

# Arc Marine

*GIS for a Blue Planet*

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*Foreword by Jane Lubchenco*

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# Contents

*Foreword*      Professor Jane Lubchenco [ *vii* ]

*Preface* [ *ix* ]

*Acknowledgments* [ *xi* ]

Chapter 1      Introduction [ 1 ]

Chapter 2      Common Marine Data Types [ 9 ]

Chapter 3      Marine surveys [ 21 ]

Chapter 4      Marine animal data applications [ 45 ]

Chapter 5      Implementing time series and measurements [81 ]

Chapter 6      Nearshore and coastal/shoreline analysis [ 107 ]

Chapter 7      Model meshes [ 141 ]

Chapter 8      Multidimensional GIS [ 163 ]

Chapter 9      Epilogue [ 177 ]

*About the authors* [ 183 ]

*Index* [ 185 ]

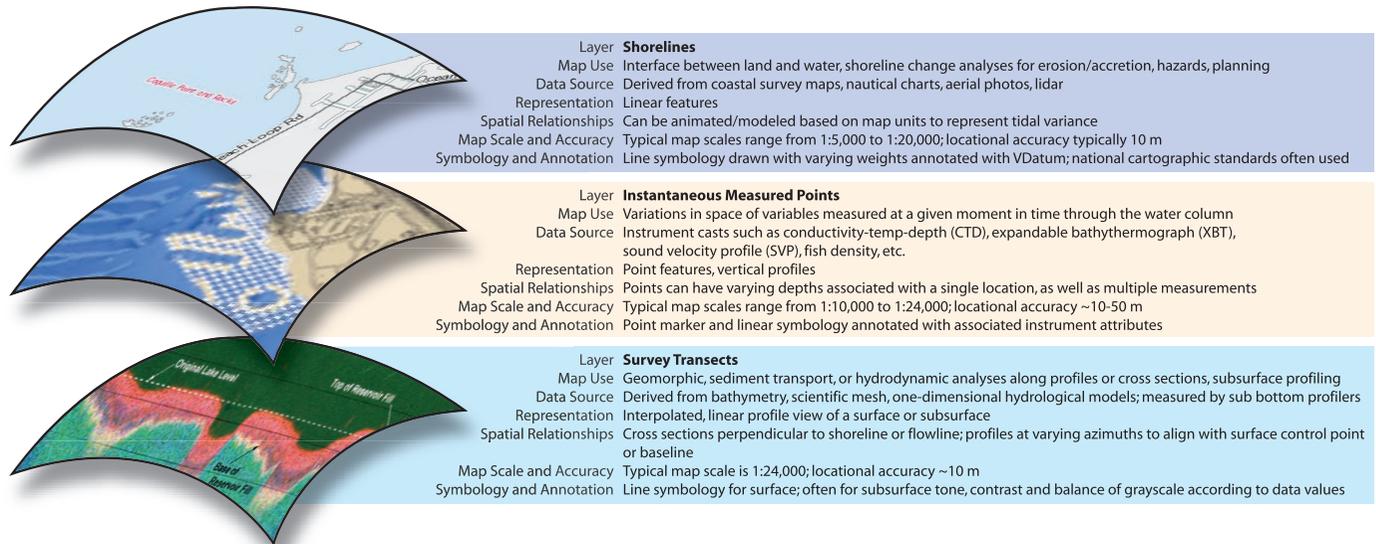
# 6

## chapter six



## Nearshore and coastal/ shoreline analysis

*This chapter discusses the linear feature classes in the Arc Marine data model and their varied implementation in mapping important entities such as present and historical shorelines, sediment budget profiles, alongshore hurricane tracks, nearshore SCUBA survey transects, and jurisdictional boundaries. Concepts are illustrated by a coastal engineering/resource management case study in Florida and a coastal evolution/sediment budget case study in Denmark. While linear features themselves are certainly important, observations, measurements, and samples along with these features are also critical. Two nearshore studies of coral reef fish and invertebrates in Hawai'i demonstrate the utility of the Survey subtype of the InstantaneousPoint feature class and the SurveyInfo object table.*



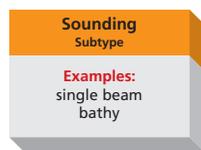
## Introduction

The coast (or shore) represents one of the most important linear features on earth, marking the interface between land, sea, and the overlying atmosphere, and between different levels of government, judicial responsibility, or research management (see overviews in Bartlett 2000 and Sherin 2000). The shoreline is also used as a baseline for delimiting nearshore boundaries such as state territorial waters, exclusive economic zones (EEZs), and marine protected areas (MPAs). Only in the past century has the need to establish maritime territorial claims been proposed, and only within the past few decades have protocols been internationally adopted for drawing such lines in the ocean to create maritime boundaries (see overview of Palmer and Pruett 2000). And disconnected lines in the neashore are used for data collection (transects, tracklines, vehicle tows, and the like). This is important in a navigation framework such as the ArcGIS International Hydrographic Organization (IHO) S-57 data model for electronic nautical charts (<http://support.esri.com/datamodels>) or the U.S. Hydrographic Data Content Standard for Inland and Coastal Waterways (<http://www.fgdc.gov/standards/projects/FGDC-standards-projects/coastal-and-inland-waterways/>).

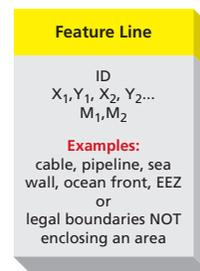
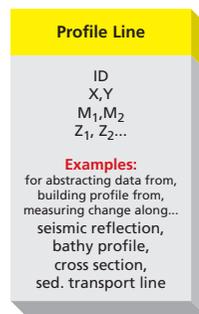
Byrnes et al. (1991) cite five critical factors to consider when mapping coastal and nearshore linear features: coastal and ocean processes, relative sea level, sediment budget, climate, and human activities. This chapter discusses the linear feature classes in the Arc Marine data model and their varied implementation in mapping some of these important factors (figure 6.1). Oftentimes, the interest is not primarily in the linear features and attributes describing the lines (as is typically implemented in terrestrial applications that look at electrical networks, roads, and rivers, for example) but rather in what occurs or is observed along that line. Generally, it is a point measurement, sample, or observation taken at some location along that line (such as the SurveyPoint in figure 6.1) that is of interest.

## Common Marine Data Types

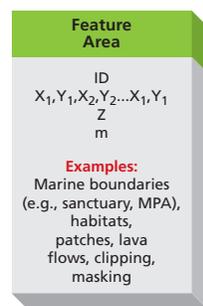
### Marine Points



### Marine Lines



### Marine Areas



**Figure 6.1** Portion of the main Common Marine Data Types diagram (from chapter 2) representing the marine data types featured in this chapter and implemented in the case studies. All headings are feature classes or subtypes of feature classes.

## Featured case studies

Two case studies from the west coast of the Big Island of Hawai'i illustrate the key role of the Survey subtype of the InstantaneousPoint feature class in Arc Marine to integrate, manage, and retrieve nearshore datasets. The first case study, implemented by Oregon State University graduate student Alyssa Aaby, used Arc Marine to integrate available nearshore fish species information from private and public sources around the main eight Hawaiian Islands (figure 6.2; Aaby 2004). Aaby integrated spatial information on nearshore fish species into Arc Marine to identify patterns of spatial habitat use and gaps in conservation. Recent studies have shown that the most effective marine protected areas represent a full range of habitat types (Leslie et al. 2003; Carr et al. 2003). The study used the querying ability of Arc Marine to evaluate the habitat use patterns of specific nearshore reef fish along the west coast of the island of Hawai'i (figure 6.3) by identifying correlations between regional-scale spatial information and fine-scale spatial information. This is important because available scientific research has not yet evaluated the current status of nearshore marine habitat use in western Hawai'i at the large scales needed by resource

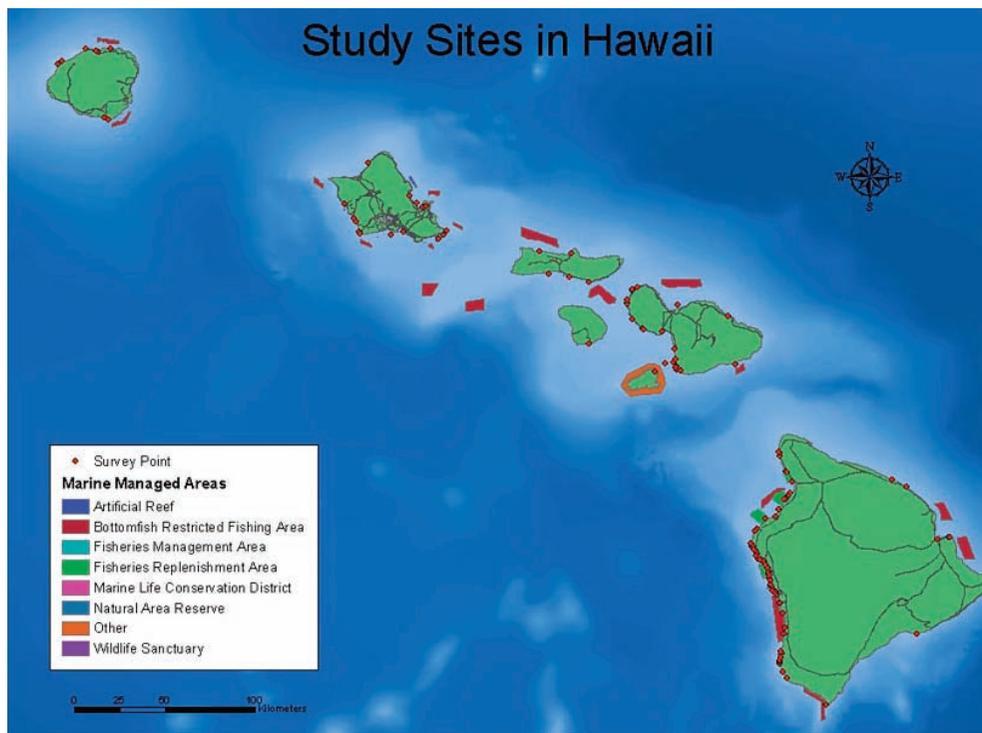


Figure 6.2 Study sites for data used in the western Hawai'i reef fish case study. Map from Aaby (2004), which also contains full documentation on data sources, some of which are proprietary.

Courtesy of Alyssa Aaby, University of Hawai'i and National Park Service (NPS).

