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Lagoon Conservation
Case Study of Elephant Pass Lagoon

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Introduction

Often extensive agricultural activities give rise to over-abstraction and contamination of surface and ground water resources. At the same time, the ecology and biology of brackish lagoons is largely dependent on the quality and quantity of these water resources entering the lagoons. Brackish lagoons are highly complex environments and are home to a variety of marine species. Consequently, any disturbance or pollution of ecological systems can directly or indirectly lead to a temporary or permanent change in the community of many living species so that it may no longer encompass the optimum conditions for many of its constituent species.

Study Background

Elephant Pass lagoon in Sri Lanka has been used as a case study to understand and identify the processes influencing the ecology of lagoons. Elephant Pass lagoon, also known as Chundikkulam lagoon, is a large salt lagoon with some fringing mangroves and seagrass beds. This lagoon is situated in the Jaffna district lying between the peninsula and the mainland and to the east of the railway line at Elephant Pass, covering an area of 100 km^2.

Figure 1: Overview of Elephant Pass lagoon

The catchment area of the lagoon is over 1000 km^2 and is predominantly forest with rice fields, palms and coconut trees in the surrounding areas. Elephant Pass lagoon features an outlet to sea which is blocked by formation of sand bars in the dry season. It originally formed part of the Jaffna lagoon system and was well-recognised for its salt production as well as its

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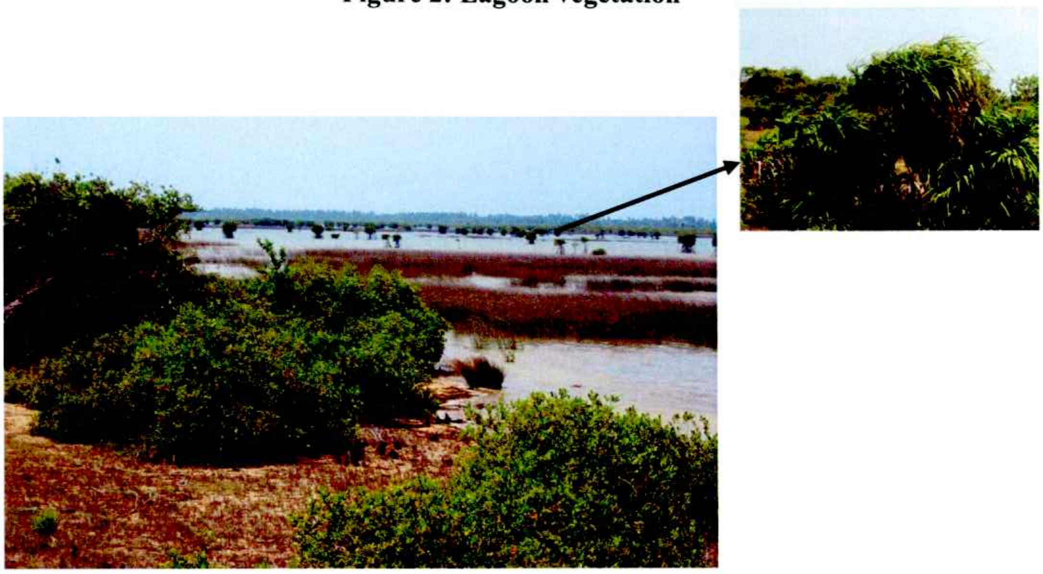
high quality prawn harvest. However, with the closure of the Elephant Pass causeway at its west end, the salinity of the lagoon has been dramatically reduced, and large areas dry out during the dry season.

Figure 2: Lagoon vegetation



Construction of the Elephant Pass causeway on the western part of the Elephant Pass lagoon has isolated it from the Jaffna lagoon. This has caused adverse impacts on the habitats of the lagoon, not only because it discontinued their migration to Jaffna lagoon, but also because of water quality changes. This has resulted from the fact that partially isolated lagoons are more susceptible to water quality changes as they have restricted water exchange with the sea or other water bodies. In this case, the water exchange between such water bodies becomes very poor so that any particles of contaminant mix inadequately with water and do not produce a dilute solution. Therefore, large concentrations of pollutants accumulate close to the shorelines which would have serious consequences on the ecology of the lagoon.

