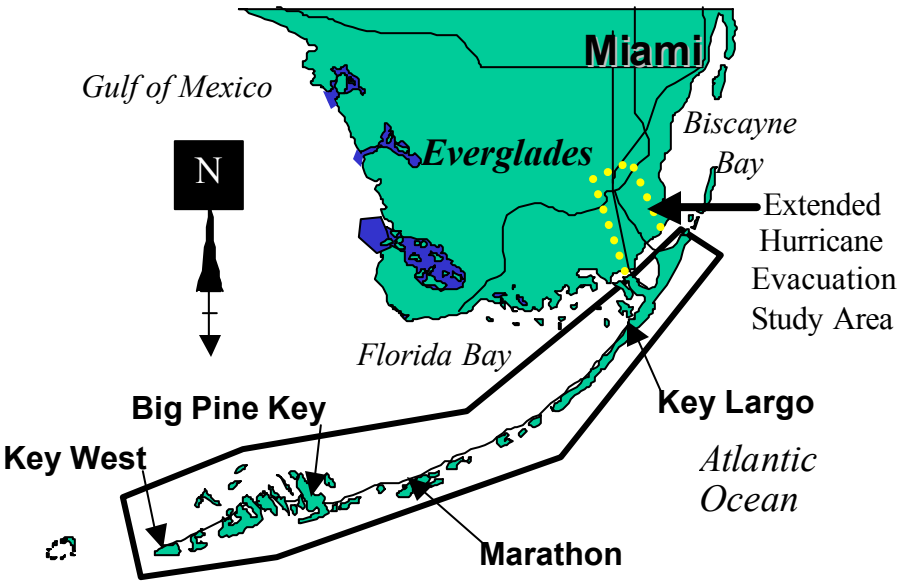
2.0 CARRYING CAPACITY/IMPACT ASSESSMENT MODEL OVERVIEW

2.1 Study Area: The Florida Keys Context

The Florida Keys are a 113-mile long chain of low-elevation islands with a combined area of approximately 100 square miles, and over 200 additional minor islands. The study area encompasses the portion of Monroe County that spans from Key Largo to directly east of the Marquesas, and follows the same boundaries as the FKNMS (Figure 2.1). While the mainland portion of Monroe County at the southernmost tip of the Florida peninsula is excluded, the study area considers the hurricane evacuation route to the Florida Turnpike in Miami-Dade County.

FIGURE 2.1
STUDY AREA



The Florida Keys have unique characteristics that affect future planning. First, commercial activities and residential development are largely concentrated along the U.S. 1 corridor. U.S. 1 provides not only a structural backbone to the Keys, but also its only land-based evacuation route. Second, the economy of the Florida Keys largely relies upon the tourism industry, which creates external demands for land and services. Third, over 60% of the land mass is in government ownership, the vast majority of which is set aside for conservation. Conservation lands in the Keys include three state parks and four National Wildlife Refuges, which harbor over 100 protected species of flora and fauna; in addition, the Florida Keys National Marine Sanctuary includes the marine waters around the Florida Keys. Finally, upland habitats in the

Florida Keys, namely hammocks and pinelands, include over 30 endemic species of plants and animals. Hammocks in the Keys harbor several plant tropical species, which reach the northern limit of their distribution in the Florida Keys.

The Florida Keys have a long history of human occupation, dating back to Calusa and Tequesta Indians settlements. A number of prehistoric and historic sites in the Florida Keys are included in the National Registry of Historic Places. Today, there are nearly 80,000 permanent residents in the Florida Keys; over 2.5 million people visit the Keys annually.

2.2 Key Concepts and Processes of the Carrying Capacity/Impact Assessment Model

2.2.1 Key Concepts

The CCIAM is a spatially explicit, GIS-based, automated model that evaluates the end-state effects of additional land development activities on the Florida Keys ecosystems, including impacts on socio-economics, human infrastructure, and social preferences. Land development activities modify land use patterns, including the type, location, intensity, and distribution of land uses. The CCIAM analysis is triggered by changes in land use. The user defines alternative scenarios by modifying land use patterns and specifying stormwater and wastewater treatment types. The model recognizes three types of development actions: new development, redevelopment, and restoration. New development considers the conversion of undeveloped areas, whether disturbed or in a natural state, to a developed land use. Redevelopment either converts developed land from one type of use to another or changes the intensity of the land use. Restoration reverts developed land to a "natural" or restored habitat. CCIAM is designed so that all coefficients, databases, and algorithms can be updated when more current data and/or scientific understanding becomes available.