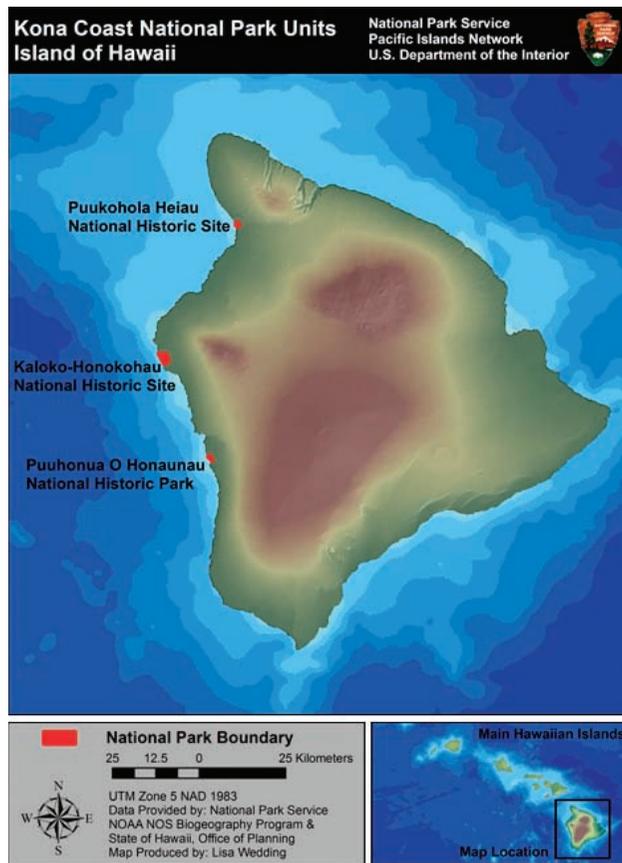


**Figure 6.3** Western Hawai'i Aquarium Project (WHAP) study sites used in the western Hawai'i reef fish case study.

Courtesy of Alyssa Aaby, University of Hawai'i and the National Park Service (NPS).

managers. While most marine studies have been conducted at very small scales, management units are usually on the scale of a single island, and resource evaluation therefore should reflect this larger scale (Friedlander and Brown 2003). By determining which combinations of habitat types are necessary for survival, the efficacy of the network of MPAs in western Hawai'i can be evaluated.

Similarly, Lisa Wedding, marine GIS database manager/research assistant; Dr. Larry Basch, senior marine scientist; and their colleagues at the Pacific Islands Coral Reef Program (PICRP) and the Pacific Islands Network Inventory and Monitoring Program, both of the National Park Service (NPS), implemented Arc Marine as a pilot project to develop new geodatabase standards and protocols for moving their data holdings to the geodatabase structure. The geodatabase gives resource managers and biologists at Pacific Islands National Parks the ability to easily access, view, and integrate different datasets (e.g., from inventory, monitoring, and research efforts) to generate maps and graphics; perform simple



**Figure 6.4** Location of the national park units on the west coast of Hawai'i that served as study sites for the Hawaiian NPS case study.

Map produced by Lisa Wedding, University of Hawai'i. Courtesy of National Park Service (NPS).

analyses; and make well-informed, science-based decisions about marine management and conservation actions (Wedding and Basch 2006). Specific tasks include comparing inventories between the parks, tracking research efforts within and across parks (from local and regional to national levels), and monitoring ecological change in parks over time. As such, the geodatabase is not limited to marine data but includes watersheds, land-use practices, subsistence fisheries use, and other terrestrial data. The idea is to increase work efficiency, eliminating the need to sacrifice time and resources to implement a database on their own. The parks in question are on the west coast of Hawai'i: the Pu'ukohola Heiau National Historic Site (PUHE), the Kaloko-Honokohau National Historical Park (KAHO), and the Pu'u honua o Honaunau National Historical Park (PUHO), all of which are connected by the 175-mile long corridor of the Ala Kahakai National Historic Trail (ALKA) (figure 6.4). The initial efforts focused on this network of national parks and surrounding areas nearshore because of the many ongoing marine research, inventory, and monitoring studies there.

A third case study focused on the central Atlantic coast of Florida in Martin County (figure 6.5), where Kathy Fitzpatrick, coastal engineer of the Martin County Engineering



Figure 6.5 Index map of Martin County on the southeast coast of Florida, south of Orlando.

Data source: ESRI Data & Maps CD, 1998.

Department; Heather Mounts, senior database developer at Photo Science, Inc., (PSI) in St. Petersburg, Florida; and Rob Hudson, project manager of PSI, used Arc Marine to store and query an extensive variety of datasets by way of FeatureLine, Shoreline, and FeatureArea (as explained in sections below), and several kinds of raster layers. The Coastal Division of the Martin County Engineering Department houses and maintains data from 21 miles of shoreline and 114 miles of inland waterways. It also maintains data on beach nourishment and management projects, water inlet management, water quality monitoring programs, and the construction and management of several nearshore artificial reefs. The region includes two major inland waterways: the Atlantic Intracoastal (AIWW) and Okeechobee Waterways (OWW). The AIWW runs north–south within the Indian River Lagoon, designated a Lagoon of National Significance partly because it provides essential habitat to juvenile sea turtles, West Indian manatee, and many ocean fish species. Endangered sea turtles also rely heavily on nearby beaches for nesting sites. Effective management requires rapid access to this information coupled with the capability for rapid analysis, particularly regarding hurricane recovery projects (two hurricanes hit Martin County in 2004). Shoreline hardening, coastal development projects, and public lands management are areas of growing concern within the county. Each project represents a substantial and long-term financial investment in the planning, permitting, construction, and monitoring phases of the recovery projects. Using Arc Marine as a guide, the county has been building a sustainable, standardized, and documented coastal GIS to meet local needs while contributing and conforming to evolving state and national coastal geospatial initiatives (Fitzpatrick et al. 2004).

Ann Skou of DHI Water & Environment implemented the chapter’s fourth and final case study. This study is more complex, involving historical coastline evolution, measurements of bathymetry for cross-shore profiles, and simulation of sediment transport rates with the use of numerical models. Recently, the municipality of Køge, Denmark, announced plans to construct a new harbor to support cargo traffic, directly competing with the Copenhagen harbor a few kilometers to the north. The new harbor will rise between an existing harbor to the south and a yacht harbor to the north. Køge is situated along the inner side of Køge

bay on the east coast of Zealand, the main island of Denmark. The area has weak currents, and the waves, which are the driving force behind sediment transport, approach the coast almost perpendicularly, resulting in small net transport rates. This has left the bay with a reasonably sandy and stable coastline.

In studies such as this, modelers need to know if the sediment transport is nonexistent overall or if the harbor entrance is just beyond the active transport zone. Even if the harbor doesn't have any problems with sedimentation, the adjacent coastline will be affected because the harbor will block the longshore sediment transport. In this case, where the municipality of Køge plans to more than double the size of the harbor, planners must consider the impact of the adjacent coastline. The volume of upstream sediment and downstream erosion could increase by extending the harbor (if indeed longshore transport does exist), which would change the stability orientation of the coastline and thus the coastline location. Danish authorities require these kinds of investigations before they proceed on such projects.

To investigate the morphological conditions in the area, DHI used its MIKE Marine GIS software ([http://www.dhisoftware.com/general/Marine\\_overview.htm](http://www.dhisoftware.com/general/Marine_overview.htm)) to examine the coastline and preprocess input data for DHI LITPACK software. LITPACK is a numerical modeling software that applies a unique deterministic approach to a wide range of coastal zone management applications. It simulates wave and current scenarios along coastlines and combines these simulations into predictions of coastal profiles and long-term coastal evolution. The MIKE Marine GIS is an ArcMap extension that consists of a suite of tools to manage, display, and analyze marine-based model data in ArcGIS, relying on a geodatabase with an extended version of Arc Marine for its data structure. DHI has extended Arc Marine's core classes with additional feature classes, object classes, and relationship classes necessary to accommodate the storing of model data. Using MIKE Marine GIS to store, process, and present the data smoothed the workflow and facilitated a better understanding of the investigation findings to nontechnical and technical users.

## Linear features and surveys

Similar to chapter 3, which first introduced the superclass `MarineFeature` and the subsequent point feature subclasses, this chapter focuses on the various linear feature classes, which also inherit from the `MarineFeature` superclass. `MarineLine` is an abstract class used to categorically group all of the linear feature classes. Under `MarineLine` there are three subclasses to be implemented: `FeatureLine`, `ProfileLine`, and `TimeDurationLine`.

`FeatureLine` is an instantiable feature class that inherits the attributes `FeatureID` and `FeatureCode` from `MarineFeature` but does not introduce new attributes. It is meant simply to be a template for storing physical linear features such as maritime boundaries, sea walls, cables, pipelines, and navigational chart lines. Consequently, Arc Marine also introduces a subclass to `FeatureLine` called `Shoreline`. The `Shoreline` feature class introduces one new attribute, `VDatum`, which stores the vertical datum used in identifying the specified

shoreline. Arc Marine does not define what a shoreline is, but provides an efficient storing mechanism for information making that determination.

The ProfileLine feature class inherits from MarineLine but adds no new attributes beyond the FeatureID and FeatureCode obtained through the inheritance. However, the properties HasM and HasZ have been enabled so that the feature can have a linear measurement system and a depth value that can change along the line. ProfileLine represents a linear feature designed for data interpolation along the distance of the line based on another data source, specifically surveys. The concept behind this collection of classes is that users can associate a ProfileLine with one or many Surveys and can associate a Survey with one or many features of the ProfileLine feature class. Essentially, this emulates a many-to-many relationship, where many features in one class (ProfileLine) can be associated with many instances in a second class (SurveyInfo). To replicate this multiplicity, an additional table called SurveyKey is inserted between the two classes. This table contains two key fields, SurveyID and FeatureID, which are used to relate back to their respective sources, ProfileLine and SurveyInfo. Users can repeat the values for these two fields in SurveyKey in any number of instances, allowing multiple combinations of the same values. FeatureID stores its value in the ProfileLine feature class. FeatureID will repeat each time it associates with a Survey. The value of SurveyID, which identifies a specific

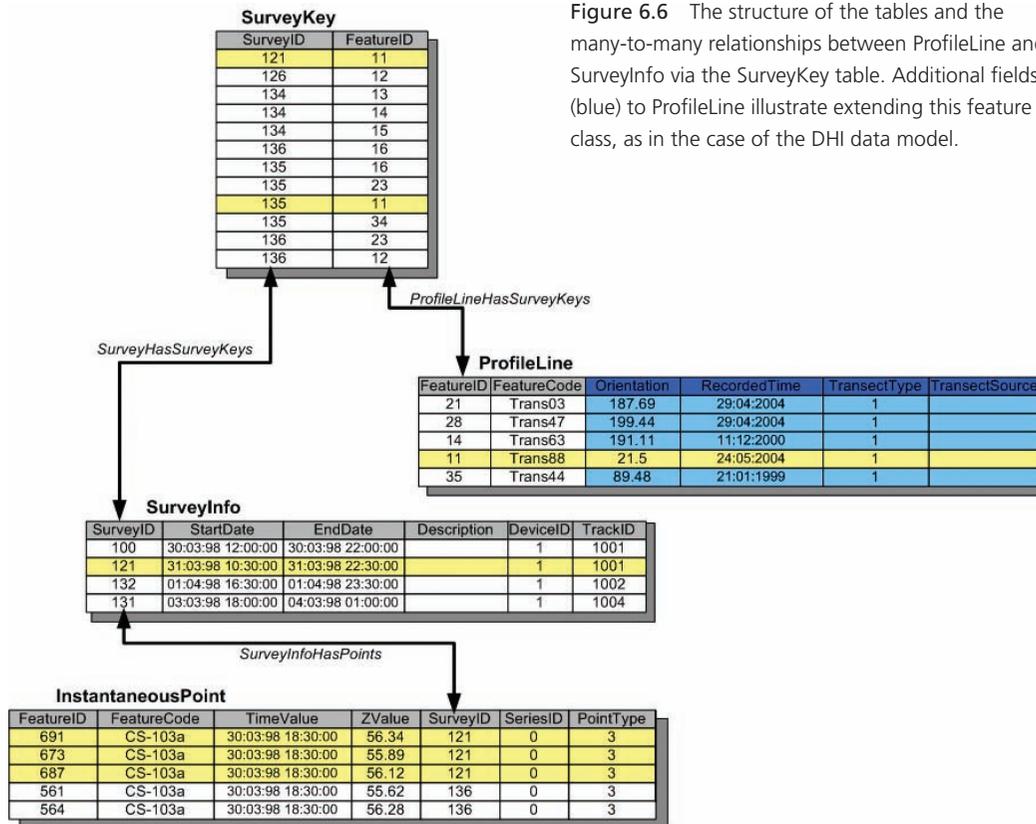


Figure 6.6 The structure of the tables and the many-to-many relationships between ProfileLine and SurveyInfo via the SurveyKey table. Additional fields (blue) to ProfileLine illustrate extending this feature class, as in the case of the DHI data model.

