The Use of Geographic Information Systems for the Manipulation and Display of Coastal Data Collected at Invaders Bay, Trinidad

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Abstract

The Caribbean region due to the nature of its small island states and coastal cities is particularly vulnerable to issues such as sea-level rise and urban development that impact the marine-land interface. The regular collection of data in the coastal zone has proven to be a critical step towards monitoring and planning for the future. This study was carried out on a section of reclaimed land on the west coast of Trinidad and its seaward boundary known as Invaders Bay. Traditional surveying techniques and environmental sampling methods were used to collect data on; the topography and cross-section of the shoreline along with the bathymetry of the bay, water, sediments, tides, as well as current direction and current speed. The collected data was input into a Geographic Information System (GIS) for storage, analysis and display. Through the use of ArcGIS 9.0, the datasets were integrated for effective display and analysis. Interpolation methods were used to create continuous surfaces for the features represented by the point data. These were then utilized to detect any existing patterns in the related spatial phenomena. Temperature and salinity surfaces generated in this way revealed patterns that were uncharacteristic for the area but were explained through hypotheses based on existing variables. 3-Dimensional visualization techniques were used to develop and display both the topography and the bathymetry of the study sites based on the acquired data. Data from the beach survey delineating the coastline was mapped and overlain onto historical coastline data for the years 1980, 1986, 1994 and 2003 which were digitized from aerial photos. This method demonstrated the change in the morphology and extent of the coastline of the study area due to coastal reclamation over a period of 25 years (1980-2004).

Keywords: Geographic Information Systems, Manipulation and Display of Coastal data, Coastal Change Analysis, Invaders Bay Trinidad, ArcGIS 9.0.

1. Introduction

The Gulf of Paria of which Invaders Bay (see Figure 1) is a constituent, is a semi-enclosed sea that separates the island of Trinidad from the mainland of Venezuela and covers an area of approximately 5100 km^2 (Neale, 1995). It is generally shallow with a mean depth of approximately 25 m and is open to the oceanic regimes of the Caribbean Sea and the Atlantic Ocean only through narrow straits at its northern and southern boundaries. Such sheltered conditions has allowed the area to support commercial ports, industrialized coastal zones and heavy recreational usage. Indeed 90% of the Trinidad population live or work in the coastal area of the Gulf. Its physical oceanography is therefore of great social and economic importance to the bordering states (Neale, 1995). As a site of heavy hydrocarbon exploitation for the last fifty years the area is threatened by intense marine pollution. In recent years oil spills of varying magnitudes have highlighted the area's susceptibility to pollution and the need for increased

knowledge of its oceanographic conditions especially its surface circulation patterns and the effects of the tides. Salinity is the most important hydrographic signal in the Gulf of Paria. It is strongly affected by the seasonal variation in the freshwater discharge mainly from the Orinoco River with some influence from local riverine systems. The largest contribution is from the Caroni River with an average annual mean discharge of 13.3 m^3 /s. During the dry season when the Orinoco flow is low, most of its discharge flows northward along the South American coast and enters the Gulf of Paria en route to the Caribbean Sea (Muller-Karger *et al.* 1994). It may be reasonable to assume that during the wet season even larger volumes enter the Gulf of Paria. The Orinoco River has a mean discharge of 33,950 m^3/s (Lerman, 1980). The need for collecting oceanographic data for this area is highly justified by the constantly evolving conditions and their impacts on society, the economy and the environment. Burrough and McDonnell (1998) define a GIS as a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular purpose. The common attribute of each data set is its geographic positioning. Oceanographic and coastal datasets have in recent times been displayed and visualized using GIS with great success. The display and visualization properties of a GIS are immense and give the user a well informed perspective of the data. The GIS can be used not only for display and visualization but once the data is stored with proper geographic referencing, it can be used to meet user defined queries, or perform analyses for development or any other purpose that may arise.

Figure 1: Photograph of Invaders Bay, Trinidad

2. Objectives

- To collect data from the coastal environment through the use of traditional coastal surveying and environmental sampling techniques
- To input this data into a Geographical Information System for effective display and analysis.
- To use the results of the analysis to illustrate for the study area, any trends or changes that may be occurring that may impact sustainable development and/or the natural environment.

