	1.10	4.60	5.70
	Bottom	24.50	7.80	2.10	38.90	125.40	1.30	1.20	1.70	0.40	1.20	3.90	0.90

Table 3.17: Variation in water quality variables along Dubai Creek during winter on the ebb conditions of 22 January 2006.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	24.40	8.00	6.60	40.00	20.70	0.07	0.01	0.39	0.10	0.10	2.50	0.49
	Bottom	24.40	8.00	6.50	40.10	30.40	0.06	0.01	0.31	0.10	0.10	2.40	0.39
2	Surface	24.50	7.90	6.40	40.00	50.60	0.08	0.02	0.40	0.20	0.70	3.30	1.50
	Bottom	24.30	8.00	6.00	40.00	54.50	0.05	0.05	0.16	0.20	0.50	3.10	0.75
3	Surface	24.00	8.30	9.40	38.00	47.20	0.70	0.01	1.40	0.40	1.40	3.50	2.50
	Bottom	23.70	8.20	6.90	38.30	50.10	0.80	0.01	1.44	0.30	1.00	3.20	1.60
4	Surface	23.50	8.50	12.60	37.50	60.10	2.40	0.30	3.84	0.40	1.30	4.50	5.10
	Bottom	23.60	8.10	2.60	40.00	66.30	1.80	0.90	1.94	0.40	1.10	3.90	1.20
5	Surface	23.50	8.30	9.70	37.80	4.00	3.90	0.70	6.63	1.40	4.30	6.80	65.00
	Bottom	23.40	8.10	3.10	38.30	3.50	2.20	1.70	6.80	0.40	1.10	5.30	0.73
6	Surface	23.70	8.00	8.80	38.30	177.30	1.20	0.02	2.16	0.40	1.40	3.90	6.20
	Bottom	24.10	8.00	1.30	39.00	125.40	0.90	0.60	1.62	0.40	1.10	3.00	0.90

Table 3.18: Variation in water quality variables along Dubai Creek during winter on the flood conditions of 22 January 2006.

Station	Sampling Depth	Water temperature °C	pH	DO (mg/L)	Salinity (‰)	Suspended Solids (mg/L)	$N0_3$-N (mg/L)	NH_4-N (mg/L)	Total Nitrogen (mg/L)	PO_4-P (mg/L)	Total Phosphorous (mg/L)	DOC (mg/L)	POC (mg/L)
1	Surface	24.30	8.10	6.10	40.30	19.60	0.09	0.01	0.50	0.10	0.10	2.80	0.56
	Bottom	24.20	8.00	6.30	40.30	35.20	0.10	0.01	0.52	0.10	0.10	2.20	0.44
2	Surface	24.20	8.10	6.80	30.90	48.30	0.08	0.01	0.40	0.20	0.60	3.10	1.20
	Bottom	24.20	8.00	6.30	40.20	52.10	0.11	0.01	0.35	0.20	0.50	2.90	0.86
3	Surface	3.70	8.50	12.30	38.20	45.20	0.80	0.01	1.60	0.30	1.00	4.10	2.00
	Bottom	23.80	8.30	8.70	38.40	47.30	0.70	0.01	1.26	0.20	0.70	3.30	1.50
4	Surface	23.80	8.20	8.30	39.20	65.60	1.20	0.05	1.92	0.40	1.10	4.10	6.30
	Bottom	23.70	8.10	1.90	40.00	71.50	0.80	0.90	0.86	0.40	1.10	3.80	2.10
5	Surface	23.50	8.20	8.90	37.40	5.90	2.20	0.60	3.30	1.20	3.70	6.20	0.90
	Bottom	23.40	8.00	4.80	38.20	4.60	1.20	1.60	5.70	0.40	1.10	5.00	0.82
6	Surface	23.80	8.10	14.10	38.10	180.40	0.80	0.02	1.12	0.40	1.30	4.50	5.70
	Bottom	23.50	8.00	2.40	38.90	135.60	0.70	0.09	1.10	0.40	1.10	3.20	1.30

Appendix II

Table 4.1: Biological characteristics along Dubai Creek during summer on the ebb conditions of 11 April 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	20.12	185.5	19	0.06	6	275	-	-	-
	Bottom	12.32	154.0	19	-	-	-	4.38	8	1362.00
2	Surface	45.80	15982.3	19	0.03	7	968	-	-	-
	Bottom	39.87	15699.4	20	-	-	-	15.63	13	5229.00
3	Surface	46.91	18269.8	19	0.03	7	117	-		-
	Bottom	30.66	11541.4	20	-	-	-	14.48	14	7906.00
4	Surface	64.65	28310.0	19	0.02	7	1172	-	-	-
	Bottom	58.54	19420.6	20	-	-	-	0.05	4	137.00
5	Surface	71.29	38839.2	19	0.10	7	9995	-	-	-
	Bottom	38.37	13405.0	20	-	-	-	0.05	5	534.00
6	Surface	81.47	47102.2	19	0.11	6	897	-	-	-
	Bottom	33.79	12858.0	20	-	-	-	0.05	5	212.00

Table 4.2: Variation in biological characteristics parameters along Dubai Creek during summer on the ebb conditions of 28 April 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	5.67	205.7	13	0.11	14	2085	-	-	-
	Bottom	4.51	240.6	15	-	-	-	*	*	*
2	Surface	19.55	4104.0	8	0.15	12	5173	-	-	-
	Bottom	10.16	1996.0	8	-	-	-	*	*	*
3	Surface	25.26	4666.0	10	0.50	12	9263	-	-	-
	Bottom	18.76	2244.0	9	-	-	-	*	*	*
4	Surface	16.80	3801.0	9	1.41	9	17406	-	-	-
	Bottom	10.52	1941.0	10	-	-	-	*	*	*
5	Surface	18.61	7923.0	8	0.01	8	4243	-	-	-
	Bottom	12.93	2388.0	9	-	-	-	*	*	*
6	Surface	22.56	4480.0	11	0.33	10	6030	-	-	-
	Bottom	8.68	2064.0	11	-	-	-	*	*	*

- Data on zooplankton from bottom and macro-benthos from bottom were not required to collect * data could not be collected

Table 4.3: Variation in biological characteristics parameters along Dubai Creek during summer on the flood conditions of 5 May 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count ($No.x10^3/L$)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population ($No./m^3$)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population ($No./m^2$)
1	Surface	3.75	1166.0	18	0.03	10	319	-	-	-
	Bottom	3.69	842.0	16	-	-	-	5.67	15	1211.00
2	Surface	4.87	3774.5	10	0.07	12	37692	-	-	-
	Bottom	8.16	4707.3	9	-	-	-	14.44	11	3066.00
3	Surface	27.16	4539.9	12	0.08	9	568	-	-	
	Bottom	32.66	7262.7	10	-	-	-	15.77	7	4391.00
4	Surface	51.97	4332.5	10	0.03	10	381	-	-	-
	Bottom	53.65	4464.3	10	-	-	-	0.10	3	126.00
5	Surface	66.92	6872.7	11	0.04	9	101	-	-	-
	Bottom	40.24	4512.6	11	-	-	-	0.10	3	127.00
6	Surface	83.89	8035.7	11	0.01	12	289	-	-	-
	Bottom	33.87	4550.4	11	-	-	-	0.10	5	212.00

Table 4.4: Variation in biological characteristics parameters along Dubai Creek during summer on the flood conditions of 26 May 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count ($No.x10^3/L$)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population ($No./m^3$)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population ($No./m^2$)
1	Surface	3.22	225.4	15	0.14	9	85	-	-	-
	Bottom	3.54	202.3	14	-	-	-	*	*	*
2	Surface	8.92	4410.5	14	0.91	9	186	-	-	-
	Bottom	7.31	3273.4	14	-	-	-	*	*	*
3	Surface	58.55	23153.0	13	0.20	8	68	-	-	-
	Bottom	37.25	12199.4	12	-	-	-	*	*	*
4	Surface	45.60	32938.8	14	0.13	9	81	-	-	-
	Bottom	20.36	16933.4	13	-	-	-	*	*	*
5	Surface	63.34	34433.2	12	0.18	7	52	-	-	-
	Bottom	32.42	17132.8	14	-	-	-	*	*	*
6	Surface	131.50	192763.4	13	0.21	9	62	-	-	-
	Bottom	25.85	82245.0	13	-	-	-	*	*	*

- Data on zooplankton from bottom and macro-benthos from bottom were not required to collect   * data could not be collected

Table 4.5: Variation in biological characteristics parameters along Dubai Creek during summer on the ebb conditions of 7July 2006.

Station	Sampling Depth	Chlorophyll *a* mg/m³	Phytoplankton Cell count (No.x10³/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m³)	Zooplankton Species (No.)	Zooplankton Population (No./ m³)	Macro-benthos Biomass (gm/m²)	Macro-benthos Species (No.)	Macro-benthos Population (No./m²)
1	Surface	5.60	274.6	23	*	*	*	-	-	-
	Bottom	2.40	162.9	19	-	-	-	*	*	*
2	Surface	24.20	1277.7	20	*	*	*	-	-	-
	Bottom	12.20	374.9	9	-	-	-	*	*	*
3	Surface	52.30	3266.6	15	*	*	*	-	-	-
	Bottom	42.20	479.4	13	-	-	-	*	*	*
4	Surface	68.60	4299.4	12	*	*	*	-	-	-
	Bottom	34.80	509.8	10	-	-	-	*	*	*
5	Surface	102.20	94621.2	10	*	*	*	-	-	-
	Bottom	33.20	294.6	11	-	-	-	*	*	*
6	Surface	-	14471.0	10	*	*	*	-	-	-
	Bottom	23.20	1308.8	10	-	-	-	*	*	*

Table 4.6: Variation in biological characteristics parameters along Dubai Creek during summer on the flood conditions of 7 July 2006.

