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chapter one

Introduction

Just as fish adapted to the terrestrial environment by evolving into amphibians, so GIS must adapt to the marine and coastal environment by evolution and adaptation.
M. F. Goodchild (2000)

Our ability to measure change in oceans and along coasts is increasing, not only because of improved measuring devices and scientific techniques, but also because new GIS technology is helping us better understand the marine environment. The domain has progressed from applications that merely collect and display data to complex simulation, modeling, and the development of new coastal and marine research methods and concepts. Marine GIS has evolved into an established application domain adapting a technology originally designed for land-based applications. However, a two-dimensional (2D) framework has never perfectly matched the ocean environment, where processes are dynamic and multidimensional in nature. Fortunately, technology has continually improved as increased commercial, academic, and political interest in coastal regions, oceans, and marginal seas have spurred fundamental improvements in the toolbox of GIS and extended the methodological framework for marine applications. Other challenges remain, such as how to best handle the temporal and dynamic properties of shoreline and coastal processes, how to deal with the inherent fuzziness of boundaries in the ocean, and the great need for spatial data structures that vary their relative positions and values over time. For a complete and chronological discussion of these various research challenges, see Li and Saxena (1993), Bartlett (1993a and b), Lockwood and Li (1995), Wright and Goodchild (1997), Wright and Bartlett (2000 and references therein), Valavanis (2002), Breman (2002), Green and King (2003), and Wright and Halpin (2005). The development of an effective conceptual and logical data model for marine objects and phenomena provides context and direction to meet these challenges.

As we move rapidly into the information era, in which decisions are based on available data and new information is created from existing data, the body of marine knowledge has surged forward at a rate that challenges our computer capacity to store, process, and share it (e.g., Ocean Information Technology Infrastructure Steering Committee 2002; Mayer et al. 2004; National Science Board 2005). Natural phenomena such as hurricanes and tsunamis illustrate the importance of a focused effort to manage and share information, while the slower processes of erosion and climate change also influence our environment in ways that demand our attention. A data model helps us categorize and give structure to the many different ways to store and analyze marine data. The benefits and added value come in the form of geospatially enabling the data to create maps and three-dimensional (3D) scenes of the marine environment that assist in representing the information in ways that are invaluable to decision making.

A data model for marine applications is complex because of the many, varied uses of the data (as discussed in detail in chapter 2). Modern marine datasets are generated by a wide array of instruments and platforms, all with differing formats, resolutions, and sets of attributes (figure 1.1). Users must deal with a variety of data sources and a myriad of data "structures" (e.g., tables of chemical concentration versus raster images of sea surface temperature versus gridded bathymetry versus four-dimensional [4D] data). A comprehensive

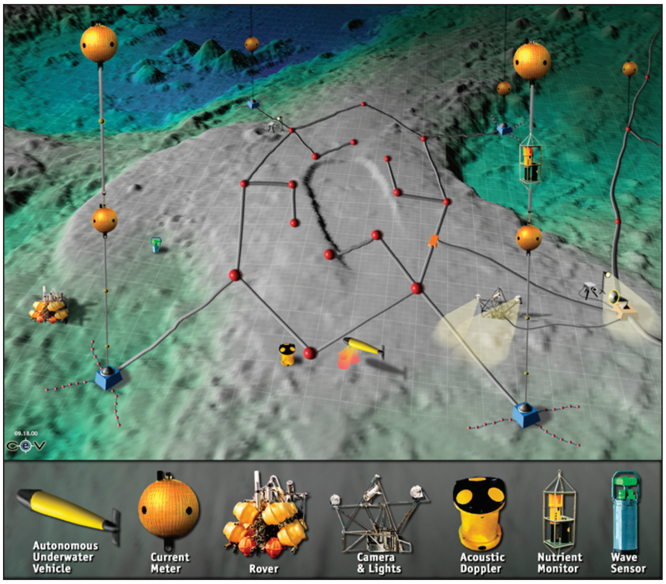

Figure 1.1 The North-East Pacific Timeseries Undersea Networked Experiments (NEPTUNE) ocean observatory envisions a hypothetical network of oceanographic instruments and vehicles to be deployed on Axial Volcano in the northeast Pacific Ocean. It is based on the existing NOAA New Millennium Observatory (NeMO) on Axial. This image also shows the many and varied sources of data that may be available from one major study site for marine GIS maps and analyses.

Graphic published by permission from NEPTUNE, University of Washington.

data model is needed to support the much wider range of marine objects. This is essential for advanced management, cartographic, and analytical tasks. The ArcGIS marine data model, hereafter referred to as Arc Marine, endeavors to identify and organize these objects.