3. Data Collection and Display

Data collection took place over a course of six days commencing from Sunday 21st November 2004 and ending on Friday 26th November 2004, with different datasets being recorded on different days. A brief outline of the data collection and manipulation procedures employed is given.

3.1   Topography

Data on topography was collected using a Real Time Kinematic (RTK) GPS System. This system consisted of two main components, one was a stationary base with an antenna and the other being hand held. The base was set up at a point on the site to be surveyed while the portable   component was carried by one of the members of the team as they traversed the area to be surveyed. As this was being done data on surface height above sea level (metres) and location in terms of Eastings and Northings were being recorded by the equipment at two second intervals. The data collected from this exercise was recorded in a table with columns showing Eastings, Northings and Height. The points which were recorded by the RTK GPS System were plotted in ArcGIS. These points were also manipulated in Surfer 8 to produce a 3 D representation of the topography (see Figure 2).
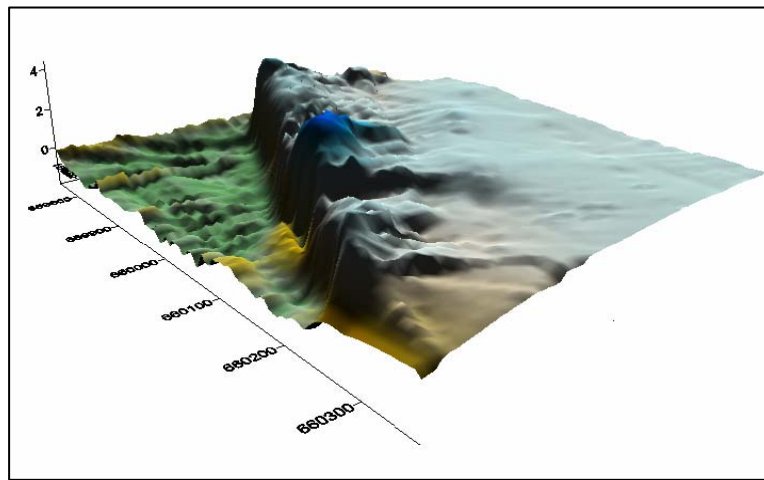

Figure 2: 3-D Representation of the Topography

3.2   Beach Profiles

Beach profiles were measured as height points relative to a base line. A basic surveyor's method of measuring profiles was used employing the use of instruments such as, Theodolite, Ruler, Staff, measuring tape etc. Heights were measured perpendicularly from the base line, every 5 metres out for a distance of 10 metres into the water or as far as was safely possible. The data collected from the beach survey was used to produce an AutoCAD drawing. This drawing showed the orientation of the profile lines to the baselines and was imported into ArcGIS. Heights recorded were plotted against distances recorded for each profile line and a graph showing the cross section of the beach (the profile) for each profile line was produced.

3.3   Bathymetry

Bathymetric data was collected using a single beam echo sounder. Depths were measured at a high frequency (200 kHz) to map the soft silt layer and a low frequency of 40 kHz to map the solid base layer. Locations at which the depths were measured were recorded by a Differential G.P.S. (D.G.P.S.) system. The boat was fitted with a motion sensor which served to detect the pitch and roll and make the appropriate corrections to the data and a compass with a digital output for direction. The final component of apparatus that was used to measure bathymetric data was a laptop computer with bathymetric software (Hypack Max) installed. The function of the computer was to receive and process data from all the other components into a collective form for viewing. An area of 0.64 km^2 was surveyed using the bathymetric equipment previously outlined. Data was collected along run lines that were both parallel and

