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Collaborative Management of Natural Resources in San Diego Bay

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This article presents the results of a three-year effort at applying information technology to the problem of collaborative natural resource management in San Diego Bay. As such, it represents an approach to integrated coastal zone management (ICZM). This effort resulted from a collaboration between the San Diego Supercomputer Center at the University of California, San Diego and the San Diego Bay Interagency Water Quality Panel for the purpose of (1) developing an environmental data repository to facilitate the acquisition and sharing of data and (2) the development of a visual model of the bay in support of the development of a comprehensive, coordinated management plan for San Diego Bay. It was determined from this study that information technology is an important and key component to ICZM but that sociopolitical factors may override the benefits of decision-support systems and should be considered at the outset of any project of this kind.

Keywords data, data management, integrated coastal zone management, San Diego Bay, visualization

Introduction

Recognition of the world's coasts as intensively used, increasingly populated, and polluted has led to efforts in countries around the world at coastal zone management (Hinrichsen, 1998; Sorensen, 1993, 1997). The term *integrated coastal zone management* (ICZM)

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was coined to describe management efforts in the coastal zone that are multisectoral with intergovernmental sociopolitical and interdisciplinary scientific involvement. ICZM addresses the unique situation of the coastal zone as an interface between land and water and thus subject to cumulative impacts from inland sources (Sorensen, 1993, 1997; Cicin-Sain, 1993; Hildebrand & Norrera, 1992; Knecht, 1993; Knecht, Cicin-Sain, & Fisk, 1996; Thia-Eng, 1993). Examples of ICZM can be found around the world (Hinrichsen, 1998), displaying differing degrees of success. In addition to resolving the competing interests of multiple users, government agencies, and other stakeholders within the coastal zone, there are computing and information technology (IT) issues that must be addressed to ensure the success of ICZM. These issues are often overlooked, but recently the National Research Council (1994) highlighted two of these: (1) the need for better modeling capabilities and (2) the need for improvements in coastal monitoring and data archival. The work reported here addresses these two issues with examples of information technology applied to ICZM.

The term *information technology* has come to refer to all aspects of computing and communications, especially in the context of the delivery of information as a commodity or as a component of the economy. Within roughly the last 10 years, this usage evolved from what had been commonly referred to as *management information systems (MIS)* in the United States and as IT in Britain and at least some of its ex-Commonwealth countries. Recently its usage has broadened, to a large degree as a result of the National Science Foundation's Information Technology Research programs (e.g., NSF 00-126, http://www.nsf.gov), to include what had previously been exclusively considered computer science research. This shift in NSF's usage is likely at least partly the result of the reports and correspondence emanating from the Clinton administration's President's Committee of Advisors on Science and Technology (PCAST).[1] For our purposes here, IT is used in the broad sense to mean the application of digital technology to the production and delivery of information. At present, this usually involves the use of the world wide web (WWW) as the access and delivery system or *portal*. The sources of information relevant to coastal management issues include, but are not limited to, numerical and visual models, geographic information systems, empirical measurements and remote sensing imagery (i.e., data). The interested reader may wish to consult Uhlir (1997) and National Research Council (1995).

Against that background, it is the purpose of this article to present and evaluate a three-year effort at applying information technology to the problem of collaborative resource management in San Diego Bay. This effort resulted from collaboration between the San Diego Supercomputer Center at the University of California, San Diego and the San Diego Bay Interagency Water Quality Panel (Bay Panel). Funding for the project was provided by members of the Bay Panel for the purpose of (1) developing an environmental data repository to facilitate the acquisition and sharing of data and (2) the development of a visual model of the bay. At the time, the project was recognized as among the most innovative applications of IT of its kind (National Science and Technology Council, 1996).

We claim that there are intrinsic sociopolitical problems in establishing an ICZM approach for any given locale that are common to all locales and independent of IT issues. For instance, consider a spectrum of natural resource management schemes ranging from the decentralized activities of competing or noncooperating organizations to an integrated scheme with ICZM and cooperating organizations. Pressures from decentralized special interests strive to direct management decisions toward their individual self-interest while the recognition of deteriorating, common natural resources drives toward a more integrated, jointly determined outcome that balances competing interests. These opposing pressures appear to be present in many contemporary situations (Pilkey

& Dickson, 1996; Dean, 1999; Dennison & Abal, 1999). Furthermore, we argue that IT is necessary but not sufficient for the success of ICZM and that the real contribution of IT is that it makes it possible to conduct independent, third-party analyses, with public verification of results. Such public results can provide a check and balance for the formation of a rational, consistent, and coherent ICZM, where the pressures for decentralization and partisanship are particularly strong. To understand this more clearly, we will examine the results from the San Diego Bay Project.

The San Diego Bay Project

San Diego Bay in southern California (Figure 1) is an example of a coastal area where there have been both formal and informal attempts to integrate coastal zone management activities with mixed results. It is a typical setting in that there are many local, state, and federal organizations and agencies with statutory authority relating to activities and resources within the bay. There is also a history of cooperation among agencies through the long-standing San Diego Bay Working Group[2] that meets periodically and informally to coordinate biological monitoring efforts within the bay and to share data. In 1987, a formal activity was initiated by California State Assembly Bill 158, authored by Assemblyman Lucy Killea, which established The San Diego Bay Interagency Water Quality Panel (Bay Panel) with a specified membership (Table 1).