Lagoon Ecology

The lagoon is used for aquaculture and it is rich in prawns and fish species. Studies show that there are more than 73 species inhabiting in the Jaffna and Elephant Pass lagoons (University of Jaffna, Sri Lanka, 2007) which are predominantly estuarine species. These organisms are primarily classified according to their habitat preferences, with the majority of them belonging to either reef-associated or estuary-associated categories. Milkfish, *Chanos chanos,* and wolf herrings, *Chirocentrus dorab*, are two of the most commercially valuable fish inhabiting Elephant Pass lagoon. Further research confirms that these organisms typically exist along the coastal areas where reefs are fully developed and have to migrate to the sea at some stages of their life cycles. Therefore, the closure of the lagoon from the western side should be seriously reconsidered in order to prevent species loss and also to protect the ecosystem of the lagoon. The south-east region of the lagoon is designated as a bird sanctuary which features a wide range of waterfowl, including the species *Mycteria leucocephala*, *Threskiornis melanocephalus* and *Platalea leucorodia*. It is also an important place for migratory ducks, shorebirds, gulls and terns.

Study Objective

This study was concerned with the protection and management of the Elephant Pass lagoon with reference to nitrate and phosphate pollution. This paper aims to present suitable management techniques to protect lagoon ecosystem through the application of hydrodynamic and water quality models. The hydraulic and dispersion processes involved in distribution of water particles and water quality parameters are very complex. As a result, it was deemed necessary to employ a fully dynamic, three-dimensional model to simulate the spatial and temporal distribution of particles, including the movement and dispersion of buoyant plumes. The HYDRO-3D model was therefore used to simulate the hydraulic and water quality of the lagoon and to assess the extent of water pollution and the subsequent impacts on the aquatic resources of the Elephant Pass lagoon.

Hydraulic Modelling

HYDRO-3D is a suite of three-dimensional hydrodynamic and water quality models developed to investigate water quality in coastal systems, lakes, rivers and estuaries under a wide range of environmental conditions and engineering scenarios. It is a fully dynamic three-dimensional model and its ability to fully analyse the momentum interactions in all directions (especially in the vertical direction) sets it above many other commonly used three dimensional water quality models. The fine element/finite integral model suite has been jointly developed by Mott MacDonald and the University of Surrey and has been applied to over 30 schemes in more than 20 countries (Mott MacDonald, 2008).

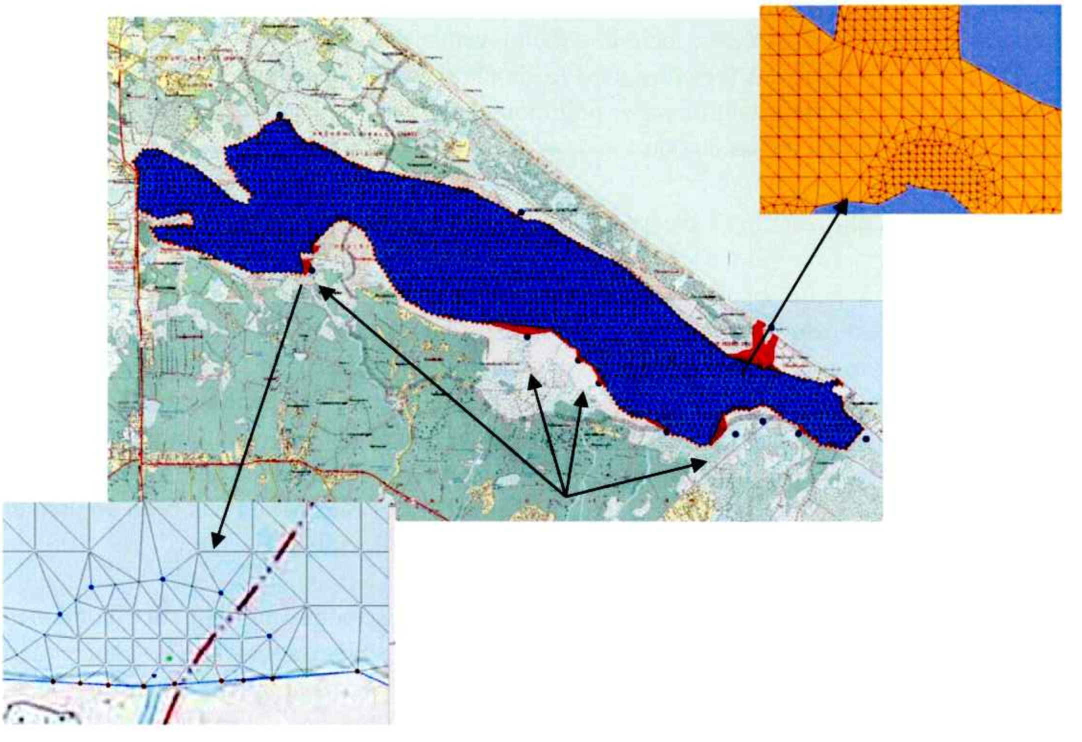
The hydraulic module of the model employs the Reynolds momentum equation combined with the Boussinesq approximation for simulation of turbulent stresses. The momentum equations are also included to account for the effects of density variations where the nodal densities are explicitly calculated at the beginning of each time step. The model also has the ability to simulate the movement of discrete buoyant particles, as well as the movement and dispersion of a buoyant plume. It can further model the spatial and temporal distribution of water elevation, current speed and direction as well as water quality parameters (Guganesharajah and Lloyd, 2007).