perpendicular to the coastline, each runline being 50 metres from its neighbour. The locational data from the bathymetric survey was mapped using the W.G.S. 84 coordinate system and had to be transformed to the local projection system of Naparima 1955. This was done using Geocalc software and the corresponding transformation parameters. This newly transformed dataset was then input into ArcGIS as a point layer showing the locations where the data was collected. The point layer for the low frequency (solid seabed) data set was then manipulated using a Spline Interpolation in the 3-D analyst extension of ArcGIS to produce a contour map showing change in depth (Figure 3). A 3-D representation of the bathymetry was also generated using Surfer 8 (Figure 4).
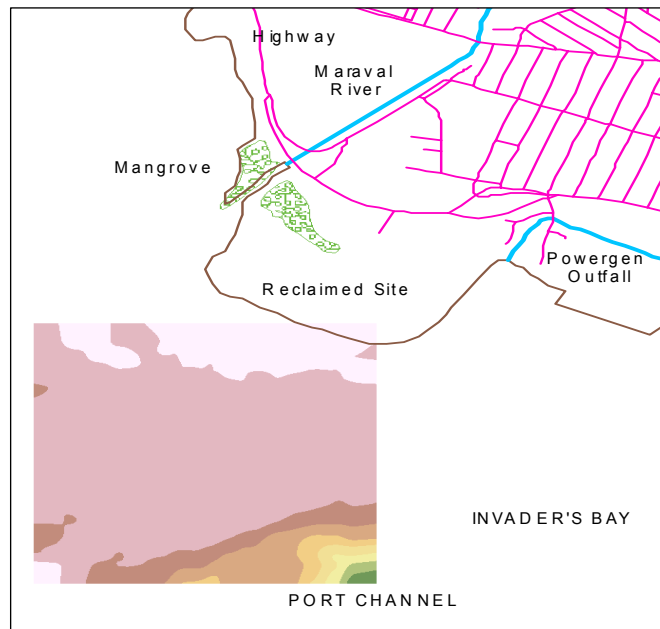

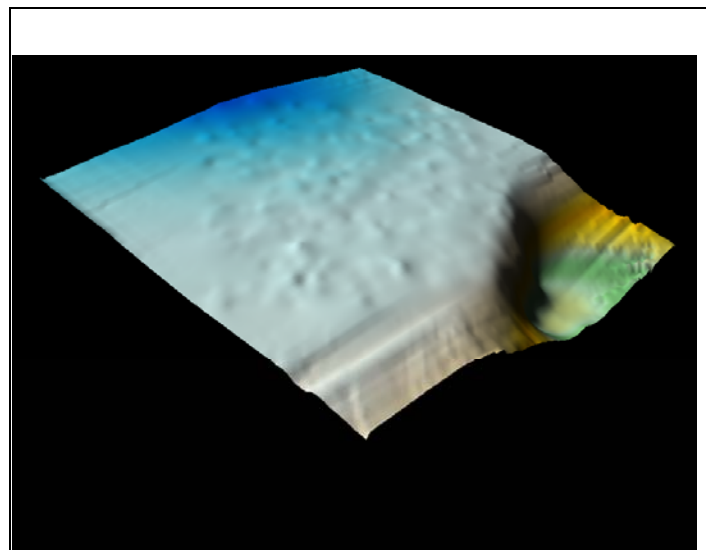**Figure 3: Contour Map Illustrating Change in Depth.**

Figure 4: 3-D Model of the Bathymetry

3.4   Currents

Two data collection methods were utilized for current measurements. The first was the La Grangian Method, a cheap method which employs the use of a drogue. A drogue is simply a float which is placed on the water with some sort of vane affixed below it at a specific depth to induce the force of the current. The motion of the drogue is observed and its location recorded at specific time intervals to produce a plot of its path over a period of time. The drogues that were used in this exercise were fixed at different depths, with drogue 1 being set the highest in the water column and drogue 5 the lowest. Drogue chasing exercises were carried out on two separate days. The second method of current measurement engaged an Eulerian technique which measures the flow of the water current past a point, the point being the current meter. The current at the site was recorded using a type of current meter called an Acoustic Doppler Current Meter (A.D.C.P.). Doppler current meters observe variation in frequency due to movement of the medium in which an acoustic signal is traveling. Current was measured using the A.D.C.P. by simply lowering the probe into the water to the required depth and taking a reading.