The legislation was designed to formally encourage governmental agencies and non-

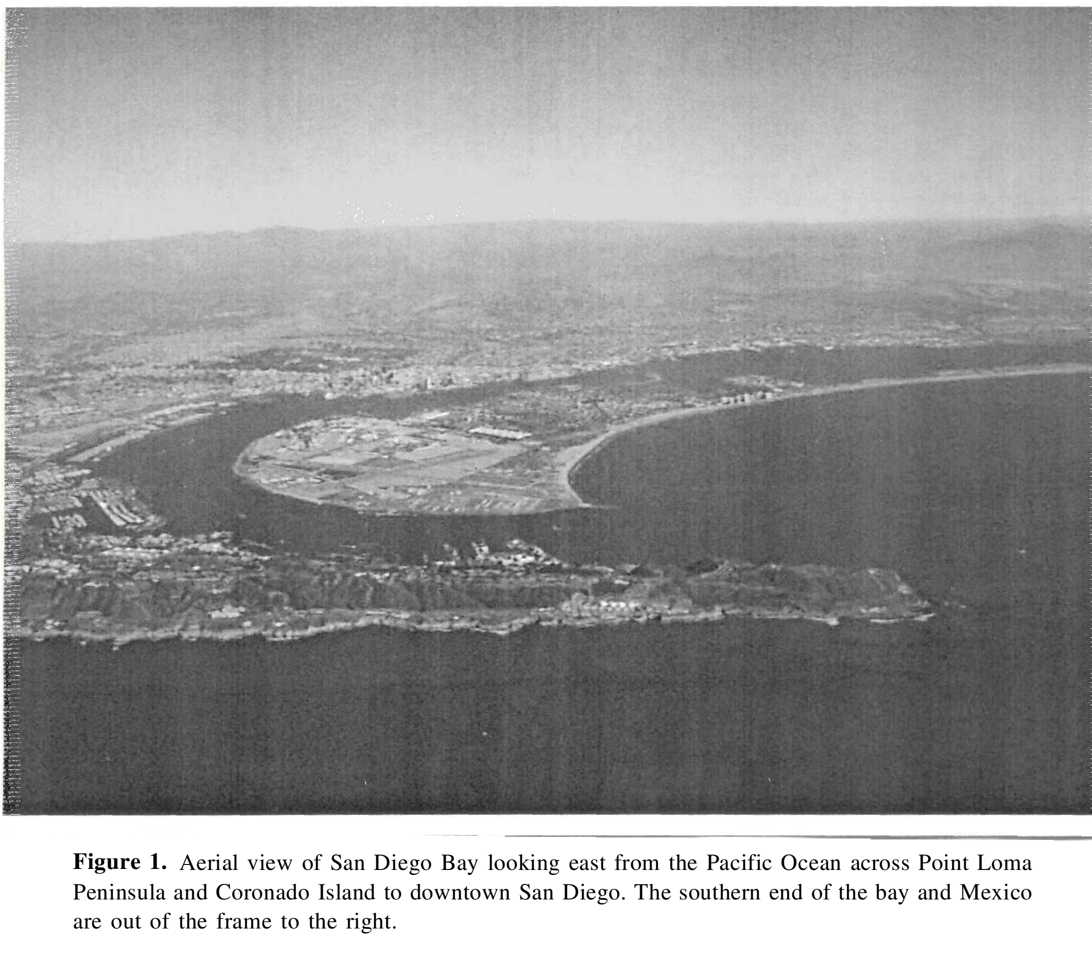

Figure 1. Aerial view of San Diego Bay looking east from the Pacific Ocean across Point Loma Peninsula and Coronado Island to downtown San Diego. The southern end of the bay and Mexico are out of the frame to the right.

Table 1
Legislatively mandated membership of the San Diego Bay Interagency Water Quality Panel (Bay Panel)

Jurisdiction	Organization or agency
Local	San Diego Regional Water Quality Control Board
	San Diego Unified Port District
	San Diego Port Tenants Association
	San Diego Marine Trade Association
	City of San Diego
	City of Chula Vista
	City of Imperial Beach
	City of Coronado
	City of National City
	San Diego Association of Yacht Clubs
	Industrial Environmental Association
	Environmental Health Coalition
	San Diego Audubon Society
County	Board of Supervisors, County of San Diego
	County of San Diego Department of Agriculture, Weights and Measures
	County of San Diego Department of Environmental Health
State	California Environmental Protection Agency
	California Coastal Commission
	Scripps Institution of Oceanography
	California Sea Grant College
	California Office of Environmental Health Hazard Assessment
	State Water Resources Control Board
	California Department of Pesticide Regulation
	California Department of Fish & Game
	State Lands Commission
Federal	United States Environmental Protection Agency
	United States Fish & Wildlife Service
	National Marine Fisheries Service
	United States Army Corps of Engineers
	United States Navy
	United States Coast Guard

governmental organizations with jurisdiction or interests in San Diego Bay to coordinate their efforts across physical, chemical, biological, and policy domains. It was also intended to provide technical information and policy advice to the San Diego Regional Water Quality Control Board (RWQCB) and the public. The RWQCB has permitting and enforcement authority in the bay for water quality issues. It is important to appreciate that the Bay Panel had neither regulatory authority nor government funding and was designed to be a consensus-building and advisory activity only. Similar groups exist in other urbanized areas such as the Chesapeake Bay (http://www.chesapeakebay.net/), Charleston Harbor (http://inlet.geol.sc.edu/chp/chpcamo.html), San Francisco Bay (http://calfed.ca.gov/), and Boston Harbor (http://www.tbha.org/).

