5TH MANCO 96

GIS APPLICATION FOR SHORELINE MANAGEMENT

By
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Department of Irrigation and Drainage Malaysia

The Pan Pacific Resort
Pangkor Island
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1 Introduction

1.1 Malaysia is situated between latitudes 1° and 7° north and longitudes 107° and 119° east. It comprises two regions, Peninsular Malaysia and the States of Sabah and Sarawak (collectively referred to as East Malaysia) on the northern part of the Borneo Island, which are separated by 640 km of South China Sea. The total land area is 330,400 km^2 while the shoreline totals approximately 4,809 km. More then 90% or, 4,300 km of the shoreline is erodible alluvium. Sandy coasts are along the shoreline of east peninsula Malaysia, Sarawak and several stretches of west peninsula Malaysia such as Penang, Port Dickson and Malacca. Coasts of clay, mud and silt etc. are distributed along the shoreline of west peninsula Malaysia and Sabah.

1.2 The coastal zone of Malaysia has a special socii-economic significance. It supports a large percentage of the population (about 70%) and it is also the centre of economic activities encompassing urbanisation, agriculture, fisheries, aquaculture, oil and gas exploitation, transportation and communication, recreation, etc. In response to the increasingly serious problem of coastal erosion in many parts of the country that threatens the livelihood and property of the coastal communities of Malaysia, the Government of Malaysia commissioned the National Coastal Erosion Study (NCES) in 1984. The study which was completed in 1986 revealed that of the 4,809 km of shoreline in Malaysia, about 1,390 km (29%) were subjected to erosion of varying degrees of severity. Based on the consideration of the rate and imminence of erosion and the economic values of the human activities threatened, coastal erosion sites have been classified into the following three groups as follows:

a) *Category 1 - Critical*
Areas suffering from coastal erosion where shore-based facilities are in imminent danger of loss or damage;

b) *Category 2 - Significant*
Areas where shore-based facilities are expected to be endangered within 5 to 10 years if no remedial action is taken; and

c) *Category 3 - Acceptable*
Erosion areas that are generally undeveloped with consequent minor economic loss if erosion continues unabated.

1.3 In cognizance of the consequences of coastal erosion which has become an important economic and social issue, the Government of Malaysia has since 1987 adopted a two-pronged strategy (short term and long term) for the control of coastal erosion as recommended by the NCES. The main objective of the short term strategy which is construction focused and reactive in nature is to protect existing facilities and properties in the Category 1 or Critical Erosion Areas subjected to the test of economic viability. The long term strategy, on the other hand, is management focused and aims to obviate the need for expensive protective works in the future. This is achieved by according due consideration to the consequences of coastal erosion in the planning and development of projects within the coastal zone through an integrated and coordinated development strategy and plan. The short-term plan hence requires structural solutions such as the construction of sea-walls, revetments, breakwaters, sand nourishment etc., whilst the long-term plan aims to control coastal erosion and its negative impact through instituting non-structural measures such as land use planning and control.

1.4 Following the completion and recommendation of the NCES, the Government acted promptly in 1987 to create and develop suitable institutions to oversee, to coordinate and to implement the strategies and proposals under the coastal erosion control master plan. This included the establishment of the National Coastal Erosion Control Council (NCECC) and the Coastal Engineering Technical Centre (CETC) in DID. The National Costal Erosion Control Council which is under the coordination of the Prime Minister's Department coordinates coastal erosion control programs and formulate policy for the management and development of the coastal zone involving the Federal and State Governments, and the private sector.

1.5 The Department of Irrigation and Drainage was given the responsibility of setting up the *CETC* which is presently also known as the *Coastal Engineering Division (CED)* of DID. The CED is responsible for the following:

a) To implement coastal erosion control works for critical erosion areas. This includes planning, feasibility studies, detailed design, construction supervision and monitoring the performance of completed works.

b) To provide technical support to the NCECC.

c) To provide technical advisory services to other government departments and agencies in the processing of development applications in the coastal zone.

d) To maintain a coastal engineering database to support the planning and design of coastal engineering works in the country.

2 Background

2.1 An Asian Development Bank (ADB) Technical Assistance Project entitled "Institutional Strengthening for Shoreline Management" was implemented at the Coastal Engineering Division (CED) over a 24-month period from July 1994 to July 1996. It was piggy-backed to a sectoral loan (National Coastal Erosion Control Sector) for shoreline protection by the ADB to the Government of Malaysia. The total project cost is US$ 443,000 which includes US$ 120,000 for the procurement of equipment (computer hardware and software). The main objective of the project is to assist CED in enhancing its capability to move from an original construction oriented role towards a longer term goal of shoreline management to maintain sustainability. It was an initiative to foster effective shoreline management for sustainable development in the coastal zone through a shoreline management programme based on planning and management principles, and supported by project specific and comprehensive coastal engineering data. It included equipping CED with state-of-the-art management and analytical tools and the setting up of a data management system incorporating Geographical Information System (GIS) as the framework for integrating data involved in shoreline management which are diverse, including spatial data, time series data, social and economic data and multimedia information.

2.2 ADB awarded the TA project to the consultant, AGRA Earth & Environmental Ltd.,Canada in association with Mofatt & Nichol Engineers, USA which brought in the services of four specialists (One GIS Specialist, one Database Management Specialist, one Coastal Engineering Specialist and one Computer Modelling Specialist). In addition, for better coordination of the specialists' input, a Senior Coastal Environment Specialist from AGRA was assigned as the project team leader. CED provided counterpart staff and office facilities for the consultants for the whole duration of the project. In summary, the scope of works includes:

- To review the existing data collection programme and database management system (hardware, software and other related application systems) at CED and other relevant government departments and agencies.
- To identify the data required for effective shoreline management and develop a data collection program and database management system.
- To design and document a data model for implementation on GIS which takes account of the data available with the data collection programme, the data needs of the numerical and physical modelling tools at CED and present and future planning and design needs;
- To review, evaluate and procure system of hardware and software for the CED database and GIS management system;
- To train the counterpart staff in the development and operation of the database and GIS management system;
- To prepare and conduct training courses in coastal sediment and numerical modelling.