Data on current speed and direction recorded by the A.D.C.P. was displayed in Time Series graphs (e.g Figure 5). Rose diagrams depicting the current direction were also produced. A rose diagram was drawn for each set of current direction values recorded, for each time, for each depth (e.g. Figure 6). The diagrams were then grouped according to depth, such that each grouping showed how current direction changed with time at each depth. This method of display is a deviation from the conventional time series graphs for current direction, as it gives a better visual perspective of the data and the actual current directions since the rose diagrams are drawn on a 360 degree circle representing direction.
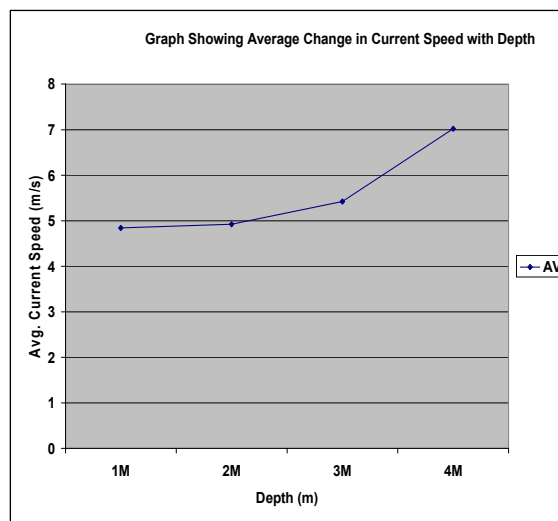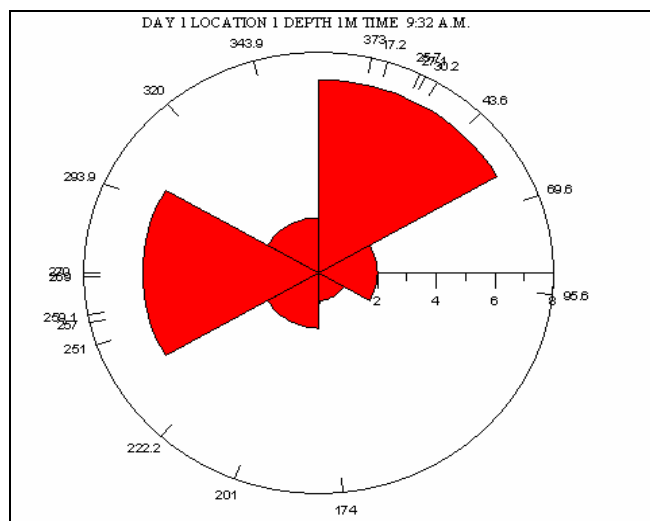

Figure 5: Graph Illustrating Current data   **Figure 6: Rose Diagram**

3.5   Temperature and Salinity

Temperature and salinity values were recorded using an YSI Temperature/Salinity meter. The instrument consisted of a probe and a display screen. The probe was simply placed into the water at the different depths and the readings for temperature and salinity read off the screen. Location was taken simultaneously with the temperature and salinity readings using a hand held G.P.S. The locational data that was recorded with the temperature and salinity values was plotted in ArcGIS as two point layers. Surface temperature and surface salinity values were extracted from the raw data and added as attributes to the respective attribute tables of the point layers. The point layer containing the temperature values was then manipulated using a Krige interpolation in the 3 D analyst extension of ArcGIS to produce a contour