The Bay Panel existed for 10 years, and at the end of its tenure, in December 1997, it had produced a Comprehensive Coordinated Management Plan for San Diego Bay (http://sdbay.sdsc.edu/html/compplan/cmp_home.html) and a number of yearly reports.[3]

One of these reports provided a survey of all the environmental monitoring activities in the bay during the previous 10 years. From this it was apparent that a considerable amount of effort had been and was being invested in environmental monitoring activities. This report raised concerns that monitoring efforts were possibly redundant and wasteful and that the data resulting from them was not being shared or used at all in the regulatory decision-making process. Consequently, some members of the Bay Panel (Scripps Institution of Oceanography, the Port of San Diego, the U.S. Navy, and the California Sea Grant College) initiated and funded the San Diego Bay Project with the San Diego Supercomputer Center (SDSC).

Role of IT in Coastal Zone Management

While every natural resource management problem has features unique to its geography and sociopolitical environment, there are elements common to many of them (National Research Council, 1999). Among these are difficulties stakeholders have in developing a joint understanding of the facts relating to any particular resource management issue and obtaining a common language in which to discuss them. This is where IT has a natural role: to provide data and tools to foster a clear, reproducible, and public record of the facts relating to the natural resources being managed.

As stated in the introduction, the purpose of the San Diego Bay project was to establish an environmental data repository for these environmental monitoring and ancillary data using the WWW and to develop a visual model of the bay through the generation of two-dimensional (2D) thematic maps. Essentially, the IT goal was to aid the Bay Panel members in coming to a common understanding of issues under consideration at any point in time rather than spending their "time talking about what they were talking about."

The use of the WWW has broadened since the time this project was conducted in 1995–1997, and so the novelty of this IT innovation in this setting is somewhat difficult to appreciate now that the WWW is commonplace in home and office and routinely used by large parts of the population to access information of all sorts. However, the principles and approaches that we developed and used to acquire, organize, and publish the monitoring data, to generate information, and to attempt to provide support for a public policy-making body offers insight into the strengths and weaknesses in the application of IT to the delivery of scientific data and analysis into the decision-making process.

While the interpretation of data and analyses will generally be open to dispute due to individual and group biases and special interests, the relative ease with which a set of relevant facts can be gleaned from data and analytical products and effectively used can substantially focus this discourse and debate (Kraemer et al., 1987). The obvious current tool for publishing digital information, the WWW, changes the terrain of discussion such that any interested citizen or agency staff member can readily access a common base of information as well as be enabled to conduct independent analyses of the data. At the time that the San Diego Bay Project started, this was a novel approach and one that, even at this late date, is only beginning to appear systematically in other settings.

From our experience in using IT in this way, we have identified a list of functions that appear to be generally applicable to collaborative natural resource problems. These are

- the acquisition of both data and metadata (Michener et al., 1997), including acquisition from sensors as well as existing data files;
- the publication of data through commonly available access methods using standard platforms, languages, and procedures (Helly et al., 2000);
- the integration of data, including quality control and quality assurance (QA/QC) processing and standardization of metrics and nomenclature (Helly et al., submitted);

- the quantitative analysis of temporally varying processes and interactions between natural and man-made systems and events;
- the visual modeling of spatial and temporal data through the use of multidimensional thematic maps and animations (Helly, 1998b).

Our efforts have focused on developing applications around these common features to ensure that our approach is readily adaptable to new applications. We will discuss each of these in turn with the exceptions of integration and quantitative analysis. These topics will be the subject of separate reports due to their extensive nature and will not be discussed here.

Data Acquisition

The main technical problem associated with the acquisition of data from a diverse set of sources, assuming that individuals and organizations will release data, is the variability of the data content and format and the difficulty of obtaining sufficient metadata to enable effective reuse of the data (Michener et al., 1997). These problems are well understood and documented and translate into a problem of obtaining sufficient labor and expert resources to convert these data into a usable form. At this point there are no general solutions to this problem, and the best current approach is to encourage the conversion of any given data file into a common format by those most expert in the original data. This approach has been used successfully in many settings and is exemplified by the CIDS (C4 Integrated Data System) system at Scripps Institution of Oceanography (http://www-c4.ucsd.edu/~cids/) based on the NetCDF (Network Common Data Format) data file format (Rew, Davis, Emmerson, & Davies, 1997). The CIDS typifies many of the scientific mission approaches in the Earth systems science community. This type of application is, however, relatively homogeneous in both its empirical data and user population. The general ICZM problem involves greater diversity in both parts of the problem.

While the goal is to obtain a consistent set of data with common conventions such as measurement units, map projections, and error estimates, an important issue that is often overlooked is the integrity of data and the ability to establish an audit trail from derived data products back to the source data. This traceability is needed to determine and evaluate the origin, history, and processing of the data used to support analytical interpretations and decision making. This type of traceability is also essential in (1) working backward from an error found in a derived data product to its source, (2) making the corrections, and (3) reprocessing the data to the point at which the error was detected. In other words, debugging a data problem (Helly et al., 2000). This, in addition to enabling independent analysis, is a key reason we publish data as both derived products and source data.