The water quality component of the HYDRO-3D model is based on the advection-dispersion equation and the characteristics finite integral method has been introduced to the model to advance its accuracy. HYDRO-3D has been developed with the adequate capacity to simulate a wide range of water quality parameters including temperature, salinity, ammonia, nitrate, nitrite, orthophosphate, organic nitrogen, organic phosphorus, dissolved oxygen, biological oxygen demand, algae and faecal and total coliform bacteria. The model can be also employed to study the effects of varying climatic conditions, such as temperature, humidity, cloud cover, wind speed and solar radiation, on the simulated area. Furthermore, the HYDRO-3D model utilises elements, which are generally tetrahedral in shape, to derive the numerical equations using the local co-ordinate system (L co-ordinate). The subsequent hydraulic and water quality parameters are simulated at the nodes or vertices of these elements.

Methodology

In this study, HYDRO-3D model was used to simulate the hydraulic and water quality of the Elephant Pass lagoon to assess the impacts of domestic and agricultural runoffs on lagoonal species. The model network was built using Micro-Fem to represent the lagoon configuration and carefully calibrated to ensure the simulation run would produce accurate results. To optimise the balance between run time and accuracy a balance of higher and lower resolution regions were used in the model. Fine resolutions (40 m to 50 m) were used near the river outlets and the main sea channel to accurately represent the near-field processes whilst larger resolutions (125 m) were used in less critical regions.

Figure 3: HYDRO-3D model network for Elephant Pass lagoon



Bathymetry information was derived from the Admiralty Charts (Admiralty Charts, 2007) and available field survey data. All of the bathymetry information was digitised into the ArcView GIS package and transformed into the model grid co-ordinate system. Where an overlap existed between the various information sources the more detailed information was used. Quality checks were carried out on the depth data to ensure that no appreciable differences were present between the two different information sources. A Triangulated Irregular Network (TIN) surface was created from the bathymetry sources and the surface converted to a fine grid. This model network was subdivided into four layers which contain five faces. The triangular prisms extended from the surface to the bed where each prism was further subdivided into six tetrahedral elements. The model was run for a 24 hour period to fully cover a semi diurnal tidal cycle and ArcView GIS was employed to extract the model outputs in the form of geographic views.

Model Input Data

Average monthly rainfall and surface runoff from Kanagarayan, Theravil, Piramenthal and Nethali rivers were used to estimate the inflows to the study area. The monthly rainfall information was based on the available data for the Pallai catchment area, which has been assumed to represent analogous meteorological characteristics to those of Elephant pass lagoon given that it is located in its vicinity. In addition, total runoffs from Kanagarayan, Theravil, Piramenthal and Nethali river basins were determined based on the surface runoff and base flow estimated for each of the sub-catchments. The evaporation data employed in this estimation corresponds to the evaporation loss from Iranamadu reservoir. The tidal data were estimated based on information available for Trincomalee port considering that it is the closest seaport to the Elephant Pass lagoon (Shanmugarajah, 1993).

