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A Computer-Directed Geographic Coastal Use Classification System for Ecologic Planning:

The Case of the Florida Keys

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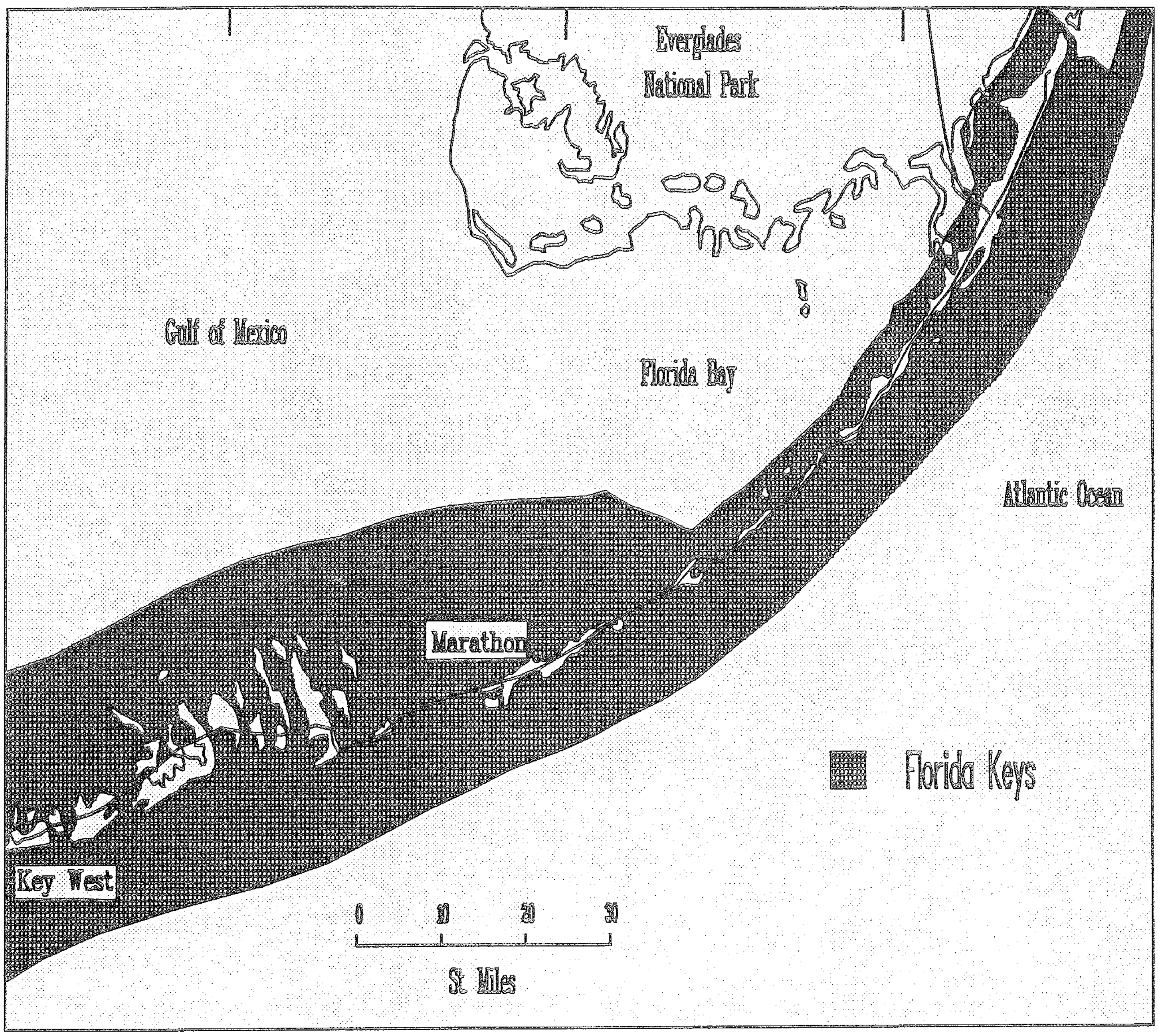

FLORIDA SEA GRANT COLLEGE PUBLICATION

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A COMPUTER-DIRECTED GEOGRAPHIC COASTAL USE CLASSIFICATION SYSTEM FOR ECOLOGIC PLANNING: THE CASE OF THE FLORIDA KEYS

by
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ABSTRACT

This report presents a baywater assimilation-capacity approach to coastal zone management, using the Florida Keys (Stock Island) as a case study. Natural and altered segments are associated in a multi-level ecologic hierarchy with vertical and horizontal links. Four broad classes are recognized at the highest level - land, shore, tidal, and water; the lowest level (generally, the smallest area) is the elemental plat parcel. Operations may be performed at any level, horizontally and vertically. When locational and descriptive data are entered into a topological geographic information system (GIS) each ecologic unit may be accessed in a relational data base. A ranked coastal use capability classification system (CUCC) is derived from ecologic attributes, management objectives and alternative use technologies of planning units, individually or collectively. Pollutant and non-pollutant flows are traced among the ecologic planning units in a spatial transaction matrix and evaluated against parcel and regional environmental goals, stated as quality parameter standards.

The biochemical-dissolved oxygen coupled reaction is used to illustrate how acquired information on land, shore, tidal, and water ecologic entities stored in GIS is applied to evaluate the movement and transformation of discharged waste materials in coastal waters. Effluents exported from land and shore activities are linked to tidal and water geo-regions. Tabular and map information may be outputed at field planning scales, for large and small areas, and for evaluations of alternate scenarios, zoned use conformities, embayment capabilities, and parcel uses. The report provides the coastal planner with a way to review available management options and outlines a methodology for carrying it out. The application of the generalized procedures to specific bay segments requires local refinement and testing prior to routinized use. The preparation of a manual for the field implementation of the ideas and methods developed in this report is planned.

CHAPTER I

INTRODUCTION AND RATIONALE

1. The Florida Keys, Local and National Setting

The Florida Keys is an inhabited 43-island coral reef and calcareous shell archipelago, extending from the southeast coast of Florida, and, separating the Gulf of Mexico from the Atlantic Ocean (Figure 1). The highest land elevation is 25 feet and the longest distance from land to water is 3000 feet. The narrow island chain has a year-round population of 60,000 which doubles during the winter season. The islands, their immediate waters, and the Everglades National Park on the mainland, comprise Monroe County. Key West, the county seat and largest city, is located at the southwestern tip of the 120 mile chain. The Florida Keys National Marine Sanctuary and Protection Act of 1990 created a 2600 square nautical mile marine sanctuary enclosing the islands of the Florida Keys.

This subtropical region has unique natural and developed ecosystems. The islands are surrounded by mangrove stands, broad shallow tidal flats, large expanses of seagrass meadows, submerged coral reefs, inshore and nearshore waters, and productive open offshore waters. Together, these natural features are the foundation of the County's social economy, exclusively dependent on tourism and fisheries. An array of supporting island-based services and materials are organized into a "developed human ecology". Collectively, these services provide access to the scenic and attractive shallow waters and shorelines. The two ecologies (natural and developed), form a merged ecosystem, linked by the operations of a natural resource market economy, based on sport and commercial fisheries, shoreline and seascape scenery, recreational boating and diving, reefal exploration, and a subtropical winter climate.

Prior to the passage of the Sanctuary Act, public and private investments in the islands' physical infrastructure had stimulated an interactive pattern of development. National and state governments constructed military installations, a cross-island highway, an aqueduct, and an electric power grid. Early private venture capital was invested in a mainland railroad link that ran the length of the Keys. Following its destruction by the hurricane of 1935, the railroad was converted to a trans-island road, which was subsequently replaced by a modern vehicular causeway with 42 bridges. Private investments also were made in warehousing and rail-boat transhipment facilities, in fish processing

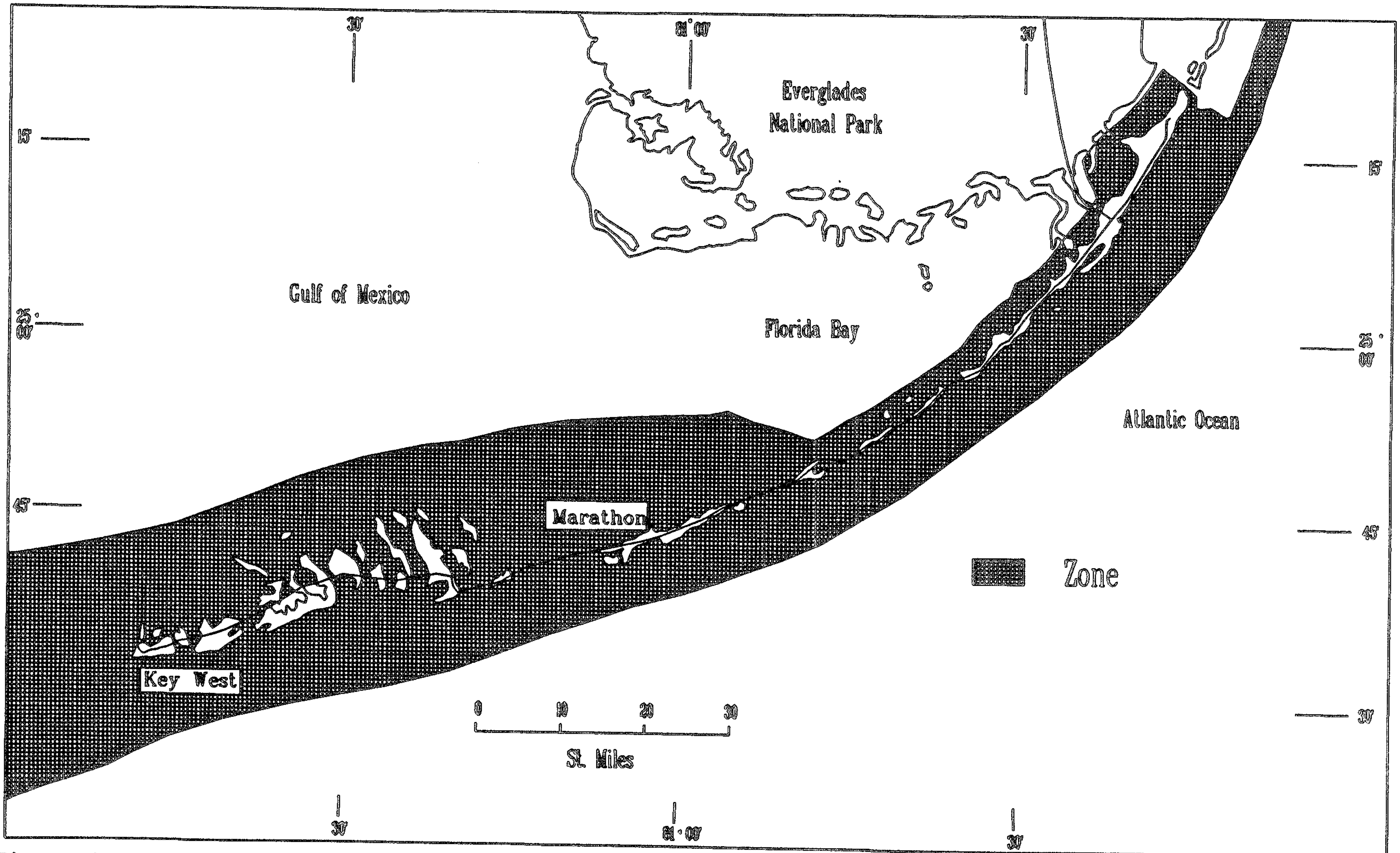


Figure 1. Location Map Showing Florida Keys National Marine Sanctuary and Protection Zone

plants, and, after World War II, in dredging for canals and channels and land-filling, and, most recently, in an array of tourist accommodations.

The two investment streams, public and private, may be attributed to several local and national historical circumstances. Proximity to the Caribbean heightened the region's national security significance; commercial interests were stimulated by the abundant fishery resources, and the environmental uniqueness of the subtropical coral reef ecology. The two streams intermingled over a 100-year period (1890-1990) during which the nation passed through agricultural-industrial-service economy stages, accompanied by population growth, rising income, increasing leisure time, and by transportation innovations which enhanced accessibility of the Keys. Collectively, these forces, whose influences continue today, have driven the development history of the Keys.

A life-style perception of the Keys, held by many local residents and visitors, of a "free-wheeling", minimum constraint social milieu prevails. This attitude was engendered by a "freedom of the seas" ethic, isolation from the mainland, and by a large transient tourist population. The explosive growth of the tourist industry since 1960 and the recent establishment of the sanctuary in 1991 set the stage for acerbic confrontations among local, county, state and national jurisdictions, and between public agencies and private property owners, and conservation activists, and between liveaboard boaters and shore residents.

The general procedure of an analytical system suitable for coastal zone management to cope with such concerns is shown by the flow chart of Figure 2. The steps link objectives to conceptual design, data collection, geographic storage, site evaluation, classification, and, use impact for decision-making. It is adaptable for a variety of coastal types and regional issues as well as to local planning for small plat parcels.

2. Overview of Report

While this report does not address directly the political issues resulting from the Sanctuary Act, much of its content is germane to shoreline and nearshore management planning at the interface of protected public waters and private-public local land where confrontation often is acerbic. The report outlines and illustrates a system for storage, retrieval, and manipulation of the large body of data for sustainable use decision-making and alternate scenario evaluations at regional and local scales. The data are assembled in a geographic information system (GIS) that relates the spatial distribution and quality attributes of areally delimited shoreline and nearshore water ecologic response units. The GIS design captures the functional ecologies of the islands and adjacent waters and relates their exchanges in a transaction matrix.

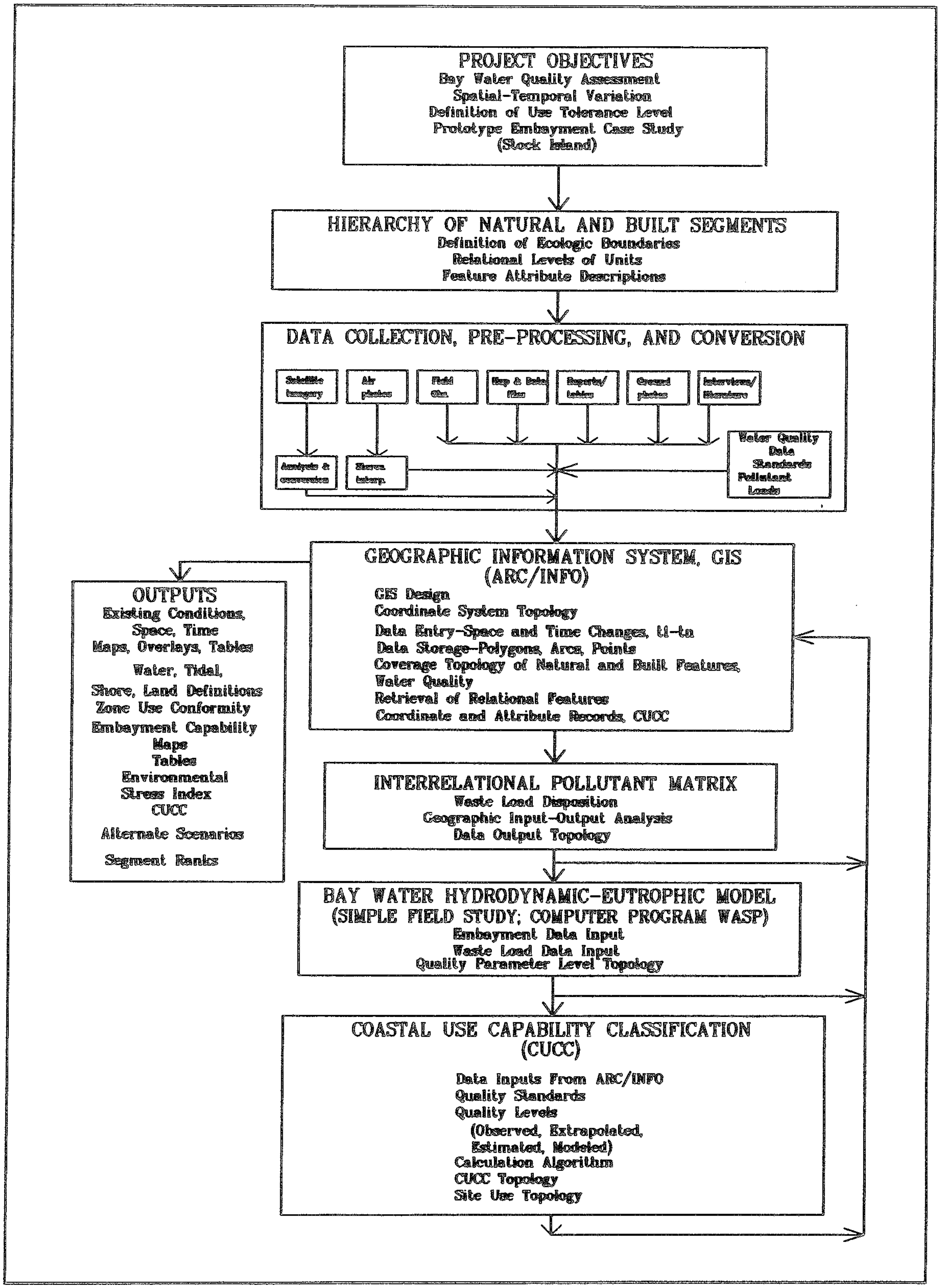


Figure 2. A Computer-Directed Coastal Capability Classification System for the Florida Keys

Effluent-influent fluxes occur across the interface zone between inland, shore, and land uses, and tidal and offshore water uses. The interface zone includes private submerged land, local public waters and sanctuary near and offshore waters, whose boundary has been set at mean high water. The mosaic pattern of spatial relations is stored as an ecologic hierarchy in a GIS, whose lowest level is an ownership parcel, or, for public lands, a subdivision thereof.

CHAPTER II

RESEARCH OBJECTIVES

The structure of the research design was formulated to respond to the following objectives:

1. Develop a general procedure to acquire and process natural and disturbed ecosystem information needed by coastal municipal and county governments in order to guide local development of shore lands and to protect the quality of adjacent waters.

2. Organize a data collection and data management system composed of ecologic entities described by attributes of separate and combined upland and submerged land parcels in order to assess the immediate and cumulative effects of public and private uses on local and regional land-aquatic ecosystems.

3. Provide a scientifically-based method for including water quality tolerance levels in local offshore water and water-related land use ordinances.

4. Facilitate decision responses to the development permit application process by reference to ecologically sustaining criteria.

CHAPTER III

ORGANIZATION OF DATA BANK

1. Design Criteria

The following criteria were used to organize the data to meet the objectives stated in Chapter II and the research agenda implied in the project title:

a. the findings should have the potential for application to a wide range of coastal areas.

b. the results should illustrate generality by application to the specific conditions of the Florida Keys.

c. the methodological procedures should include the use of electronic data processing.

d. the collection and analysis of data should capture the relevant features of the functional ecology of the study area.

e. the conclusion of the analytical stream should lead to a normative decision.

2. Design Concepts

A functioning ecosystem is an amalgam of a natural ecology and a developed ecology. Cohesion among the functioning units of the ecosystem derives from the application of developed system technologies to the natural system. The driving force of the developed system is a separate social system, (ignoring feedback effects). The social system makes the decision to develop or not to develop, and selects the available technologies to apply to a site: what, how, when, and where. Ecosystem components consist of various factors, including, economic-geographic development marketplace, political interventions, ethical values, and perceptions.

