A STUDY OF THE NEGOMBO LAGOON WITH RESPECT TO THE SALINITY VARIATION AND POLLUTION OF THE LAGOON WATER AND EFFECTS OF PROPOSED DREDGING ACTIVITIES

By

R.N. Malawaraaratchi

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By
Prof. Mrs. N. Rathnayake
Dr. S.P. Samarawickrama

Department of Civil Engineering
University of Moratuwa
Moratuwa
Sri Lanka

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Abstract

Negombo Lagoon is a shallow basin estuary, located on the West coast of Sri Lanka, serving important functions including fishing and tourism. It drains water carrying nutrients and organic matter from the heavily populated catchment area and has faced the threat of the degradation of water quality. The objectives of this research are to study the seasonal and diurnal variation of salinity in the estuary, study the pollution status of the estuary; study the effects of dredging on the water quality and to recommend remedial measures.

17 sampling locations were selected for the study, which included points in the estuary and fresh water feeders. A Sampling programme of 6 days which covered both wet and dry weather as well as the spring and neap tidal periods was carried out. Salinity, nutrients and COD were measured at the flood and ebb tides.

According to the salinity measurements, in the dry period, the estuary is fully mixed. Stratified conditions occur when the fresh water flow rate increases. Chl *a* measurements were used to assess the trophic state of the estuary and fresh water feeders. The estuary is eutrophicated both in the wet and dry periods and some locations are even hypertrophic. Out of the fresh water feeders, Hamilton canal is mesotrophic and has faced the threat of eutrophication. According to the literature, limiting potential of the tropical estuaries has been found to shift from N to P with higher fresh water flow rates and results of this study agree well with the above finding. Limiting P inflows is a remedial measure to improve the water quality. Where the loads of DIN and TN are concerned, Dandugam-Oya was found to bring the highest loads irrespective of the climatic conditions. Where the Phosphate loads are concerned, Ja-ela brings significant, constant loads on rainy season, while Dandugam-Oya brings the highest load with the highest flow rate. Out of the 7 dredging options studied, option 6 is the most feasible one.

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This is to express my deep gratitude to all those who have helped me to complete this research project successfully.

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List of Abbreviations

Abbreviation	Name
BOD	Biochemical Oxygen Demand
CEA	Central Environmental Authority
Chl *a*	Chlorophyll *a*
Chl *b*	Chlorophyll *b*
Chl *c*	Chlorophyll *c*
COD	Chemical Oxygen Demand
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic phosphorus
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
HDPE	High Density Poly Ethylene
IRMP	Integrated Resource Management Programme
LHI	Lanka Hydraulic Institute
N	Nitrogen
P	Phosphorus
PON	Particulate Organic Nitrogen
POP	Particulate Organic Phosphorus
PP	Particulate Phosphorus
SD	Secchi Depth
SE	Standard Error
TN	Total Nitrogen
TP	Total Phosphorus
UOM	University of Moratuwa

Declaration

This thesis is a report of research work carried out in the department of Civil engineering, University of Moratuwa, Sri Lanka, between February 2002 and April 2003. The work included in the thesis in part or whole has not been submitted for any other academic qualification at any institution.

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R. N. Malawaraaratchi
Department of Civil Engineering
University of Moratuwa

Prof. (Mrs).N.rathnayake
Supervisor
University of Moratuwa

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Negombo estuary (7^0 $6'$-7^0 $12'$, 79^0 $40'$ –79^0 $53'$ E) is a shallow basin estuary on the west coast of Sri Lanka (Figure1.1).

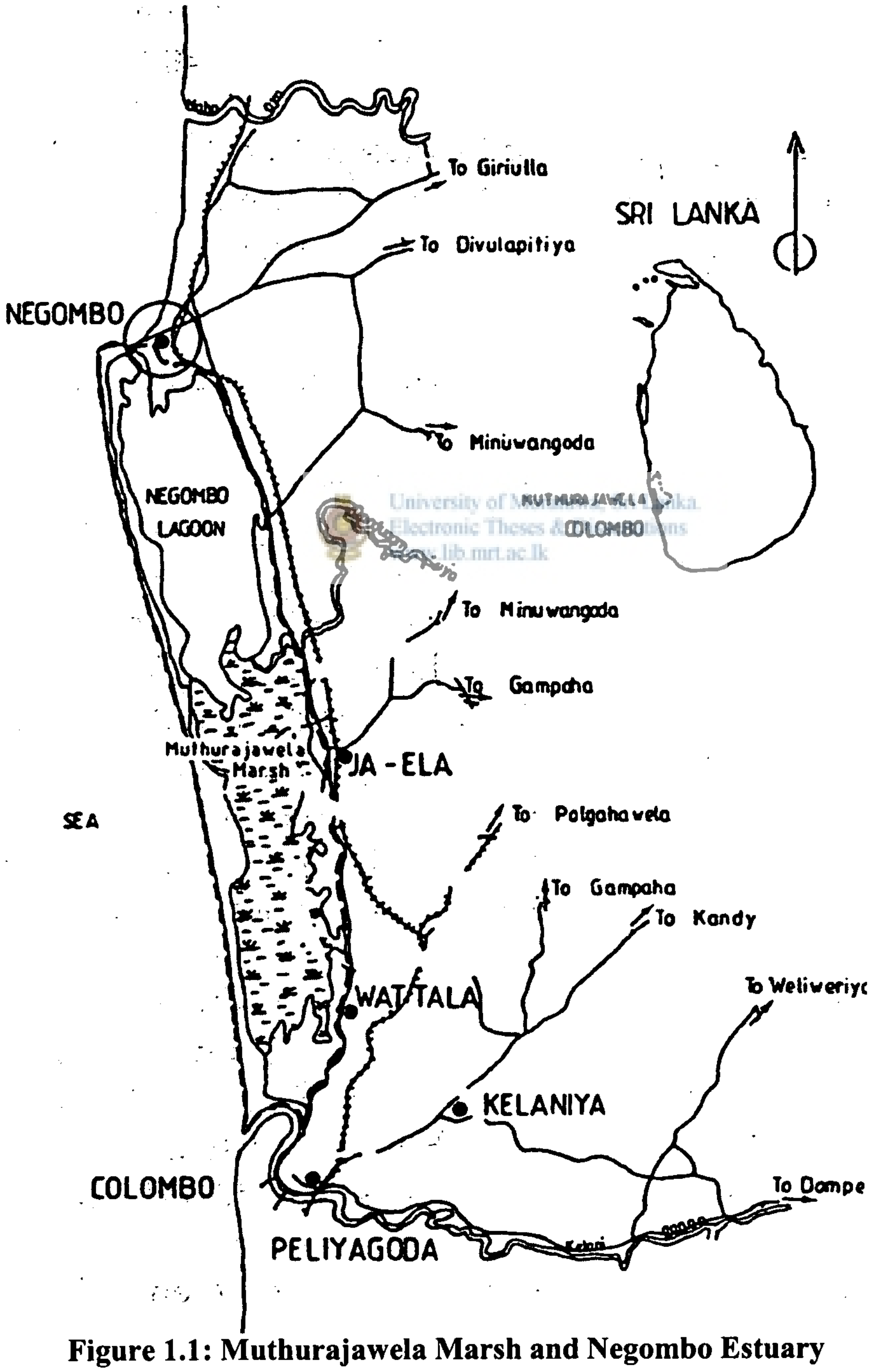


Figure 1.1: Muthurajawela Marsh and Negombo Estuary

Estuaries are meeting places of salt water and fresh water. They are governed by tidal action at sea and the river flow. McLusky (1999) reports the definition of an estuary which Pritchard forwarded in 1967 as a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage. According to this definition, coastal areas without direct river inflows can also be included as estuaries. According to Fairbridge (1980), (http: www. bbk.ac.uk/geog/study/courses/ coastal/estuary. pdf) an estuary is an inlet of the sea reaching into a river valley as far as the upper limit of the tidal rise, usually being divisible into three sectors: (a) a marine or lower estuary, in free connection with the open sea (b) a middle estuary, subject to strong salt and fresh water mixing (c) an upper estuary, characterized by fresh water but subject to daily tidal action.

The Negombo estuary is approximately 13 km in length and 0.6-3.6 km in width. The mean depth is nearly 0.65m while the surface area is 35 km^2 and the volume is 22.5 million m^3 (Hettiarachchi & Samarawickrama, 2001). The estuary receives fresh water mainly from Dandugam-oya river, which has a catchment area of 727 km^2. Ja-ela, Hamilton canal and Dandugam-oya discharge fresh water to the Southern end of the estuary. The Dutch canal which runs through the Negombo town discharges loads of wastewater at the northern part of the estuary. The estuary opens to the sea through a narrow mouth at the northern end and this mouth is partially barricaded by several islands. The exchange of water is mainly through three channels between these islands.

Most of the finfish and shellfish species living in the estuary are used as food, supporting an artisan fishery. As reported by Vithana (2001) Sideek and Jayasinghe (1985) have identified fourteen species of shrimps and six out of them are very important as commercial species and Pinto and Punchihewa (1996) have found 109 finfish species.

Over thousands of fishermen are engaged in fishing in the estuary and they use various fishing crafts and gear for a variety of fish species. Figure 1.2 shows two different fishing gears use in the Negombo estuary.

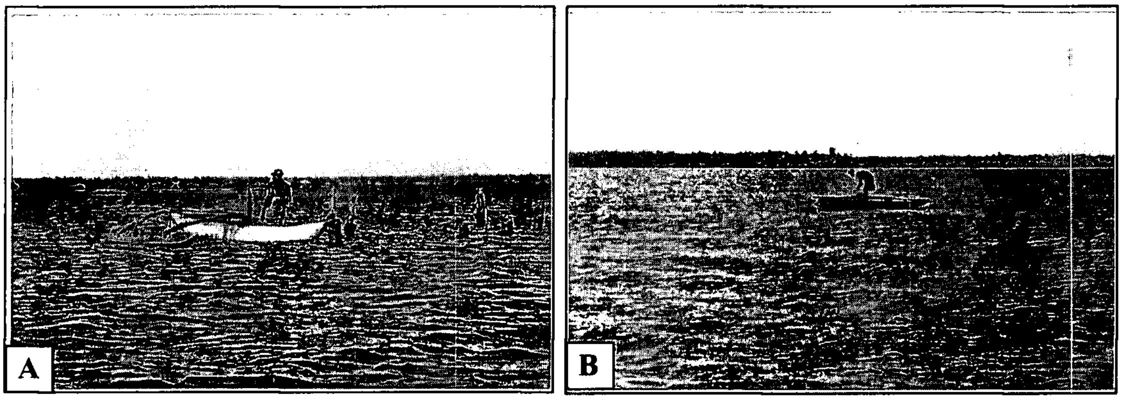


Figure 1.2: Various Fishing Gears, Used in the Negombo Estuary (A) Some Sticks have been planted as a Fish Aggregation Technique (B) Crab Harvesting

However, during the recent past, the fish catches have been gradually declined. Reduction in the riparian mangrove habitats, pollution due to industrial and domestic sewage, poor water exchange between the sea and the estuary due to choking and use of destructive fishing gear are some of the reasons for this decline.

Estuarine plants and animals are adapted to high environmental variability and possess potentially valuable genetic characteristics. According to Jayatissa, Dahdouh-Guebas & Koedam (2001), out of the 20 identified mangrove species of Sri Lanka, 12 are there in the Negombo estuary.

Human activities have adversely affected this estuarine ecosystem. As reported by Vithana (2001), a study done by Rajapaksa (1997) has revealed that the eventual fate of this basin estuary would be degradation by sedimentation and pollution.

1.1.1 Climate

Samarakoon and Van Zon (1991) have documented the climatic conditions as follows.

1. Rainfall

   Negombo is influenced by the South West monsoons. It is in a part of the wet zone, where the annual rainfall is 2000-2500 mm.

2. Evaporation and Humidity

According to the records at the Colombo Observatory, during 1964-1989, evaporation exceeds rainfall only in January, February and March.

3. Temperature

According to the daily maximum, minimum and average temperature records during 1961-1980, the highest mean daily maximum of 31.5 ^{0}C occurs in April. The lowest mean daily minimum of 22.3 ^{0}C occurs in January.

4. Wind

According to records, over 25 years for two daily times at 8.30 and at 17.30 hours, the maximum wind speed recorded at 8.30 hours was 15.3 km/hr in March and the minimum wind speed was 5.3 km/hr in April. Maximum was 11.9 km/hr in January and the minimum was 8.0 km/hr in November for 17.30 hours.

1.1.2 Geology

Muthurajawela marsh and the Negombo estuary have been developed during the Holocene period on the Pleistocene landscape that existed after the late glacial period (Samarakoon and Van Zon, 1991).

1.2 RESEARCH OBJECTIVES

The objectives of this research are to

1. Study the seasonal and diurnal variation of salinity in the lagoon water
2. Study the status of pollution of the lagoon water and water in streams feeding the lagoon
3. Study the effects of proposed dredging activities on the quality of water in the lagoon
4. Recommend remedial measures.

1.3 STRUCTURE OF THESIS

This thesis is structured as follows. The first chapter gives the background and the research objectives. The second chapter describes a detailed literature review on the salinity variation, water pollution and nutrients. It further discusses how the water quality can be improved by dredging alternatives and applying the limiting nutrient concept. The third chapter describes the methodology applied in the study. It gives the sampling locations, sampling programme and preservation techniques and methodologies used for chemical analysis. Analysis of results and discussion contain in the fourth chapter. Conclusions are given in the fifth chapter. It further presents the recommendations for the future development.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 GENERAL

Several studies of physical, chemical and biological aspects of Negombo estuary have been carried out over the last two decades. This chapter summarizes the relevant information on water quality, sedimentation and dredging from the studies carried out on the Negombo estuary and the mitigation measures to improve water quality.

2.2 WATER QUALITY

The general lack of sanitation and waste treatment facilities in high population areas of developing countries affect the degradation of water quality. The major water quality issues resulting in degradation include water borne pathogens and noxious and toxic pollutants. Despite efforts of various organizations, human health is still at substantial risk due to water quality problems in many areas of the world. Hydrogeological and biophysical environments are directly affected by changes in land use and socio-economic processes, which are largely controlled by human activities and resource management. Land alteration and associated changes in vegetation have changed the water balance as well as the processes that control water quality. The recognition of cyclical and cascading effects of human activities on the water quality and quantity along hydrologic pathways is an important issue for effective resource management. The degradation of water quality of the upstream parts of a watershed can have negative effects on downstream users. As there is a continuum of users through out the watershed, the degradation effects cascade through the watershed. Cyclical effects include the artificial movement of water upstream, such as groundwater abstraction for irrigated agriculture. Another cyclical effect is increased leaching of nutrients to waterways.

Water is a solvent and a medium for transfer of mass and heat. As water travels along a hydrologic pathway, such as ground water moving from a recharge area to a spring, a variety of interactions occur that are associated with the type of geologic media and with the biota (Vitousek *et al* 1997 a, Carpenter *et al*, 1998, Foy & O'Connor, 2002). The interaction causes some chemical elements to dissolve and precipitate, while others transform and the change of one nutrient species to another (Grimm, 1992, Mulholland, 1992, Vitousek *et al*, 1997 a, b, Schlesinger, 2000). Particles not only interact with the water, but can be transported by the water, depending on the mass, size and shape of the particle, the water velocity and the material through or over which the water flows.

2.2.1 COD

The chemical oxygen demand (COD) test is used to measure the pollutional strength of domestic and industrial wastes. Concentrated organic industrial wastes resulting from the manufacture of various foods generally create serious disposal problems because of their high organic load. These wastes are normally soluble or colloidal and have COD values varying from 200 to 5000 mg/L compared to domestic sewage with COD of about 400 mg/L (Britz, Trovec & Fourie, 2000).

2.2.2 pH

pH of seawater is buffered between 7.5 and 8.5 by the CO_2-Carbonate equilibrium (Valiela, 1995). Anaerobic metabolic reactions by microorganisms within sediments generate CO_2 in larger concentrations than in sea water and in anoxic situations pH does not depend solely on the CO_2-Carbonate system. When the CO_2 concentration becomes higher due to microbial activities, carbonic acid concentration increases and consequently H^+ concentration increases. Thus the pH is reduced within an estuary.

2.2.3 Salinity

A study of the distribution of the salinity, temperature and turbidity of the estuary was done by Wickramaratne *et al* in 1992 and Hettiarachchi analyzed these data in 1994 and came into the following major conclusions. Figure 2.1 shows the sampling points of that study.

1. The annual variation of salinity of the Negombo estuary showed high salinity levels during March 1989 and low salinity levels during May and June 1989; when the estuary water was almost fresh.

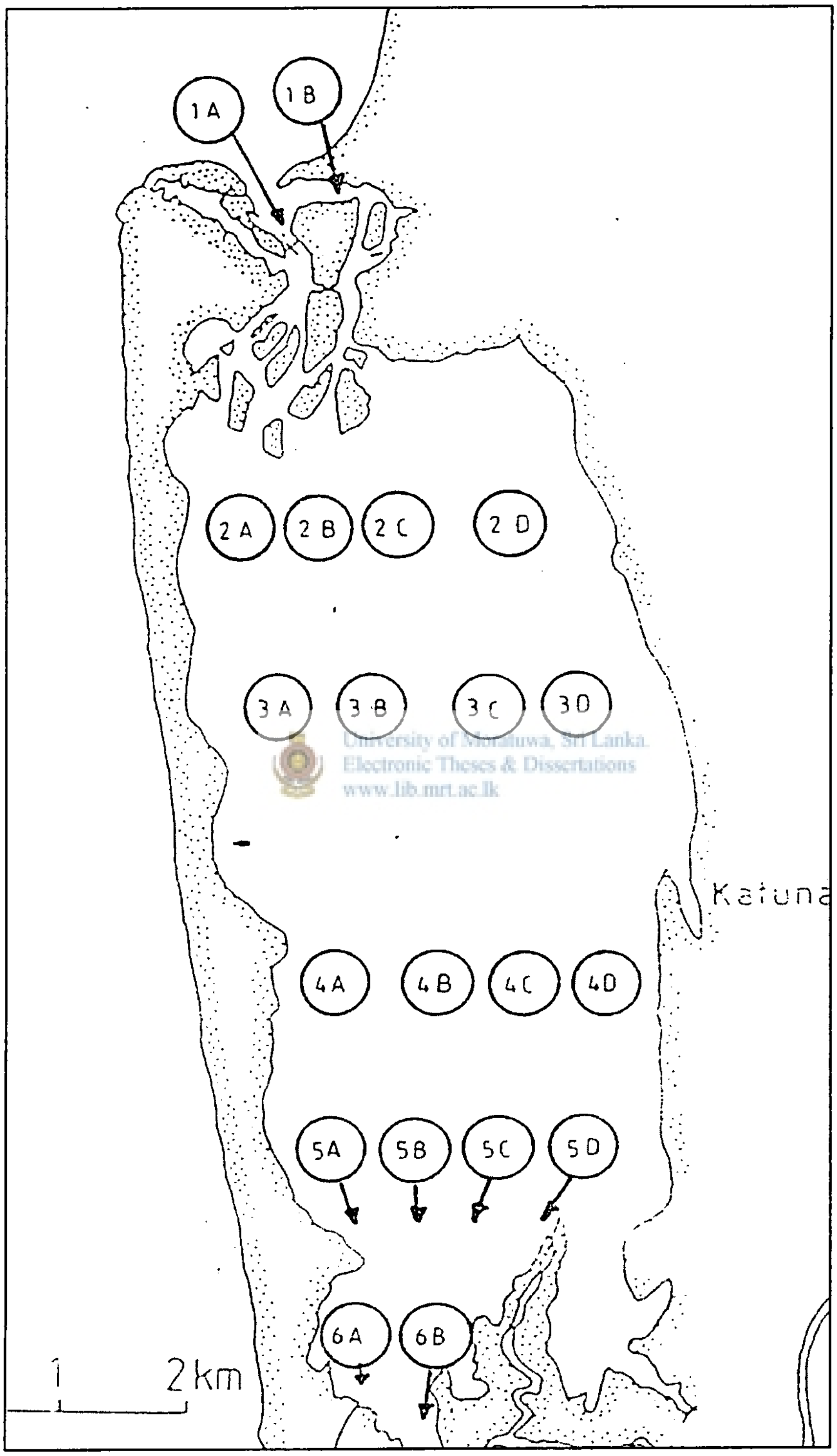


Figure 2.1: Sampling Locations. Source: Sedimentation in the Negombo Lagoon Outlet, S.S.L.Hettiarachchi, 1994

2. Salinity variation has a direct relationship with the rainfall. During the pre-monsoon periods, the salinity levels attained high values as observed in February, March and April as well as August and September. During the South-West monsoon, salinity level attained very low values as observed in May and June. During the October-November inter monsoonal period, the salinity levels attained very low values.

3. The salinity levels in the estuary were influenced by the tidal exchange at the mouth of the estuary and by the fresh water influx.

4. Salt-water intrusion was effective across the full length of the estuary.

5. Stratified flow occurs in estuarine systems that have weak tidal action, those are systems with small tidal range and or steeply sloping beds and in consequence, small storage volume. Examination of the surface and bottom salinity levels indicate the presence of stratified conditions with the bottom layers having a slightly higher level of salinity indicating intrusion of sea water along the sea bed.

2.2.4 Nutrients

(1) Nitrogen Cycle

The nitrogen cycle of the aquatic environments is schematically represented in the figure 2.2.

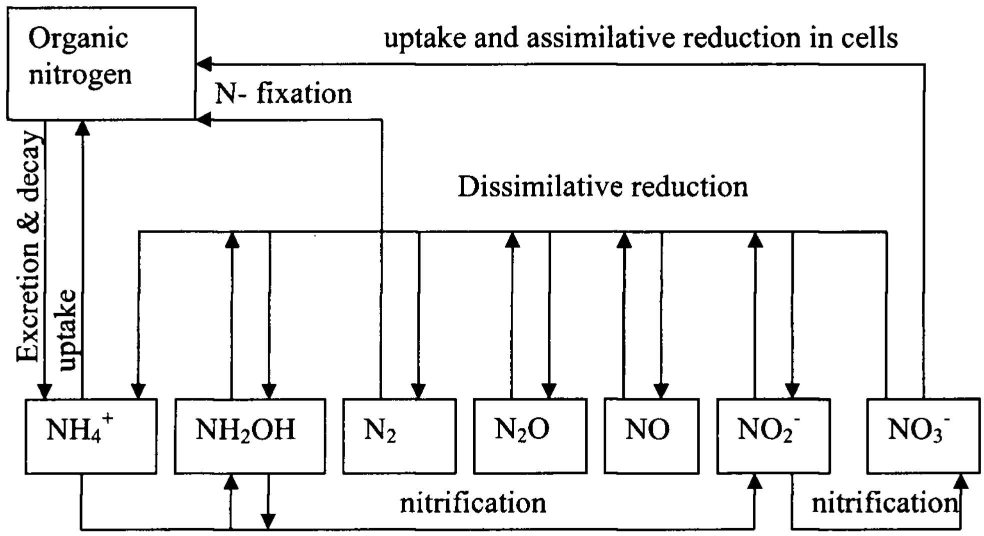


Figure 2.2: Transformations of nitrogen. The boxes show the various nitrogen species and arrows indicate the processes of transformation. (Adapted from Valiela, 1995)

Nitrate has the highest oxidation state. Nitrate is reduced to the amine form by algae, bacteria and plants through the assimilation processes. Nitrate is reduced by denitrification in series of steps and it is an anaerobic process (Risgaard-Petersen, 2003). The first step is the reduction of nitrate to nitrite. This nitrite is reduced to N_2 gas via N_2O and NO intermediates. Plants, algae and bacteria uptake ammonium for their growth(Presing *et al*, 2001,Triska, Duff & Avanzino,1993). Nitrification is an oxic process, which occurs in two steps. First step is the oxidation of ammonium to nitrite by bacteria, *Nitrosomonas*. This nitrite is further oxidized to nitrate by *Nitrobacter*. Some bacteria and algae like blue-greens can fix gaseous nitrogen through nitrogen fixation. The uptake of ammonium is energetically favoured over N fixation. Therefore when free ammonium is available, N fixation is much reduced (Wetzel, 1983, Valiela, 1995). N fixation takes place in anaerobic conditions (Moisander & Pearl, 2000). Organic detritus forms large amounts of organic nitrogen. Heterotrops decompose most of this organic nitrogen to ammonium. Fish and zooplankton also excrete ammonium.

(2) Phosphorus Cycle

Phosphorus is found in living organisms or as dissolved inorganic phosphorus (DIP), dissolved organic phosphorus (DOP) and particulate phosphorus (PP). In the figure 2.3, the sources, losses and pools of PP, DIP and DOP are schematically illustrated. The major inputs of the cycle are from the inflows of streams and discharges of human wastes. Primary producers and bacteria uptake the DIP (Paul, Duthie & Taylor,1991). This uptake results in the low DIP concentration of the surface waters. Death, shredding or moulting of organisms plus adsorption of phosphate onto particulate particles produce POP (Valiela, 1995). Phosphate is regenerated by the decay of POP and by animals (Sonzogni *et al*, 1982). When the particles decay, some of the POP is released as DOP. Some of the POP settles onto sediments. In the sediments, organic P regenerates DIP (Boynton & Kemp, 1985, Kay, 1997, Sinaj *et al*, 2001). Some of the DIP is precipitated or adsorbed (Howarth, 1988, Sharpley *et al*, 1999). Phosphates used as fertilizer adsorbs onto particles and travels to the sea through estuaries.

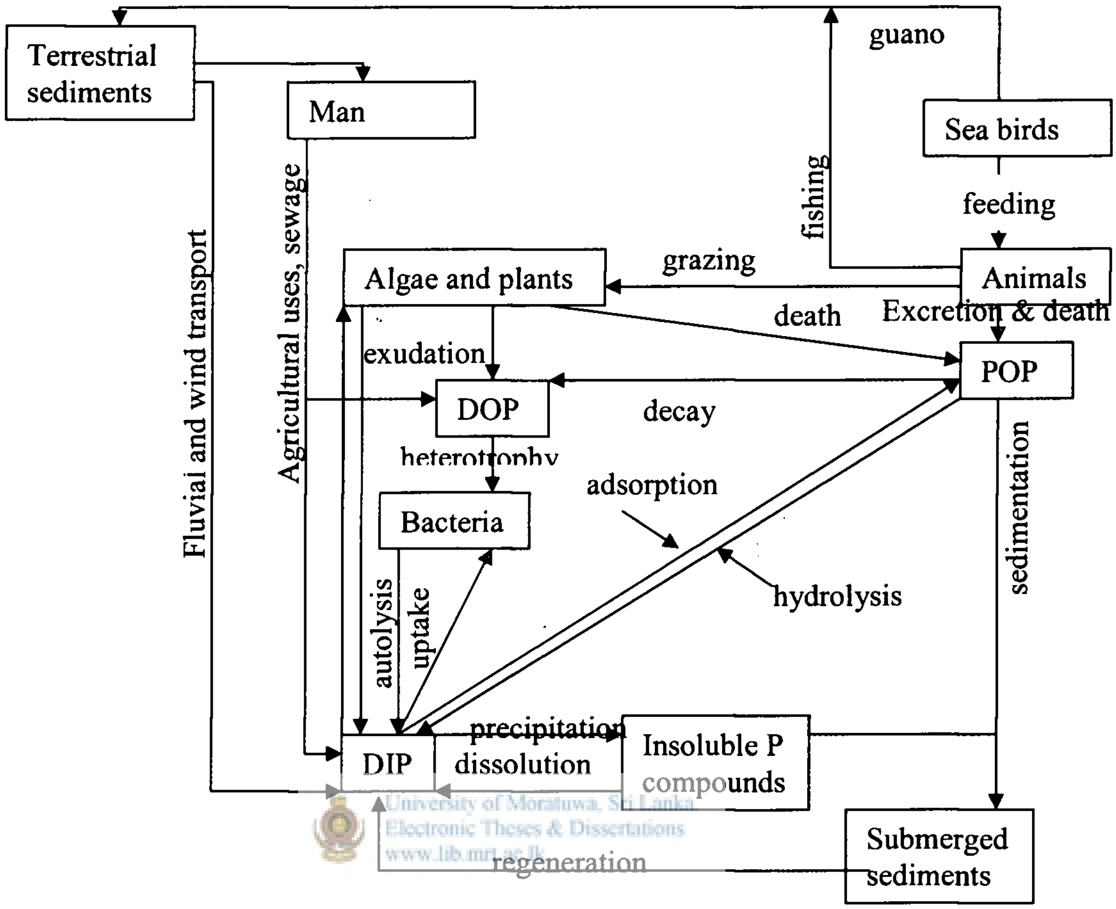


Figure 2.3: The phosphorus cycle. Boxes indicate the pools of P; arrows show processes including transport or transformations. (Adapted from Valiela, 1995)

(3) Eutrophication

According to Cooke (1986), eutrophication is defined as the process of excessive addition of inorganic nutrients, organic matter and silt to the water bodies, leading to increased biological production and a decrease in volume. Rast and Thornton (1996) state that eutrophication is the natural ageing process of lakes. Chorus and Bartram (1999) suggest that eutrophication is the enhancement of the natural process of biological production caused by nutrient enrichment. In essence, eutrophication is nutrient enrichment that causes problems. Therefore the following definition can be adopted.

"Eutrophication is the process of excessive nutrient enrichment of waters that typically results in problems associated with macrophytes, algal or cyanobacterial growth."

Natural eutrophication is a slow process, which takes many years. It depends on geological processes like weathering of rocks and natural features of the catchment. When the rate is accelerated through human activities like adding industrial wastes, domestic wastes and fertilizers it is called anthropogenic or cultural eutrophication. The added nutrients stimulate algal growth and defile the water quality. When the algal blooms die and decay it causes odorous clumps. When the dead matter uses up oxygen for decomposition, it causes oxygen depletion problems. This condition would be a threat to the fish and aquatic life. Table 2.1 gives the characteristics of different trophic states.

Table 2.1: Average characteristics of lakes, streams and coastal marine waters of different trophic states. TN, total nitrogen; TP, total phosphorus; chl *a*, chlorophyll *a*; SD, Secchi disk transparency. (Source: Smith, Tilman & Nekola, 1999)

	Trophic state	TN(mg/L)	TP(mg/L)	chl *a*(mg/L)	SD(m)
Lakes	Oligotrophic	<0.350	<0.01	<0.0035	> 4
	Mesotrophic	0.35-0.65	0.01-0.03	0.0035-0.009	2-4
	Eutrophic	0.65-1.2	0.03-0.1	0.009-0.025	1-2
	Hypertrophic	>1.2	>0.1	>0.025	< 1
				Suspended chl a(mg/L)	benthic chl a(mg/L)
Streams	Oligotrophic	< 0.7	< 0.025	< 0.01	< 0.02
	Mesotrophic	0.7-1.5	0.025-0.075	0.01-0.03	0.02-0.07
	Eutrophic	> 1.5	> 0.075	> 0.03	> 0.07
Marine				chl a(mg/L)	SD(m)
	Oligotrophic	< 0.26	< 0.01	< 0.001	> 6
	Mesotrophic	0.26-0.350	0.01-0.03	0.001-0.003	3-6
	Eutrophic	0.35-0.4	0.03-0.04	0.003-0.005	1.5-3
	Hypertrophic	> 0.4	> 0.04	> 0.005	< 1.5

Waters having relatively large supplies of nutrients are termed Eutrophic (well nourished) and those having poor nutrient supplies are termed oligotrophic (poorly nourished). Waters having intermediate nutrient supplies are termed mesotrophic. Eutrophication is the process by which water bodies become more eutrophic through the supply of nutrients. Hypertrophic is the term used for systems receiving greatly excessive nutrient inputs.