This paper is limited to highlighting the design of the functional model of the GIS system developed and implemented at CED and describes some of the results and achievements to date.

3 GIS System Design in General

3.1 GIS is basically a computerised system for spatial information collection, processing, storage, management, display, analysis and production. It basically consists of three components, namely hardware, software and database. The last component is usually the most important and costly. GIS can be utilized to support various stages of the modernized shoreline management. Data involved in shoreline management are diverse, including spatial data, time series data, social and economic data, and multimedia information. Examples of spatial data are shoreline positions, topographic data, bathymetric data, location of data collection stations, etc. The social economic and policy information is an equally important data category in coastal GIS, which is integrated with spatial data and used to support decision making. Time series data, for example wind and wave observations, can be integrated with spatial data through the locations of the sensors. The integration of the spatial data, time series data, coastal engineering modelling, environmental data, and social economic data in the GIS environment makes it possible to examine the current shoreline and coastal zone situations in terms of environmental, social, economic and other impact. Furthermore, it is an important system for decision making in shoreline and coastal zone management.

3.2 Hardware and Software Configuration

3.2.1 In assessing CED's needs, a review of current hardware and software systems at CED/DID was conducted. In addition, fact finding visits to most major GIS sites in Malaysia including PLUS, UTM, MACRES, PEGIS and DOE were made in order to provide an overview of GIS applications in Malaysia and to assess the possibility of cooperation. Taking into consideration experiences and lessons from local GIS sites and related projects, as well as compatibility and data transfer between agencies and the private sector, the hardware and software configurations shown in Figures 1 and 2 were suggested and implemented at CED. Basically the hardware and software configuration comprises of :

- Five Pentium Desktop Computers for GIS modelling and analysis, database management, digitising, engineering drawings and mathematical modelling. The computers are networked to facilitate communication between computers and peripherals in the configuration as well as to provide data communication across platforms.
- Three laptop computers for field work such as data collection, display of design data, modification of design at engineering sites etc.
- One 4 mm cartridge tape drive for backup of data as well as providing an appropriate way for data transfer between agencies without networking.
- One AO and one A3 size digitiser for digitising both large and small size maps.
- An inkjet plotter to produce maps of maximum AO size and up to 256 colours and printers for the generation of reports.
- Licensed softwares which include ARC Cad, ARC View, AutoCAD and dBASE.

3.2.2 Overall, the hardware and software configurations were designed to meet requirements of the data collection programme, shoreline management, GIS, and numerical modelling, taking into consideration existing computing resources and capabilities at CED.

3.3 Database

3.3.1 Considering the nature of the application of this GIS, the following data were identified to be essential to be incorporated / included in the GIS databases:

3.3.2 *Shoreline history*: Aerial photographs of the entire national shoreline should be taken every 5 years in order to accumulate data for monitoring long term shoreline changes (Stanley 1985, Li 1995). The photographs should have about 60% shoreline overlap so that the 3-D shoreline can be extracted from the photographs by stereo photogrammetric processing. For shoreline segments eroded severely, larger scale aerial photographs should be taken more frequently, for example every 1 - 3 years. The larger scale photographs may be used for other purposes such as coastal zone topographic mapping, beach profiling, and erosion interpretation. For very small sites, total stations and GPS receivers may be used to capture the shoreline periodically and compare the shoreline changes.

3.3.3 *Bathymetric data*: Hardcopy nautical charts of 1:15,000 and 1:200,000 provide important bathymetric information. Bathymetric data in digital format became available recently because of the advances in computer technology and application of acoustic sounding surveying systems. In Malaysia, this kind of data are maintained by Royal Malaysian Navy and some oil and gas companies. Hydrographic survey of small areas are also conducted or contracted out by CED. Bathymetric data are crucial to structure design, numerical modelling, and shoreline changes monitoring.

3.3.4 *Topographic data*: Topographic maps of 1:50,000 are maintained by Department of Survey and Mapping. Until 1995, topographic maps of about 30% of Peninsula Malaysia and 5% of East Malaysia were available in digital formats. These data cover the features on the landward side of the shoreline. DTM (Digital Terrain Models) describe the land terrain relief which determines the shoreline shape along with the bathymetric data, the water level and other factors.

3.3.5 *Attribute data*: GIS attribute data such as demography, land use, geology, soil types, environment quality etc. should be included. These data are sometimes necessary in decision making, for example for setback planning, protection of residential areas, limiting or avoiding environmental impacts and other purposes. A lot of coastal attribute data can be associated with shoreline segments, including erosion categories, structure costs etc. Once the shoreline geometry is built as routes in the network system of ArcInfo, dynamic segmentation can be used to model the change of the attributes of shoreline. It should be noted that the change of the attributes does not require the resegmentation of the shoreline.

3.3.6 *Multimedia data*: Terrestrial and aerial photographs are available for shoreline sections of different periods. They are important for interpreting erosion status. Hardcopy photos are scanned into the system. The scanned images are then related to the desired features and can be displayed by clicking the corresponding features using a hot link. Design drawings can also be associated with features so that the features and corresponding drawings can be examined at the same time. Sound of waves approaching structures, video clips, and results of simulation and animation may also be included in the future.