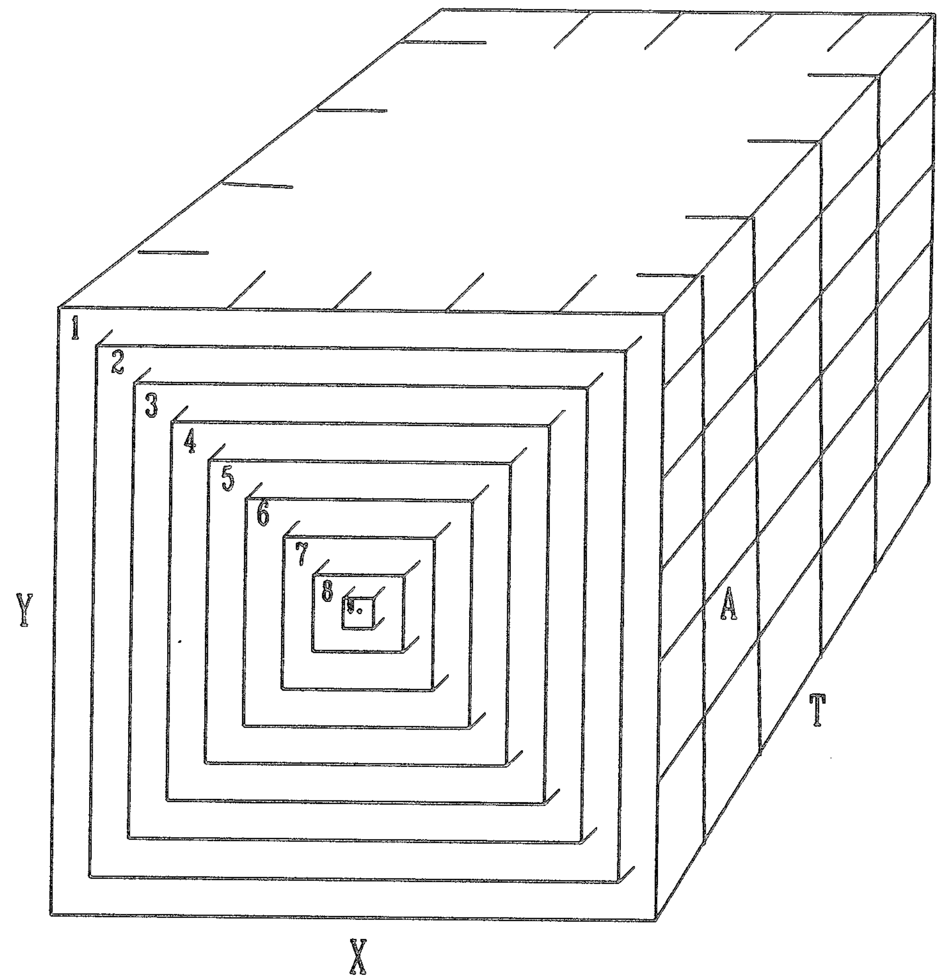
This report is not concerned with the internal kinetics of the decision-making role played by the social system. Each ecologic entity may be considered an alloy, behaving as a synthesized ecosystem unit, moving toward a steady-state equilibrium. Steady-state may occur at a higher or lower level than a prior state, as measured by quality parameter values, responding to site-specific and time-dependent preventive, remedial, or degrading technologies imposed by the social system. While the social marketplace is the nexus of these interactions, the environmental responses to market choices operate on an antecedent ecosystem. Awareness of responses indicated by state levels may induce feedback changes. The focus of this approach is sensitive to spatial, temporal, and feedback connections as shown by quality levels of indicator parameters, existing or anticipated.

3. Spatial Ecologic Data Cube

In the Florida Keys and elsewhere, various sized parcels are considered suitable for development. Each parcel is a unit that has an ecology which may be severely or moderately disturbed, or, relatively pristine. A parcel may be treated separately or aggregated into larger units based on the similarity of functioning attributes. Each unit interacts with other units, individually within the aggregate, and/or, collectively and externally with other individual units or aggregates. These relations and interactions may be represented by a relational hierarchy, whose structure enlarges upwards from the lowest level to the highest level, incorporating progressively all lower units. The vertical arrangement is defined broadly by functioning criteria. For a given level each unit is described by its unique attributes. Changes occur over time at all levels because of interventions by technology, in-situ transient states, and episodic events. A general structure for organizing these data is shown by Figure 3, Space-Time Hierarchy of Ecologic Unit Data Cube.

The data cube embodies the functional and managerial ecology of the study area. The arrangement, definition, and selection of entity attributes govern the information flow of the analysis. The data cube of Figure 3 is triaxial; x,y are geographic coordinates defining location; t is time. Data are entered in x,y,t cells of the cube. If data for past states or conditions are available, the evolution of ecologic states may be traced; else, the analysis is time constrained. Future states may be predicted from simulations if an applicable and validated model is available.

Hierarchy levels are shown by cube inserts (2 through 9) within the outer cube. All cubes have the same overall x,y,t time-location dimensions (i.e., area and time); each ecologic entity is contained within and linked to its immediate higher level unit. The levels developed for this study were: the Florida Keys (universe), Key island, embayment (study site), geo-region, region, subregion, area, existing use, and parcel. The focus is on nearshore water-land interrelations. Location is shown 2-dimensionally, X,Y, by Figure 3; depth of the water column may be given as Z, in place of T in the figure.



CROSS-SECTION SLICE X, Y, T
X, Y MAP COORDINATES

T - TIME
A - ATTRIBUTE DATA

HIERARCHY LEVEL

1. KEYS
2. ISLAND
3. EMBAYMENT
4. GEO-REGION
5. REGION
6. SUBREGION
7. AREA
8. EXISTING COVER/USE
9. PARCEL

Figure 3. Space-Time Hierarchy of Ecologic Unit Data Cube

For privately owned land and water parcels, the market links the developed ecosystem with the natural ecosystem, subject to constraints of political institutions of varying stringencies. Publicly owned areas are more directly subjected to political decisions. Developable parcels may be of varying areal sizes and include a range of ecologic entities.

4. Ecologic Structure of the Data Bank

a. Overview of Hierarchic Ecology. The diagram of the data cube (Figure 3) is transformed into a multi-level hierarchy of natural and developed units arranged as an information flow chart, with horizontal and vertical links shown by Figure 4 (in pocket). The linkages preserve the ecologic functionality of the system (O'Neill et al., 1986; Watt, 1982). The positions and relations of each entity in the developed ecosystem are defined by its attributes. The attribute set applies to the Florida Keys (the highest level) and becomes particularized toward lower levels, finally reaching the developable parcel. The parcel is characterized by its unique attributes plus its linked higher level attributes. Like parcels may be aggregated according to similarity of selected attributes, or, kept distinct according to user interests; parcels which include more than one ecologic unit may be subdivided (sub-parcel not shown). Parcel boundaries are property lines established by the social system and need not be coincident with ecologic boundaries.

The hierarchical format of units may be generalized to an area or region by the user. Figure 4 (in pocket) was structured for the unique management concerns of the Keys and was used to design the geographic information system. Geo-regional and regional levels reflect the basic broad ecology; four geo-regions are recognized - land, shore, tidal, water; each has been divided into natural and developed categories. The geographic bases of these higher level ecologic unit groups are illustrated by Figure 5.

b. Building the Hierarchy, Stock Island. The pattern of the developed ecosystem of the Keys has been dictated by its basic physical geography, a string of low, small, irregularly shaped, partly submerged islands of oolitic and reefal limestone, and shallow surrounding waters (see Figure 5). In the Lower Keys (Big Pine Key southwestward to Key West, including Stock Island), reefal limestone is overlain by younger deposits of oolitic limestone, 20-35 feet thick, (assuming land surface elevation as 10 feet above sea level, and below sea level thickness of the oolite as 10-15 feet). The oolite is moderately permeable and contains scattered freshwater and brackish groundwater lenses. A saltwater-freshwater "interface" between the offshore seawater and the groundwater of the oolite may be present, and there may be a tidal influence in the below sea level part of the deposit. The underlying

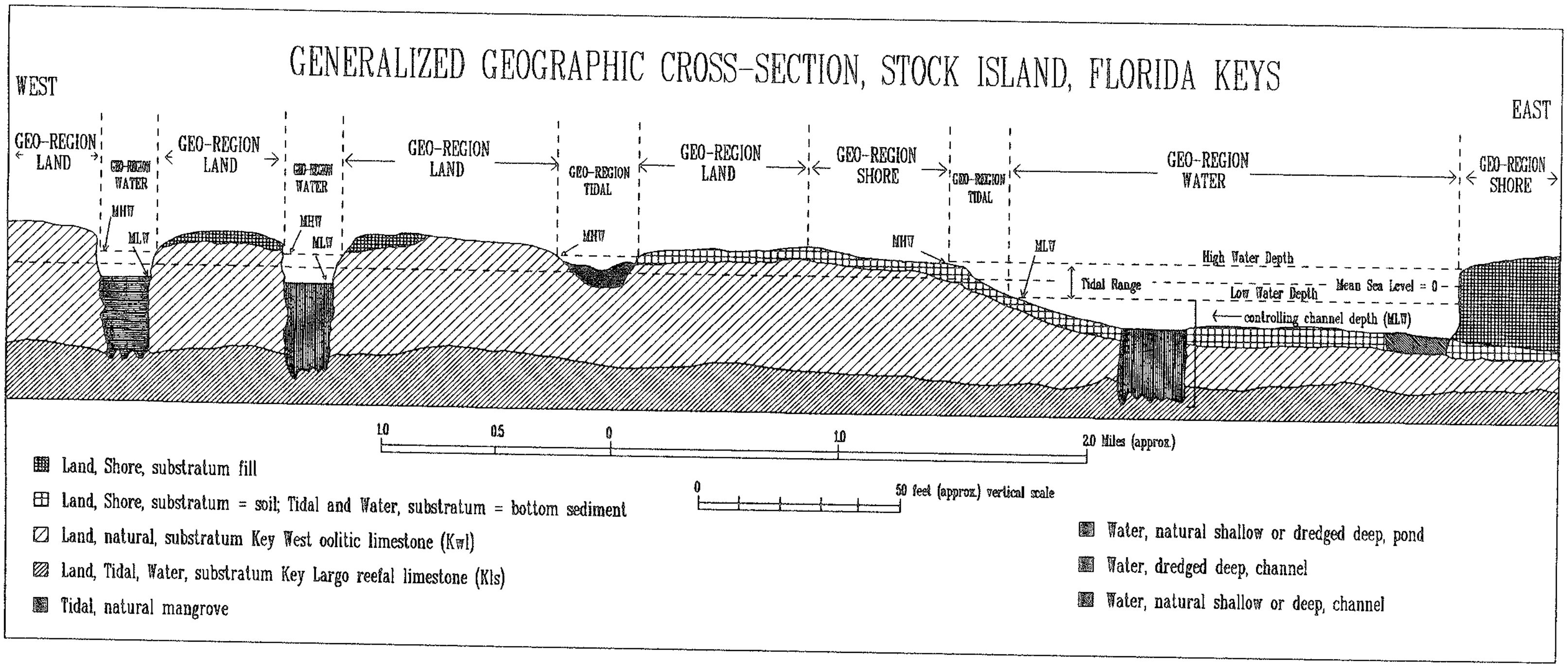


Figure 5. Generalized Geographic Cross-Section, Stock Island, Florida Keys

reefal limestone has a much higher permeability. Some free water movement occurs between the reefal groundwater below sea level and adjacent nearshore open waters, subject to tidal influence. These relations are shown in Figure 5 by the landward projection of sea level.

Dredge-and-fill operations are widespread on the Keys. They are two sides of the same development coin. In areas of shoal open and nearshore waters, navigation channels have been deepened or constructed; canals have been dug to gain access to shore docking facilities and inland locations. The excavations serve as borrow pits which furnish landfill material for shoreline extension, leveling wet areas, road construction, and bank stabilization, after packing and grading. The two phases of dredge-and-fill are planned jointly. Bore holes often are dug as vertical drains for storm water runoff, raw and treated sanitary waste and grey water disposal from package plants, septic tanks, and cesspools, and for manufactural processing waste water. As shown by Figure 5, if the depth of the excavations or penetrations exceed 10-15 feet below sea level, they may reach the reefal limestone, and the effluent will be dispersed into the nearshore waters by tidal flushing. Dredge-and-fill operations have occurred on the Keys since the early days of railroad construction. On Stock Island our calculations show that over 40 percent of land and shore areas are fill. The rate of filling and dredging reached a peak during 1955-1975.

c. Definition of Ecologic Entities. An important effect of widespread dredge-and-fill operations was to severely and irreversibly impact the natural ecology of the land and nearshore waters. As shown by Figure 5, dredge-and-fill established a mixed landscape pattern of water and land. These patterns were adapted to the relational data bases of the ecologic entities by the following methods:

(i) Levels and Relations - Referring to Figure 4 (Hierarchy of Natural and Developed Ecologic Units of the Florida Keys Data Bank, in pocket), the four natural eco-divisions at the geo-regional level are land, shore, tidal, and water. At the next lower level, region, each geo-region bifurcates into natural and developed, which distinguishes filled land from natural land, natural shore from filled shore, natural tidal from filled or dredged tidal, and natural water from dredged water. It also is possible to locate inland water and in-water land units resulting from dredge-and-fill.

Toward the lower hierarchical levels (subregion, area, existing use, parcel), the number of units increases, are of smaller area, and are defined more precisely by their attributes. The user may enter the flow chart at any planning level, depending on the information detail required to satisfy management objectives. The pathway followed from a selected lower level unit to the highest level recovers the intervening attributes and, thus, also characterizes the lower level unit. The trade-off is between detail and generality. The lowest level is the parcel. During the permitting-planning process the parcel site is the existing natural-developed ecologic unit which interfaces with the social marketplace. Its attribute set includes natural (geographic location, area, vegetation, soils, slope, geology, hydrology, bathymetry, meteorology, etc.), developed (use technologies, spatial entity, building dimensions, waste loads, traffic generation, etc.), and social (property boundaries, ownership, taxes, values, conformality with zoning ordinance, use compatibility, etc.) systems characteristics.

(ii) Boundary Descriptions - Units at all levels are defined precisely by stipulating the attribute set associated with the bounded unit area of the developable site. The following is an illustration for the geo-regional level (refer to Figure 5, Generalized Geographic Cross-Section, Stock Island, Florida Keys). Illustrative descriptions for the other levels are given in Appendix A.

a. Land - natural or fill sites never submerged except during "rare" storm events; seaward boundary defined by a line 100 feet landward of mean high water.

b. Shore - natural land or fill sites never submerged except during "rare" storm events; seaward boundary defined by mean high water; landward boundary defined as 100 feet from mean high water (Note: land and shore may not adjoin at all locations). Structures attached to the shore, or to the land where shore is not present, and extending seaward of mean high water, are included in shore.

c. Tidal - periodically submerged and exposed land following the daily tidal cycle; landward boundary defined by mean high water, except as noted for shore projections; seaward boundary defined by mean low water.

d. Water - continuously submerged land; landward boundary defined by mean low water (Note: water depth reflects tidal cycle and dredging).

CHAPTER IV

DATA COLLECTION AND CONVERSION

1. General Categories and Sources

A large amount of coordinated information is required as shown by Figure 2. The data fall into five broad categories: (a) functionality of the existing developed-natural ecosystem, especially in relation to the technology imposed on the pristine components, (b) existing system state and goal states, (c) available technology to alter the existing state, including default, and preventive, remedial, restorative impacts, (d) locational sources and concentrations of waste load substances, (e) identification and location of ecologic units. In addition to their substantive content, much of the data need to be site and time specific, geographically, and temporally coded.

The data for the case study of Stock Island were collected by a variety of methods for the physical, biological, geographical, and developmental attributes of the ecologic units given in Figure 4 (in pocket). The methods included interviews, literature reviews, direct field observations, published maps, aerial photography, and digital satellite imagery. The "raw" data required pre-processing and conversion to appropriate formats for entry into a geographic information system (GIS) and computer processing routines. A description of the procedures follows.

2. Data Collection and Pre-Processing

a. Field Observations. Field inspection prior to initiating photo interpretation enhanced accuracy by enabling interpreters to correlate photo signatures with cover and use distributions and offered the empirical base needed for reliable classification. Ground truthing after initial photo interpretations provided an opportunity to check interpretations and to identify unlabelled or mislabelled features. The county's biologist and extension agent accompanied the photo interpreters in the field and provided valuable local knowledge.

Use/cover classification and mapping of land and shore features by field traverse methods were undertaken by trained Florida student interns during summer 1990. Data were recorded directly on a 1989 photo mosaic, 1:7,200 scale, and included: identification of developed structure/open space ratios; classification of shoreline features; inventory of wastewater disposal sites, storm water drains and sewer outfalls. While the 1990 use/cover map was the focus of analysis, supplemental information was gleaned to correct interpretations on earlier coverages.

b. Interviews and Photo Collections. References to Stock Island are non-existent in the literature on the geography and ecology of the Florida Keys. In order to compensate for this lack of information island residents (Appendix B) provided oral histories of Stock Island and made available extensive ground and air photo collections. This information provided evidence to corroborate photo and map interpretations for the years 1850, 1907, 1945, 1959, 1963, 1975 and 1985.

c. Literature. An historical sketch of Stock Island, based on newspaper articles from the Coral Tribune, Key West Citizen, and Miami Herald, was compiled (Appendix C). This sketch highlighted particular developed features identifiable on the historical aerial photographs: hospitals, county home, botanical garden, sanitary landfill, community college, elementary school, golf course, railroad and highway, Safe Harbor, dog track, drive-in, speedway, electric plant, desalination plant, and residential housing. The sketch offered an effective ground truthing mechanism to corroborate historic photo signatures.

A systematic search of references, as, State University System of Florida Library User Information Services, and, perusal of the county's archives uncovered a substantial collection of published and unpublished sources which provided background documentation. Selected bibliographic materials are included in the Reference List of this report.

d. Maps and Data Files. Map information, on a variety of physical, social, and economic characteristics, and covering a broad time span, was used to compile historic coverages for the 1850-1990 period. Principal chart, map and profile reference materials and local, state, and federal sources are listed in Appendix D. The 1:1,200 scale plat parcel map of Stock Island was used for reference purposes only, since a digitized file of this map, which served as the project's GIS base map, was obtained from the County Property Appraiser's Office.

A valuable source of planning information at the plat parcel level was found on the county's Property Record Cards. There are 1079 plat parcels on Stock Island; the County Property Appraiser's Office provided a preliminary card listing containing 601 plat records. Property records are stored in machine-readable form and include plat information on owner, zoning, buildings, changing value (land, building, improvement, exemption, tax), and sales history.

e. Air Photo Interpretation. Laboratory procedures for characterizing changing land, shore, tidal, and water conditions consisted of plotting and analysis from time sequential aerial photographs and a compilation and synthesis of maps of the Stock Island area. The photo interpretation and map compilation methodology is flow-charted in Figure 6.

A synopsis of aerial photographic coverage is given in Appendix E. Good mapping quality vertical black-and-white panchromatic coverage is available from 1945 at approximately 1:20,000 scale, from state and federal sources. High resolution normal color photography is available for 1960 and 1981. Supplemental reconnaissance quality oblique photography, at large scale, covers selected sites.

A stereoscope with 4X binocular magnification was used for direct mapping from stereo pairs at approximately 1:20,000 to obtain a 1:5,000 scale. Direct interpretation practices were followed to identify cultural use features on panchromatic black-and-white photography. Historical sources of information on the development history of Stock Island, obtained by direct interviews, personal photograph collections, back issues of local newspapers, and other archival materials, were a valuable source of supplemental validation of the interpretations (see Appendixes B, C). After preliminary inspection, existing cover/use source maps of land, shore, tidal, and water conditions were compiled from vertical black-and-white photographs, available for the years 1945, 1959, 1960, 1963, 1975, 1981 and 1985, using the above interpretation procedures. Photo interpretation of seagrass meadows was limited to 1960 and 1981 normal color coverages, and followed standardized procedures (Patterson and Colby, n.d.). Interpretation was carried out at hierarchical level 8 (Figure 4, in pocket), existing cover/use, which corresponds to the Florida Land Use, Cover and Land Form Classification System level 4 (Kuyper et al, 1981). A zoom transferscope was used to rectify radial line displacement. The County Land Use District Map, 1:4,600 scale, provided the plotting base.

f. Remote Sensing. A preliminary analysis was conducted to determine the utility of satellite digital imagery as a data source. Conventional supervised classification algorithms were evaluated. The algorithms are based on spectral and radiometric characteristics of digital images. A Landsat thematic mapper scene, dated July 8, 1985, was obtained from the Florida Marine Research Institute, St. Petersburg, Florida. The scene contains 7 spectral bands and has a 30 meter spatial resolution. Pre-processing included radiometric and geometric corrections. This was followed by experimental accuracy testing of the capacity to locate natural and developed feature attributes. The classification accuracy was found to be inferior to that obtained from air photo interpretation methods at the lower hierarchical levels. Appendix F contains a proposal for a contextually-guided remote sensing classification methodology.