Taste and odour problems are caused by the eutrophication of lakes. Phytoplankton of slow moving rivers and peryphyton of shallow streams can reach high biomass when the watercourses are subject to eutrophication (Elwood, Newbold & Trimble, 1981, Fatoki, Muyima & Lujiza, 2001, Strauss & Lamberti, 2002). As a system becomes more productive, different species of algae may become more competitive and species composition can shift. However, the public is not concerned until such shifts cause water quality problems or aesthetic problems. Aesthetic impairment due to eutrophication is difficult to quantify. But usually it is linked with filamentous algal forms.Human uses of the flowing waters have been interfered by the eutrophication (Correll, Jordan & Weller, 2002, Cruzado *et al*, 2002). One example of these interferences is the reduction of the flow rate of canals caused by the high amounts of filamentous green alga *Cladophora*. Further it would interfere with swimming and fishing. Excessive algal growth would clog screens of water intakes of water treatment plants and industries. In one of the worst cases, eutrophication caused cyanobacteria to bloom in the stagnant Murray-Darling river system in Australia during a drought leading to livestock deaths (Dodds & Welch, 2000).

As most of the streams drain into oceans, eutrophication by the nutrient enrichment is a concern for estuaries and coastal areas (Strain & Yeats, 1999, Smith & Underwood, 2000). Eutrophication disrupts the delicate balance between carbon production and metabolism in coastal systems (Meyer-Reil & Koster, 2000, Kodama *et al*, 2002, Eyre & Ferguson, 2002, Kontas *et al*, 2003). Chesapeake Bay in the northern United States and the estuary of the Purari River in New Guinea are another two examples of eutrophic estuaries with valuable fisheries (Horne & Goldman, 1994, Norton & Fisher, 2000). Extensive public awareness of the cultural eutrophication in coastal waters has been developed recently with the publicity and public involvement in the Chesapeake Bay studies in 1980s (Fisher & Butt, 1994, Gibson *et al*, 2001). The zone of hypoxia that develops in the Gulf of Mexico is an example of marine eutrophication (Dodds &Welch,

2000). The production of toxic dinoflagellate blooms is another example (Valielà, 1995). In North-Adriatic Sea, both phyto and zooplankton blooms periodically occur, increasingly affecting the system due to chronic coastal eutrophic conditions (Rubino *et al*, 2000). Eutrophication has been considered the most serious environmental problem of the Baltic Sea as a whole (Tamminen & Seppala, 1999). Other than the lakes and estuaries, very enriched, slow moving and non-turbid rivers are vulnerable for such toxic blooms.

(4) Controlling Factors of Eutrophication

Sunlight and the concentrations of nutrients are the key factors, which control the algal production rate. As controlling of sunlight is not feasible, the approachable way is to manage the nutrients. P and N are the two nutrients that control the algal growth. According to Liebig's law of the minimum (Masters, 2000), growth of a plant is dependent on the amount of the nutrient that is presented to it in minimum quantity. Plant and bacterial growth in an aquatic system is limited by the availability of an essential nutrient. The concept of nutrient limitation, which was first applied in crop plant productivity, is now used in algal bloom investigations (Goldman *et al*, 1973). The limiting nutrient to the biomass of phytoplankton is always the nutrient in the lowest concentration relative to the demand for other nutrients (Ghilarov, 1983). In most estuaries around the world nitrogen has been identified as the major nutrient limiting annual production. The studies of Wilson Inlet, Moreton Bay, Queensland and Port Phillip Bay, Victoria have shown nitrogen is the limiting nutrient of them (Thomson, Rose & Robb, 2001).

Nutrient ratios in the water column determine the potential for nutrient limitation. Nutrients in coastal waters and estuaries are more abundant than those in the open ocean. But even in estuaries, nutrients are usually depleted in the photic zone. Thus phytoplanktons exert a major influence on the availability of nutrients and by reducing the supply of their essential resources, limit their own growth (Valiela, 1995, Wade *et al*, 2001). Carrying out a series of studies, Redfield developed a concept in 1958, that the algae under reasonably good growth conditions have an atomic ratio of N to P about 15 to

16:1. This ratio is known as the Redfield ratio. When N to P ratio is less than the Redfield ratio, N is considered potentially limiting and if greater than that, P becomes the limiting nutrient (Correll, 1999). This limiting nutrient concept is used for the ultimate limitation of the ecosystem primary production (Harrison *et al*, 1990, Correll, 1999). Numerous investigations proved that P is the limiting nutrient of the primary production of lakes. For estuaries and coastal waters, the situation is different with respect to P limitation. In estuaries there is an apparent shift from P limitation to N limitation (Correll, 1999). The obvious reasons are

1. The more efficient recycling of P in estuaries.
2. The high losses of fixed N to the atmosphere due to denitrification of coastal waters.
3. The role of sulfate in recycling P in coastal sediments.

Therefore identifying the limiting element is very important in controlling eutrophication. The amounts of N and P required for algal growth have been illustrated by the following representation of algal photosynthesis (Masters, 2000).

$$106CO_2 + 16NO_3^- + HPO_4^{-2} + 122\,H_2O + 18\,H^+ \rightarrow C_{106}H_{263}O_{110}N_{16}P + 138\,O_2 \longrightarrow (1)$$

Using a simple stoichiometric analysis, the ratio of the mass of N to P in this algae

$$\frac{N}{P} = \frac{16 \times 14}{1 \times 31} = 7.2 \longrightarrow (2)$$

According the equation (2), N:P is nearly 7. To produce a given mass of algae, it takes about 7 times more N than P. Masters (2000) reported that according to Thomann and Mueller (1987), when the concentration of N (mg/l) is more than 10 times the concentration of P (mg/l), the water body is P limited. Most marine waters have N/P ratio less than 5 and are N limited. As estuaries are transition zones, they are sometimes P limited and sometimes N limited (Correll,1999). Kamer & Fong (2001) found that the abundance of *Entermorpha intestinalis*-a green macroalga was largely governed by N availability indicating that blooms of macroalgae will likely continue to proliferate in estuaries unless nutrient loading is reduced. Cai *et al* (2003) found that the biological production of shelf waters appears to be limited by P availability according to the study done in the Pearl River estuary and its adjacent continental shelf in the Northern South China Sea.

Dodds & Welch (2000) say that developing a single value that can be used for nutrient criteria in streams and rivers will be difficult, given the variety of reasons for setting the criteria. According to Dodds & Welch (2000), if the streams and rivers are not turbid, preventing maximum benthic chlorophyll levels from exceeding 200 mg/m^2 is reasonable because the streams and rivers with higher levels are not aesthetically pleasing. For this, TN should remain below 3mg/L and TP below 0.4mg/L. To maintain the chlorophyll level below 100mg/m^2, TN and TP would be set at 0.47 and 0.06 mg/L respectively. Tank & Dodds (2003) found N limitation was the most frequent response and P was never the sole limiting nutrient of the ten streams they studied in USA.

2.3 MAJOR PROBLEMS ENCOUNTERED IN THE NEGOMBO ESTUARY

2.3.1 Reduction of the water area by sedimentation

Brooke (2002) says that the rate of sedimentation of many estuaries has been significantly increased during the last century with the increase in land clearance and disturbance. The rates of sedimentation of the last century are higher than the previous centuries and ranges between 4-10 mm/yr. During the previous centuries, the rates have been varied between 0.2 mm/yr to 0.3 mm/yr (Brooke, 2002). Figure 2.4 schematically illustrates how the infilling is enhanced due to the increased amounts of organic material accumulated as a result of abundant planktonic and benthic algal growth in association with sedimentation.

Suspended sediments enter estuarine system through a variety of sources, including catchment area surface runoff, bank erosion and advection due to tidal and river currents. Once sediment has entered the system, it will either continue to be advected or be deposited on the bed. The deposited sediment will remain trapped until it is disturbed by aquatic fauna activity, high tidal or river induced shear flows or human derived activities (Webster & Lemkert, 2002). According to the number of studies, Webster and Lemkert

(2002), report that the principal physical cause of sediment resuspension in most estuaries is tidal currents. The higher the current velocity, the greater the potential for resuspension due to the increased shear stresses placed on the bed. Generally flood tide has a greater velocity but shorter duration than that of the ebb tide when the riverine flow is insignificant. Hence flood tide produces more resuspension. This results in a net landward transport of sediment into an estuary. This has the effect of increasing the deposited and suspended sediment levels within the upper reaches of an estuary, until it is flushed out by storm events. The effective water area of the Negombo estuary has been reduced by 791 ha between 1956 and 1981 as a result of sedimentation and land filling (Vithana, 2001).

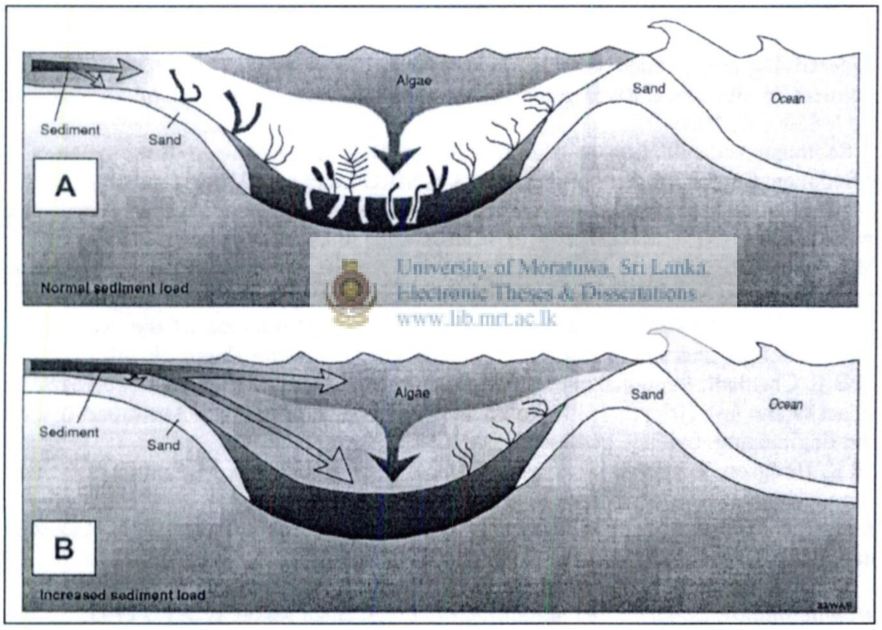


Figure 2.4: Schematic Cross-sections of an Estuary with (A) Natural Rates of Sedimentation (B) Increased Sedimentation (Adapted from Brooke, 2002)

The main conclusions of the investigation by Hettiarachchi (1994) analyzing the data of the study by Wickramaratne *et al* (1992) are

1. Both inland drainage and tidal flow have a pronounced influence on the sedimentation in the main body (basin) of the estuary and its outlet. Inland drainage has a greater effect on the region close to the outlet.

2. The prevailing hydrology encourages a large proportion of the sediment load to settle within the main body and outlet.

3. The main sediment deposition areas within the basin occur some distance from the discharge point of the river and where the basin flows into the channel segment. (Sampling stations 2A, 2B, 4A, 4B, 5A and 5B in figure 2.1).

4. A proportion of sand carried into the lagoon by tidal flow becomes deposited in the outlet.

5. It is likely that fine sand is transported by tidal inflow into the basin of the estuary to settle at slack tide as cohesive deposits.

6. The existing sedimentation processes will ensure that segments of the estuary will progressively fill and become unavailable for fishing and navigation.

The evidence from aerial photographs and interviews with estuary fishermen agree with the findings of the study (Van Zon & Benthem, 1994).

2.3.2 Poor water exchange

The formation of sand bars across the mouths of estuaries is a common phenomenon in Sri Lanka. The causes of sand bar formation could be generalized as insufficient fresh water flow, low tidal range, insufficient gradient of bed, non-optimal outlet size and waves and currents. The effect of such closure affects the productivity of the estuary by decreasing salinity levels, siltation, and concentration of pollutants beyond accepted levels and insufficient flushing and exchange. The channels of the Negombo estuary have formed as a result of the natural process of delta formation. The processes of island formation and sand shoaling have impeded the water exchange. Arial photographs clearly show the sand shoaling along the eastern channel.

When the natural conditions and human activities are reviewed, it is clear that siltation of the estuary and its inlet is also a key issue linked with the most problematic areas. It is important to note that the entire tidal exchange between the ocean and the estuary is restricted to mainly two channels. According the feasibility study of dredging the Negombo estuary to improve water flow and water quality, done by the University of Moratuwa in 2003, 90 % of water exchange is through the main channel and only 10 % is through the eastern channel. Hence there is a demand for engineering interventions, which will ensure the required water quality to obtain the desired ecological balance by maintaining the saline estuarine system.

2.3.3 Unplanned Human Settlement

Estuaries have always attracted human settlements. Sheltered harbours and good fishing grounds have been the important reasons of the evolution of cities along the shores of estuaries. The supply of large areas of cheap, flat land, accessibility from both land and sea, availability of water supply and ease of waste disposal and the sheltered nature of estuarine environment are the other pull factors (French, 1997). The location of road and rail transport routes along the coastline is another reason, which has contributed to the growth of heavily populated urban cities along the coast of Sri Lanka. As the human population grew during the 19^{th} and 20^{th} century, human settlements along the estuarine shores of Negombo increased in size. Table 2.2 shows the growth of the population in the Negombo municipality.

Table 2.2: Growth of the Population in the Negombo Municipality, 1946-1991

Sources: Dept.of Census and statistics; Divisional Secretariat, Negombo

Year	Population	Average annual growth rate (%)
1946	32,479	2.51
1953	38,628	1.92
1963	46,908	2.32
1971	56,759	2.21
1981	60,762	0.75
1991	72,637	2.70

In 1956, only 11 islands existed in the channel segment. In 1993, 13 islands and sand shoals existed (Figure 2.5). In 1955, only two islands Munnakkare and Siriwardene Pedesa were inhabited. By 1993, the number of inhabited islands increased to four. Out of them, Pitipana Duwa 1 and 2 were artificially stabilized islands (Van Zon& Benthem, 1994). In 1956, the land extent utilized for housing was 16.95 ha and in 1993, 20.55 ha.

Construction of the two bridges in 1950s has greatly facilitated the transportation and housing construction. Landfill for housing is carried out in small scale as well as in large scale. In small-scale landfill operations, house owners first plant mangrove seedlings at the border of the area to be filled. Natural process of siltation then fills up the required area within some six months. Large-scale landfill for housing has been done by the municipal council in collaboration with the National Housing Development Authority (NHDA) and the church to regularize the squatter settlements, when the Sirikurusapura Housing Scheme and Monaco Gama Housing Project were implemented (Van Zon & Benthem, 1994). Each unit of channel area lost brings the estuarine ecosystem closer to the degradation.

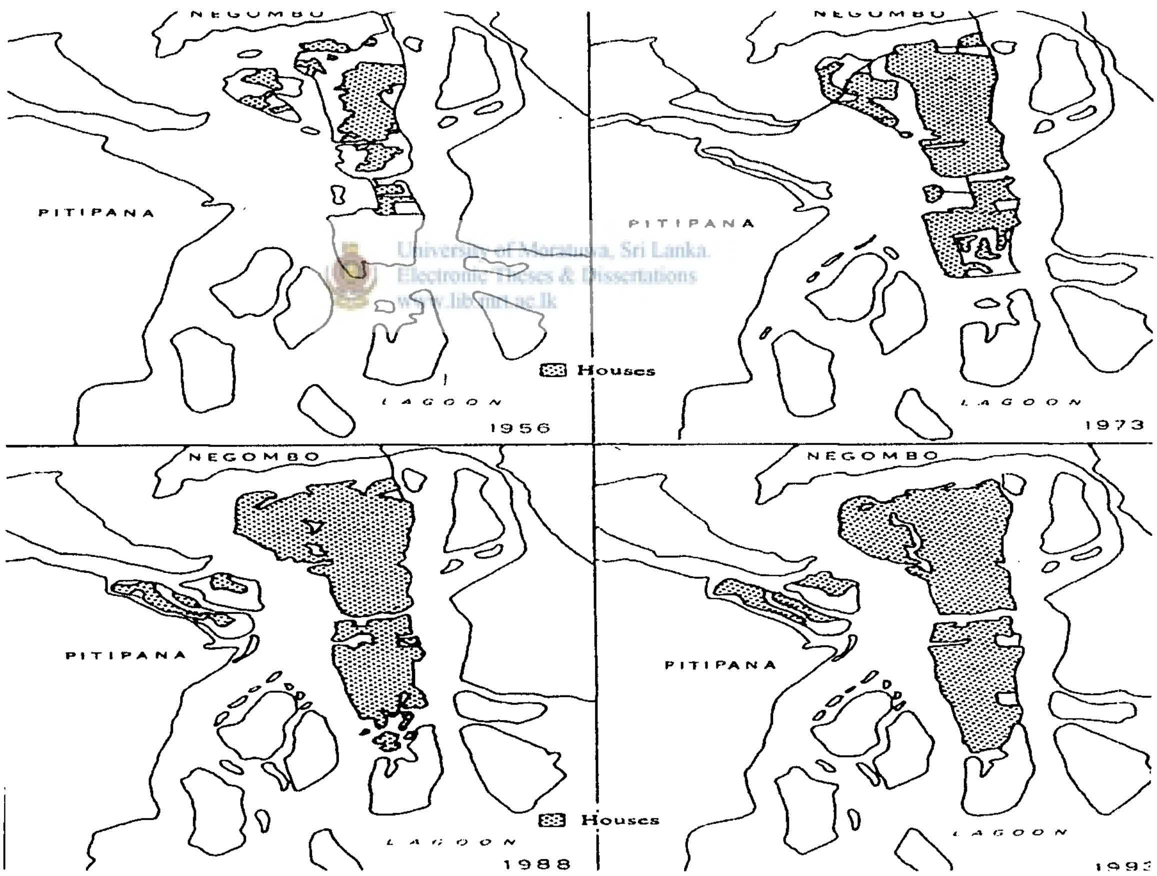


Figure 2.5: Housing Development in the islands from 1956 to 1993
Source: Conservation Management Plan, Van Zon & Benthem, 1994,

2.3.4 Unplanned fishery harbour

Presence of an unplanned fishery harbour leads to the environmental degradation due to unplanned activities. Since the early 1980s, ad-hoc development of piers and landing points has contributed to the alterations in the flow patterns.

2.3.5 Degradation of the ecosystem

Most of the finfish and shellfish species living in the estuary are used as food. Over thousands of fishermen are engaged in fishing in the estuary and they use various fishing crafts and gear for a variety of fish species. Jayawardane, McLusky & Titler (2002) have found that the juveniles of penaeids of which *Penaeus indicus*, use the estuary as a nursery ground and new post-larval immigrants inhabit the shallow near shore areas and move progressively to deeper central areas as they grow. But the deployment of fishing gear by local fishermen exploits this size distribution.

The estuarine ecosystem is unique and diverse due to variety of habitats. Mangroves of the estuary system contribute in the formation of an important ecosystem by providing food and shelter for finfish and shellfish. *Rhizophora*, *Brugiera*, *Lumnitzera*, *Acanthus*, *Avicennia* and *Ceriops* are the common mangrove species found in the Negombo estuary (Samarakoon & Van Zon, 1991). *Soneratia* is found rarely and is used as a beverage. *Acrostichum,* which is used as a vegetable, is the only fern found in the mangrove area. Eagles and crows use this plant to build up their nests. Reeds and rushes are also associated with these mangrove areas. But people cut mangroves for the purposes like construction of brush parks, as a timber, extraction of dyes for tanning and also as firewood. Mangrove species, which are planted for land-claim purposes, also will be cut once the soil has been stabilized.

Sea grass beds are highly productive ecosystems. The investigation on the sea grass beds on the Negombo estuary carried out by De Silva and Ranatunga in 1987 reports the presence of six species- *Halophila Ovalis*, *Halophila minor*, *Halophila* beccarii, *Ruppia maritime*, *Syringodium isotifolium* and *Halodule pinifolia*. According to De Silva & Ranatunga (1987), the extent of the sea grass beds is much more extensive and it covers

22% of the total area of the estuary. According to Vithana (2001), Abeywickrama & Arulgnanam (1991) have identified the area of the sea grass cover as 900 ha. Sea grass beds are critical nursery habitats for many finfish and shellfish. They provide food and shelter for fish. They play an important role in water clarity, sediment deposition, maintenance of the shoreline and recycling nutrients. Polycheates are found in large numbers on sea grass beds. They are a rich food source of many grazers. Undesirable fishing practices such as bottom trawling and collection of polychaetes in the estuary by scooping during the low tide disturbs the sea grass beds by which the larval stages of associated invertebrates and vertebrate fauna get affected (Van Zon & Benthem, 1994). As a result of the degradation, sea grass beds have been limited to the north-eastern and south-western part of the estuary (Van Zon & Benthem, 1994).

Although estuarine ecosystem is naturally dynamic and resilient, it cannot withstand extreme human interventions. The threat of water pollution and disturbance are two main factors, which threaten the calmness of estuarine ecosystem. With the ever-increasing pressure for human settlements, land claim exert a heavy toll on the ecosystem by reducing the estuarine area as well as the adjoined Muthurajawela marsh. This delicate ecosystem also faces the challenges of the possible challenges of the possible impacts of global climate change and accelerated sea level rise over the next few decades. Sea level rise may aggravate the existing environmental pressures and the impacts of coastal erosion, flooding, salt water intrusion and the degradation of coastal wetlands. Climate change would have impacts on the wind patterns. Hence the complex overall influence of global climate change and sea level rise and its impacts on the coastal zone should be clearly identified.

2.3.6 Water pollution

Estuary water is subject to be polluted by different sources. It has been noted that six different types of water pollution take place namely faecal pollution, visual pollution, eutrophication, organic and heavy metal pollution, oil pollution and thermal pollution. Table 2.3 describes the each type of pollution. The generic quality of water can be described using water quality parameters that describe the physical, chemical and biological status of the water body by comparing with the threshold values detailed in the proposed ambient water quality standards for coastal waters and inland waters given in the appendices. The different user classes given in the coastal water quality standards are assigned for various beneficial uses are given in the table 2.4.

Table 2.3: Significant Adverse Impacts that could occur by Each Type of Pollution

Type of pollution	Adverse Impacts
Faecal pollution	• Prone to water borne diseases. • Affects the growth of flora and fauna. • Susceptible for bad odours and unpleasant sights. • May lead to anoxic environments.
Visual pollution	• Imparts unpleasant sights. • Affects habitats, breeding ground of fauna. • Affects growth of vegetation such as sea grass by reducing the light penetration.
Eutrophication	• Stimulates algal growth. • Changes bio-diversity. • Introduces water quality problems.
Organic and heavy metal pollution	• Bio-accumulate in fauna, which are either carcinogenic or causing health hazards. • Declines bio-diversity due to toxicity. • Persistent in the marine or coastal environment for longer periods. • Affects growth, reproduction of marine fauna.
Oil pollution	• Gives unpleasant sights. • Perishes marine fauna and flora. • Affects benthic fauna with the formation of oil slicks and balls. • Affects migration patterns of fauna.
Thermal pollution	• Affects the growth of flora and fauna. • Causes changes in ecosystems. • Stimulates algal growth.

With respect to the classification of use for coastal waters in Sri Lanka given in table 2.4, Negombo estuary is subject to the following beneficial uses.

(1) Ecosystem conservation (class 1)

(2) Science and education (class 1)

(3) Aesthetic enjoyments (class 1)

(4) Fishery of shellfish (class 2)

(5) Aquaculture of shellfish (class 2)

(6) Water contact recreations (class 2)

(7) Fishery of finfish (class 3)

(8) Non water contact recreations (class 4)

Table 2.4: Proposed Classification of use for Coastal Waters in Sri Lanka.

Class	Description	Use
1	Nature conservation	Ecosystem conservation Science and education Aesthetic enjoyment
2	Fishery of shellfish	Fishery of shellfish (mollusca) Aquaculture of shellfish (mollusca) Saltpans Water contact recreations Ornamental production
3	Fishery of finfish	Fishery of finfish Aquaculture of finfish Fishery of non-molusca invertebrates Aquaculture of non-molusca invertebrates
4	Non-consumption use	Non-water contact recreations Navigation Harbour Waste disposal Sand mining Coral mining

The different user classes of the inland water quality standards are given in the table 2.5.

Table 2.5: Classification of Inland Waters

Class	Category	Description
1	1	Nature conservation
	2	Drinking water with simple treatment
11	3	Bathing
	4	Fish and aquatic life
	5	Drinking water with conventional treatment
	6	Irrigation and agriculture
111	7	Minimum quality (other uses)

(a) Faecal Pollution

Main sources of faecal pollution are low-income settlements, municipal sewage carried with the fresh water inflows and tourist sector. Many people of the area use pit latrines situated away from the house. In the dry seasons, feces remain confined to the pits but with the rain, the canals and the other water bodies in the encroached areas become hydrologically connected to the latrine pits (Samarakoon and Van Zon, 1991). The very high levels of faecal coliform indicate that the raw sewage is in contact with the estuary water. Table 2.6 shows the total and faecal coliforms in the Negombo estuary. When the microbiological quality of water at the Hamilton canal was compared between 1991 and 2003, coliform levels have been reduced in 2003. The present total coliform levels in Dandugam-oya and Ja-ela indicate higher values, greater than 1000 per ml; which is the threshold value of category 3 of the inland water quality standards. Faecal coliform levels of them, overly exceed the threshold value of 50 of the category 3 of class11 waters and not suitable for bathing. This is an indication of the inputs of municipal sewage into the estuary with the fresh water inflows of Dandugam-oya and Ja-ela. In 1991, total and faecal coliforms were tested at 18 sampling locations. Many of the sampling locations were situated at the margins of the estuary. In 2003, University of Moratuwa has tested the total and faecal coliforms mainly at the sampling locations inside the estuary. Therefore it is difficult to compare the coliform levels in the middle part, between 1991 and 2003. However, in 1991, water quality analysis revealed the faecal coliform levels in water bodies in proximity to the human settlements are excessively high (Samarakoon & Van Zon, 1991).

Table 2.6: Total and Faecal coliforms in the Negombo Estuary

No	Location	Total Coliforms per 100ml		Faecal Coliforms per 100ml	
		1991[1]	2003[2]	1991[1]	2003[2]
1	Sea		300-500		70-80
2	Entrance-main channel	8010	270-9000	50-3500	70-110
3	Confluence Dutch canal	11,200	500-16,000	0-2500	140-170
4	Middle		17		2-4
5	Middle		13-50		4
6	Middle		8-11		2
7	Middle		17		4
8	Hamilton canal	23,200	340-500	70-3000	70-90
9	Ja-ela		5000-16,000		140-220
10	Dandugam-oya		2200-9000		140-170

Sources: 1.Samarakoon & Van Zon, 1991 2. UOM, 2003

(b) Visual Pollution

The major cause of the visual pollution of the estuary is informal dumping of solid waste. The floating matter moves with the tidal fluctuation and gets deposited in the margins of mangrove islands. Rotten debris adds a bad odour to the environment. Informal solid waste dumpsites are common along the banks of the populated islands and shoreline closer to the mouth. Scattered fish parts, thrown here and there, is a common in the vicinity of "Lellama" at Pitipana. Waste matter gets trapped in shoals, which are formed as a result of the sedimentation. These polluted shoals cause not only the visual pollution; they hinder the navigation of fishing boats. Unauthorized, haphazard developments along the banks which are carried out as a result of the lenience of the legislation and the lack of a proper management system, has created an unpleasant, disorganized environment. Figure 2.6 shows the unpleasant sights of the estuary.

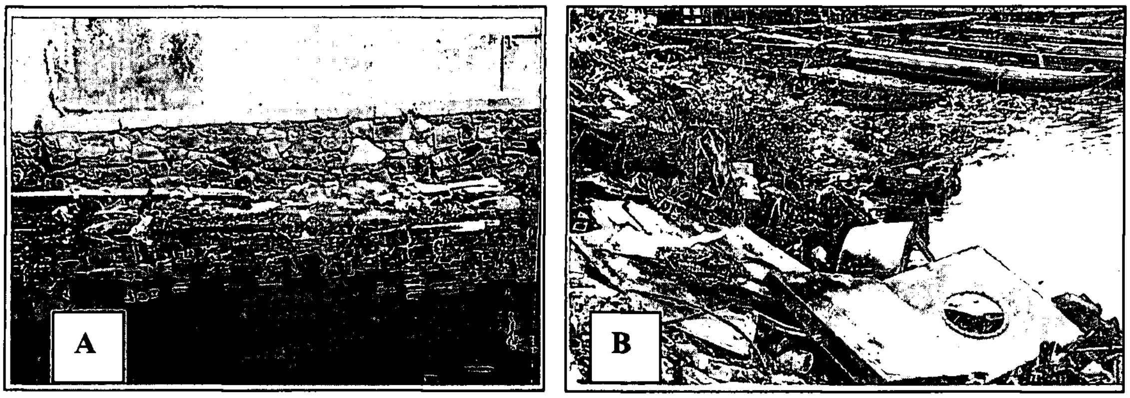


Figure2.6: Visual Pollution (A) along the Channel Segment (B) at harbour

(c) Eutrophication

While nutrients are necessary for the growth and reproduction of biota within the food web, too many nutrients can over-fertilize the waters creating excessive algae growth. When the algae die, they are decomposed by bacteria, using up large amount of oxygen and hence creating water quality problems. Therefore the definition of eutrophication focuses on excessive production of an algal biomass, imbalance in terms of bio-diversity and the hypoxia level resulting from excess degradation of organic matter (http://www.ifremer.fr/envlit/documentation).

More than sixty industries are situated in Ekala Industrial Estate, which consists of textile, battery manufacturing, asbestos and food canning factories. There is a tannery too and once the Batta-Atta Industrial Estate is formed, it has been proposed to shift there. According to Van Zon & Benthem (1994), forty-five of those industries directly discharge their untreated effluents to the Negombo estuary through Ja-ela. At the moment some of them have installed treatment plants. Katunayake Export Promotion Zone (KEPZ) discharges partially treated effluents (Van Zon & Benthem, 1994). Apart from the larger scale industries, small-scale industries situated in the close proximity, directly and indirectly discharge their effluents to the estuary (Van Zon & Benthem, 1994). Raddolugama sewage treatment plant discharges effluents to Dandugam-oya to a point 15 km downstream of it. Tourist sector and squatter settlements are also responsible for enriching the water with nutrients.

Vithana (2001) reports the occurrence of filamentous algae *Chaetomorpha* near Kadolkelle, located at the northern end of the estuary. This emphasizes that the waterbody is under the threat of eutrophication. Waters of this area is subject to stagnation due to the poor exchange of water along the eastern channel. The proliferation of these nuisance algae declines the bio-diversity and impairs the water quality. It devastates the seagrass beds, which are important in the rich diversity of benthic fauna.

(d) Organic and Heavy Metal Pollution

The values of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) are used in the analysis of domestic and industrial wastes of water. While BOD indicates the biologically decomposable organic matter, addition to that COD indicates the biologically resistant organic matter too. Organic pollution is generally due to municipal waste, industrial effluents and domestic wastewater. Toxins derived in the industrial activities and agricultural activities of applying agronomials, give rise to the toxic component. The investigation carried out by Samarakoon & Van Zon in 1991 revealed that the maximum and minimum BOD values of the estuary waters at several sampling locations lie within the range of 6 to 40. According the proposed standards of coastal waters in the table A 2, BOD must be less than 10 mg/L for class 4 and less than 5mg/L for both classes 2 and 3. Therefore it showed the organic pollution of the estuary. According the standards, water cannot be recommended for any beneficial uses except the nature conservation. As the toxic component of the organic pollution by the agronomical products and other industrial effluents have not been measured or estimated so far, no conclusive remarks can be made (Jayaweera, 2003).

As LHI reported in 1991, the heavy metal loading of mercury and chromium was approximately 20 kg/year and lead, copper and cobalt was 10 kg/year. As Vithana (2001) reports, an investigation done by Dassanayaka (1994) found that the state Distilleries Company in Seeduwa discharges effluents containing Sulphur, Organic compounds, Copper and Tin, which also finally drains to the estuary. These compounds can be accumulated in the water bodies and hence accumulate in the bodies of fauna and flora through bio-accumulation. The heavy metal levels and their concentration in fish/shell fish bodies in the Negombo estuary exemplify this (Vithana, 2001). Periodic fish kills were recorded as a result of episodic discharges of toxic effluents. (Van Zon & Benthem, 1994). Persistence of skin ulceration among sensitive fish such as chromides and rabbit fishes is an indication of the chronic pollution.