Throughout this report, the following key terms are used frequently. A glossary is found in Appendix E.

- **Carrying Capacity Indicators:** Indicators include thresholds, criteria, levels, or standards, which, if exceeded, would result in a significant level of impact or damage to a resource or element. In some cases this level of impact may be sufficient to impair the sustainability of the resource. In the CCIAM, three types of indicators or thresholds have been used to address the carrying capacity limit of a resource:
  - Government mandated thresholds are based on quantitative standards mandated by local, state, or federal agencies (e.g., permitted volume of water supply).
  - Environmental thresholds are based on a tolerance range or limit for a resource or species, beyond which it is not sustainable (e.g., Lower Keys marsh rabbit habitat). These thresholds are established in the scientific literature or through consultation with technical experts.

- Socioeconomic thresholds are based upon a tolerance range for a given socioeconomic measure, which, if exceeded, would degrade quality of life in the Florida Keys (e.g., population demand for non-residential uses).

- **Impact assessment variables (IAV):** Environmental and socioeconomic variables for which assessments are conducted. Generally, an IAV is a module output. For example, the Species Richness Index (Section 9) is an output of the terrestrial module that provides a measure of direct impacts to species-area habitat.

- **Modules:** A module is a self-contained analysis unit with distinguishing inputs and outputs that may be derived from, or provided to, other modules. Each of the major categories of assessment (e.g., terrestrial habitats and species) is represented by a module, within which all operations relating to that category are executed.

- **Components:** Modules consist of components, which are discrete subsets of inputs, calculations, and outputs. For example, the Integrated Water Module is comprised of the Potable Water, Stormwater, and Wastewater components.

- **Elements:** Elements include algorithms, coefficients, data tables, and other computational aspects within each component. One or more elements may constitute a component.

- **Planning Units:** For the analysis, the Florida Keys were divided into 28 planning units (Table 2.1; Appendix G, Map 1) which approximately correspond to the planning units used in the Monroe County Sanitary Wastewater Master Plan (CH2M HILL 2000):

TABLE 2.1
FKCCS PLANNING UNITS

Wastewater Planning Unit Name	
Ocean Reef Club	Marathon Primary
PAED 21 (North Key Largo)	Bahia Honda Key
PAED 22 (Cross Key)	Big Pine Key
PAED 19 and 20 (Garden Cove)	Big/Mid Torch Key
PAED 18 (John Pennecamp State Park)	Little Torch Key
PAED 17 (Rock Harbor)	Ramrod Key
PAED 16 (Rodriguez Key)	Summerland Key
PAED 15 (Tavernier)	Cudjoe Key
Plantation Key	Upper Sugarloaf
Windley Key	Lower Sugarloaf
Upper Matecumbe	Bay Point
Lower Matecumbe	Boca Chica
Long Key/Layton	Stock Island
Key Colony Beach	Key West

2.2.2 Key Processes

The structure and key processes of the CCIAM encompass the following four elements (Figure 2.2):

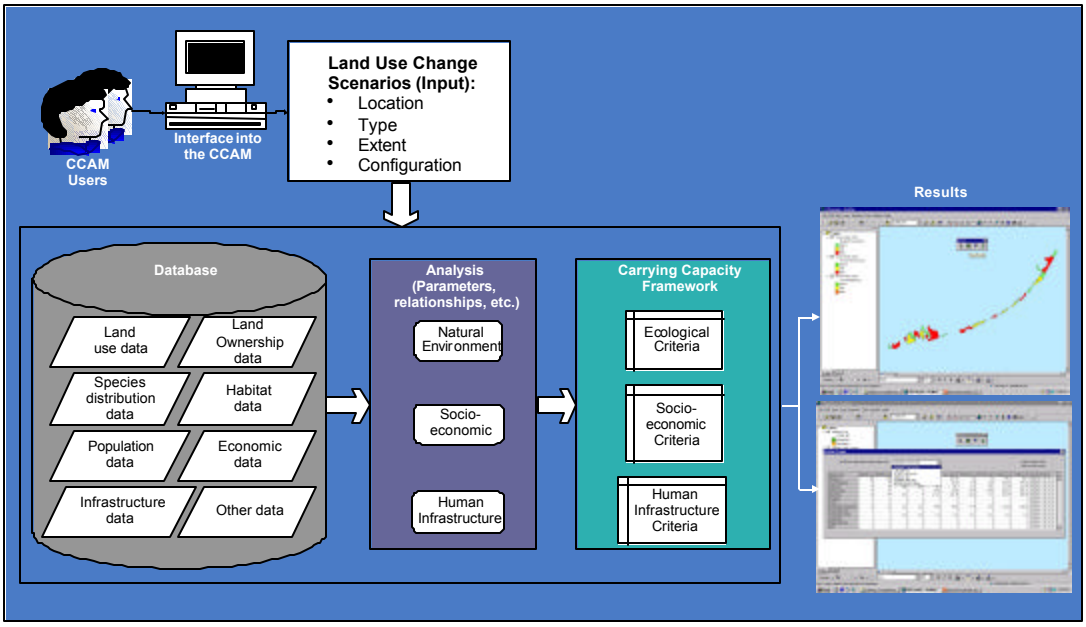
- **Data:** Datasets were identified, compiled, assimilated, and organized into a series of databases for use in the model. Examples of key data required include land use and land cover; land ownership; population; socio-economics; infrastructure; terrestrial and marine habitat; and species distributions.