Extensive agricultural activities, sewage runoff and the disposal of domestic and industrial wastes into rivers are serious environmental threats to Elephant Pass lagoon. Of all the rivers discharging into the lagoon, Kanagarayan River contributes the largest amount of flow to the lagoon. Kanagarayan River has a catchment area of about 906 km^2 and is the main feeder stream to Elephant Pass lagoon. This river provides irrigation water to a great number of paddy fields and also receives untreated sewage and agrochemical effluents before flowing into the lagoon. It is therefore anticipated that the focal source of contamination originates from the river effluents discharging into the lagoon. This project investigates the water quality of Elephant Pass lagoon with reference to nitrate-N and phosphate-P concentrations exclusively at the Kanagarayan estuary. Due to the absence of a rigid and continuous water quality monitoring programme in the study area, the study did not include any of the past data. As an alternative, the input data for nitrate-N and phosphate-P concentrations were purely estimated from the reference values provided in the literature (Landon, 1991). In this estimation it was assumed that only 7% of the given nutrient loads enter into the Kanagarayan River in December. Table 1 details the literature values along with the estimated concentrations of nutrient loads which used for water quality simulation of the lagoon.

Table 1: Reference values and estimated concentrations of N and P in Kanagarayan River

Nutrient requirements for rice (paddy) provided by Landon (1991)		7% of reference values	Concentration of nutrients in Kanagarayan river
N	150 kg/ha	10 kg/ha	5.41 mg/l
P	40 kg/ha	3 kg/ha	1.62 mg/l

However, the reader should note that this work is a preliminary study and further investigation should be undertaken to verify the water quality data, particularly near the river outlets.

Special attention was given to the southern part of the lagoon, where all river outlets exist, and also the Chundikkulam channel on the eastern side of the lagoon. The hydrologic regime around this area was the main focus of the study and the model outputs were used for assessing the water quality of the lagoon. Velocity distributions were predicted for the southern and eastern parts of the lagoon and it was observed that the highest velocity occurred at the narrow channel of Chundikkulam. The flooding tide transports sands into the lagoon while sand is eroded when the tide ebbs. Of all river outlets, the highest water velocity occurred at the Kanagarayan river outlet. This is mainly because the Kanagarayan River is the largest stream, and the lagoon receives an average monthly inflow of 8.15 m^3/s from the river which is nearly ten times greater than that of the other three streams.