Data Publication

Figure 2 displays a table of the number of individual data files published by the San Diego Bay Project data as well as derived products in the physical, chemical, and biological categories. A complete listing of files is too long to be provided here but can be obtained from the San Diego Bay Project website (http://sdbay.sdsc.edu). The concept of controlled publication of digital scientific data is new and the technical issues surrounding it have been the subject of a number of publications and a key research topic at SDSC for a number of years (Helly et al., 2000; Helly, 1998a; Gross et al., 1995). One point that needs to be emphasized here, however, is the importance of publishing source data in a highly transportable and reusable form with all the flaws and weaknesses intact as well as any “cleaned-up” and easy-to-use versions that we refer to as

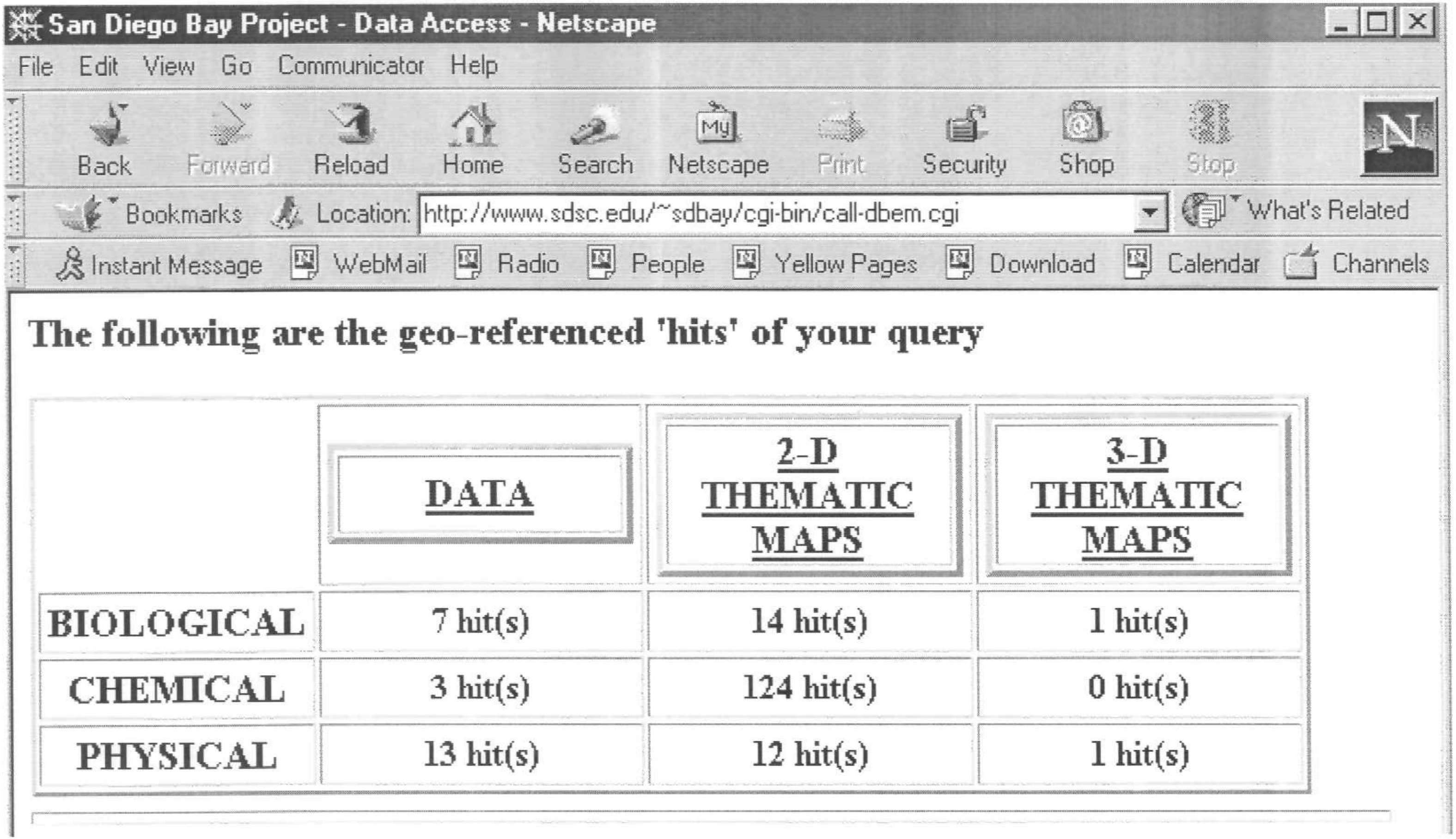

Figure 2. Matrix showing the number of data sets and thematic maps published on the sdbay.sdsc.edu web site. This matrix results from a spatial query of the repository. A complete listing and associated metadata, to the extent provided by contributing organizations or individuals, can be found on the site.

derived data products. We have previously described the means by which some of this interoperability can be achieved and sustained (Helly et al., 1999).

This emphasis is needed because it is a common practice for those who make data available through the WWW to use proprietary software, such as database management systems (DBMSs), to enable a user to search for data by content rather than by a metadata catalogue and without providing the actual source data in the form of files that the user can access with their local collection of analytical software. Contrast this with the approach we used in which data are indexed through a metadata catalogue and the user searches for the data via location, data, and theme or topic. Similar approaches are now used widely in the scientific community. While a content-based search approach is appropriate for many commercial and nonscientific applications, a system based on the use of proprietary software to access data requires a user's complete trust in the data publisher for its data quality without any independent means of checking the accuracy of the data, as we will argue below. However, in our view, the ability to conduct independent analysis is essential to collaborative management in the spirit of "trust but verify." It is also, of course, one of the key principles of the scientific method.