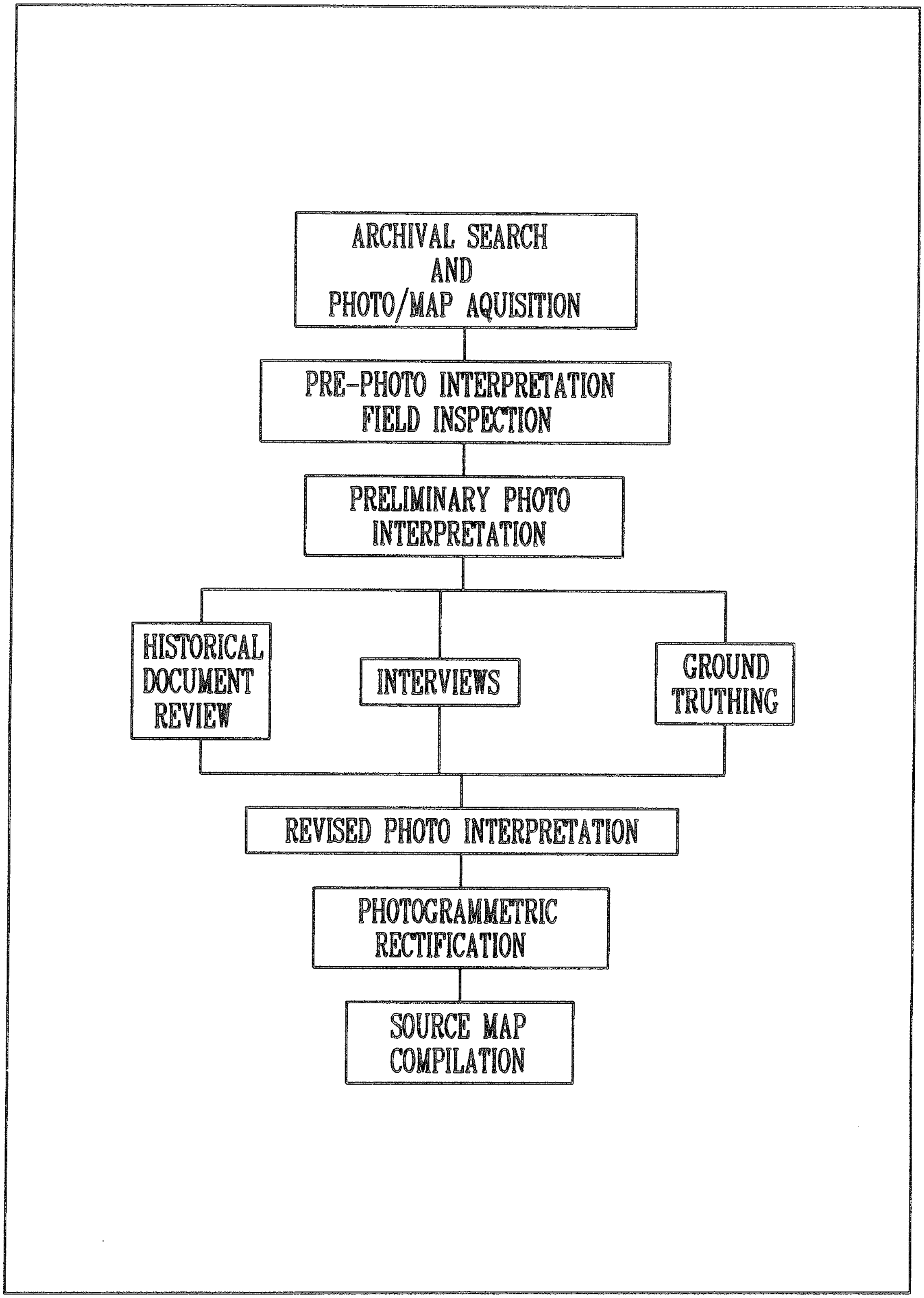


Figure 6. Photo Interpretation and Source Map Compilation Methodology

g. Normative Site Data. These data were applied to specific sites that correspond to selected levels of the data hierarchy. The subsets consisted of three categories of information that facilitated the evaluation of unit ecologic states compared to acceptable standards and the evaluation of use choices. They are: (1) water quality and standards, (2) receipt of pollutant loads from in-situ activities or inflows from other land or water units, (3) impact of alternate technologies on existing load functions, with and without geographic relocation of the existing use.

Like other attributes of the ecologic unit, the set of normative data changes temporally as available processing and effluent pre-treatment technologies improve and as impact analysis methods become more precise in the laboratory and in the field.

A large array of pollutant data may be collected on ecologic sites for comparison with standards (Clark, 1974; EPA, 1982; Lapointe and Clark, 1990). If data are collected for chemical and biological evaluations, the field work should be preceded by a sample design that adheres to the data bank structure. STORET (U.S. Environmental Protection Agency) water quality data files obtained from the Florida Department of Environmental Regulation contain records that vary widely in place, time, and parameter. Waste discharge constituent water quality problems, and allowable concentrations are available (EPA, 1982). The Florida standard for dissolved oxygen (DO) is 5.0 mg/l. Appendix G contains illustrations of the type of data to be collected to assess the impact of land runoff and industrial waste on the aquatic ecosystem. The specific parameters selected for analysis depend on the objectives of the study, which may require further classification as point or non-point source(s) when discharged into a segmented receiving water body (Note: a segment is an ecologic sub-area of a water body).

CHAPTER V

GEOGRAPHIC INFORMATION SYSTEM (GIS)

1. GIS Selection, ARC/INFO

While numerous geographic information systems are available, the functionality of each particular system limits its range of applicability. During the data entry phase of this research, it became apparent that the IBM Geo-Facilities Information System (GFIS version 2, release 2), was inadequate to meet project objectives (IBM, 1990). This assessment led to the choice of an alternative GIS which would provide the necessary functionality and retain a level of connectivity with the Monroe County Geo-Facilities Information System.

After review, it was decided that the Environmental Systems Research Institute, Inc. (ESRI) ARC/INFO (version 3.4D) adequately fulfilled the aforementioned criteria (ESRI, 1990). While several factors contributed to the choice of ARC/INFO, the fundamental reason stems from inherent design differences between the two geographic information systems. GFIS was designed primarily for management of network facilities. Network design necessitates the establishment of geographic position, connectivity, and flows between system facilities. In contrast, ARC/INFO was developed for applications involving environmental or areal analysis. As a result, the polygon processing capabilities of ARC/INFO are considerably more robust than are those of GFIS. The timely completion of project objectives dictated a system which would provide an ample set of polygon processing functions.

2. Relation to Data Bank Structure

Data collection, pre-processing, and conversion prepared the information for entry into a GIS. The data bank hierarchy formed the conceptual design of the GIS, which acted as the "computer director" of planning. Ecologic areas were entered into the GIS with pertaining attributes, including geographic location, for selected observation times. The areas and attributes were outputed in map and tabular form for different times. Calculations can be performed on attribute relations for a given area. Time-dependent functions, resulting from ecosystem responses to perturbations of an existing steady or transient state, are observable.

The attributes of a selected ecologic unit may be compared to those of any other unit in the data bank for the same or different times by relating their spatial data sets. Stipulated data sets may be superimposed spatially, thus, creating new units. Ecologic units, as entered initially or synthesized, may be shown as geographically defined areas at a scale of the source map or reduced. The map scale used in this report, 1:5,000, is suitable for on-site planning.

In summary, this GIS preserves topology, i.e. homeomorphic properties of the ecologic network. Attributes interact in the real world space they jointly occupy. If attribute values are introduced from the same or different hierarchic levels to simulate the areal ecologic response, a new entity may be derived. Responses depend on the transformation dynamics of the ecologic system. GIS cartographically represents the manifestation of these responses.

3. Data Entry

ARC/INFO employs a vector data model to represent the spatial locations of geographic phenomenon (features). This model portrays features as points, lines (arcs), or areas (polygons) located in a coordinate reference system. Whether a feature is represented as a point, arc, or polygon depends on the proposed application. Points may depict a class of features whose areal extent is below the specified minimum size for a mapping unit. For example, vessels are considered point features in the Stock Island data model. Arcs represent one-dimensional linear features, as boundary lines. Polygons, which represent areal features (e.g., seagrass meadows), are bounded by a closed set of arcs. Each feature is labelled with a unique numeric identifier which serves to link features with user designated attributes. Feature topology is established and subsequently utilized for spatial analysis of geographic databases (coverages).

Spatial location and attribute information were entered into ARC/INFO coverages by importation of digital files, and, by manual entry by project personnel. The Stock Island plat parcel map served as the base map for GIS data entry. A three section digital plat map in GFIS format was obtained from the Monroe County Property Appraisers' Office. Ferguson Cartographic, Inc., Dallas, Texas, digitized the plat parcel map utilizing an arbitrary coordinate system. The three map segments were edge-matched, transformed into the state plane coordinate system, and translated to ARC/INFO format by the staff of the GEOPLAN Center, University of Florida.

Digitizing procedures were used to trace area boundaries from source maps to GIS data files. Polygons were labeled and boundary vertices marked on hard copy maps to facilitate manual entry. The topological structure of each spatial database (coverage) was checked for completeness and accuracy.

Digital information for the spatially and temporally distributed features of the natural and developed environments was stored in a series of coverages. A separate coverage was created for each year of analysis included in the project (1850, 1907, 1945, 1959, 1963, 1975, 1985, 1990). A coverage is a collection of computer files which serve to maintain the topological relationships of features and their attributes, and, thus, facilitate spatial analysis. Users may manipulate the information contained within coverages. This functionality is provided by relational database management and by graphic editing tools.

The database creation process proceeded through several steps. Ecologic units were digitized in hierarchically descending order: small-scale (large area) features first (e.g., geo-regions), large-scale (small area) features last (e.g., parcel plat). Another criterion used was to digitize first features with well established, sharp boundaries. The nested design of the data structure allowed this digitization scheme. After boundaries were digitized, polygons were labeled with associated attribute information.

4. Data Analysis Examples

A powerful advantage of GIS is the ability to transcend limitations inherent in manual methods of spatial analysis. The processing power of GIS technology affords the user the ability to iterate spatially and facilitates the merging of data sources. However, the inherent accuracy of each data source defines the accuracy of the analytical results (i.e., the chain is as strong as its weakest link). Spatial analysis proceeds from the input data taken from source maps and from variables derived from initial primary observations. A detailed application of the GIS method is illustrated by Stock Island, situated east of Key West in the Lower Keys (Figure 7).

a. Regional Patterns. Geo-regions (Figure 8, in pocket) contain thematic information in bounded areas or polygons and correspond to hierarchical level 4 information (Figure 4, in pocket). Source maps for this data level were time sequential aerial photography, geo-rectified to a common base, and large-scale archival field maps and hydrographic charts. The outlines of the land, tidal, and water geo-regions were digitized by electronically coding coordinate locations of the outlines of the three regional polygons taken from the source maps. Since activities within the shore zone impact directly on coastal water quality, special attention was given to this area in the GIS analysis. The shore geo-region was defined to contain land and over-water features (docks and piers) located within 100 feet of the mean high water mark.

A series of steps was necessary to delineate member features of the shore geo-region. Each step was implemented using functions provided within ARC/INFO. The first step involved the re-selection of

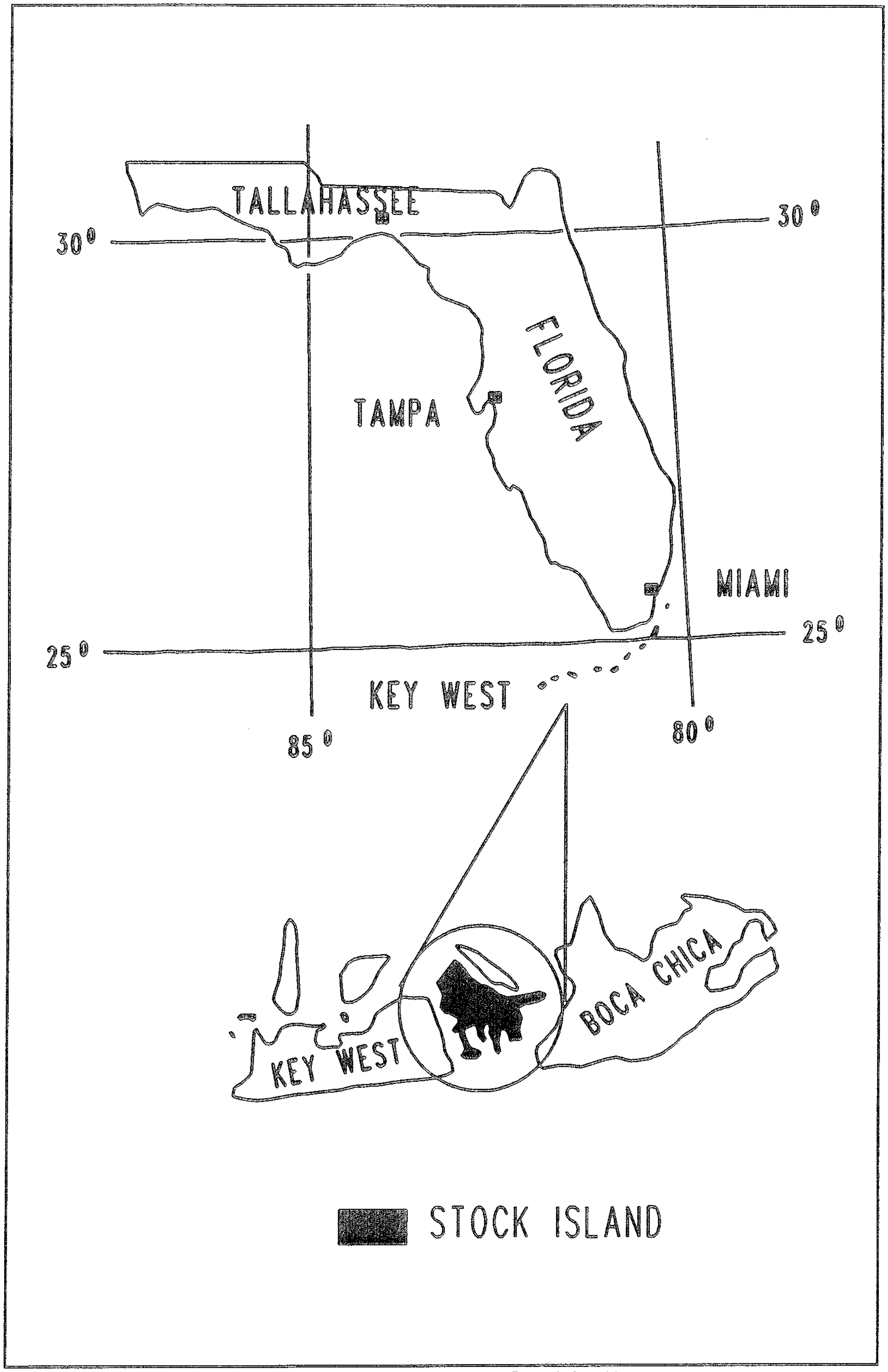


Figure 7. Location of Stock Island, Florida Keys

the shore boundary line from the entire set of coverage features. A 100-foot buffer zone was constructed on both sides of the selected line. Those features within this buffer zone which met the aforementioned criteria were summarized and mapped as the shore geo-region. This example illustrates how features may be selected based on their contiguity to a specific geographic phenomenon. Note in Figure 8 (in pocket), the changes in land, shore, tidal, and water areas in the 1907-1985 period. Table 1 summarizes these changes between 1945 and 1985 in total area (acres) and relative area (percent). The Stock Island study area totals 2807 acres. Tidal area declined by proportionately the same amount (-6 percent) as land area increased (+6 percent); water declined by the same amount (-4 percent) as shore increased (+4 percent).

Table 1. General Ecologic Areas of Stock Island

GEO-REGIONS	Total Area (acres)		Area Change		
				Percent	
	1945	1985	Acres	Geo-Regions	Study Area
LAND	324	508	+184	+36	+6
SHORE	87	191	+104	+54	+4
TIDAL	392	228	-164	-42	-6
WATER	2004	1880	-124	-6	-4
TOTAL	2807	2807	288	--	--

b. Ecologic History. Natural and developed land are level 5 coverages. Natural is a combined class that includes native marsh and hammock and disturbed grass, bare ground, and exotic vegetative features. Developed combines public, commercial, and residential classes, which include features, as roads, retail establishments, and single family homes. Initial changes can be discerned between 1907 and 1945 with nascent settlement of the island. Developed land expands after 1945 at the expense of natural cover and continues to the present (Table 2).

Table 2. Changes in Natural and Developed Regions of Stock Island (1945 to 1985; acreage and percent change within regions)

Regions		Acres	Percent
NATURAL	Land	-15	5
	Shore	-34	58
	Tidal	-233	62
	Water	-377	19
	All	-659	23
DEVELOPED	Land	+199	89
	Shore	+138	83
	Tidal	+69	78
	Water	+253	89
	All	+659	23

c. Dredge and Fill. Developed features, which correspond to hierarchical level 5 (Figure 4, in pocket), include dredged water and filled land, shore, and tidal features (Figure 9, in pocket). Note that fill corresponds to the expansion of the land areas shown spatially and temporally in the previous map. Very little land or shore was created prior to 1945, while large areas of fill were produced between 1945 and 1985. GIS facilitates this type of trend analysis by creating successive spatial overlays to reveal temporal progression. Table 2 shows additions by dredge and fill to land, shore, tidal, and water areas which occurred at the expense of natural regions. Greatest within region changes were: decreases in natural tidal and shore areas;

increases in developed (filled) land and (dredged) water. Area (acreage, percent) statistics for all hierarchical levels on Stock Island for the years 1945 and 1985 are presented in Appendix H.

d. Use Conformance Matrix. Mapping scale and resolution increase at the higher level numbers of the hierarchical chain: level 8 shows the greatest detail over a smaller ground surface area. Figure 10 (in pocket) shows zoned use according to the Monroe County Comprehensive Plan (Monroe County, 1986). The source map for these polygons was the county zoning map for 1990. The map excludes the portion of Stock Island in the City of Key West. GIS was used to overlay existing land conditions for 1990 (Figure 11, in pocket) onto the county 1990 zoned use map (Figure 10, in pocket). Spatial queries were performed to identify conforming and non-conforming areas for the county portion of Stock Island, located south of Highway US 1. A conformance matrix was constructed to show the decision process. The decision whether a given observed use conformed to the zoned use was made by county planners. The question, "Does existing use conform to the zoned use?" was asked. The conformality map and accompanying matrix for Stock Island (Figure 12, in pocket) were created by performing a spatial union of the two coverages: 1990 zoned land use and 1990 existing land use. The spatial union resulted in a new coverage which embodied the combined characteristics of zoned and existing use. The tape file of the parcel plats was superimposed on the land use conformance map to obtain a parcel polygon intersection with conformance/non-conformance polygons. This analysis indicated which parcels had uses in accordance with the zoning ordinance and which did not.

e. Attribute Values. GIS permits data entry of attribute information at any hierarchical level. The polygon attribute table consists of a series of unique records, each of which corresponds to a coverage feature. Each record maintains attribute values for its linked polygon, and, additional items (attributes) may be assigned to the table. The attributes may be referenced by the user and mapped for the polygon to which a particular record is assigned. An example of this GIS utility is Figure 13 (in pocket) which depicts the changes in assessed land and building values from 1982 to 1990. Assessed values were taken from the County Property Record Card File. Of a total 1079 plat records, data were available for 601 parcels located south of Highway US 1. The 1989 values were adjusted for inflation to a 1982 base value.

f. Plat Parcel History. An atlas of Stock Island, 1:5,000 scale, was compiled to demonstrate the value of GIS for local planning and small plat area analysis (Appendix I). This case study illustrates how GIS can be used to examine spatial-temporal changes on the Florida Keys. GIS can be used to connect the natural and developed ecologies to parcel plat locations, use, and ownership. The existing environmental ecosystem has ties to the development system which is directed by market valuations. The nodal link is the parcel: it has an ecology, a use, and, a decision-making owner who seeks a public or private income return from the parcel's use.

The environmental impact of parcel use can be monitored and its internal impact on the parcel plus its external impact on other parcels can be traced. The next chapter describes the interrelations among ecologic units.

CHAPTER VI

INTERRELATIONAL POLLUTANT ANALYSIS

1. Exchanges Among Ecologic Entities

The geographic space of the Florida Keys and Stock Island has been segmented into ecologic entities which conform to the units of the hierarchical data structure (Figure 4, in pocket). Data were entered into the GIS as polygons, arcs, and points, geographically located and described by feature attributes. The developed ecologies of some units generate waste loads which may impact other units. The purpose of this chapter is to develop an accurate method for tracing these spatial flows of pollutant loads, as shown generally by Figure 14, Flow Chart of Coastal Zone Waste Load Disposition. The chart describes the exchange network at the geo-regional level; it may be depicted for any level or across levels. Waste loads may be generated by a geo-region (or an entity within it) which may be wholly or partly exported to another geo-region (or entity) in a treated or untreated condition, or, accumulated within the same entity, or exported to the outside world. The residual impact is absorbed by the source entity and/or a geo-regional entity or in another geo-region. The capacity of a target to mitigate the impact of the waste load receipts is a function of its assimilative capacity for the pollutant. The interest of this report is on the unidirectional effect of land and shore entity uses on tidal and water geo-regions. The latter may affect each other and also may have in-situ activities which generate waste loads. Data are required on the load functions of technologies, treatment reductions, transformations, and disposal pathways. Reasonable estimates of these usually can be made.

The exchange system is structured as an interrelational matrix among ecologic entities for selected pollutants. It is set up in an input-output analysis format.