Survey, will repeat for each instance of a ProfileLine. Consequently, a relationship class, termed ProfileLineHasSurveyKeys, links the ProfileLine feature class with the SurveyKey table. A second relationship class, SurveyHasSurveyKeys, links the SurveyInfo table to the SurveyKey table (figure 6.6). Chapter 3 introduced the SurveyInfo table, which describes how the SurveyID attribute distinguishes one survey from another and then correlates to a collection of points stored in the InstantaneousPoint feature class.

## Linear surveys of west Hawaiian reef fish

The western Hawai'i reef fish case study makes significant use of SurveyInfo, as linked to the Survey subtype of the InstantaneousPoint feature class, in dealing with observations along linear SCUBA transects. Fish observation datasets from all of the main Hawaiian Islands were obtained from various federal, local, and academic institutions through the Hawai'i Natural Heritage Program (HNHP), which included SCUBA surveys conducted by the Western Hawai'i Aquarium Project (WHAP), the Coral Reef Assessment and Monitoring Program (CRAMP), the state of Hawai'i's Division of Aquatic Resources (DAR), the Saving Maui's Reefs project, and individual peer-reviewed journal articles input into a database for the HNHP. The datasets obtained through the HNHP contain information on 121 sites located throughout the main Hawaiian Islands (figure 6.2).

The study area for habitat use analysis on the west coast of Hawai'i extends from Lapakahi to Manuka (figure 6.3) and represents approximately 212 sq km of shoreline, 15 different habitat types, 5 reef zones, and varying levels of protected status (NOAA Biogeography Team, [http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi\\_mapping.html](http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi_mapping.html)). The availability of fish survey data and habitat information led researchers to choose this area from among the eight Hawaiian Islands.

They combined all datasets into a single Microsoft Access database consisting of four primary tables: (1) survey location information, (2) Divemaster, (3) Run Detail, and (4) species information. All tables used a key field to relate one table to another, allowing users to perform queries involving variables of space, time, and fish species.

Researchers used the Survey subtype of the InstantaneousPoint feature class to store the x-, y-, and z-locations of an observation along a linear fish survey. Many survey point locations in this case study represent only an approximation of the location where the fish survey was conducted, as the exact latitude and longitude coordinates are unknown. The information recorded in the geodatabase reflects the best possible estimate.

Researchers established the spatial extent and project of the feature classes before adding any datasets to the geodatabase. They imported the NAD83 UTM Zone 4 projection information and spatial extent from a polygon shapefile of the main Hawaiian Islands (DBEDT 2004) into the Arc Marine data model. Accordingly, all subsequent shapefiles imported into the geodatabase would need to be in the same projection (i.e., NAD83 UTM Zone 4) and fall within maximum x,y spatial extent.

Researchers then used the CREATEXY function to import the Microsoft Access table containing the survey latitude and longitude coordinates into ArcGIS to generate a point

shapefile. This two-dimensional (2D) shapefile was converted into a three-dimensional (3D) shapefile using the z-values (depth) in the attribute table. This was necessary because all shapefiles imported into the Survey subtype must be 3D in accordance with the established data model parameters, even if the 3D values do not exist.

It was initially thought that Survey could be further defined with information stored in the SurveyInfo object class. However, this was not possible due to the large amount of data. With more than 250,000 entries, it took too long to perform one query if all of the data were combined into one table representing the main Hawaiian Islands. But by separating data by island, queries took less than one minute, and multiple queries could be conducted if information on more than one island was needed. As a result, Arc Marine was customized by adding additional field names and tables to the geodatabase: Divemaster, Run Detail, and Integrated Species, which were specific to each island (e.g., Oahu Divemaster, Hawai'i Run Detail). These tables further describe Survey by providing information such as survey dates, who conducted the survey, and which species were observed along the way.

When all the data was entered into the geodatabase, relationships were established between the feature classes (spatial) and the tables (nonspatial) (figure 6.7). These relationships consisted of one-to-one and one-to-many relationships. A one-to-one relationship matches one entry to an identical entry in a separate column/table. A one-to-many relationship matches one entry to multiple identical entries in a separate column or table. Additionally, due to the nature of the geodatabase, these relationships are permanent. And unlike joins, the relationships will not have to be reestablished in each new project.

Researchers used Arc Marine in the habitat utilization analysis in large part because the resulting geodatabase could be easily and efficiently queried for space, time, and fish species. This allowed researchers to determine where a specific fish species was observed (figure 6.8). These sites could then be overlain on large-scale habitat types to determine what species were found in what habitat types.

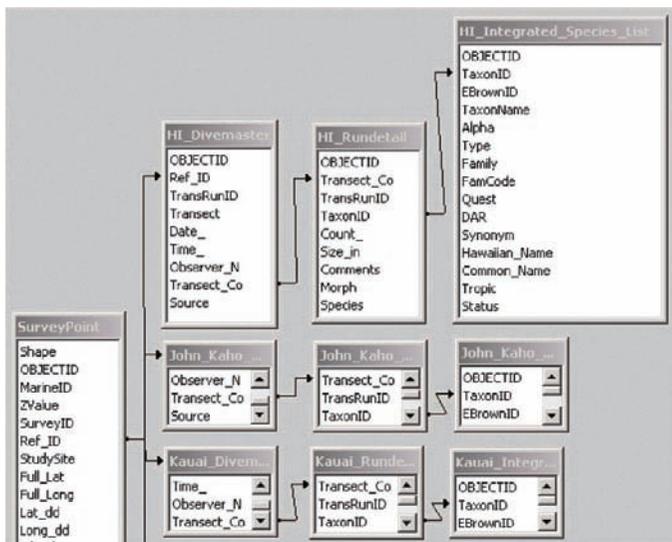


Figure 6.7 The relationships established between the Survey subtype (renamed SurveyPoint) and the various attribute tables in the western Hawai'i reef fish case study, as seen in Microsoft Access.

Courtesy of Alyssa Aaby, University of Hawai'i and the National Park Services (NPS).

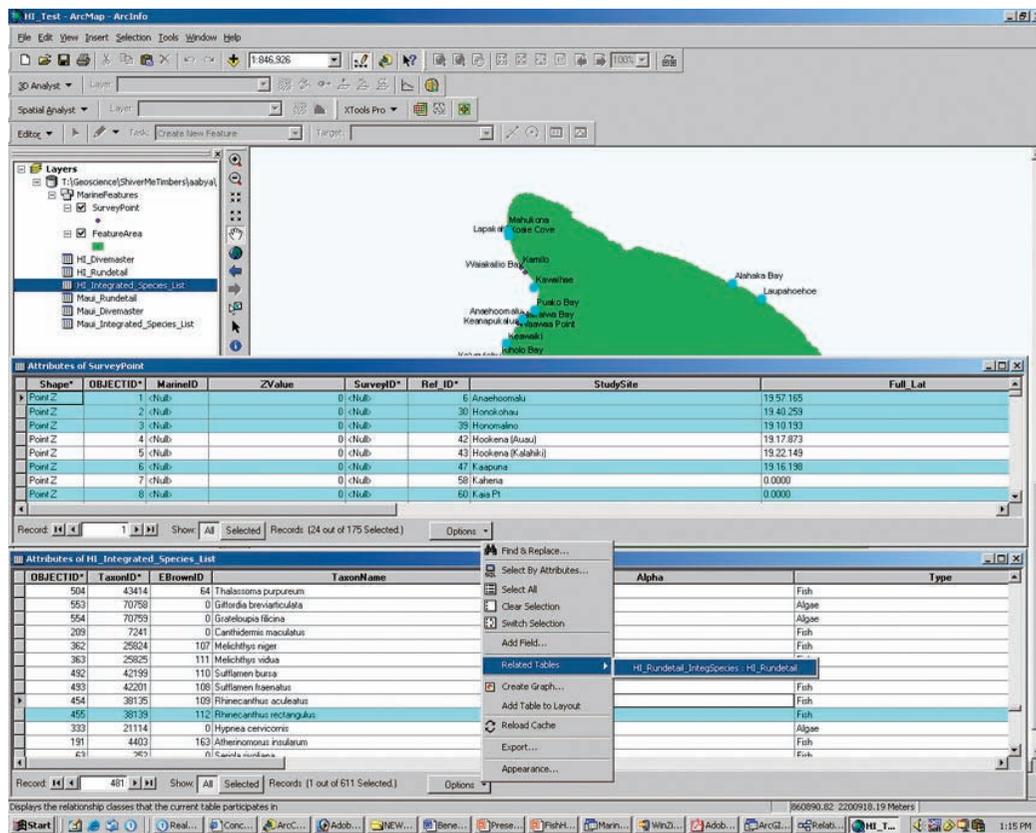


Figure 6.8 Illustration of a query in ArcGIS using Arc Marine to show the sites where the *Rhinecanthus aculeatus* (Blackbar triggerfish) was observed during fish surveys by SCUBA. This information was then used in the regional habitat analysis.

Courtesy of Alyssa Aaby, University of Hawai'i and the National Park Services (NPS).

Researchers examined the spatial habitat utilization patterns of reef fish along the western Hawai'i coast after importing the fish datasets into Arc Marine. They used three spatial datasets to determine these patterns: (1) the WHAP fish survey dataset stored in Arc Marine, (2) the NOAA Biogeography Team's large-scale habitat delineations (Coyne et al. 2001) stored in Arc Marine, and (3) the WHAP substrate dataset. Researchers investigated three questions to answer the question of habitat utilization: (1) How do specific fish species use certain habitat types? (2) Does depth play a significant role in the classification of these habitat types? (3) Does small-scale substrate information correlate with large-scale NOAA habitat information?

Researchers used the WHAP dataset because it is one of the most comprehensive and statistically significant Hawaiian reef fish datasets. Additionally, it covers 23 sites along the

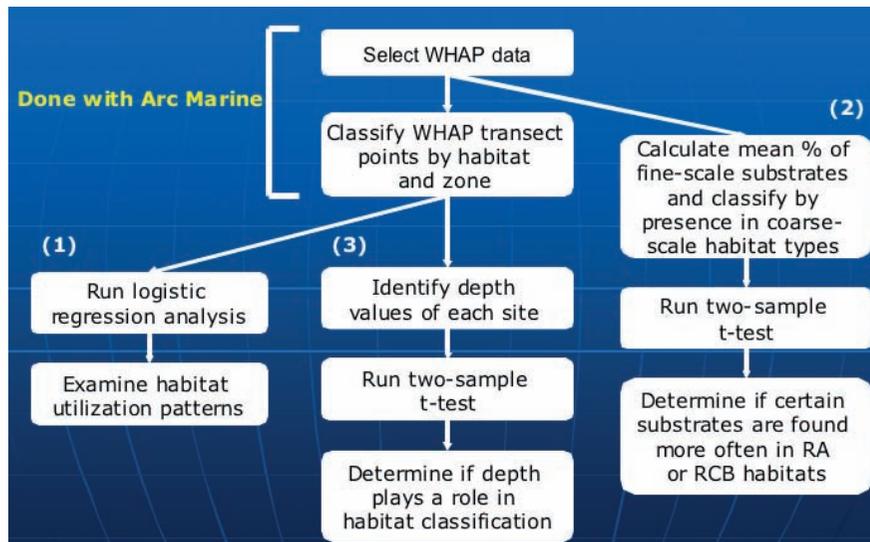


Figure 6.9 Flowchart of the specific steps taken in the fish analysis portion of western Hawai'i reef fish case study.

west coast and spans a multiyear time period. The detailed steps taken to answer each of the three subquestions are outlined below (figure 6.9).