(e) Oil Pollution

Negombo fishing anchorage is located at the inlet along the eastern channel. It facilitates around 1300 fishing boats including 200 offshore boats. They use diesel, kerosene or petrol powered engines. Spillage of oil in the process of refuelling forms oil slicks, constantly. These layers of oil cause much damage to the bio-diversity of the estuary as well as the adjacent coastal waters by depleting the dissolved oxygen level. Storm water runoff brings the discharges of land-based sources and contributes in the formation of oil slicks. Careless handling of oil products in service stations situated close by the canals is a threat to the water quality of the estuary. Even though the damage cause by the oil waste remains unknown quantitatively, oil specks are visible in ditches, marshes, and estuary and even in the sea and impair the visual quality too.

(f) Thermal pollution

Temperature is an important factor for the fish and aquatic life. Thermal pollution is usually caused by the power sector or industries. As the temperature had been always less than 34^0 C, it reflects the fact that the estuary is not polluted thermally yet.

2.4 REDUCTION OF FLUSHING TIME WITH DREDGING

Without any major adversities, sewage disposal into estuaries has been carried out for centuries. But it became a problem when this practice is continued on a much larger scale. The harmful waste products were disposed into the estuarine systems with the introduction of new industries. Therefore, managing the estuarine ecosystem is a necessity. One method of estuarine management is flushing time concept. Flushing time T_f of an estuary is defined as the time needed to replace its fresh water volume V_f at the rate of the net flow through the estuary, which is given by the river discharge rate R (Day *et al*,1989).

$$T_f = V_f/R$$

Flushing time is used to determine the allowable disposal loads for a particular estuary. In addition it would give a guidance to handle accidental spills of harmful toxic material.

Estuarine flushing time regulates phytoplankton succession. Hamilton *et al* (2000) have reported that dinoflagellates and marine diotoms tend to dominate during the periods of low flow and high flushing times, whereas the faster-growing freshwater diatoms and chlorophytes are associated with higher flow rates and low flushing times in the Swan River estuary in Western Australia.

2.4.1 Previous Studies on Dredging

In the Engineering Study on the Feasibility of Dredging the Negombo Lagoon to Improve Water Quality, University of Moratuwa, October 2003, the following studies on dredging are discussed.

(a) Modelling the Negombo Lagoon Outlet – developing dredging scenarios

Birgit Cloin and Marcel ter Wengul, June 1996, Delft University of Technology, Faculty of Engineering.

Eight alternative dredging scenarios have been developed and each scenario implies dredging different channels. The channels are referred here according to the cross section numbers given in the figure 2.7. Brief description of the alternatives is given below.

Alternative 1: Channel 13 dredged to 1.52 m

The discharge in channels 13 has been increased and this will make the channel usable for stake-net fishery. The quantity of material to be dredged is 25,800 m^3. There is no increase in total volume exchange. Actual plan indicates dredging two parallel channels, which are represented as a single channel with same cross sectional area in the present model.

Alternative 2: Channel 13 dredged to 3.50 m

The discharge in channels 13 has been increased and this will make the channel usable for stake-net fishery. The quantity of material to be dredged is 56,500 m^3. A 4% increase in discharge could be expected.

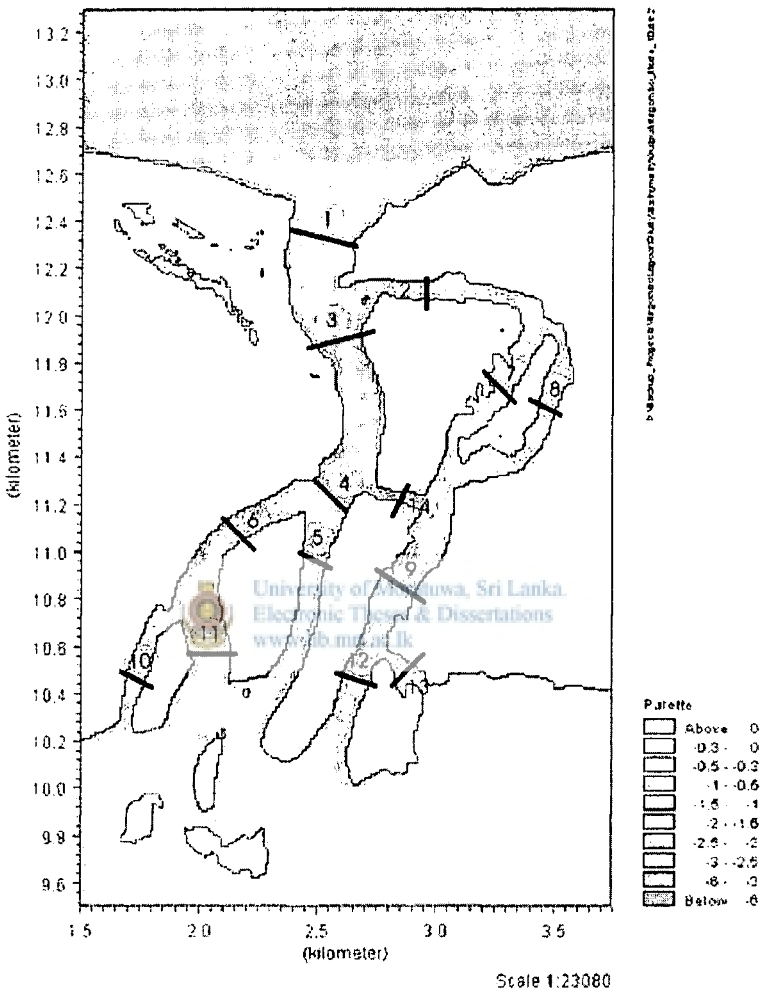


Figure 2.7: Estuary inlet Showing the Selected Channel Sections

Alternative 3: Dredging parallel channels in mangrove islands

The dredging of channels through the mangrove islands hardly has any effect on the flow pattern in the lagoon (only 2% increase). The volume of dredged material is 69,700 m^3.

Alternative 4: Enlarging the opening to the sea

There is a 4% increase in discharge and the volume of dredged material involved is 326,570 m^3. The practical implementation of this alternative is very difficult as the area to be dredged is now used for housing.

Alternative 5: Dredging at all Stake-net stations in Channels to 3.5 m

Volume of dredging involved is 676,700 m^3 and 11% increase of discharge can be expected. Stake-net fishing will be possible at all the stations but the dredged locations are most likely to be silt up.

Alternative 6: Decreasing the width of the south-western channels (15% at both sides)

By filling up the edges of the lagoon channel water movement has reduced by 17% and the volume needed for filing is 187,200 m^3.

Alternative 7: Dredging proposed areas

There is a strong increase in the water movement between the sea and the lagoon (39% increase of discharge). Channel 3 has shown an increase in erosion whereas all the other channels showed an increase in sedimentation. This is a good alternative in order to increase the water movement and to restore its depth; however, because of the sedimentation of the channels, costly maintenance is needed. Quantity of dredging required is 995,700 m^3.

Alternative 8: Dredging north-eastern channels to 3.5 m (channels 2 and 7)

There is a 17% increase of discharge and the volume of the dredged material is 601,800 m^3. The erosion and sedimentation patterns have completely changed, but the siltation process in general has decreased.

A comparison has been made among alternatives based on water movement; rate of siltation, fishing, displacement of people, mangroves, maintenance and cost involved, but no firm selection has been made.

(b) Integrated resources management Programme in wetlands (IRMP) – Feasibility study on dredging the Negombo Lagoon inlet. – Central Environmental Authority and Arcadis Euroconsult, the Netherlands, 1999.

Under this study they have compared the dredging scenarios proposed by Birgit Cloin and Marcel ter Wengul in 1996. Alternatives 1, 7 and 8 were selected for further assessment after the pre selection process.

The long-term development together with the costs is taken as the most important criteria. The order of importance of different criteria taken into account is as follows.

- Costs
- Long-term sedimentation
- Fishing
- Water exchange
- User effects

- Since long-term sedimentation and costs are the most decisive criteria, alternative 7 has eliminated, though this scenario benefits the fishermen and the ecosystem the most. They have also said that the uncertainties about the maintenance and the costs are too high in comparison with the benefits.
- Alternative 8 has been compared with alternative 1. Water exchange will be more enhanced with alternative 8, but on all the other criteria this alternative considers disadvantages in comparison with alternative 1.
- Alternative 1 has been selected as the most feasible dredging scenario. They have emphasized that a pilot project should be carried out to monitor the consequences of dredging the channel 13.

CHAPTER THREE

3.0 METHODOLOGY OF THE STUDY.

3.1 GENERAL

This chapter describes the methodology adopted in this study. It includes the sampling locations, sampling program, preservation techniques used and the methods of chemical analysis.

3.2 SAMPLING SITES

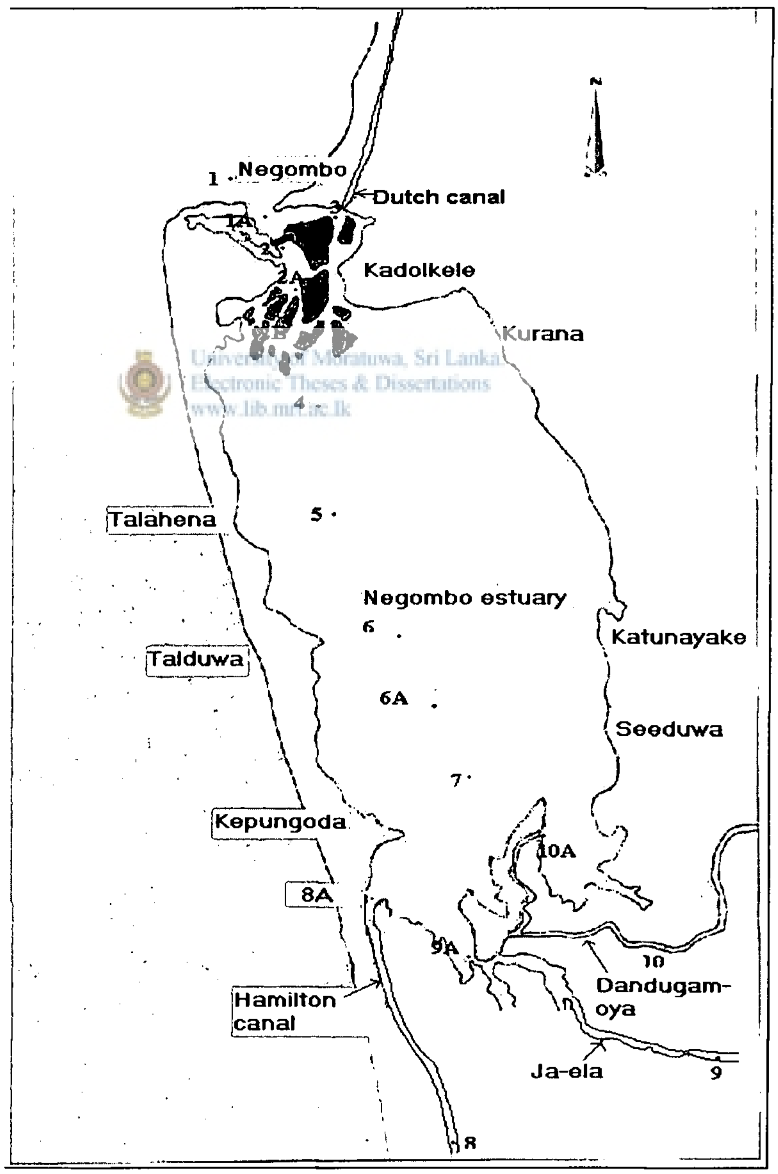


Figure 3.1: sampling Locations

For the purpose of this study the middle part of the estuary was divided into five cross sections. Figure 3.1 shows the sampling locations. Sampling point 1 was selected to measure the degree of pollution and nutrient levels of the sea, close to the outfall of the estuary to the sea. Sampling location 2 is at the entrance of the main channel. Sampling locations 2A and 2B are along the main channel. Sampling point 3 was selected from the northern part of the estuary, at the outfall of the Dutch canal, which leads to Puttalam. Sampling points 4, 5, 6, 6A and 7 are in the middle part of the estuary and the samples were taken from both top and bottom of the water column from those five sampling points. Sampling point 10A is at the outfall of Dandugam-oya, while 9A and 8A are at the outfalls of Ja-ela and Hamilton canal respectively. The major river, Dandugam-oya and Ja-ela as well as the Hamilton canal were monitored for flow and nutrient concentrations. The sampling points are 10, 9 and 8 respectively. As the flow is insignificant, upstream of the Dutch canal was not monitored.

3.2 SAMPLING PROGRAMME

The first sampling was carried out on 4th September 2002, where only 11 sampling locations were covered on the flood tide. Afterwards, sampling was carried out twice a day in flood and ebb tides to cover dry and rainy periods in both spring and neap tides. Thus, sampling was done on 25th September 2002 (spring), 15th October 2002 (neap) and 7th November 2002 (spring). The sampling programme is given in the table 3.1. Additionally, the water quality data of the Coastal Resource Management Project (CRMP) carried out by the University of Moratuwa on 2nd January 2003 (spring) and 10th February 2003 (neap) were used, with permission.

Table 3.1: Sampling Programme

Sampling Day	Date	Tidal Period	Weather
Day-1	04.09.2002	neap	Dry
Day-2	25.09.2002	spring	Dry
Day-3	15.10.2002	neap	Wet
Day-4	07.11.2002	spring	Wet
Day-5	02.01.2003	spring	Wet
Day-6	10.02.2003	neap	Dry

3.2.1 Hydrology

Rainfall measurements in the year 2002 of the Department of Meteorology were used with permission. Flow rates and tidal velocities were extracted from MIKE 11 and MIKE 21 models set up and calibrated for CRMP project by the University of Moratuwa.

3.2.2 Physico-Chemical data

Depth, temperature, conductivity, pH and time were recorded .pH probe was calibrated before each day of data collection against standard solution. As the conductivity meter is a factory set one, it was not calibrated. Bottom samples of the water column were taken *in situ* with a Rutner sampler, at the five cross sections of the sampling locations 4, 5, 6, 6A and 7 in the middle part of the estuary.

3.2.3 Nutrients

Water samples from the surface and bottom of the water column at the middle part of the estuary and surface water samples from the other sampling points were analyzed for the major nutrient species. Analysis was done for the following parameters. Total Nitrogen (TN), nitrate–Nitrogen (NO_3^--N), ammonium nitrogen (NH_4^+-N), Total phosphorus (TP), reactive phosphorus (PO_4^{-3}-P), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD). COD was measured to reveal the chemically degradable waste in the water column. The interference of the chloride levels to the COD test was eliminated with higher doses of mercuric sulphate. Dissolved Oxygen was measured only at the fresh water outfalls.

3.3 SAMPLE PRESERVATION

Table 3.2 shows the preservation techniques applied during the sampling program. The preservation techniques followed were in accordance with the Standard Methods for the Examination of Water and Wastewater, APHA, 1995.

Table 3.2: Preservation Techniques Used For Various Parameters

Parameter	Sample Type	Container	Preservation	Holding time
Ammonia	Discrete	HDPE 500ml	H_2SO_4 to pH<2	14 days
Nitrate,Phosphate,TDS	Discrete	HDPE 2L	Cooled to 4^0C	24 hours
Chemical Oxygen Demand (COD)	Discrete	HDPE 500ml	H_2SO_4 to pH<2	28 days
TN, TP	Discrete	HDPE 2L	Cooled to 4^0C	28 days

3.5 CHEMICAL ANALYSIS

Laboratory analyses of the water samples were carried out as soon as possible and in all cases analyses followed the standard methods for the examination of water and wastewater, 1995.Table 3.3 indicates the methodologies used for the analysis.

Table 3.3: Methodology Used for Chemical Analysis

Parameter	**Methodology**
pH	PH meter
Temperature	Thermometer
Conductivity	Conductivity meter
Salinity	Calculated by the salinity calculator using the conductivity,temperature and pressure which had been calculated according the depth, (matthias.tomczak@ flinders.edu.au).
TDS	Filtration, Evaporation on a water bath drying at 103^0C-105^0C and Weighing using the Analytical balance
COD	Open reflux/Titrimetry
Total N	Persulfate Digestion & determination by diatozization
Total P	Persulphate digestion & determination by molybdenum blue method
Nitrate N	Reduction to nitrite & determination by diatozization
Phosphate P	Determination by molybdenum blue method
Ammoniacal N	Phenate method using spectrophotometer

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 PHYSICO-CHEMICAL PARAMETERS.

4.1.1 Hydrology

(a) Rainfall

The Figure 4.1 shows the monthly rainfall in the year 2002. The variation of rainfall shows the seasonal pattern with little rainfall from January to March and July to August with the higher rainfall in April (intermonsoon) , May and June (South West monsoon) and October (intermonsoon).

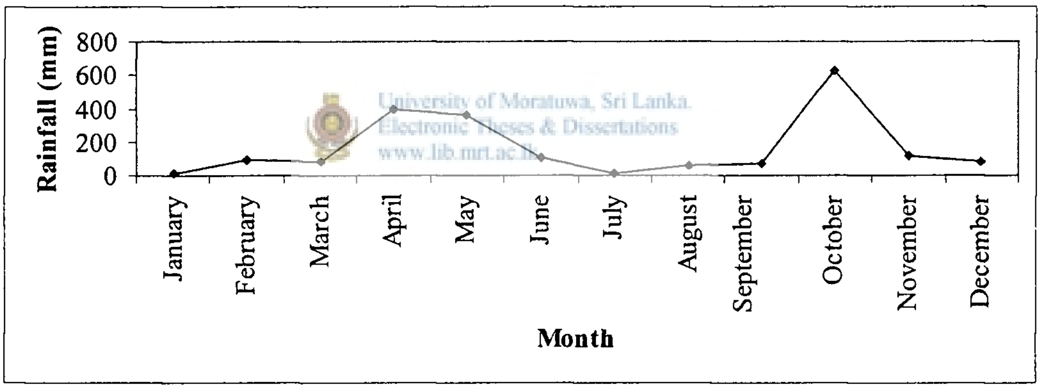


Figure 4.1: Monthly Rainfall in Year 2002

(b) Fresh Water Discharges

The figure 4.2 gives the collective value of the fresh water flows of Dandugam oya, Ja-ela and Hamilton canal. It shows the highest discharge is on 21 October 2002 during the period of measurements taken. Using this figure, average discharges on day 2, day 3 and day 4 were obtained as 6.5 m^3/s, 35.0 m^3/s and 103.0 m^3/s respectively. Separate values of discharges show that Dandugam-oya accounts for the greater percentage of the estuary inflows than Ja-ela and Hamilton canal and are given in the table A11 in the annexes.

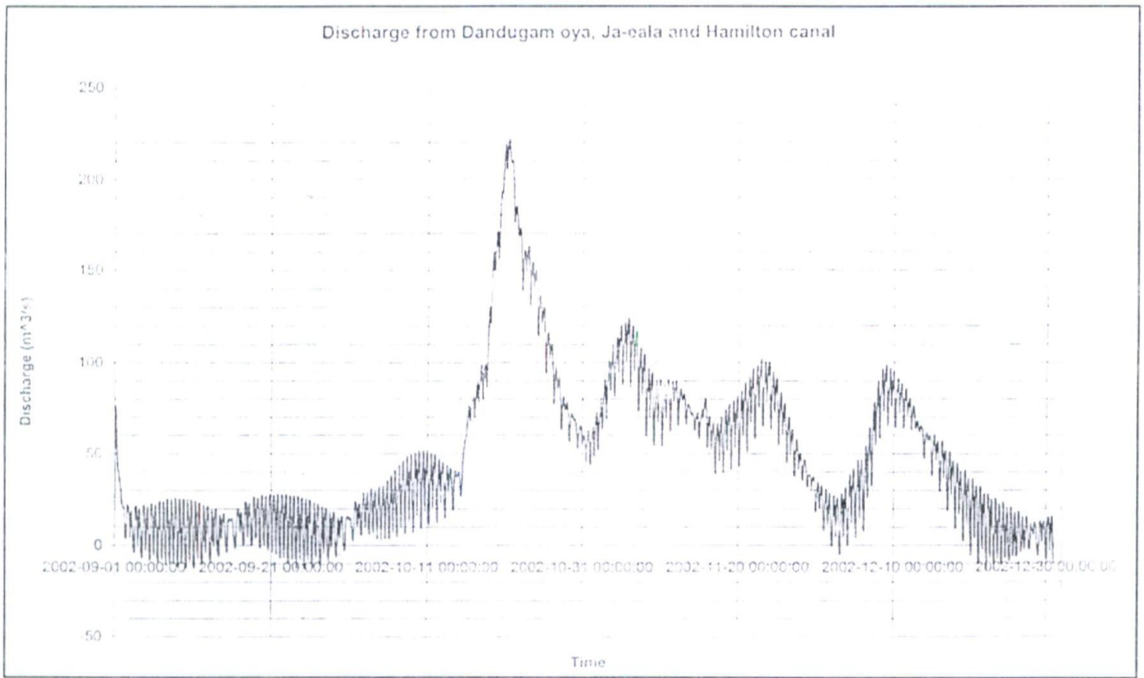


Figure 4.2: Variation of Total Fresh Water Discharge from River and Canals Source: Engineering Study on the Feasibility of Dredging the Negombo Lagoon to Improve Water Quality, University of Moratuwa, 2003

4.1.2 Salinity

Figure 4.3 shows the temporal variations of salinity.

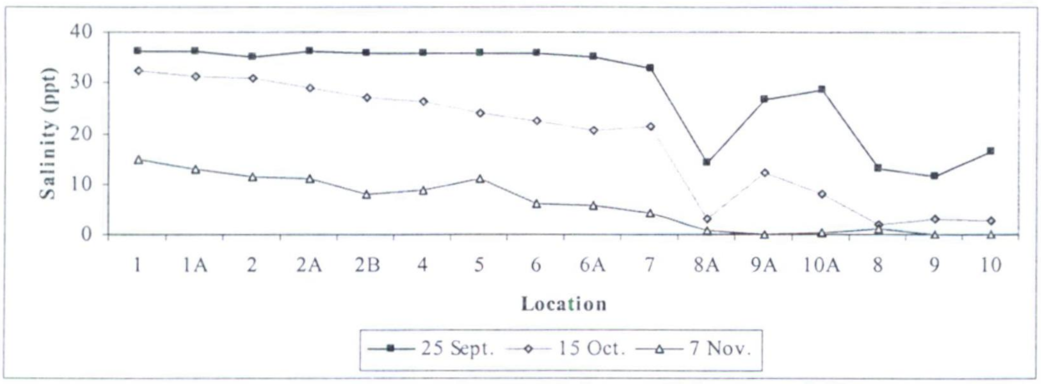


Figure 4.3: Variation of Salinity. (Flood and Ebb Average)

Using salinity as a conservative tracer it is possible to explain the relative influence of the tidal exchange and freshwater inflows on the hydrodynamic behavior. At the end of September, there is a longitudinal gradient along the length of the estuary, ranging from

28 ppt at the river outfall, nearly 13 km from the mouth, to >35 ppt in the mouth of the estuary. The top and bottom salinity values are almost alike and it is an indication of the formation of almost vertical isohalines. During such times, according to hydrodynamic classification schemes given in Kramer (1994), the estuary can be classified as a fully mixed estuary. On day 3, in mid- October (dry, neap), after the commencement of the inter- monsoonal rain in the catchment, fresh water enters the upper estuary and top and bottom salinity levels show a bigger difference than on day 2. The change from approximately vertical isohalines to mostly horizontal and the development of two distinct surface and bottom layers leads to the estuary being characterized as "highly stratified." On day 4 (7^{th} November-wet, spring), after a period of heavy rain, the fresh water inflows (<1ppt) are relatively large compared to the tidal volume, and have almost completely flushed the saline and brackish waters from the upper part of the estuary. Dronkers (1988) says if a river flow is imposed upon the system, the bottom flow would be arrested and a salt wedge is formed. Therefore we can say that this is a typical salt wedge formation of an estuary. Hamilton Canal is not saline on both day 3 and day 4.

4.1.3 Dissolved Oxygen

Table 4.1 shows the DO values of the fresh water feeders of the estuary.

Table 4.1: DO

Location	25.09.2002-Day 2	15.10.2002-Day 3	11.07.2002-Day 4
8	5.8	5.6	4.9
9	5.4	6.0	4.8
10	-	17.7	5.3

When the organic matter uses up oxygen to decompose, DO level reduces and when there is less organic matter entrained in water, DO level rises up. On day 3, the DO level of the Dandugam-oya upstream has a very high value. This may be due to lesser amount of organic matter entrained in running water in Dandugam-Oya upstream.

4.1.4 Temperature

Thermal stratification is visible in the middle of the estuary as well as the mouth. Stratification becomes significant towards the mouth (Figure 4.4). This thermal stratification leads to low solubility of oxygen and it would result in anoxia at the bottom (Fisher & Butt, 1994).

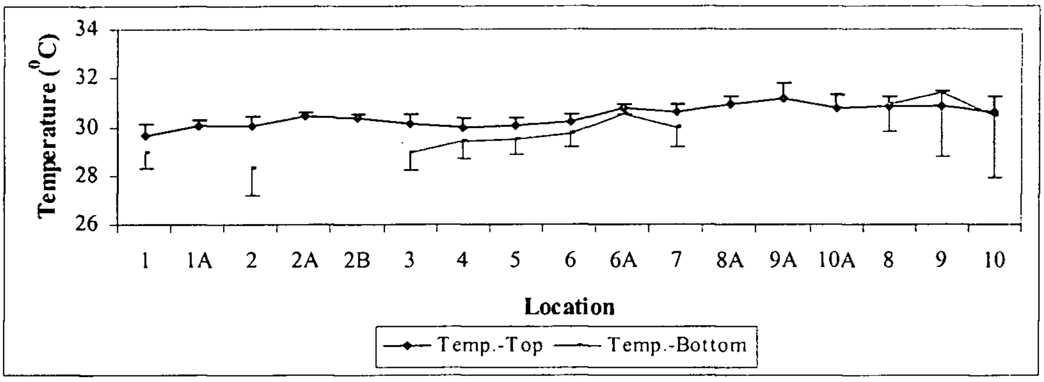


Figure 4.4: Variation of Mean Temperature. Vertical Bars Denote SE

4.1.5 pH

The pH value gradually decreases from mouth to fresh water inflows (Figure 4.5).

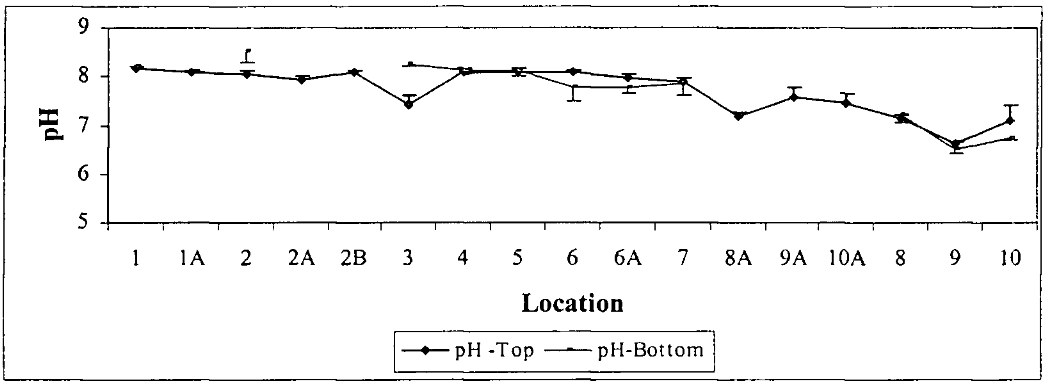


Figure 4.5: Variation of Mean pH. Vertical Bars Denote SE

Sodium ions and chloride ions have no influence on the pH of the seawater (Howard, 1998). Therefore seawater can be considered as a simple solution containing calcium ions and carbonate species. Dissolution of gaseous carbon dioxide is also an important factor governing its pH. Based on the following equations, pH of the seawater can be estimated as 8.4 – not far from the real value (Howard, 1998).

$CaCO_3 \Leftrightarrow Ca^{2+} + CO_3^{2-}$ log K_{Ca}= -8.3

$H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$ log K_1 = -6.4

$HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$ log K_2 = -10.3

$H_2O \Leftrightarrow H^+ + OH^-$ log K_w = -14.0

$pCO_2 + H_2O \Leftrightarrow H_2CO_3$ log Kco_2 = -6.5

Anaerobic metabolic reactions by microorganisms within sediments generate CO_2 in larger concentrations than in seawater. In anoxic situations, pH does not depend solely on the CO_2-carbonate system. When the CO_2 concentration becomes higher due to the microbial activities, carbonic acid concentration increases and consequently H^+ concentration increases according to the following equilibrium

$CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$

Thus the pH decreases and that may be the reason of the gradual decrease of pH towards the head of the estuary.

4.2 NUTRIENTS

4.2.1 Nitrogen

In this section the dissolved nitrogen species (nitrate-N and nitrite-N, ammoniacal N) and the total nitrogen (TN) are considered. The collective value of the dissolved species of nitrogen is referred as dissolved inorganic nitrogen(DIN).Total Nitrogen (TN) is the sum of organic nitrogen, nitrate-nitrogen (NO_3^-- N), nitrite-nitrogen (NO_2^- -N) and Ammoniacal nitrogen (NH_4^+ -N).

(a). Nitrate-N

Nitrate-N (NO_3^--N) is very mobile in the environment and easily passes through soil into the ground water, where it can strongly influence concentrations in rivers during base flow conditions. Natural sources of NO_3^--N are geological, plant and animal breakdown products.

The use of inorganic fertilizers and increased levels of animal and plant wastes can have a significant impact on surface water NO_3^--N concentrations. Deforestation of land for cultivation also increases soil aeration, enhancing the action of nitrifying bacteria, which increases the soil NO_3^--N concentrations. Nitrate is the most highly oxidized form of nitrogen and usually the most abundant form in streams. Nitrite, the partially reduced form of nitrate is usually present in trace amounts. The higher concentrations of NO_3^--N at fresh water inflows as well as at the cross sections closer to the river outfalls manifest the load of NO_3^--N enters into the estuary entrained with fresh water (Figure 4.6).

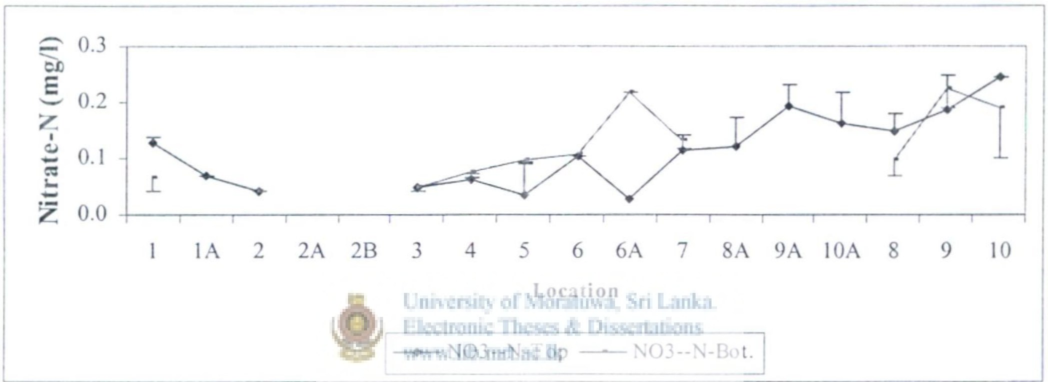


Figure 4.6: Variation of Nitrate-N . Vertical Bars Denote SE

(b). Ammoniacal N

Ammoniacal nitrogen (NH_4^+-N) is naturally present in surface waters as a result of the breakdown of organic and inorganic material. However, NH_4^+-N is also generated by biota through excretion and production of organic waste, and as such higher concentrations can be an indicator of organic pollution. The higher concentrations of NH_4^+-N at the entrance of the main channel and at the fresh water inflows, especially the Hamilton canal, signify the organic pollution (Figure 4.7). Wastes discharged by the people of shanties around location 2 must be a possible cause of this.