2. Input-Output Analysis

Input-output (I-O) analysis is used widely in national, regional, and interregional economic planning and forecasting. The format can be adapted to coastal management because I-O rests on the general ecosystem assumption that "everything is related to everything else." It is an analytical tool for tracking spatial pollutant exchanges. Input-output analysis was formulated by Leontieff (1951) to describe inter-industry

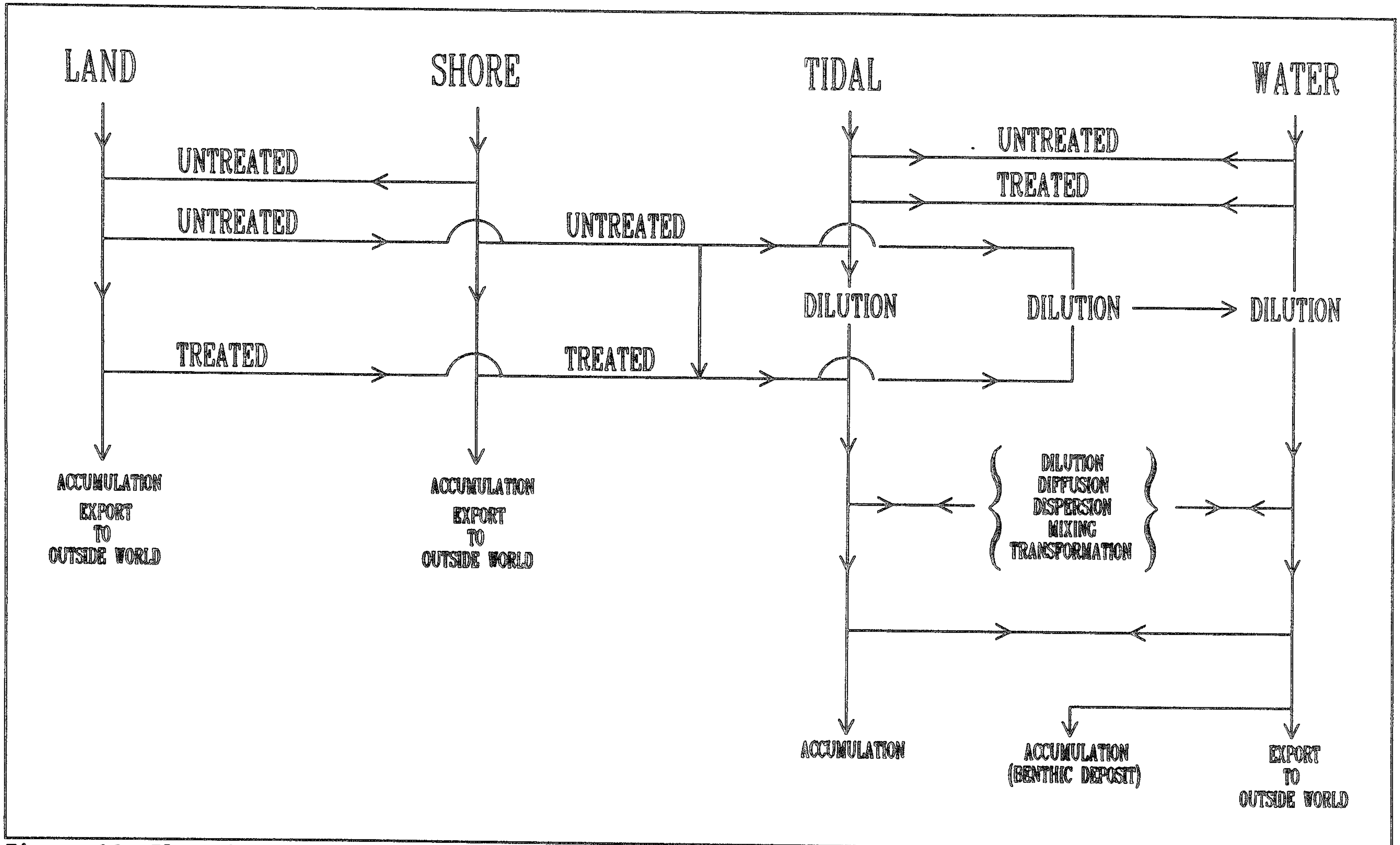


Figure 14. Flow Chart of Coastal Zone Waste Load Disposition (Conservative and Non-Conservative Discharge)

relationships of the entire economy of a country. The structure of an economy is examined by recording the details of inter-industry commercial activities within the economy. The data are entered into a matrix of raw materials, goods and services produced, received, and delivered (including to self), among economic sectors. Every exchange consists of a sale from a sector to a purchase by a sector.[1] Such exchanges reveal interdependencies among the entities for dissimilar commodities and services, which are expressed in currency values as the common denominator. Relations among entities are summarized by technical coefficients.[2]

The initial formulation of input-output analysis by Leontieff was performed on a whole national economy. Later versions were made for smaller areas and applied to multi-regional economies and interregional flows (Leontieff, 1951, 1965; Leontieff and Strout, 1963; Miernyk, 1965; Isard, 1975). Isard (1972, 1975) has applied input-output analysis to the coastal zone at large scale (small area) in a study of shoreline ecologic-economic relations. He treated the impacts of development, including pollutants, as residuals of commodity production and consumption evaluated as diseconomies. The two primary directions of Isard's reports were: (1) "to develop improved conceptual frameworks and new empirical materials for acquiring increased knowledge of the mutual dependencies of environmental processes, and, (2) to develop techniques for identifying and analyzing the important linkages between environmental processes and economic-social systems at various scales" (Isard, 1972, p. 228).

The format of an interregional input-output model is shown by Table 3. A transaction table shows the sales of a given industry to all other industries within the region and the sales of that industry to all other industries in other regions in the system. With adequate data on interindustry and interregional transactions, it is possible to compute

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[1]The exchanges may be described also at the level of the firm. This hierarchical approach is analogous to the data bank structure. For a defined economic area, the procedure works upward from the operating level of the firm and traces input and output connections to all other firms. Firms may be aggregated to the next higher level, to manufacturing, agriculture, trade and services, to delineate flows among included sector categories. The more sector categories are divided, the greater is the precision of results. Links to an outside world also are shown. The firms and sectors examined are set by the purpose of the analysis and the availability of data.

[2]Knowing the level of output of a sector and the level of inputs to that sector by a firm or another sector, a technical coefficient can be calculated which gives the input of the supplying firm or sector per unit of output of the producing sector or firm; similarly, the share of the use of a given input going to a firm or sector divided by the total output of the firm or sector supplying the input can be determined.

Table 3. Interregional and Multiregional Input-Output (Miernyk, 1965)

		East							South							West									Subtotals						
		1 Agriculture & Fishing	2 Food Processing		9 Chemicals			20 Households & Govt.	1 Agriculture & Fishing	2 Food Processing		9 Chemicals			20 Households & Govt.	1 Agriculture & Fishing	2 Food Processing		9 Chemicals			20 Households & Govt.	Exports (national)	Total Output	1 Agriculture & Fishing	2 Food Processing		9 Chemicals			20 Households & Govt.
East	1. Agriculture & Fishing																														
	2. Food Processing																														
	9. Chemicals																														
	20. Households & Govt.																														
South	1. Agriculture & Fishing																														
	2. Food Processing																														
	9. Chemicals																														
	20. Households & Govt.																														
West	1. Agriculture & Fishing																														
	2. Food Processing																														
	9. Chemicals																														
	20. Households & Govt.																														
	Imports (national)																														
	Total Input																														
Subtotals	1. Agriculture & Fishing																														
	2. Food Processing																														
	9. Chemicals																														
	20. Households & Govt.																														

input coefficients for each region and the effect of changes in demand for each industry in each region (Miernyk, 1965).

3. Adaptation to Safe Harbor Study

The input-output analysis format has been adapted to the real world ecologic conditions of the Safe Harbor embayment. The interregional relations among the geo-regions of the entire study area, land, shore, tidal, and water, are shown by Table 4. The connectivities of the interrelational table were set up according to the following rules: (1) exchanges are amounts of pollutants; (2) connections between land and shore geo-regions to tidal and water are made, but the reverse flow is interdicted; (3) tidal and water are two-way linked to each other; (4) tidal and water are connected to themselves.

These guidelines facilitated the description of the ecologic processes of the embayment as an origin (pollutant source) - destination (pollutant impact) matrix in which the primary focus is on the qualities of the tidal and the water geo-regions. The row and column headings of Table 4, land, shore, tidal, water, are geo-regions analogous to economic sectors of formal input-output analysis. Within each of the linked geo-region cells, selected lower level ecologic entities and the associated pollutants values may be inserted in rows and columns, which intersect in a "from-to" matrix. The position of an ecologic entity in the data bank ecologic hierarchy of the Stock Island embayment shows its geographic-pollutant relation to other entities. The selection of ecologic entity level is governed by objectives of the study. The following ascending order of detail is implied: geo-region, region, subregion, area, existing use, and parcel (the order parallels the hierarchical structure of the data bank). Table 4 shows the table structure at the geo-regional level. These data are entered into GIS as descriptive feature attributes of the ecologic entities.

Pollutant technical coefficients, analogous to those of input-output analysis, may be calculated for the ecologic entities, singly or paired for each pollutant parameter, expressed as a ratio or percent. Thus, the following questions can be asked: What percent of pollutant P1 produced in ecologic entity land is delivered to ecologic entity tidal?; What share of land's pollutant P1 is exported to water?; Of the total amount of pollutant P1 in tidal, what share comes from land and what share comes from shore, and what share comes from itself? The ecologic entities are positioned at the same level in the embayment data hierarchy. The relation between ecologic entities at different levels may be examined, as, What share of deep water's P2 pollutant comes from boatyard? If pathway field data are available, geographic cross-tabulations will identify environmental "hot spots" and ecologic entity "victims."

Table 4. Pollution Production and Transfer Among Geo-Region Ecologic Entities (kg/l)

FROM → TO → ECOLOGIC ENTITY	POLLUTANTS	LAND			SUBTOTAL	SHORE			SUBTOTAL	TIDAL			SUBTOTAL	WATER			SUBTOTAL	TOTAL
		P_1	P_2	P_n		P_1	P_2	P_n		P_1	P_2	P_n		P_1	P_2	P_n		
LAND	P_1																	
	P_2																	
	P_n																	
SUBTOTAL																		
SHORE	P_1																	
	P_2																	
	P_n																	
SUBTOTAL																		
TIDAL	P_1																	
	P_2																	
	P_n																	
SUBTOTAL																		
WATER	P_1																	
	P_2																	
	P_n																	
SUBTOTAL																		
TOTAL																		

CHAPTER VII

COASTAL WATERS ASSESSMENT

1. Levels of Analysis

The stepwise procedures described in the previous chapters are rationally coordinated and may be used to establish site planning priorities in the coastal zone. The required analytical detail depends on policy objectives, urgency of environmental concerns, training and skills of staff, and fiscal resources. Regardless of objective, the same body of information should be considered, whether obtained from hearsay, casual observations, guesstimates, common sense judgements, in-depth data collection, simplified assumptions for mathematical estimates, or, the application of physical, chemical, biological and ecological principles incorporated in computer models. Each of these methods provides guidance and will require validation by subsequent empirical observations of local conditions. Land-shore-tidal-water zones are delicately balanced sensitive systems. Approaches that incorporate the experience of other areas, including reliably assembled data to calibrate bio-hydrodynamic model equations, are most likely to provide the kind of guidance needed for an environmentally compatible Florida coastal management program.

2. Data Requirements

a. Biochemical Oxygen Demand-Dissolved Oxygen Coupled Reactions. Most of the discharges into embayment waters are non-conservative biochemical oxygen demanding (BOD) components. Non-conservative substances decay as a function of time and temperature. In addition, conservative and non-conservative elements are diluted by dispersion and tidal mixing. Hence, the concentration of non-conservative pollutants will be less than for conservative pollutants, whose decay rates are zero, for equal concentrations of discharge rates. The dissolved oxygen (DO) content of bay waters is the single most important quality parameter. DO is linked to the BOD constituents of water, as described by the BOD-oxygen sag model. (The DO content of water also is an inverse function of temperature and salinity). For these reasons, the BOD-DO system is used to illustrate how the acquired information on ecologic entities stored in GIS is applied to the Safe Harbor case study embayment.

The movement and transformation of discharged waste materials through coastal waters is governed by hydrodynamic transport functions and biochemical reactions involving biota, plant growth, suspended materials, and benthic deposits of varied organic and inorganic compositions, and conservative and non-conservative wastes. The following sequence of Figures 15 and 16, and Tables 5 and 6 describe an assumed steady-state dynamics of the baywater environmental reaction system.

The overall relationships are shown by the flow chart in Figure 15 for the coupled reaction of BOD and DO. The flow chart shows that reactions are subject to environmental controls and forcing functions. The aquatic reaction system requires a renewable supply of free oxygen to cope with the effluent load of BOD waste materials in order to maintain system state levels and avoid a degraded state.

The two processes involved are biochemical oxidation and reaeration. The rates of the two reactions are combined and the resulting equations expressed as a dissolved oxygen deficit (DO). Interaction of the deoxygenation of BOD polluted water and its reoxygenation by reaeration from the atmosphere and by aquatic plant photosynthesis creates a dissolved oxygen (DO) sag curve when oxygen water content is plotted against time. The DO decline occurs in a flowing body of water with mean velocity and direction along the path of water movement. The DO path is called the Streeter-Phelps DO sag curve (1925). Reaeration and deoxygenation are related by the curves shown in Figure 16.

From Figure 15, the sources and sinks of oxygen can be identified:

(1) sources (a) ambient water movement into the embayment during the flood tide flow, (b) reaeration from the atmosphere across the aquatic interface, (c) photosynthesis by aquatic plants and algae and the liberation of oxygen.

(2) sinks (a) oxidation of organic matter, (b) decomposition of accumulated bottom deposits, (c) respiration of aquatic plants, algae, fish, and crustaceans, (d) oxygen demands of chemicals.

Both source and sink transformations and benthic storages have reaction rates and storage functions reflecting environmental conditions and refractory biochemical properties of the materials. The coefficients of the transformation equations and the flux rates determine the assimilative capacity of the receiving body of water, as summarized in Tables 5 and 6. The rate coefficients for the sources and sinks of oxygen are affected by changes in temperature, characteristics of waste discharges, and degree of waste treatment (Eckenfelder, 1980). Preventive and remedial management strategies also are suggested by relating Tables 5 and 6.

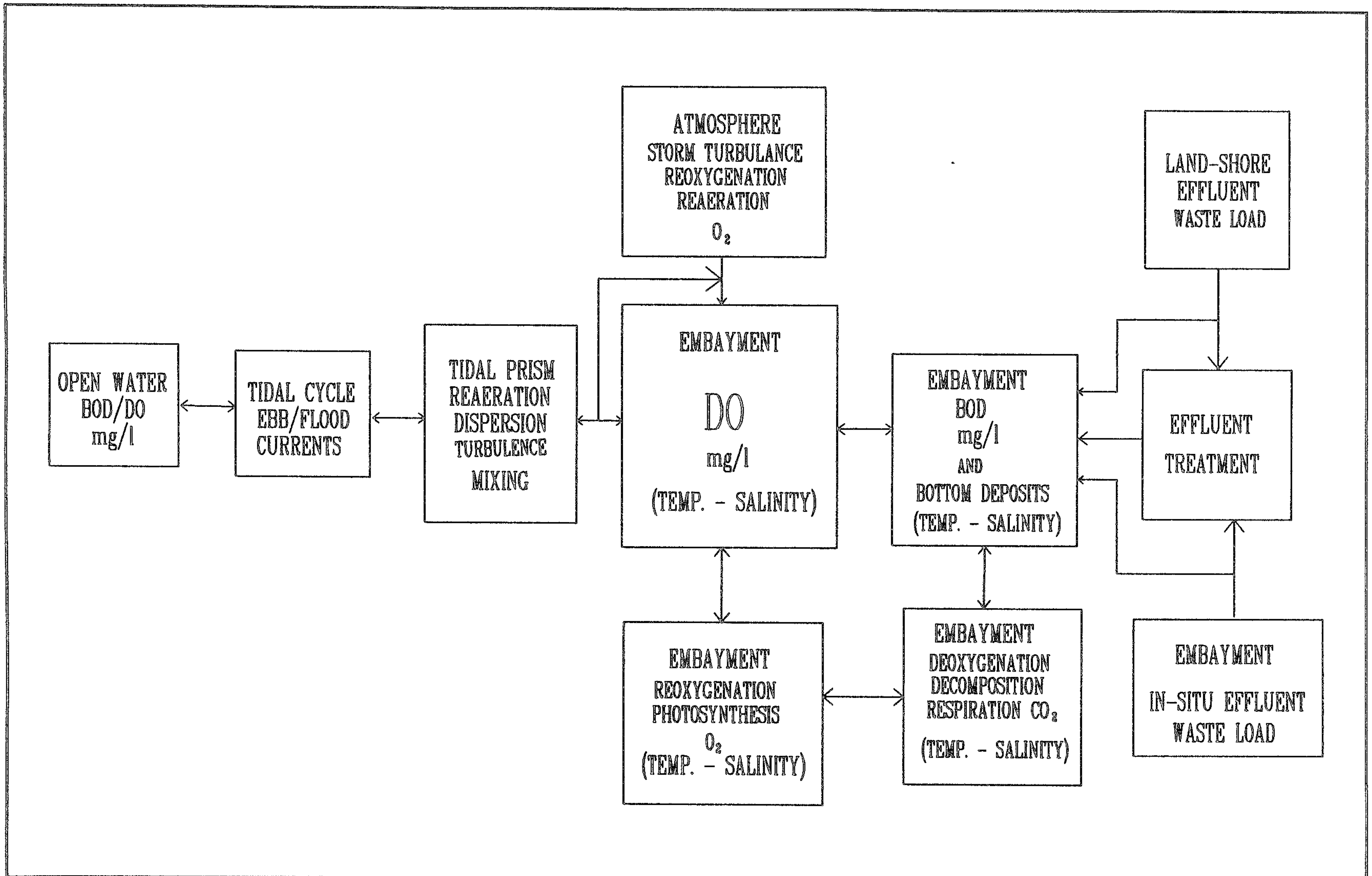

Figure 15. Biochemical Oxygen Demand - Dissolved Oxygen Demand Coupled Reaction in Embayment Waters

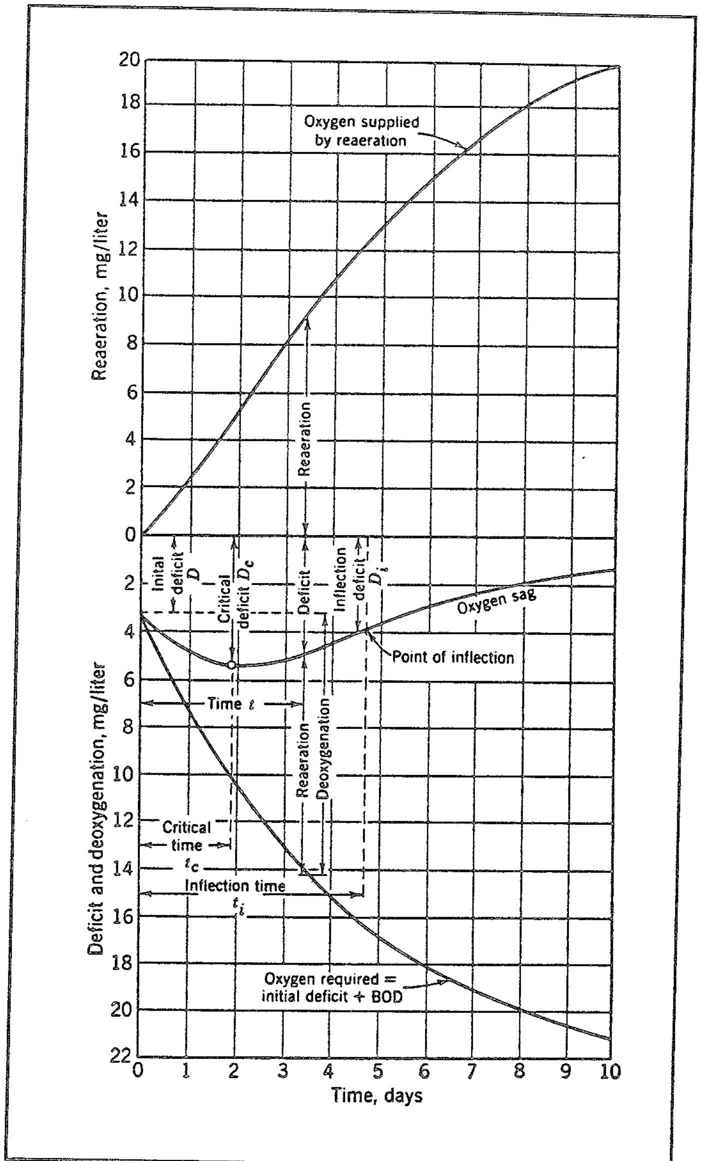

Figure 16. The Dissolved Oxygen Sag and its Components: Deoxygenation and Reaeration (Fair and Geyer, 1958)

Table 5. Coefficients for the Evaluation of the Assimilative Capacity (Eckenfelder, 1980)

Coefficient	Definition	Dependent on	Temperature Coefficient(-)
K_1	Oxidation-rate coefficient for soluble organics	Concentration and nature of organics remaining	1.065-1.075
K_r	Removal-rate coefficient for all organics; includes oxidation, sedimentation, and immediate demands	Concentration of total organics remaining	1.00-1.075
K_3	Removal rate by sedimentation	Concentration of settleable organics	---
K_2	Reaeration coefficient	Stream velocity and depth	1.028
K_n	Rate coefficient for nitrification	Nitrogen concentration present; concentration of organics and presence of secondary sewage effluent	1.106
k	BOD-bottle-rate coefficient	Nature of organics, i.e. raw waste or treated effluent	1.065-1.075

Table 6. Changes in Rate Coefficients as a Result of Environmental Effects (Eckenfelder, 1980)

Coefficient	Temperature Coefficient	General Effects
K_r	1.0-1.075	Reduced by removal of suspended solids by treatment; temperature coefficient increases as K_r ---> K_1
K_1	1.075	For complete removal of suspended solids $K_r = K_1$; increases by addition of readily assimilable waste; decreases with degree of treatment of wastewater; increases with increasing stream fertilization
K_n	1.106	Increases with degree of treatment (domestic sewage); low for nitrified effluent
K_2	1.028	Decreases with the addition of untreated wastes or surface-active agents; increases with degree of treatment of wastewaters; increases with velocity; decreases with increasing depth

b. Data Acquisition. Figure 15 and Tables 5 and 6 indicate the governing parameter values of a water body that need to be evaluated in order to assess the biochemical response of an aquatic ecosystem to receipts of waste discharges, (refer to Appendix G). The following physical hydraulic data and biochemical water quality data should be collected:

> **Physical and hydraulic data** - water velocity, water volume, water depth, cross-sectional area of water flows, channel characteristics, time variations in the water flux, impoundments or backwater areas, transport processes, tidal prisms, bottom deposits, boundary concentrations, and initial states.
> **Water quality data** - temperature, salinity, dissolved oxygen, biochemical oxygen demand (soluble and non-soluble), suspended solids, ammonia and nitrate nitrogen, chlorophyll, living organisms, waste loads, and, locations, identifications, volumes, and concentrations of point and nonpoint pollutant sources.