3.3.7 *Time series data*: Wave data, wind data, current data, wave surface elevations (tides), river data (daily discharge), and other time series data describe the processes affecting the shoreline and other coastal phenomena. A link between the time series data and the spatial data opens a new way of unified database management scheme and an integrated coastal modelling environment. In most cases, time series data have the following characteristics: a) the position of a sensor can be treated as a constant, and b) the observation data which are large in size and expand rapidly along with time. Currently, the time series data included in this system are:

- LEO (Littoral Environment Observation) data containing wave, wind, beach slope, current, and water level information. Two tables in dBASE format are given, one for location and general information and the other for the observations (Willis 1995, Kjerfve 1995). 18 LEO sites are distributed in the country and provide data every month to CED since 1987.
- Wave data: Waverider™ data are results of statistical analysis of wave data based on 20 minutes records sampled at 2.56Hz every 3 hours (Willis 1995). Pressure Gauge data of two locations and water level data from two other sites are also available.
- SSMO (Surface Ship Meteorological Observations) data from National Climatic Data Centre of USA from 1949 - 1993 which cover the Malaysian waters. Marsden squares are used as indexing frames, with each square of 10° (latitude) x 10° (longitude). The SSMO data in dBASE format include both general information such as a Marsden square number, data and time of the data acquisition, and data fields containing information about wave, swell, wind, meteorological conditions, and ship speed and direction (Kjerfve 1995).

4 GIS Functional Model for Shoreline Management

4.1 Functions to be supported by GIS

4.1.1 In designing the GIS functional model for shoreline management, an assessment of the major functions /activities of the Coastal Engineering Division was carried out. The functions which can be incorporated in a GIS framework can be summarized in the following four aspects:

4.1.2 *Coastal engineering*: Coastal erosion control works are implemented by CED in areas which have been categorised as facing critical erosion. Such areas can be indicated in a digital shoreline condition map. A land/bathymetric survey has to be carried out to provide topographic/bathymetric maps (e.g., 1:1,000) for structure design. Tides, water level, and storm surge data should be made available for determining structure heights. In addition, geotechnical data such as shear strength of soil etc. are also needed. Design drawings are generated using AutoCAD. With all these data available in digital form in the GIS database, a computerized (or partially) design procedure can be developed, which will make the design process much more efficient and systematic. Another aspect is the overview of construction and development projects in the whole country. An inventory system will be a good solution to this need. A database with status of all projects completed and planned in the GIS will enhance the project management and efficiency of administration.

4.1.3 *River mouth dredging*: CED implements river mouth dredging works to improve port access and enable navigation of fishing boats at both high and low tides. Detailed design boundaries need to be determined by CED on a topographic map (1:1 mile) and upon consultation with local fishing authorities. Thereafter, a detailed bathymetric survey of the specific area is performed and a survey map of 1:2,000 is produced. The final design boundary of the dredging area is located based on the survey map. A post-dredging survey estimates the volume of the dredged material solely for estimating dredging charges. Periodical surveys may be used to monitor trends of sedimentary movement and predict dredging sites. This may be combined with numerical modelling techniques. If the topographic database is in digital form and survey data can be supplied in digital form as well, the design procedure, volume estimation, and long term trend analysis can be accomplished in a GIS environment.

4.1.4 *Coastal project implementation and monitoring*: Services such as cost estimation, project budget justification, tender calls, and budget monitoring etc. are included in the project monitoring function. These services can be enhanced by applying GIS technology. After a design is accomplished and the contract is awarded, CED has to monitor the progress of project implementation. This is currently done by reviewing reports from State DID offices and contractors. If site conditions and other factors change, technical support may be provided to solve problems. Measures may be undertaken to make the project running smoothly and on time. In the monitoring work, important information needed is what has been done and what still has to be carried out. Since the current monthly reports are text based and photos may be supplied in addition, no intuitive view of the project progress is available. If the general layout plan with a scale of 1:1500 (which is a map overlaying the structure design drawing on the survey map) can be input as a digital map, the project progress report can be supplied in a digital form with both text and progress status in the map. For example, comparison of progress and costs can be performed by comparing progress maps in individual time periods. Overview of project status will become much more efficient. Financial statements and progress payment may also be supported by real status maps showing work completed.

4.1.5 *Numerical Modeling*: Numerical modelling is a technique to investigate the behaviour of shorelines and the physical coastal environment using computer technology. It can be used for studying erosion processes, shoreline changes, structure design, and shoreline erosion prediction. Data needed for numerical modelling including shoreline location, bathymetric data, grain size, wave data, tidal data, and wave approach direction. More sophisticated numerical model considers effects of wind as well. In an integrated system, if digital data are available, data for numerical modelling can be organized in GIS and provided to modelling system such as MIKE 21. The result of the numerical modelling can then be displayed in the GIS environment. For example, changes of shorelines caused by different input data sets can be overlaid and compared. The simulated shoreline can also be displayed with other features such as land parcels, and land use classes, so that effects of erosion can be assessed. After modelling, the newly calculated bathymetry can also be displayed in 3-D with other data layers together.

4.2 GIS Functional Model

4.2.1 Based on the review of the internal and external working environment and GIS needs, as well as suggested hardware and software configurations, a general design of functions is presented which serves as a base for the detailed data model design. Figure 3 depicts the function model of the GIS system. Data sets input to the system could be meta data of time series,digitized/scanned hard copy maps, existing digital maps, coastal engineering drawings, and scanned aerial photographs. These data are all in certain digital formats, if the digital format does not match the native format of GIS, in the case ArcInfo, a data format conversion (filtering) becomes necessary. If the data source is of an analog form, an analog to digital (A/D) conversion such as digitizing or scanning has to be performed before the information can be used in GIS. Three major application areas will be concerned in the development of the GIS, namely Shoreline Erosion Monitoring, Coastal Engineering Management and Coastal Data Inventory. They will be built based on ArcInfo system.