To analyze this WHAP dataset, researchers used Arc Marine to query and separate the WHAP data from the other data in the geodatabase. This required isolating data specific to WHAP to avoid confusing a fish species observed on a DAR survey at the same site as fish species observed on a WHAP survey. Moreover, it was important to separate the WHAP data because survey methodologies differed between datasets. Separating the data created a new feature class called WHAP Location, along with three tables: WHAP Divemaster, WHAP Run Detail, and WHAP Species. This data remained in Arc Marine, and new relationships formed between the tables and feature class, following the initial Arc Marine schema.

To determine the habitat type and zone for each of the WHAP sites, the WHAP Location feature class was overlain on a NOAA large-scale benthic habitat layer, derived from hyperspectral and IKONOS satellite imagery for the Island of Hawai'i (NOAA Biogeography Team, [http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi\\_mapping.html](http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi_mapping.html)). Based on this imagery, a hierarchical classification scheme was created to define and delineate habitats zones (NOAA Biogeography Team, [http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi\\_mapping.html](http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi_mapping.html)). This classification shows only continuous habitats greater than 1 acre in size (Coyne et al. 2001). Using the Select by Location function in ArcGIS, the habitat types and benthic habitat zones for each of the WHAP sites were determined.

After classifying each WHAP site according to habitat type and zone, researchers used a logistic regression analysis to determine the pattern of habitat utilization of six aquarium and seven nonaquarium fish species (figure 6.10) between the different habitat types. These fish species were selected because they represent commonly collected aquarium and reef fish observed during WHAP surveys. Following the methodology outlined by

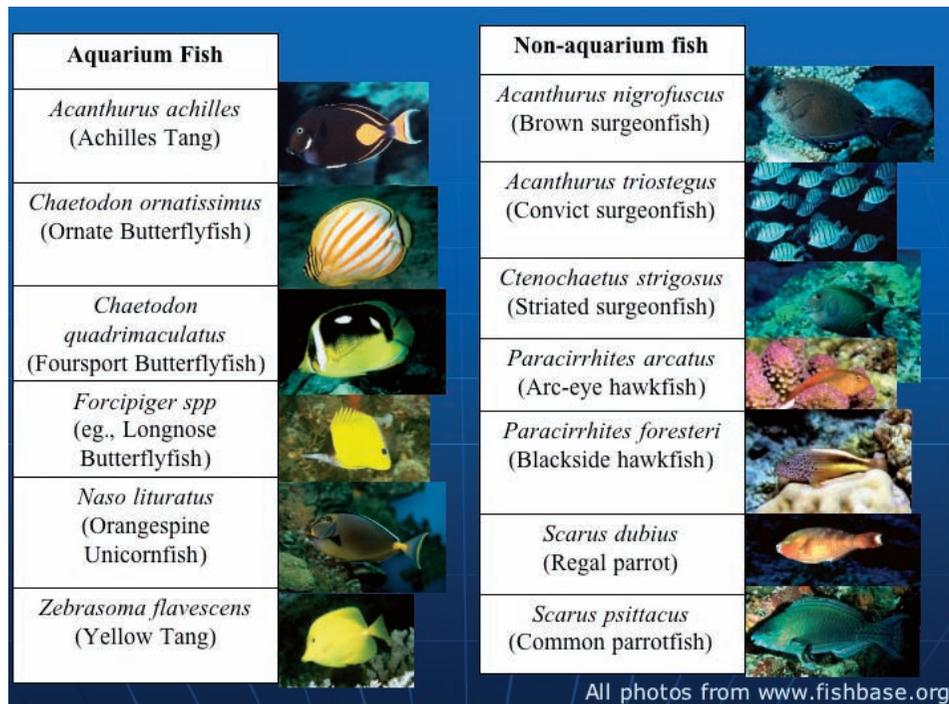


Figure 6.10 Aquarium and nonaquarium fishes examined in the western Hawai'i reef fish case study.

Photos courtesy of Larry Basch, NPS. Reprinted by permission.

Christensen et al. (2003), a binary response ( $y=1$  if present or 0 if not present) was fit to the independent variable ( $x$ =habitat type). This meant that for each column, there was either a probability of being present ( $p$ ) or of not being present ( $p-1$ ). Arc Marine was then used to query the location of each specific fish to determine its presence or absence at each WHAP site.

Researchers conducted further analysis into the habitat utilization of specific fish species to determine possible correlations between the small-scale substrate information gathered in 1999 by the WHAP researchers (Tissot et al. 2004) and the large-scale habitat information delineated by NOAA (NOAA Biogeography Team, [http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi\\_mapping.html](http://ccma.nos.noaa.gov/ecosystems/coralreef/main8hi_mapping.html)). To do this, they calculated mean percentages of each small-scale substrate type found at each WHAP site. The WHAP sites were then categorized according to habitat type, and the information was compared using a two-sample t-test.

Researchers determined the depth values of each WHAP site to learn if depth values played a role in the classification of NOAA's large-scale habitat types. The WHAP sites were then categorized by habitat type, and the information was compared using a two-sample t-test.

For the 23 WHAP fish sites, the benthic habitat type of each WHAP survey site was determined by overlaying the WHAP location feature class on NOAA's benthic habitat shapefile (table 6.1).

Habitat type	Reef/Aggregate Coral (RA)	Reef/Colonized Volcanic Rock/Boulder (RCB)	No data
<b>Location</b>	Aneehoomalu	Kalahiki Beach	Honokohau
	Keawaiki	Kamilo Gulch	Hookena (Auau)
	Keei	Kaupulehu	Makalawena
	N. Keahouhou	Kealakekua Bay	Manuka
	S. Oneo Bay	Keopuka	Omakaa
	Red Hill	Kualanui Point	Wawaloli
	Waiakailio Bay	Lapakahi	Wawaloli Beach
		Papawai	
		Puako	

Table 6.1 WHAP study sites (figure 6.3) categorized by habitat type, western Hawai'i reef fish case study.

Once the WHAP sites were categorized by habitat type, a logistic regression was used to determine the habitat utilization patterns of the selected reef fishes. Researchers found some habitat utilization preference between the RA and RCB habitat types for these selected species (table 6.1). A slight preference for the RCB habitat type was observed, but further studies are needed to verify these results. Complete results are presented and discussed in Aaby (2004).

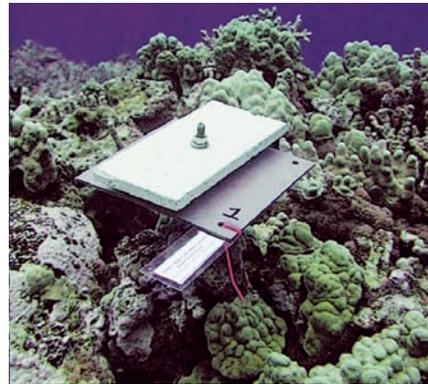
## More surveys: National Park Service coral reef monitoring

The Hawaiian NPS case study started with a large number of data tables, lookup tables, and cross-reference tables of fish observations from a visual census during SCUBA transects or free swims (figure 6.11), invertebrate recruitment data and classifications (figures 6.12 and 6.13), taxonomies and descriptions of life histories for invertebrates, sampling events, cross-reference tables between events and contacts, and more. These were initially stored in Microsoft Access with relationships drawn between fields similar to figure 6.7 for the western Hawai'i reef fish case study. Next, shapefiles were created and organized according to the NPS standard file structure (Park Name † Data, Images [and within that digital raster graphics or photos], Tools [and within that extensions or legends], and Workspace [and within that documents and metadata]). Organizing shapefiles this way streamlined the process of exporting them to the geodatabase. The four main shapefile directories eventually became the four feature datasets created in the geodatabase: (1) Hawai'i Island, (2) KAHO (Kaloko-Honokohau NHP), (3) PUHO (Pu`uhonua o Honaunau NHP), and (4) PUHE (Pu`ukohola Heiau NHS). The Hawai'i Island folder contained marine datasets obtained from NPS and partners that were clipped to the boundary of Hawai'i. The KAHO, PUHE, and PUHO folders contained appropriate terrestrial datasets that were all clipped to the watershed boundary. All datasets are projected in UTM Zone 5 NAD 1983.



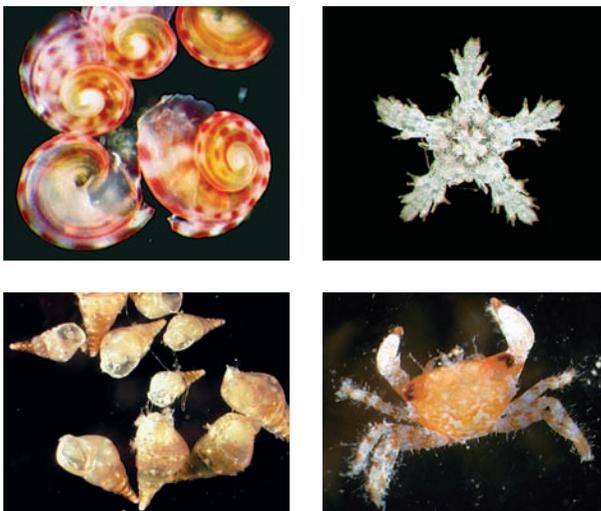
**Figure 6.11** Example of fishes observed (mostly convict surgeonfish) during SCUBA or free swim surveys for the Hawaiian NPS case study.

Photo courtesy of Jennifer Smith, University of California, Santa Barbara. Reprinted by permission.



**Figure 6.12** An invertebrate recruitment settlement plate as a primary data collecting device, Hawaiian NPS case study.

Photo courtesy of Larry Basch, NPS. Reprinted by permission.



**Figure 6.13** Examples of the invertebrate recruits commonly collected by settlement plates as shown in Figure 6.12, Hawaiian NPS case study.

Photos courtesy of Larry Basch, NPS. Reprinted by permission.

As with the western Hawai'i reef fish case study, the Survey subtype of the Instantaneous-Point feature class was used to store the x-, y-, and z-locations in all the data tables. The lookup and cross-reference tables were imported from the Microsoft Access database and all relationships were established. The spatial reference was set to the main Hawai'ian Islands, and the projection used was UTM Zone 5 because the dataset was almost entirely located around the perimeter of the island of Hawai'i.

Shapefiles were imported as feature classes and organized within feature datasets according to the NPS standard file structure. All shapefiles were batch exported to the feature datasets according to park unit or island. The marine datasets were not limited to individual park units, as most were from coastal locations along the west coast of Hawai'i. This was done with the understanding that marine ecosystems are open systems and do not lend themselves as well as terrestrial datasets to clipping based on boundaries such as watersheds.