Station	Sampling Depth	Chlorophyll *a* mg/m³	Phytoplankton Cell count (No.x10³/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m³)	Zooplankton Species (No.)	Zooplankton Population (No./ m³)	Macro-benthos Biomass (gm/m²)	Macro-benthos Species (No.)	Macro-benthos Population (No./m²)
1	Surface	4.20	269.4	22	*	*	*	-	-	-
	Bottom	1.20	181.3	20	-	-	-	*	*	*
2	Surface	18.60	272.7	21	*	*	*	-	-	-
	Bottom	14.60	170.8	20	-	-	-	*	*	*
3	Surface	42.60	5348.0	16	*	*	*	-	-	-
	Bottom	24.20	343.6	14	-	-	-	*	*	*
4	Surface	44.60	8110.6	12	*	*	*	-	-	-
	Bottom	24.20	344.2	10	-	-	-	*	*	*
5	Surface	84.60	14756.2	10	*	*	*	-	-	-
	Bottom	24.60	2600.2	10	-	-	-	*	*	*
6	Surface	123.00	24524.2	10	*	*	*	-	-	-
	Bottom	24.80	224.6	10	-	-	-	*	*	*

- Data on zooplankton from bottom and macro-benthos from bottom were not required to collect   * data could not be collected

Table 4.7: Variation in biological characteristics parameters along Dubai Creek during winter on the flood conditions of 21February 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m³	Phytoplankton Cell count (No.x10³/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m³)	Zooplankton Species (No.)	Zooplankton Population (No./ m³)	Macro-benthos Biomass (gm/m²)	Macro-benthos Species (No.)	Macro-benthos Population (No./m²)
1	Surface	2.16	*	*	*	*	*	-	-	-
	Bottom	2.12	*	*	-	-	-	*	*	*
2	Surface	16.74	*	*	*	*	*	-	-	-
	Bottom	9.65	*	*	-	-	-	*	*	*
3	Surface	42.61	*	*	*	*	*	-	-	-
	Bottom	16.4	*	*	-	-	-	*	*	*
4	Surface	105.74	*	*	*	*	*	-	-	-
	Bottom	19.65	*	*	-	-	-	*	*	*
5	Surface	86.67	*	*	*	*	*	-	-	-
	Bottom	10.25	*	*	-	-	-	*	*	*
6	Surface	118.02	*	*	*	*	*	-	-	-
	Bottom	8.91	*	*	-	-	-	*	*	*

Table 4.8: Variation in biological characteristics parameters along Dubai Creek during winter on the ebb conditions of 1 March 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m³	Phytoplankton Cell count (No.x10³/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m³)	Zooplankton Species (No.)	Zooplankton Population (No./ m³)	Macro-benthos Biomass (gm/m²)	Macro-benthos Species (No.)	Macro-benthos Population (No./m²)
1	Surface	5.96	*	*	*	*	*	-	-	-
	Bottom	4.64	*	*	-	-	-	*	*	*
2	Surface	22.46	*	*	*	*	*	-	-	-
	Bottom	7.75	*	*	-	-	-	*	*	*
3	Surface	26.57	*	*	*	*	*	-	-	-
	Bottom	11.33	*	*	-	-	-	*	*	*
4	Surface	32.40	*	*	*	*	*	-	-	-
	Bottom	4.41	*	*	-	-	-	*	*	*
5	Surface	30.50	*	*	*	*	*	-	-	-
	Bottom	7.85	*	*	-	-	-	*	*	*
6	Surface	29.40	*	*	*	*	*	-	-	-
	Bottom	7.26	*	*	-	-	-	*	*	*

- Data on zooplankton from bottom and macro-benthos from bottom were not required to collect * data could not be collected

Table 4.9: Variation in biological characteristics parameters along Dubai Creek during winter on the ebb conditions of 13 March 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m³	Phytoplankton Cell count (No.x10³/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m³)	Zooplankton Species (No.)	Zooplankton Population (No./ m³)	Macro-benthos Biomass (gm/m²)	Macro-benthos Species (No.)	Macro-benthos Population (No./m²)
1	Surface	13.20	*	*	*	*	*	-	-	-
	Bottom	10.02	*	*	-	-	-	*	*	*
2	Surface	18.14	*	*	*	*	*	-	-	-
	Bottom	12.01	*	*	-	-	-	*	*	*
3	Surface	17.81	*	*	*	*	*	-	-	-
	Bottom	9.76	*	*	-	-	-	*	*	*
4	Surface	29.25	*	*	*	*	*	-	-	-
	Bottom	5.50	*	*	-	-	-	*	*	*
5	Surface	46.07	*	*	*	*	*	-	-	-
	Bottom	9.58	*	*	-	-	-	*	*	*
6	Surface	58.99	*	*	*	*	*	-	-	-
	Bottom	9.97	*	*	-	-	-	*	*	*

Table 4.10: Variation in biological characteristics parameters along Dubai Creek during winter on the flood conditions of 27 March 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m³	Phytoplankton Cell count (No.x10³/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m³)	Zooplankton Species (No.)	Zooplankton Population (No./ m³)	Macro-benthos Biomass (gm/m²)	Macro-benthos Species (No.)	Macro-benthos Population (No./m²)
1	Surface	4.34	*	*	*	*	*	-	-	-
	Bottom	3.59	*	*	-	-	-	*	*	*
2	Surface	7.19	*	*	*	*	*	-	-	-
	Bottom	4.78	*	*	-	-	-	*	*	*
3	Surface	35.37	*	*	*	*	*	-	-	-
	Bottom	10.80	*	*	-	-	-	*	*	*
4	Surface	72.33	*	*	*	*	*	-	-	-
	Bottom	12.48	*	*	-	-	-	*	*	*
5	Surface	63.44	*	*	*	*	*	-	-	-
	Bottom	9.96	*	*	-	-	-	*	*	*
6	Surface	57.53	*	*	*	*	*	-	-	-
	Bottom	10.91	*	*	-	-	-	*	*	*

- Data on zooplankton from bottom and macro-benthos from bottom were not required to collect   * data could not be collected

Table 4.11: Variation in biological characteristics parameters along Dubai Creek during winter on the ebb conditions of 15 December 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	5.20	596.448	19	0.22	18	2764	-	-	-
	Bottom	4.60	386.384	14	-	-	-	6.00	7	1566
2	Surface	8.00	1605.12	16	0.24	13	2374	-	-	-
	Bottom	4.60	845.12	13	-	-	-	22.00	13	6967
3	Surface	10.20	4006.72	13	0.14	8	1354	-	-	-
	Bottom	8.40	1374.08	13	-	-	-	12.00	13	6812
4	Surface	26.20	3763.52	14	0.30	8	2956	-	-	-
	Bottom	10.60	1121.76	11	-	-	-	0.04	3	270
5	Surface	32.60	4851.84	12	0.14	7	1410	-	-	-
	Bottom	8.60	1161.28	11	-	-	-	0.10	3	380
6	Surface	28.80	7646.208	14	0.10	8	1316	-	-	-
	Bottom	6.40	1108.384	12	-	-	-	0.02	1	120

Table 4.12: Variation in biological characteristics parameters along Dubai Creek during winter on the flood conditions of 15 December 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	5.00	474.24	23	0.30	19	2904	-	-	-
	Bottom	2.00	451.136	17	-	-	-	*	*	*
2	Surface	20.00	532	15	0.40	15	2904	-	-	-
	Bottom	14.00	291.84	12	-	-	-	*	*	*
3	Surface	52.00	802.56	13	0.22	14	3434	-	-	-
	Bottom	20.00	517.408	13	-	-	-	*	*	*
4	Surface	45.00	1088.928	13	0.22	11	2408	-	-	-
	Bottom	22.00	511.328	12	-	-	-	*	*	*
5	Surface	68.00	1161.888	12	0.24	10	3408	-	-	-
	Bottom	20.00	359.328	12	-	-	-	*	*	*
6	Surface	-	968.544	14	0.20	10	1149	-	-	-
	Bottom	14.00	388.512	13	-	-	-	*	*	*

- Data on zooplankton from bottom and macro-benthos from bottom were not required to collect * data could not be collected

Table 4.13: Variation in biological characteristics parameters along Dubai Creek during winter on the ebb conditions of 27 December 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	6.00	595.84	22	0.22	17	2764	-	-	-
	Bottom	4.00	294.88	13	-	-	-	*	*	*
2	Surface	20.00	1389.28	13	0.24	12	2374	-	-	-
	Bottom	14.00	748.144	9	-	-	-	*	*	*
3	Surface	34.00	4667.008	12	0.14	9	1354	-	-	-
	Bottom	16.00	736.288	10	-	-	-	*	*	*
4	Surface	-	10402.88	9	0.14	7	1410	-	-	-
	Bottom	20.00	1057.92	9	-	-	-	*	*	*
5	Surface	164.00	13965.76	9	0.30	8	2956	-	-	-
	Bottom	24.00	1368	9	-	-	-	*	*	*
6	Surface	-	15309.44	11	0.10	9	1316	-	-	-
	Bottom	20.00	997.424	9	-	-	-	*	*	*

Table 4.14: Variation in biological characteristics parameters along Dubai Creek during winter on the flood conditions of 27 December 2005.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	6.00	470.896	18	0.20	19	1878	-	-	-
	Bottom	4.00	228.608	10	-	-	-	6.00	16	1566
2	Surface	24.00	4824.48	9	0.14	15	1661	-	-	-
	Bottom	12.00	763.648	9	-	-	-	22.00	7	6967
3	Surface	142.00	13065.92	10	0.14	13	1420	-	-	-
	Bottom	20.00	1442.784	7	-	-	-	12.00	12	6812
4	Surface	190.00	10756.74	9	0.10	8	1064	-	-	-
	Bottom	20.00	1107.168	6	-	-	-	0.10	2	380
5	Surface	160.00	14567.68	9	0.10	9	1174	-	-	-
	Bottom	22.00	1185.6	7	-	-	-	0.04	2	270
6	Surface	180.00	16282.24	10	0.10	8	1112	-	-	-
	Bottom	32.00	1678.688	8	-	-	-	0.02	1	120

- Data on zooplankton from bottom and macro-benthos from bottom were not required to collect   * data could not be collected

Table 4.15: Variation in biological characteristics parameters along Dubai Creek during winter on the ebb conditions of 15 January 2006.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	5.00	573.952	17	0.50	16	3026	-	-	-
	Bottom	5.00	680.96	15	-	-	-	10.00	20.00	4840
2	Surface	12.00	955.168	12	0.20	11	1396	-	-	-
	Bottom	6.00	517.408	9	-	-	-	12.00	9.00	4983
3	Surface	20.00	1945.6	12	0.14	8	1494	-	-	-
	Bottom	8.00	760	9	-	-	-	18.00	12.00	15380
4	Surface	22.00	1811.84	7	0.18	8	1706	-	-	-
	Bottom	8.00	638.4	6	-	-	-	0.02	2.00	80
5	Surface	20.00	1264.64	9	0.10	7	1142	-	-	-
	Bottom	8.00	747.84	8	-	-	-	0.02	2.00	80
6	Surface	32.00	8056.608	9	0.10	8	858	-	-	-
	Bottom	24.00	2103.68	7	-	-	-	0.02	1.00	80

Table 4.16: Variation in biological characteristics parameters along Dubai Creek during winter on the flood conditions of 15 January 2006.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	5.00	501.6	16	0.60	16	3502	-	-	-
	Bottom	4.00	285.152	11	-	-	-	*	*	*
2	Surface	24.00	1637.344	10	0.20	12	1884	-	-	-
	Bottom	5.00	362.976	11	-	-	-	*	*	*
3	Surface	32.00	2159.008	11	0.12	10	1602	-	-	-
	Bottom	5.00	375.744	9	-	-	-	*	*	*
4	Surface	24.00	2003.968	10	0.20	7	1420	-	-	-
	Bottom	6.00	324.064	9	-	-	-	*	*	*
5	Surface	34.00	2057.472	12	0.12	7	1428	-	-	-
	Bottom	8.00	341.088	9	-	-	-	*	*	*
6	Surface	18.00	1299.296	11	0.14	6	2078	-	-	-
	Bottom	16.00	1625.184	10	-	-	-	*	*	*

- Data on zooplankton from bottom and macro-benthos from bottom were not required to collect * data could not be collected

Table 4.17: Variation in biological characteristics parameters along Dubai Creek during winter on the ebb conditions of 22 January 2006.