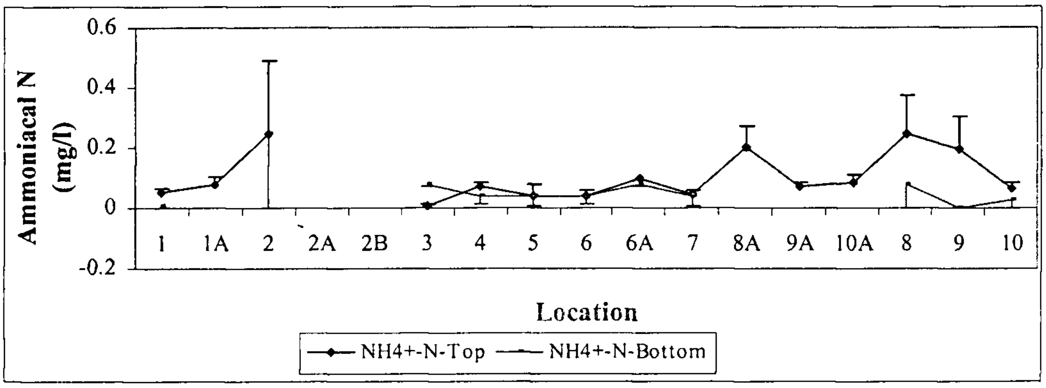


Figure 4.7: Variation of Mean Ammoniacal N . Vertical Bars Denote SE

(c) Total Nitrogen (TN)

TN levels are higher at 2A and 2B along the main channel and at fresh water outfalls-3, 8A, 9A and 10A. The organic nitrogen carried by the Dutch canal as well as the other fresh water inflows would have contributed for that (Figure 4.8). In the middle part of the estuary, at 4, 6 and 7, TN levels are relatively low.

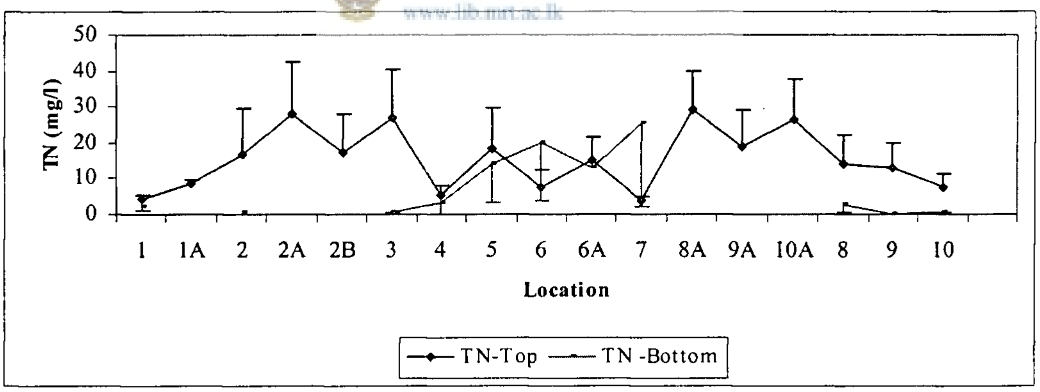


Figure 4.8: Variation of Mean TN . Vertical Bars Denote SE

4.2.2 Phosphorus

In this section, total reactive phosphorus (dissolved reactive phosphorus and particulate reactive phosphorus) and the Total Phosphorus (TP) are considered.

(a) Total Reactive Phosphorus (TRP)

Average phosphate-P levels at the entrance (Location 2) shows the highest concentration during the period of study (Figure 4.9). Bottom concentrations are always higher than the surface. This implies that sediments are a greater source of TRP. TRP inputs of Hamilton canal and Ja-ela are higher than Dandugam-oya.

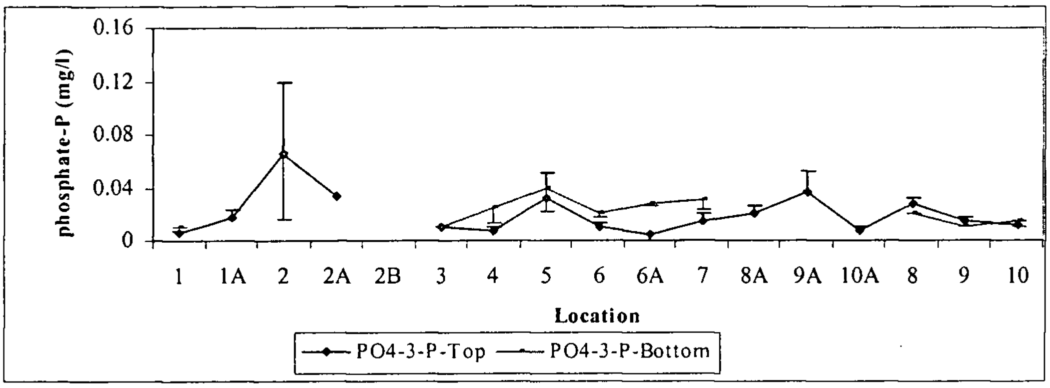


Figure 4.9: Variation of Mean TRP. Vertical Bars Denote SE

(b) Total Phosphorus (TP)

TP levels at 8A, 9A and 10 are relatively high (Figure 4.10). This shows that fresh water feeders significantly contribute to the P budget of the estuary. The TP levels of the water in the middle part of the estuary are low, indicating that the TP was in the suspended matter would have settled within the estuary. TP levels are high at the mouth and it may be due to the releasing process of sediment bound P due to anoxic condition of the bottom.

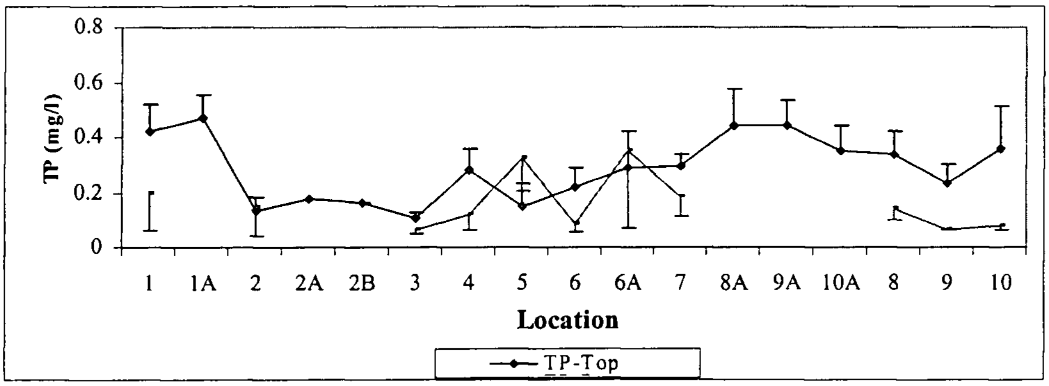


Figure 4.10: Variation of Mean TP. Vertical Bars Denote SE

4.3 TEMPORAL VARIATIONS (AVERAGE FLOOD AND EBB) OF WATER QUALITY PARAMETERS

4.3.1 Temperature

Figure 4.11 shows the temporal variations of temperature. With the heavy runoff on day-4, the temperatures of the fresh water inflows are low. Temperatures of fresh water inflows are high on day-2 reflecting the higher ambient temperature in the dry season.

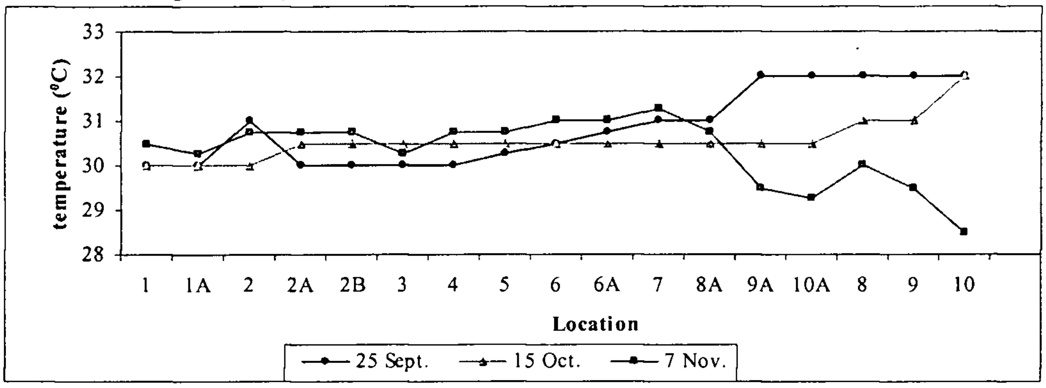


Figure 4.11: Temporal and Spatial Variations of Temperature

4.3.2 Organic Pollutants (COD)

COD levels on day 3 (15th Oct.) show the highest values and day 4 (7th Nov.) shows the lowest values (Figure 4.12).

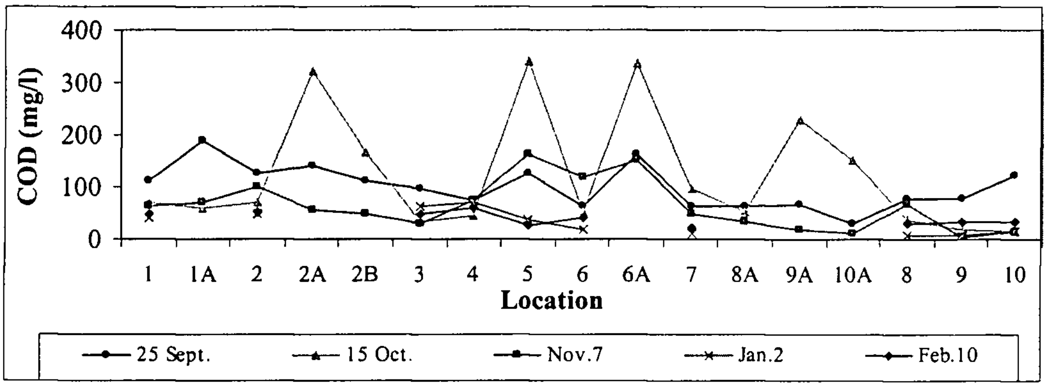


Figure 4.12: Temporal and Spatial Variations of COD.
Day 2-25 September 2002 (Dry, Spring)
Day 3 -15 October 2002 (Wet, Neap)
Day 4 -7 November 2002 (Wet, Spring)
Day 5- 2 January 2003 (Wet, Spring)
Day 6- 10 February 2003 (Dry, neap)

Figure 4.13 shows the variation of mean COD level with the fresh water discharge. According to that graph, the least mean COD value is observed on day 4 and the highest value is on day 3. On day 3 (15th Oct.), it was noted that a heavy precipitation in the morning with the commencement of intermonsoonal rain. The organic pollutants entrained with the storm water have increased the COD values. Due to flushing of organic pollutants with a higher average fresh water flow rate of 103.0 m^3/s, after a period of precipitation, COD values are lower on day 4 (7th Nov.).

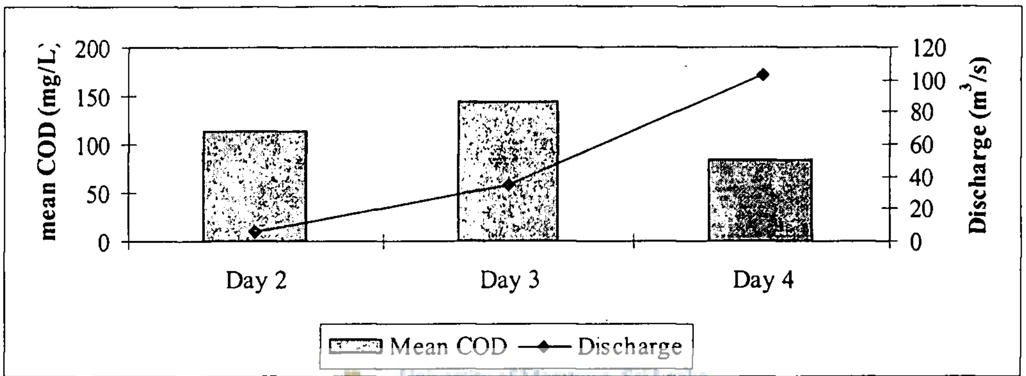


Figure 4.13: Variation of Mean COD with Freshwater Discharge

4.3.3 Nitrate-N

Higher Nitrate-N values can be noted on day 2 (25th Sept.) at several locations, especially at the fresh water inflows (Figure 4.14).

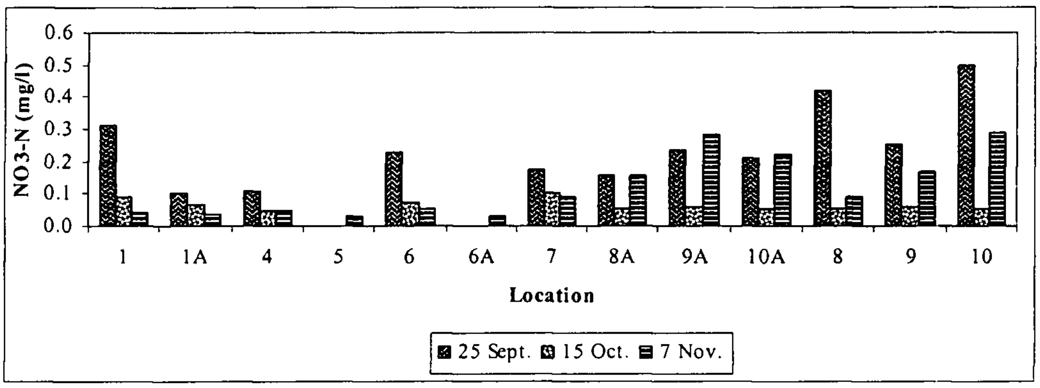


Figure 4.14: Temporal and Spatial Variations of Nitrate-N

4.3.4 Ammoniacal- N

On day 3 (15th Oct., wet, neap) NH_4^+-N concentrations are higher at the fresh water inflows (Figure 4.15), because of the ammonification of organic pollutants entrained with the runoff. On day 2 (25th Sept. dry, spring), NH_4^+-N concentrations in the middle part of the estuary are relatively low. Results manifest nitrification predominates in the middle part of the estuary and conversion of NH_4^+-N to NO_3^- -N has reduced NH_4^+-N concentrations. But on day 4 (7th Nov., wet, spring), NH_4^+-N concentrations are relatively higher and almost homogeneous through out the entire estuary. Having flushed with the higher flow, the spatial variations have become minimum. Microbial transformations are also not manifested due to the lesser retention time on day 4.

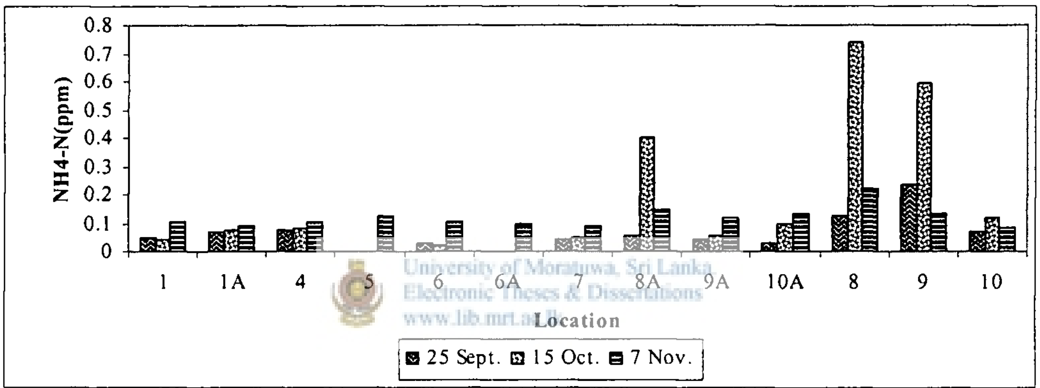


Figure 4.15: Temporal and Spatial Variations of Ammoniacal N

On day 4, concentrations of ammoniacal N in bottom waters are slightly higher than the surface waters at the locations 4 and 5, which are closer to the mouth of the estuary. Two explanations can be given for the higher ammoniacal N near the sediment surface. One is the higher ammoniacal N concentration of groundwater discharges. Other explanation is that the anoxic conditions may have blocked the nitrification denitrification processes. The pathway for N in the decomposition of organic matter can be depicted as follows.

$$\text{Org. N} \xrightarrow{\text{Decomposition}} NH_4^+ \xrightarrow{\text{Nitrification}} NO_x \xrightarrow{\text{Denitrification}} N_2$$

In the absence of oxygen, the nitrification and denitrification is hindered. It leads to build up ammonium.

4.3.5 TN

When the temporal variations of nutrients are considered, TN levels are markedly high on 25th Sept. (Figure 4.16).

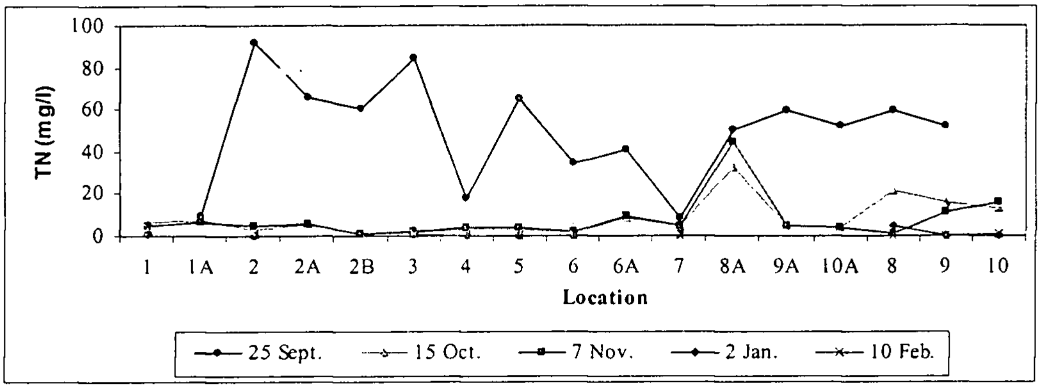


Figure 4.16: Temporal and Spatial Variations of TN

The higher amount of org. N entrained in lesser dynamic water in the estuary due to less fresh water inflows and variations of the watershed would be the reason.

4.3.6 Total Reactive Phosphorus (TRP)

P adsorbs under aerobic conditions onto $Fe(OH)_2$,MnO_2,$CaCO_3$ and clay mineral particles (Yilmaz,2002). But under anaerobic waters, bacteria reduce Fe^{3+} to Fe^{2+} and this process release P. On 25th Sept. and on 15th Oct., phosphate-P concentration is high at the location 1A (Figure 4.17). As the denser saline water makes the bottom sediments anoxic, released P from the adsorbed Fe^{3+} would be the reason of this increment.

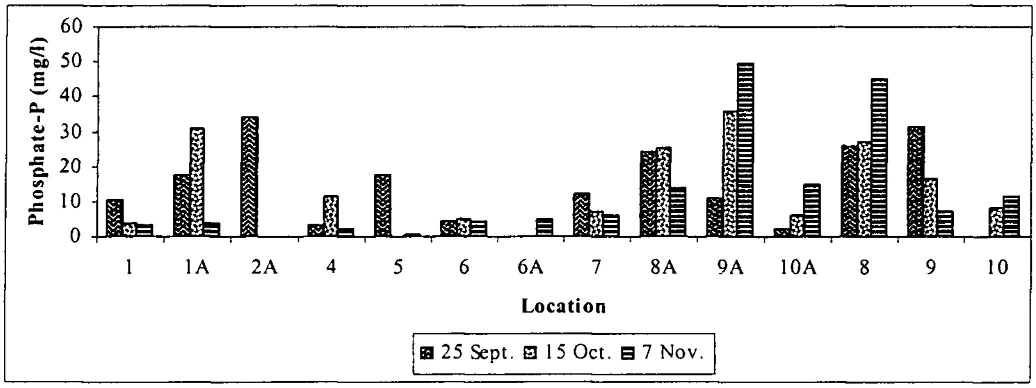


Figure 4.17: Temporal and Spatial Variations of TRP

4.3.7 TP

Income of P to the estuary with fresh water inflows is visible by the (8A-10) fresh water inflows. TP input with the runoff can be clearly seen by the higher TP levels on 7th Nov.02 (Figure 4.18).

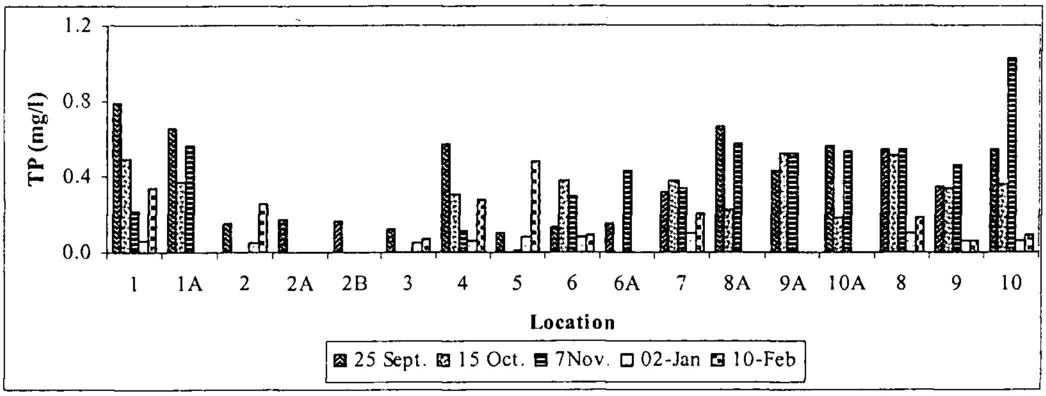


Figure 4.18: Temporal and Spatial Variations of TP

4.4 LOADS OF NUTRIENTS

For the calculations of loads discharges have been extracted from Mike 21 model of set up and calibrated for the Engineering Study on the Feasibility of Dredging the Negombo Lagoon to Improve Water Quality by the University of Moratuwa, October 2003. Discharge is denoted as Q. Sign Convention: Flood Tide – Ebb Tide +

4.4.1 Loads of DIN

Table 4.2, 4.3 and 4.4 show the calculation of loads of DIN in the morning, evening and the average of the each day respectively.

Table 4.2: Calculation of Loads of DIN in the Morning Sampling Session.

Location	Day 2				Day 3				Day 4			
	Q (m^3/s)	NO_3-N (mg/L)	NH_4^+-N (mg/L)	Load (g/s)	Q (m^3/s)	NO_3-N (mg/L)	NH_4^+-N (mg/L)	Load (g/s)	Q (m^3/s)	NO_3-N (mg/L)	NH_4^+-N (mg/L)	Load (g/s)
8A	-1.3	0.25	0.02	-0.35	-0.64	0.05	0.28	-0.21	-1.79	0.17	0.17	-0.59
9A	6.4	0.25	0.03	1.79	11.04	0.05	0.05	1.09	17.06	0.18	0.14	5.39
10A	15.7	0.21	0.03	3.78	32.01	0.06	0.06	3.59	90.88	0.16	0.11	24.27

Table 4.3: Calculation of Loads of DIN in the Evening Sampling Session.

Location	Day 2				Day 3				Day 4			
	Q (m^3/s)	NO_3-N (mg/L)	NH_4^+-N (mg/L)	Load (g/s)	Q (m^3/s)	NO_3-N (mg/L)	NH_4^+-N (mg/L)	Load (g/s)	Q (m^3/s)	NO_3-N (mg/L)	NH_4^+-N (mg/L)	Load (g/s)
8A	0.77	0.06	0.09	0.11	-1.37	0.07	0.52	-0.80	0.37	0.14	0.13	0.10
9A	-3.39	0.22	0.05	-0.92	16.78	0.08	0.06	2.27	6.80	0.38	0.10	3.26
10A	-4.26	0.22	0.02	-1.00	35.35	0.06	0.14	6.91	71.06	0.28	0.15	30.56

Table 4.4: Calculation of Average Loads of DIN on Each Sampling Days

	Day 2			Day 3			Day 4		
	Load (g/s) (Morning)	Load (g/s) (Evening)	Average Load(g/s)	Load (g/s) (Morning)	Load (g/s) (Evening)	Average Load (g/s)	Load (g/s) (Morning)	Load (g/s) Evening	Average Load (g/s)
8A	-0.35	0.11	-0.12	-0.21	-0.80	-0.51	-0.60	0.10	-0.25
9A	1.79	-0.92	0.44	1.09	2.27	1.68	5.39	3.26	4.33
10A	3.78	-1.01	1.38	3.59	6.93	5.26	24.27	30.56	27.42

Figure 4.19 shows the variation of the DIN loads on three sampling days -day2, day 3 and day 4. The highest load is observed on day 4 in Dandugam-Oya. Dandugam-Oya brings the highest loads of DIN on these three sampling days irrespective of the climatic conditions. The loads of Hamilton canal on these three sampling days are insignificant.

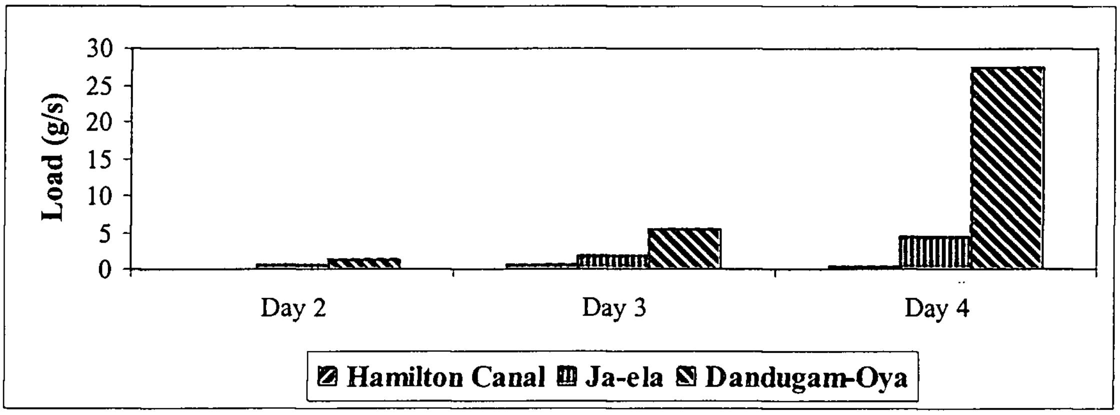


Figure 4.19: Variation of the DIN Loads on Three Sampling Days- Day2, Day 3, Day 4

4.4.2 Loads of TN

Table 4.5, 4.6 and 4.7 show the calculation of loads of TN in the morning, evening and the average of the each day respectively.

Table 4.5: Calculation of Loads of TN in the Morning.

Location	Day 2			Day 3			Day 4		
	Q (m^3/s)	TN (mg/L)	Load (mg/s)	Q (m^3/s)	TN (mg/L)	Load (mg/s)	Q (m^3/s)	TN (mg/L)	Load (mg/s)
8A	-1.3	_	_	-0.64	7.70	-4.9	-1.79	28.24	-50.6
9A	6.4	58.80	367.9	11.04	5.00	55.21	17.06	6.26	106.8
10A	15.7	51.90	816.4	32.01	3.80	121.6	90.88	7.87	715.2

Table 4.6: Calculation of Loads of TN in the Evening.

Location	Day 2			Day 3			Day 4		
	Q (m^3/s)	TN (mg/L)	Load (mg/s)	Q (m^3/s)	TN (mg/L)	Load (mg/s)	Q (m^3/s)	TN (mg/L)	Load (mg/s)
8A	0.77	49.9	38.3	-1.37	57.0	-77.9	0.37	1.4	0.5
9A	-3.39	-	-	16.78	5.0	83.9	6.80	19.7	134.0
10A	-4.26	-	-	35.35	4.0	141.4	71.06	18.3	1296.9

Table 4.7: Calculation of Average Loads of TN on Each Sampling Days

	Day 2			Day 3			Day 4		
	Load (g/s) (Morning)	Load (g/s) (Evening)	Average Load(g/s)	Load (g/s) (Morning)	Load (g/s) (Evening)	Average Load (g/s)	Load (g/s) (Morning)	Load (g/s) Evening	Average Load (g/s)
8A	_	38.3	38.3	-4.9	-77.9	-41.4	-50.6	0.5	-25.1
9A	367.9	_	367.9	55.21	83.9	69.6	106.8	134.0	120.4
10A	816.4	_	816.4	121.6	141.4	131.5	715.2	1296.9	1006.1

Figure 4.20 shows the variation of the TN loads on three sampling days -day2, day 3 and day 4. According to this graph, Dandugam-Oya brings the highest TN loads on these three sampling days. But on day 2 (Dry, Spring) Dandugam–Oya and Ja-ela bring

significant loads irrespective of the lower discharge rates during dry climatic condition. TN loads of Hamilton Canal on these three sampling days are insignificant.

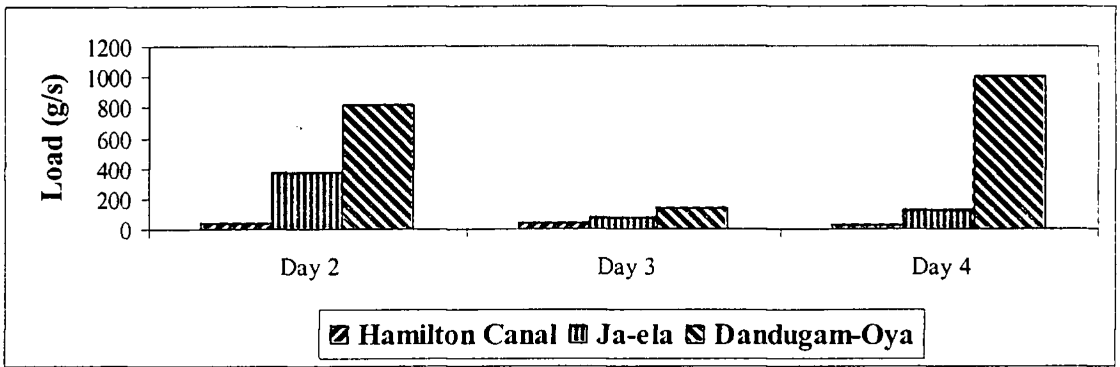


Figure 4.20: Variation of the TN Loads on Three Sampling Days -Day2, Day 3, Day 4

4.4.3 Loads of Phosphate-P

Table 4.8, 4.9 and 4.10 show the calculation of loads of TN in the morning, evening and the average of the each day respectively.

Table 4.8: Calculation of Loads of PO_4^{-3}-P in the Morning.

Location	Day 2			Day 3			Day 4		
	Q (m^3/s)	P (mg/L)	Load (g/s)	Q (m^3/s)	P (mg/L)	Load (g/s)	Q (m^3/s)	P (mg/L)	Load (g/s)
8A	-1.3	0.009	-0.012	-0.64	0.011	-0.007	-1.79	0.015	-0.03
9A	6.4	0.011	0.070	11.04	0.064	0.706	17.06	0.012	0.21
10A	15.7	0.002	0.032	32.01	0.010	0.330	90.88	0.015	1.40

Table 4.9: Calculation of Loads of PO_4^{-3}-P in the Evening.

Location	Day 2			Day 3			Day 4		
	Q (m^3/s)	P (mg/L)	Load (g/s)	Q (m^3/s)	P (mg/L)	Load (g/s)	Q (m^3/s)	P (mg/L)	Load (g/s)
8A	0.77	0.04	0.031	-1.37	0.039	-0.054	0.37	0.013	0.005
9A	-3.39	-	-	16.78	0.008	0.134	6.80	0.087	0.592
10A	-4.20	-	-	35.35	0.002	0.071	71.06	0.014	0.995

Table 4.10: Calculation of Average Loads of PO_4^{-3}-P on Each Sampling Days

	Day 2			Day 3			Day 4		
	Load (g/s) (Morning)	Load (g/s) (Evening)	Average Load(g/s)	Load (g/s) (Morning)	Load (g/s) (Evening)	Average Load (g/s)	Load (g/s) (Morning)	Load (g/s) Evening	Average Load (g/s)
8A	-0.012	0.031	0.0095	-0.007	0.055	0.024	-0.03	0.005	-0.01
9A	0.070	-	0.070	0.706	0.008	0.357	0.21	0.59	0.40
10A	0.032	-	0.032	0.330	0.002	0.166	1.40	1.00	1.20

Figure 4.21 shows the variation of the PO_4^{-3}-P loads on three sampling days -day2, day 3 and day 4. Graph shows that Ja-ela brings the highest phosphate-P loads on day 2 (Dry, Spring) and day 3 (Wet, Neap), while Dandugam-Oya brings the highest load on day 4 (Wet, Spring). Ja-ela brings rather a constant load of 0.4 g/s during the wet climatic conditions on both day 3 and day 4. Industrial effluents which contain phosphate-P may be a possible cause of this constant supply.