- **Scenarios:** Scenarios represent specific sets of land use conditions that the user defines for analysis. Land use conditions are defined in terms of the location, type, extent, and configuration of the land use change.

- **Analysis:** Effects of land use changes on the human infrastructure, socioeconomic conditions, and natural environment within the study area are evaluated. Relationships between land use change and model elements define the analytical basis of the CCIAM.

- **Carrying Capacity Indicators:** Thresholds, limiting factors, and other criteria associated with the ecological, socioeconomic, and human infrastructure categories of the model help evaluate overall carrying capacity. These indicators are used to evaluate results of the analysis and assess whether modeled scenarios are likely to exceed the carrying capacity indicators.

FIGURE 2.2
CARRYING CAPACITY/IMPACT ASSESSMENT MODEL PROCESS



2.3 Carrying Capacity/Impact Assessment Model Function

The two primary functional parts of the model are the Scenario Generator and the Analysis Modules. The Scenario Generator is a Graphic User Interface (GUI) and a set of preliminary calculations to create a land use GIS layer from the user-defined scenario. Using these land use conditions, the Analysis Modules calculate scenario effects on each of the IAVs. Finally, the Analysis Modules compare resulting IAVs with indicator values and identifies conditions that may exceed these indicators.

2.3.1 Scenario Generator

A GUI has been designed for the CCIAM. The GUI provides menu options, which allow the user to define the scenario. The user can specify the characteristics of land use change and environmental interventions. The scenario generator allows for multiple changes within a planning unit.

As the scenario is defined, the CCIAM performs internal checks for consistency and validity of data entry. For example, it compares the area of a land use entered in the "Change From" category to the amount of that land use actually available in the analysis area to ensure that the existing total is not exceeded. The user may also use the GUI to input environmental interventions, such as wastewater treatment options.

An output of the Scenario Generator is a GIS layer specific to the user's defined land use changes. The model stores the scenario parameters in a database for future retrieval. The Analysis Modules utilize the GUI-generated land use layer to execute the impact assessment calculations.

2.3.2 Analysis Modules

Scenarios are analyzed in modules (Table 2.2). Inputs and outputs are exchanged among certain modules. For example, population from the socio-economic module and costs of potable water infrastructure from the water module are used as inputs for the fiscal module.

TABLE 2.2
CCIAM ANALYSIS MODULES AND COMPONENTS

CCIAM Module	Module Components
Socioeconomic	Population/Residential; Economic/Nonresidential; Socioeconomic Indicators
Fiscal	Government Expenditures
Infrastructure	Traffic; Hurricane Evacuation
Integrated Water	Potable Water; Wastewater; Stormwater; Groundwater; Cost of Infrastructure
Terrestrial	Habitat Conversion and Fragmentation Secondary Impacts; Species-Specific Effects

In summary, the CCIAM evaluates the following effects of land use change:

- **Effects of land use changes on population (Socioeconomic Module):** Changes in land use may result in changes in the population of the study area. This can include changes to the permanent, seasonal, and transient populations.

- **Effects of population changes on socioeconomic parameters and government expenditures (Socioeconomic and Fiscal Modules):** Changes in the number and distribution of people result in changes in economic variables, such as employment, income, and demand for services and infrastructure. These in turn affect the government expenditures required to meet population demands.

- **Effects of population changes on infrastructure (Infrastructure Module):** Changes in the number and distribution of people also result in changes in traffic patterns. This in turn affects the time required for hurricane evacuation.