At least in settings we have observed to date, empirical data are usually first acquired and stored as computer files in some kind of row-column format. From these source data come derived data products (i.e., "clean data") that result from subjective, but hopefully expert, judgments about observational anomalies as well as the introduction of transcription and processing errors that can affect many aspects of quantitative analysis that, in turn, potentially affect the subsequent interpretation of the data. It is commonly the case that it is derived data that ends up in proprietary software systems, such as DBMSs. As well as potentially masking the introduction of subjective judgment and inadvertent errors, the use of these systems requires the user to have the often expensive proprietary software and requisite expertise to extract the data needed to conduct an independent analysis. However, only by providing the source data as well as derived data can there be a competitive check-and-balance process and independent analysis.

The first problem in the use of proprietary software systems, the subjective censorship of data and the introduction of unintentional errors, is true of any processing, not just that required for ingestion by a proprietary software system. However, it is our experience that this type of preprocessing, as it is often called, is frequently done by individuals who are expert in the software but not in the data. This often leads to mystifying results like the following one: During the San Diego Bay Project, we had received a particular data set from a government agency both as an early, unofficial release of source data and, much later, as an "improved" official release derived from a conversion of source data to a popular proprietary software system file format (i.e., proprietary software). During this conversion, the number of decimal places in latitude and longitude data were truncated from five to three decimal places, and the data was then released. This truncation inadvertently introduced a circular error of approximately 100 meters in the data related solely to the processing into the spreadsheet format and the default settings used for numerical data in the spreadsheet. The error was discovered in preparing the visual model of San Diego Bay by noticing that many of the locations of marine sediment samples were on land. By comparing the derived spreadsheet data with source data, previously acquired as an early unofficial release of the data, it was possible to infer what had happened, to make the appropriate corrections, and to notify the responsible government agency.

Visual Modeling

The San Diego Bay visual model was defined initially with the intent of providing a common and standard representation of the bay within which topically relevant data could be presented and incorporated in 2D thematic maps (Figures 3, 4). Separate funding from the U.S. Navy led to the additional development of an interactive three-dimensional (3D) visual model of the bay, which incorporated interactive theme selection and the animation of dynamic processes represented through the output of hydrodynamic and watershed models. We call this model *Bayview* (Figures 5, 6). The Bayview model was built using VRML (virtual reality modeling language) and was designed to be displayed through commonly available web browsers. An MPEG animation file depicting this system's capabilities is available at http://sdbay.sdsc.edu. These 2D and 3D tools were designed to be complementary and to serve as decision-support resources for the Bay Panel members as well as the public.

An important aspect of an interactive 3D visual model such as Bayview is the ability of multiple stakeholders (or users) to focus on the aspects of interest to them from a representation that is internally consistent and commonly used. In other words, the visual model is computed as a self-consistent whole from which different views may be obtained and interpreted. This provides a relatively high degree of quality control and consistency versus the production of a separate model for a given topic or view. This is not to say that the same level of quality control cannot be achieved using the separate model approach, but rather that some method of additional cross-checking must be applied to achieve it. This type of visual model is also very effective in presenting temporal

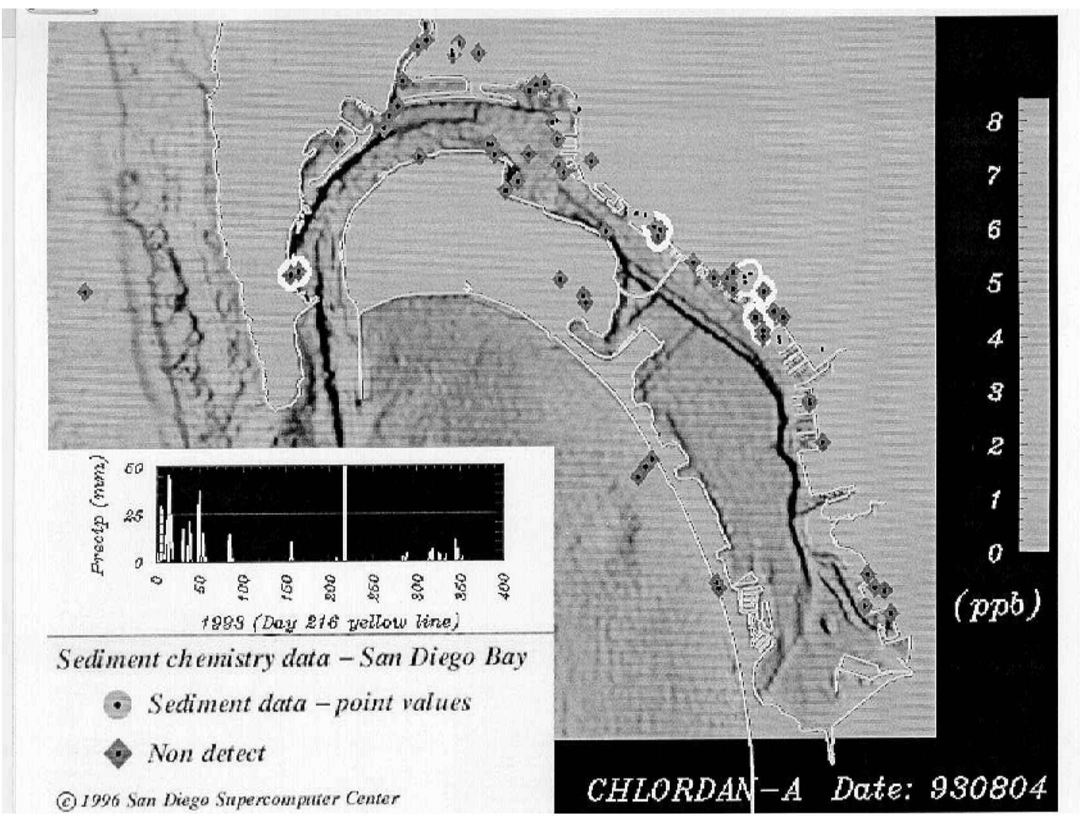

Figure 3. Sediment chemistry data for Chlordane-A. This image depicts the integration of four different data sources: bathymetry, coastline, chlordane (ppb), and rainfall. The white circles indicate which stations were sampled on the date 93/08/04, since stations were not sampled contemporaneously. The inset plot depicts the proximity of this date to significant rainfall that can cause sediment erosion and transport versus in situ deposition.