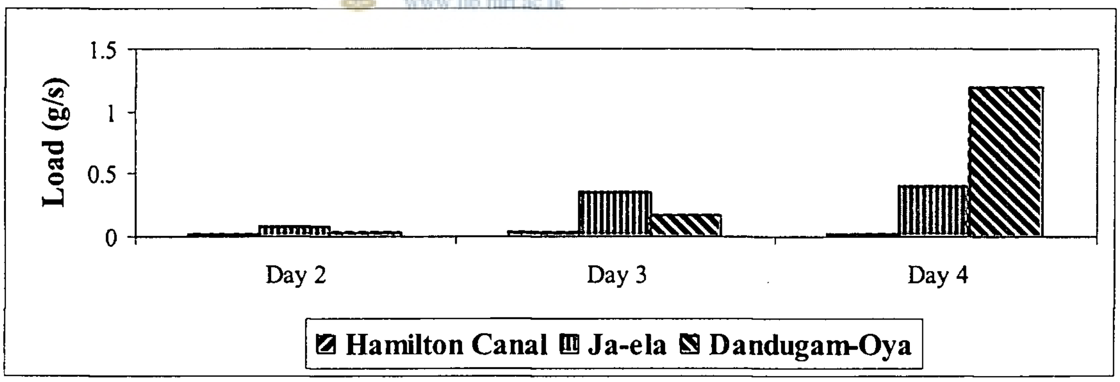


Figure 4.21: Variation of the PO_4^{-3}-P Loads on Three Sampling Days -Day2, Day 3, Day 4

4.4.2 Loads of TP

Table 4.11, 4.12 and 4.13 show the calculation of loads of TP in the morning, evening and the average of the each day respectively.

Table 4.11: Calculation of Loads of TP in the Morning.

Location	Day 2			Day 3			Day 4		
	Q (m^3/s)	TP (mg/L)	Load (mg?s)	Q (m^3/s)	TP (mg/L)	Load (mg/s)	Q (m^3/s)	TP (mg/L)	Load (mg/s)
8A	-1.3	1.06	-1.38	-0.64	0.09	-0.06	-1.79	0.83	1.49
9A	6.4	0.10	0.66	11.04	0.68	7.50	17.06	0.54	9.20
10A	15.7	0.56	8.80	32.01	0.01	0.35	90.88	0.53	48.20

Table 4.12: Calculation of Loads of TP in the Evening.

Location	Day 2			Day 3			Day 4		
	Q (m^3/s)	TP (mg/L)	Load (g/s)	Q (m^3/s)	TP (mg/L)	Load (g/s)	Q (m^3/s)	TP (mg/L)	Load (g/s)
8A	0.77	0.26	0.20	-1.37	0.36	-0.49	0.37	0.32	0.12
9A	-3.39	0.75	-2.54	16.78	0.36	6.04	6.80	0.51	3.47
10A	-4.26	-	-	35.35	0.35	12.37	71.06	0.54	38.37

Table 4.13: Calculation of Average Loads of TP on Each Sampling Days

	Day 2			Day 3			Day 4		
	Load (g/s) (Morning)	Load (g/s) (Evening)	Average Load(g/s)	Load (g/s) (Morning)	Load (g/s) (Evening)	Average Load (g/s)	Load (g/s) (Morning)	Load (g/s) Evening	Average Load (g/s)
8A	-1.38	0.20	-0.59	-0.06	-0.49	-0.28	1.49	0.12	0.81
9A	0.66	-2.54	-0.94	7.50	6.04	6.77	9.20	3.47	6.34
10A	8.80	–	8.80	0.35	12.37	6.36	48.20	38.37	43.29

Figure 4.22 shows the variation of the TP loads on three sampling days -day2, day 3, day 4. It shows that Dandugam-Oya brings the highest loads of TP on day 2 (Dry, Spring) and day 4 (Wet, Spring), while Ja-ela and Dandugam-Oya brings almost equal loads on day 3 (Wet, Neap). Phosphates applied as agricultural fertilizers in the watershed and the effluents of the sewage treatment plant at Raddolugama may be two possible causes of

the higher loads of TP in Dandugam-Oya on day 4. Phosphate containing industrial effluents may have contributed to the higher loads of TP in Ja-ela.

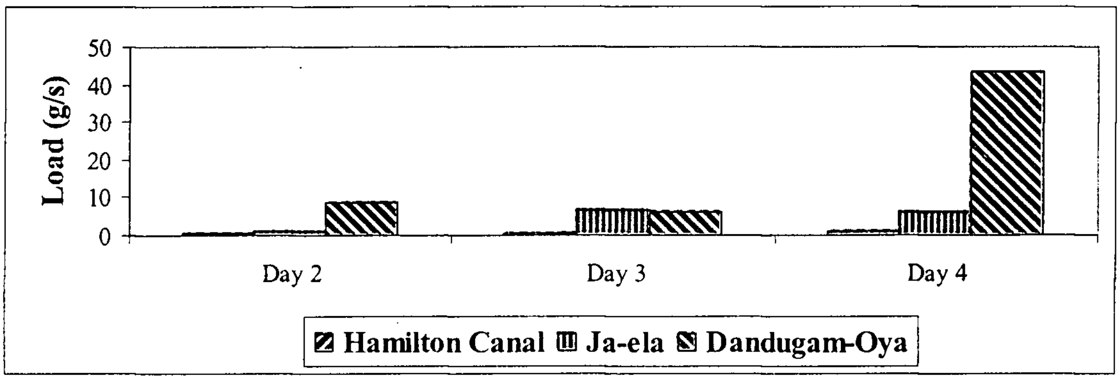


Figure 4.22: Variation of the TP Loads on Three Sampling Days -Day2, Day 3, Day 4

4.5 LIMITING NUTRIENT

In the following discussion, the nutrient limitation potential is considered. Figure 4.23 shows the temporal variations of the limiting nutrient. Table 4.14 shows the N/P ratio of the sampling days.

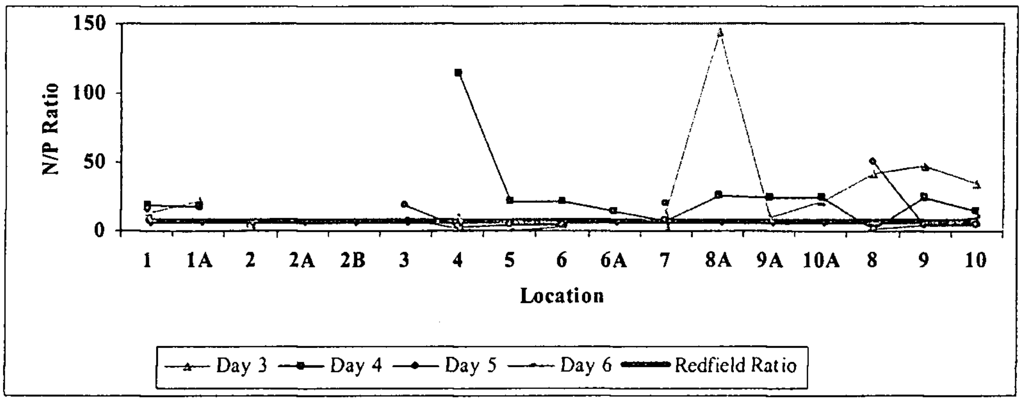


Figure 4.23: Temporal and spatial Variation of N/P Ratio

4.5.1 Limiting Nutrient in Dry Season

On day 2, TN levels are exceptionally high because of a sudden discharge of nitrogen source, which should be addressed separately and the nutrient ratios at all locations are above the Redfield ratio indicating P limitation. But on day 6 amidst the lower flow rate of fresh water inflows in dry season, almost all the locations are N limited.

4.5.2 Limiting Nutrient in Wet Season

On day 3, nutrient ratios are generally above the Redfield ratio indicating the potential for P limitation.

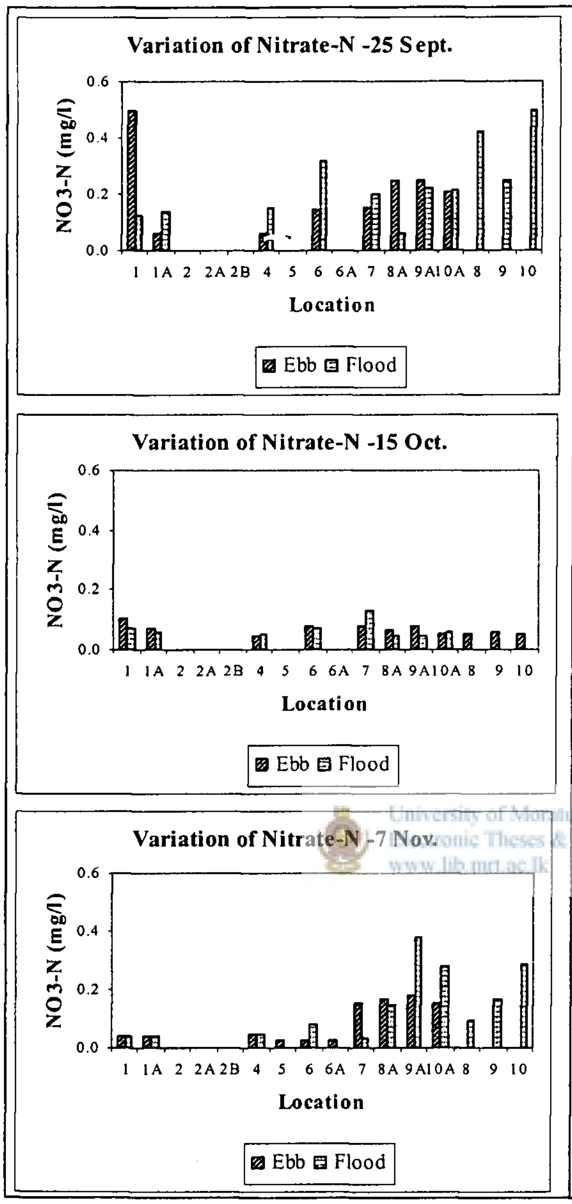
Table 4.14: Variation of TN/TP Ratio at Different Locations

Location	Day 2			Day 3			Day 4			Day 5			Day 6		
	25.09.02			15.10.02			07.11.02			02.01.03			10.02.03		
	TN mg/L	TP mg/L	N/P	TN mg/L	TP mg/L	N/P	TN mg/L	TP mg/L	N/P	TN mg/L	TP mg/L	N/P	TN mg/L	TP mg/L	N/P
1	-	0.79	-	6.25	0.45	13	4.04	0.22	18	0.98	0.06	16	3.5	0.34	10
1A	9.6	0.65	15	7.75	0.37	21	9.6	0.56	17	-	-	-	-	-	-
2	92	0.15	613	3	-	-	9.9	-	-	0.15	0.05	3	0.56	0.26	2
2A	65.8	0.18	365	5.5	-	-	13	-	-	-	-	-	-	-	-
2B	60.5	0.16	378	1.3	-	-	11	-	-	-	-	-	-	-	-
3	84	0.12	700	3.1	-	-	19	-	-	0.95	0.05	19	0.59	0.07	8
4	17.7	0.5	35	2.85	0.31	9.3	6.6	0.06	114	0.18	0.06	3	0.23	0.28	0.8
5	65	0.12	541	2.65	-	-	6.09	0.28	21	0.3	0.08	4	0.18	0.48	0.4
6	50.9	0.15	339	1.65	0.38	4.3	6.56	0.29	22	0.43	0.08	5	0.26	0.09	3
6A	40.6	0.11	369	8.4	-	-	7.7	0.54	14	-	-	-	-	-	-
7	8.35	0.29	29	5.05	0.37	13	2.2	0.34	6.5	2	0.1	20	0.28	0.21	1
8A	49.9	0.66	76	32.3	0.22	144	14.8	0.57	26	-	-	-	-	-	-
9A	58.8	0.43	137	5	0.52	9.6	13	0.53	25	-	-	-	-	-	-
10A	51.9	0.56	93	3.9	0.18	21	13	0.53	25	-	-	-	-	-	-
8	41.9	0.54	77	21	0.51	41	1.03	0.55	2	5.02	0.1	50	0.36	0.18	2
9	37.5	0.35	107	16.1	0.34	47	11.2	0.46	24	0.26	0.06	4	0.22	0.06	4
10	-	0.54	-	12.8	0.36	35	15.3	1.03	15	0.3	0.06	5	0.86	0.09	9.5

Nutrient ratios on day 4 were generally above the Redfield ratio indicating the potential for P limitation. This shows that there is a tendency of P limitation with the higher fresh water discharge to the estuary.

4.6 VARIATIONS OF NUTRIENTS IN FLOOD AND EBB TIDES

Figure 4.24 shows the nitrate-N levels in the flood and ebb tides. Figure 4.24 shows the flood and ebb differences of NH_4^+-N. During the dry season; in the middle part of the estuary, flood and ebb concentrations are almost alike. But on the day-3 (15th Oct.), there is a marked difference at the fresh water inflows and this is mainly due to the NH_4^+-N enters with the runoff. In the middle part of the estuary, NH_4^+-N concentrations are lower. At the higher retention time, biotic uptake and microbial transformation of NH_4^+-N to NO_3^- -N reduces the NH_4^+-N concentrations. On the day-4 (7th Nov.), a rather higher level of NH_4^+-N concentration manifests through out the estuary because there is insufficient time for the biotic uptake or microbial transformation of ammonia to nitrate.



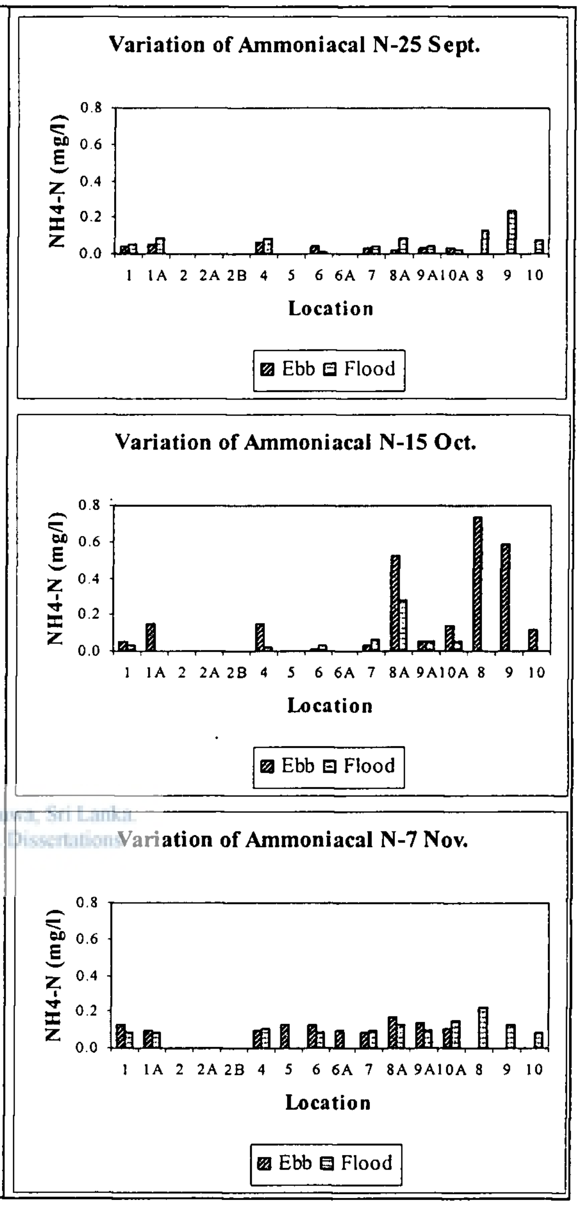


Figure 4.24: Difference in Nitrate-N in flood and Ebb

Figure 4.25: Difference in Ammoniacal N in Flood and Ebb

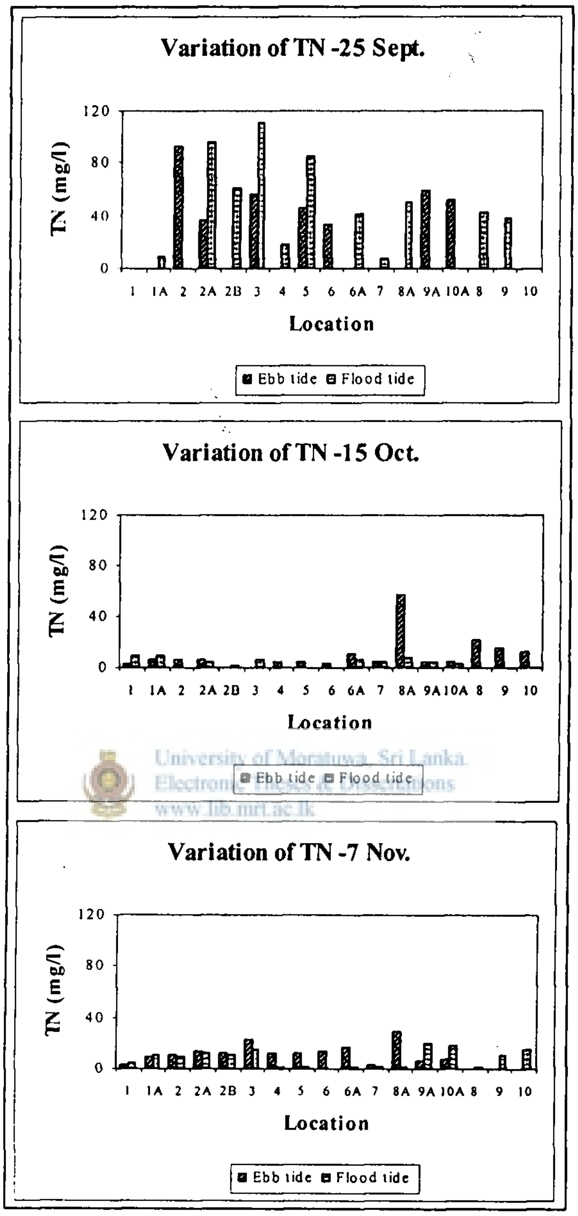


Figure 4.26: Difference in TN in Flood and Ebb

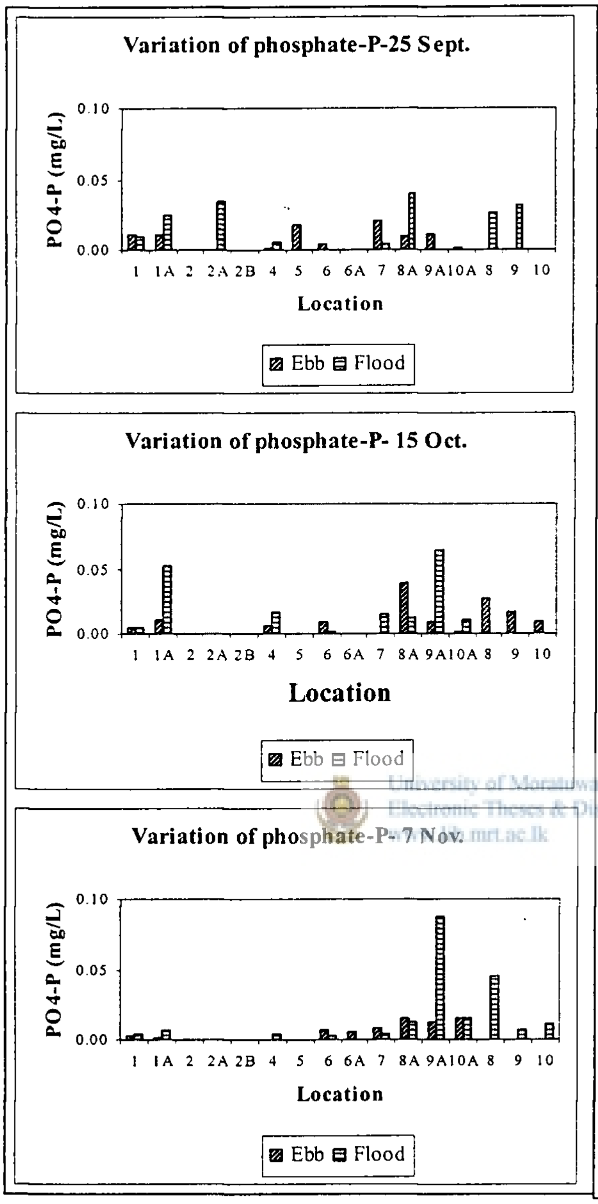


Figure 4.27: Difference of TRP in Flood and Ebb

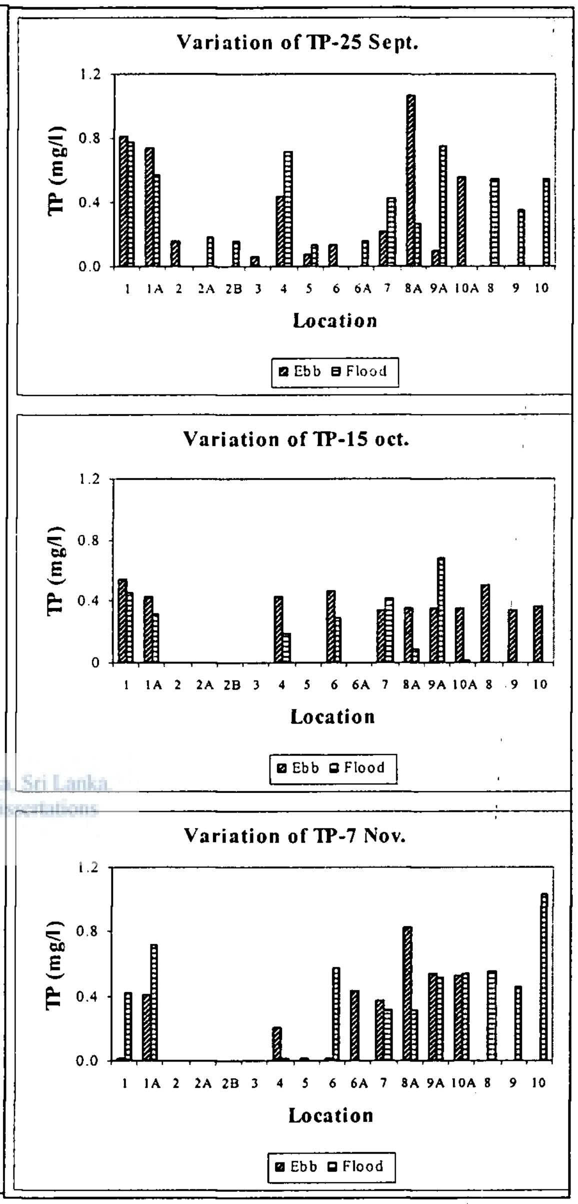


Figure 4.28: Difference of TP in Flood and Ebb

On day 2 (25th Sept.) at flood tide 2A, 3 and 5 have higher TN levels than at the ebb tide. On day 2 (25th Sept.) as the riverine flow is very low (6.5 m^3/s), the tidal action predominates the water movement at the mouth. Tidal mixing enhances the TN level in the water column by resuspension. In ebb tide TN levels of fresh water inflows are higher than locations 5 and 6 in the middle part as well as the locations 2A and 3 closer to the mouth. This may be because of flushing has taken place at the higher discharge rate of around 35 m^3/s. There is no significant difference between the flood and ebb tides. On day 4 (7^{th} Nov.), after a period of precipitation, discharge rate remains very high around 103 m^3/s lowering the residence time. All the locations in the middle part of the estuary have lower TN in flood tide than in the ebb tide. With the high flow rate nutrients are transferred by advection rather than diffusion. It was noted that the TN vs. Velocity possesses a linear relationship along the main channel (locations 2, 2A, and 2B). TN vs. discharge also showed a linear relationship with a correlation coefficient of nearly 1.

4.7 DETERMINATION OF THE TROPHIC STATES OF THE ESTUARY AND FRESH WATER FEEDERS

To determine the trophic status of the estuary and the fresh water feeders, chlorophyll levels are used. Tables 4.15 and 4.16 show the chlorophyll levels in Negombo estuary on 5^{th} January 2003 and 10^{th} February 2003.

4.7.1 Chlorophyll

Table 4.15: Chlorophyll and Algal Biomass on 5^{th} of January 2003

(source: Biological Sampling and Analysis-Negombo Lagoon, National Aquatic Resources Research and Development Agency, Colombo 15, 2003)

Location	Chl *a* mg/L	Chl *b* mg/L	Chl *c* mg/L	Algal biomass mg/L
1	0.0037	0.0015	0.0025	0.25
2	0.0037	0.0015	0.0020	0.25
3	0.0051	0.0020	0.0023	0.33
4	0.0049	0.0017	0.0030	0.32
5	0.0041	0.0020	0.0026	0.28
6	0.0060	0.0011	0.0028	0.40
7	0.0065	0.0012	0.0025	0.43
8	0.0128	0.0019	0.0055	0.86
9	0.0045	0.0032	0.0044	0.30
10	0.0060	0.0020	0.0025	0.40

Table 4.16: Chlorophyll and Algal Biomass on 10th of February 2003-Day 6

(source: Biological Sampling and Analysis-Negombo Lagoon, National Aquatic Resources Research and Development Agency, Colombo 15, 2003)

Location	Chl *a* mg/L	Chl *b* mg/L	Chl *c* mg/L	Algal biomass mg/L
1	0.0038	0.0012	0.0016	0.25
2	0.0053	0.0023	0.0021	0.35
3	0.0048	0.0018	0.0020	0.033
4	0.0051	0.0020	0.0023	0.34
5	0.0049	0.0017	0.0025	0.33
6	0.0053	0.0015	0.0024	0.38
7	0.0062	0.0018	0.0025	0.42
8	0.0240	0.0020	0.0047	1.62
9	0.0026	0.0017	0.0018	0.17
10	0.0050	0.0023	0.0031	0.37

(a) Trophic State of the Sea

Table 4.17 shows the TN, TP and Chlorophyll a levels at the location 1, which is in the sea. Chl *a* level is 0.004 mg/L on both 05.01.2003 and 10.02.2003 (Day 6). Eutrophic marine waters have 0.003- 0.004 mg/L of chl a (Table 2.1). It is evident that the location 1 is eutrophic according the chl *a* levels. TN and TP levels on all the six days exceed the mesotrophic-eutrophic boundaries of 0.35 mg/L and 0.03 mg/L respectively (Table 2.1).

Table 4.17: TN, TP and Chlorophyll a levels at Location 1(Sea)

Day 2		Day 3		Day 4		Day 5		05.01.2003	Day 6		
TN mg/L	TP mg/L	TN mg/L	TP mg/L	TN mg/L	TP mg/L	TN mg/L	TP mg/L	chl a mg/L	TN mg/L	TP mg/L	chl a mg/L
-	0.79	6.25	0.45	4.04	0.22	0.98	0.06	0.004	3.5	0.34	0.004

(b) Trophic State close to the Mouth

Table 4.18 shows the TN, TP and Chl *a* levels of the locations close to the mouth of the estuary. Chl a levels were measured only at locations 2 and 3 and Chl a levels of those two locations lie within the range 0.003-0.005, which is the chl a range of eutrophic marine waters (Table 2.1) and manifest that both are eutrophied irrespective of the wet and dry seasonal changes. When the TN levels are considered, TN levels at all the location on all the days, except the location 2 on Day 5, exceed 0.4 mg/L, which is the Eutrophic-Hypertrophic boundary of TN for marine waters. TP levels of all these locations too exceed 0.04 mg/L, which is the eutrophic-hypertrophic boundary of marine waters (Table 2.1).

Table 4.18: TN, TP and Chl *a* Levels at the Mouth the Estuary

Location	Day 2		Day 3		Day 4		Day 5		05.01. 2003	Day 6		
	TN mg/L	**TP mg/L**	**TN mg/L**	**TP mg/L**	**TN mg/L**	**TP mg/L**	**TN mg/L**	**TP mg/L**	**chl a mg/L**	**TN mg/L**	**TP mg/L**	**chl a mg/L**
1A	9.6	0.65	7.8	0.37	9.6	0.56	-	-	-	-	-	-
2	92.0	0.15	3.0	-	9.9	-	0.15	0.05	0.004	0.56	0.26	0.005
2A	65.8	0.18	5.5	-	13.0	-	-	-	-	-	-	-
2B	60.5	0.16	1.3	-	11.0	-	-	-	-	-	-	-
3	84.0	0.12	3.1	-	19.0	-	0.95	0.05	0.005	0.59	0.07	0.05

Table 4.19 shows the TN, TP and Chl *a* in the middle part of the estuary. Chl *a* levels of all these locations on both wet and dry periods exceed the mesotrophic- eutrophic boundary of 0.003 mg/L. Chl *a* levels of locations 6 and 7 on both wet season (05.01.2003) and dry season (Day 6- 10.02.2003) exceed even the Eutrophic-hypertrophic boundary, which is 0.005 mg/L. Location 4 on day 6 also exceeds the 0.005 mg/L. It manifests that the locations 6 and 7 are hypertrophic on both dry and wet seasons and location 4 is hypertrophic on dry season.

Table 4.19: TN, TP and Chl a Levels at the Middle Part of the Estuary

Location	Day 2		Day 3		Day 4		Day 5		05.01.2 003	Day 6		
	TN mg/L	TP mg/L	TN mg/L	TP mg/L	TN mg/L	TP mg/L	TN mg/L	TP mg/L	chl a mg/L	TN mg/L	TP mg/L	chl a mg/L
4	17.7	0.5	2.85	0.31	6.60	0.06	0.18	0.06	0.0049	0.23	0.28	0.0051
5	65.0	0.12	2.65	-	6.09	0.28	0.30	0.08	0.0041	0.18	0.48	0.0049
6	50.9	0.15	1.65	0.38	6.56	0.29	0.43	0.08	0.0060	0.26	0.09	0.0053
6A	40.6	0.11	8.40	-	7.70	0.54	-	-	-	-	-	-
7	8.35	0.29	5.05	0.37	2.20	0.34	2.00	0.10	0.0065	0.28	0.21	0.0062

(c) Trophic State of Freshwater inflows

Quality of freshwater was tested at outfalls as well as the upstreams. Locations 8A, 9A and 10A are the fresh water outfalls of Hamilton canal, Ja-Ela and Dandugam-Oya River to the estuary and 8, 9 and 10 are the respective upstream locations.

Table 4.20 shows the TN, TP and Chl a levels of the fresh water inflows of the estuary. Those parameters were compared with the trophic characteristics of the streams given in table 2.1.

Table 4.20: TN, TP and Chl *a* Levels of the Fresh water Inflows

Location	Day 2		Day 3		Day 4		Day 5		05.01.2 003	Day 6		
	TN mg/L	TP mg/L	TN mg/L	TP mg/L	TN mg/L	TP mg/L	TN mg/L	TP mg/L	chl a mg/L	TN mg/L	TP mg/L	chl a mg/L
8A	49.9	0.66	32.3	0.22	14.8	0.57		-	-	-	-	-
9A	58.8	0.43	5.0	0.52	13.0	0.53	-	-	-	-	-	-
10A	51.9	0.56	3.9	0.18	13.0	0.53	-	-	-	-	-	-
8	41.9	0.54	21.0	0.51	1.03	0.55	5.02	0.10	0.0128	0.36	0.18	0.0240
9	37.5	0.35	16.1	0.34	11.2	0.46	0.26	0.06	0.0045	0.22	0.06	0.0026
10	-	0.54	12.8	0.36	15.3	1.03	0.30	0.06	0.0060	0.86	0.09	0.0050

TN and TP levels of outfalls at all the locations exceed the mesotrophic-eutrophic boundaries of TN and TP, which are 1.5 mg/L and 0.075 mg/L respectively. When the TN and TP levels of the upstreams are considered, TN level at location 8 on day 4, falls into the mesotrophic state. Except that instance, TN levels of day 2, day 3 and day 4 show the signs of eutrophic characteristics. But only the nutrient levels of Hamilton canal on day 5 exceed the mesotrophic- eutrophic boundary conditions of 1.5 mg/L and 0.075 mg/L of TN and TP respectively. On day 6, TP levels of Hamilton canal and Dandugam-Oya are above the boundary level and show eutrophic potential while only the TN level of Dandugm-Oya shows eutrophic potential. Chl *a* levels of Hamilton canal are higher than that of the Other two fresh water feeders. According the Chl *a* levels, only the upstream of the Hamilton canal manifest the waterbody is mesotrophic. Even though the fresh water feeders bring higher levels of nutrients, so far only the Hamilton canal has faced the threat of being eutophicated.