- **Effects of land use change on the dynamics of water and the demand for water supply (Integrated Water Module):** Changes in land use and the application of best management practices (BMPs) may result in changes in the impervious surface area, thereby altering stormwater runoff and the volume of water discharged into groundwater and the marine environment. BMPs determine the treatment level for stormwater and affect the pollutant load discharge into the marine environment. Population changes resulting from changes in land use also affect water consumption and the production of wastewater, which ultimately may affect water quality in nearshore waters.

- **Direct and indirect effects of land use change on terrestrial habitats and species (Terrestrial Module):** Conversion of undeveloped land into developed land results in a corresponding decrease in habitat area. This reduction in habitat area results in habitat fragmentation and degradation. In restoration scenarios, developed lands are reverted to natural conditions, increasing habitat area.

Specific inputs and outputs used to drive the derivation of the consequences are detailed in Sections 3 to 10 and Appendix C.

2.3.3 Carrying Capacity Indicators

Sections 3 to 10 describe the technical basis of the model, including a discussion of how available data were incorporated into the CCIAM. Lack of relevant available data on some topic areas limited the success of attempts to establish carrying capacity thresholds for all environmental parameters. However, carrying capacity indicators exist for several parameters (Table 2.3). Some of these indicators are regulatory and, while currently binding, may be subject to change. Others are documented in the peer-reviewed scientific literature. Together, the carrying capacity indicators provide a framework to explore carrying capacity issues in the Florida Keys.

TABLE 2.3
CARRYING CAPACITY INDICATORS FOR THE FKCCS

Indicator	Value or definition	Type*	Comments
Population demand for non-residential uses	Demand is higher than the available non-residential uses	III	Population demand for retail, services and other non-residential uses, increases development demand. The user may input further development in the scenario and run model again.
Business demand for employees	Demand is higher than the available local labor force	III	If the business demand for employees surpasses the available local labor force, pressure builds to increase commuting employees.
Per capita government expenditures	Increase in the per capita expenditures as a result of the scenario	III	An increase in per capita government expenditures means that the government will have to seek increased revenues to match increased expenditures. Therefore, it indicates pressure to increase taxes.
LOS of U.S. 1	Median speed. U.S. 1 wide, the threshold speed of 45 mph. Required speed may be different for different segments.	I	Current regulations require the Monroe County maintain an adequate LOS. A failure to maintain the required LOS results in a building moratorium.
Hurricane evacuation clearance time	24 hours – the time required to evacuate the Keys in case of an impending hurricane.	I	Current regulations required that the Keys population evacuate in 24 hours.
Permitted volume of water supply	Daily average: 15.83 MGD Maximum day: 19.19 MGD	I	Per South Florida Water Management District permit which expires December 2005.
Minimum patch size for upland Keys forests	13 acres	II	Keys hammocks smaller than 5.9 ha. are considered "all edge," with forest interiors lacking the buffering effects of edge vegetation (Strong and Bancroft 1994).
Lower Keys marsh rabbit habitat	Species is in danger of extinction	II	Species is currently in danger of extinction, mainly due to habitat loss (Forys and Humphrey 1994). Only habitat restoration would be beneficial for the Lower Keys marsh rabbit.
Key deer habitat	Habitat quality classification – Tier 2 and 3 (Figure 9.3).	II	Recent studies (Lopez 2001) have determined habitat needs for Key deer.
Patch size requirement for forest- nesting birds in the Florida Keys	Minimum patch size: Black-whiskered vireo: 0.5 acres; White-eyed vireo: 5 acres; Northern flickers: 7.5 acres; Yellow-billed cuckoo: 16 acres; Mangrove cuckoo: 12.8.	II	Documented in Bancroft et al. (1995), who studied 27 Upper Keys forests ranging in size from 0.5 to 217 acres.
White-crowned pigeon habitat	Fledglings hatch in mangroves but require large (12 acres) hammock patches within 72 hours.	II	Documented in Strong and Bancroft (1994), who studied post-fledging dispersal of white-crowned pigeons in the Florida Keys.

* I = Regulatory, II = Scientific, III = Social (see Section 2.2.1 for further description).