Model Results

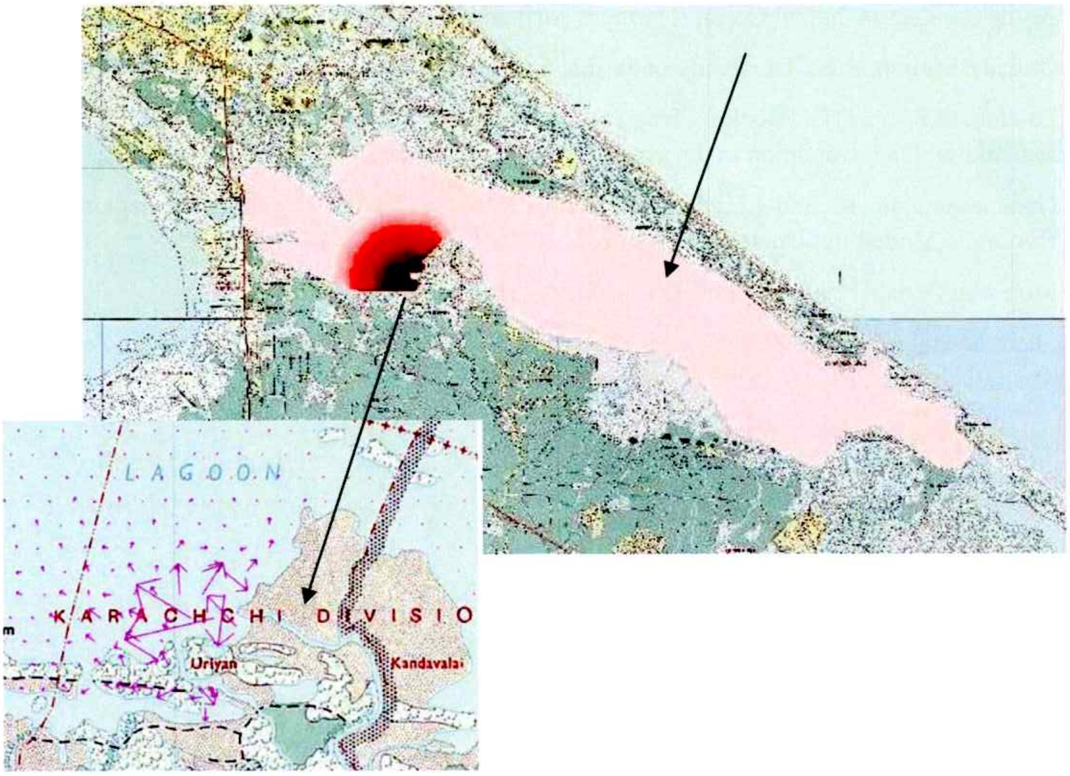
Hydraulic Modelling

The rapid variations of water pressure and velocity around the river outlets were found to create a turbulent flow regime at which unsteady vertices appear and interact with each other. This subsequently assists the mixing of particles in water and enhances the process of water aeration that can maintain adequate dissolved oxygen in water. Rapid variations in water velocity generate flow circulation and subsequently a strong turbulent regime in the vicinity of the Kanagarayan estuary. This is an important concept, particularly for the water quality analysis of the lagoon. Therefore, special attention should be given to the water quality of the Kanagarayan River as the river effluents discharge directly into the lagoon. Turbulent flows in water produce a pollution cloud that is diluted at first by the pollutant-free water and later by contaminated water returned by the large scale turbulent circulation pattern.

Water Quality Modelling

The HYDRO-3D model was employed to simulate the extent and dispersion of the nutrient contamination in the Elephant Pass lagoon. The simulated results associated with nitrate-N and phosphate-P concentrations were retrieved by the use of the post-processor ArcView. The analysis was conducted for the wet season (December) at which the surface runoff and rainfall intensity is the greatest. It was observed that the maximum nutrient concentrations occur at the Kanagarayan estuary where the river effluents enter to the lagoon; however, the intensity of pollutants decrease as particles enter the turbulent flow and start mixing with the pollutant-free water. The concentrations of nitrate and phosphate fall below 0.5 mg/l and 0.25 mg/l as they move away from the river mouth.

Figure 4: Examples of HYDRO-3D model outputs



Although this study does not account for the initial concentration of nutrients present in the lagoon, it is important to note that not all of the present pollution is contributed directly from the river. In fact, after extensive water evaporation during the dry season, a portion of nutrients settle down at the bottom of the lagoon bed and remain there until the wet period begins. By the start of rainfall events, the settled particles will become dispersed in water and transported into different directions depending on the water flow. It is also worth noting that the water quality information used for simulation of nitrate-N and phosphate-P are purely based on estimated values; therefore, the results are not entirely representing the true water quality state of the Elephant Pass lagoon

Conclusions and Recommendations

Water quality monitoring programmes are not presently available for the Elephant Pass lagoon but should be established with reference to nitrate, phosphate, dissolved oxygen, BOD5 and salinity. Additional monitoring locations are proposed for the southern shores of the lagoon given the fact that this part receives a relatively large quantity of discharge from numerous small rivers. Additional meteorological, topographical and water quality data should be collected from the study area to recalibrate the HYDRO-3D model. Recalibration of the model using actual data would create a more accurate model network, and consequently simulate output results that truly represent the situation of the lagoon. Furthermore, a fish corridor is proposed on the western side of the lagoon, to reconnect the Elephant Pass lagoon to the Jaffna lagoon. This will re-establish tidal flow on the western shores of the lagoon and also will allow fish migration between the two lagoons.

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