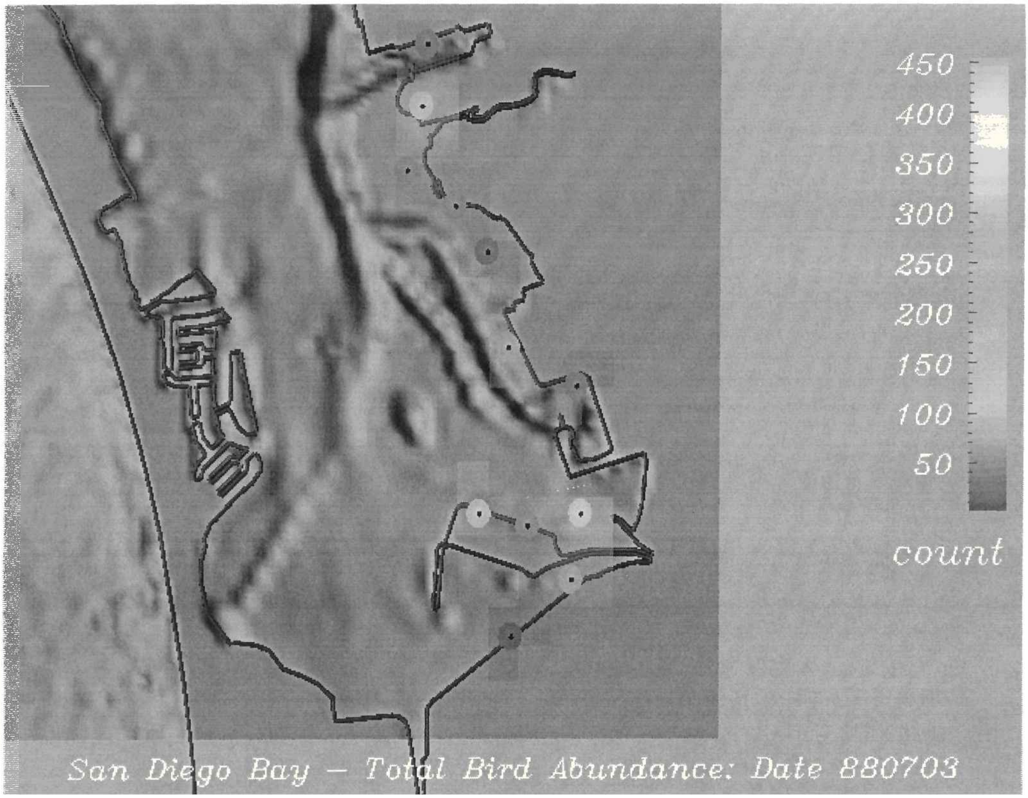

Figure 4. Bird abundance in south San Diego Bay. This image typifies the field survey and map data collected in San Diego Bay. Discrete empirical observations are depicted as opaque circles joined by translucent squares resulting from nearest-neighbor interpolation to suggest habitat continuity.

dynamics such as the circulation within the bay or the outflow of stormdrains into the bay and distribution resulting from the coupling of watershed and hydrodynamic models. This is a capability beyond that of current geographic information systems (GISs). An animation depicting this feature, as well as many other 2D thematic maps, is available on the San Diego Bay Project web site (http://sdbay.sdsc.edu). This requires the capability to initiate the execution of dynamic models, such as hydrodynamic circulation models, from within the visual model domain and to select thematic layers (e.g., distribution of eelgrass, fish, or surface vessel traffic) to be displayed in conjunction with the processes being modeled so that the interactions between environmental components can be examined. This allows risks to be considered in light of time-varying events such as oil spills and stormwater transport within a particular static, thematic setting.

The Role of the Technical Review Committee

At the outset of the San Diego Bay Project, we requested the establishment of a Technical Review Committee. This committee was comprised of scientists from academia and industry as well as technically skilled individuals from organizations with membership in the Bay Panel. The committee was chaired by a member of the Bay Panel who reported directly to the Bay Panel chair and membership. It was the job of this commit-