map showing change in surface temperature (Figure 7). The point layer containing the surface salinity values was then manipulated using an I.D.W. interpolation to produce a contour map showing change in surface salinity (Figure 8).
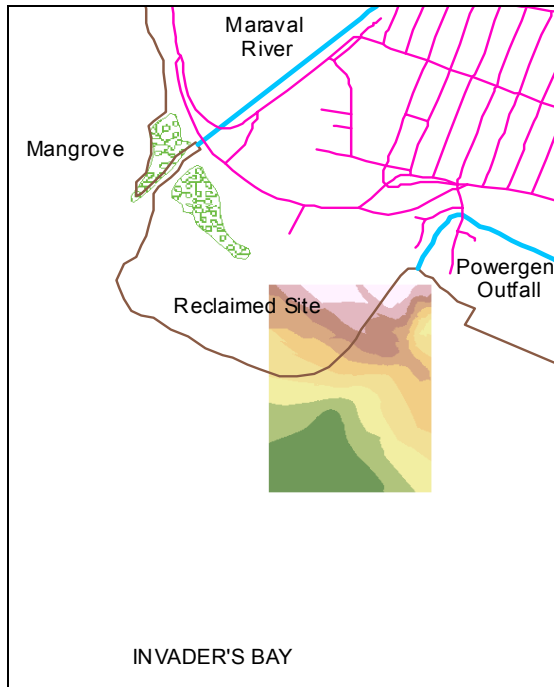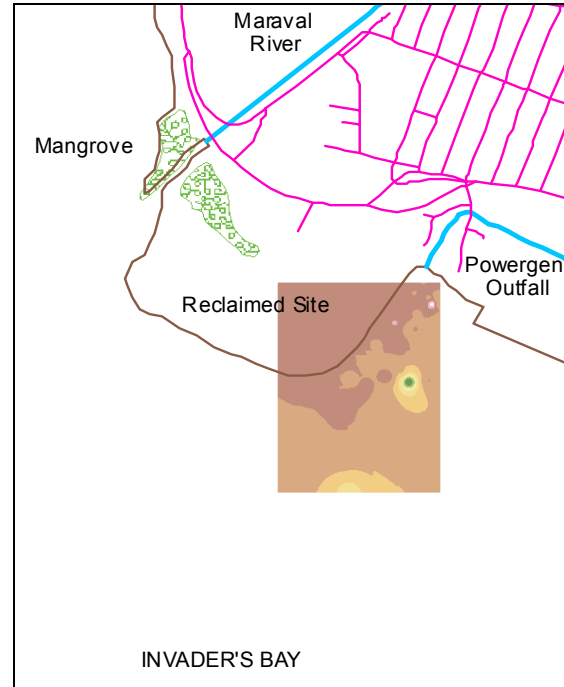

Figure 7: Surface Temperature Contours

Figure 8: Surface Salinity Contours

3.6   Water and Sediments.

Water and sediment samples were collected using, a Niskin Water Sampler and a Van Veen Grab respectively. Both these instruments work on basically the same principle, i.e. they are lowered into the water in the open position then shut from onboard the vessel via an automatic device, thereby trapping the water or sediment that is in the apparatus and then brought back up onboard using a rope. The apparatus is of a fixed volume so the sample usually represents a fixed amount of the matter. Once safely onboard, the equipment is opened and the sample is transferred into a sample jar for analysis. The water and sediment samples collected during the field week were analyzed at labs at the University of the West Indies. Tests were done on the water samples for levels of fecal coliform, Total Petroleum Hydrocarbons (TPH), Lead (Pb), Iron (Fe) and Zinc (Zn). The location of each water and sediment sample taken was also recorded, using a hand held GPS. The G.P.S. data for the samples was input into ArcGIS and displayed as a point layer showing all the locations of each of the water and sediment samples. Data received from the laboratory analyses was then added via the attribute table of each sample point. Display of the level of chemical or biological pollutant present at the sample point would be achieved via the identify button in ArcGIS.

3.7   Tides

Tidal data was collected using a Valeport 740 tide gauge which was attached to a jetty at the Port of Spain Harbour. Data was collected over a period of two days. On day one tidal heights were measured from 8:00 a.m. to 11:00 p.m. while on day two they were measured from 7:00 a.m. to 2:00 p.m. The tidal data that was recorded was plotted as Time/Series graphs showing changes in tidal height with time for both periods (e.g. Figure 9).
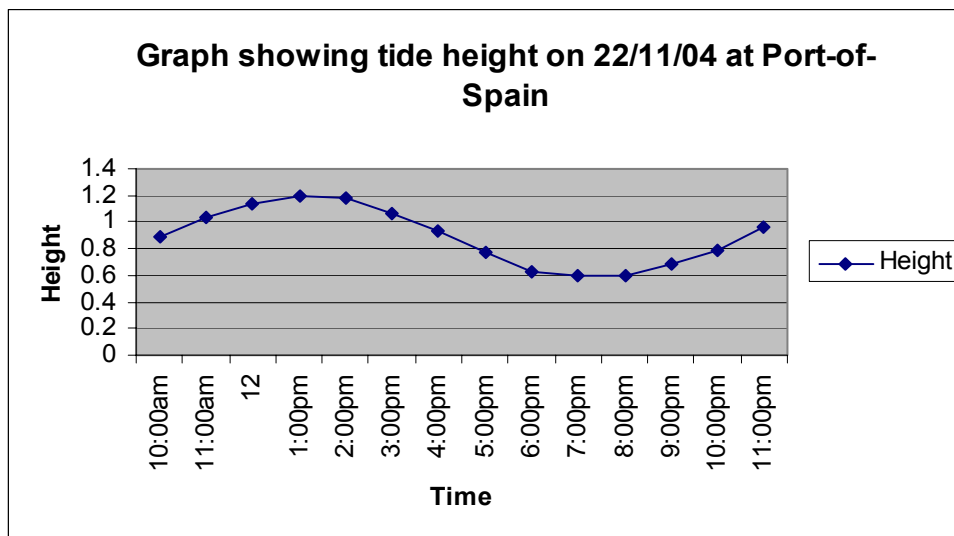
Graph showing tide height on 22/11/04 at Port-of-Spain