2.4 Spatial Databases Used in the Study

Numerous state, federal, and local agencies and organizations provided datasets for potential use in this study. The FMRI, a branch of the FWC, is the primary database contractor for the study. Spatial datasets were reviewed to determine their suitability for inclusion according to the following criteria:

- Spatial coverage of data;
- Resolution of the data and concurrence with map accuracy standards for that level of resolution;
- Completeness of data;
- Vintage of data;
- Accuracy of data set attribution;
- Accuracy in polygon closure, edge mapping, and other topology parameters;
- Completeness of documentation or metadata;
- Degree of spatial error and ability to match to other data sets;
- Ability to be analyzed with other data sets;
- Accuracy and documentation of data acquisition methods; and
- Projection parameters.

Two important factors determining data suitability are spatial accuracy and applicability to the needs of the CCIAM. In several cases, a particular dataset contained critical information not available from another source, but was in an incompatible format or contained discrepancies or was incomplete. If data limitations did not represent a fatal flaw, necessary steps were performed to bring the dataset to an acceptable state for use in this study.

The following spatial databases are examples of data that were incorporated into the study:

- Monroe County parcel GIS layer and associated Tax Roll database from the Monroe County Property Appraiser.
- Planning units and other spatial data from the Monroe County Sanitary Wastewater and Stormwater Master Plans (CH2M HILL 2000, CDM 2000).
- The FMRI Advanced Identification of Wetlands (ADID) dataset, which provided terrestrial habitat distribution data.

- Habitat distribution within the FMRI benthic communities' dataset.
- Terrestrial and marine species distribution from the U.S. Fish and Wildlife Service, FWC and FMRI.

The adequacy of these datasets, as well as adjustments that were necessary to use them in the study, are discussed in Sections 3 through 10.

2.5 Information Technology

The CCIAM is implemented as a customized ArcInfo 8.1 map document (MXD). This MXD houses the Visual Basic for Applications code that is used to automate the analysis, result reporting, and graphical user interface. ArcInfo 8.1 represents the latest GIS technology that is widely used in both Florida and the United States. Agencies such as the Florida Fish and Wildlife Conservation Commission, Monroe County Property Appraiser's Office, and the DCA employ ArcInfo.

Over 50 gigabytes of data were generated while testing and refining the CCIAM. The final model should consist of approximately 5 to 10 gigabytes of data. Some datasets are large, both in number of records and fields (attributes) in the associated tables. For example, there are approximately 70,000 records in the parcel dataset, 13,500 records in the benthic communities' dataset, and 9,700 in the Advanced Identification of Wetlands dataset. In addition, there are fifty-four attributes associated with the parcel dataset and most analyses in the CCIAM add at least one field to several different tables. The CCIAM relies on several personal geodatabases and ArcInfo workspaces to manage, access, and generate data. Personal geodatabases employ Component Object Model (COM) technology and are implemented as Microsoft Access 2000 databases. ArcInfo workspaces are unique to the grid and coverage formats of the GIS software vendor, Environmental Systems Research Institute (ESRI).

The study team investigated the utility of a relational database management system and required middleware, Spatial Database Engine (SDE). Due to the cost of this solution, approximately $12,000 to $15,000, and the uncertainty regarding the capabilities of the implementing organization, the study team chose to build the CCIAM with personal geodatabases and grid workspaces. This data management solution provides flexibility in selecting a long term CCIAM steward. The CCIAM can be implemented using the current data management configuration or be migrated directly to a relational database management system using SDE.

Study team programmers used Visual Basic for Applications to manipulate ArcObjects and execute structured query language (SQL) statements that, in turn, automate all analytical processes in the model. All code is documented both within the code itself as headers and in technical manuals that will be provided to the CCIAM steward. Additional Visual Basic for Applications code has been written that displays and operates the GUI as forms within ArcInfo 8.1. Lastly, code was also written to display results as maps, charts, and tables from within the GIS software package.

In addition to GIS, Microsoft's Visio software is used to represent the CCIAM processes and relationships in a graphical format. The use of diagrams is a common technique for tracking processes, functions, results, and influences during complex modeling exercises. Likewise, ancillary software solutions such as help systems, metadata (Spatial Metadata Management System), and database management are used to complement the GIS.

Data compiled and resulting from the FKCCS will be delivered to the general public and local planners via the Internet. Arc Internet Map Server (ArcIMS) is currently available as an "off the shelf" software package for the delivery of GIS information via the Internet. The study team built a Routine Planning Tool using ArcIMS as the technology solution. Minor customizations, using Java Script, were made to the "out of the box" solution to enhance the application. The Internet application will supplement the model, provide wide access to the CCIAM information base, and allow for data downloads.