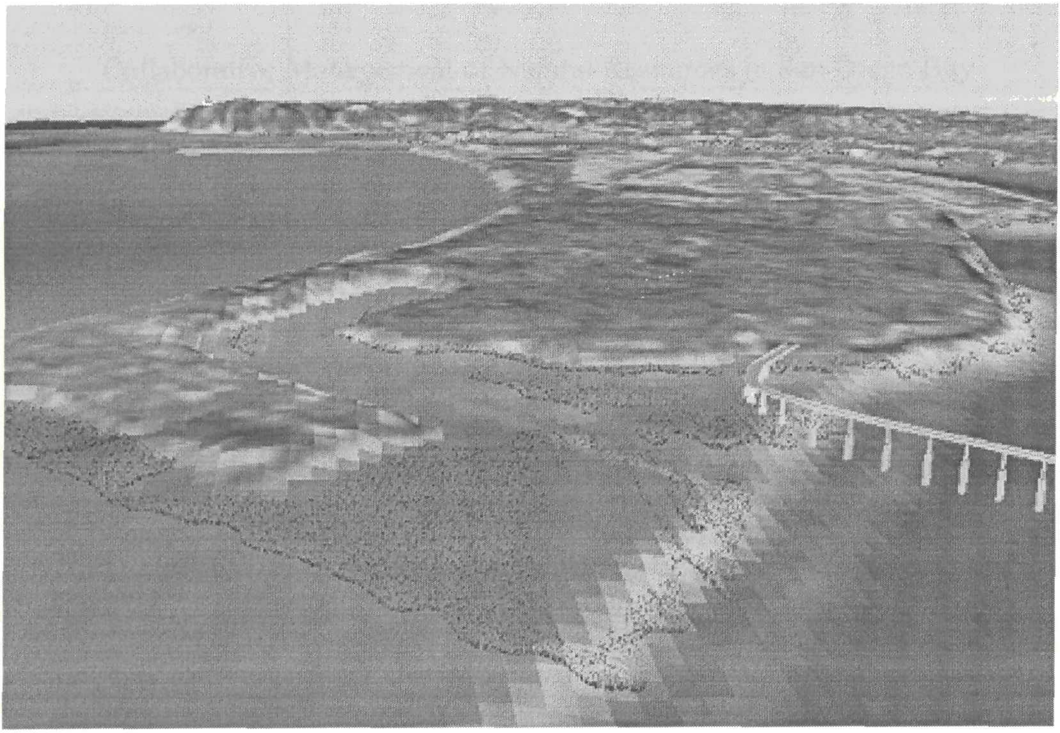

Figure 5. Bayview depiction of eelgrass beds measured with sidescan sonar by the U.S. Navy. This view is from the south end of the bay looking north across Coronado Island with Point Loma in the distance. Eelgrass bed density is proportional to the sonar returns.

tee to review our work and authorize the publication on the Bay Panel web site of source data delivered to us as well as the derived data products we produced—primarily thematic maps. This was done to improve the quality of the work product with respect to the particular needs of the Bay Panel, to ensure that we did not make unilateral decisions about what should or should not be on the Bay Panel's web site, especially concerning the release of contributed data, and to isolate us from responding directly to the competing interests and uneven technical background of the Bay Panel members. In this way the Technical Review Committee contributed to both the apparent and real independence of SDSC as a trustworthy, neutral third party with respect to derived data product content. This was a very important feature of the project and one that would benefit any similar effort. The neutrality of an information provider is essential to the acceptance of the information to such a strong degree as to warrant it being considered a prerequisite.

Sociopolitical Aspects of Information Utilization

The main sociopolitical hindrance to effective integration of scientific data into a policy development process involving competing vested interests is the fear of exposure of those data to public and alternative interpretations of it by competitors or opponents. This problem exists in science (Helly, 1998a) as well as in the public and commercial sectors and can overwhelm the technical problems of effectively using data. Unfortunately, this fear is a rational one that is based on real negative outcomes of releasing

Figure 6. Bayview depiction of stormdrain and creek output using coupled watershed and hydrodynamic models. A panchromatic SPOT image is overlaid on U.S. Geological Survey digital elevation data. Bathymetry is provided by the U.S. Navy.

data about one's activities to an opposing group. This pits special interests against the common interest. In our view, one approach to overcoming this impasse is to ensure that all data collected with public money, where not in conflict with individual rights and personal privacy (Marshall, 2000), be published in digital form without restrictions and with appropriate metadata (Michener et al., 1997). Additionally, data collected by private organizations for the purpose of supporting a permitted activity under the jurisdiction of a regulatory body should also be published as a condition of the permit. The acquisition process should be managed and effected by a group that is clearly independent of the competing special interests. The utility of this approach is exemplified by the evolution of the debate on global warming as it is informed by the IPCC (Intergovernmental Panel on Climate Change, 2000). This group has served as a neutral, third party in the highly charged political debate on greenhouse gases, and while its interpretation of data and conclusions are disputed (Demeritt & Rothman, 1999), its efforts have substantially shifted the debate from a subjective, qualitative basis to a more objective, quantitative basis.

In addition to the acquisition and publishing of data, preparing data for use in a visual model poses a number of technical as well as sociopolitical issues. Most of the technical issues have been discussed in Helly (1998b), but particularly relevant issues in contentious settings include the choice of colormaps and effects of interpolation processing on sparse data. For example, in scientific visualization, there is a commonly used red-green-blue colormap such that high values are red and low values are blue. While in scientific analysis this type of colormap is commonly used to achieve the greatest color separation (i.e., maximum dynamic range) between values being depicted, in the Bay Panel setting it was deemed to be needlessly inflammatory due to the red usually indicating danger, unless that is clearly understood and agreed to be the case.

Usually the dangerous limits for sediment contaminants are highly controversial and often the subject of litigation. Consideration of these human factor issues should be given to technically acceptable choices that improve clarity but lead to conflict. The technologist may interpret this as censorship, and so it is a delicate issue and a challenge to the balance of independence versus effectiveness. For example, is a technically correct but disregarded product useful? While there is a considerable literature on effective methods of visualization (Tufte, 1974, 1990), the real issue in this case turned on whether or not the objection to the use of red constituted censorship and whether it therefore violated the neutrality of SDSC's role. This is a delicate issue and not a trivial one. In this case it was decided that since the initial colormap choice was arbitrary then the use of another colormap was not a substantive change with respect to the accuracy of the visual model and orange was substituted for red.