Height

1.4
1.2
1
0.8
0.6
0.4
0.2
0

10:00am 11:00am 12 1:00pm 2:00pm 3:00pm 4:00pm 5:00pm 6:00pm 7:00pm 8:00pm 9:00pm 10:00pm 11:00pm

Time

◆ Height

Figure 9: Graph Showing Daily Fluctuation in Tide.

4. Findings and Conclusions

This study examined the display and analysis functions of Geographical Information Systems (G.I.S.) through an application to the coastal environment. Data that was collected from beach and marine surveys was integrated into ArcGIS 9 for display. The storage and display of the data through the use of G.I.S. was effortless, uncomplicated and highly effective. The G.I.S was able to manage and store the data in such a way that its display and visualization was straightforward. The G.I.S was capable of storing each dataset in a separate layer with proper geographic referencing such that a single layer could be overlain on any other layer for display and analysis. The overlay function is one of the chief functions of a G.I.S and was used extensively and successfully throughout the data manipulation. A brief outline of the critical spatial trends revealed through a preliminary analysis of the data collected, using tools available within the GIS, is given here.

The topography of the area surveyed was shown to be relatively flat with a fall in the terrain representing the drop from the berm to the water's edge. The 3-D representation of the bathymetry gave a clear impression of the form of the seabed of the study area which was shown to be relatively flat with a sharp drop at one corner. This could have been attributed to the port channel due to the close proximity of the study area to the city port. The map showing surface temperature contours indicated that temperature values close to the Powergen (local power company) outfall were high (approx. 35^0 C) but gradually decreased as you moved seaward. This was anticipated as the water from the outfall was wastewater that was used for cooling power systems and was at a high temperature. The map showing surface salinity contours illustrated a decrease in salinity values in a seaward direction. This was not expected and could have probably been due to the influence of a major river, the Caroni River which empties into the Bay. The results obtained from laboratory analyses on the chemistry of the water and sediment samples showed that levels of the metals tested for, were all below the detection limit. The results of the biological tests which tested for fecal coliform concentration showed surprisingly low levels. Standards outlined in the World Health Organization (W.H.O) "Bathing Water Criteria for Sewage Contamination" show that these levels were acceptable. The low levels of fecal coliform could have been attributed to the nature of the water from the Powergen outfall. The high temperature would more than likely have affected the proliferation of bacteria in the environment. Also, about 91 to 94 percent of coolant is glycol almost always ethylene glycol (EG), this compound gives the coolant its green colour and performs the heat transfer and boiling/freezing protection functions, it is also highly toxic to microorganisms (Richards,