The scale and detail of data acquisition depends on available resources, data accessibility, "model" requirements, and research objectives.

3. Safe Harbor Case Study

a. Data Collection and Storage. A case study application of the GIS will be illustrated in this section. Safe Harbor is a dredge-and-fill constructed embayment on Stock Island (Figure 17, in pocket). The geographic cross-section of Stock Island (Figure 5) shows the geologic material used in the operations and the depth of and to the oolite and limestone beds. Safe Harbor was built in the mid-1950s to satisfy the anticipated increase in passenger and commercial traffic to and from Cuba, 90 miles distant (see Appendix C, Historical Sketch of Stock Island). The embayment is in the water geo-region and is related directly to the adjoining shore and land geo-regions. The tidal geo-region is barely present, but, daily tidal cycle flows occur. Shoreside docks extend into the embayment water.

Ecologic feature attributes (level 8, Hierarchical Data Structure, Figure 4, in pocket) are mapped in Figure 17 as: land - roads, utilities, residential-commercial, mobile home, tourism, general commercial, industrial; shore - exotic vegetation, roads, utilities, residential-commercial, marinas and boatyards, fish processing, warehousing, salvage yards, boats; tidal - mangrove; and, water - natural shallow, natural deep, developed shallow, developed deep, navigation, and dockage. Area statistics on all feature attributes of Safe Harbor for 1985 are given in Appendix J. Not all land, shore, tidal, and water features affect the quality of Safe Harbor's embayment waters. The interior land boundary between linked land units and embayment water was based on field observations, air photo studies, and archival maps of predevelopment drainage patterns. Attribute descriptions for each of the ecologic units cited above are immediately available from the relational data files stored in the GIS Data Bank. The position of the feature attribute in the data bank provides ancillary information. Table 4 illustrates the arrangement of the information, which may be used to calibrate the DO-BOD equations. Alternate values may be substituted for simulation experiments by validated models.

These additional descriptive data fall into the physical hydraulic and water quality data categories mentioned earlier, and relate to segmentations of the embayment, associated mainly with the water and tidal geo-regions. Water quality data readily acquired on a regular basis or periodically obtained by grab samples, can provide a sound basis for establishing bay segment priorities. Reliable, portable, easy-to-use chemical kits are available to estimate DO, BOD, and toxic substances.

Waste load estimates are associated with land and shore geo-regions. (Anchored live-aboard vessels are excepted.) The source activities are associated with the existing use level of the data bank. Waste loads usually can be categorized as: (1) point sources from sewage treatment plants and industrial, manufactural processing activities; and (2) non-point sources with diffuse areas of entry into the water body. Non-point include urban and other residential storm water runoff, agricultural drainage (or eroded sediments, fertilizers, pesticides and animal manures), forested or other vegetated watersheds, and highway, street, and parking lot runoff.

The required accuracy of these data depends on the intensity of the empirical research effort to ascertain the concentration of the pollutant in the waste effluent and the total volume of its discharge, including time distribution variations. Estimates of the values may be made by direct sampling or monitoring, interviews, non-sampling informal observations, or by reference to prototype average ranges of the given activity adapted to local conditions. Corrections should be made for waste treatment prior to effluent discharge. These data can be stored in ARC/INFO as a descriptive attribute. Table 7 illustrates this for municipal sewage (Eckenfelder, 1980).

b. Coastal Hydrography and Simplified Field Study. Research and field studies on the impact of waste discharge on the quality of receiving waters have focused on rivers, streams, lakes, reservoirs, and estuaries. A widely accepted definition of an estuary is " ... a semi-enclosed coastal body of water which has a free connection with open sea and within which sea water is measurably diluted with freshwater derived from land drainage" (Pritchard, 1967). The coastal waters of the Keys do not receive freshwater stream inflows in any significant amounts because of the small area and low elevation of the islands. Like estuaries, however, the Keys' waters are subject to tidal action, but the ratio of stream flow to tidal flow is minimal, and a sharp interface does not develop between deeper saltwater and surface freshwater discharge. Advective or turbulent mixing between the two across the interface is restricted. The coastal waters of the Keys tend to be vertically homogeneous in their salinity contents. Mixing in the embayment occurs by transport of water quality constituents, by advection, and by dispersion. Tidal currents carry quality constituents to ambient water and results in dilution by inflow. Dispersion causes further mixing and dilution between regions of high and low concentration gradients. However, in general, water column exchanges which influence the transport of dissolved and particulate pollutants in coastal embayments and estuaries where the freshwater flow is very small, can be neglected. Hence, the dispersion coefficient plays a crucial role in the dissolved oxygen and pollutant contents of the nearshore waters of the Keys.

Table 7. Average Characteristics of Municipal Sewage (Eckenfelder, 1980)

Characteristics	Maximum	Mean	Minimum
pH	7.5	7.2	6.8
Settleable solids, mg/l	6.1	3.3	1.8
Total solids, mg/l	640	453	322
Volatile total solids, mg/l	388	217	118
Suspended solids, mg/l	258	145	83
Volatile suspended solids, mg/l	208	120	62
Chemical oxygen demand, mg/l	436	288	159
Biochemical oxygen demand, mg/l	276	147	75
Chlorides, mg/l	45	35	25

The basic water quality governing parameter for an estuary receiving polluting inflows is the flushing time, which is defined as the length of time (usually measured in tidal cycles) required to replace existing freshwater in an estuary (Tetra Tech Inc, 1977). The replacement rate is calculated from the stream discharge rate, and, thus, represents the time required to flush a pollutant out of the estuary, adjusted for the location of the pollutant outfall from the embayment inlet. Stream discharge is non-tidal seaward flow. It is the driving force of estuarine flushing, responsible for the advective displacement of pollutants. The oscillatory motion of the tides and the volume of tidal water involved in flushing are defined by the embayment's configuration (surface area) and by its tidal range (depth). Flood and ebb tide current velocities are set by the width of tidal inlet and tidal range. Flushing action of the coastal waters of the Keys is less effective than flushing in estuaries which receive substantial freshwater inflows.

A simple field method of estimating flushing time adaptable to the Keys' conditions would be to segment an embayment into uniform lesser areas subject to different levels of pollutant stress. The length of each segment is definable by the observed path of water dye tracers or floating debris or markers during a tidal cycle. The tidal prism can be compared to the total segment volume and the volume ratio used as a measure of the flushing potential of the segment per tidal cycle. This method assumes mixing of the flood tidal waters with the low water volumes within the segment (Tetra Tech Inc., 1977). The results enable the user to rank or prioritize segments within an embayment. The method also should be very helpful to planners concerned about water quality of canal networks, especially residential canals (Morris, 1981). Waste loads and water quality parameter values can be obtained and related to the circulation of segment waters (see section 3). Approximate analyses of physical conditions and biochemical transformations under alternative uses adequate for initial quality impact assessment may be derived from nomographs based on empirical segment studies. These can be used to set local planning priorities and, possibly, regionally generalized goals (Hydroscience, 1971).

c. Computer Model WASP4 Application. Water quality computer modeling programs have been applied successfully to a variety of water resource management problems. The programs are able to represent and simulate real world quality levels and the bio-hydrodynamics of water bodies. Water Quality Analysis Simulation Program (WASP) has been applied to many water resource concerns, in various physical, chemical, and biological modeling frameworks, as BOD-DO, eutrophication, and toxic materials, for different hydrographic environments, streams, lakes, and estuaries. Within its general structure, WASP provides wide user flexibility and allows the modeler to specify exchange coefficients, advective flows, boundary and initial conditions, waste loads, and kinetic processes. The user is able to incorporate intuition, judgements, and a full range of local empirical data. In addition, the programs perform at a range of geographic scales (Ambrose et al, 1988). For these reasons, WASP (version 4.3) was applied to the BOD-DO relationship of Safe Harbor, to assess embayment capacity to assimilate waste loads.

The purpose in demonstrating the use of WASP4 on Safe Harbor was to illustrate also the integration of the entire process into a continuous information-analytical system. Several simplifying assumptions were made to facilitate the computer runs. These were:

1. Safe Harbor was treated as one segment;

2. Boundary conditions and initial values were obtained from the literature and no samples were taken of Safe Harbor waters or the ambient water. The sources consulted for BOD and DO values on the Keys were STORET and research publications (Lapointe et al, n.d.; Schroeder, 1987a; Heatwole, 1987; CH_2M Hill; 1984);

3. Waste pollutant concentrations and volumes were estimated from direct observations, interviews, and literature values. These data are stored in GIS attribute files related to polygons,

arcs, and points. The effluent values were converted to BOD concentrations, aggregated, and treated as a point discharge. The sources of the BOD loadings were from land and shore activities: (a) land - residential home sanitary waste treated by a shore area package plant, and, street storm water, discharging into separate vertical drains drilled into the underlying porous limestone[3]; (b) shore - marina with live-aboard vessels, fish processing with washings and disposition of carcasses in water, shrimp washings to remove sodium bisulfite preservative applied to catch at sea (sulphite has a high immediate demand for DO), crews living aboard dockside vessels.

4. Information on the hydrography of Safe Harbor and environs was obtained by field observation and from maps, and air photo interpretation. These descriptive data files also were stored in GIS.

5. Several parameter input values required by WASP4 were estimated following the suggestions of program instructions and EPA consultants on the staff of the Environmental Research Laboratory, EPA (Ambrose et al, 1988).

6. The total waste BOD load discharged into Safe Harbor was estimated from shoreline uses to be 200 kg/day. For the purposes of this illustration, seasonal variations were not calculated.

7. The "observation location" was the center point of the Safe Harbor embayment.

User options in the WASP4 program make it possible to model tidal oscillations as stream flow by fitting a piecewise time function to the tidal velocity curve to obtain dispersion coefficients (m^2/sec).

Current velocity used in the simulation was derived from the basic discharge equation (discharge = velocity x cross-sectional area), by relating the effective cross-section of the inlet area to the volume of flood and ebb tidal flows in one cycle. The volume of flow was determined from the tidal range and surface area. The cross-sectional area through which the flow volume passed in a 12 hour period (1 cycle) was obtained from the tidal range and the inlet width.

The output of the BOD-DO reaction system simulated by WASP was compared to earlier observations of Safe Harbor and nearshore waters made in 1983 to monitor the impact of an adjacent power plant. The results of the earlier monitoring study showed a depression in DO content for observations at stations located inside the harbor, below the Florida state level of 5.00 mg/l, (Table 8). The WASP simulation

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[3]The effluent from the vertical drains goes into the permeable Key Largo limestone, and is discharged into the bay waters, subject to tidal influence (Lapointe and Clark, 1990, Hanson, 1980).

Table 8. Dissolved Oxygen in Safe Harbor - Comparison of Wasp Simulation and CH_2M Hill Observations.[1]

ITEMS	WASP SIMULATION	Sample Location A3			Sample Location A4			Sample Location 06			Sample Location 01		
		Date			Date			Date			Date		
		2	3	4	2	3	4	2	3	4	2	3	4
DO mg/l	4.6	4.5	4.4	4.4	4.2	4.8	4.5	5.6	5.4	5.3	4.6	1.4	2.5
Time to steady State, days	25	-	-	-	-	-	-	-	-	-	-	-	-
Temperature, C	28.0	27.8	33.9	26.0	27.7	34.1	26.0	28.0	31.9	25.9	32.0	38.6	29.0

[1]CH_2M Hill (1984) observations at assumed steady state surface water.
Time of observations: 2 = 5/20/83, 3 = 8/25/83, 4 = 12/01/83
Locations: A3-Inland water, A4-Channel Water, 01-Discharge canal of steam power plant, 06-ambient water, WASP-Assumed central point of water
Note: Florida DO coastal water standard = 5.00 mg/l

was sensitive to the fall in DO despite simplifying assumptions, agreeing with embayment station observations. WASP and these stations are below the ambient water level, which is above the state coastal water standard.

The next chapter will discuss a procedure for quantitatively evaluating the capability of a nearshore water body to furnish the resources needed by existing or projected uses without degradation. The method facilitates the search for effective regulation of existing or potential uses (preventive, avoidance, remedial) or alternative uses and/or locations.

CHAPTER VIII

COASTAL USE CAPABILITY CLASSIFICATION

1. Introduction

The previous chapter brings to a close the information collection, pre-processing, arrangement, storage, and analytical phases of the report. Ecologic entities have been related geographically and hierarchically with their attributes, and have been described from the highest level of the geo-region to the lowest level of the plat parcel. The data have been stored topologically in a GIS, i.e., each member of the system can be spatially identified with its attribute features individually, and, associated with all other members, separately or collectively. A pollutant transactional matrix shows waste effluent linkages. Together, these steps provide insight into entity internal dynamics and functions of each entity in the whole water-tidal-shore-land system at a range of geographic scales.

This chapter presents a method for utilizing the information normatively, that is, to satisfy the objective of using the nearshore waters of the Keys in ways that will sustain their ecologic qualities at stipulated levels. To resolve the dilemma, there clearly must be an accommodation between use technologies, intensities, and magnitudes, and the inherent capacities of the coastal waters to survive the interventions. A Coastal Use Classification System (CUCC) facilitates the evaluation of the suitability of an ecologic entity for an existing or intended use. Provision is made for the inclusion of modulations that enhance suitability.

The extension of the resource capability concept of CUCC to coastal waters is the latest development in the continuum of earth resources management history that relates natural local site environmental conditions to site use technology. The application of CUCC to nearshore waters is the outgrowth of two land resource evaluation methods: (a) land use capability classification system of the U.S. Soil Conservation Service which classifies the agricultural capability of land, using soil erosion as the decision parameter. Parcels are ranked nationally for use type and intensity, after being site examined locally; and (b) multiple use classification method of the U.S. Forest Service which classifies forest land as a management tool for allocating areas to partially competitive uses in a way that maximizes public benefits on a sustainable basis (Klingebiel and Montgomery, 1966; Convery, 1977) (see Appendix K).

Similar concerns face coastal states, counties and municipalities. Coastal waters are in an early stage of classification and evaluation. Site evaluation is difficult, however, because of the complexities of nearshore land-water bio-hydrodynamic ecologies. The spatial mixing of physical site properties enhances analytical problems. Clark (1977) has followed the above land capability approach, using Corpus Christi Bay, Texas, to show principal water and land units (Figure 18). The Monroe County Comprehensive Plan (1986) has a partially developed system to make a habitat evaluation index of land and shore sites (Schroeder, 1987b).

As indicated earlier, CUCC linked to GIS topology, merges planning issues into an analytical planning tool. The detail and scale of analysis are related to entity category, level, type, function, use, area, and normative objectives. For nearshore water classification, each of the ecologic water units is treated as a unique ecosystem. Their water-land bio-hydrodynamic time dependencies appear to be more sensitive than land ecosystems. CUCC will have the ability to work at the scale of Figure 18 and larger scales to the level of the elemental plat parcel.

2. CUCC Algorithm

The suitability of a coastal aquatic entity for an existing or intended use, whose ecology and technology are known, can be evaluated based on empirical and empirical-theoretical considerations.

a. Empirical. This permits identification of incompatibilities. The existing state of a water body is determined from an adequately designed sample. Selected quality parameters are appropriately analyzed and compared to accepted standards. Site adjustments may consist of technologic changes, effluent treatment, or, off-site waste disposal.

Thus, let P_{ij} = value of the i parameter in the j ecologic entity
S_{ij} = value of the i standard parameter for j ecologic entity

with Pij and Sij values adjusted to same conditions, as temperature, salinity, depth etc.

for a given ecologic entity, j, i=1…n, i may be weighted;
j=1…N

And, (1) $$E_{ij} = \frac{P_{ij}}{S_{ij}}$$

the state of an ecologic entity for one parameter, i=1, j=1

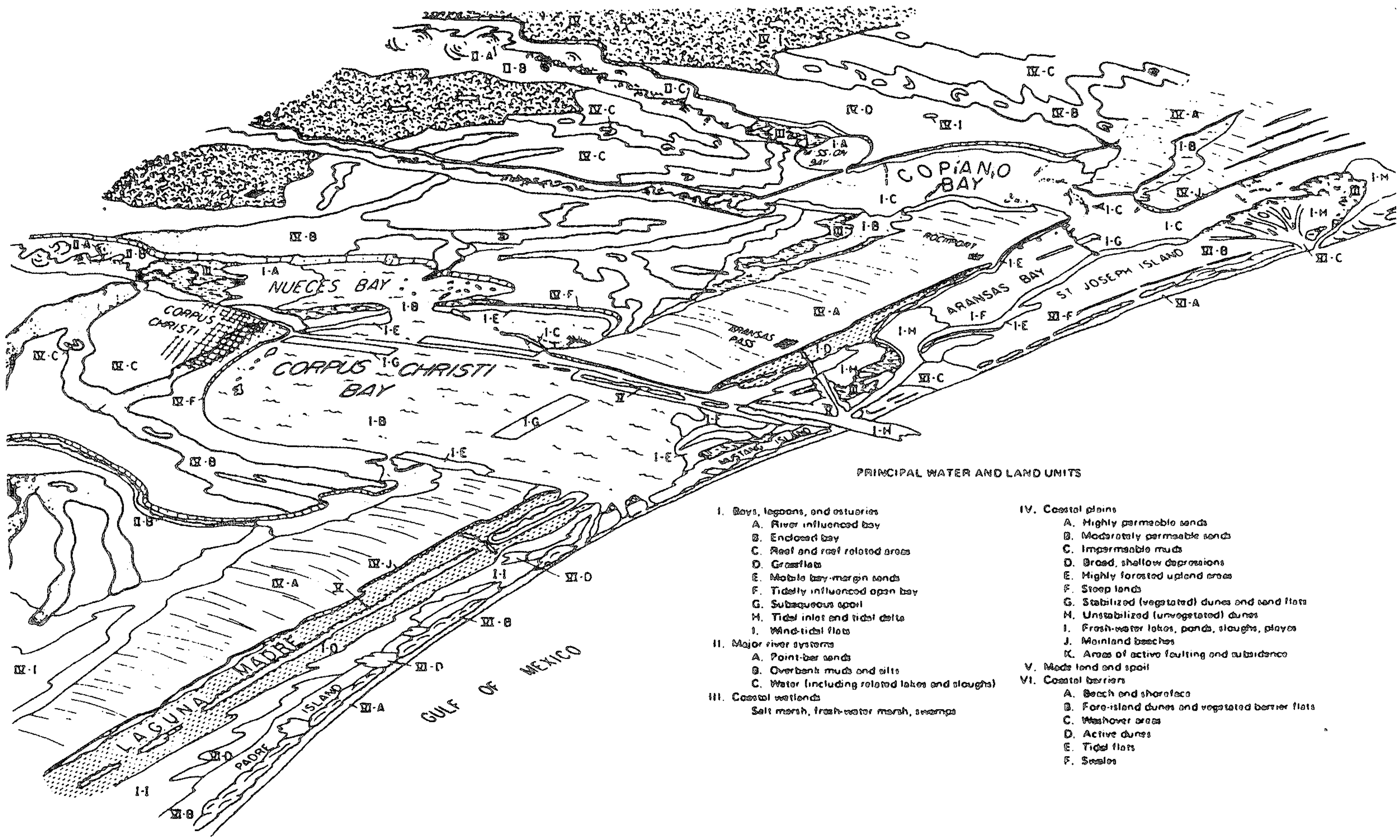

Figure 18. Environmental Capability Units (Clark, 1974)

(2) $$E_{j=1} = \sum_{1}^{n} \frac{\left(\frac{P_{ij}}{S_{ij}}\right)}{n}$$

the state of an ecologic entity for more than one parameter, i=n, j=1

(3) $$E_{j=N} = \sum_{j=1}^{N} \frac{\left(\sum_{1}^{n} \frac{\frac{P_{ij}}{S_{ij}}}{n}\right)}{N}$$

the state of an ecologic entity composed of smaller ecologic entities whose states have been evaluated over several parameters and entities, i=1, j=n

b. <u>Empirical-Theoretical</u>. Permits identification of incompatibilities and the avoidance of potential adverse impacts of intended uses; is the aquatic site adequate to meet the demands of the use technology?, can site capacity be enhanced by in-situ innovation: technology alteration, effluent treatment, or reduction of output; would an alternative use be less demanding?