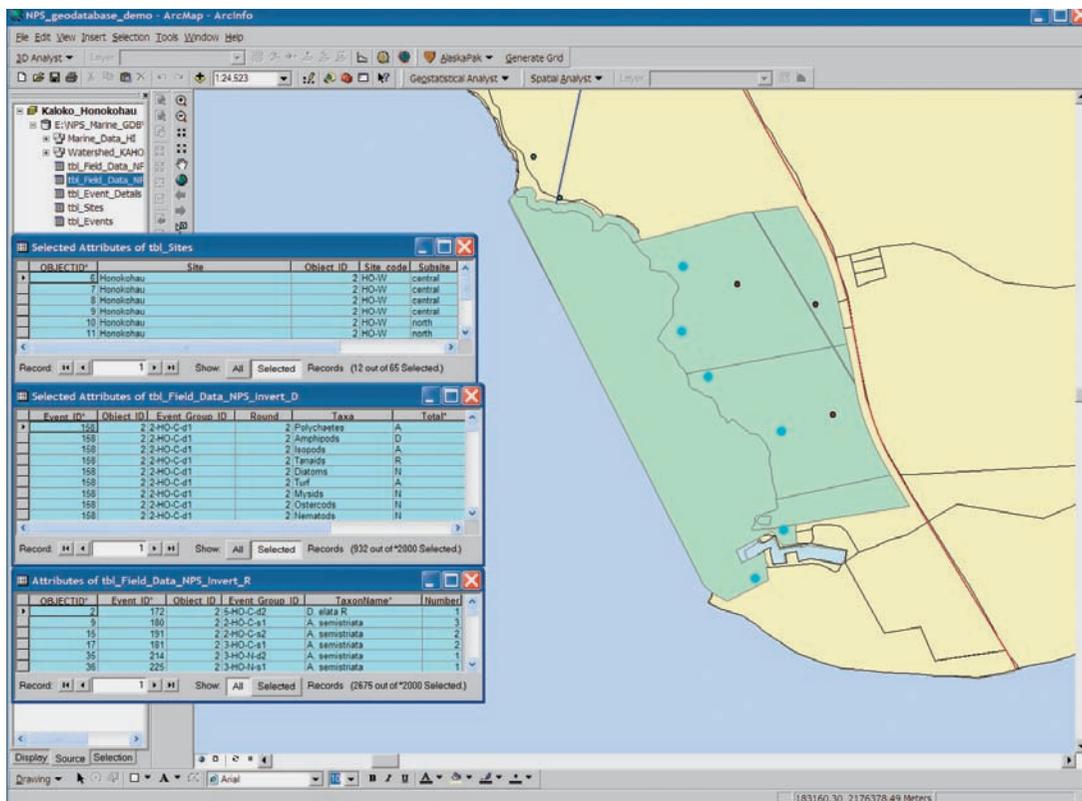
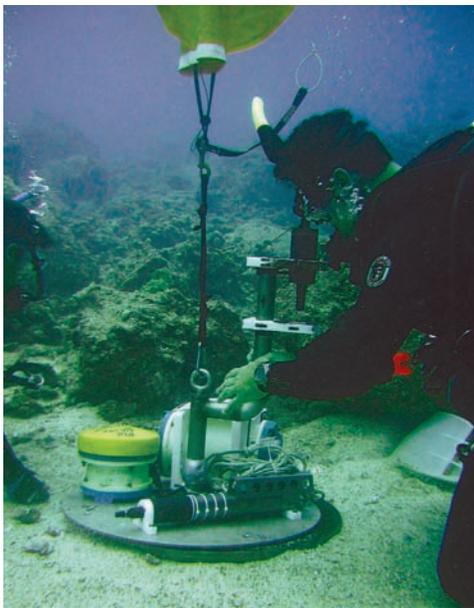


Figure 6.14 Screen capture of the Hawaiian NPS case study geodatabase, with sample queries demonstrating how users can extract useful information to aid management decisions at Pacific Islands National Parks. More examples are available on the book's accompanying Web site, <http://dusk.geo.orst.edu/djl/arcgis>.

Courtesy of Lisa Wedding, University of Hawai'i, NPS.

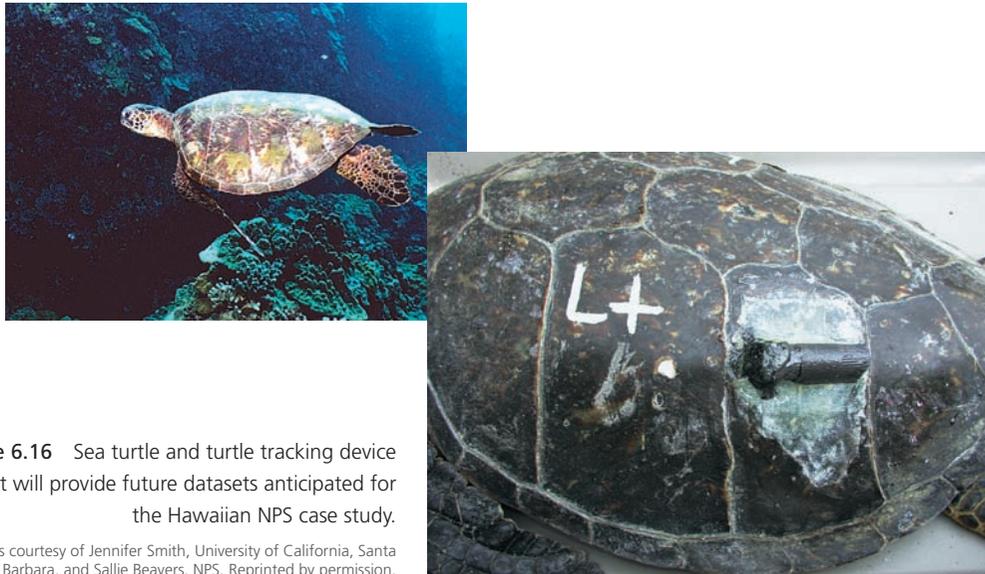
With the geodatabase fully populated with data, researchers test it with a series of initial queries. Two scenarios discussed by Wedding et al. (2005) are (1) a resource manager at KAHO wants to generate a species list of all marine organisms in the park unit based on data from several research sites in the area, and (2) a resource manager at PUHO is planning a marine monitoring program and wants to review the monitoring protocols used in recent research projects near the park. Figure 6.14 shows one of many possible examples of queries that may be performed to fulfill these needs. The Microsoft PowerPoint file associated with this chapter on the book's accompanying Web site, <http://dusk.geo.orst.edu/djl/arcgis/>, includes many more screen captures of successful queries.

Arc Marine contains feature classes and tables that do not entirely match the NPS logical model, but these are being kept because the PICRP is continuing to obtain and create new datasets that will take advantage of these feature classes in the future. These will include time series points from marine species inventories, water quality instrumentation data (figure 6.15), digital underwater video, benthic fisheries harvest monitoring, more invertebrate recruitment monitoring, and locations series from sea turtle tracking data (figure 6.16). As a result, the use of Arc Marine allows NPS to include future datasets with ease while managing existing data to support management decisions.



**Figure 6.15** Installation of a joint NPS/USGS/State of Hawai'i oceanographic instruments (e.g., current meters, water clarity/quality sensors) representing new marine and coastal datasets that will be incorporated into the Hawai'i NPS case study geodatabase in the near future.

Photo courtesy of Larry Basch, NPS. Reprinted by permission.



**Figure 6.16** Sea turtle and turtle tracking device that will provide future datasets anticipated for the Hawaiian NPS case study.

Photos courtesy of Jennifer Smith, University of California, Santa Barbara, and Sallie Beavers, NPS. Reprinted by permission.

## Shorelines, FeatureLines, and FeatureAreas in Martin County, Florida

The Martin County, Florida, case study aimed to integrate disparate datasets to streamline the management of its coastal programs. This is part of a phased strategy to implement a coastal GIS infrastructure (Phase I, a scoping exercise in 2003; Phase II, assessment, refinement, and the creation of a coastal GIS implementation framework in 2004; Phase III, the prototype implementation itself to build a first generation Coastal GIS Geodatabase in 2005; Phase IV, migration to a production system in 2006; and Phase V, maintenance and ongoing enhancements). The Arc Marine case study largely comprised Phase III.

First, researchers conducted an inventory of potential data for inclusion in the coastal GIS. The inventory included nearly 250 datasets associated with Martin County field projects, Florida Department of Environmental Protection (FDEP) datasets (hurricane track-lines, point locations of photography, and videography), and basemap or framework data as defined by the Federal Geographic Data Committee (FGDC). Researchers obtained the framework data from sources such as the NOAA Coastal Services Center, Florida Marine Research Institute, Florida Inland Navigation District, Florida Geographic Data Library, Florida Land Boundary Information System, the USGS, and NorthStar Geomatics. Table 6.2 summarizes the wide variety of imagery and raster grids gathered or generated for input to the geodatabase.

The datasets were further cataloged based on thematic groupings and Arc Marine feature classes, using primarily the Shoreline, FeatureLine, and FeatureArea feature classes where appropriate; and with the determination and specification of customized subtypes such as ArtificialReefs, BeachManagement, NavigationManagement, HabitatManagement, and

CoastalMonitoring. A FeatureID and a ProjectID were created and can be traced throughout the entire geodatabase. Any additional GIS layers associated with that project will contain the same MarineID. Additional tables (some for customized Arc Marine object classes) were created to store project fieldwork information such as benthic species lists, artificial reef site attributes, and nearshore cruise information, and administrative details such as organizations involved, permitting information, grant agency details for proposals info, and Martin County program information. Relationships were then created between spatial and nonspatial data, and between spatial data and topological rules. Finally, researchers established procedures for the efficient creation and population of FGDC-compliant metadata on all datasets, as necessary.

Next, the geodatabase was fully populated, with priority GIS layers and related tables loaded into ArcSDE. This effort included adherence to several protocols and procedures developed in Phase II:

- Specifications for conversion to geodatabase format of coastal related GIS data to be stored in Oracle and ArcSDE. This included vector data, raster data, and related stand-alone tables.
- Procedures related to the implementation of the Arc Marine UML for the creation of a coastal geodatabase schema in ArcSDE.
- Procedures to populate the coastal geodatabase with Martin County coastal data, including vector data and related tables, and as raster layers.
- Creation and QA/QC (quality assurance/quality control) procedures on all relationships for GIS layers and related business tables. QA/QC procedures for all ArcSDE coastal layers, rules, and behaviors.
- Procedures for implementation of FGDC compliant metadata on all relevant layers.
- Procedures for the connection of the county's existing financial database to Florida's Critical Infrastructure Management System (for, among other things, emergency planning and response in the wake of natural hazards).

Fitzpatrick et al. (2006) discuss ways in which coastal engineers and resource managers would need to use the coastal geodatabase, such as management of Martin County's habitat, beach, inlet, and artificial reef resources through the effective implementation of engineering and restoration projects; monitoring and analyzing the effectiveness of the Coastal Program's engineering and restoration projects; and tracking permit requirements and automating the required permit submittals. Queries (selections, reselections, and relates) and retrieval from the geodatabase can fulfill many initial needs, as shown by the example in figure 6.17.

The county also used the FDEP ArcIMS site (<http://www.dep.state.fl.us/beaches/>) to obtain additional datasets for the coastal geodatabase. The Martin County team downloaded and then stored in Arc Marine the FDEP hurricane tracks, satellite imagery, and aerial photography (pre- and post-hurricane). The team created hyperlinks from point layers to allow point-and-click viewing of digital photos and videography at selected locations (figures 6.18 and 6.19). The team stored photo and video files outside the geodatabase as flat files. In similar applications involving artificial reef data, point locations were hyperlinked to associated PDF files.