4.2.2 *Shoreline Erosion Monitoring Sub-system:* Under coastal erosion monitoring, shoreline erosion conditions at the national level are stored in the database. Shorelines are classified into four categories and represented on a map. This is implemented by using the existing results of the National Coastal Erosion Study (Stanley 1985). In this digital map, a base map with state and district boundaries is included. Shoreline with different erosion categories are represented by different colors and/or patterns as shown in Figure 4. Specific information can be queried by clicking a mouse at a shoreline segment of interest. This kind of information is saved in databases and associated with spatial entities of the map, including location, length of coast affected, area or number of lots affected, protection works, description of erosion categories, and even a picture of a typical scene of the erosion in this area. In this sense, a map in GIS is not only a map. It integrates spatial and non-spatial data in a unique system and allows flexible queries. Similar digital maps are also generated, for example digital shoreline material distribution, critical erosion sites, and locations of existing erosion control structures. The digital map displayed could represent various erosion related factors. If a specific location is of interest, it can be zoomed at an appropriate scale factor. Further queries may be performed as well.

4.2.3 Monitoring of shoreline erosion needs a long term commitment. Objective decisions should be made based on erosion monitoring data acquired cumulatively during a long period of time. Therefore, efficient and economic ways for acquiring these data are an important issue in implementing the GIS application in erosion monitoring. Shoreline mapping is a procedure to locate the geometric position of the shoreline. Depending on the scale of maps to be generated, various methods can be selected. For example, if a segment of shoreline is found to be severely eroded, a large scale shoreline mapping may be performed to record the hard evidence of the erosion status. These data can also be used to design coastal engineering protection structures. Small scale mapping covers large areas. However, details of objects are not mapped. Usually, small scale mapping is used to provide global information covering large areas. Currently, there are two key technologies in mapping which make survey and mapping efficient, affordable, and easier, namely Gps (Global Positioning System) and Softcopy Photogrammetry. With these new technologies, periodical shoreline mapping will become easier. A lot of field work can be reduced and most of the shoreline measurement can even be performed in offices.

4.2.4 *Coastal Engineering Management Sub-system*: The coastal engineering subsystem will cover functions related to current activities of CED. A successful implementation of this part will greatly improve the productivity of CED. In this GIS environment, basic data for design such as topographic data, bathymetric data, locations of time series data etc. are managed and geo-referenced in a unique system, without influence of scale, projection, and information generalization. For example, a digital topographic/ hydrographic map can be overlaid with a cadastral map and an erosion condition map to find lots/parcels that will be affected by coastal erosion. Design of a coastal structure may be accomplished on the screen in an interactive mode. Rivermouth dredging may be planned more efficiently using GIS as powerful tools because this system provides a unique environment for interactively defining the dredging boundaries, monitoring dredging progress, and representing post-dredging survey results. In this part of the system, a lot of CED tasks such as structure design, coastal project monitoring, river mouth dredging, coastal zone development management, numerical modeling, and shoreline identification and mapping, are involved. These activities need specifif coastal engineering and modeling software packages that are usually not provided by a commercial GIS software system. This will require the integration of these functions fo special application software to the GIS environment. Figure 5 shows a sample output of a coastal erosion control project monitoring system.

4..2.5 *Coastal Data Inventory Sub-system:* The third part of the GIS system is coastal data inventory. The GIS is also a central coastal data inventory unit at the same time. If digital data are available at CED, they will be directly stored in the database. For digital data that are very large and not of spatial nature such as time series data, a meta data file may be stored instead of the actual data set itself. The meta data supplies information such as data collector, reference system, datum, date of collection, format for retrieving, storage site, availability, contact person etc. With this meta data information, users would be able to have an overview of data collected and to know how to request. This is also beneficial to data collection planning. Other data which can be registered as meta data are hardcopy maps and photos, as well as digital data at other government agencies and the private sector. Query of the database should be graphic and interactive and the user can query either by location or by data types. A sample base map displaying meta data about LEO stations and flight paths of aerial photographs is as shown in Figure 6.

4.3 Output

The system will output results in various forms. Graphic display on the computer screen is the best way to check the results and perform operations for further improvements. This is especially important when data sets involved are multi-layer oriented, and complicated spatial operations are applied. Digital maps will be generated in ArcInfo format. They will be output to a plotter if necessary. In many cases, users/clients would prefer databases instead of maps. However, this requires that the user has a compatible system which will be able to read the data.

5 Implementation

5.1 The Technical Assistance Project was implemented through close collaboration between the Specialists and CED. In introducing GIS technology and data management systems to CED, the Project focused on the concept of 'appropriate technology' which could be integrated into CED's programmes seamlessly taking into consideration the following factors:

- That computer and data management technology already resided at CED and the staff were knowledgeable in the use of such resident technology;
- Plans to introduce new technology should make full use of existing skills and technology;
- New work should be integrated into existing workloads seamlessly;
- Future work generated by new technology should build on existing capability and make use of existing datasets and;
- Further development of GIS and data management technology at CED should be self-directed.

5.2 In summary, at the end of the TA in July 1996, a state of the art computer system with relevant hardware and software was installed in CED, models for spatial and non-spatial data were developed and installed, and training of CED's staff was successfully conducted. Considering the extremely detailed and vast volume of data and limited time available for the project, the GIS functional model developed was implemented and tested at both the national and local levels for the Shoreline Erosion Monitoring Subsystem, Coastal Engineering Management Subsystem and Coastal Data Inventory Subsystem with real spatial and time series data for a pilot project in Penang. Provisions are currently being made to collect and enter all relevant data to extend the coverage of the GIS system to the whole country.