Just as language and the use of common symbols help us communicate and share our ideas, a data model with commonly accepted terminology and semantics (or ontology) helps us exchange information. We have spent a considerable amount of time and energy serving as translators or "semantic mediators" for a community that holds many of the same interests in gathering, understanding, and sharing information about the world's oceans and seas. Users can apply the resulting data model in many marine applications. It can serve as a starting point for the novice or as a resource for the expert in marine GIS and its implementation.

For the sake of clarity, "marine" (as in marine community, marine applications, and marine GIS) throughout this book refers to deep oceans and coasts. In the past, a distinction was made between ocean and coastal GIS because they developed fairly independently of each other (Wright 2000; Bartlett 2000). In this way, traditional oceanography departments in North America often grouped biological, chemical, physical, and geological studies of the ocean as "oceanography science programs" while creating a separate category for coastal studies, particularly if the emphasis was on coastal resource management. In general, ocean applications of GIS have traditionally been more in the realm of basic science, whereas coastal applications, due in part to the intensity of human activities, have encompassed basic and applied science and policy and management. But this is fast changing. Both subdomains collect similar datasets and have common interests and needs in terms of GIS implementation. In other words, the datasets are the same, regardless of how they are used (for basic or applied science, conservation, education, applied commercial use, etc.). As such, an essential data model should be applicable to all. Therefore, Arc Marine is for people applying GIS to the coasts, estuaries, marginal seas, and the deep ocean: academic, government, and military oceanographers; coastal resource managers and consultants; marine technologists; nautical archaeologists; marine conservationists; marine and coastal geographers; fisheries managers and scientists; ocean explorers/mariners, and so on.

Why Arc Marine?

As noted by Bartlett (2000) and Li (2000), rigorous modeling of data before attempting to implement a GIS database is one of the most important lessons to be learned from collective experience in the application domain of marine GIS. Data models lie at the heart of GIS, determining the ways in which real-world phenomena may best be represented in digital form. With regard to ESRI products, many marine and coastal practitioners and organizations have invested in the coverage or shapefile data structure (under the rubric of a "georelational data model"). Although this has largely been successful, there have been important shortcomings, such as the inability to distinguish between a feature that merely marks a location from one that may actively collect some form of data. In recent years, ESRI has introduced a new object-oriented data model called the geodatabase, in which GIS features are "smarter," that is, they can be endowed with "behaviors" and more complex relationships. "Behavior" here primarily means providing the basic data input and data quality safeguards to ensure clean, consistent data. A geodatabase allows people to build validation rules, apply real-world behavior to features, and combine or link them to tables using relationship classes. For instance, a point representing a seafloor marker can be readily distinguished from a point that actually does something, such as a transponder that sends an acoustic pulse back to the surface. A line representing a coast can be attributed with time-varying sequences or intervals to enable it with behavior that more closely represents a dynamic shoreline. These capabilities are especially useful for large enterprise databases of geographic information (i.e., a GIS integrated in multiple departments or sections within an organization, institute, observing system, large project, etc.). For an overview of ArcGIS object and geodatabase concepts, see Zeiler (1999) or Arctur and Zeiler (2004).

One key benefit of the ArcGIS data model is its ability to help users take advantage of the most advanced manipulation and analysis capabilities of the GIS, particularly the capacity of the geodatabase to respond to events and processes acting on it (just as the marine environment itself is acted on by events and processes). For users, Arc Marine provides a basic template to implement a marine GIS project. This facilitates the process of extracting, transforming, and loading data (ETL), in addition to data input, formatting, geoprocessing, and analysis. For developers, it provides a framework for writing program code and maintaining applications. While ArcGIS data models do not create formal data standards, they do promote existing ones. This helps managers simplify data integration at various jurisdictional levels (i.e., local, state/provincial, national, global). Using a common data model (and the accompanying data structure) helps users merge disparate data sources, particularly as the exchange of Internet information becomes paramount. Data sharing and growth cycles accelerate if many people and organizations rely on the same model as their foundation.

Arc Marine aims to provide more accurate representations of the location and spatial extent of marine features and to help users conduct more complex spatial analyses of this data. The model also guides users in new approaches that effectively integrate marine data in space and time. The specific goals of the model include the following:

- Creating a common structure—a geodatabase template—for assembling, managing, and publishing marine data in ArcGIS. For example, the model is specified in an industry-standard modeling notation called the Unified Modeling Language (UML). Because UML code is easily converted to an ArcGIS geodatabase (or to data structures in other GIS packages), users can immediately begin populating the geodatabase rather than designing it from scratch.
- Producing, sharing, and exchanging data with a similar format and structure design.
- Providing unified approaches that encourage development teams to extend and improve ArcGIS for marine applications.

- Extending the power of marine GIS analyses by providing a framework for incorporating behaviors in data and dealing more effectively with scale dependencies.
- Providing a mechanism to implement data content standards such as the Federal Geographic Data Committee's Hydrography Data Content Standard for Inland and Coastal Waterways, critical for the Coastal National Spatial Data Infrastructure.
- Helping many users learn and understand the geodatabase in ArcGIS.