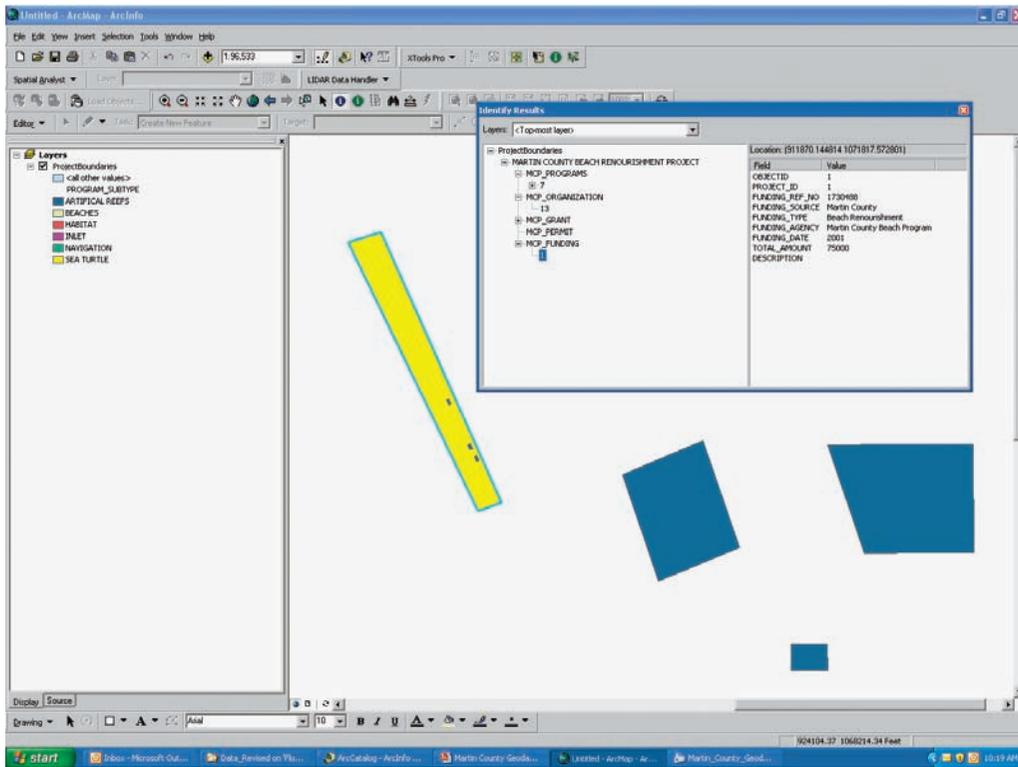
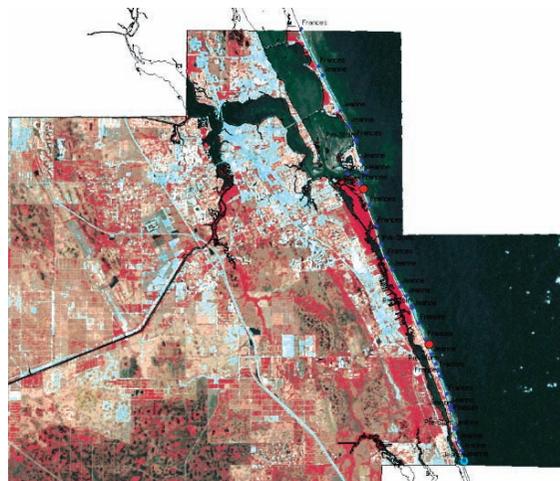


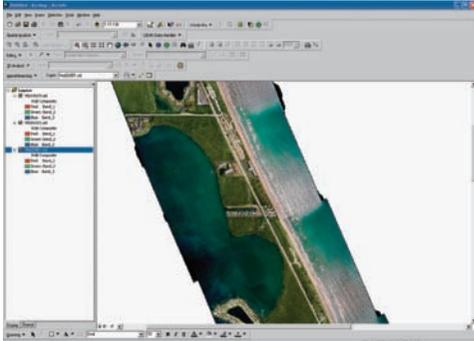
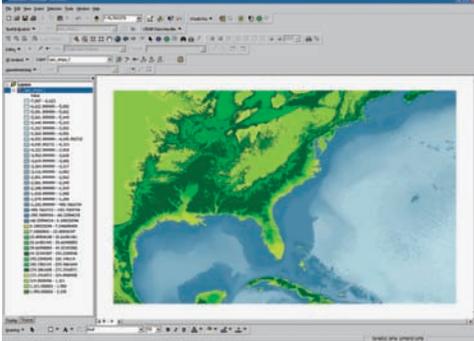
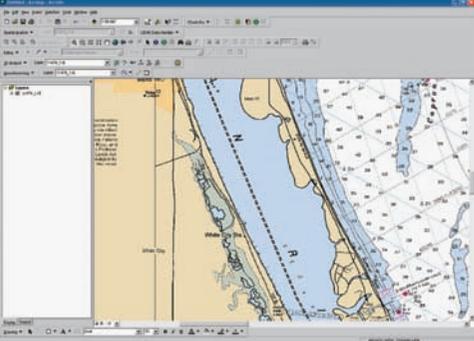
Figure 6.17 Screen capture of the Martin County case study geodatabase with a sample query and selection of beach nourishment FeatureAreas. More examples are available on the book's accompanying Web site, <http://dusk.geo.orst.edu/dji/arcgis>.

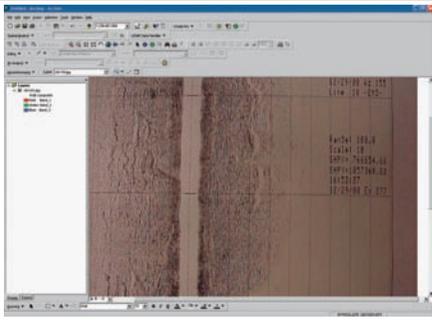
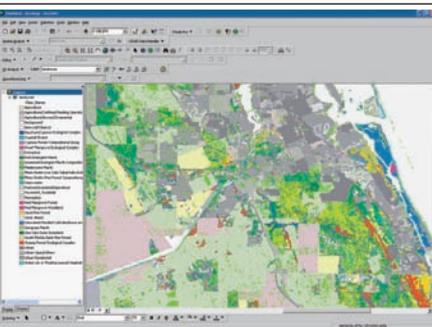
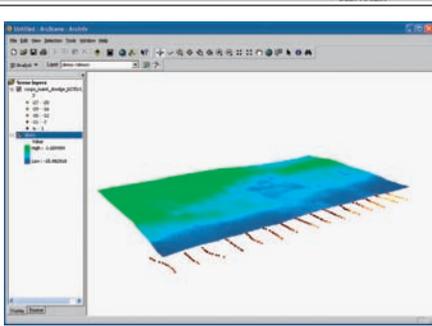
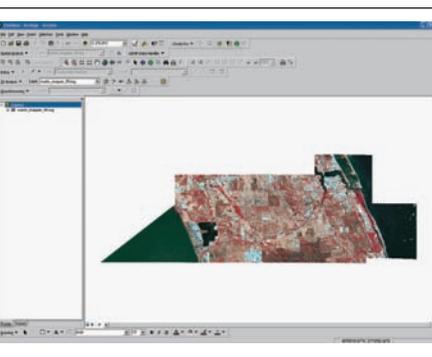
Data provided by Martin County and Photo Science, Inc.

Figure 6.18 Screen capture from the FDEP ArcIMS site provides some of the data for the Martin County, Florida, case study. Landsat Thematic Mapper imagery is the underlay, blue dots show impact monitoring points for Hurricanes Frances or Jeanne, and red dots are hyperlinked points for video files.

Data provided by Martin County and Photo Science, Inc.



Data Type	Description	Thumbnail Example
<p>DOQQ—Digital Orthophoto Quarter Quadrangles</p>	<p>DOQQs were obtained from FDEP on DVD. The images were mosaicked and made available for loading into ArcSDE. Since NorthStar currently has aerial photos loaded in the Martin County production geodatabase, duplication of the aerial photographs into the Martin County coastal geodatabase was not necessary.</p>	
<p>ETOPO</p>	<p>ETOPO 2 layer was obtained by NOAA Coastal Services Center. The image shows both bathymetry and topography for the southern United States, and may be clipped to Martin County to provide an additional basemap layers.</p>	
<p>Nautical Charts</p>	<p>NOAA Nautical Charts were downloaded and mosaicked in order to form a seamless layer in the Martin County coastal geodatabase.</p>	

<p>Sidescan Sonar</p>	<p>Sidescan sonar datasets were provided by Martin County. Photos do not contain georeferenced information. Additional rectifying and/or registering of the images will allow for GIS overlays. The layers can then be stored in the geodatabase.</p>	
<p>Land Use</p>	<p>Land-use raster layer was downloaded from the Florida Cooperative Fish &amp; Wildlife Research Unit. The layer was clipped to Martin County.</p>	
<p>Surfaces</p>	<p>Surfaces were created from point data layers as appropriate. These surfaces allow for detailed viewing and analysis of static tabular information.</p>	
<p>TM Imagery</p>	<p>Thematic Mapper (TM) imagery was downloaded from the USGS. The sensor is a multispectral scanning radiometer that was carried on board Landsats 4 and 5, and has provided nearly continuous coverage from July 1982 to present, with a 16-day repeat cycle. The layer was clipped to Martin County.</p>	

**Table 6.2** Raster grids and images and associated procedures of the Martin County, Florida, case study (from Fitzpatrick et al. 2006).

Data provided by Martin County and Photo Science, Inc.

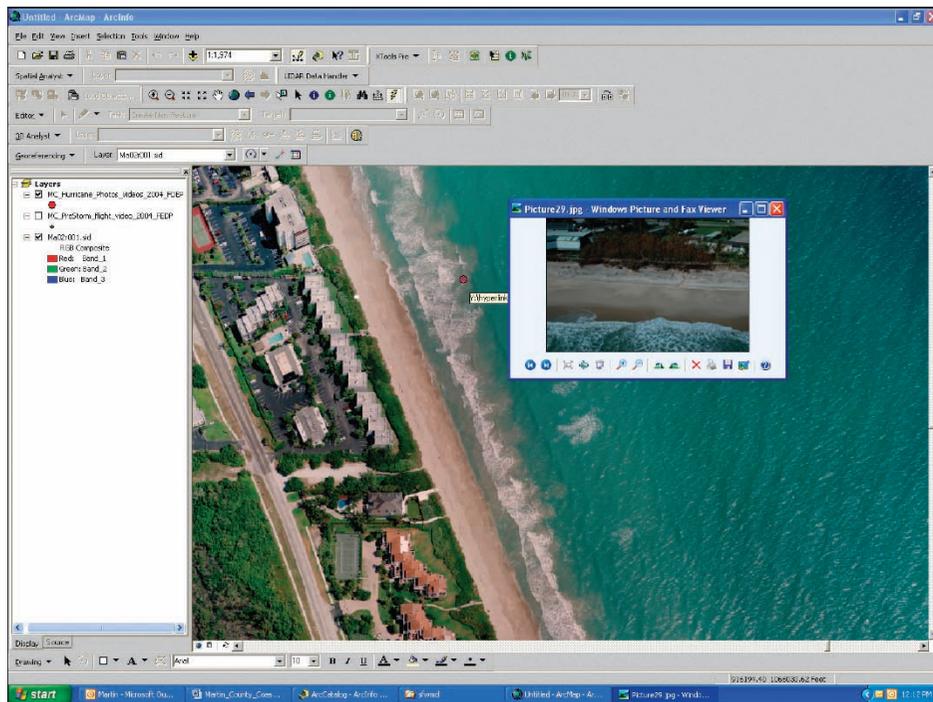


Figure 6.19 Another example of FDEP data used in the Martin County case study; this time aerial photography, with a red dot serving as a hyperlink, points to a 2004 hurricane photo snapped at that location.