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	6.0	364.8	18	0.10	15	610	-	-	-
	Bottom	5.20	258.4	10	-	-	-	*	*	*
2	Surface	6.20	322.24	9	0.10	13	1086	-	-	-
	Bottom	5.00	191.52	9	-	-	-	*	*	*
3	Surface	14.40	504.64	8	0.10	7	1364	-	-	-
	Bottom	5.40	279.68	9	-	-	-	*	*	*
4	Surface	12.80	510.72	8	0.10	7	686	-	-	-
	Bottom	12.80	334.4	8	-	-	-	*	*	*
5	Surface	14.20	586.72	9	0.10	7	204	-	-	-
	Bottom	8.80	291.84	8	-	-	-	*	*	*
6	Surface	26.80	1214.176	10	0.10	8	558	-	-	-
	Bottom	8.20	190	10	-	-	-	*	*	*

Table 4.18: Variation in biological characteristics parameters along Dubai Creek during winter on the flood conditions of 22 January 2006

Station	Sampling Depth	Chlorophyll *a* mg/m^3	Phytoplankton Cell count (No.x10^3/L)	Phytoplankton Species (No.)	Zooplankton biovolume (ml/m^3)	Zooplankton Species (No.)	Zooplankton Population (No./ m^3)	Macro-benthos Biomass (gm/m^2)	Macro-benthos Species (No.)	Macro-benthos Population (No./m^2)
1	Surface	5.20	425.6	20	0.10	18	824	-	-	-
	Bottom	4.40	213.104	11	-	-	-	12.00	19	4600
2	Surface	10.00	853.328	15	0.12	13	955	-	-	-
	Bottom	8.00	343.824	8	-	-	-	18.00	7	4190
3	Surface	14.00	1085.888	10	0.10	8	576	-	-	-
	Bottom	8.00	375.136	10	-	-	-	14.00	11	11483
4	Surface	24.00	1213.568	10	0.10	8	640	-	-	-
	Bottom	8.00	316.16	8	-	-	-	0.20	2	60
5	Surface	20.00	1071.296	11	0.10	7	506	-	-	-
	Bottom	10.00	373.92	8	-	-	-	0.04	2	140
6	Surface	26.00	1195.328	11	0.10	8	620	-	-	-
	Bottom	8.00	270.56	8	-	-	-	0.02	1	40

-zooplankton from bottom and macro-benthos from bottom were not required to collect   * data could not be collected

Table 4.19: Phytoplankton cell counts (no x 10^3/L) from different stations of Dubai Creek during ebb tide on 11 April 2005.

Species	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
	S	B	S	B	S	B	S	B	S	B	S	B
BACILLARIOPHYCEAE												
Chaetocerose sp	0.24	0.24	0.24	0.12	0.24	0.12	0.40	0.20	0.20	0.40	0.40	2.00
Corethron sp	0.12	0.12	0.12		0.12		0.20		0.20		0.20	
Coscinodiscus spp	1.80	2.38	2.38	1.19	2.38	1.19	4.00	2.00	1.00	1.00	2.00	2.00
Cyclotella												
Guinardia delicatula	1.19	1.19	1.19	1.19	1.19	1.19	2.00	2.00	2.00	2.00	2.00	2.00
Gyrosigma sp												
Melosira sp	8.00	1.19	1.19	1.19	1.19	1.19	2.00	2.00	2.00	2.00	2.00	2.00
Navicula sp	0.80	0.80	1.19	1.19	1.19	1.19	2.00	2.00	2.00	2.00	2.00	2.00
Nitzschia closterium	1.19	1.19	1.19	1.19	1.19	1.19	2.00	2.00	2.00	2.00	2.00	2.00
Nitzschia sigma	1.79	1.79	1.79	0.60	1.79	0.60	3.00	1.00	3.00	1.00	3.00	1.00
Nitzschia spp	58.00	62.00	1254.00	980.00	1820.00	1240.00	2760.00	1256.00	3248.00	1240.00	4256.00	2254.00
Pleurosigma sp	0.12	0.12	0.12	0.06	0.12	0.06	0.20	0.10	0.20	0.10	0.20	0.10
Pseudo-nitzschia serriata	0.12	0.12	0.12	0.06	0.12	0.06	0.20	0.10	0.20	0.10	0.20	0.10
Rhizosolenia sp	12.00	4.00	157.14	73.81	157.14	73.81	264.00	124.00	324.00	124.00	268.00	68.00
Skeletonema costatum				0.06		0.06		0.10		0.10		0.10
Synedra ulna												
Thalassionema nitzschioides				0.06		0.06		0.10		0.10		0.10
EUGLENOPHYCEAE												
Euglena sp	4.00	6.00	14.29	8.33	14.29	8.33	24.00	14.00	24.00	14.00	24.00	14.00
CYANOPHYCEAE												
Pseudanabaena sp	72.00	54.00	14520.00	14620.00	16240.00	10200.00	25200.00	18000.00	35200.00	12000.00	42500.00	10500.00
DINOPHYCEAE												
Ceratium sp	7.14	4.80	7.14	1.19	7.14	1.19	12.00	2.00	10.00	4.00	12.00	2.00
Glenodinium sp	14.00	12.00	14.29	5.95	14.29	5.95	24.00	10.00	12.00	6.00	12.00	2.00
Gyrodinium spirale	0.60	0.60	0.60	0.60	0.60	0.60	1.00	1.00	0.20	0.20	2.00	0.20
Prorocentrum micans	1.80	1.19	4.76	2.00	6.20	4.00	8.00	1.00	8.00	4.00	14.00	4.00
*Protoperidinium*sp	0.60	0.30	0.60	0.60	0.60	0.60	1.00	1.00	0.20	2.00	0.20	0.40
Total	185.50	154.02	15982.33	15699.38	18269.77	11541.38	28310.00	19420.60	38839.20	13405.00	47102.20	12858.00

Table 4.20: Phytoplankton cell counts (no x 10^3/L) from different stations of Dubai Creek during ebb tide on 28 April 2005.

Species	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
	S	B	S	B	S	B	S	B	S	B	S	B
BACILLARIOPHYCEAE												
Chaetocerose sp												
Corethron sp												
Coscinodiscus spp		0.01										
Cyclotella	0.01	0.02			2.00			2.00			2.00	2.00
Guinardia delicatula	1.00	2.00										
Gyrosigma sp												
Melosira sp	2.00	1.00	4.00	2.00	4.00	2.00	15.00	2.00	15.00	2.00	14.00	2.00
Navicula sp	0.20	0.20			2.00	1.00	2.00	2.00		2.00	2.00	2.00
Nitzschia closterium	2.00	1.00	2.00	2.00	8.00	2.00	4.00	1.00	8.00	2.00	40.00	46.00
Nitzschia sigma	102.00	134.00	124.00	25.00	120.00	22.00	180.00	45.00	210.00	45.00	260.00	64.00
Nitzschia spp											2.00	2.00
Pleurosigma sp												
Pseudo-nitzschia serriata	0.12	0.10										
Rhizosolenia sp	0.10	0.01	102.00	24.00	142.00	12.00	48.00	12.00	98.00	22.00	75.00	26.00
Skeletonema costatum												
Synedra ulna	0.06	0.05										
Thalassionema nitzschioides												
EUGLENOPHYCEAE												
Euglena sp		0.01	240.00	20.00	48.00	32.00	120.00	12.00	240.00	20.00	320.00	24.00
CYANOPHYCEAE												
Pseudanabaena sp	98.00	102.00	3568.00	1896.00	4256.00	2146.00	3280.00	1820.00	7200.00	2250.00	3675.00	1854.00
DINOPHYCEAE		0.12										
Ceratium sp												
Glenodinium sp	0.20	0.02										
Gyrodinium spirale			62.00	12.00	82.00	12.00	150.00	30.00				
Prorocentrum micans	0.02		2.00	15.00	2.00	15.00	2.00	15.00	150.00	30.00	45.00	28.00
Protoperidinium sp		0.02							2.00	15.00	45.00	14.00
Total	205.72	240.57	4104.00	1996.00	4666.00	2244.00	3801.00	1941.00	7923.00	2388.00	4480.00	2064.00

Table 4.21: Phytoplankton cell counts (no x 10^3/L) along different stations of Dubai Creek during flood tide on 5 May 2005.

Species	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
	S	B	S	B	S	B	S	B	S	B	S	B
BACILLARIOPHYCEAE												
Chaetocerose sp	2.00	2.00			0.20							
Corethron sp												
Coscinodiscus spp	2.00		26.00	2.00	10.00	4.00	8.00	2.00	42.00	42.00	26.00	2.00
Cyclotella												
Guinardia delicatula	2.00	2.00		0.10	0.20	0.10		0.10	0.20	0.10	0.20	0.10
Gyrosigma sp	1.00	1.00										
Melosira sp	2.00		0.20	1.00	0.20	0.20	0.20	1.00	0.20	2.00	0.20	1.00
Navicula sp	1.00	1.00										
Nitzschia closterium	2.00	2.00										
Nitzschia sigma												
Nitzschia spp	140.00	80.00	12.00	22.00	12.00	24.00	18.00	8.00	24.00	42.00	42.00	22.00
Pleurosigma sp			0.10		0.10		0.10		0.10	0.10	0.10	0.10
Rhizosolenia sp	140.00	120.00	42.00	4.00	42.00	4.00	42.00	4.00	42.00	4.00	42.00	4.00
Skeletonema costatum	2.00	2.00										
Synedra alna	1.00	1.00										
Thalassionema nitzschioides	1.00	1.00										
EUGLENOPHYCEAE												
Euglena sp	14.00	14.00	10.00	6.00	8.00	8.00	4.00	2.00	42.00	10.00	4.00	2.00
CYANOPHYCEAE												
Pseuanabaena sp	420.00	240.00	3656.00	4658.00	4450.00	7200.00	4232.00	4420.00	6300.00	4200.00	7800.00	4420.00
DINOPHYCEAE												
Ceratium sp	2.00	2.00	0.20	0.20	0.20	0.40	0.20	0.20	0.20	0.40	0.20	0.20
Glenodinium sp	14.00	14.00	18.00	14.00	15.00	20.00	26.00	26.00	420.00	210.00	120.00	98.00
Gyrodinium spirale												
Prorocentrum micans	280.00	220.00	10.00		2.00	2.00	2.00	1.00	2.00	2.00	1.00	1.00
Protoperidinium sp	140.00	140.00										
Total	1166.00	842.00	3774.50	4707.30	4539.90	7262.70	4332.50	4464.30	6872.70	4512.60	8035.70	4550.40

Table 4.22: Phytoplankton cell counts (no x 10^3/L) along different stations of Dubai Creek during flood tide on 26 May 2005.