2004).Figure (10) illustrates the change in the landform of the study area, due to coastal reclamation, over a period of 25 years (1980-2004). The display was produced by overlaying layers of coastline digitized from 1980, 1986, 1994 and 2003 aerial photographs of the area, together with baseline data collected from the beach survey for the shape of the coast. From the diagram it can be clearly seen how coastal reclamation has changed the morphology of the defined portion of coastline during the 24 year period. An additional layer showing the existence of the current road network for the area was included to emphasize the magnitude of the reclaimed area.
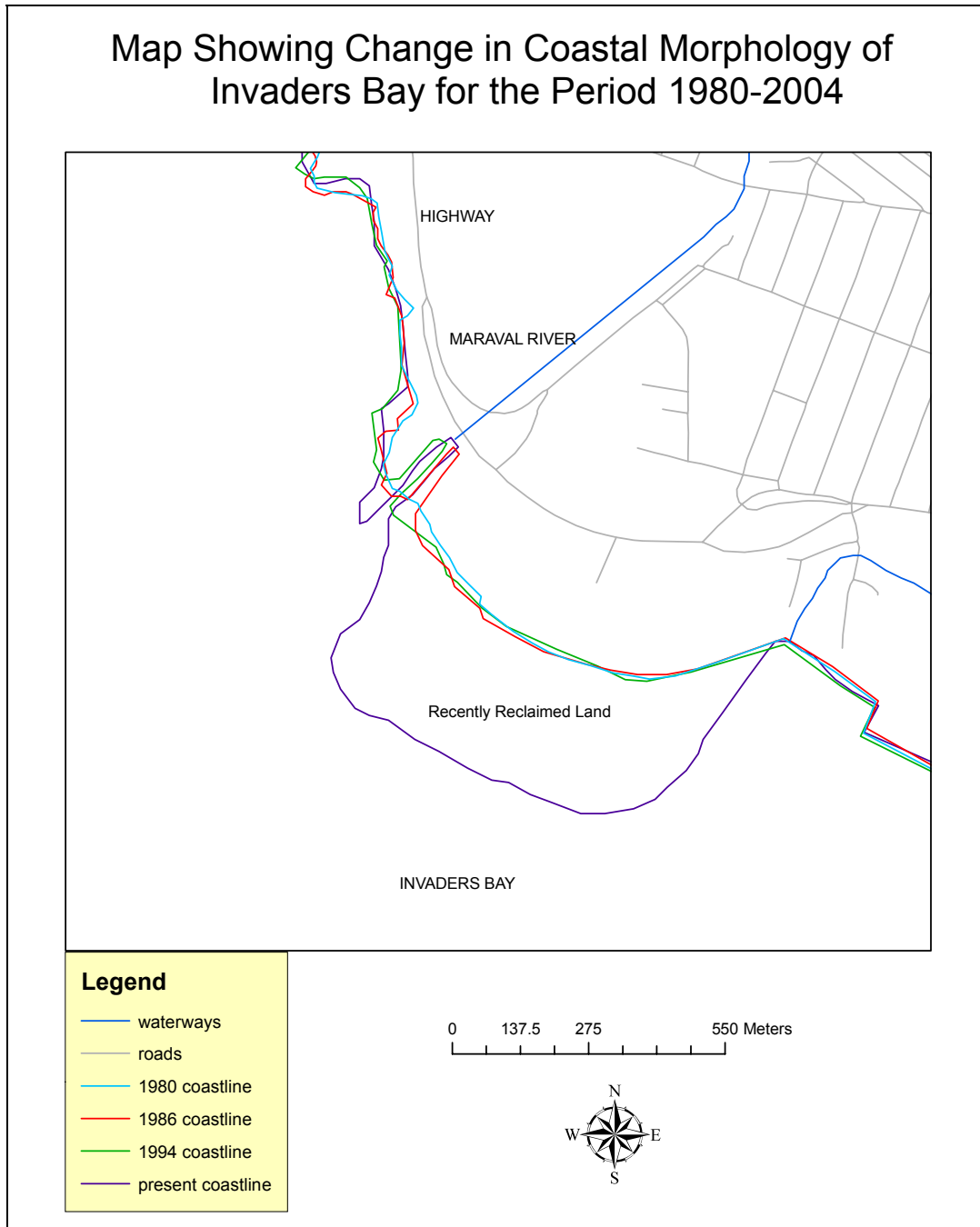

Map Showing Change in Coastal Morphology of Invaders Bay for the Period 1980-2004

HIGHWAY

MARAVAL RIVER

Recently Reclaimed Land

INVADERS BAY

Legend
— waterways
— roads
— 1980 coastline
— 1986 coastline
— 1994 coastline
— present coastline

0   137.5   275   550 Meters

N
W   E
S

Figure 10: Map Illustrating the Change in Coastal Morphology of Invaders Bay For the Period 1980-2004

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