Intended audience and scope of Arc Marine

Arc Marine focuses on the deep ocean and the coast (and attempts to represent the essential elements for a broad range of marine and coastal data types and processes) but cannot include a comprehensive catalog of objects meeting the needs of all user groups and applications, data structures, and standard processes. However, the model is a starting point on which to build and leverage the experiences of a broader range of practitioners—a range much broader than the specialties of the authors.

Many marine GIS users have substantial experience with a smaller set of marine models and with existing data and metadata standards. Therefore, it is important to understand existing relationships to related efforts such as Arc Hydro (Maidment 2002) and other ArcGIS data models at http://support.esri.com/datamodels such as Climate and Weather, Groundwater, Biodiversity/Conservation, S-57 for Electronic Navigational Charts, and even Parcels (for coastal land development). As noted by Steve Grisé (pers. comm. 2001), designing a data model is like designing a new minivan: once it's designed and built, you still don't know how families will actually use it (there will be so many variations depending on the family). So once a data model is designed and initially implemented, the many ways it can be implemented become clearer, and it is refined accordingly.

Outline of book and accompanying resources

Chapter 1 discusses the need for a marine data model and lays out the objectives and scope of Arc Marine. Chapter 2 introduces the critical concept of Common Marine Data Types and summarizes the main thematic layers of Arc Marine. Chapters 3 through 7 describe the main components of the core data model: feature and object classes for various kinds of marine surveys, location series and time duration lines and areas, time series and measurements, nearshore and coastal/shoreline analysis, and model meshes. These chapters present the feature classes, attributes, relationships, and object tables used for these components, illustrating them with case studies contributed by several organizations. These case studies use a variety of datasets to show how users might adapt and implement the model within their desired application area. Some organizations, particularly smaller groups and those without marine GIS experience, may have trouble understanding the best way to implement the data model. The goal of Arc Marine, as discussed earlier, is to make it easier for people to implement successful, enterprise-level GIS projects so their organizations can enjoy the benefits of GIS. Chapter 8 discusses grid-based and multidimensional GIS (including 2D time series and network Common Data Form, also known as netCDF), and similarities and possible linkages to other models such as the Groundwater and Atmospheric data models. And finally, chapter 9 looks forward with a discussion of the importance of common tools arising from or serving data models, issues of interoperability, and the relationship of data models to generic Web services. Also discussed is the relationship to project-specific Internet map servers such as OBIS-SEAMAP (Ocean Biogeographic Information System-Spatial Ecological Analysis of Megavertebrate Populations), and the emergence of capabilities for streaming data from these sites directly into the Arc Marine structure.

This book serves as the primary reference for describing and explaining the data model (including feature-class glossaries), demonstrating its use in ArcGIS, and providing examples of marine applications that use the model and pointers to other reference material. The book should not stand alone, however, and is best used in conjunction with several additional resources available on the book's accompanying Web sites:

- A specification of Arc Marine in UML or XMI (XML Interchange) that marine application development teams can use as a starting point to structure marine data. These are detailed machine-readable schema of the design, providing specifications of data types, relationships, and other details. Users can create an actual ArcGIS geodatabase from these views of the database design. An additional design document that summarizes objects found in the database is the Common Marine Data Types diagram. The specific data needs of a given user may require modifications of, or extensions to, the basic data model.
- A detailed poster that presents the logical design of the data model. Project teams, managers, and technical leads can use this to review the data model as a starting point for finding similarities and common data types and to better understand the use of relationship classes and other elements of the database.
- A step-by-step guide on the practical use of the model, complete with a tutorial dataset. This should also be useful in university classrooms and professional workshops.
- Several Arc Marine schemas and geodatabases from the case studies that can be used to demonstrate the efficacy of the marine data model for several different applications. Public domain marine data comprises the datasets and may be freely used to support specific projects.

The data model has been tested, and organizations have implemented their datasets using the design, resulting in many common best practices and patterns. As one pattern, the model most often serves as a starting point. Users then modify the model to fit the needs of individuals and organizations. The model is designed to work this way, and specific tools make this process an easy revision. In working with marine data, it is important to harness the dynamic qualities of the data. Users can create and derive new information from tools for processing and analysis. Using a commonly shared data model design helps facilitate the transfer of the information stored in the model. It also provides a common frame of reference for design decisions and a foundation for further data interpretation.

The importance of an effective data model design is paramount in an era when our response to natural phenomena such as tsunamis, hurricanes, and global warming may be a matter of life and death. Together, drawing from the case studies in this book and other successful projects, we can realize the true potential of this community-driven, collaborative data model design, created to serve the discipline of marine GIS.

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