Species	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
	S	B	S	B	S	B	S	B	S	B	S	B
BACILLARIOPHYCEAE												
Chaetocerose sp	0.20	0.10	0.50	10.00	1.00	2.00	0.40	0.40	0.20	0.40	0.40	2.00
Corethron sp	0.20			0.40								
Coscinodiscus spp	30.00	28.00	20.00	23.00	8.00	6.00	12.00	1.00	2.00	12.00	18.00	22.00
Cyclotella												
Guinardia delicatula	20.00	23.00	2.00	4.00	4.00	7.00	2.00	6.00	8.00	8.00	4.00	8.00
Gyrosigma sp	2.00											
Melosira sp	20.00	20.00	12.00									
Navicula sp	1.00	1.00	2.00	2.00	2.00							
Nitzschia closterium										50.40		
Nitzschia sigma	12.00	16.00	12.00	8.00	8.00	4.00	3.00	2.00	2.00	1.00	1.00	2.00
Nitzschia spp	24.00	12.00	120.00	140.00	240.00	220.00	60.00	60.00	120.00	120.00	600.00	68.00
*Pleurosigma*sp							2.00			2.00		2.00
Psedo-nitzschia serriata							0.20					
Rhizosolenia sp	2.00	2.00	12.00	24.00	12.00	23.00	12.00	3.00	4.00	8.00	8.00	8.00
Skeletonema costatum	68.00	42.00										
Synedra alna												
Thalassionema nitzschioides											2.00	
EUGLENOPHYCEAE												
Euglena sp	10.00	24.00	1400.00	600.00	9600.00	7600.00	2800.00	2460.00	7200.00	5600.00	72000.00	24000.00
CYANOPHYCEAE												
Pseuanabaena sp	10.00	20.00	2800.00	2420.00	13200.00	4200.00	28800.00	14240.00	26400.00	11200.00	120000.00	58000.00
DINOPHYCEAE												
Ceratium sp	24.00	10.00	2.00	2.00	2.00	0.40	2.00	6.00	8.00	3.00	2.00	1.00
Glenodinium sp	2.00	4.00	24.00	24.00	60.00	120.00	1244.00	124.00	680.00	120.00	120.00	124.00
Gyrodinium spirale							1.00	2.00	2.00	2.00	2.00	2.00
Prorocentrum micans		0.20	2.00	4.00	2.00	5.00	0.20	6.00	7.00	6.00	6.00	6.00
*Protoperidinium*sp			2.00	12.00	14.00	12.00		23.00				
Total	225.40	202.30	4410.50	3273.40	23153.00	12199.40	32938.80	16933.40	34433.20	17132.80	192763.40	82245.00

Table 4.23: Phytoplankton cell counts (no x 10^3/L)along different stations of Dubai Creek during flood tide on 7 July 2006

Species	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
	S	B	S	B	S	B	S	B	S	B	S	B
BACILLARIOPHYCEAE												
Chaetocerose sp	0.20	0.10	0.50	2.00	1.00	2.00	0.20					
Corethron sp	0.20			0.20								
Coscinodiscus spp	12.00	22.00	24.00	20.00	18.00	12.00	6.00	4.00	0.20	0.20	0.20	0.20
Cyclotella	2.00		2.00									
Guinardia delicatula	10.00	12.00	4.00	2.00	2.00							
Gyrosigma sp	2.00											
Melosira sp	20.00	20.00	12.00									
Navicula sp	1.00	1.00	2.00	2.00	2.00							
Nitzschia closterium	12.00	14.00	20.00	24.00	34.00	24.00	48.00	24.00	52.00	24.00	24.00	20.00
Nitzschia sigma	10.00	12.00	2.00	4.00	8.00	4.00	2.00	4.00	4.00	4.00	2.00	4.00
Nitzschia spp	34.00	24.00	38.00	28.00	160.00	140.00	120.00	40.00	48.00	24.00	48.00	24.00
*Pleurosigma*sp	2.00	2.00	0.20	0.40								
Psedo-nitzschia serriata	2.00	2.00	2.00	2.00	2.00	0.20	0.20					
Rhizosolenia sp	2.00	2.00	12.00	24.00	12.00	4.00	8.00	4.00	4.00	2.00	4.00	6.00
Skeletonema costatum	12.00	24.00	12.00	4.00								
Synedra alna					2.00	4.00	4.00	8.00	4.00	2.00	2.00	4.00
Thalassionema nitzschioides	2.00	2.00	2.00	0.20								
CHLOROPHYCEAE												
Tetraselmis sp	108.00	24.00	120.00	28.00	4860.00	120.00	7240.00	222.00	13400.00	2200.00	22980.00	140.40
EUGLENOPHYCEAE												
Euglena sp	20.00	10.00	10.00	8.00	240.00	24.00	680.00	36.00	1240.00	340.00	1460.00	22.00
CYANOPHYCEAE												
Pseuanabaena sp	2.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
DINOPHYCEAE												
Ceratium sp	12.00	4.00	2.00	2.00	2.00	0.40						
Glenodinium sp	2.00	2.00	2.00	2.00	2.00	2.00						
Prorocentrum micans		0.20	2.00	4.00	2.00	5.00	0.20	0.20	2.00	2.00	2.00	2.00
*Protoperidinium*sp	2.00	2.00	2.00	12.00								
Total	269.40	181.30	272.70	170.80	5348.00	343.60	8110.60	344.20	14756.20	2600.20	24524.20	224.60

Table 4.24: Phytoplankton cell counts (no x 10^3/L)along different stations of Dubai Creek during ebb tide on 7 July 2006

Species	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
	S	B	S	B	S	B	S	B	S	B	S	B
BACILLARIOPHYCEAE												
Chaetocerose sp	0.20	0.10	0.50	2.00	1.00	2.00	0.20					
Corethron sp	0.20			0.20								
Coscinodiscus spp	12.00	22.00	24.00	20.00	18.00	12.00	6.00	4.00	0.20	0.20	0.20	0.20
Cyclotella	2.00		2.00									
Guinardia delicatula	10.00	12.00	4.00	2.00	2.00							
Gyrosigma sp	2.00											
Melosira sp	20.00	20.00	12.00									
Navicula sp	0.40	0.80	2.00	2.00	2.00							
Nitzschia closterium	14.00	8.00	12.00	12.00	48.00	12.00	28.00	12.00	44.00	14.00	12.00	12.00
Nitzschia sigma	8.00	8.00	8.00	2.00	2.00	4.00	2.00	2.00	4.00	2.00	2.00	4.00
Nitzschia spp	46.00	36.00	108.00	154.00	142.00	120.00	108.00	24.00	24.00	12.00	36.00	22.00
Pleurosigma sp	2.00	2.00	0.20	0.40								
Psedo-nitzschia serriata	4.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00	2.00	2.00	2.00	2.00
Rhizosolenia sp	4.00	4.00	4.00	12.00	12.00	4.00	8.00	4.00	4.00	2.00	4.00	6.00
Skeletonema costatum	10.00	12.00	8.00	2.00								
Synedra alna					1.00	1.00	1.00	1.00	2.00	1.00	1.00	1.00
Thalassionema nitzschioides	2.00	2.00	1.00	0.20								
CHLOROPHYCEAE												
Tetraselmis sp	98.00	10.00	1060.00	120.00	2982.00	248.00	3980.00	340.00	94200.00	220.00	14400.00	1220.00
EUGLENOPHYCEAE												
Euglena sp	20.00	10.00	20.00	20.00	40.00	62.00	160.00	120.00	340.00	40.00	12.00	40.00
CYANOPHYCEAE												
Pseuanabaena sp	2.00											
DINOPHYCEAE												
Ceratium sp	14.00	8.00	4.00	8.00	4.00	8.00	2.00					
Glenodinium sp	1.60	1.80	1.60	1.80	2.40	2.20				0.20		
Prorocentrum micans	0.20	0.20	0.40	0.30	0.20	0.20	0.20	0.80	1.00	1.20	1.80	1.60
*Protoperidinium*sp	2.00	2.00	2.00	12.00								
Total	274.60	162.90	1277.70	374.90	3260.60	479.40	4299.40	509.80	94621.20	294.60	14471.00	1308.80

Table 4.25: Phytoplankton cell counts (no x 10^3/L) at different stations along Dubai Creek during ebb Spring Tide on 15 December 05

Species	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
	S	B	S	B	S	B	S	B	S	B	S	B
Bacillariophyceae												
Amphora sp												
Biddulphia sp	6.1											
Chaetocerose sp	36.5	42.6	24.3	12.2	18.2	24.3	6.1		6.1		0.6	
Corethron sp												
Coscinodiscus spp	30.4	12.2	6.1	18.2	6.1	18.2	24.3	15.2	18.2	6.1	15.2	6.1
Cyclotella			6.1									
Guinardia delicatula	24.3		12.2									
Gyrosigma sp	6.1											
Melosira sp	6.1											
Navicula sp	12.2	12.2	18.2	6.1	6.1	6.1	12.2	12.2	6.1	6.1	3.0	0.6
Nitzschia closterium											30.4	0.6
Nitzschia sigma	60.8	60.8	121.6	121.6	121.6	60.8	364.8	60.8	425.6	60.8	486.4	60.8
Nitzschia spp	36.5	73.0	243.2	121.6	121.6	60.8	243.2	121.6	243.2	60.8	121.6	30.4
*Pleurosigma*sp												
Psedo-nitzschia serriata												
Rhizosolenia habitata	36.5	6.1										
Rhizosolenia sp	60.8	18.2	36.5	6.1	24.3	6.1	18.2	6.1	36.5	12.2	30.4	6.1
Skeletonema costatum	6.1	3.0	18.2	6.1	6.1	12.2	6.1	6.1	6.1	12.2	15.2	6.1
Synedra alna												
Thalassionema nitzschioides	60.8	6.1	12.2	60.8	6.1	24.3			6.1			
Euglenophyceae												
Euglena sp	60.8	36.5	60.8	6.1	243.2	60.8	243.2	60.8	182.4	121.6	152.0	60.8
Euglena tripteries												
Cyanophyceae												
Pseuanabaena sp	36.5	36.5	60.8	60.8	42.6	60.8	48.6	42.6	60.8	30.4	60.8	9.7
Limnothrix sp	0.6	0.3	243.2	60.8	243.2	60.8	60.8	60.8	60.8	60.8	30.4	12.2
Dinophyceae												
Ceratium sp	6.1		6.1									
Glenodinium sp												
Gyrodinium spirale									6.1		6.1	
Prorocentrum micans	103.4	66.9	729.6	243.2	3161.6	972.8	2675.2	729.6	3769.6	729.6	6688.0	912.0
Peridinium sp	6.1	12.2	6.1	121.6	6.1	6.1	60.8	6.1	24.3	60.8		
Protoperidinium sp											6.1	3.0
Others												
Total	596.4	386.4	1605.1	845.1	4006.7	1374.1	3763.5	1121.8	4851.8	1161.3	7646.2	1108.4