Data provided by Martin County and Photo Science, Inc.

The case study generated five main products (the nonproprietary items are available on the book's accompanying Web site at <http://dusk.geo.orst.edu/djl/arcgis>):

- A data inventory spreadsheet in Microsoft Excel
- A UML diagram of the modified Arc Marine data model, using Microsoft Visio and ESRI Geodatabase Designer
- A geodatabase report describing GIS layers, relationships, tables, and raster datasets
- A populated Martin County coastal geodatabase with vector data, raster data, stand-alone tables, spatial and nonspatial relationships, and rules stored in Oracle and ArcSDE according to Arc Marine schema
- Martin County coastal geodatabase documentation

The next steps include the building of associated tools and portals.

## Extending ProfileLine to transects and baselines

The objective of the ProfileLine feature class is to assign values at locations along the feature based on values associated with the points of a survey. In earlier examples, points marked locations of observations or samples along a FeatureLine or Shoreline. But this case study shows that points may be graphed using the distance along the ProfileLine feature as the x-axis and the values associated with the survey points (logically selected within a specified distance from the ProfileLine feature) as the y-axis (figure 6.20).

At DHI Water & Environment, the customized version of the Arc Marine data model uses ProfileLine features for implementing transects and baselines. Transects derive profile data from a survey, and baselines are used to measure the changes in accretion and erosion along the shoreline. Although both features derive data from a survey, they are used in different applications with different attributes. Consequently, they were added as two new feature classes. In other words, ProfileLine was changed to an abstract class for this case study, and two new subclasses, Transect and Baseline, were added. Transect can be used to create a bathymetric profile along a Transect feature. A bathymetric profile is

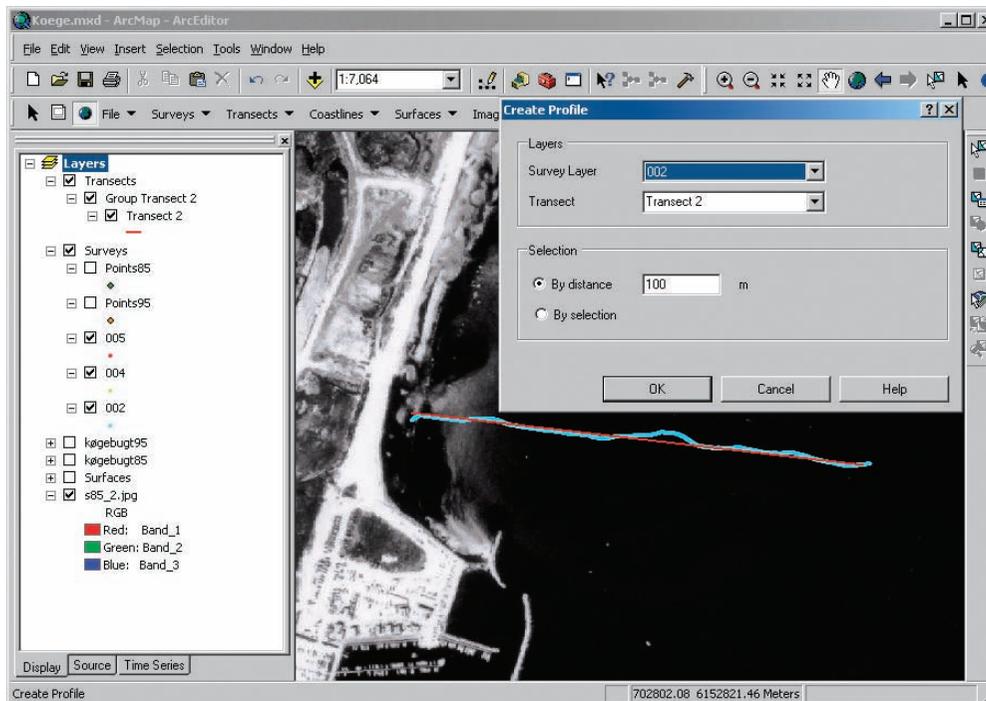


Figure 6.20 DHI's MIKE Marine GIS joins a survey with a Transect for the purpose of deriving values of a profile along the Transect feature.

Courtesy of Uwe Jacobs, Køge Kommune.

often imported into a numeric model for defining the shape of the seafloor, which in turn influences the transport area for sediment. In the Transect feature class, four additional attributes exist: Orientation, for storing the orientation of a Transect; RecordedTime, the time stamp when the Transect was created; TransectType, for determining if the Transect feature was digitized or imported from a numeric model; and TransectSource, the input file of a model-generated Transect. Within DHI's MIKE Marine GIS, software tools are available for either digitizing a Transect or importing data from DHI's modeling software (figure 6.21). In either case, once a Transect has been added, users can create a bathymetric Profile by collecting the ZValues from the points of a selected survey that are within a specified distance of the Transect feature (figure 6.22).

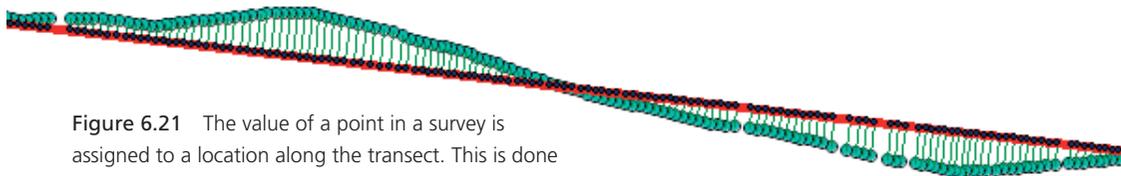


Figure 6.21 The value of a point in a survey is assigned to a location along the transect. This is done by constructing perpendicular lines between the survey points and the transect.

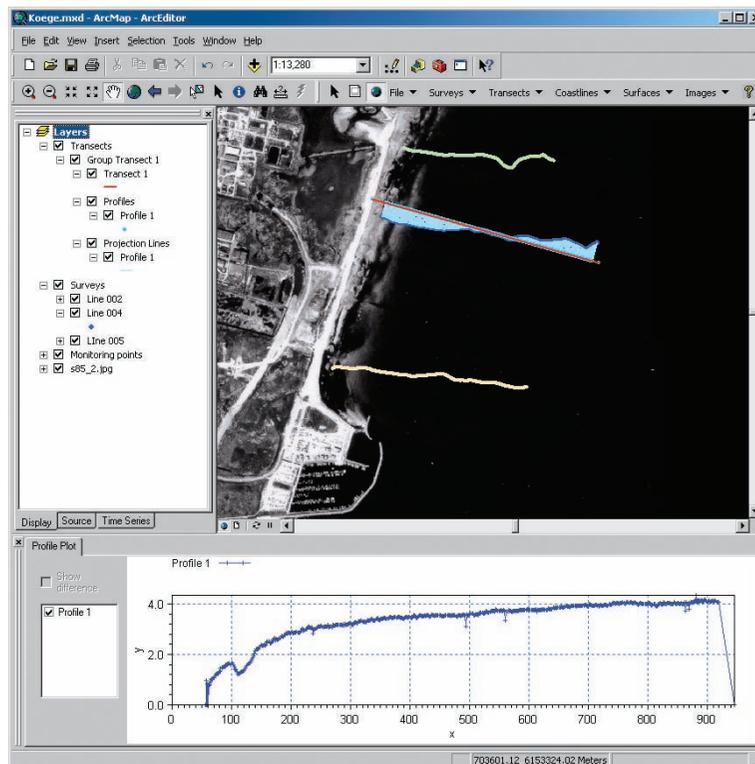


Figure 6.22 A profile is drawn using MIKE Marine GIS where the x-axis is based on the length of the transect feature and the y-axis is determined from the values of the survey points as positioned along the transect.

Survey data provided by Køge municipality. Background image provided by Geographic Institute of Denmark.

When deriving a profile, the survey points should be projected to a location that is determined along the transect by constructing a perpendicular line from the survey point to the transect (figure 6.21). The points may then be stored as point events in a new object class called *TransectPoints*, where the position along the *Transect* feature is stored and has been assigned with a *ZValue* of the original survey point. Additional attributes for describing sediment transport, such as *Roughness*, *d50*, and *Spreading*, may be stored in the *TransectPoints* table.

The second subclass of *ProfileLine* implemented in the DHI data model is termed *Baseline*. This feature class is used similarly to *Transect* except that rather than assigning the depth (*ZValue*) of the points to the transect feature, the distance from the survey point is projected to a perpendicular location along the *Baseline* feature. This allows for measuring the changes in one shoreline survey to another based on an established feature—the *Baseline*. By storing a *Baseline* feature in a geodatabase when new surveys are available, the original *Baseline* would be used for deriving changes in the shoreline. Similar to the *TransectPoints* object class, an additional object class called *CoastlinePoints* is added for storing the point events along the baseline and the distance from the point to *Baseline*. Additionally, a line is drawn through the survey points that have been selected and projected to *Baseline*. This line is added as a *Shoreline* feature. The combination of a *Shoreline* and a *Baseline* constitute what is termed a *Coastline*. The *Coastline* feature can then be plotted as a graphic using MIKE Marine GIS where further volumetric differences can be calculated and plotted in conjunction with *Coastline*.

The final subclass of *MarineLine* is the *TimeDurationLine* feature class. The *TimeDurationLine* feature class is discussed in great detail in chapter 4. Please refer to this chapter for a complete description.

## Sediment transport

In the DHI case study of sediment transport simulation, a combination of recent bathymetric surveys along the coast of Køge is used together with *Transect* features for generating profiles. These profiles can then be used as input to the numerical model known as LITPACK. Tools are available in MIKE Marine GIS for exporting the profile data into a format that LITPACK recognizes. With knowledge of local wave conditions and sediment properties, the profile can be used to simulate the littoral drift along the coastline. Figure 6.23 shows the simulated littoral drift for typical eastern wave conditions. Notice that the resulting transport direction for this wave direction is southward. In the present situation, sand is transported along the coast toward the north when waves arrive from southern directions and toward the south when waves arrive from northern directions. The annual net transport is defined as the difference between the total northward transport and the total southward transport. The net transport determines the shoreline evolution at both sides of the port. Using nearshore wave conditions, calculated by DHI for the purpose of this study, and sampled sediment data, the profile formed the basis of the calculation of annual sediment drift.