4.8 DREDGING SCENARIOS

The inlet of the Negombo lagoon and the lagoon itself is subjected to sedimentation.As a result, the water exchange between the sea and the lagoon has been decreased and it is harmful for fresh-salt eco-system of the lagoon. UOM in association with LHI is presently carrying out a mathematical model study on Negombo estuary, "Engineering Study on the Feasibility of Dredging the Negombo Lagoon to Improve Water Flow and Water Quality". The objective of this study is to improve the circulation in the lagoon so that further siltation of the lagoon can be minimized and the water quality can be improved. Previous studies carried out by Birgit Cloin and Marcel ter Wengul and IRMP-CEA have considered 8 alternatives and the alternative 1 has been selected as the most feasible dredging scenario on the basis of cost and long-term sedimentation. Improvement of water circulation through the increase of water exchange has been given a very low priority. The most feasible alternative (alternative 1) has no increase in total volume exchange at all. Four other alternatives have very small increase in water exchange and alternative 6 gives a 17% reduction. Only alternatives 7 and 8 give reasonable increase in water exchange but not considered as feasible due to the volume of dredging involved.

Results of "Engineering Study on the Feasibility of Dredging the Negombo Lagoon to Improve Water Flow and Water Quality" are presented here to understand the effects of dredging on water quality. Under the present study, 8 options are considered. Water exchange and the long-term sedimentation are considered as the most important criteria in the selection of the most feasible option. Stake net fishing in the lagoon entrance channels and other types of lagoon fishing and also the other user effects are given due consideration. Water circulation can be improved through the increase in the dredging quantity, which in turn will increase the cost involved.

4.8.1 Option 1

Figure 4.29 gives the maximum flood discharges for the option –1. As indicated in the figure channels 2 and 7 are dredged up to a depth of 1.5 m. There is a 33% increase of discharge in channel 2 and 92% increase in discharge in channel 7. Discharge through channel 8 has reduced by 44% and through the main channel 3 by about 3%. This option involves a total dredging volume of 60,000 m^3 and the total increase of discharge through the entrance channel system is only by 1%.

4.8.2 Option 2

Figure 4.30 gives the maximum flood discharges for the option –2. As indicated in the figure channels 2 and 7 are dredged up to a depth of 2.5 m. There is a 100% increase of discharge in channel 2 and 217% increase in discharge in channel 7. Discharge through channel 8 has reduced by 56% and through the main channel 3 by about 7%. This option involves a total dredging volume of 220,000 m^3 and the total increase of discharge through the entrance channel system is by 4%.

4.8.3 Option 3

Figure 4.31 gives the maximum flood discharges for the option 3. As indicated in the figure channels 2, 7, 9 and 12 are dredged up to a depth of 2.5 m. There is a 152% increase of discharge in channel 2 and 292% increase in discharge in channel 7. Channels 9 and 12 experience the increases in discharges of 45% and 50% respectively. Discharge through channel 8 has reduced by 33% and there is only a minor effect to main channel 3.

This option involves a total dredging volume of 350,000 m^3 and the total increase of discharge through the entrance channel system is by 14%.

4.8.4 Option 4

Figure 4.32 gives the maximum flood discharges for the option –4. As indicated in the figure channels 2, 7,9,12 and 13 are dredged up to a depth of 2.5 m. There is a 176% increase of discharge in channel 2 and 333% increase in discharge in channel 7. Channel 9 experiences an increase in discharge of 62% and there is no significant change of flow in channel 12. Discharge through channel 8 has reduced by 33% and there is only a minor effect to main channel 3. This option involves a total dredging volume of 540,000 m^3 and the total increase of discharge through the entrance channel system is by 19%.

Options 1, 2, 3 and 4 focus the attention of dredging the eastern channel system. Options 1 and 2 have only a local effect and the total increase of discharge is only by 1% and 4% respectively. These two options drastically reduce the flow rate of channel 8 and also through the western channel system. On the other hand, options 3 and 4 have a total percentage increase of 14% and 19% respectively, and there is hardly any effect to western channel system. The reduction of discharge through channel 8 is also quite low but involves comparatively high dredging volume.

4.8.5 Option 5

Figure 4.33 gives the maximum flood discharges for the option –5. As indicated in the figure channels 6 and 11 are dredged up to a depth of 2.5 m. There is a 45% increase of discharge in channel 6 and 69% increase in discharge in channel 11. Discharge through the other 2 western channel segments 5 and 10 reduce by 11% and 41% respectively. There is a varying percentage reduction 5%-29%, through the eastern channel system and also reduction in flow through the cross channel 14 towards the eastern channel system. This option involves a total dredging volume of 315,000 m^3 and the total increase of discharge through the entrance channel system is by 9%.

4.8.6 Option 6

Figure 4.34 gives the maximum flood discharges for the option –6. As indicated in the figure both eastern and western channels are dredged up to a depth of 2.5 m. There is a 181% and 333% increase of discharge through two northeastern channels 2 and 7. Southeastern channel, number 9, provides an increase of 59% and there is no significant change in channel number 12. Channel 13, which provides water to the northeastern part of the lagoon water body, provides an increase of discharge from 7 to 47 m^3/s, a 571% increase. In the western channel segment, main channels 3 and 4 gives and percentage increase of 17 and 21 and the branches 6 and 11 provide a percentage increase of 45 and 66. Channels which left without dredging indicates and decreases in discharge. This option involves a total dredging volume of 900,000 m^3 and the total increase of discharge through the entrance channel system is by 34%.

4.8.7 Option 7

Figure 4.35 gives the maximum flood discharges for the option –7. As indicated in the figure both eastern and western channels are dredged up to a depth of 2.5 m and channel 12 was blocked to obtain a higher discharge through channel 13 in view of getting more water to the presently stagnant northeastern part of the lagoon main water body. Discharge through the channel 13 has increased from 7 to 78 m^3/s, a 1014% increase but the total increase of discharge through the entrance channel system has dropped to 25% from 34% (option 6).

Table 4.21 gives the summary of maximum flood discharges for the existing condition and different dredging scenarios and table 4.22 gives the percentage increase/decrease of discharge as a result of dredging. Positive values indicate the percentage increase whereas negative values indicate the percentage decrease in discharge. Existing condition is denoted by 0.

Table 4.21: Maximum Flood Discharges (m^3/s) for Different Dredging Scenarios

	Dredging Scenario								
	Channel Number	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Main entrance channel	**1**	201	203	210	230	240	220	270	252
Western channel segments	**3**	180	175	168	177	182	200	211	202
	4	132	128	130	130	128	160	160	171
	5	56	52	54	54	53	50	50	55
	6	76	76	76	76	75	110	110	116
	10	17	17	18	17	18	10	12	12
	11	59	59	58	59	57	100	98	104
Eastern channel segments	**2**	21	28	42	53	58	20	59	50
	7	12	23	38	47	52	11	52	45
	8	9	5	4	6	6	9	7	5
	9	69	75	80	100	112	60	110	81
	12	62	67	73	93	64	55	63	3
	13	7	8	7	7	48	5	47	78
	14	48	47	38	47	54	40	51	31

Table 4.22: Percentage (%) increase/decrease in Flood Discharge for Different Dredging Scenarios

	Dredging Scenario								
	Channel Number	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Main entrance channel	**1**	-	1	4	14	19	9	34	25
Western channel segments	**3**	-	-3	-7	-2	1	11	17	12
	4	-	-3	-2	-2	-3	21	21	30
	5	-	-7	-4	-4	-5	-11	-11	-2
	6	-	0	0	0	-1	45	45	53
	10	-	0	6	0	6	-41	-29	-29
	11	-	0	-2	0	-3	69	66	76
Eastern channel segments	**2**	-	33	100	152	176	-5	181	138
	7	-	92	217	292	333	-8	333	275
	8	-	-44	-56	-33	-33	0	-22	-44
	9	-	9	16	45	62	-13	59	17
	12	-	8	18	50	3	-11	2	-95
	13	-	14	0	0	586	-29	571	1014
	14	-	-2	-21	-2	13	-17	6	-35

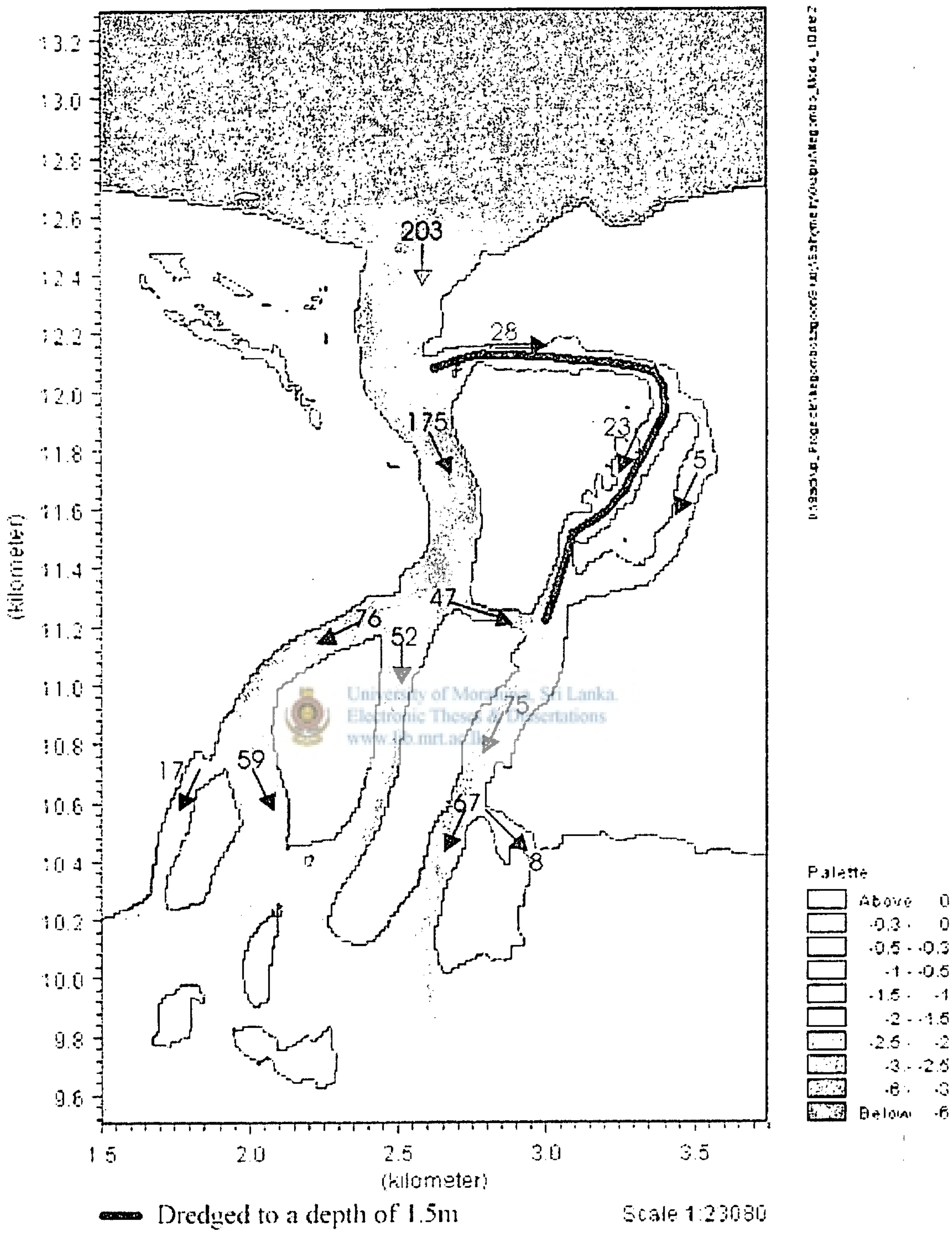


Figure 4.29: Maximum Flood Discharge for Option 1

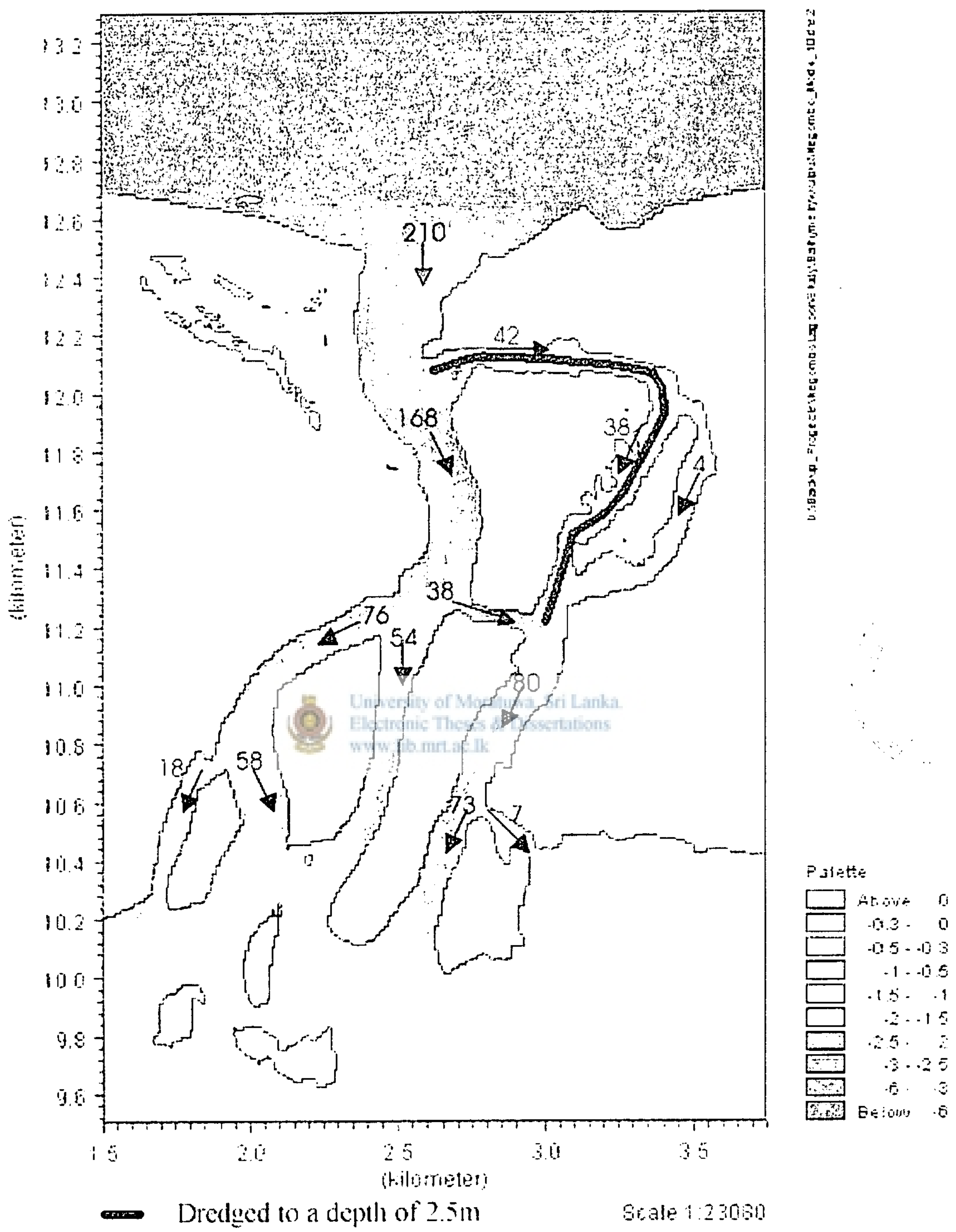


Figure 4.30: Maximum Flood Discharge for Option 2

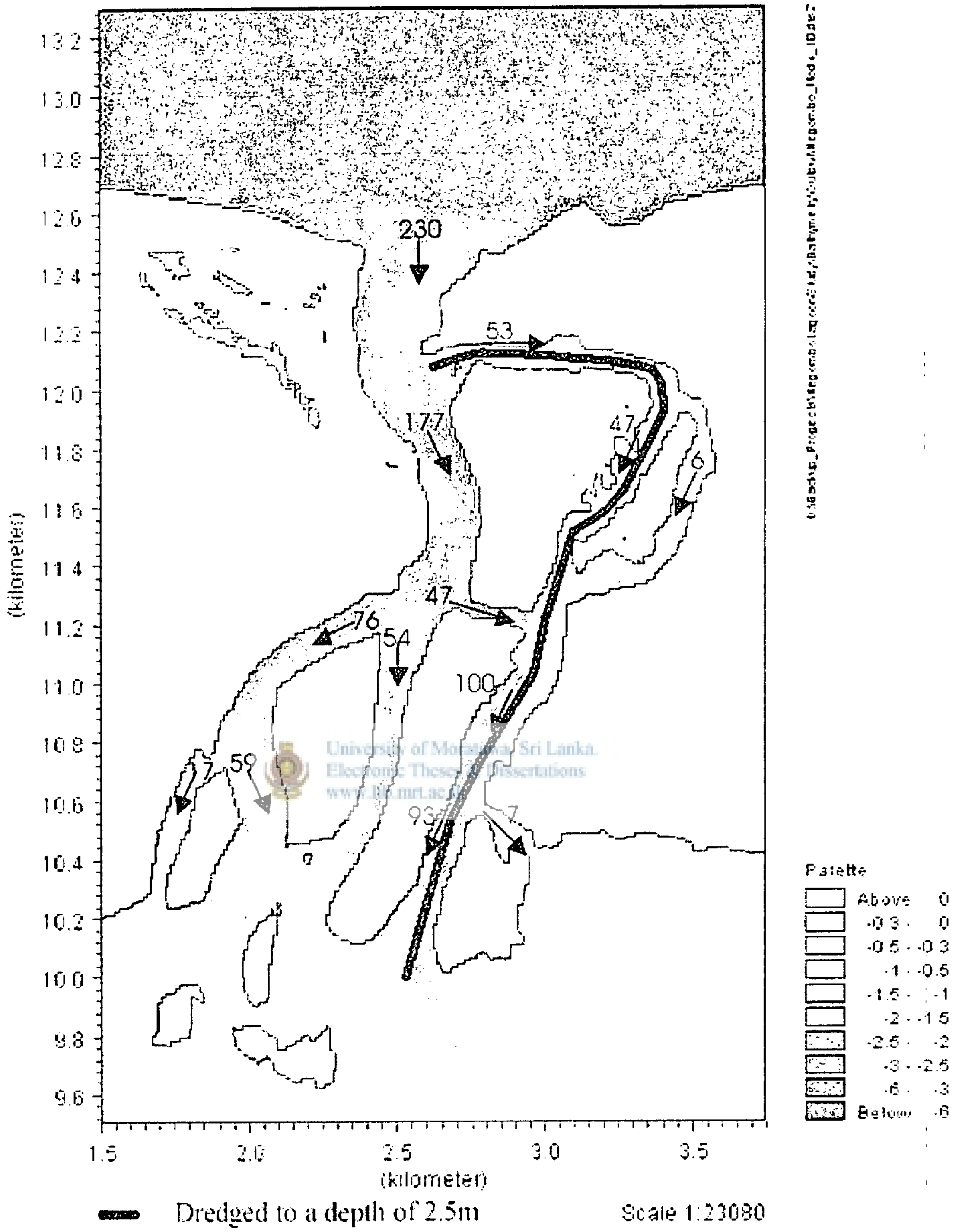


Figure 4.31: Maximum Flood Discharge for Option 3

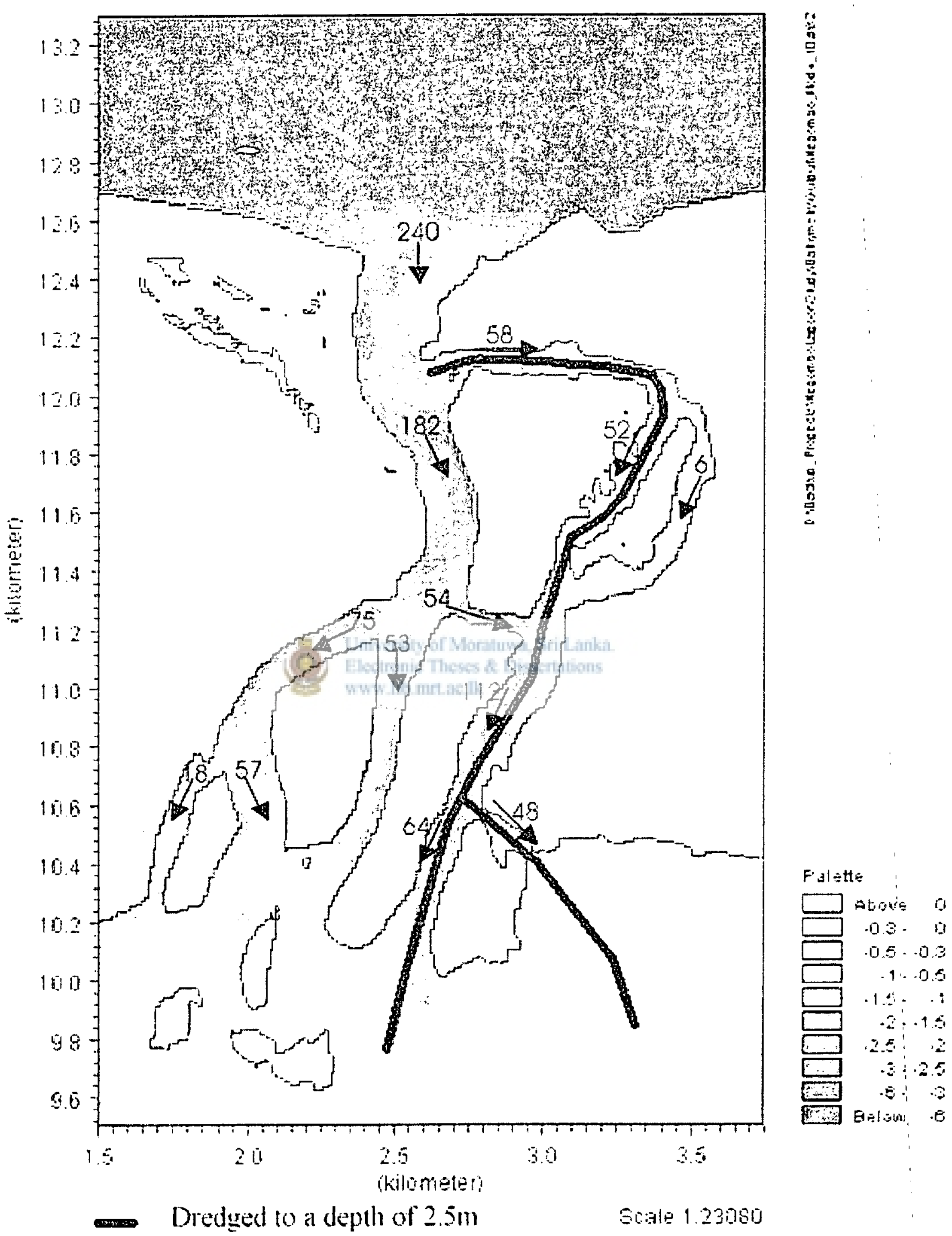


Figure 4.32: Maximum Flood Discharge for Option 4

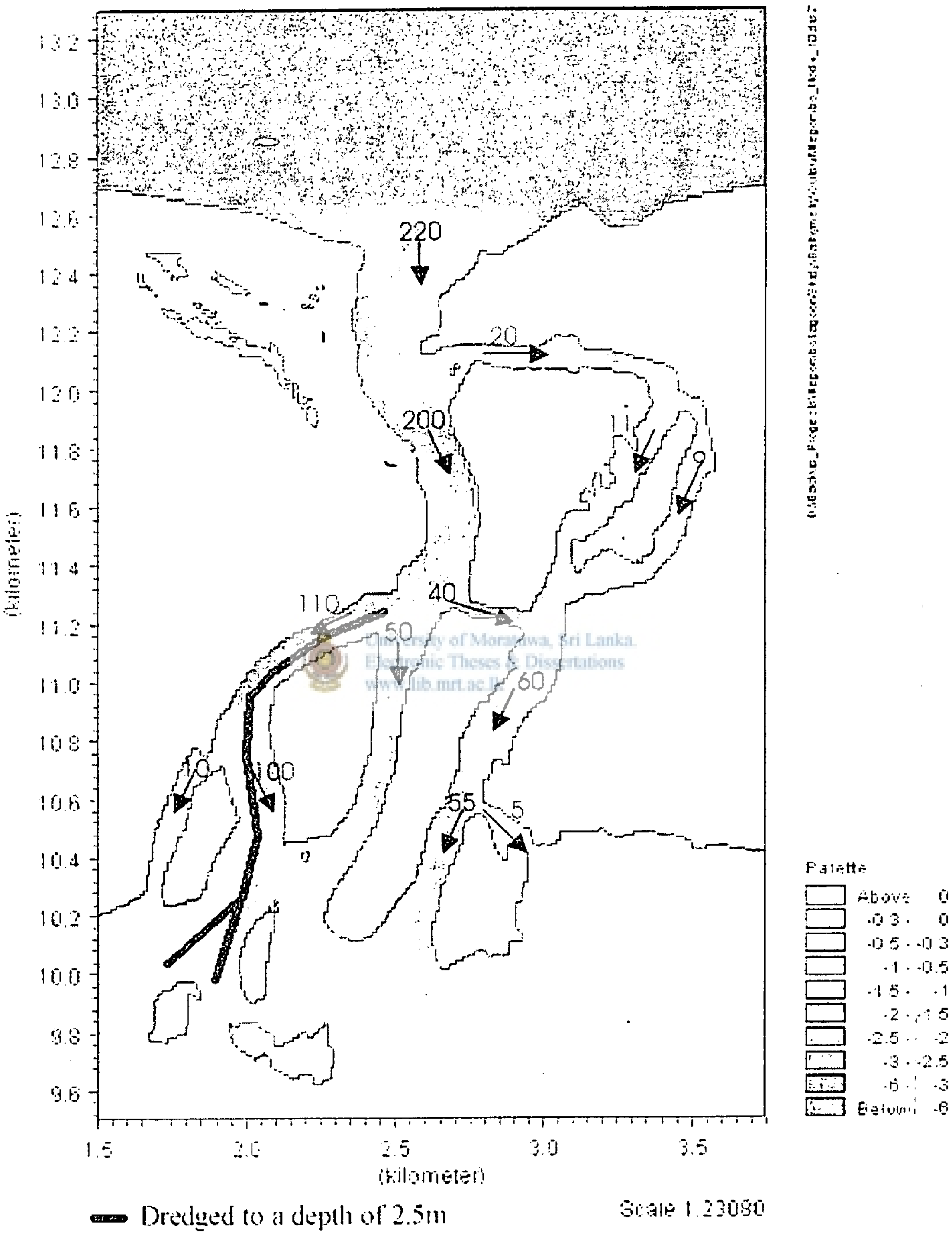


Figure 4.33: Maximum Flood Discharge for Option 5

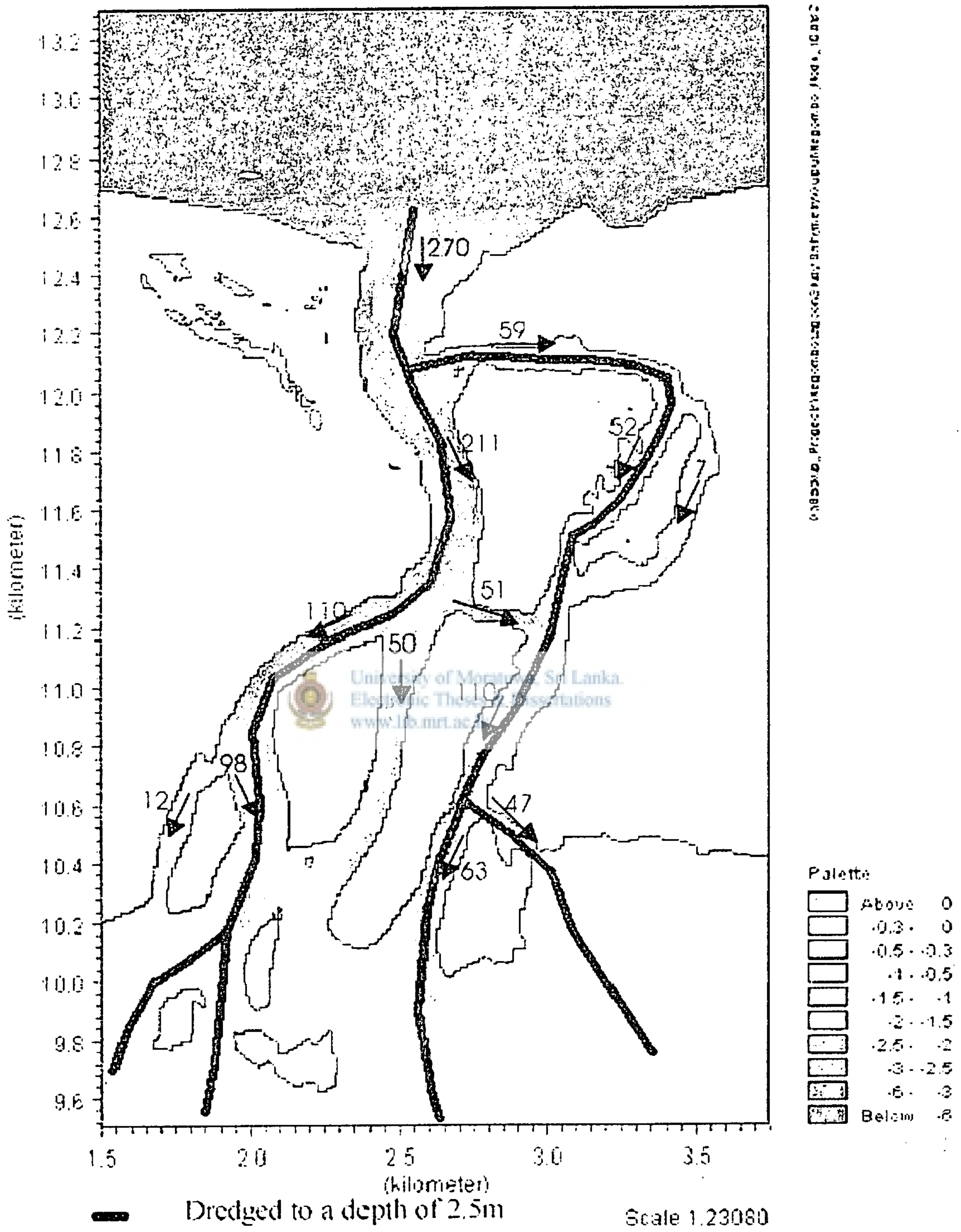


Figure 4.34: Maximum Flood Discharge for Option 6

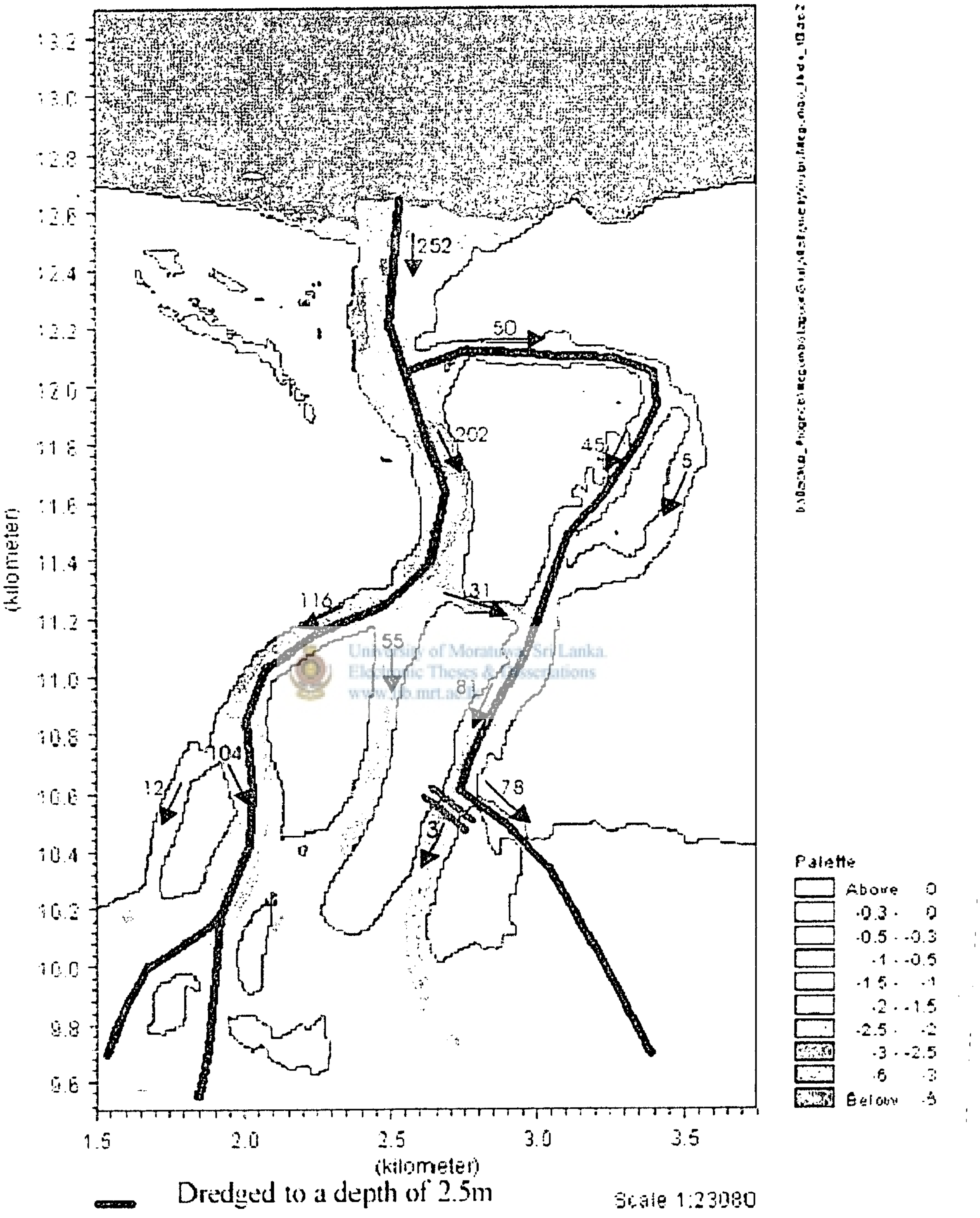


Figure 4.35: Maximum Flood Discharge for Option 7

4.9 COMPARISON OF DREDGING

The figure 4.36 shows the plan view of the entrance channels showing maximum flood discharges at the existing condition. Figure shows that there are three dominant flow paths 3-6-11, 3-5 and 3-14-9-12, which carry almost 90% of the flow. These flow paths are termed according to the channel numbers given in the figure 2.7. Figure 4.37 gives the computational domain which shows the output points.