Table 4.26: Phytoplankton cell counts (no x 10^3/L) at different stations along Dubai Creek during flood Spring Tide on 15 December 05

	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Species	S	B	S	B	S	B	S	B	S	B	S	B
Bacillariophyceae												
Amphora sp	3.0		3.0									
Biddulphia sp	3.0	3.0										
Chaetocerose sp	24.3	12.2	6.1	6.1	12.2	6.1	12.2	6.1	6.1	6.1	0.6	0.6
Corethron sp												
Coscinodiscus spp	24.3	12.2	12.2	6.1	6.1	0.6	0.6	0.6	0.6	0.6	1.2	0.6
Cyclotella	3.0	6.1	3.0									
Guinardia delicatula	1.2		6.1									
Gyrosigma sp	0.6	3.0										
Melosira sp	1.2											
Navicula sp	6.1	12.2	18.2	6.1	6.1	6.1	12.2	12.2	6.1	6.1	3.0	0.6
Nitzschia closterium											30.4	0.6
Nitzschia sigma	54.7	42.6	6.1	12.2	12.2	24.3	18.2	6.1				
Nitzschia spp	60.8	139.8	121.6	60.8	127.7	73.0	121.6	60.8	145.9	139.8	60.8	6.1
*Pleurosigma*sp	6.1	6.1										
Psedo-nitzschia serriata	6.1											
Rhizosolenia habitata	36.5	6.1										
Rhizosolenia sp	36.5	12.2	42.6	42.6	48.6	54.7	42.6	6.1	60.8	6.1	54.7	6.1
Skeletonema costatum	12.2			6.1	6.1	18.2	6.1	12.2	6.1	12.2	12.2	12.2
Synedra alna												
Thalassionema nitzschioides	42.6	24.3	42.6	30.4	36.5	66.9			12.2	6.1	6.1	6.1
Euglenophyceae												
Euglena sp	6.1	1.2	6.1	12.2	60.8	6.1	73.0	36.5	60.8	18.2	121.6	36.5
Euglena tripteries												
Cyanophyceae												
Pseuanabaena sp	66.9	60.8	73.0	42.6	48.6	36.5	60.8	60.8	60.8	60.8	121.6	60.8
Limnothrix sp	6.1	12.2			66.9	60.8	36.5	54.7	36.5	36.5	54.7	6.1
Dinophyceae												
Ceratium sp	6.1		6.1									
Glenodinium sp												
Gyrodinium spirale									12.2		3.0	6.1
Prorocentrum micans	60.8	36.5	182.4	60.8	364.8	121.6	668.8	243.2	729.6	60.8	486.4	243.2
Peridinium sp	6.1	60.8	3.0	6.1	6.1	42.6	36.5	12.2	24.3			
*Protoperidinium*sp										6.1	12.2	3.0
Others												
Total	474.2	451.1	532.0	291.8	802.6	517.4	1088.9	511.3	1161.9	359.3	968.5	388.5

Table 4.27: Phytoplankton cell counts (no x 10^3/L) at different stations along Dubai Creek during ebb Neap Tide on 27 December 05

	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Species	S	B	S	B	S	B	S	B	S	B	S	B
Bacillariophyceae												
Amphora sp	3.0		3.0									
Biddulphia sp	0.6											
Chaetocerose sp		6.1			6.1		6.1				121.6	
Corethron sp	3.0											
Coscinodiscus spp	6.1	6.1	30.4	60.8	60.8	6.1	60.8	18.2	60.8	12.2	6.1	6.1
Cyclotella	0.3											
Guinardia delicatula	6.1	6.1	6.1		0.6							
Gyrosigma sp												
elosira sp	3.0		3.0			0.6						
Navicula sp	0.6			0.3	3.0							
Nitzschia closterium	6.1	6.1	6.1	60.8	30.4	30.4	30.4	30.4	30.4	18.2	24.3	6.1
Nitzschia sigma	0.6		6.1			6.1			6.1		6.1	
Nitzschia spp	91.2	73.0	182.4	73.0	121.6	66.9	182.4	73.0	121.6	66.9	60.8	60.8
*Pleurosigma*sp	0.6											
Psedo-nitzschia serriata	6.1	6.1										
Rhizosolenia habitata	6.1											
Rhizosolenia sp	85.1	24.3	42.6	24.3	304.0	66.9	243.2	66.9	97.3	36.5	60.8	121.6
Skeletonema costatum												
Synedra alna	3.0											
Thalassionema nitzschioides	6.1	6.1	6.1	6.1	60.8	6.1	30.4	6.1	24.3	6.1	6.1	3.0
Euglenophyceae												
Euglena sp	0.3	3.0	3.0		6.1					6.1	6.1	9.4
Euglena tripteries												
Cyanophyceae												
Pseuanabaena sp	60.8	60.8	60.8	60.8	60.8	6.1	364.8	6.1	6.1	6.1	1641.6	304.0
Limnothrix sp	60.8	30.4	66.9	36.5	364.8	182.4	972.8	121.6	2553.6	608.0	1824.0	364.8
Dinophyceae												
Ceratium sp	3.0											
Glenodinium sp												
Gyrodinium spirale												
Prorocentrum micans	243.2	60.8	972.8	425.6	3648.0	364.8	8512.0	729.6	11065.6	608.0	11552.0	121.6
Peridinium sp												
*Protoperidinium*sp		6.1						6.1				
Others												
Total	595.8	294.9	1389.3	748.1	4667.0	736.3	10402.9	1057.9	13965.8	1368.0	15309.4	997.4

Table 4.28: Phytoplankton cell counts (no x 10^3/L) at different stations along Dubai Creek during flood Neap Tide on 27 December 05

	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Species	S	B	S	B	S	B	S	B	S	B	S	B
Bacillariophyceae												
Amphora sp												
Biddulphia sp	0.6											
Chaetocerose sp		3.0	3.0	3.0	6.1		6.1		6.1		6.1	6.1
Corethron sp												
Coscinodiscus spp	60.8	6.1	6.1	24.3	30.4	18.8	7.3	0.6	6.1		6.1	
Cyclotella												
Guinardia delicatula	0.6											
Gyrosigma sp												
Melosira sp	6.1	6.1										
Navicula sp	6.1											
Nitzschia closterium	6.1											
Nitzschia sigma	6.1											
Nitzschia spp	91.2	60.8	364.8	182.4	364.8	121.6	486.4	121.6	425.6	121.6	364.8	243.2
*Pleurosigma*sp	30.4											
Psedo-nitzschia serriata	0.3											
Rhizosolenia habitata												
Rhizosolenia sp	30.4	6.1	121.6	60.8	121.6	24.3	60.8	6.1	121.6	127.7	139.8	121.6
Skeletonema costatum												
Synedra alna												
Thalassionema nitzschioides		6.1	6.1	6.1	6.1		6.1		6.1		12.2	0.6
Euglenophyceae												
Euglena sp	0.6		6.1	0.6	66.9	1.2	97.3	36.5	60.8	18.2	121.6	30.4
Euglena tripteries												
Cyanophyceae												
Pseuanabaena sp	6.1	6.1	364.8	60.8	972.8	182.4	608.0	206.7	985.0	188.5	918.1	364.8
Limnothrix sp	30.4	12.2	304.0	60.8	912.0	364.8	608.0	370.9	1404.5	364.8	972.8	608.0
Dinophyceae												
Ceratium sp	6.1											
Glenodinium sp												
Gyrodinium spirale	6.1											
Prorocentrum micans	182.4	121.6	3648.0	364.8	10579.2	729.6	8876.8	364.8	11552.0	364.8	13680.0	304.0
Peridinium sp	0.6	0.6			6.1						60.8	
*Protoperidinium*sp												
Others												
Total	470.9	228.6	4824.5	763.6	13065.9	1442.8	10756.7	1107.2	14567.7	1185.6	16282.2	1678.7

Table 4.29: Phytoplankton cell counts (no x 10^3/L) at different stations along Dubai Creek during ebb Spring Tide on 15 January 06

	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Species	S	B	S	B	S	B	S	B	S	B	S	B
Bacillariophyceae												
Amphora sp												
Biddulphia sp	0.6											
Chaetocerose sp												
Corethron sp												
Coscinodiscus spp	6.1	6.1	36.5	0.6	66.9	24.3	60.8	12.2	60.8	6.1	121.6	6.1
Cyclotella												
Guinardia delicatula	0.6											
Gyrosigma sp	6.1											
Melosira sp												
Navicula sp	0.6		0.6		6.1		6.1				0.6	
Nitzschia closterium	6.1											
Nitzschia sigma												
Nitzschia spp	364.8	547.2	364.8	182.4	1216.0	364.8	729.6	182.4	547.2	364.8	7296.0	1580.8
*Pleurosigma*sp	0.6											
Psedo-nitzschia serriata	6.1											
Rhizosolenia habitata	6.1											
Rhizosolenia sp	54.7	60.8	36.5	127.7	182.4	66.9	127.7	73.0	194.6	73.0	121.6	152.0
Skeletonema costatum												
Synedra alna	6.1											
Thalassionema nitzschioides	6.1		12.2		12.2				6.1		30.4	
Euglenophyceae												
Euglena sp			60.8	60.8	30.4	60.8	30.4	60.8	30.4	60.8	60.8	60.8
Euglena tripteries												
Cyanophyceae												
Pseuanabaena sp												
Limnothrix sp	60.8	60.8	364.8	60.8	364.8	121.6	729.6	243.2	364.8	121.6	304.0	212.8
Dinophyceae												
Ceratium sp	6.1											
Glenodinium sp												
Gyrodinium spirale												
Prorocentrum micans	36.5	6.1	73.0	85.1	60.8	121.6	121.6	60.8	60.8	121.6	60.8	60.8
Peridinium sp											60.8	30.4
*Protoperidinium*sp	6.1		6.1		6.1		6.1	6.1				
Others												
Total	574.0	681.0	955.2	517.4	1945.6	760.0	1811.8	638.4	1264.6	747.8	8056.6	2103.7

Table 4.30: Phytoplankton cell counts (no. x 10^3/L) at different stations along Dubai Creek during flood Spring Tide on 15 January 06