6 Conclusions

The GIS framework for shoreline management and the coastal engineering database for time series, spatial and meta data are extremely useful tools in a variety of coastal engineering applications and for the generation of reports. This will enhance CEDs capability in its current coastal erosion control programme and assist CED in moving towards a longer term goal of shoreline management for sustainable development in the coastal zone. However, to make the GIS database a truly useful coastal engineering tool on a routine basis will require substantial training of existing staff; acquisition of new staff in GIS related field; an on-going investment in updating the database by appending new data; the continual operation and maintenance of the GIS database and associated files; the development of appropriate application programmes and upgrading or expansion of hardware and software to keep abreast of current technology .

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Ramcharan, E. and C.A. Ooi 1996. *Institutional Strengthening for Shoreline Management - Approaches, Strategies and Results of a Technical Assistance Project.*

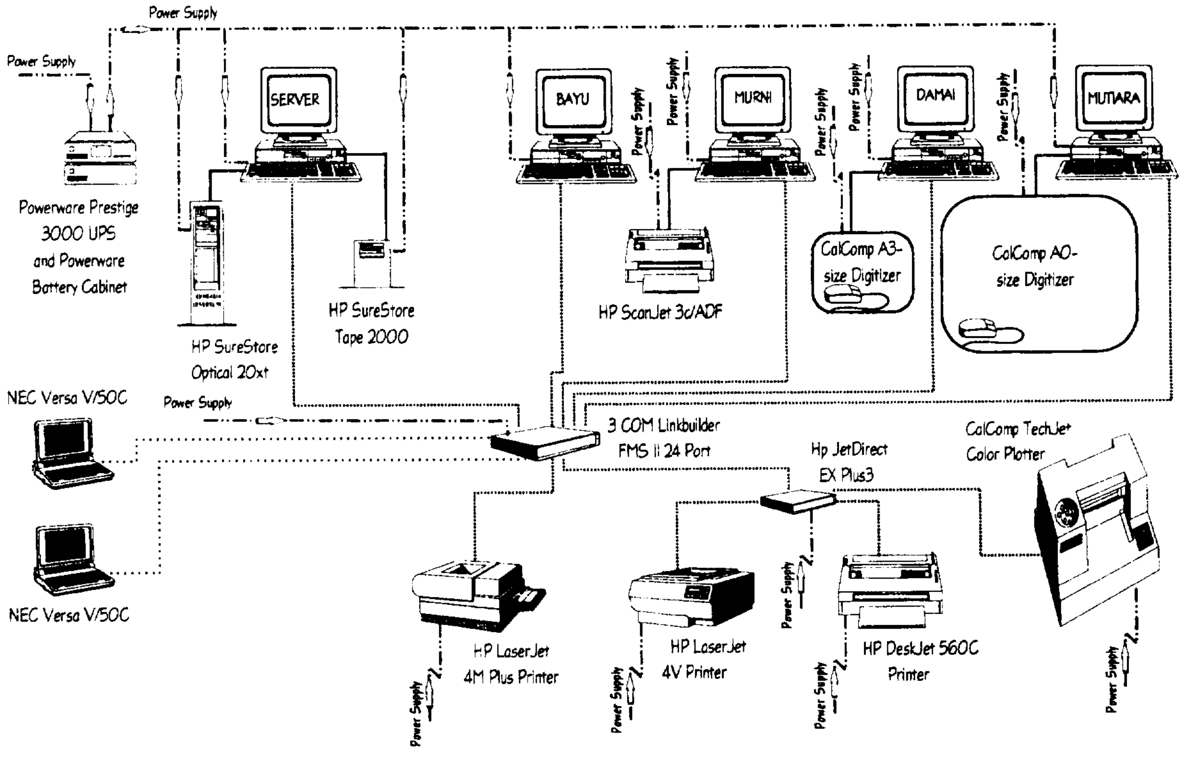


Figure 1 : Hardware Configuration

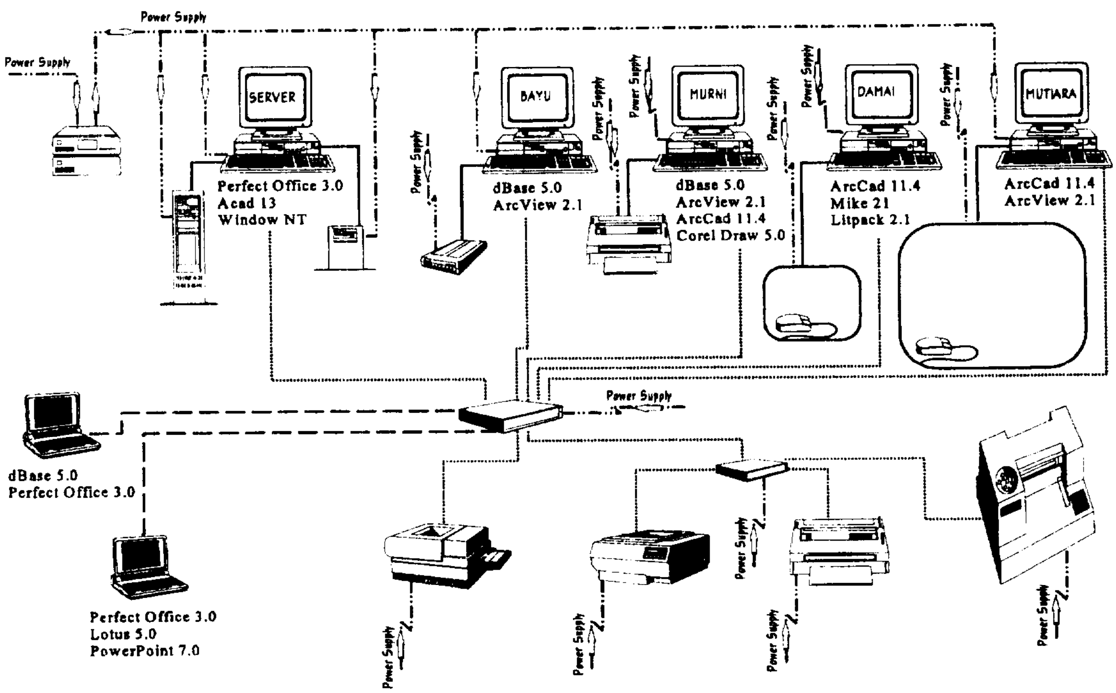


Figure 2 : Software Configuration

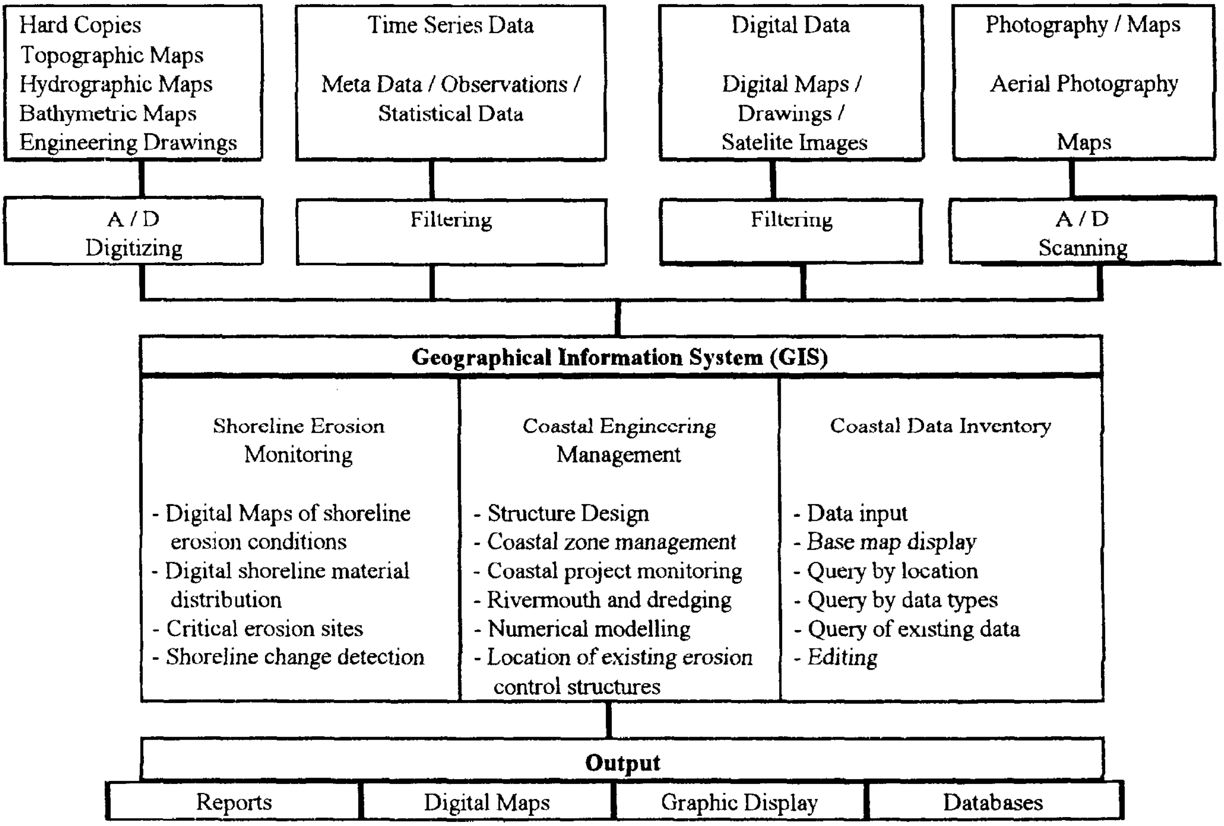
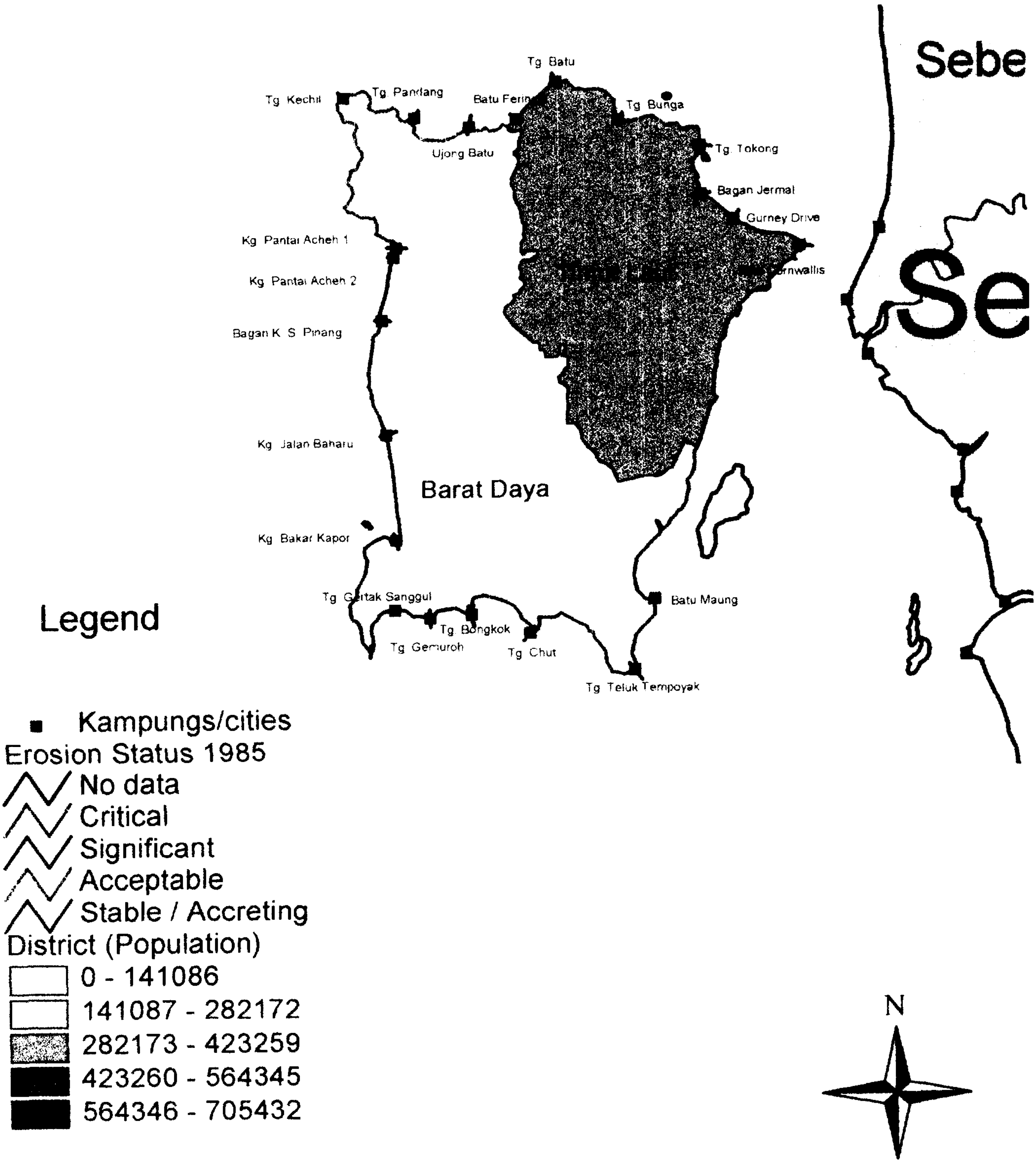