The following information is required: identify the physical site requirements of the intended use technology at stipulated levels of output; identify the availability of the same set of physical attributes at the site, can site physical attributes be enhanced?

Compare by matching the two correspondent sets of attributes, use technology and aquatic ecology, evaluated in same dimensions.

Thus,
let A_{ij} = value of i attribute parameter of j parcel
U_{iw} = value of i required parameter of w use technology

with A_{ij} and $U_{iw,j}$ correspondent sets of i, and j=1…N, i=1…n for j and w,

And, (4) $$C_{iw=ij=1} = \frac{A_{ij}}{U_{iw,j}}$$

the compatibility between the i attribute of the j ecologic entity and the i required attribute of the w use technology.

(5) $$C_{i=n, w=j=1} = \frac{\sum_{1}^{n}\left(\frac{A_{ij}}{U_{iw,j}}\right)}{n}$$

mean compatibility between several attributes of the j entity and required attributes of w use technology.

(6) $$C_{i=n, j=N, w=1} = \sum_{j=1}^{N} \frac{\left(\frac{\sum_{1}^{n} \frac{A_{ij}}{U_{iw,j}}}{n}\right)}{N}$$

mean compatibility between the attributes of an ecologic entity including smaller entities and the attributes required by a given use technology evaluated over several parameters and entities, i=n, j=N, w=1. Equation (6) can be solved separately for alternative (w) use technologies.

As aquatic systems models improve, their ability to predict the interactions between use technology and the ecologic state of an embayment will become more reliable. Alternative choice decisions can be evaluated with greater precision. The accuracy of physical data inputs will enhance understanding of the relation between hydrodynamics and biochemical transformations.

Equation (1), (2), and (3) evaluate the existing state of an entity for selected observed quality parameter values compared to standard values for the same parameters. Equations (4), (5), and (6) assess the impact on a quality parameter of a selected use technology applied to an entity. If the use drives the level of parameter value below the standard, it is degrading; if use does not reduce quality below the standard level, it is acceptable.

The assimilative capacity of a given entity for a specific use technology at a stipulated output can be defined. Managerial strategies are available to the planner - reduce output, change use technology, treat the effluent prior to discharge, enhance the capacity of the entity to transform the effluent, export the effluent.

CHAPTER IX

SUMMARY AND CONCLUSIONS

1. Islands of the Keys and the Sanctuary

It is common knowledge that the days of going down to the shoreline of the United States and building a house or boarding a boat and doing whatever you please are numbered. The reasons are many and varied - population growth, more leisure time, rising income, amenity recreational life-styles in post-industrial society. A socially acceptable way of meeting the demand for coastal resources that does not threaten their ecologic survival remains elusive. Nearshore water-land ecosystems are attractive, unique, varied and vulnerable to user pressures, as mounting evidence shows. The Keys are the quintessential case - as the threatened site of the nation's only living coral reef, as the single viable basis of Monroe County's private economy, and as the island core of the new Federal Marine Sanctuary.

The public, elected officials, planners and private citizen users, all of whom have the responsibility for preventing the impending collapse of coastal ecosystems, are in need of realistically based guidance. It is no longer sufficiently satisfying to isolate people from nature to protect natural ecosystems. Protection and use may be achieved by regionally integrating human ecosystems with coastal water and land ecosystems and still maintain economic vitality. Holistic ecological characterization of sensitive coastal zones, using a functional synthesis of physical, biological, and socioeconomic information provides a way to design comprehensive resource management programs (Mathews et al., 1980).

A functional synthesis of human and natural systems will identify presently observed water problems and those projected under future development and population growth. The Keys, in addition, will experience new difficulties likely to stem from the establishment of the federal Sanctuary, which encloses the island chain. The landward boundary of the Sanctuary has been set at the mean high water line. Enclosure has made the islands a <u>de facto</u> part of the Sanctuary. The effect of the boundary will exacerbate a history of conflicting relations between shore and land owner-developers and tidal and water owners and users, and, now, Sanctuary managers will be a party. The former have livelihoods that depend on the maintenance of an attractive and productive water environment but supporting facilities and direct uses generate waste loads. Land and shore activities export effluent to the tidal and water geo-regions, as septic tank discharge, street runoff, and processing waste. When added to in-water wastes of live-aboard vessels docked or at anchor, the combined loads have reduced the dissolved oxygen content of nearshore waters to minimum acceptable levels in many embayments. A recent survey has estimated these waste loads to be threatening (Continental Shelf Associates, 1991).

2. Hierarchical Ecology, Geographic Information System, and Coastal Capability

Coastal water quality management in the Keys is a mix of regional and local planning. Sanctuary waters require a regional view; county and municipal waters require a local view. Together, they illustrate the dilemma of the conservationist's exhortation - "think globally, act locally". The basis of this dichotomy is that the county and municipality deal with many property owners whose small parcels may have negligible marginal impacts on water quality, but, collectively will have a profound impact on regional water quality, including the Sanctuary. The situation enhances the county and municipal planners' responsibilities and job complexities. Water zoning and land zoning for use and quality should be coordinated at large scale (small area) and small scale (large area). The hydrodynamic properties of nearshore waters are related to waste disposal systems on the land and shore that are responsible for water quality problems, whose solutions depend on knowledge of the assimilative mechanisms and reactions of aquatic systems. Some problems can be addressed fairly quickly employing simplistic models. Other problems may require mathematical models for analysis of hydraulic circulations and transformations to consider alternative choices. Ameliorating use technologies, preventive, pre-treatment, avoidance, must be part of the tool kit. Use of simple field surveys and test kits would aid in establishing zoning priorities and locating "hot spots". Effluent sources are point and non-point. The difficulties of planning for localized small area shoreline-nearshore water embayments on the Keys are enhanced by highly irregular island coastlines, both natural and created by dredge and fill operations.

A prime objective of this report was to develop a scientifically-based procedure to facilitate the implementation of management decisions. This was accomplished by the logistical integration of analytical steps that link land, shoreline, and water planning objectives to a coastal use capability classification system: (a) definition of natural and built segments arranged as a functional hierarchical ecology, (b) raw data collection and conversion for entry into a geographic information system that topologically stores and links ecologic entities, and (c) an interrelational pollutant transaction matrix. The method preserves the ecologic entities from the highest level at the geo-region to the lowest elemental level of the plat parcel, so that each can be environmentally examined. Such detailed local and regional information is immediately available to the planner for assessment of use capability and conformity with zoning regulations based on quality levels and standards and segment assimilation capacity.

The following steps are suggested for Monroe County:

1. delineate a multi-level functional hierarchy of local and regional ecologies,

2. design a geographic information system linked to a coastal use capability classification system,

3. organize a monitoring program in coordination with the Sanctuary program,

4. develop a field manual and training program for county and municipal environmental planning staff at the level of field studies described in the text.

The Florida Keys is a national treasure worthy of the designation, National Marine Sanctuary. The Sanctuary envelopes state, county, municipal and private surface and submerged lands. Prior rights to these lands should be protected together with the Sanctuary rights. The two areas are intimately connected naturally and socially. The hierarchical ecologic geographic information system coupled to the coastal use capability classification system developed in this report will facilitate the attainment of these twin objectives.

APPENDIX A

Natural and Developed Ecologic Unit Descriptions
(Definitions are for those units mapped on Stock Island)

LAND - natural or fill sites never submerged except during "rare" storm events; sea boundary defined by a line 100 feet landward of mean high water.

Natural - sites composed of residual in situ soils, parent material and bedrock.

Developed - sites composed of transported, sorted, compacted fill.

Vegetation - native natural communities and disturbed plant communities.

Native - pristine, undisturbed natural systems utilizing energy and cycling nutrients at an optimal level, including,

Marsh - transitional wetland upland communities, salt and fresh forms, and, buttonwood associations,

Hammock - tropical hardwood terrestrial forest "tree island" systems.

Disturbed - successional sites which display conditions resulting from human activities, including,

Bare - open, vegetation-free, with soil, parent material, or bedrock at surface,

Grass - herbaceous introduced plants,

Exotics - introduced shrubs and trees, as Brazilian pepper and Australian pine.

Built - areas of intensive use, covered by structures, as,

Public - federal, state, county and city lands, devoted to Roads and Parking, Schools (primary, middle, high schools and community college) and Government (social services), Sanitary Landfill, Utilities (electric power plants, including fuel terminals and wharfs, pumping, storage, distribution, and, water supply storage and distribution systems), Military - training site and practice range.

Residential - Single Family (noncontiguous permanent dwellings) and Multi-family (contiguous permanent dwellings), Mobile Homes (temporary structures), and Campground (recreational vehicle parks). This category includes Residential-Commercial (mixed use areas).

Commercial - permanent structures predominantly connected with the sale of products and services, including, Tourism (motels and hotels), General Commercial (retail sales and service), Industrial (assembly, processing, storage), Farm (citrus groves).

SHORE - natural land or fill sites never submerged except during"rare" storm events; seaward boundary defined by mean high water; landward boundary defined as 100 feet from mean high water. Structures attached to the shore, or to the land where shore is not present, and extending seaward of mean high water, are included in shore.

Natural and Developed unit descriptions are same as Land.

Vegetation

Native - units are same as Land.

Disturbed - units include Land units, as Grass, Bare, Exotics, and those units unique to Shore Vegetation, as Beach (berm and dune systems).

Built - areas of intensive use, covered by structures, as,

Public - units are same as Land.

Residential - units include Land dwelling categories and a special Dockside Boat Living unit associated with marina and canal live-aboards.

Commercial - units are specifically defined as Marina, Motel, Restaurant, Boatyard, Fish-processing, Warehousing, Salvage Yard.

TIDAL - periodically submerged and exposed land following the daily tidal cycle; landward boundary defined by mean high water, except as noted for shore projections; seaward boundary defined by mean low water.

Natural - sites composed of residual material and bedrock.

Developed - sites disturbed either by fill (placement of transported, sorted, compacted material), or dredge (excavated to remove surficial material for placement or disposition elsewhere).

Surface Material - natural plant and surface/substrate geologic units, including,

Mangrove (fringing and scrub varieties),

Mudflats (unconsolidated, fine-textured sediments),

Beach (as in Shore). Note that Beach may be either naturally occurring and self-sustaining, artificially renourished, or artificially created.

WATER - continuously submerged land; landward boundary defined by mean low water. Note water depth reflects the tidal cycle and dredging.

Natural - undisturbed by dredge and fill operations, including, Beach (as in Shore, Tidal), Seagrass Meadows, Pond, Bay),

Developed - disturbed by dredge and fill operations, artificially deepened sites, including, Pond (borrow pit), Inland Channel, Inland Basin, Bay Seagrass Meadows.

Natural and Developed sites are further distinguished by depth.

Shallow (<3 feet),

Deep (=>3 feet).

APPENDIX B

List of Interviewees

Craig, D., former Director, Monroe County Planning Department, currently Donald Craig Associates, Inc., Key West.

Davis, J., Sanitary Waste Disposal, Key West Resort Utility, Key West.

De Claire, T., Reference Librarian, Geography and Map Division, Library of Congress, Washington, D.C.

Garrett, G., Director, Monroe County Marine Resources Planning Department, Key West.

Hambright, T., Librarian, Monroe County May Hill Russell Library, Key West.

Harvey, W., Mayor, Monroe County, Key West.

Higgs, E., Property Appraiser, Monroe County, Key West.

Jones, J.K., Assistant Director, Henry Morrison Flagler Museum, Palm Beach.

Kruer, C., Biologist, Summerland Key.

Lapointe, B., Director of Marine Conservation, Florida Keys Land and Sea Trust, Marathon.

Miller, M., Extension Agent, Monroe County, Key West.

Park, H., Resident, Stock Island.

Toppino, F., Contractor, Rockland Key.

APPENDIX C
(Prepared by Deborah Cupples)

Historical Sketch of Stock Island

1. Introduction

This paper sketches the land use history of Stock Island. The study area is divided into north and south divisions: north lies within the City of Key West and contains hospitals, county home, botanical garden, sanitary landfill, community college, elementary school, and golf course; south is part of Monroe County and contains railroad, highway, Safe Harbor, dog track, drive-in, speedway, electric plant, desalination plant, and residential subdivisions.

2. Methodology

Research began with perusal of microfilms containing area newspapers dated from the early 1800s to the present. References to Stock Island rarely appeared since there was little Key West-related information about Stock Island. The May Hill Russell Library, Key West provided access to its newspaper indexes and files. This was supplemented by oral histories provided by the staff librarian. Information on residential subdivisions is from microfilms of the county plat maps. Newspapers are referenced by initials and date of issue (CT - Coral Tribune, KWC - Key West Citizen, MH - Miami Herald).

3. North Stock Island

a. Hospitals. Monroe General Hospital was established in 1944 at the location which now serves as the county office complex. Beginning at least as far back as the early 1960s, the hospital suffered structural and sanitary-related problems. The State Board of Health investigated the hospital in 1966 and found: the incinerator was inadequate for disposition of tissue, dressings and contaminated waste; the fire evacuation plan had not been rehearsed three times in the last year, and, there were numerous deficiencies in construction (KWC, 5-26-66). Construction deficiencies included cracked tiles and accumulated dirt, leaking roof, and exposed piping.

The State Board of Health, five years earlier, had given Monroe General a provisional license which stated that the institution must clean up its sewage system; allegedly the hospital pumped waste into Cow Key Channel. Monroe General failed to met the State Board of Health's requirements but served as an interim facility until the Florida Keys Memorial Hospital opened on October 17, 1971.

b. County Home. The county home for the elderly is a twenty-room facility located next to the botanical garden. The City of Key West gave Monroe County the 75' x 150' lot in 1947 (KWC, 7-16-47). The construction firm of Charles Toppino and Sons won the bid in August 1947 (KWC, 8-6-47). In March 1948, the county home was completed and occupied (KWC, 3-11-48). The building presently is called Bay Shore Manor.

c. Botanical Garden. The garden is part of a large land parcel that was owned by Walter Maloney. The City of Key West acquired the parcel in the 1920s with the condition that it be used for recreational purposes (KWC, 7-9-86). The garden began on 6 acres of hardwood hammock in 1935 as a WPA project. With funding from a Federal Emergency Relief Administration grant, the garden grew to 30 acres by 1939 and included an exhibition house and office, a potting shed and tool room, and extensive greenhouses. The grounds grew to 55 acres, but large portions of the garden have been reassigned for other civic purposes, leaving only an irregularly shaped parcel of about 11 acres (unpublished pamphlet). The garden has had a roller coaster history. Work on the garden halted during World War II. In the 1950s, the Key West Garden Club, the Girl Scouts, and the Boy Scouts began to clean up the property (MH, 7-12-68). In 1960, the Coral Tribune published an editorial "Why Not Restore Key West's Botanical Garden" (CT, 8-13-60).

Hurricane Donna in 1960 damaged the garden (MH, 1-21-62). It reopened in June 1961 after the City Commission designated it a wildlife sanctuary so as to preserve the last remaining natural hammock undeveloped on the Lower Keys (KWC, 1-29-61). The garden suffered damage from Hurricane Betsy in 1965, and was without a caretaker (MH, 11-24-65). Public interest in the garden waned throughout the remainder of the 1960s. In 1972, the City leased the garden to the Key West Garden Club in an attempt to better maintain the grounds (KWC, 7-9-86).

d. Sanitary Landfill. The City of Key West in January 1944 awarded a bid for the clearing of 20 acres on north Stock island for the city landfill (KWC, 8-26-44). Roughly 2300 feet of roadway also was cleared. The landfill began operating in January 1951. The City in 1968 considered installing an incinerator (MH, 6-14-68). In 1976, the City commissioned a feasibility study on the installation of incinerators (KWC, 7-27-76). The shredder compost resource recovery system was completed in 1979. (KWC, 10-22-79). The solid waste was hand-sorted and put on a conveyor belt which moved the material through three phases:

shredder; classifier, which removed metals, etc.; and digester, which produced topsoil. The City installed an incinerator in 1985 because the mulcher plant was habitually out of service. Plant workers were paid even if the plant "went down," so, it was common for them to mis-feed the mulcher system in order to temporarily put it out of commission. The City of Key West does have to find an alternative solid waste disposal site. State law mandates that Key West must close the Stock Island landfill by 1993 or pay a large fine (KWC, 4-25-90).

e. Community College. Monroe County Junior College was established in August of 1965; it was located in Key West at 1400 United Street. It moved to Fort Street in downtown Key West, and then to Stock Island, at which point it was named the Florida Keys Community College (FKCC). The college occupies roughly 125 acres of filled bay bottom. The initial building plan called for 170,000 cubic yards of fill material (KWC, 5-11-66). Dredge-and-fill began in August 1966. Charles Toppino and Sons took the $169,000 contract and were given 160 days to fill all of the space which was required for buildings (KWC, 8-26-66). The campus opened in August 1968.

In December 1968, some students from the sailing class built the floating dock (KWC, 12-13-68). The tennis courts were finished in June 1974 (KWC, 6-17-74). The library was completed in 1975. The campus in 1976 had two main buildings: a marine propulsion laboratory, and a two-story houseboat which housed art studios (KWC, 8-17-76). The Tennessee Williams Arts Center was completed in the fall 1979. The college's new marine propulsion laboratory was opened in 1990.

f. Elementary School. Gerald Adams Elementary School opened for the fall 1977 school year. Being located next to the sanitary landfill, the school has had problems but is still open and operating. The principal, in 1984, complained to the State Department of Environmental Regulation (DER) about the landfill: "...tremendous problems with flies, gritty dirt, stench..." as well as pollutants (KWC, 1-15-84). The principal's concern was that since waste could not be placed near the bay, it would be dumped toward the school. The Assistant City Manager claimed that dumping was "going up, not out"; he also stated that the new incinerator should reduce volume by 80 percent. A DER representative claimed: "as long as the landfill is not extended toward the school, there should be no problem of contamination of school grounds" (KWC, 1-15-84).

g. Golf Course. Land clearance began in July 1923 (KWC, 1-28-24). As early as August 1923 the golf course was still a proposal: three people (Cash, Otto and Maloney) had sold land to the city but the City had not yet secured all the necessary land (KWC, 8-8-23). The City, in December 1923, decided to complete 9 holes for the winter season, rather than have 18 incomplete holes; equipment-related problems had caused delays in construction (KWC, 12-18-23). Also, in December, plans were submitted for building a clubhouse, and the City publicly resolved to complete 18 holes: the public had misunderstood officials to have said that they would stop construction after completion of the ninth hole (KWC, 12-19-23). By the end of December, roughly 60 of the 100 acres were cleared: 9 tees and 9 greens were finished (KWC, 1-28-24). The first 9 holes were ready for the 1924 winter season.

The golf course suffered damage from the 1935 hurricane, and WPA provided funds for partial repairs (KWC, 9-17-36). The Golf Club was given operational jurisdiction in 1938. The original clubhouse was located in the building which now houses the American Legion: in 1947 the golf club leased the building to the American Legion for $100 per year for 100 years. The course now has 18 holes.

4. South Stock Island

a. Railroad and Highway. With Henry Flagler aboard, the first train of the Florida East Coast Railway Key West Extension arrived in the City of Key West in January 1912. The exact date that the railroad was completed is unclear. The railroad was destroyed by the September 1935 hurricane. Casa Marina Hotel, another of Flagler's projects, was completed in 1922; its completion is probably linked to the beginning of the overseas highway project.