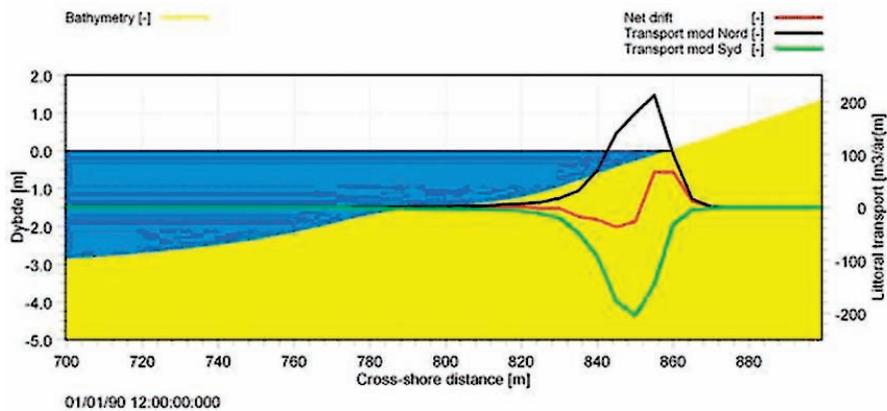


Figure 6.23 The result from the LITDRIFT module of LITPACK showing the calculated transport rates north of the port based on the bathymetric profile derived in MIKE Marine GIS. The black and green curves indicate the total northward and southward transport, respectively. The red curve represents the net annual transport.

Data provided by Ann Skou, DHI Water & Environment.

## Shoreline evolution

In addition to the sediment transport, the DHI case study also looked at the Shoreline evolution. Using the tools in MIKE Marine GIS, a straight baseline feature was drawn and positioned parallel to the coastline. The measured coastline data, derived from aerial photographs and stored as two separate surveys from 1985 and 1995, was used to create a shoreline by projecting the respective positions and distances of the survey points to the common baseline. From this, the coastlines could be plotted along with the calculated volumetric differences. The analysis in this case showed the volume difference to be approximately 7,200 m<sup>3</sup>/m for the 10-year interval (figure 6.24). The total volume in cubic meters can be found by multiplying the length and width of the coastline with the depth of the active layer. Assuming the active layer thickness is about 3 m, the net sediment transport rate in the area can be estimated as 22,160 m<sup>3</sup> in 10 years. This corresponds to an annual accumulation of 2,160 m<sup>3</sup>/year, a relatively small amount, which supports the general perception about the coastline in this area being stable.

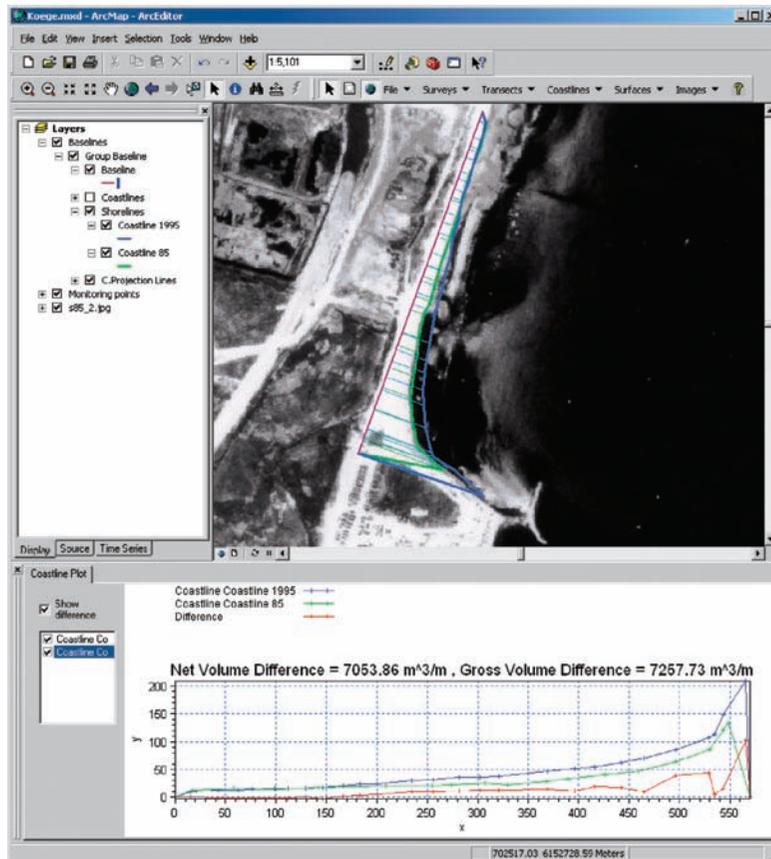


Figure 6.24 Coastline plots and shoreline processing of the net volume difference and the gross volume difference from MIKE Marine GIS. The image shows a baseline in purple, a 1985 shoreline in green, and a 1995 shoreline in blue.

Image courtesy of Niels Nielsen, Institute of Geography, Denmark, and Uwe Jacobs, Køge Kommune.

## Conclusion

This chapter and the case studies it revolves around amply illustrate the flexibility of the Arc Marine data model. In each of these case studies, the data model was highly customized and extended to accommodate the application and the data used. The researchers preserved the core classes, while also adding their own feature classes or object classes where they saw fit. This illustrates a fundamental concept that the Arc Marine data model is not meant to be the solution, but rather the foundation from which a solution can be built.

Linear features play an important role in marine applications, even without the networks of linear infrastructure that are so typical of terrestrial applications. In marine applications, linear features often delineate a path or track along which measurements, observations, or samples have been made. So this chapter is less about describing the linear features than it is about describing how the lines are used as part of the process of determining where or what happens along the line. The lines are mapped using GIS not because they represent a physical feature but because something has happened, has been measured, or has been derived along that line.

## Arc Marine class definitions featured in this chapter

FEATURE CLASSES	<b>InstantaneousPoint</b> —A feature class representing features that are single observations in time and space. The x- and y-coordinates, plus a time stamp, create the unique feature. An InstantaneousPoint can have multiple ZValues by implementing a relationship to the Measurement object class.		
	<b>Subtype</b>	Survey	
	<b>Notes</b>	InstantaneousPoint is a subclass of the superclass MeasurementPoint.	
	<b>Properties</b>	None apply	
	<b>Fields</b>	FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships
		FeatureCode	A user-defined code used for identifying a feature
		CruiseID	A key field for relating this feature class to a Cruise
		TimeValue	The time stamp for the point
		ZValue	A single depth value for the point
		SurveyID	A foreign key to the SurveyInfo object class
		SeriesID	A foreign key to the Series object class
		PointType	Defines the subtype to be one of the following: 1 = Instant (default value) 2 = Sounding 3 = Survey 4 = LocationSeries
	<b>ProfileLine</b> —A feature class representing linear features that are not physical features themselves, but rather features that are interpolated, along the line, from another source. For example, a profile interpolated from a bathymetry survey.		
	<b>Subtype</b>	None apply	
	<b>Properties</b>	HasM = True HasZ = True	
	<b>Notes</b>		
	<b>Fields</b>	FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships
		FeatureCode	A user-defined code used for identifying a feature
		CruiseID	A key field for relating this feature class to a Cruise
	<b>ShoreLine</b> —A feature class representing the measured intersection between the shore and mean high waterline.		
	<b>Subtype</b>	None apply	
	<b>Properties</b>	HasM = True HasZ = True	
	<b>Notes</b>		
	<b>Fields</b>	FeatureID	A geodatabase-wide unique identifier and key for participating in relationships
		FeatureCode	A user-defined code used for identifying a feature
		CruiseID	A key field for relating this feature class to a Cruise
		VDatum	Defines the vertical datum for the Shoreline feature

FEATURE CLASSES (cont'd)	<b>FeatureArea</b> —A feature class representing homogeneous areas.																		
	<b>Subtype</b>	None apply																	
	<b>Properties</b>	None																	
	<b>Notes</b>																		
	<b>Fields</b>	<table border="1"> <tr> <td>FeatureID</td> <td>A geodatabase-wide unique identifier and key field for participating in relationships</td> </tr> <tr> <td>FeatureCode</td> <td>A user-defined code used for identifying a feature</td> </tr> <tr> <td>CruiseID</td> <td>A key field for relating this feature class to a Cruise</td> </tr> </table>	FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships	FeatureCode	A user-defined code used for identifying a feature	CruiseID	A key field for relating this feature class to a Cruise											
FeatureID	A geodatabase-wide unique identifier and key field for participating in relationships																		
FeatureCode	A user-defined code used for identifying a feature																		
CruiseID	A key field for relating this feature class to a Cruise																		
OBJECT CLASSES	<b>SurveyInfo</b> —Designed for storing information about a specific survey.																		
	<b>Notes</b>																		
	<b>Fields</b>	<table border="1"> <tr> <td>SurveyID</td> <td>A key field for relating this table to a feature class</td> </tr> <tr> <td>StartDate</td> <td>The beginning date of the survey</td> </tr> <tr> <td>EndDate</td> <td>The ending date of the survey</td> </tr> <tr> <td>Description</td> <td>A general description of the survey</td> </tr> <tr> <td>DeviceID</td> <td>A key field for relating a survey with a Measuring device</td> </tr> <tr> <td>TrackID</td> <td>A key field for relating a survey with a Track</td> </tr> </table>	SurveyID	A key field for relating this table to a feature class	StartDate	The beginning date of the survey	EndDate	The ending date of the survey	Description	A general description of the survey	DeviceID	A key field for relating a survey with a Measuring device	TrackID	A key field for relating a survey with a Track					
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	Description	A general description of the survey																	
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	TrackID	A key field for relating a survey with a Track																	
	<b>SurveyKey</b> —Designed as an intermediate key table with one-to-many relationships on both sides of it for modeling a many-to-many relationship between the ProfileLine and SurveyInfo tables.																		
	<b>Notes</b>	The two fields, SurveyID and FeatureID, can be repeated any number of times forming unique combinations of relationships between features and survey																	
	<b>Fields</b>	<table border="1"> <tr> <td>SurveyID</td> <td>A key field for relating this table to the SurveyInfo table</td> </tr> <tr> <td>FeatureID</td> <td>A key field for relating this table to a feature class</td> </tr> </table>	SurveyID	A key field for relating this table to the SurveyInfo table	FeatureID	A key field for relating this table to a feature class													
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	<b>Cruise</b> —Defines the characteristics of a ship for the duration of an expedition.																		
<b>Notes</b>																			
<b>Fields</b>	<table border="1"> <tr> <td>CruiseID</td> <td>An identifier for a given cruise</td> </tr> <tr> <td>Code</td> <td>An user-defined code for a given cruise</td> </tr> <tr> <td>Name</td> <td>The name of the cruise</td> </tr> <tr> <td>Purpose</td> <td>The purpose of the cruise</td> </tr> <tr> <td>Status</td> <td>Defines the status of the cruise</td> </tr> <tr> <td>Description</td> <td>A general description of the cruise</td> </tr> <tr> <td>StartDate</td> <td>The beginning time stamp for the cruise</td> </tr> <tr> <td>EndDate</td> <td>The ending time stamp for the cruise</td> </tr> <tr> <td>ShipName</td> <td>The name of the ship participating in the cruise</td> </tr> </table>	CruiseID	An identifier for a given cruise	Code	An user-defined code for a given cruise	Name	The name of the cruise	Purpose	The purpose of the cruise	Status	Defines the status of the cruise	Description	A general description of the cruise	StartDate	The beginning time stamp for the cruise	EndDate	The ending time stamp for the cruise	ShipName	The name of the ship participating in the cruise
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RELATIONSHIPS	<b>SurveyInfoHasPoints</b>	1 : *	One Survey can have zero or many points
	<b>ProfileLineHasSurveyKeys</b>	1 : *	One ProfileLine can have zero or many SurveyKeys
	<b>SurveyHasSurveyKeys</b>	1 : *	One Survey can have zero or many SurveyKeys
	<b>CruiseHasTracks</b>	1 : *	One Cruise can have zero or many Tracks

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