Figure 3: **GIS Functional Model**

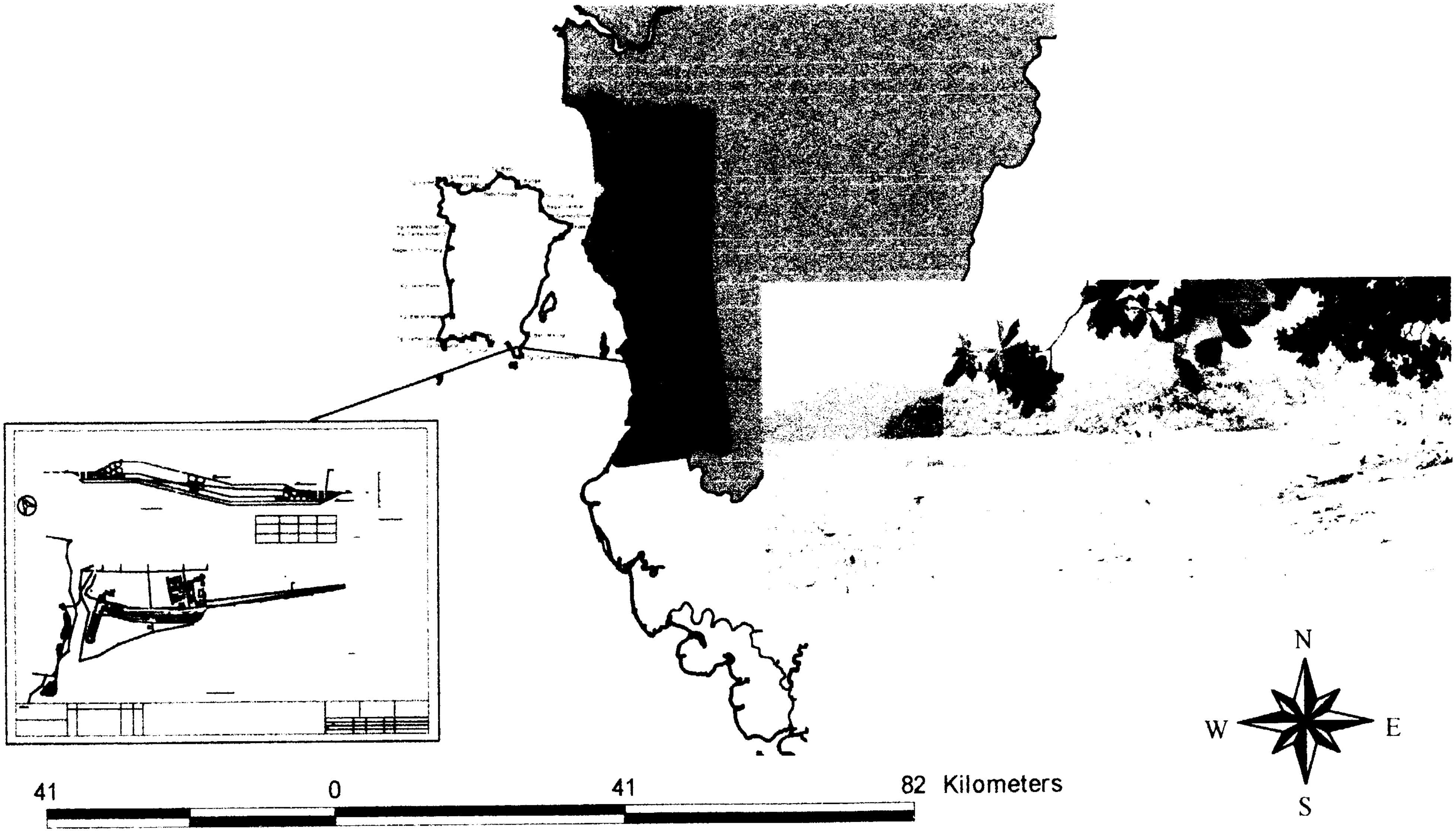
Figure 4



Tg Batu
Tg Kechil
Tg Pandang
Tg Bunga
Ujong Batu
Tg Tokong
Bagan Jermal
Gurney Drive
Kg Pantai Acheh 1
Kg Pantai Acheh 2
Bagan K S Pinang
Kg Jalan Baharu
Barat Daya
Kg Bakar Kapor
Tg Bongkok
Tg Gemuroh
Tg Chut
Batu Maung
Tg Teluk Tempoyak
Sebe
Se
Legend
Kampungs/cities
Erosion Status 1985