A $300,000 bond issue was approved in October 1923 for beginning construction of highway bridges in the Lower and Upper Keys (KWC, 10-16-23). Building contracts were awarded in July 1924 (KWC, 7-8-24). According to a county published flyer, $650,000 in bonds were sold to fund the completion of the first overseas highway. The original route was not straight but ran parallel to the railway. The bridges were wooden trestles. On Stock Island, the highway was routed from the southwest tip of Boca Chica, to what is now Peninsular Marine, and followed Maloney Avenue northwestward. The highway opened on January 25, 1928; ferries transported cars across water gaps between Lower Matacumbe Key and Grassy Key, and between Hog Key and No Name Key (unpublished guide/map, 1928). The gaps were bridged in 1937. Concrete railway bridges were converted to highway bridges during World War II, and, in 1945, the original wooden highway bridges were dismantled. Today's Highway US 1 follows the railroad right-of-way, except where the highway has been widened. A major highway and bridge modernization scheme took place during the 1970s.

b. Safe Harbor. The West Indies Fruit and Steamship Company, in August 1955, bought 10 acres of Toppino Terminals' land in order to build the Key West - Havana Auto Ferry. According to a Key West Citizen article (1-12-56), the first ferry was to leave Havana and arrive at Safe Harbor the next day (a 6 hour trip). Another KWC article (11-1-60) states that the first Havana - Key West run took place on 1-21-56. Regardless of its questionable beginning date, its last run was October

31, 1960 (KWC, 11-1-60). The Toppinos in December 1959 opened a marina sales and service facility near the Havana - Key West Ferry Terminal. The marina included a 2,400 square foot building for offices and showrooms, 110 feet of dockage, and wet-dry storage for approximately 200 boats (KWC, 12-13-59).

c. Dog Track. Land for the greyhound dog track was sought in October 1947 (KWC, 10-18-47). The project was supported by the local hotel association, and voters approved the project in October 1952. The dog track and grandstand were built by Toppino and Sons and opened in January 1953 (KWC, 1-31-53).

d. Drive-In. Planning for the drive-in, which was owned by the Bernsteins, began in 1956 (KWC, 6-16-56). There was some debate over whether or not it was to be built in Key West (KWC, 7-3-56). It was located, finally, on Stock Island and opened in March 1957 (KWC, 3-12-57).

e. Speedway. The auto speedway opened on October 30, 1955 (KWC, 11-2-55).

f. City Electric Plant. The City of Key West's steam generating plant on Stock Island was completed in 1969. The Surless Ship Repair Corp. had a 2 year lease on the dock and warehouse; the lease specified that Surless had to build offices and shops at the property (KWC, 3-19-69). Brown- and black-outs were common occurrences in Key West during the mid-1970s due to equipment failures at the Stock Island plant. City Electric had not installed a new generator since the plant had opened (MH, 8-20-78). The plant's operation since has been far from trouble-free; still, the Stock Island plant is the city's main power facility.

g. Desalination Plant. A contract was awarded in May 1958 for construction of a tank foundation on Stock Island. Contracts were awarded for building the pump houses and laying pipes in November 1958. the Westinghouse desalination plant began operation in July 1967: "when operating at capacity, the cost of water runs less than $.85 per 1,000 gallons. For every 3 gallons of salt water drawn into the system, 1 gallon of fresh water is produced, over 1,800 gallons per minute" (KWC, 7-19-67).

The plant began to malfunction in the mid-1970s. In 1978, the Farmer's Home Administration lent Monroe County $53 million to help solve their water shortage, that is, to build a new pipeline from the mainland (KWC, 10-5-78). A reverse osmosis plant, also located on south Stock Island, began freshwater production in 1980 and worked in conjunction with the desalination plant to ease the city's water shortage (KWC, 12-1-80). The desalination plant continued operating until the pipeline was completed; the reverse osmosis plant remains ready for emergency use.

h. Residential Subdivisions. The following is a list of residential subdivisions on Stock Island.

Subdivision	Owner	Date Platted
E.M. Semple	unclear	Sep. 1908
Sunkrest	unclear	Apr. 1925
Water's Edge	unclear	Sep. 1926
Sunshine	J. Sirugo	Jul. 1951
Balido	C. Toppino	Apr. 1958
Resub. Part of Block 48	C. Toppino	Dec. 1958
Balido #2	C. Toppino	Sep. 1959
Blue Water's	D. Navarro	Nov. 1959
Lincoln Manor Estates+	B. Bernstein	May 1961
Amended Linc. Man. Est.+*	B. Bernstein	Oct. 1962
Robyn	G. McDonald	Nov. 1964
Lincoln Gardens #1*	B. Bernstein	Jun. 1965
Lincoln Gardens #2	B. Bernstein	Jun. 1965
Stuart	B. Bernstein	Jul. 1971

+An interesting difference exists between the original Lincoln Manor Estates and the amended one. The original subdivision, which never materialized, was planned as a more "upscale" development: it occupied a larger parcel, included more homes, a central park, and cul-de-sac street grid.

*These properties were recorded under F&B Corp. and/or Riviera Drive-In, Inc. Both are owned by the Ben and Miriam Bernstein family.

5. Conclusions

Stock Island historically was not a newsworthy area, except on those aspects of the island's development that directly affected the City of Key West. It is the home of the golf course, botanical garden, community college - public facilities which the City could not accommodate on the island of Key West. In a very real sense, Stock Island is Key West's dumping ground: it is home to "Mount Trashmore," the sanitary landfill and hosts much of its low income, high density housing.

Stock Island had the potential of becoming a subtropical paradise in the early 1900s, especially after the golf course was built. However, siting the landfill on the island in the 1940s doomed it. The dog track and speedway brought gambling and related crimes.

Residential housing development occurred on south Stock Island in the late 1950s and 1960s. Had subdivision siting been better planned, and the original Lincoln Manor Estates built rather than the amended complex, Stock Island might have come closer to reaching its potential. The spatial distribution of public facilities on north Stock Island is odd: the botanical garden is across the street from the sanitary landfill; the hospital and golf course are also adjacent to the landfill, as is the elementary school. Many citizens are baffled that a school was built next to a 100 foot high mound of trash.

APPENDIX D: Chart, Map, and Profile Coverage of Stock Island

Date	Type	Source	ID No	Title	Scale	Quality	Coverage
1843	hydrographic chart	British Admiralty (PKYL)	--	Tortugas and Florida Keys or Martyrs	1:126,720	poor reconnaissance	complete
1850	topographic map	U.S. Coast Survey (NA)	291 (Drawer 75, sheet 43)	Stock Island and Adjacent Keys	1:10,000	good reconnaissance	complete
1905	topo-hydro-geo profile	FECR (HMFM)	--	Profile of Proposed Location -- Saddle Bunch Key to Key West, FECR, Key West Extension	1:4,800	excellent reconnaissance	E-W transect
1907	topographic map	FECR (HMFM)	--	Map Showing Proposed Location -- Saddle Bunch to Key West	1:12,000	excellent mapping	complete
1907	hydrographic chart	FECR (HMFM)	--	Openings Between Saddle Bunch and Stock Island	1:12,000	excellent mapping	complete
1909	hydrographic chart	USCGS (MHRL)	584	Florida: Key West Harbor and Approaches (1st Ed)	1:30,000	good reconnaissance	complete
1942-43	planimetric map	USGS (MHRL)	--	Boca Chica, Florida	1:24,000	fair reconnaissance	complete
1946	planimetric map	Edgar Tobin Aerial Surveys (LC)	--	Monroe County, Florda	1:4,800	good reconnaissance	complete
1954	planimetric map	FDOT (MHRL)	--	General Highway Map Monroe County	1:20,000	fair reconnaissance	complete
1987	planimetric map	Sunbelt Maps, Inc.	--	The Florida Keys	1:42,240	good reconnaissance	complete
1988	planimetric map	Monroe County Planning Dept.	569-571 576-578 580-583	Land Use District Map, Monroe County	1:4,600 (also 1:2,300)	excellent mapping	complete
1989	planimetric map	Monroe County Property Appraiser's Office	--	Plat Parcel Map, Stock Island North (1 sheet) and South (2 sheets)	1:1,200	excellent mapping	land complete; water partial

Abbreviations:

MHRL May Hill Russell Library, Key West
PKYL P. K. Yonge Library of Florida History, Gainesville
NOS National Archives, Washington
NA National Archives, Washington
USCGS U.S. Coast & Geodetic Survey
FECR Florida East Coast Railway, Key West Extension
HMFM Henry M. Flagler Museum, Palm Beach
FDOT Florida Department of Transportation
LC Library of Congress, Washington
USGS U.S. Geological Survey

APPENDIX E: Aerial Photographic Coverage of Stock Island

Date	Type	Source	Project/Roll/Print #	Scale	Quality	Coverage
1930's	black-and-white low oblique	Aviation Div., State Road Dept. (MHRL)	9 2-3	variable	poor reconnaissance	partial near horizon
1-14-42 11-3-43	black-and-white low/high obliques	U.S. Navy (Boca Chica) MHRL	-- --	variable	poor reconnaissance	N. Stock Island complete; rest partial
3-13-45	black-and-white panchromatic vertical	USCGS (NOS)	20 FLA 11 402481 1795-1798	1:19,125	good mapping	stereo complete
2-12-49	black-and-white low oblique	U.S. Navy (MHRL)	8552	variable	fair reconnaissance	complete
1950's	black-and-white obliques/verticals	Curtis Kruer Collection	not catalogued	various	good-excellent reconnaissance	some complete, others partial many large-scale low altitude hand-held
2-22-59	black-and-white panchromatic vertical	FDOT	MON 2 9-13 MON 3 8-10	1:19,246	good mapping	stereo complete
3-11-60	normal color vertical	USCGS (NOS)	570-573	1:20,340	excellent mapping	stereo lacking east border
11-15-63	black-and-white vertical	FDOT	9000-1602, 1/04-1/0 2/06-2/07	1:25,000	good mapping	stereo complete
3-9-75	black-and-white panchromatic vertical	FDOT	VG-7, 415-416 430-433	1:19,500	good mapping	stereo complete
12-12-81	normal color vertical	NOS	ZC 9458-9460	1:36,000	excellent mapping	stereo complete
12-30-85	black-and-white panchromatic vertical*	FDOT	PD 3117 2/04-2/06	1:18,000	excellent mapping	stereo complete
2-89	black-and-white panchromatic vertical	Redi Corp.	--	1:7,200	excellent reconnaissance	mosaic

MHRL -- Mary Hill Russell Library, Key West
USCGS -- U.S. Coast & Geodetic Survey
FDOT -- Florida Department of Transportation, Tallahassee
NOS -- National Ocean Survey

* also available in ozalid prints at 1:2,400 from Monroe County and City of Key West Planning Depts.

APPENDIX F

Proposal for a Contextually-Guided Remote Sensing Classification Methodology

Knowledge of change in the natural and developed environment is increasingly important for both ecologic and economic reasons (Janssen et al., 1990). Effective management requires adequate and timely information which conveys the current resource situation as well as apparent trends. Conventional methods for determining environmental change are increasingly inadequate in light of the growing demand for information. Automated, digital techniques offer the potential to capitalize on the growing supply of remotely-sensed imagery in order to provide the necessary data.

Aerial photography is the most common source of remotely-sensed information. However, Haddad and Harris (1985) determined that, when compared with standard photogrammetric techniques, the utilization of satellite imagery can reduce costs by 69 to 72 percent and time requirements by 83 percent. Cost reductions were associated with the use of a geographic information system and a digital image processing system.

An important issue regarding the utilization of remote sensing imagery is the accuracy of interpretation. The utilization of satellite imagery for resource mapping and monitoring has encountered much criticism (Haddad and Ekberg, 1987). Past research has indicated that satellite data often provide inadequate and inaccurate information to accomplish certain objectives. Although often valid, past criticisms have established a lingering skepticism of this technology despite recent advancements. Currently available second generation imagery embodies many technological advances which address past inadequacies of first generation Landsat multispectral scanner (MSS) data.

In addition to hardware improvements, much effort has been expended to devise automated classification techniques to derive land use/cover information from satellite imagery. Unfortunately, digital image analysis remains more of an art form than a science (Argialas, 1989). Conventional classification techniques rely on the analysis of multispectral data coupled with statistically based decision rules followed by visual confirmation. Automated methodologies are needed which incorporate cognitive processes inherent to photo interpretation. Gong and Howarth (1990) conducted an assessment of conventional computer-classification techniques. Their results underscored the difficulty involved in selecting appropriate training signatures when conducting supervised classifications. Guerney and Townshend (1983) argue that imprecise classification from conventional techniques are to be expected since many land features have inherently similar spectral characteristics. Furthermore, mixed pixels, which represent the integrated reflection from various ground features, confound the classification process.

Conventional classification methods assign pixels to coastal cover classes based on multispectral reflectance properties (Civco, 1989). Civco (1989) outlines a number of problems inherent to these techniques. First, per pixel classifiers often produce fragmented results. Second, those pixels which deviate substantially from training signatures are often misclassified or left unclassified. Third, supplemental information, such as soils or elevation attributes, which might assist in the classification process, is not easily integrated into algorithm-based computer programs. Fourth, spatial and contextual attributes, such as size, shape, texture, pattern, association and proximity, are not usually considered. Finally, conventional classification procedures are highly scene dependent and thus, are unable to generalize between scenes.

In contrast to computerized techniques, visual image interpretation and classification proceed in a series of inductive and deductive steps (Gong and Howarth, 1990). Interpretation relies on a variety of information types, as tone, color, shape, size, shadow, pattern, and texture examined in a temporal context (Civco, 1989). An human analyst interprets areas of similar properties rather than discrete pixels. Although objective and quantitative criteria are employed, visual interpretation usually is based on heuristics rather than statistically-based algorithms (Civco, 1989). Furthermore, an human interpreter has the ability to generalize.

Currently, much research effort is directed towards the development of classification techniques which aim to supersede conventional per-pixel methods. These efforts, often referred to as expert or knowledge-based approaches, attempt to incorporate ancillary information sources into the classification process. Ancillary information sources often embody those factors and decision criteria employed by human analysts when interpreting remotely sensed imagery.

Gurney and Townshend (1983) suggest a typology of context which has important implications for the design of improved classification methods. Contextual classification considers distance, direction, connectivity and containment relationships when pixels are assigned to classification categories. Contextual operators need to serve as decision criteria in order to increase the accuracy of automated digital classification techniques.

Further remote sensing research should be pursued to develop a contextually-guided classification method using the GIS inventory of Stock Island, Florida Keys. The specific objectives of such research would be to design an automated change detection algorithm which 1) merges the distinct analytical capabilities of GIS and image processing systems, 2) incorporates a Bayesian decision rule, 3) incorporates the contextual operators of distance, containment and connectivity, and 4) achieves an accuracy level of 85 percent for detection and classification of coastal use/cover.

Photo interpreted and ground truthed information contained within a GIS coverage will serve as reference data for an iterative classification and monitoring process. Changes will be detected and classified via a comparative analysis of the reference GIS coverage and a satellite image. The changes detected will serve to update the reference GIS coverage. The updated GIS coverage will serve as the basis for future change detection.

The detection of changes in the natural and developed environments involves the use of two or more data sets of the same location collected on different dates. The procedures for digital change detection are summarized as follows: (1) selection of appropriate satellite imagery; (2) radiometric correction of satellite imagery; (3) geometric registration of GIS data bases and satellite imagery; (4) design and execution of change detection algorithms and (5) analysis and output of results.

Accessible satellite imagery includes SPOT (Systeme Pour l'Observation de la Terre) multispectral and panchromatic data. Merging SPOT data and Landsat Thematic Mapper data enhances the spatial and spectral characteristics of each. Ancillary information will consist of photo interpreted and digitized land, shore, tidal, and water use/cover classifications for Stock Island.

Preprocessing activities involve radiometric restoration of the satellite imagery and geometric rectification of both satellite imagery and GIS coverages. Geometric rectification of satellite imagery tends to distort the spatial and/or spectral characteristics of ground features. Normal procedure entails imagery classification prior to geometric rectification in order to eliminate potential classification bias. The proposed methodology requires that the GIS data base and the imagery are rectified prior to classification.

Change Detection Algorithm

The proposed research will include development of a change detection algorithm. The decision criteria for change detection will be based on a combination of spectral and contextual analyses. The algorithm will consist of a modified Bayesian decision rule weighted by the contextual operators of distance, connectivity and containment. The contextual operators, embodied within the GIS data base, serve to guide the assignment of pixels to appropriate classification categories.

The Bayesian decision rule is a modification of the Gaussian maximum likelihood rule (Lillesand and Kiefer, 1987). The maximum likelihood rule determines the probability of a pixel belonging to each classification category within a digital image. Probabilities are based on the mean vector and covariance matrix of each classification signature. Pixels are assigned to categories according to highest probability. This method works well when classification categories have distinct spectral signatures.

The Bayesian decision rule utilizes two weighting factors which are applied to the probability estimates derived by the maximum likelihood rule (Lillesand and Kiefer, 1987). Both weighting factors are input parameters which are usually defined by the analyst. The weighting factors are assigned to each classification category and consist of: 1) a probability of occurrence and, 2) a "cost" of misclassification. The Bayesian decision rule is especially effective when categories are indistinct or overlap in spectral space (Campbell, 1987).

The incorporation of a GIS data base into the classification process enables the utilization and enhancement of the Bayesian decision rule. The Bayesian weighting factors can be more accurately determined using a GIS reference coverage. The algorithm will be enhanced by incorporating weighting factors to account for the aforementioned contextual operators.

The change detection algorithm will operate simultaneously on a reference GIS coverage and a remotely-sensed digital image. The GIS coverage will contain recent information on coastal use/cover and, thus, serve to detect coastal use/cover change in a subsequent digital image. Corresponding pixels in the image and the GIS coverage will be examined by the modified Bayesian classifier to determine if coastal use/cover change has occurred. Change detection will be based on the spectral signatures of land, shore, tidal, and water use/cover categories located within the study area. Ultimately, pixel assignment will be based on its contextual location and statistical relationship to spectral signatures.

Execution of Change Detection Algorithm

The statistical properties of the pixels which comprise these groups will be determined and then utilized to convert each GIS coverage into simulated digital imagery. Next, a time-sequential change-detection analysis will be made utilizing the simulated digital imagery. The first step will involve a comparison of the 1945 and 1955 GIS coverages. The 1945 GIS coverage will serve as the reference data base, while the 1955 GIS coverage will serve as the simulated satellite image. Changes detected by the modified Bayesian classifier will be appended to the 1945 GIS coverage in order to create an updated coverage. In theory, the updated GIS coverage will reflect 1955 conditions. Next, the updated coverage will serve as a reference for change detection with the 1963 simulated satellite imagery. The above procedure will be repeated for each available GIS coverage. During this process the change detection algorithm will be validated and necessary modifications will be made. As a final check, the modified classifier will be tested on the 1985 and 1989 satellite imagery.

Accuracy Assessment

Classification error occurs when a pixel is assigned to the wrong coastal use/cover category. An error matrix will be utilized to detect sources of error generated during the change detection process. The error matrix consists of an n by n array, where n is equal to the number of classification categories. The lefthand side of the matrix is labeled with the categories of the reference GIS coverage. The upper edge of the matrix is labeled with the same n categories which refer to the resultant digital coverage generated during the process of change detection. The contingency matrix will serve to determine overall classification error as well as particular problem categories.