We also discovered that there was a very strong negative reaction to any method of displaying sediment chemistry data that involved continuous interpolation based on discrete sampling such as bottom grabs or cores (see Figure 3). We developed this approach to display an inferred or interpolated distribution of sediment contaminants based on discrete samples as part of our research in developing effective methods of visualizing different types of data such as discrete, continuous, and categorical. We chose to display the interpolated data as translucent symbols, while the actual observed value and location were displayed using opaque symbols. The idea was to ensure that the viewer recognized that there was a difference in the nature of the data being displayed. However, the suggestion of continuous dispersion of a contaminant across sampling sites was highly contested, and since there were no empirical data to validate the interpolation, we eliminated it from the plots. Figure 4 depicts such a method applied to bird abundance data and this was less controversial since the goal was to get a sense of the connectedness of the bird habitat and traffic routes based on spatially indefinite observations made by an observer counting birds in their vicinity.

Discussion

The IT components we have discussed in this article can be applied to many settings where the problem of collaborative resource management or conflict resolution can be aided by data sharing and a common framework of problem articulation and description (McFadden, 1994; Finkel, 1998). During the San Diego Bay Project, although readily available, these capabilities were underutilized for a rather surprising reason that we think of and refer to as the *ambiguity-of-ignorance* syndrome of groups in which there is no fundamental decision-making responsibility and little or no accountability. This somewhat infelicitous phrase is substituted by others with "fact-free decision-making" or the "ignorance is bliss effect" that apparently recurs in sociopolitical conflicts but is difficult to document or quantify since individuals with vested interests rarely care to go on record about it. Without external pressures to address particular questions but charged only with the function of consensus building, the Bay Panel consistently avoided asking questions that could be answered from data. It is our view, based on our discussions with colleagues, that this kind of limitation is actually quite common and found by others in similar situations.

Similar behavior is described in an interesting study conducted in Hawaii by faculty and students at the University of Hawaii in which decision-support techniques were applied to the problem of reallocating irrigation water that became available after the demise of the sugarcane industry (Ridgeley, Penn, & Tran, 1997). Consider the following excerpt from that paper:

> Prior to the completion of that report, we wanted to present the analysis to the full [commission]. . . . However, citing the political sensitivity of the case, and speculating aloud that attending such a session might later make the [commission] vulnerable to charges of bias, the State deputy attorney general serving as counsel to the commission for the case advised them to decline the invitation. It is further indicative of the contextual challenges to the use of [these] methods that [commission] staff members originally also declined the invitation, and later agreed "to participate" under the proviso that they would not say anything!

We have substituted bracketed words for expressions that require more context than is necessary to make the point. The issue in Hawaii was already pointed and near or at the stage of litigation. However, the reaction to potentially receiving additional information is nonetheless remarkable from a rational perspective and clearly represents information avoidance. The heart of this effect may lie in the nature of individual response to direct conflict in the face of a negative outcome, as described in Ritov and Drory (1996). In a setting in which direct conflict requires an expression of individual investment in a particular outcome that may not come to pass, maintenance of ambiguity is a preferred strategy or condition for avoiding individual loss or accountability for loss. It is difficult to avoid considering how this individual reaction may be amplified by corporate or organizational interests.

Since information about the natural system being managed in some cases limits flexibility in negotiation and confronts the group with evidence some members would prefer to ignore, there is a strong disincentive to using the measured data above and beyond the technical considerations discussed above. This may explain why so little environmental monitoring data is actually used in decision making.

This is a fundamental problem for IT implementers and should be considered in the development of all types of decision-support systems, not just those for ICZM. While the data repository was used by members of the panel individually, in only one case was it used by the panel as a whole to determine a subsequent field-sampling program. This was when the sediment chemistry maps were used to prioritize the follow-up sampling. However limited, this is exactly the kind of decision-support we had envisioned, and it clearly demonstrates the utility of this approach. In addition, there was and continues to be frequent access to the web site by a wide range of users including students, consultants, and agencies. This type of use is also a measure of success even under the *ambiguity-of-ignorance* limitation. Although the group as a whole avoided issues that could be answered by existing data, the data and thematic maps were used by individuals and it was clear that many found them useful in understanding the condition of the bay.

It is held that the lack of effective IT is a weakness in ICZM approaches (National Research Council, 1994). Our experience indicates that although this is true, IT must be applied to well-defined problems in a setting in which decision-making authority desires information products and in which they can be developed and exposed in a neutral and objective forum. Toward this end we would recommend that any approach to ICZM consider including the following components in the policy development process:

- an independent, verifiably neutral, technical organization responsible for the production of objective information from environmental monitoring and scientific data;
- a technical review group with responsibility for vetting the information from the technical group and for presenting this information in the policy discussion;
- a process for the development of clear and explicit questions to be addressed by the technical organization and to be put to that organization by the technical review group;

- publication of all source and derived data used by the technical group in developing and presenting its analyses.

Notes

1. Letter from the PCAST to President William J. Clinton, Executive Office of the President, President's Committee of Advisors on Science and Technology, Washington, DC, December 6, 1996.

2. Conducted and moderated by Mitch Perdue, U.S. Navy Southwest Division, San Diego.

3. Copies of these can be found at the Scripps Institution of Oceanography Library, La Jolla, CA (http://www.sio.ucsd.edu/loc_services/).

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