	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Species	S	B	S	B	S	B	S	B	S	B	S	B
Bacillariophyceae												
Amphora sp	0.3											
Biddulphia sp	0.3											
Chaetocerose sp			0.6	6.1	6.1		0.6		0.6	6.1		6.1
Corethron sp												
Coscinodiscus spp	0.6	1.2					1.2	1.2			1.2	1.2
Cyclotella						1.2						
Guinardia delicatula	0.6	1.2										
Gyrosigma sp		1.2	1.2	1.2			1.2					
Melosira sp	6.1											
Navicula sp		1.2		1.2	1.2		1.2		1.2		1.2	
Nitzschia closterium												
Nitzschia sigma												
Nitzschia spp	182.4	127.7	608.0	60.8	1033.6	121.6	1276.8	127.7	1580.8	79.0	972.8	1216.0
*Pleurosigma*sp	6.1											
Psedo-nitzschia serriata												
Rhizosolenia habitata	6.1											
Rhizosolenia sp	188.5	12.2	304.0	121.6	364.8	60.8	243.2	60.8	121.6	60.8	60.8	30.4
Skeletonema costatum												
Synedra alna	0.6										1.2	
Thalassionema nitzschioides	6.1	6.1	6.1	6.1	12.2	6.1	12.2	6.1	12.2	6.1	12.2	6.1
Euglenophyceae												
Euglena sp	6.1	4.3	6.1	0.6	4.3	0.6	4.3	0.6	0.6	0.6	0.6	0.6
Euglena tripteries												
Cyanophyceae												
Pseuanabaena sp	6.1	6.1	60.8		304.0	60.8	182.4	36.5	30.4	60.8	30.4	60.8
Limnothrix sp	60.8	60.8	608.0	127.7	364.8	76.0	243.2	36.5	243.2	66.9	121.6	243.2
Dinophyceae												
Ceratium sp	0.6	1.2			1.2							
Glenodinium sp												
Gyrodinium spirale												
Prorocentrum micans	30.4	60.8	42.6	36.5	66.9	48.6	36.5	54.7	66.9	60.8	97.3	60.8
Peridinium sp		1.2		1.2			1.2					
*Protoperidinium*sp												
Others												
Total	501.6	285.2	1637.3	363.0	2159.0	375.7	2004.0	324.1	2057.5	341.1	1299.3	1625.2

Table 4.31: Phytoplankton cell counts (no. x 10^3/L) at different stations along Dubai Creek during ebb Neap Tide on 22 January 06

	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Species	S	B	S	B	S	B	S	B	S	B	S	B
Bacillariophyceae												
Amphora sp												
Biddulphia sp	6.1											
Chaetocerose sp	36.5	42.6	24.3	12.2	18.2	24.3	6.1		6.1		0.6	
Corethron sp												
Coscinodiscus spp	6.1	60.8									15.2	0.3
Cyclotella												
Guinardia delicatula												
Gyrosigma sp		6.1										
Melosira sp		6.1										
Navicula sp	6.1											
Nitzschia closterium	6.1											
Nitzschia sigma	6.1											0.6
Nitzschia spp	36.5	18.2	66.9	6.1	194.6	66.9	188.5	54.7	243.2	60.8	547.2	30.4
*Pleurosigma*sp												
Psedo-nitzschia serriata	6.1											
Rhizosolenia habitata	6.1											
Rhizosolenia sp	121.6	60.8	121.6	76.0	121.6	91.2	121.6	91.2	121.6	60.8	304.0	60.8
Skeletonema costatum	6.1		6.1	6.1		6.1		12.2		6.1	0.6	6.1
Synedra alna	6.1											
Thalassionema nitzschioides	60.8											
Euglenophyceae												
Euglena sp			6.1	6.1	60.8	6.1	30.4	6.1	30.4	6.1	54.7	60.8
Euglena tripteries							6.1					
Cyanophyceae												
Pseuanabaena sp	6.1	12.2	60.8	36.5	60.8	6.1	60.8	36.5	30.4	30.4	121.6	9.7
Limnothrix sp	6.1	6.1	6.1	6.1	6.1	6.1	6.1	30.4	3.0	30.4	79.0	12.2
Dinophyceae												
Ceratium sp	6.1											
Glenodinium sp												
Gyrodinium spirale												
Prorocentrum micans	30.4	15.2	24.3	12.2	36.5	42.6	85.1	73.0	145.9	66.9	60.8	6.1
Peridinium sp												
*Protoperidinium*sp	6.1	30.4	6.1	30.4	6.1	30.4	6.1	30.4	6.1	30.4	30.4	3.0
Others												
Total	364.8	258.4	322.2	191.5	504.6	279.7	510.7	334.4	586.7	291.8	1214.2	190.0

Table 4.32: Phytoplankton cell counts (no. x 10^3/L) at different stations along Dubai Creek during flood Neap Tide on 22 January 06

	Station 1		Station 2		Station 3		Station 4		Station 5		Station 6	
Species	S	B	S	B	S	B	S	B	S	B	S	B
Bacillariophyceae												
Amphora sp												
Biddulphia sp	6.1											
Chaetocerose sp	6.1					6.1	3.0	6.1	6.1	3.0	3.0	3.0
Corethron sp		3.0	6.1									
Coscinodiscus spp	6.1		3.0		3.0		3.0	6.1	3.0	6.1	6.1	6.1
Cyclotella	6.1											
Guinardia delicatula			6.1			3.0	3.0					
Gyrosigma sp	6.1											
Melosira sp	6.1	0.3	3.6									
Navicula sp					6.1	6.1	6.1		3.6		3.6	
Nitzschia closterium	6.1		3.6									
Nitzschia sigma	6.1	3.0										
Nitzschia spp	121.6	60.8	243.2	66.9	182.4	66.9	243.2	66.9	364.8	188.5	152.0	73.0
*Pleurosigma*sp	6.1		3.6									
Psedo-nitzschia serriata				12.2								
Rhizosolenia habitata	6.1											
Rhizosolenia sp	60.8	30.4	243.2	60.8	364.8	60.8	364.8	121.6	121.6	60.8	304.0	60.8
Skeletonema costatum	30.4											
Synedra alna	6.1											
Thalassionema nitzschioides	30.4	30.4	12.2	12.2	30.4	1.2	30.4	12.2	30.4	30.4	15.2	30.4
Euglenophyceae												
Euglena sp	6.1	30.4	0.3	0.3	30.4	6.1	30.4	6.1	6.1	6.1	30.4	30.4
Euglena tripteries			6.1		0.6		0.6		0.6			
Cyanophyceae												
Pseuanabaena sp												
Limnothrix sp	36.5	36.5	66.9	66.9	73.0	121.6	164.2	36.5	170.2	18.2	121.6	6.1
Dinophyceae												
Ceratium sp	6.1	6.1										
Glenodinium sp			6.1			6.1					6.1	
Gyrodinium spirale												
Prorocentrum micans	60.8	6.1	243.2	121.6	364.8	97.3	364.8	60.8	364.8	60.8	547.2	60.8
Peridinium sp	6.1	6.1	6.1	3.0	30.4						6.1	
*Protoperidinium*sp												
Others												
Total	425.6	213.1	853.3	343.8	1085.9	375.1	1213.6	316.2	1071.3	373.9	1195.3	270.6

Table 4.33: Zooplankton biovolume (ml/m^3) and density (no../m^3) along different stations of during ebb on 11 April 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Cnidaria						
Anthomeduseae						
Medusae		1	10	7	26	5
Chaetognatha						
Sagitta bruuni						
Annelida						
Polychaetae		10	1	1	1	
Mollusca						
Gastropods						
Bivalve larvae						
Arthropoda						
Copepods						
Acartia tropica	1849	6399	95	1094	9332	874
Bestiolina similis			1			1
Canthocalanus pauper						
Centropages orsinii		1	1			
Clytemnestra scutellata				1		
Corycaeus speciosus		1		1	1	
Psuedodiaptomus ardjuna	870	1219	11	70	289	18
Temora turbinata	1	1	1	1	1	1
Amphipods	3					
Maera othonides						
Quadrivisio bengalensis						
Decapods						
Paguriids						
Porcellanid zoea						
Crab zoea						
Alphieds						
Lucifer sp						
Ostracoda						1
Other decapods						
Cerepede larvae						
Tanaidaceans						
Pisces						
Fish egg	6	10			69	
Fish larvae						
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae						
Insect larvae						
Biovolume (ml/m^3)	0.06	0.17	0.03	0.02	0.10	0.11
Population (no./m^3)	2745	7639	117	1172	9995	897

Table 4.34: Zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during ebb on 28 April 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Cnidaria						
Anthomeduseae						
Medusae	4	27	48	24	3	18
Chaetognatha						
Sagitta bruuni						
Annelida						
Polychaeta	157	14	24	12		9
Mollusca						
Gastropods						
Bivalve larvae						
Arthropoda						
Copepods						
Acartia tropica	1291	8216	8228	16144	4013	5803
Bestiolina similis	1	1	1	1		
Canthocalanus pauper	1	1	1			
Centropages orsinii	1		1		1	1
Clytemnestra scutellata	1	1				
Corycaeus speciosus	1	1	1	1	1	1
Psuedodiaptomus ardjuna	608	1565	914	1030	124	118
Temora turbinata						
Amphipods						
Maera othonides						
Quadrivisio bengalensis						
Decapods	1	2	1	1	1	1
Paguriids	4	1	1			
Porcellanid zoea						
Crab zoea						
Alphieds						
Lucifer sp						
Ostracoda						
Other decapods		14	36	183	18	81
Cerepede larvae						
Tanaidaceans						
Pisces						
Fish egg	4	14	12	12	85	1
Fish larvae						
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae						
Insect larvae						
Biovolume (ml/m^3)	0.11	0.40	0.50	1.41	0.01	0.33
Population (no./m^3)	2085	9852	9263	17406	4243	6030

Table 4.35: Distribution of zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during flood on 5 May 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Cnidaria						
Anthomeduseae						
Medusae	1	1	8	12	6	3
Chaetognatha						
Sagitta bruuni						
Annelida						
Polychaeta	24	10	13	1	12	1
Mollusca						
Gastropods						
Bivalve larvae						
Arthropoda						
Copepods						
Acartia tropica	156	159	519	351	74	254
Bestiolina similis	1	1	1	1	1	
Canthocalanus pauper						1
Centropages orsinii		1		1	1	
Clytemnestra scutellata						1
Corycaeus speciosus	1	1	1	1		
Psuedodiaptomus ardjuna	88	18	16	4	1	2
Temora turbinata		1	1	1	1	1
Amphipods		16	6			
Maera othonides						
Quadrivisio bengalensis						
Decapods						
Paguriids						
Porcellanid zoea						
Crab zoea						
Alphieds						
Lucifer sp						
Ostracoda						
Other decapods					1	1
Cerepede larvae						
Tanaidaceans	1					
Pisces						
Fish egg	51	26	6	11	6	26
Fish larvae	1	1		3		2
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae						
Insect larvae						
Biovolume (ml/m^3)	0.03	0.05	0.08	0.03	0.04	0.04
Population (no./m^3)	319	230	568	381	101	289