Figure 4.38 shows how the surface elevation at Point 4 is increased when the dredging of option 6 is implemented. All other selected points inside the estuary give the higher surface elevation than the existing condition. It results in 45-60 % increase in tidal range in the estuary. The time lag of the existing condition is 4 hours. Dredging decreases the time lag up to 2.5 hours and it contributes to the increase of the above mentioned tidal range.

The variations of longitudinal and transverse velocities of the dredging option 6 with that of the existing condition are given in figures 4.39 and 4.40. Longitudinal component of flood velocity increases from 0.06 m/s to 0.10 m/s and the ebb velocity from 0.045 m/s to 0.08 m/s, which is a 65-75 % increment. Figure shows that there is an increase of the transverse component of velocity too.

The longitudinal velocity is increased at points 5, 5A, 6, 6A, 7 and 7A. But these points do not experience a significant increment of the transverse velocity component. Even though the percentage increment of the velocity is high, magnitude of these velocities are very small. At points 5, 5A, 6 and 6A, velocities are in the range of 0.025 m/s- 0.04 m/s. At points 7 and 7A, the longitudinal velocity ranges between 0.015m/s- 0.025 m/s.

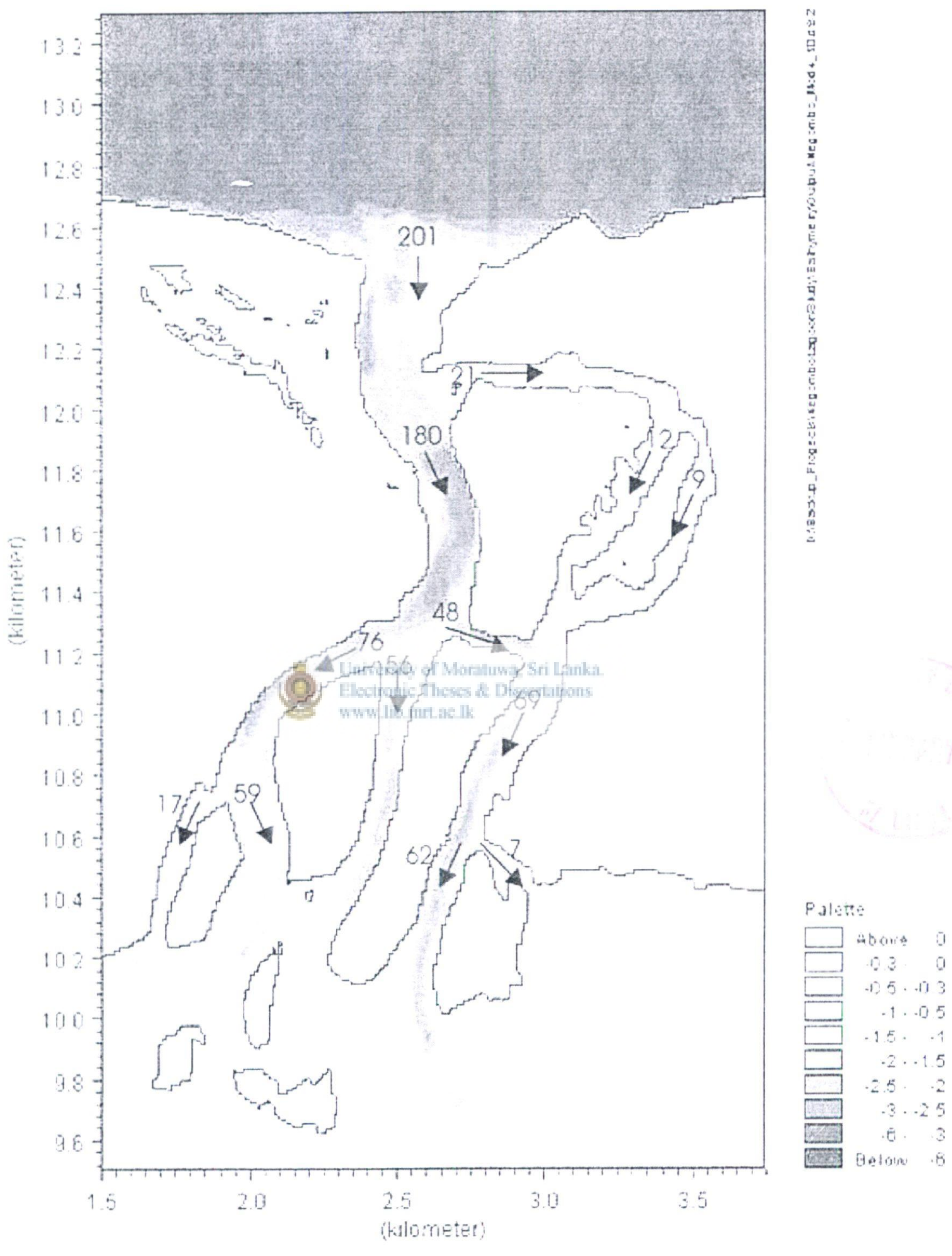


Figure 4.36: Maximum Flood Discharges at the Existing Condition

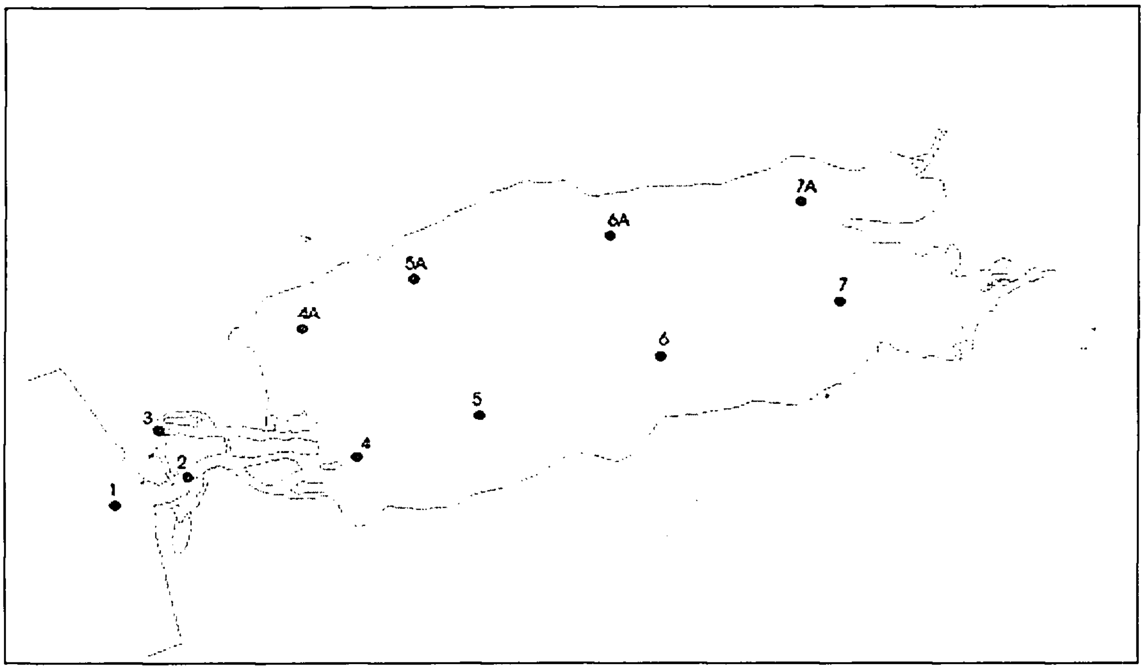


Figure 4.37: Computational Domain Showing Output Points

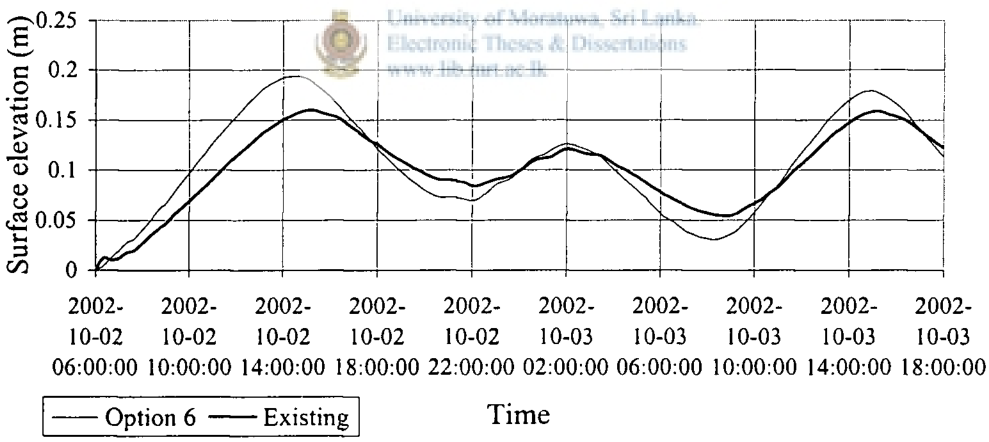


Figure 4.38: Variation of Surface elevation at point 4

Comparison of longitudinal velocities at points 5 and 5A, before and after dredging is given in the figure 4.41. Dredging results in a percentage increase of 40 % at point 5 and 75 % at point 5A.

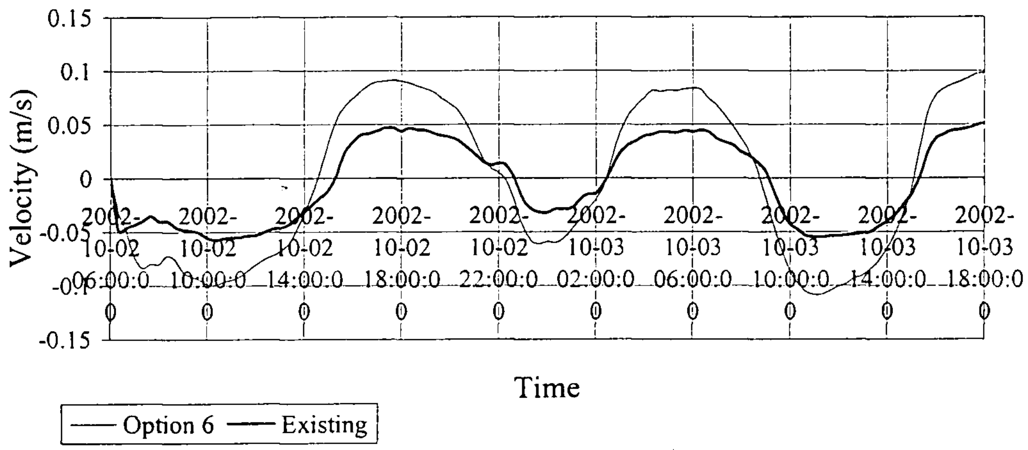


Figure 4.39: Variation of Longitudinal Component of Velocity at Point 4

Dredging the channel 13, under the option 6, supplies water to the eastern segment of the estuary. The figure 4.41 clearly depicts the improvement of the water circulation of the eastern side of the estuary up to the present conditions of the western segment.

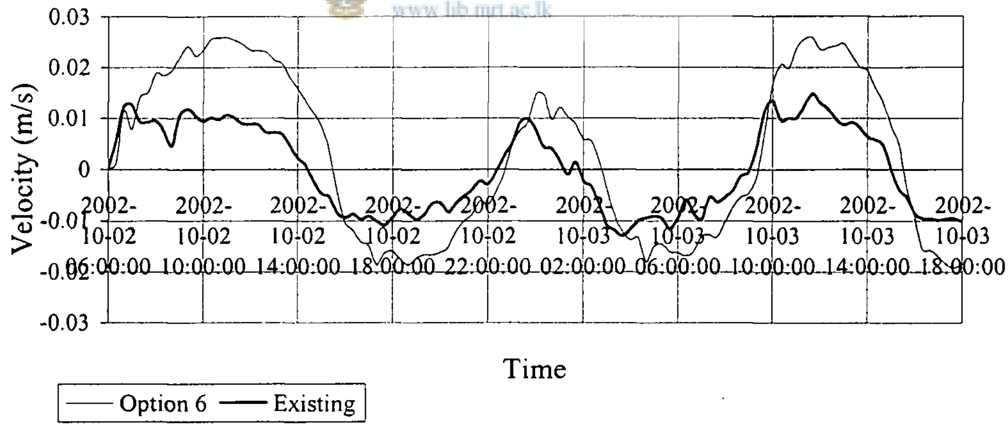


Figure 4.40: Variation of Transverse Component of Velocity at Point 4

The cross sectional area, maximum flood flow discharge, maximum flood velocity, percentage increase/decrease in discharge and velocity as a result of dredging are given in the table 4.23.

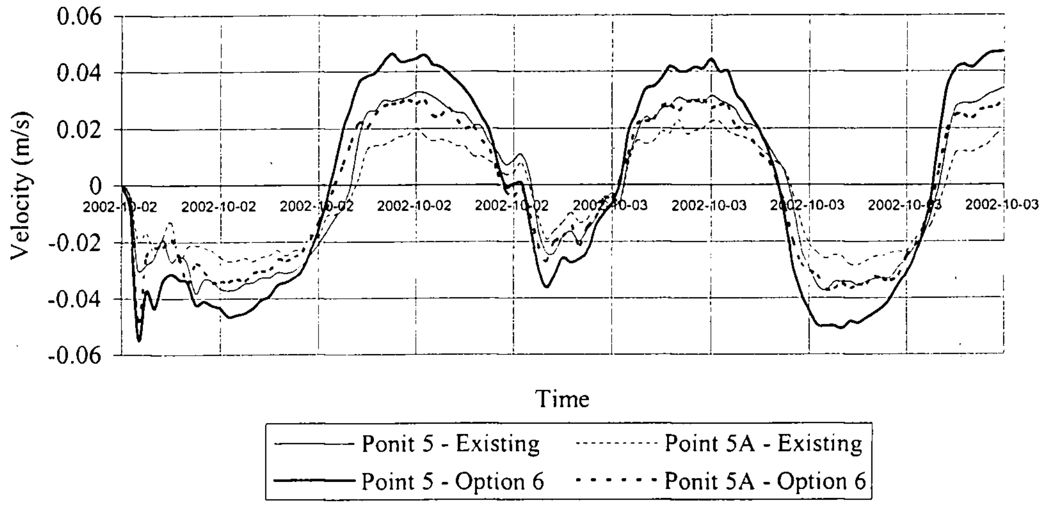


Figure 4.41: Comparison of Longitudinal Velocities at Points 5 and 5A

There is a percentage increase in discharge in all channels except 5, 8 and 10 which left out without dredging. Decrease in velocity would result in sedimentation in these channels. Though the contribution of dredging these channels to the total volume exchange is insignificant, according to the stakeholders' requirements, dredging of these channels could be considered. Dredging would result in an increase in discharge and a decrease in velocity in channels 11 and 12. As the velocity reduction is insignificant, it would not enhance sedimentation. Though 18 % of the velocity is reduced in the main entrance channel, the magnitude of the predicted velocity is still high enough to prevent the sedimentation. Figure 4.42 shows the cumulative exchange of water into and out of the estuary. Flow into the estuary is considered as positive. The option 6 results in an increment of 25-50% of volume exchanged into and out of the estuary.

In the Engineering Study on the Feasibility of Dredging the Negombo Lagoon to Improve Water Quality, UOM, 2003, flushing time of the estuary under the existing condition and option 6 were calculated for an early spring period with a low river discharge. Existing condition provides a flushing time of 19.5 days whereas under same conditions, flushing time for option 6 is around 14.5 days. About 25 % reduction in residence time could be achieved with the proposed dredging option. There is a significant variation of flushing time with the variation of inland drainage and tidal levels. In the dredging option6, dry-spring period provides a flushing time of about 16 days and wet-neap provides a flushing time of about 4 days.

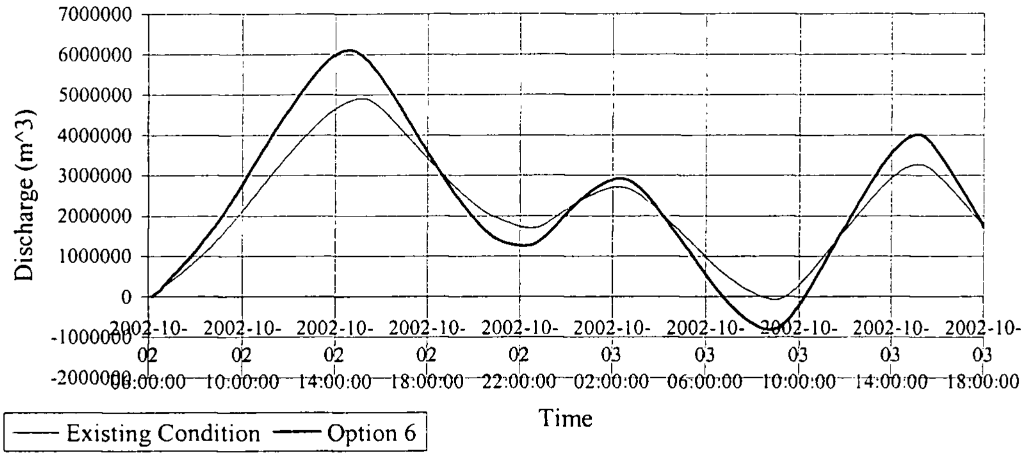


Figure 4.42: Comparison of Cumulative Exchange of Water into and out of the Estuary

Table 4.23: Comparison of Discharge, Velocity and Cross Sectional Areas in Entrance Channel Segments for Existing Condition and Dredging Option 6

	Channel Number	Existing Condition			Option 6				
		Cross section (m^2)	Discharge (m^3/s)	Velocity (m/s)	Cross section (m^2)	Discharge (m^3/S)	% increase in discharge	Velocity (m/s)	% increase
Main entrance channel	1	517	201	0.39	821	270	34	0.33	-18
Western channel segment	3	474	180	0.38	434	211	17	0.49	29
	4	349	132	0.38	349	160	21	0.46	21
	5	188	56	0.30	188	50	-11	0.27	-10
	6	228	76	0.33	254	110	45	0.43	30
	10	77	17	0.22	77	12	-29	0.16	-27
	11	228	59	0.26	392	98	66	0.25	-4
Eastern channel segment	2	82	21	0.26	133	59	181	0.44	69
	7	100	12	0.12	211	52	333	0.25	108
	8	76	9	0.12	76	7	-22	0.09	-25
	9	249	69	0.28	370	110	59	0.30	7
	12	196	62	0.32	214	63	2	0.29	-9
	13	38	7	0.18	96	47	571	0.49	172
	14	117	48	0.41	117	51	6	0.44	7

CHAPTER FIVE
5.0 CONCLUSIONS

5.1 GENERAL

This chapter summarizes the key results and comments of water quality analysis and recommendations to improve the water quality and recommendations for future researches.

5.2 KEY RESULTS AND COMMENTS

- Hydrodynamic and hydrological forcing drives much of the spatial and temporal water quality dynamics within the Negombo estuary.

- The highest COD values were recorded on day 3 and the lowest on day 4. This indicates that the organic pollutants, entrained with storm water are the major cause of the organic pollution. Once flushed with the higher rate of discharge after a period of heavy precipitation, on day 4, COD values have become minimal.

- Flushing has played a significant role in keeping nutrient concentrations down. Nitrate and phosphate concentrations are relatively lower within the estuary on day 4.

- Intense storm with the commencement of the intermonsoonal rain on day 3 delivered abundant ammoniacal N to the estuary.

- On day 4, concentrations of ammoniacal N through out the estuary are relatively high. It indicates that the microbial transformations of ammoniacal-N to nitrates have been minimal as a result of the least retention time on day 4.

- On day 4, abundant nitrate-N is delivered to the estuary from catchment runoff.

- The nitrate-N concentration of the marine water is around 0.04 mg/L and the fresh water inputs have higher nitrate-N concentrations indicating that the source of nitrate is fresh water inputs.

- Dandugam-Oya has brought the highest loads of DIN and TN irrespective of the climatic conditions.

- Dandugam-Oya has brought the highest loads of phosphate-P and TP on day 4. But Jaela has brought the highest load of phosphate-P on day 3.

- Higher concentrations of ammoniacal N, TN, phosphate and TP have been delivered to the estuary on day 3 and day 4 with the catchment runoff.

- When the fresh water discharge is high, results showed that there is a potential of P limitation of the primary production. When the fresh water discharge is low, there is a potential of N limitation. Though the studies of the estuaries in temperate zone have shown the potential of N limitation, this study shows that in Negombo estuary, which is in the tropical region, P has the limiting potential at many locations when the fresh water discharge is high. Limiting potential shifts from P to N when the fresh water discharge becomes low in the dry season.

- According the TN, TP and Chl *a* levels, location 1 (sea) is eutrophic both in dry and wet seasons.

- Chl *a* levels of locations 2 and 3 manifest that these two locations are eutrophicated.

- Chl *a* levels of the upstream of the Hamilton canal are higher than that of Dandugam-Oya and Ja-ela and manifest the waterbody is mesotrophic. Hamilton canal has faced the threat of eutrophication.

- Chl *a*, TN and TP levels in all the sampling locations at the middle part of the estuary, shows the waterbody is eutrophicated. Chl *a* levels of locations 6 and 7 on the wet season (05.01.2003) and location 7 on dry season (Day 6- 10.02.2003) has exceeded even the Eutrophic-hypertrophic boundary, which is 0.005 mg/L. This manifests that the location 7 is hypertrophic on both wet and dry seasons while the location 6 is hypertrophic on wet season.

5.3 RECOMMENDATIONS TO IMPROVE THE WATER QUALITY

- Discharges of nutrients to the estuary with the fresh water inflows should be strictly maintained below the permissive levels.

- Effluents of the wastewater treatment plants should be monitored to assure their proper functioning.

- As dredging reduces the flushing time and increases the water exchange, it would be the most preferred option to improve the water quality.

- As the most feasible dredging option is the alternative 6, it is recommended.

- To be able to effectively manage the nutrient over-enrichment, criteria of acceptable nutrient loads should be defined.

- As there is a tendency of P limitation of the primary production, limiting P is important in controlling the eutrophication.

- Keeping a riparian vegetated strip adjacent to the water course is reported to eliminate P leakage to the water course by sedimentation and deposition.

5.4 RECOMMENDATIONS FOR FUTURE RESEARCHES

- Maximum acceptable levels of nutrients in streams and rivers are not established so far. Therefore data analyses are needed to establish them.

- In this study, nutrient limitation was determined using the nutrient levels of the water column. It should be further investigated by bioassays.

- The dissolved oxygen (DO) profile of the estuary is very important as it is closely linked with the efficiency of nitrification-denitrification, release of phosphates from sediments, pH etc. In this study, due to the practical inabilities, it could not be done. In future researches it is better to study the variation of the DO profile with the other variables.

- To assess the health of the water body continuously, it is better to introduce a water quality index.

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ANNEXES

A 1: PROPOSED AMBIENT WATER QUALITY STANDARDS FOR INLAND WATERS

Parameter	Unit, Type of limit	CLASS 1 Waters		CLASS 11Waters (Sensitive waters)			Irrigation and agriculture	Class 111 Waters (general Waters)
		Nature Conservation 1	Drinking water With simple Treatment 2	Bathing 3	Fish and aquatic Life 4	Drinking water, With conventional Treatment 5	6	Minimum Quality (Other Uses) 7
General								
1. Colour (after simple filtration	Pt mg/l, max.	n	20	-	-	100	-	-
2. Total dissolved solids (TDS)	Mg/l, max.	n	-	-	-	-	500	-
3. Conductivity	dS/m, max.	n	-	-	-	-	0.7	-
4. Odour	-	n	unobj	unobj	-	unobj	-	-
5. Taste	-	n	unobj	-	-	unobj	-	-
6. Turbidity	NTU, max.	n	5	-	-	-	-	-
7. Sodium absorption ratio (SAR)	-	n	-	-	-	-	6-15	-
8. Residual sodium Carbonate (RSC)	Meq./l, max.	n	-	-	-	-	1.25	--
9. Total hardness	As $CaCo_3$ mg/l, max.	n	250 des. 600 max	-	-	-	-	-
10. pH	-	n	6.0-8.5	6.0-9.0	6.0-8.5	6.0-9.0	6.0-8.5	5.5-9.0
11. Dissolved Oxygen at 25^0C	Mg/l, min	n	6	5	3	4	3	3
12. BOD (5 days at 20^0C or 3 days at 30^0C)	Mg/l, max.	n	3	4	4	5	5	5
13. COD	Mg/l, max	n	15	20	15	30	-	40

Parameter	Unit, Type of limit	CLASS 1 Waters		CLASS 11Waters (Sensitive waters)			Irrigation and agriculture	Class 111 Waters (general Waters)
		Nature Conservation 1	Drinking water With simple Treatment 2	Bathing 3	Fish and aquatic Life 4	Drinking water, With conventional Treatment 5	6	Minimum Quality (Other Uses) 7
Nutrients								
14. Nitrates ($No_3 - N$)	mg/l, max.	n	5	5	5	5	5	5
15. Total ammonia (NH_3-N) - pH < 7.5 - pH= 8.0 - pH= 8.5	mg/l, max.	 n - -	 - - -	 - - -	 0.94 0.59 0.22	 - - -	 - - -	 9.1 4.9 1.6
16. Total phospate (PO_4-P)	mg/l, max.	n	0.7	0.7	0.4	0.7	0.7	0.7
Other Substances								
17. Chlorides (Cl)	mg/l,max	n	200	-	-	200	100	-
18. Cyanides (CN)	mg/l, max.	n	0.005	0.005	0.005	0.005	0.005	0.005
19. Fluorides (F)	mg/l, max.	n	1.5	-	-	1.5	-	-
20. Sulphates (SO_4)	mg/l, max.	n	250	-	-	250	1000	--
Metals								
21. Total cadmium (Cd)	μg/l, max.	n	5	-	**H** **Cd** <60 0.2 60-120 0.8 120-180 1.3 >180 1.8	5	-	5
22. Total chromium (Cr)	μg/l, max.	n	50	-	2	50	-	50
23. Total copper (Cu)	μg/l, max.	n	-	-	**H** **Cu** <60 2 60-120 2 120-180 3 >180 4	-	-	100

Parameter	Unit, Type of limit	CLASS 1 Waters		CLASS 11Waters (Sensitive waters)			Irrigation and agriculture	Class 111 Waters (general Waters)
		Nature Conservation 1	Drinking water With simple Treatment 2	Bathing 3	Fish and aquatic Life 4	Drinking water, With conventional Treatment 5	6	Minimum Quality (Other Uses) 7
24. Iron (Fe)	µg/l, max.	n	300 des. 1000 max	-	300	200	-	-
25. Lead (Pb)	µg/l, max.	n	50	-	**H** **Pb** <60 1 60-120 2 120-180 4 >180 7	50	-	50
26. Manganese (Mn)	µg/l, max.	n	1000	1000	1000	1000	1000	1000
27. Mercury (Hg)	µg/l, max.	n	1	1	0.1	1	1	2
28. Nickel (Ni)	µg/l, max.	n	100	100	**H** **Ni** <60 25 60-120 65 120-180 110 >180 150	100	100	100
29. Selenium (Se)	µg/l, max.	n	10	10	1	10	-	-
30. Zinc (Zn)	µg/l, max.	n	1000	1000	30	1000	1000	1000
31. Boron (B)	µg/l, max.	n	-	-	-	-	500	--
32. Total arsenic (As)	µg/l, max.	n	10	50	50	10	50	50
33. Aluminium (Al)	µg/l, max.	n	200	-	-	200	5.0	-
Organic Micro Pollutants								
34. Phenol index	µg/l, max.	n	2	5	1	5	5	5
35. Oil and grease	µg/l, max.	n	100	200	10	100	-	300

Parameter	Unit, Type of limit	CLASS 1 Waters		CLASS 11Waters (Sensitive waters)			Irrigation and agriculture	Class 111 Waters (general Waters)
		Nature Conservation 1	Drinking water With simple Treatment 2	Bathing 3	Fish and aquatic Life 4	Drinking water, With conventional Treatment 5	6	Minimum Quality (Other Uses) 7
36. Anionic surfactants (detergent) as MBAS	µg/l, max.	n	200	300	1000	200	1000	1000
37. Total pesticides	µg/l, max.	n	10	30	30	30	50	50
Micro Organisms								
38. Total coliform	MPN/100ml, (*P=95%)	n	5000	1000	20,000	5000	1000	-
39. Faecal coliform	MPN/100ml, (*P=95%)	n	250 des 600 max	50	-	-	-	-

Abbreviations :

n	- Nature or baseline values
H	- Hardness in terms of $CaCO_3$ in mg/l
des.	- Desirable highest level
max.	- Maximum permissible substances
MBAS	- Methylene blue active substances
*P=95%	- 95% of the samples give a value that is equal to or less than the indicated limit
1	- Mean – during longer period
2	- Min. dly – average of daily waters
3	- prevention of eutrophication, excessive weed growth, etc., may require lower, site specific, for stagnant waters

A 2 : COASTAL WATER QUALITY STANDARDS

Parameter	Unit	Value for different use classes			
		Nature conservation 1	Fishery of Shell Fish 2	Fishery of Fin Fish 3	Non Consumption 4
1. Floatable solids		n	n	n	NO
2. Floatable oil & grease		n	n	n	NO
3. Suspended solids		n	n	n	NO
4. Transparency [1]		n	<10%	<10%	<50%
5. Colour		n	NV	NV	NO
6. Odour		n	n	n	NO
7. Temperature	^{0}C	<32	<32	<32	<32
8. Coliform (total)	MPN / ml	n	n	<10	<20
9. Coliform (faecal)	MPN / ml	n	n	<3	<6
10. pH		n	7.0-8.5	7.0-8.5	6.5-9.0
11. Salinity	g/l	n	29-35	<10%	<20%
12. Dissolved Oxygen	Saturation value	n	>80%	>70%	>60%
13. BOD_5 at 20^0 C or BOD_3 at 30^0 C	mg/l	n	<5	<5	<10
14. Phosphate (total) as N	mg/l	n	NA	NA	NA
15. Nitrogen (total) as N	mg/l	n	NA	NA	NA
16. Ammonia (free) as N	mg/l	n	<0.4	<0.4	<1.2
17. Cyanide (CN)	µg/l	n	<10	<10	<20
18. Sulphide (H_2S)	µg/l	n	<5	<5	<10
19. Fluoride (F)	µg/l	n	<1.5	<1.5	<3
20. Mercury (Hg)	µg/l	n	<0.1	<0.1	<0.2
21. Cadmium (Cd)	µg/l	n	<5	<5	<10
22. Chrome (hex.) (Cr^{6+})	µg/l	n	<25	<25	<50
23. Lead (Pb)	µg/l	n	<25	<25	<50
24. Copper (Cu)	µg/l	n	<25	<25	<50
25. Manganese (Mn)	µg/l	n	<100	<100	<200
26. Zinc (Zn)	µg/l	n	<50	<50	<100
27. Iron (Fe)	µg/l	n	<300	<300	<600
28. Arsenic (As)	µg/l	n	<50	<50	<100
29. Phenols (C_6H_5OH)	µg/l	n	<30	<30	<60
30. PCB (total)	µg/l	n	<0.03	<0.03	<0.06
31. Pesticides (total)	µg/l	n	<0.05	<0.05	<0.1

[1] % = Change from natural condition
n = Natural condition
NO = Not Objectionable
NV = Not Visible
NA = Below level causing algae bloom (to be established)

A3: Project: Water Quality of Negombo Lagoon.
Sampling Date: 25, September, 2002 10.00 a.m.-12 .00 noon.