No data
Critical
Significant
Acceptable
Stable / Accreting
District (Population)
0 - 141086
141087 - 282172
282173 - 423259
423260 - 564345
564346 - 705432
N

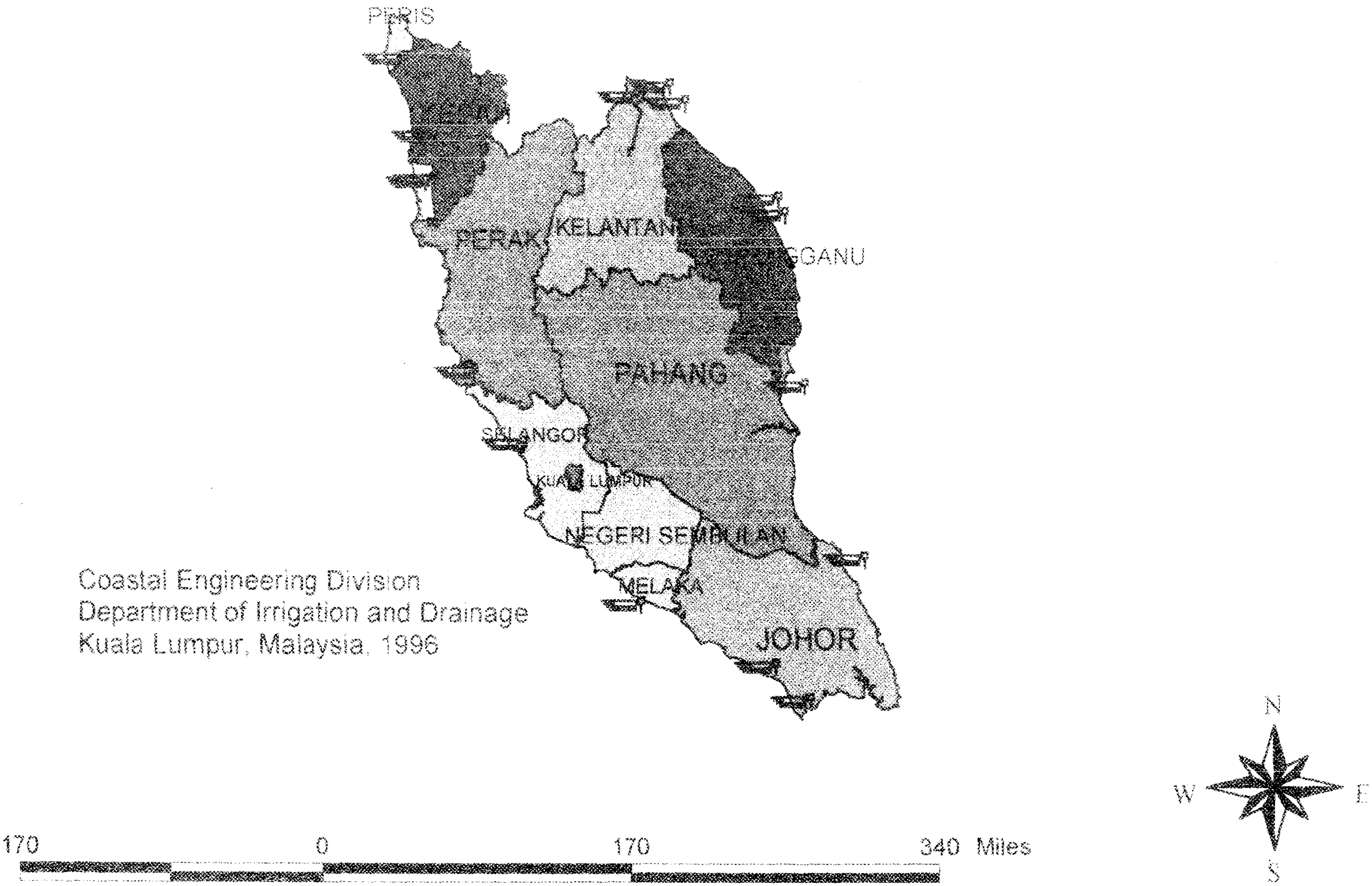
Figure 5

Coastal Erosion Control Project Management



Coastal Data Inventory System
- Location of LEO Stations

Figure 6



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