Table 4.36: Distribution of zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during ebb on 26 May 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Cnidaria						
Anthomeduseae	13	1	1	1	18	1
Medusae						
Chaetognatha						
Sagitta bruuni						
Annelida						
Polychaeta						
Mollusca						
Gastropods						
Bivalve larvae						
Arthropoda						
Copepods						
Acartia tropica	42	5	45	47	7	26
Bestiolina similis						
Canthocalanus pauper						
Centropages orsinii						
Clytemnestra scutellata						
Corycaeus speciosus						
Psuedodiaptomus ardjuna	1	1	3	1	1	1
Temora turbinata	11	3				
Amphipods	4	1	6	5		5
Maera othonides						
Quadrivisio bengalensis						
Decapods						
Paguriids						
Porcellanid zoea	1					
Crab zoea						
Alphieds						
Lucifer sp						
Ostracoda						
Other decapods	13	1	12	24	7	27
Cerepede larvae	1	1	1	1	1	1
Tanaidaceans		1				
Pisces						
Fish egg				2	18	1
Fish larvae		1		1		1
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae						
Insect larvae						
Biovolume (ml/m^3)	0.14	0.06	0.20	0.13	0.18	0.21
Population (no./m^3)	85	12	68	81	52	62

Table 4.37: Distribution of zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during flood on 15 December 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Protozoa						
Oikopluera sp.	20	24	26			
Cnidaria						
Anthomeduseae						
Medusae	20	8	4			
Siphonophora						
Ctenophora						
Chaetognatha						
Sagitta bruuni	12	12	12	16	6	8
Annelida						
Polychaeta				2		
Mollusca						
Gastropods	4	8	6	10	12	4
Bivalve larvae						
Echinodermata						
Echinoderm larvae			2			
Arthropoda						
Copepods						
Acartia tropica	1600	1850	1300	1800	1200	335
Bestiolina similis	450	500	1000	850	500	0
Canthocalanus pauper	2		2			
Centropages orsinii	2					
Clytemnestra scutellata	4					
Corycaeus speciosus	2					
Psuedodiaptomus ardjuna	470	92	900	590	442	530
Temora turbinata	20	32	24	12		
Amphipods						
Maera othonides	12		24			
Quadrivisio bengalensis	8	20		2		
Decapods						
Paguriids	80	128	24	36	55	75
Porcellanid zoea	20	12				
Crab zoea			10			
Alphieds						
Lucifer sp	12	2				
Ostracoda	12	2	0	0	0	0
Other decapods	154	214	100	90	187	145
Pisces						
Fish egg					2	40
Fish larvae						
Cynoscion sp.						6
Preflexion (sciaenidae)					2	
Myctophidae						
Other fish larvae					2	6
Biovolume (ml/m^3)	0.3	0.4	0.22	0.24	0.22	0.2
Population (no./m^3)	2904	2904	3434	3408	2408	1149

Table 4.38: Distribution of zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during flood on 27 December 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Protozoa						
Oikopluera sp.	10	4	6			
Cnidaria						
Anthomeduseae	12	8	4			
Medusae	4		2			
Siphonophora						
Ctenophora						
Chaetognatha						
Sagitta bruuni	12	14	22	4	8	4
Annelida						
Polychaeta						
Mollusca						
Gastropods	4	1	12	24	18	6
Bivalve larvae		2				
Echinodermata						
Echinoderm larvae						
Arthropoda						
Copepods						
Acartia tropica	750	575	495	365	425	428
Bestiolina similis	500	450	400	321	295	315
Canthocalanus pauper	4					
Centropages orsinii	6					
Clytemnestra scutellata	12					
Corycaeus speciosus						
Psuedodiaptomus ardjuna	270	437	351	300	304	285
Temora turbinata	24	26	2			
Amphipods						
Maera othonides	12	14	12			
Quadrivisio bengalensis	2					
Decapods						
Paguriids	115	50	55	22	50	32
Porcellanid zoea						
Crab zoea	2					
Alphieds		4				
Lucifer sp						
Ostracoda	12	22	12			
Other decapods	125	42	47	20	48	30
Pisces						
Fish egg	2	12		8	12	
Fish larvae					14	12
Cynoscion sp.						
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae						
Biovolume (ml/m^3)	0.2	0.14	0.14	0.1	0.1	0.1
Population (no./m^3)	1878	1661	1420	1064	1174	1112

Table 4.39: Distribution of zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during flood on 15 January 2006

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Protozoa						
Oikopluera sp.	48	2	12			
Cnidaria						
Anthomeduseae						
Medusae	4	8				
Siphonophora						
Ctenophora						
Chaetognatha						
Sagitta bruuni	4	8	8	0	0	0
Annelida						
Polychaeta				2		
Mollusca						
Gastropods	168	40	0	0	0	0
Bivalve larvae			2			
Echinodermata						
Echinoderm larvae						
Arthropoda						
Copepods						
Acartia tropica	1180	600	540	780	950	530
Bestiolina similis	645	500	475	500	430	350
Canthocalanus pauper	4					
Centropages orsinii	8					
Clytemnestra scutellata	12					
Corycaeus speciosus	12					
Psuedodiaptomus ardjuna	795	440	405	580	580	360
Temora turbinata						
Amphipods						
Maera othonides	12	14	16			
Quadrivisio bengalensis						
Decapods						
Paguriids	88	140	70	96	46	40
Porcellanid zoea						
Crab zoea						
Alphieds						
Lucifer sp						
Ostracoda	428	24	0	0	0	0
Other decapods	92	100	50	108	80	46
Pisces						
Fish egg	2	8	24	12	46	48
Fish larvae					24	54
Cynoscion sp.						
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae						
Biovolume (ml/m^3)	0.6	0.2	0.12	0.14	0.16	0.12
Population (no./m^3)	3502	1884	1602	2078	2156	1428

Table 4.40: Distribution of zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during flood on 22 January 2006

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Protozoa						
Oikopluera sp.	24	12				
Cnidaria						
Anthomeduseae						
Medusae	12	12				
Siphonophora						
Ctenophora						
Chaetognatha						
Sagitta bruuni	8	4	2	0	0	0
Annelida						
Polychaeta				2		
Mollusca						
Gastropods	12	12	6	10	14	12
Bivalve larvae						
Echinodermata						
Echinoderm larvae						
Arthropoda						
Copepods						
Acartia tropica	245	380	210	225	135	143
Bestiolina similis	200	200	180	173	100	120
Canthocalanus pauper		8				
Centropages orsinii	4	2				
Clytemnestra scutellata	12					
Corycaeus speciosus	14					
Psuedodiaptomus ardjuna	195	260	130	130	149	123
Temora turbinata						
Amphipods						
Maera othonides	2		2			
Quadrivisio bengalensis	4	4				
Decapods						
Paguriids	36	26	22	40	30	5
Porcellanid zoea						
Crab zoea						
Alphieds	2					
Lucifer sp						
Ostracoda	28	14				
Other decapods	20	20	24	44	28	7
Pisces						
Fish egg	0	0	0	42	12	68
Fish larvae						24
Cynoscion sp.	2					
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae	4					4
Biovolume (ml/m^3)	0.1	0.12	0.1	0.1	0.1	0.1
Population (no./m^3)	824	955	576	666	468	506

Table 4.41: Distribution of zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during ebb on 15 December 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Protozoa						
Oikopluera sp.	12	12	4			
Cnidaria						
Anthomeduseae	8					
Medusae	2	4	2			
Siphonophora	2					
Ctenophora						
Chaetognatha						
Sagitta bruuni	64	56	14	24	8	0
Annelida						
Polychaeta						
Mollusca						
Gastropods	8	12	12	12	2	8
Bivalve larvae						
Echinodermata						
Echinoderm larvae						
Arthropoda						
Copepods						
Acartia tropica	1165	950	486	1188	565	512
Bestiolina similis	680	500	258	600	350	430
Canthocalanus pauper	12					
Centropages orsinii	24					
Clytemnestra scutellata	2					
Corycaeus speciosus						
Psuedodiaptomus ardjuna	635	596	338	680	325	300
Temora turbinata						
Amphipods						
Maera othonides	24	2				
Quadrivisio bengalensis						
Decapods						
Paguriids	80	112	138	200	55	22
Porcellanid zoea						
Crab zoea						
Alphieds						
Lucifer sp						
Ostracoda						
Other decapods	46	130	102	234	65	24
Pisces						
Fish egg	0	0	0	18	40	20
Fish larvae						
Cynoscion sp.						
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae						
Biovolume (ml/m^3)	0.22	0.24	0.14	0.3	0.14	0.1
Population (no./m^3)	2764	2374	1354	2956	1410	1316

Table 4.42: Distribution of zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during ebb on 27 December 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Protozoa						
Oikopluera sp.	4	4				
Cnidaria						
Anthomeduseae						
Medusae	24	12				
Siphonophora						
Ctenophora						
Chaetognatha						
Sagitta bruuni	22	18	2	6	2	6
Annelida						
Polychaeta						
Mollusca						
Gastropods	2	2			12	12
Bivalve larvae						
Echinodermata						
Echinoderm larvae	2			2		
Arthropoda						
Copepods						
Acartia tropica	575	485	463	165	328	212
Bestiolina similis	395	265	300	100	265	128
Canthocalanus pauper	12					
Centropages orsinii	14					
Clytemnestra scutellata		20				
Corycaeus speciosus						
Psuedodiaptomus ardjuna	310	296	319	159	253	146
Temora turbinata	12	24				
Amphipods						
Maera othonides						
Quadrivisio bengalensis						
Decapods						
Paguriids	135	26	38	33	12	22
Porcellanid zoea						
Crab zoea						
Alphieds						
Lucifer sp	12	14	2			
Ostracoda	24	32				
Other decapods	113	30	44	23	20	18
Pisces						
Fish egg	8		6	12		24
Fish larvae					4	12
Cynoscion sp.						
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae						
Biovolume (ml/m^3)	0.2	0.1	0.1	0.1	0.1	0.1
Population (no./m^3)	1664	1228	1174	500	896	580

Table 4.43: Distribution of zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during ebb on 15 January 2006

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Protozoa						
Oikopluera sp.	4	8				
Cnidaria						
Anthomeduseae	2	6				
Medusae		2				
Siphonophora	4					
Ctenophora						
Chaetognatha						
Sagitta bruuni	4	4	12			4
Annelida						
Polychaeta				2		
Mollusca						
Gastropods	320	48				
Bivalve larvae						
Echinodermata						
Echinoderm larvae						
Arthropoda						
Copepods						
Acartia tropica	880	525	540	595	455	325
Bestiolina similis	450	280	375	400	260	148
Canthocalanus pauper	12					
Centropages orsinii	4					
Clytemnestra scutellata	8					
Corycaeus speciosus	2					
Psuedodiaptomus ardjuna	530	315	325	445	305	207
Temora turbinata						
Amphipods						
Maera othonides	2			8		
Quadrivisio bengalensis						
Decapods						
Paguriids	156	85	119	78	30	55
Porcellanid zoea						
Crab zoea						
Alphieds						
Lucifer sp						
Ostracoda	480	48				
Other decapods	168	75	115	86	28	39
Pisces						
Fish egg			8	92	52	38
Fish larvae					12	42
Cynoscion sp.						
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae						
Biovolume (ml/m^3)	0.5	0.2	0.14	0.18	0.1	0.1
Population (no./m^3)	3026	1396	1494	1706	1142	858