APPENDIX G-1: Characteristic Values for Urban Stormwater and Sewer Overflow water Quality

Water Quality Parameter	Combined Sewer Overflow Characteristic Concentration (mg/l)	Urban Stormwater Characteristic Concentration (mg/l)
BOD_5	100 - 500	11 - 500
TSS	100 - 1500	500 - 11,300
Total Solid	300 - 2000	1000 - 14,600
Organic N	3.5 - 30.1	0.9 - 16
NH_3N	1.1 - 11.5	0.4 - 2.5
PO_4	1 - 62	10 - 125
Total coliform	$5x10^4$ - $30x10^6$ MPN/ml	$2x10^3$ - $14x10^5$
pH	4.9 - 8.4	*
Fecal coliform	$5x10^4$ - $11x10^6$ MPN/ml	
Chloride		200 - 25,000
Oils		10 - 110
Phenols		0 - 0.2
Lead		0 - 1.9

* No data available
(Tetra Tech Inc., 1977)

APPENDIX G-2: Summary of Current and Projected Waste Loads in one Region 208 Area (by SIC)

SIC GROUP		CURRENT LOADINGS		BEST PRACTICABLE WASTE REDUCTION TECHNOLOGY			PROJECTED LOADINGS	
		BOD (lb/day)	SS (lb/day)		Expected Reductions		BOD (lb/day)	SS (lb/day)
No.	Description	Sewer	Sewer	Description	BOD(%)	SS(%)	Sewer	Sewer
201	Meat Products	1,523	1,059	Anaerobic Lagoon to Stabilization Pond	90	85	152	117
202	Dairy Products	973	400	Anaerobic Digestion & Clarification	85	90	71	40
204	Grain Mill Prods.	180	50	Oxidation Ditch & Clarification	85	75	27	13
205	Bakery Prods.	935	910	Rotating Bio-Filters & Clarification	85	65	140	319
208	Soft Drinks	330	40	Fixed Activated Sludge	85	65	53	14
211	Tobacco Man.	2,024	1,750	Activated Sludge (E.A.) & Clarification	85	75	304	438
22_	Textile Mill	2,530	2,173	Activated Sludge & Alum-Aided Clarif.	85	75		543
226	Dyeing & Fin.	0	0	Carbon Adsorption & Clarification	75	60		
251	Furniture	0	0	--	--	--		
265	Paperboard Con.	245	150	Screening, Ext. Aeration, Clarification	35	65	159	53
27_	Print & Pub.	0	0	--	--	--		
28_	Chem. & Allied P.	64	29	Activated Sludge & Clarification	85	75	10	18
32_	Stone, Clay P.	0	0	Stilling Ponds, Water Recycle	30	70		
35_	Machinery	32	79	Oil & Grease Traps	50	65	16	28
36_	Elect. Equip	659	402	Ion Exchange (for Plating Process)	10	90	593	40
379	Trans. Equip	100	100	Oil & Grease Traps	50	65	50	50
---	Non-Manuf.	1,374	170	See Text	70	90	412	17
9999	Mun. W.W.T.P.	0	0	Upgrade Six Largest Plants	Varies for Each Plant			
	TOTALS	10,469	7,312	--	--		2,367	1,690

(Tetra Tech Inc., 1977)

APPENDIX H-1: Area Statistics of Land Feature Attributes of Stock Island for 1945 and 1985

Feature Attributes	All Land				Natural Land				Developed Land			
	1945		1985		1945		1985		1945		1985	
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Land	323.79	11.53	507.49	18.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural	303.87	10.82	288.71	10.29	303.87	10.82	288.72	10.29	0.00	0.00	0.00	0.00
Developed	19.92	0.71	218.77	7.79	0.00	0.00	0.00	0.00	19.92	0.71	218.77	7.79
Vegetation	286.18	10.19	188.20	6.70	268.29	9.56	136.11	4.85	17.89	0.64	52.07	1.86
Native	145.57	5.18	8.60	0.31	129.38	4.61	7.02	0.25	16.19	0.58	1.58	0.06
Marsh	105.04	3.74	1.58	0.06	89.26	3.00	0.00	0.00	15.78	0.56	1.58	0.06
Hammock	40.53	1.44	7.02	0.25	40.12	1.43	7.02	0.25	0.41	0.01	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Disturbed	140.61	5.01	179.60	6.40	138.91	4.95	129.09	4.60	1.70	0.06	50.51	1.80
Grass	56.79	2.02	109.24	3.89	56.79	2.03	91.86	3.27	0.00	0.00	17.38	0.62
Bare	0.88	0.03	23.94	0.85	0.88	0.03	19.37	0.69	0.00	0.00	4.57	0.16
Exotic	82.94	2.94	46.42	1.65	81.24	2.90	17.86	0.64	1.70	0.06	28.56	1.02
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Built	37.61	1.34	319.29	11.37	35.58	1.27	152.61	5.44	2.03	0.07	166.68	5.94
Public	29.85	1.06	142.29	5.06	27.83	0.99	69.14	2.46	2.02	0.07	73.15	2.61
Park	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Roads, Bridges, Pking.	27.68	0.99	100.55	3.58	26.50	0.94	57.58	2.05	1.18	0.04	42.97	1.53
School, Govt.	0.00	0.00	9.29	0.33	0.00	0.00	7.07	0.25	0.00	0.00	2.22	0.08
Landfill	0.00	0.00	16.60	0.59	0.00	0.00	0.00	0.00	0.00	0.00	16.60	0.59
Utilities	0.00	0.00	15.69	0.56	0.00	0.00	4.33	0.15	0.00	0.00	11.36	0.40
Military	2.17	0.08	0.00	0.00	1.33	0.05	0.00	0.00	0.84	0.03	0.00	0.00
Wildlife	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.16	0.01	0.00	0.00	0.16	0.01	0.00	0.00	0.00	0.00
Residential	0.31	0.01	113.91	4.06	0.30	0.01	57.46	2.05	0.01	0.00	56.45	2.01
Single Family	0.31	0.01	17.70	0.63	0.30	0.01	5.28	0.19	0.01	0.00	12.42	0.04
Multi-family	0.00	0.00	6.33	0.23	0.00	0.00	1.25	0.04	0.00	0.00	5.08	0.18
Residential-Comml.	0.00	0.00	28.15	1.00	0.00	0.00	18.75	0.67	0.00	0.00	9.40	0.33
Mobile Home	0.00	0.00	57.78	2.06	0.00	0.00	29.96	1.07	0.00	0.00	27.82	0.99
Campground	0.00	0.00	3.95	0.14	0.00	0.00	2.22	0.08	0.00	0.00	1.73	0.06
Commercial	7.45	0.27	63.09	2.25	7.45	0.27	26.01	0.93	0.00	0.00	37.08	1.32
Tourism	0.00	0.00	17.05	0.61	0.00	0.00	7.25	0.26	0.00	0.00	9.80	0.35
General Commercial	2.33	0.08	18.22	0.65	2.33	0.08	9.80	0.35	0.00	0.00	8.42	0.30
Industrial Service	0.00	0.00	25.07	0.89	0.00	0.00	8.56	0.30	0.00	0.00	16.51	0.59
Farm	3.59	1.28	0.00	0.00	3.59	0.13	0.00	0.00	0.00	0.00	0.00	0.00
Other	1.53	0.05	2.75	0.10	1.53	0.05	0.40	0.01	0.00	0.00	2.35	0.08

*Note: rounding ± 1.00

APPENDIX H-2: Area Statistics on Shore Feature Attributes of Stock Island for 1945 and 1985

Feature Attributes	All Shore				Natural Shore				Developed Shore			
	1945		1985		1945		1985		1945		1985	
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Shore	87.38	3.11	190.92	6.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural	59.82	2.13	25.41	0.91	59.82	2.13	25.41	0.91	0.00	0.00	0.00	0.00
Developed	27.56	0.98	165.51	5.90	0.00	0.00	0.00	0.00	27.56	0.98	165.51	5.89
Vegetation	56.60	2.01	19.73	0.71	37.45	1.33	0.71	0.03	19.15	0.68	19.02	0.68
Native	35.22	1.25	2.09	0.07	20.75	0.74	0.00	0.00	14.47	0.52	2.09	0.07
Marsh	35.12	1.25	2.09	0.07	20.65	0.74	0.00	0.00	14.47	0.52	2.0	0.07
Hammock	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Disturbed	21.38	0.76	17.64	0.63	16.70	0.59	0.71	0.03	4.68	0.17	16.93	0.60
Grass	0.00	0.00	1.11	0.04	0.00	0.00	0.04	0.00	0.00	0.00	1.07	0.04
Bare	0.78	0.28	5.80	0.21	0.78	0.03	0.00	0.00	0.00	0.00	5.80	0.21
Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exotic	20.60	0.73	10.73	0.38	15.92	0.54	0.67	0.02	4.68	0.17	10.06	0.21
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Built	30.78	1.10	171.19	6.10	22.37	0.80	24.70	0.88	8.41	0.30	146.49	5.21
Public	30.42	1.08	77.24	2.75	22.34	0.79	12.35	0.44	8.08	0.28	64.89	2.31
Park	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Roads, Bridges, Pkg.	30.11	1.07	57.74	2.05	22.34	0.79	11.85	0.42	7.77	0.28	45.89	1.63
School, Govt.	0.00	0.00	1.13	0.04	0.00	0.00	0.46	0.02	0.00	0.00	0.67	0.02
Landfill	0.00	0.00	5.12	0.18	0.00	0.00	0.00	0.00	0.00	0.00	5.12	0.18
Utilities	0.00	0.00	12.98	0.46	0.00	0.00	0.04	0.00	0.00	0.00	12.94	0.46
Military	0.31	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.01	0.00	0.00
Wildlife	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.27	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.01
Residential	0.33	0.01	25.84	0.92	0.00	0.00	6.50	0.23	0.33	0.01	19.34	0.69
Single Family	0.33	0.01	4.67	0.17	0.00	0.00	0.44	0.02	0.33	0.01	4.23	0.15
Multi-family	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residential-Comml.	0.00	0.00	0.85	0.03	0.00	0.00	0.29	0.01	0.00	0.00	0.56	0.02
Mobile Home	0.00	0.00	16.08	0.57	0.00	0.00	5.59	0.20	0.00	0.00	10.49	0.37
Campground	0.00	0.00	4.17	0.15	0.00	0.00	0.11	0.00	0.00	0.00	4.06	0.14
Dockside Boat Living	0.00	0.00	0.07	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Commercial	0.03	0.00	68.11	2.42	0.03	0.00	5.85	0.21	0.00	0.00	62.26	2.22
Tourism	0.00	0.00	18.11	0.06	0.00	0.00	1.62	0.06	0.00	0.00	16.49	2.22
General Commercial	0.03	0.00	7.58	0.27	0.03	0.00	0.33	0.01	0.00	0.00	7.25	0.69
Industrial Service	0.00	0.00	42.42	1.51	0.00	0.00	3.90	0.14	0.00	0.00	38.52	1.37
Farm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX H-3: Area Statistics on Tidal Feature Attributes of Stock Island for 1945 and 1985

Feature Attributes	All Tidal				Natural Tidal				Developed Tidal			
	1945		1985		1945		1985		1945		1985	
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Tidal	392.50	13.98	228.27	8.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural	373.49	13.30	140.37	5.00	373.49	13.30	140.37	5.00	0.00	0.00	0.00	0.00
Developed	19.01	0.68	87.90	3.13	0.00	0.00	0.00	0.00	19.01	0.67	87.90	3.13
Surface Material	392.50	13.98	228.27	8.13	373.49	13.30	140.37	5.00	19.01	0.67	87.90	3.13
Mangrove	128.65	4.58	147.78	5.26	113.42	4.04	86.09	3.07	15.23	0.54	61.69	2.20
Mudflat	263.85	9.40	80.49	2.87	260.07	9.26	54.28	1.93	3.78	0.13	26.21	0.93
Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Built	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX H-4: Area Statistics on Water Feature Attributes of Stock Island for 1945 and 1985

Feature Attributes	All Water				Natural Water				Developed Water			
	1945		1985		1945		1985		1945		1985	
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Water	2003.19	71.36	880.41	66.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Natural	1972.16	70.24	1595.68	56.84	1972.16	70.24	1565.68	56.84	0.00	0.00	0.00	0.00
Shallow	1269.06	45.20	913.66	32.55	1269.06	45.20	913.66	32.55	0.00	0.00	0.00	0.00
Deep	703.10	25.04	682.02	24.30	703.10	25.04	682.02	24.30	0.00	0.00	0.00	0.00
Developed	31.75	1.13	284.73	10.14	0.00	0.00	0.00	0.00	31.75	1.13	284.73	10.14
Shallow	0.00	0.00	28.74	1.02	0.00	0.00	0.00	0.00	0.00	0.00	28.74	1.02
Deep	31.75	1.13	255.99	9.11	0.00	0.00	0.00	0.00	31.75	1.13	255.99	9.12

APPENDIX I

Stock Island Atlas Table of Contents

APPENDIX J-1: General Ecologic Areas of Safe Harbor

GEO-REGION	1985 Total Area	
	Acres	Percent
Land	38.53	14.72
Shore	47.94	18.32
Tidal	0.23	0.09
Water	175.00	66.87
Total	261.70	100.00

APPENDIX J-2: Area Statistics of Land Feature Attributes of Safe Harbor for 1985

Feature Attributes	Natural		Developed		Total	
	Acres	Percent	Acres	Percent	Acres	Percent
Shore	0.0000	0.00	0.0000	0.00	38.5299	14.17
Natural	11.6616	4.46	0.0000	0.00	11.6616	4.46
Developed	0.0000	0.00	26.8683	10.26	26.8683	10.26
Vegitation	0.0000	0.00	0.0000	0.00	0.0000	0.00
Native	0.0000	0.00	0.0000	0.00	0.0000	0.00
Marsh	0.0000	0.00	0.0000	0.00	0.0000	0.00
Hammock	0.0000	0.00	0.0000	0.00	0.0000	0.00
Other	0.0000	0.00	0.0000	0.00	0.0000	0.00
Disturbed	0.0000	0.00	0.0000	0.00	0.0000	0.00
Grass	0.0000	0.00	0.0000	0.00	0.0000	0.00
Bare	0.0000	0.00	0.0000	0.00	0.0000	0.00
Exotic	0.0000	0.00	0.0000	0.00	0.0000	0.00
Other	0.0000	0.00	0.0000	0.00	0.0000	0.00
Built	11.6616	4.46	0.0000	0.00	0.0000	0.00
Public	1.2597	0.48	0.0000	0.00	11.6616	4.46
Park	0.0000	0.00	11.3516	4.33	12.6113	4.82
Roads, Bridges, Parking	1.2577	0.48	0.0000	0.00	0.0000	0.00
School, Government	0.0000	0.00	0.0000	0.00	1.2597	0.48
Landfill	0.0000	0.00	0.0000	0.00	0.0000	0.00
Utilities	0.0000	0.00	0.0000	0.00	0.0000	0.00
Military	0.0000	0.00	11.3516	4.33	11.3516	4.33
Other	0.0000	0.00	0.0000	0.00	0.0000	0.00
Residential	2.8857	1.10	0.0000	0.00	0.0000	0.00
Single Family	0.0000	0.00	0.0000	0.00	2.8857	1.10
Multi-Family	0.0000	0.00	0.0000	0.00	0.0000	0.00
Residential-Commercial	2.5390	0.97	0.0000	0.00	0.0000	0.00
Mobile Home	0.3467	0.13	0.0000	0.00	2.5390	0.97
Campground	0.0000	0.00	0.0000	0.00	0.3467	0.13
Commercial	7.5162	2.87	0.0000	0.00	0.0000	0.00
Tourism	2.3826	0.91	15.5167	5.92	23.0329	8.80
General Commercial	0.6193	0.23	6.5596	2.50	8.9422	3.42
Industrial Service	4.5143	1.72	0.5266	0.20	1.1459	0.44
Farm	0.0000	0.00	8.4305	3.22	12.9448	4.95
Other	0.0000	0.00	0.0000	0.00	0.0000	0.00
			0.0000	0.00	0.0000	0.00

APPENDIX J-3: Area Statistics of Shore Feature Attributes of Safe Harbor for 1985

Feature Attributes	Natural		Developed		Total	
	Acres	Percent	Acres	Percent	Acres	Percent
Shore	0.0000	0.00	0.0000	0.00	47.9403	18.32
Natural	11.1061	4.23	0.0000	0.00	11.1061	4.23
Developed	0.0000	0.00	36.8342	14.11	36.9538	14.11
Vegitation	0.2315	0.09	2.1273	0.81	2.3588	0.90
Natural	0.0000	0.00	0.0000	0.00	0.0000	0.00
Marsh	0.0000	0.00	0.0000	0.00	0.0000	0.00
Hammock	0.0000	0.00	0.0000	0.00	0.0000	0.00
Other	0.0000	0.00	0.0000	0.00	0.0000	0.00
Disturbed	0.2315	0.09	2.1273	0.81	2.3588	0.90
Grass	0.0000	0.00	0.0000	0.00	0.0000	0.00
Bare	0.0000	0.00	0.0000	0.00	0.0000	0.00
Beach	0.0000	0.00	0.0000	0.00	0.0000	0.00
Exotic	0.2315	0.09	2.1273	0.81	2.3588	0.90
Other	0.0000	0.00	0.0000	0.00	0.0000	0.00
Built	10.8746	4.14	34.7069	13.26	45.5815	17.42
Public	0.7524	0.28	13.3829	5.11	14.1353	5.40
Park	0.0000	0.00	0.0000	0.00	0.0000	0.00
Roads, Bridges, Parking	0.2691	0.10	2.7316	1.04	3.0007	1.15
School, Government	0.0000	0.00	0.0000	0.00	0.0000	0.00
Landfill	0.0000	0.00	0.0000	0.00	0.0000	0.00
Utilities	0.4833	0.18	10.6513	4.07	11.1346	4.25
Military	0.0000	0.00	0.0000	0.00	0.0000	0.00
Wildlife	0.0000	0.00	0.0000	0.00	0.0000	0.00
Other	0.0000	0.00	0.0000	0.00	0.0000	0.00
Residential	0.0300	0.01	0.0000	0.00	0.0300	0.01
Single Family	0.0000	0.00	0.0000	0.00	0.0000	0.00
Multi-Family	0.0000	0.00	0.0000	0.00	0.0000	0.00
Residential-Commercial	0.0300	0.01	0.0000	0.00	0.0300	0.01
Mobile Home	0.0000	0.00	0.0000	0.00	0.0000	0.00
Campground	0.0000	0.00	0.0000	0.00	0.0000	0.00
Dockside Boat Living	0.0000	0.00	0.0000	0.00	0.0000	0.00
Commercial	10.0922	3.85	21.3240	8.14	31.4162	12.00
Marina	0.2440	0.09	1.9039	0.73	2.1479	0.82
Boatel-Motel	0.0000	0.00	0.0000	0.00	0.0000	0.00
Restaurant	0.0000	0.00	0.0000	0.00	0.0000	0.00
Boatyard	2.2492	0.86	3.6927	1.41	5.9419	2.27
Fish Processing	4.4885	1.71	8.1698	3.12	12.6583	4.84
Warehousing	1.6020	0.61	2.8665	1.09	4.4685	1.71
Salvage Yard	1.5085	0.58	4.6911	1.79	6.1996	2.37
Other	0.0000	0.00	0.0000	0.00	0.0000	0.00

APPENDIX J-4: Area Statistics of Tidal Feature Attributes of Safe Harbor for 1985

Feature Attributes	Natural		Developed		Total	
	Acres	Percent	Acres	Percent	Acres	Percent
Tidal	0.00	0.00	0.2329	0.09	0.2329	0.09
Natural	0.00	0.00	0.0000	0.00	0.0000	0.00
Developed	0.00	0.00	0.2329	0.09	0.2329	0.09
Surface Material	0.00	0.00	0.2329	0.09	0.2329	0.09
Mangrove	0.00	0.00	0.2329	0.09	0.2329	0.09
Mudflat	0.00	0.00	0.0000	0.00	0.0000	0.00
Beach	0.00	0.00	0.0000	0.00	0.0000	0.00
Built	0.00	0.00	0.0000	0.00	0.0000	0.00
Beach	0.00	0.00	0.0000	0.00	0.0000	0.00

APPENDIX J-5: Area Statistics of Water Feature Attributes of Safe Harbor for 1985

Feature Attribute	Natural		Developed		Total	
	Acres	Percent	Acres	Percent	Acres	Percent
Water	0.0000	0.00	0.0000	0.00	174.9990	66.87
Natural	76.0212	29.05	0.0000	0.00	76.0212	29.05
Shallow	25.9547	9.91	0.0000	0.00	25.9547	9.91
Deep	50.0665	19.12	0.0000	0.00	50.0665	19.12
Developed	0.0000	0.00	98.9778	37.78	98.9778	37.78
Shallow	0.0000	0.00	2.3755	0.90	2.3755	0.90
Deep	0.0000	0.00	96.6023	36.88	96.6023	36.88
Navigation	23.5824	9.00	76.5525	29.23	100.1349	38.26
Dockage	0.0000	0.00	17.1887	6.56	17.1887	6.56
Total Area	98.7889		162.9132		261.7021	

APPENDIX K

Coastal Use Capability Classification (CUCC)

A Note on Background and Development of CUCC

The Coastal Use Capability Classification (CUCC) system, defined by this research, is derived from agricultural, suburban, and forestry land evaluation systems, as bluebelting for waterfronts has been extrapolated from greenbelting in agriculture to discourage the conversion of productive farmland to suburban housing. Two basic concepts and practices are combined and used to develop CUCC algorithms as an analytical tool for local comprehensive shoreline and water planning: (a) land use capability classification, U.S. Soil Conservation Service, and (b) multiple use, U.S. Forest Service. CUCC had initially been developed by two of the investigators (Antonini and Zobler) from an unpublished technical study of tropical steepland agriculture in the Dominican Republic (Antonini et al., 1985).

The Soil Conservation Service has developed a method of classifying land according to agricultural capability in which soil erosion is the decision parameter. The classification ranks parcels nationally according to sustainable use intensities (Klingebiel and Montgomery, 1966). The national rankings of land use combinations are adapted to local farming systems and environmental conditions of delimited uniform areas of the operating farm unit. A land use capability map is prepared marking areas to which suitable farm practices are applied. Multiple use of forest lands was developed by the U.S. Forest Service as a public management tool to allocate forest areas to partially competitive uses in a way that would maximize public benefits on a sustainable basis. The use system is systemically ordered because all lands simultaneously produce more than one output, as timber, water, fauna and flora, and aesthetic satisfactions, even though there may be a singular prime objective (Convery, 1977). With an increase in recreation and amenity demands and values, the Forest Service is now reappraising the role of each of the output sectors. What are the most valuable products under present multiple use management goals? What shall the new input-output mix be to maximize benefits? The increased value of amenity-recreation use is now under review (Robertson, 1987).

The issues raised and solutions sought by the Soil Conservation and Forest Services parallel the resource management concerns facing counties and municipalities located along the coastal United States. Classification and evaluation in coastal areas are especially difficult because of the varied technical requirements within and among water-land ecosystems. These variations are exacerbated by the spatial mixing of physical site properties (Ortolano, 1984).

Many systems have been devised to classify the suitability of land for agricultural, forestry, urban, and industrial areas (Beek, 1978). Methodologies for classification and evaluation may differ in data content, logical structure, decision rules, and analysis routines used to assess regional resources, recommend use patterns, or set parcel limitations. The detail and scale of analysis are related to parcel size, taxonomy and evaluation objectives. Locations and constraints of parameters can be used to construct a meaningful normative index (USDA, 1974; Clark, 1976; Fabos and Caswell, 1976; Dobson, 1979). Constraining use parameters may be weighted. Such classifications are applicable to scenic values and other amenities and are incorporated in zoning regulations and tax ratable schedules (Beatty et al., 1979; Reganold and Singer, 1979; Storie, 1976). These principles of classification are applicable to coastal zones (Heatwole and West, 1982). The seminal work by Clark (1983) has drawn on the experiences of the Soil Conservation Service and the Forest Service to find technical-developmental accommodations for ecological problems in coastal areas.

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