Sampling Point No.	Coordinates of each Point		Depth (m)	Time	pH		Temperature (^{0}C)		Conductivity (ms/cm)		Salinity (ppt)	
	N	E			top	bottom	top	bottom	top	bottom	top	bottom
1	07^{0} 12.644^{1}	079^{0} 49.493^{1}	4.98	10.05a.m.	7.93		30.0		58.8		35.3	
1A	07^{0} 12.492^{1}	079^{0} 49.500^{1}		10.10a.m.	7.95		30.0		58.5		35.1	
2	07^{0} 12.186^{1}	079^{0} 49.832^{1}	3.45	10.12a.m.	7.97.		30.0		57.7		34.6	
2A	07^{0} 11.868^{1}	079^{0} 49.776^{1}	1.5	10.20a.m.	7.95		30.0		58.4		35.0	
2B	07^{0} 11.256^{1}	079^{0} 49.818^{1}	1.85	10.25 a.m.	8.02		30.0		58.2		34.9	
3	07^{0} 12.460^{1}	079^{0} 50.224^{1}	1.02	10.17 a.m.	6.83		30.0		10.2		5.2	
4	07^{0} 10.796^{1}	079^{0} 49.910^{1}	1.63	10.30a.m.	8.01	7.95	30.0	30.0	58.4	60.1	35.0	36.2
5	07^{0} 10.366^{1}	079^{0} 50.247^{1}	1.29	10.45a.m.	7.98	7.91	30.0	30.0	59.4	60.5	35.7	36.5
6	07^{0} 10.210^{1}	079^{0} 50.592^{1}	1.57	11.02a.m.	7.94	7.52	30.0	30.5	59.2	58.3	35.6	34.6
6A	07^{0} 8.838^{1}	079^{0} 51.252^{1}	1.35	11.20a.m.	7.88	7.64	30.5	30.5	59.6	58.2	35.5	34.5
7	07^{0} 08.383^{1}	079^{0} 51.716^{1}	1.17	11.30a.m.	7.78	7.42	30.0	32.0	57.5	54.8	34.4	31.3
8A			1.25	12.00noon.	7.15		30.0		26.2		14.4	
8	07^{0} 02.618^{1}	079^{0} 51.772^{1}	1.27									
9A			0.73	11.55a.m	7.33		32.0		47.4		26.6	
9	07^{0} 04.814^{1}	079^{0} 53.444^{1}	2.21									
10A			1.92	11.40a.m	7.49		32.0		51.0		28.9	
10	07^{0} 06.588^{1}	079^{0} 52.964^{1}	4.98									

Sampling Point No.	Total Nitrogen (mg/l)		Nitrates - N (mg/l)		Ammonia - N (mg/l)		Total Phosphorous (mg/l)		Phosphate - P (mg/l)		COD (mg/l)		Total dissolved solids (mg/l)	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
1			0.499		0.041		0.80689		0.01127		163.78			
1A			0.065		0.054		0.74102		0.01041		155.16			
2	92.00						0.15232				181.02			
2A	35.7										163.78			
2B											77.58			
3	56.70						0.06484				103.44			
4			0.059	0.160	0.068	0.025	0.04405	0.12865	0.00086	0.06311	86.20	155.16		
5	45.1	46.2		0.258		0.034	0.07307	0.16364	0.01757	0.04214	163.78	241.36		
6	33.90	68.00	0.142	0.284	0.044	0.048	0.13585	0.16467	0.00431	0.02494	83.68	58.52	41440	41482
6A				0.404		0.072		0.06793		0.02577	200.64	58.58	42380	40696
7		95.50	0.150	0.218	0.036	0.017	0.21407	0.07822	0.01993	0.01068	92.05	75.31	36790	38980
8A			0.247		0.018		1.06213		0.00933		41.80			
8														
9A	58.8		0.246		0.033		0.10292		0.01075		83.68			
9														
10A	51.9		0.208		0.028		0.55989		0.00195		58.52			
10														

A 4: Project: Water Quality of Negombo Lagoon.
Sampling Date: 25 September,2002 3.00 p.m.-7.00 p.m.

Sampling Point No.	Coordinates of each Point		Depth (m)	Time	pH		Temperature (^{0}C)		Conductivity (ms/cm)		Salinity (ppt)	
	N	E			top	bottom	top	bottom	top	bottom	top	bottom
1	07^0 12.644^1	079^0 49.493^1	4.98	3.00p.m.	8.02		30.0		61.6		37.2	
1A	07^0 12.492^1	079^0 49.500^1		3.02p.m.	7.99		30.0		61.2		36.9	
2	07^0 12.186^1	079^0 49.832^1	3.45	3.04p.m.	7.99		32.0		61.1		35.4	
2A	07^0 11.868^1	079^0 49.776^1	1.5	3.15p.m.	8.00		30.0		61.8		37.3	
2B	07^0 11.256^1	079^0 49.818^1	1.85	3.20p.m.	8.01		30.0		61.4		37.0	
3	07^0 12.460^1	079^0 50.224^1	1.02	3.10p.m.	7.14		30.0		24.9		13.6	
4	07^0 10.796^1	079^0 49.910^1	1.63	3.30p.m.	8.04		30.0		61.0		36.8	
5	07^0 10.366^1	079^0 50.247^1	1.29	3.40p.m.	7.78		30.5		60.5		36.1	
6	07^0 10.210^1	079^0 50.592^1	1.57	3.50p.m.	7.95		31.0		60.8		35.9	
6A	07^0 8.838^1	079^0 51.252^1	1.35	4.00p.m.	7.89		31.0		59.3		34.9	
7	07^0 08.383^1	079^0 51.716^1	1.17	4.10p.m.	7.81		32.0		54.5		31.1	
8A			1.25	4.43p.m.	7.56		32.0		26.5		14.0	
8	07^0 02.618^1	079^0 51.772^1	1.27	6.55p.m.	7.29		32.0		24.8		13.0	
9A			0.73	4.35p.m.	7.53		32.0		47.9		26.9	
9	07^0 04.814^1	079^0 53.444^1	2.21	6.30p.m.	6.78		32.0		22.2		11.5	
10A			1.92	4.20p.m.	7.65		32.0		50.5		28.6	
10	07^0 06.588^1	079^0 52.964^1	4.98	6.15p.m.	6.99		32.0		30.5		16.3	

Sampling Point No.	Total Nitrogen (mg/l)		Nitrates - N (mg/l)		Ammonia - N (mg/l)		Total Phosphorous (mg/l)		Phosphate - P (mg/l)		COD (mg/l)		Total dissolved solids (mg/l)	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
1			0.124		0.054		0.77808		0.00968		58.52			
1A	9.60		0.136		0.084		0.57223		0.02505		225.72			
2											71.06			
2A	96.00						0.17805		0.03406		117.04			
2B	60.50						0.15953				147.83			
3	111.1						0.17394				91.96			
4	17.70		0.152		0.087		0.71221		0.00579		58.58			
5	84.50						0.13071				86.96			
6			0.319		0.013						43.48			
6A	40.60						0.15335				121.74			
7			0.199		0.046		0.42631		0.00383		34.78			
8A	49.97		0.062		0.086		0.26348		0.03961		86.96			
8	41.9		0.422		0.123		0.54342		0.02575		78.26			
9A			0.223		0.048		0.75337				47.83			
9	37.50		0.249		0.237		0.34993		0.03158		78.26			
10A			0.215		0.023						4.34			
10			0.499		0.072		0.54342				121.74			

A 5: Project: Water Quality of Negombo Lagoon.
Sampling Date: 15, October, 2002 10.10 a.m.-12 .10 p.m.

Sampling Point No.	Coordinates of each Point		Depth (m)	Time	pH		Temperature (^{0}C)		Conductivity (ms/cm)		Salinity (ppt)	
	N	E			top	bottom	top	bottom	top	bottom	top	bottom
1	07^0 12.644^1	079^0 49.493^1	4.98	10.10a.m.	7.97		30.0		54.2		32.212	
1A	07^0 12.492^1	079^0 49.500^1		10.20a.m.	8.05		30.0		53.2		31.545	
2	07^0 12.186^1	079^0 49.832^1	3.45	10.30a.m.	8.10.		30.0		52.1		30.815	
2A	07^0 11.868^1	079^0 49.776^1	1.5	10.45a.m.	8.06		30.0		51.0		30.087	
2B	07^0 11.256^1	079^0 49.818^1	1.85	10.55a.m.	8.05		30.0		45.3		26.357	
3	07^0 12.460^1	079^0 50.224^1	1.02	10.35 a.m.	6.94		30.0		23.2		12.61	
4	07^0 10.796^1	079^0 49.910^1	1.63	11.00a.m.	8.03		30.0	30	42.6	46.6	24.615	27.2
5	07^0 10.366^1	079^0 50.247^1	1.29	11.10a.m.	8.04		30.0	30	39.8	44.8	22.826	26
6	07^0 10.210^1	079^0 50.592^1	1.57	11.15a.m.	7.93		30.0	30	36.7	44.0	20.867	25.5
6A	07^0 8.838^1	079^0 51.252^1	1.35	11.30a.m.	7.91		30.0	30	35.9	42.4	20.365	24.5
7	07^0 08.383^1	079^0 50.716^1	1.17	11.40a.m.	7.79		30.0	30	35.3	38.6	19.989	22.1
8A			1.25	12.10p.m.	7.05		30.0		5.2		2.518	
8	07^0 02.618^1	079^0 51.772^1	1.27									
9A			0.73	12.00noon	8.42		30.0		18.1		9.622	
9	07^0 04.814^1	079^0 53.444^1	2.21									
10A			1.92	11.48a.m.	7.03		30.0		13.8		7.172	
10	07^0 06.588^1	079^0 52.964^1	4.98									

Sampling Point No.	Total Nitrogen (mg/l)		Nitrates - N (mg/l)		Ammonia - N (mg/l)		Total Phosphorous (mg/l)		Phosphate - P (mg/l)		COD (mg/l)		Total dissolved solids (mg/l)	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
1	9.4		0.072		0.034		0.4487		0.00385		88.8			
1A	9.5		0.061		0.000		0.3169		0.0515		58.5			
2	0.3										60.7			
2A	4.4										144.0			
2B	1.9										108.0			
3	5.8										22.5			
4	0.7		0.050		0.021		0.1894		0.0165		22.5			
5	0.3										153.0			
6	0.3		0.070		0.037		0.2964		0.00206		45.0			
6A	6.4										56.1			
7	5.1		0.130		0.067		0.4132		0.01440		130.0			
8A	7.7		0.047		0.276		0.0908		0.01132		74.8			
8														
9A	5.0		0.045		0.054		0.6838		0.0638		58.5			
9														
10A	3.8		0.056		0.056		0.011		0.01029		256.5			

A 6: Project: Water Quality of Negombo Lagoon.
Sampling Date: 15, October, 2002 2.45 p.m. a.m.-7.00 p.m.

Sampling Point No.	Coordinates of each Point		Depth (m)	Time	pH		Temperature (^{0}C)		Conductivity (ms/cm)		Salinity (ppt)	
	N	E			top	bottom	top	bottom	top	bottom	top	bottom
1	07^0 12.644^1	079^0 49.493^1	4.98	2.45p.m.	8.06		30.0		54.2		32.212	
1A	07^0 12.492^1	079^0 49.500^1		2.50p.m.	7.93		30.0		51.8		30.616	
2	07^0 12.186^1	079^0 49.832^1	3.45	2.55p.m.	8.02		30.0		51.8		30.616	
2A	07^0 11.868^1	079^0 49.776^1	1.5	3.15.m.	8.03		31.0		48.98		28.176	
2B	07^0 11.256^1	079^0 49.818^1	1.85	3.20p.m.	8.09		31.0		48.2		27.675	
3	07^0 12.460^1	079^0 50.224^1	1.02	3.05p.m.	6.96		31.0		36.7		20.447	
4	07^0 10.796^1	079^0 49.910^1	1.63	3.30p.m.	8.02		31.0		48.29		27.733	
5	07^0 10.366^1	079^0 50.247^1	1.29	3.40p.m.	7.95		31.0		43.7		24.812	
6	07^0 10.210^1	079^0 50.592^1	1.57	3.45p.m.	7.95		31.0		43.1		24.434	
6A	07^0 8.838^1	079^0 51.252^1	1.35	3.50p.m.	7.90		31.0		37.2		20.755	
7	07^0 08.383^1	079^0 50.716^1	1.17	4.00p.m.	7.81		31.0		40.1		22.554	
8A			1.25	4.35p.m.	6.99		31.0		6.9		3.337	
8	07^0 02.618^1	079^0 51.772^1	1.27	6.50p.m.	6.99		32.0		4.4		2.026	
9A			0.73	4.25p.m.	8.15		31.0		26.7		14.41	
9	07^0 04.814^1	079^0 53.444^1	2.21	6.25p.m.	6.61		32.0		6.7		3.171	
10A			1.92	4.10p.m.	7.95		31.0		16.7		8.641	
10	07^0 06.588^1	079^0 52.964^1	4.98	6.10p.m./	8.49		32.0		5.9		2.768	

Sampling Point No.	Total Nitrogen (mg/l)		Nitrates - N (mg/l)		Ammonia - N (mg/l)		Total Phosphorous (mg/l)		Phosphate - P (mg/l)		COD (mg/l)		Total dissolved solids (mg/l)	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
1	3.1		0.107		0.055		0.5393		0.00412		49.5			
1A	6.0		0.071		0.154		0.4282		0.0103		63.0			
2	5.7										79.4			
2A	6.5										500.0			
2B	0.7										228.8			
3	0.4										42.1			
4	5.0		0.045		0.149		0.424		0.00618		67.5			
5	5.0										526.8			
6	3.0		0.078		0.011		0.4652		0.00823		58.5			
6A	10.4										616.1			
7	5.0		0.076		0.030		0.3376		0.00		58.5			
8A	57.0		0.066		0.518		0.3582		0.03911		31.5			
8	21.0		0.054		0.737		0.5105		0.02676		37.4			
9A	5.0		0.079		0.056		0.3582		0.00823		400.5			
9	16.1		0.061		0.590		0.3376		0.0165		18.0			
10A	4.0		0.055		0.141		0.3541		0.00206		49.5			
10	12.8		0.054		0.120		0.3623		0.00823		13.5			

A-7 Project: Water Quality of Negombo Lagoon.

Sampling Date:7,November,2002 10.00 a.m.-12 .20 p.m.

Sampling Point No.	Coordinates of each Point		Depth (m)	Time	pH		Temperature (^{0}C)		Conductivity (ms/cm)		Salinity (ppt)	
	N	E			top	bottom	top	bottom	top	bottom	top	bottom
1	07° 12.644′	079° 49.493′	4.98	10.30a.m.	8.03		30.0		24.0		13.085	
1A	07° 12.492′	079° 49.500′		10.40a.m.	8.00		29.5		15.6		8.273	
2	07° 12.186′	079° 49.832′	3.45	10.45a.m.	8.01		30.0		14.1		7.34	
2A	07° 11.868′	079° 49.776′	1.5	11.00a.m.	8.05		30.5		13.5		6.933	
2B	07° 11.256′	079° 49.818′	1.85	11.10a.m.	7.96		30.5		10.0		5.017	
3	07° 12.460′	079° 50.224′	1.02	10.50a.m.	7.36		29.0		14.8		7.895	
4	07° 10.796′	079° 49.910′	1.63	11.15a.m.	7.59	8.12	30.5	30.5	13.3	16.5	6.822	8.615
5	07° 10.366′	079° 50.247′	1.29	11.25.m.	7.87	8.24	30.5	30.5	9.4	30.1	4.694	16.602
6	07° 10.210′	079° 50.592′	1.57	11.30a.m.	8.17	8.12	30.5	30.5	9.0	24.8	4.48	13.426
6A	07° 8.838′	079° 51.252′	1.35	11.40a.m.	8.03	7.93	31.0	30.5	9.0	18.1	4.436	9.525
7	07° 08.383′	079° 50.716′	1.17	11.45a.m.	7.66	7.62	31.0	30.5	5.9	11.5	2.823	5.831
8A			1.25	12.20p.m.	6.90		30.5		1.8		0.813	
8	07° 02.618′	079° 51.772′	1.27	7.00p.m.	7.04		30.0		2.1		0.966	
9A			0.73	12.10p.m.	7.33		30.0		0.2		0.09	
9	07° 04.814′	079° 53.444′	2.21	6.25p.m.	6.53		29.5		0.2		0.09	
10A			1.92	12.00noon	7.80		29.5		0.8		0.357	
10	07° 06.588′	079° 52.964′	4.98				28.5		0.2		0.092	

Sampling Point No.	Total Nitrogen (mg/l)		Nitrates - N (mg/l)		Ammonia - N (mg/l)		Total Phosphorous (mg/l)		Phosphate - P (mg/l)		COD (mg/l)		Total dissolved solids (mg/l)	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
1	3.28		0.037		0.128		14.90		2.68		78.84			
1A	8.52		0.037		0.093		403.6		1.34		74.46			
2	10.35										48.62			
2A	14.40										39.78			
2B	12.40										12.71			
3	23.05										48.62			
4	12.66	9.54	0.043	0.051	0.096	0.122	207.3	4.4	0.00	7.20	48.18	66.30		
5	11.43	10.13	0.028	0.045	0.125	0.140	6.3	553.4	0.41	8.00	51.28	286.32		
6	14.17	11.37	0.029	0.050	0.129	0.099	17.8	12.3	6.59	8.95	89.75	397.44		
6A	16.12	13.01	0.027	0.028	0.096	0.089	431.2	641.8	4.94	28.40	61.88	274.00		
7	3.75	3.40	0.152	0.132	0.089	0.132	370.4	368.9	8.34	45.18	17.68	114.90		
8A	28.24		0.165		0.167		831.8		14.92		44.20			
8	1.03		0.091		0.220		546.6		45.29		65.70			
9A	6.26		0.181		0.135		540.3		12.35		30.94			
9	11.15		0.166		0.133		459.5		7.10		4.38			
10A	7.87		0.156		0.111		525.6		15.44		21.37			
10														

A 8 Project: Water Quality of Negombo Lagoon.
Sampling Date:7 November,2002 3.10 p.m.-7.00 p.m.

Sampling Point No.	Coordinates of each Point		Depth (m)	Time	pH		Temperature (^{0}C)		Conductivity (ms/cm)		Salinity (ppt)	
	N	E			top	bottom	top	bottom	top	bottom	top	bottom
1	07^0 12.644^1	079^0 49.493^1	4.98	3.10p.m.	8.44		31.0		30.1		16.435	
1A	07^0 12.492^1	079^0 49.500^1		3.15p.m.	8.49		31.0		31.9		17.519	
2	07^0 12.186^1	079^0 49.832^1	3.45	3.17p.m.	8.36		31.5		29.2		15.738	
2A	07^0 11.868^1	079^0 49.776^1	1.5	3.30.m.	7.57		31.0		28.0		15.181	
2B	07^0 11.256^1	079^0 49.818^1	1.85	3.35p.m.	8.37		31.0		21.3		11.258	
3	07^0 12.460^1	079^0 50.224^1	1.02	3.23p.m.	7.70		31.5		8.4		4.079	
4	07^0 10.796^1	079^0 49.910^1	1.63	3.40p.m.	8.40		31.0		20.3		10.683	
5	07^0 10.366^1	079^0 50.247^1	1.29	3.45p.m.	8.43		31.0		31.1		17.036	
6	07^0 10.210^1	079^0 50.592^1	1.57	3.50p.m.	8.34		31.5		15.1		7.671	
6A	07^0 8.838^1	079^0 51.252^1	1.35	3.55p.m.	8.29		31.0		13.9		7.084	
7	07^0 08.383^1	079^0 50.716^1	1.17	4.02p.m.	7.99		31.5		11.4		5.663	
8A			1.25	4.40p.m.	7.11		31.0		0.9		0.392	
8	07^0 02.618^1	079^0 51.772^1	1.27	7.00p.m.	7.04		30.0		2.1		0.966	
9A			0.73	4.25p.m.	6.86		29.0		0.2		0.091	
9	07^0 04.814^1	079^0 53.444^1	2.21	6.25p.m.	6.53		29.5		0.2		0.09	
10A			1.92	4.15p.m.	7.93		29.0		0.1		0.049	
10	07^0 06.588^1	079^0 52.964^1	4.98	6.15p.m.	6.26		28.5		0.2		0.092	

Sampling Point No.	Total Nitrogen (mg/l)		Nitrates - N (mg/l)		Ammonia - N (mg/l)		Total Phosphorous (mg/l)		Phosphate - P (mg/l)		COD (mg/l)		Total dissolved solids (mg/l)	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
1	4.80		0.042		0.085		0.422		0.0036		43.80			
1A	10.65		0.039		0.089		0.7204		0.0069		67.80			
2	9.56										152.54			
2A	12.10										67.80			
2B	9.95										84.75			
3	15.17										13.04			
4	2.20		0.050		0.111		0.0085		0.0043		99.82			
5	1.40										273.90			
6	0.42		0.082		0.081		0.571		0.00216		147.56			
6A	0.77										243.48			
7	0.85		0.034		0.095		0.3064		0.00391		78.26			
8A	1.40		0.145		0.128		0.3158		0.01276		21.90			
8	1.03		0.091		0.220		0.5466		0.04529		65.70			
9A	19.70		0.380		0.100		0.5137		0.08717		4.38			
9	11.15		0.166		0.133		0.4595		0.0071		4.38			
10A	18.25		0.282		0.148		0.5345		0.01441		4.35			
10	15.30		0.288		0.085		1.0276		0.01163		13.14			

A 9: Water quality of Negombo Lagoon (2nd January 2003)

Sampling Point No.		1	2	3	4	5	6	7	8	9	10
Coordinates of each point	N	07⁰ 12.644'	07⁰ 12.186'	07⁰ 12.460'	07⁰ 10.796'	07⁰ 10.366'	07⁰ 10.210'	07⁰ 08.383'	07⁰ 02.618'	07⁰ 04.814'	07⁰ 06.588'
	E	079⁰ 49.493'	079⁰ 49.832'	079⁰ 50.224'	079⁰ 49.910'	079⁰ 50.247'	079⁰ 50.592'	079⁰ 50.716'	079⁰ 51.772'	079⁰ 53.444'	079⁰ 52.964'
Depth (m)		4.98	3.45	1.02	1.63	1.29	1.57	1.17	1.22	1.95	4.94
Time		11.24 am	11.44 am	11.58 am	12.26 pm	12.36 pm	12.47 pm	1.07 pm	4.17 pm	3.43 pm	3.37 pm
pH	Top	8.46	8.38	8.20	8.41	8.30	8.36	8.32	7.13	6.42	6.86
	Bottom	8.20	8.28	8.27	8.32	8.36	8.29	8.53	7.07	6.41	6.81
Temperature (^0C)	Top	26.8	27.1	28.3	28.1	28.0	28.5	28.9	29.5	28.6	29.1
	Bottom	28.3	27.2	28.2	27.5	27.7	27.9	27.9	29.8	28.8	27.9
Conductivity (mS/cm)	Top	58.6	52.0	58.2	43.1	35.8	34.2	14.4	6.4	0.2	0.4
	Bottom	58.6	55.4	58.8	58.8	54.2	56.6	23.4	6.4	0.2	0.5
Salinity (ppt)	Top	37.6	32.7	36.1	25.9	21.2	19.9	7.7	3.2	0.1	0.2
	Bottom	37.6	35.0	36.5	37.0	33.8	35.3	13.3	3.2	0.1	0.2
Total Nitrogen (mg/l)		0.98	0.15	0.95	0.18	0.30	0.43	2.00	5.02	0.30	0.40
Nitrates – N (mg/l)		0.04	0.04	0.04	0.04	0.04	0.06	0.09	0.12	0.26	0.28
Ammonia – N (mg/l)		0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.05
Total Phosphorous (mg/l)		0.06	0.05	0.05	0.06	0.08	0.08	0.10	0.10	0.06	0.06
Phosphate – P (mg/l)		0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.02	0.01	0.02
COD (mg/l)		40	48	65	69	36	20	22	8	8	16
BOD_5 (mg/l)		10	20	30	35	8	14	12	6	4	9
Total Coliforms In 100ml (MPN)		300	270	16000	17	50	11	17	340	16000	9000
Faecal Coliforms In 100ml (MPN)		80	70	170	2	4	2	4	90	220	170
Total dissolved solids (mg/l)		42950	40135	43735	42880	34430	27010	9695	2415	115	280

A 10 : Water quality of Negombo Lagoon (10^{th} February 2003)

Sampling Point No.		1	2	3	4	5	6	7	8	9	10
Coordinates of each point	N	07^0 12.644^1	07^0 12.186^1	07^0 12.460^1	07^0 10.796^1	07^0 10.366^1	07^0 10.210^1	07^0 08.383^1	07^0 02.618^1	07^0 04.814^1	07^0 06.588^1
	E	079^0 49.493^1	079^0 49.832^1	079^0 50.224^1	079^0 49.910^1	079^0 50.247^1	079^0 50.592^1	079^0 50.716^1	079^0 51.772^1	079^0 53.444^1	079^0 52.964^1
Depth (m)		4.70	3.45	1.02	1.57	1.52	1.47	1.29	1.27	2.21	4.98
Time		11.37 am	11.48 am	12.01 pm	12.14 pm	12.26 pm	12.36 pm	12.53 pm	3.52 pm	3.16 pm	3.03 pm
pH	Top	8.30	7.46	8.28	8.24	8.20	8.19	7.97	6.96	6.60	6.71
	Bottom	8.22	8.76	8.20	8.09	8.03	8.12	7.80	7.39	6.59	6.71
Temperature (^{0}C)	Top	29.7	29.5	29.3	29.2	29.2	29.5	30.3	31.6	30.6	29.8
	Bottom	29.6	29.4	29.7	29.5	29.7	30.1	29.6	32.0	31.3	30.0
Conductivity (mS/cm)	Top	58.7	35.3	51.3	42.2	31.9	27.7	7.6	9.0	0.1	0.1
	Bottom	58.7	57.9	51.5	46.3	42.6	33.4	16.3	9.6	0.1	0.1
Salinity (ppt)	Top	35.6	20.2	30.7	24.8	18.2	15.5	3.8	4.4	0.1	0.1
	Bottom	35.6	35.1	30.7	27.3	24 .8	18.8	8.7	4.7	0.1	0.1
Total Nitrogen (mg/l)		3.50	0.56	0.59	0.23	0.18	0.26	0.28	0.36	0.22	0.86
Nitrates – N (mg/l)		0.09	0.04	0.06	0.06	0.04	0.04	0.08	0.07	0.19	0.10
Ammonia – N (mg/l)		0.00	0.49	0.00	0.01	0.00	0.00	0.00	0.15	0.00	0.00
Total Phosphorous (mg/l)		0.34	0.26	0.07	0.28	0.48	0.09	0.21	0.18	0.06	0.09
Phosphate – P (mg/l)		0.01	0.12	0.01	0.01	0.09	0.03	0.03	0.02	0.01	0.01
COD (mg/l)		47	32	48	60	27	39	24	31	35	35
BOD_5 (mg/l)		15	15	36	28	16	21	15	16	20	25
Total Coliforms In 100ml (MPN)		500	9000	500	17	13	8	17	500	5000	2200
Faecal Coliforms In 100ml (MPN)		70	110	140	4	< 2	< 2	< 2	70	140	140
Total dissolved solids (mg/l)		34860	25620	26470	19990	19360	14360	5170	3710	100	470

A 11: Discharges of Hamilton Canal (8A), Ja-ela (9A) and Dandugam-Oya (10A) on Day 2 (25 September 2002, Day 3 (15 October 2002) and Day 4 (7 November 2002). These values have been extracted from MIKE 21 model of the CRMP project.

Time	Day 2			Day 3			Day 4		
	8A	9A	10A	8A	9A	10A	8A	9A	10A
0:00	-1.426	5.829	13.284	-1.065	7.93	30.545	-1.792	17.041	96.811
1:00	-1.177	2.189	4.438	-1.106	8.051	30.316	-1.354	13.816	91.118
2:00	-0.89	0.111	-6.769	-1.11	7.937	29.501	-0.843	11.123	84.55
3:00	-0.326	-0.068	-6.205	-1.048	7.457	27.866	0.287	6.582	76.529
4:00	0.709	-4.522	-6.022	-0.881	6.563	25.166	1.363	3.632	69.72
5:00	1.228	-5.117	-8.84	-0.684	5.946	23.867	1.736	3.454	65.544
6:00	1.445	-5.238	-9.062	-0.444	4.973	23.443	1.216	7.476	68.209
7:00	1.148	-2.528	0.459	-0.158	4.152	23.568	0.513	10.393	74.244
8:00	0.476	3.466	19.031	0.257	3.953	23.118	-0.704	12.65	80.511
9:00	-0.528	5.49	21.371	0.36	4.547	22.736	1.441	15.147	85.181
10:00	-1.074	7.101	19.312	0.52	5.892	23.527	-1.67	16.838	88.271
11:00	-1.245	6.972	17.311	0.019	8.828	27.983	-1.772	17.308	90.251
12:00	-1.3	6.408	14.943	-0.636	11.042	32.007	-1.791	17.056	90.879
13:00	-1.239	5.039	10.686	-0.995	12.803	34.332	-1.707	16.062	89.72
14:00	-0.864	1.161	-1.054	-1.165	14.169	34.842	-1.226	12.939	83.992
15:00	-0.41	0.311	-6.191	-1.244	15.244	34.881	-0.711	10.163	77.786
16:00	0.467	-2.867	-4.231	-1.327	16.297	35.233	-0.009	6.861	71.724
17:00	0.913	-3.916	-4.307	-1.409	17.26	35.949	0.561	6.75	69.077
18:00	0.913	-2.228	-1.232	-1.468	18.017	36.535	-0.287	10.061	73.03
19:00	0.059	3.301	13.725	-1.504	18.563	36.962	-1.057	12.43	77.575
20:00	-0.698	5.747	19.406	-1.519	18.872	37.382	-1.419	14.454	81.29
21:00	-1.117	6.801	17.881	-1.506	18.851	37.579	-1.62	15.708	84.366
22:00	-1.305	7.01	16.712	-1.423	18.35	37.172	-1.729	16.056	86.517
23:00	-1.4	6.846	15.604	-1.369	17.943	37.821	-1.77	15.846	87.498