Table 4.44: Distribution of zooplankton biovolume (ml/m^3) and population (no/m^3) along different stations of during ebb on 22 January 2006

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Protozoa						
Oikopluera sp.	12	24				
Cnidaria						
Anthomeduseae						
Medusae	12	10				
Siphonophora						
Ctenophora	2					
Chaetognatha						
Sagitta bruuni	8	12	8			
Annelida						
Polychaeta						
Mollusca						
Gastropods	14	4	8	12	18	18
Bivalve larvae						
Echinodermata						
Echinoderm larvae						
Arthropoda						
Copepods						
Acartia tropica	225	375	535	280	18	178
Bestiolina similis	125	280	395	150	14	156
Canthocalanus pauper	14	2				
Centropages orsinii		8				
Clytemnestra scutellata	2					
Corycaeus speciosus						
Psuedodiaptomus ardjuna	130	325	350	194	20	138
Temora turbinata						
Amphipods						
Maera othonides						
Quadrivisio bengalensis						
Decapods						
Paguriids	22	14	29	22	8	6
Porcellanid zoea						
Crab zoea						
Alphieds	2					
Lucifer sp	8	4				
Ostracoda	14	18				
Other decapods	20	10	39	20	6	8
Pisces						
Fish egg				8	120	40
Fish larvae						14
Cynoscion sp.						
Preflexion (sciaenidae)						
Myctophidae						
Other fish larvae						
Biovolume (ml/m^3)	0.1	0.1	0.1	0.1	0.1	0.1
Population (no./m^3)	610	1086	1364	686	204	558

Table 4.45: Distribution of macro-benthos during 15 December 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Class Crustacea						
Anthurid sp.		255				
Grandidierella exilis	1020	75	120			
Diogenes c.f. avarus		700				
Ilyoplax frater			80			
Apseudes latreille		75				
Thalamita poissoni				10		
Pilumnus savignyi	40	85				
Cumaceans	120	85	320			
Ostracods	80					
Phyllum Annelida						
Class Polychaetes						
Nephthys sp.		2560				
Capittalidae sp.			2400	240	240	120
Serpuliidae sp.	40					
Nereis sp.	60					
Nereis c.f. falcaria	200	1240				
Nereis lamellose					120	
Glyceridae sp.						
Spionidae sp.		320		20		
Chaetopteridae sp.			40			
Ammotrypans sp.			40			
Syllis sp.		430				
Gonadia sp.			120			
Eunice antennata			120			
Eunice sp.			240			
Capitella capitata		840	2400			
Loimia medusa					20	
Lumbriconereis sp.			640			
Phyllum Rhynchocoela						
Nemertean sp.		240	40			
Phyllum Mollusca						
Class Gastropods						
Class Pelecypods						
Barbatia plicata		40	240			
Spondylus sp.						
Biomass (g/m^2; wet wt.)	6.00	22.00	12.00	0.04	0.10	0.02
Population (no/m^2)	1566	6967	6812	270	380	120

Table 4.46: Distribution of macro-benthos during 27 December 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Phyllum Arthrpoda						
Class Crustacea						
Anthurid sp.						
Grandidierella exilis	80				20	
Ilyoplax frater	80		4800			
Apseudes latreille	40	543	3200			
Pilumnus savignyi	40	480				
Cumaceans	840					
Ostracods	2400	520				
Phyllum Annelida						
Class Polychaetes						
Nephthys sp.		2890				
Capittalidae sp.	40		7800	40	120	40
Serpuliidae sp.	20					
Nereis sp.	20					
Nereis c.f. falcaria	20	43				
Nematonereis unicornis			120			
Glyceridae sp.	80					
Spionidae sp.				20		
Chaetopteridae sp.			120			
Gonadia sp.	10					
Eunice antennata			120			
Eunice sp.	10		43			
Capitella capitata		43	1200			
Loimia medusa	10		80			
Lumbriconereis sp.			80			
Phyllum Rhynchocoela						
Nemertean sp.			40			
Phyllum Mollusca						
Class Gastropods						
Diadora rueppeli						
Nassarius c.f.crematus	240		80			
Class Pelecypods						
Barbatia plicata		80				
Spondylus sp.						
Phyllum Echnodermata						
Class Stelleroidea						
Ophiothrix c.f. savignyi	120					
Biomass (g/m^2; wet wt.)	8.00	24.20	12.00	0.04	0.10	0.02
Population (no/m^2)	4050	4599	17683	60	140	40

Table 4.47: Distribution of macro-benthos during 15 January 2006

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Phyllum Arthrpoda						
Class Crustacea						
Grandidierella exilis	120				40	
Elasmopus pectenicrus	20					
Ilyoplax frater	40		5200			
Metaplex indica						
Scopimera crabicauda	20					
Apseudes latreille	40	580	480			
Thalamita poissoni						
Leptocheila savignyi						
Pilumnus savignyi	80	1080				
Cumaceans	1240					
Ostracods	2640	240				
Phyllum Annelida						
Class Polychaetes						
Nephthys sp.		2890				
Capittalidae sp.	40		8200	40	40	80
Serpuliidae sp.	20					
Nereis sp.	20					
Nereis c.f. falcaria	20	43				
Nematonereis unicornis			240			
Glyceridae sp.	80					
Spionidae sp.		20		40		
Terebellidae sp.						
Chaetopteridae sp.			120			
Gonadia sp.	10					
Eunice antennata			120			
Eunice sp.	10		40			
Capitella capitata	10	40	800			
Loimia medusa	10	10	40			
Lumbriconereis sp.	20		40			
Phyllum Rhynchocoela						
Nemertean sp.			60			
Phyllum Mollusca						
Class Gastropods						
Nassarius c.f.crematus	360		40			
Class Pelecypods						
Barbatia plicata		80				
Phyllum Echnodermata						
Class Stelleroidea						
Ophiothrix c.f. savignyi	40					
Biomass (g/m^2; wet wt.)	10.00	12.00	18.00	0.02	0.02	0.02
Population ($no./m^2$)	4840	4983	15380	80	80	80

Table 4.48: Distribution of macro-benthos during 22 January 2006

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Phyllum Arthrpoda						
Class Crustacea						
Grandidierella exilis	40				20	
Elasmopus pectenicrus						
Diogenes c.f. avarus						
Ilyoplax frater	80		4800			
Apseudes latreille	80	240	3200			
Thalamita poissoni						
Leptocheila savignyi						
Pilumnus savignyi	40	480				
Cumaceans	840					
Ostracods	2800	520				
Phyllum Annelida						
Class Polychaetes						
Nephthys sp.		2890				
Goniadae sp.	20					
Sabella sp.						
Capittalidae sp.			2400	40	120	40
Serpuliidae sp.	20					
Nereis sp.	20					
Nereis c.f. falcaria	40	20				
Nereis lamellose	20					
Nematonereis unicornis			120			
Glyceridae sp.	40					
Spionidae sp.				20		
Chaetopteridae sp.			120			
Gonadia sp.	10					
Eunice antennata	10		40			
Eunice sp.	10		43			
Capitella capitata		20	600			
Loimia medusa	10		40			
Phyllum Rhynchocoela						
Nemertean sp.			40			
Phyllum Mollusca						
Class Gastropods						
Diadora rueppeli	40					
Nassarius c.f.crematus	240		80			
Class Pelecypods						
Barbatia plicata		20				
Phyllum Echnodermata						
Class Stelleroidea						
Ophiothrix c.f. savignyi	240					
Biomass (g/m^2; wet wt.)	12.00	18.00	14.00	0.20	0.04	0.02
Population (no./m^2)	4600	4190	11483	60	140	40

Table 4.49: Distribution of macro-benthos during 11 April 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Class Crustacea						
Anthurid sp.	0	128	0	0	0	0
Grandidierella exilis	935	0	155	0	11	0
Diogenes c.f. avarus		850				
Ilyoplax frater			205			
Apseudes latreille						
Thalamita poissoni	0	0	0	0	0	0
Pilumnus savignyi	43					
Cumaceans	43	100	300	0	0	0
Ostracods	43		2100			
Phyllum Annelida						
Class Polychaetes						
Nephthys sp.		543				
Nephthys paradoxa						
Capittalidae sp.	11	660	200	6243	4323	4333
Serpuliidae sp.	43					
Nereis sp.	44					
Nereis c.f. falcaria	200					
Nereis lamellose		1700				
Nematonereis unicornis						
Glyceridae sp.	0	0	0	0	0	0
Spionidae sp.				120		466
Chaetopteridae sp.			120			
Syllis sp.	0	0	0		0	0
Gonadia sp.	0	0	0	0	0	0
Eunice antennata						
Eunice sp.			230			
Capitella capitata			7880			
Loimia medusa					320	
Lumbriconereis sp.			790			
Phyllum Rhynchocoela						
Nemertean sp.	0	425	340	0	0	0
Phyllum Mollusca						
Class Gastropods						
Diadora rueppeli		85	340			86
Nassarius c.f.crematus						
Class Pelecypods						
Barbatia plicata	0	0	0	0	0	0
Ophiothrix c.f. savignyi						
Biomass (g/m^2; wet wt.)	4.38	15.63	9.72	18.20	4.62	5.24
Population (no./m^2)	1362	4491	12660	6363	4654	4885

Table 4.50: Distribution of macro-benthos during 5 May 2005

Species/Groups	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Class Crustacea						
Anthurid sp.		325				
Grandidierella exilis	43				44	
Diogenes c.f. avarus		325				
Ilyoplax frater	86		5200			
Apseudes latreille	43	43	2888			
Thalamita poissoni	0	43				
Pilumnus savignyi	43					
Cumaceans	86	389				
Ostracods	489					
Phyllum Annelida						
Class Polychaetes						
Nephthys sp.		1256				
Nephthys paradoxa						
Capittalidae sp.	21		6840	3466	2466	1246
Serpuliidae sp.	7					
Nereis sp.	14					
Nereis c.f. falcaria	14					
Nematonereis unicornis		256	120			
Glyceridae sp.	50					
Spionidae sp.				43		43
Chaetopteridae sp.			120			
Syllis sp.		256				
Gonadia sp.	7					
Eunice antennata			120			43
Eunice sp.	7		43			
Capitella capitata			1000			
Loimia medusa			43			
Lumbriconereis sp.			43			
Phyllum Rhynchocoela						
Nemertean sp.		44				
Phyllum Mollusca						
Class Gastropods						
Diadora rueppeli						
Nassarius c.f.crematus	215		43	43	43	43
Class Pelecypods						
Barbatia plicata		43				
Ophiothrix c.f. savignyi	86	86				
Biomass (g/m^2; wet wt.)	5.67	14.44	8.77	8.76	4.34	2.24
Population ($no./m^2$)	1211	3066	16460	3552	2553	1375