Integration of Multimedia Cartography, GPS, and GIS to Evaluate Environmental Policies: Results of a Pilot Project in Massachusetts

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1. Introduction

The topic of this presentation is the use of geographic information technologies as a tool to evaluate the effects of environmental protection policies, facilitate the public's access to government information, and assist researchers in the exploration of historical databases. In particular, I will discuss the results of a pilot project involving the creation of a web-based geographical database concerning environmental protection policies in coastal Massachusetts.

2. The Chapter 91 pilot project

The Department of Environmental Protection (DEP) is the agency responsible for protecting human health and the environment in Massachusetts. The Wetlands and Waterways Program, part of the Watershed Management Division, is the office within DEP in charge of regulating human activities in coastal and wetlands areas. One of the responsibilities of the Wetlands and Waterways Program is the administration and enforcement of the Public Waterfront Act (Chapter 91).[1] Designed to protect public rights in Massachusetts waterways and adopted in 1866 (the first program of its kind in the United States), the main purpose of Chapter 91 is to protect the environment, while at the same time protecting the rights of property owners and ensuring that the general public receive some benefit from the structures or activities licensed. Under Chapter 91, license or permits must be obtained in order to place new structures or fills, change the use of existing structures or fills, and dredge in tidelands, great ponds[2] and non-tidal rivers and streams in the State. The license review process accomplishes these objectives by ensuring that projects do not interfere with navigation, are structurally sound, provide proper public purposes, do not significantly interfere with public rights and the rights of adjacent waterfront property owners, and will not adversely affect natural resources (or, if they do, that public benefits will outweigh these damages). Examples of structures that require Chapter 91 authorization include piers, wharves, floats, retaining walls, bridges, and dams.

Since 1866, the Wetlands and Waterways Program has issued about 20,000 Chapter 91 licenses and permits. This material is currently available exclusively on paper. [3] Licenses are numbered progressively and their location is marked on various USGS small-scale maps. The information on the licenses, usually composed of text and graphics (a large-scale map and detailed engineering plans), is retrieved whenever needed by personnel at the Boston's DEP offices. A typical case (see left side of Figure 1 below) might involve an individual who asks for a permit to build a pier

[1]: Information on the program is available at *www.state.ma.us/dep/brp/ww/rpwwhome.htm*
[2]: According to the DEP definitions, great ponds are "water surface areas of 10 acres or more in their natural state" (from the agency's web site).
[3]: To my knowledge, DEP does not consistently keep copy of applications that have been denied.

on his or her property. To gather the information needed to make a decision, DEP officials must first find the location of the property on the appropriate map, then look for the progressive number assigned to licenses issued in the past to that property, and finally pull up the licenses one by one from large file cabinets. This process can be very slow (a license can take 6 months to get approved), and in general does not serve the general public efficiently and effectively. Waiting times can be even greater, as when local governments, businesses, commercial operators, civil engineering firms, or researchers, ask for all licenses issued in a certain community or for a large property (the Boston harbor, for example) since the beginning of Chapter 91.

In order to improve the current situation, the University of Massachusetts at Boston has received a grant from the Wetlands and Waterways Program and the United States Environmental Protection Agency (EPA) to design a prototype digital database of Chapter 91 licenses and permits. The geographical extent of the prototype is limited to New Bedford, a city with a long and diverse industrialization history, and to the Pleasant Bay area, a rural area on Cape Cod. Together, these areas account for about 300 permits.
In this presentation, I will discuss the New Bedford part of the project, by far the most interesting. At the time of this writing (May 2001), the prototype has been almost entirely completed, and DEP is considering extending it to the entire State.

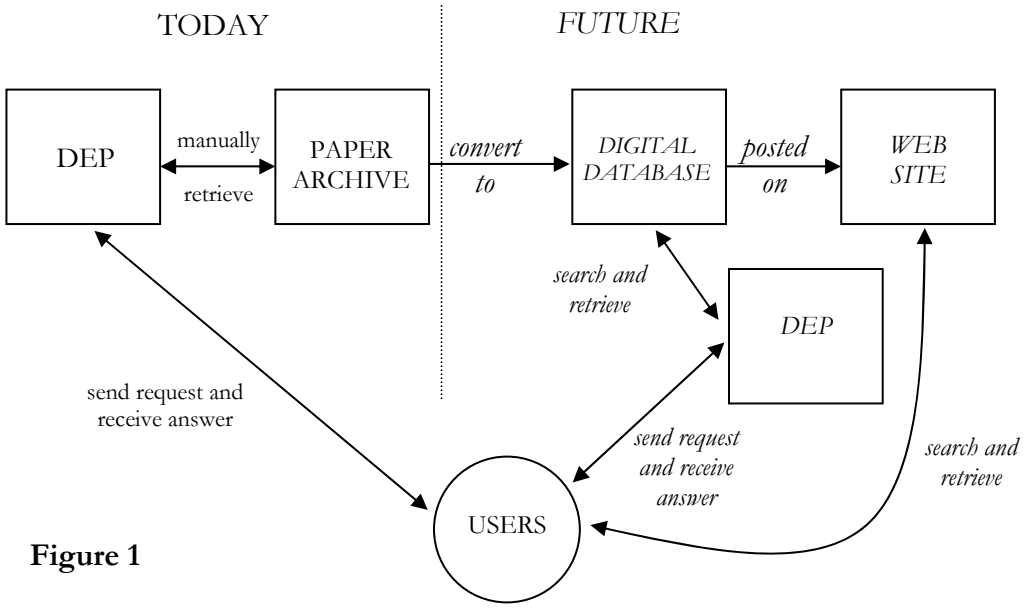

Figure 1

The project involved the conversion of paper information to a digital format, the creation of a geographical database, and the design of a web site that the public can access to retrieve Chapter 91 information (see right side of Figure 1 above).
Once implemented, the project will not fundamentally change the licensing process. The public will still need to fill the required forms, prepare the maps and the engineering plans, and submit them to DEP (although this could conceivable be done online). DEP will then conduct its decision making process based on the agency policies. What will change is that the relevant information will be accessed much faster, and that the process has the potential of being more transparent, because the public will be able to access the same digital database DEP officials use. For DEP there is an additional, important advantage: the digital geographic database will facilitate the enforcement of existing policies. The agency believes that several built-up structures have never been licensed—and we have witnessed this fact during fieldwork in New Bedford and during visual exploration of orthophotos of coastal Massachusetts. A digital geographic database

will make it easier to enforce Chapter 91 regulations, and the fact that is available on the Internet guarantee at a least a certain degree of public control.
While not replacing entirely the old way of obtaining a Chapter 91 permit, the web site will constitute a convenient alternative for those with access to the Internet—nowadays a large part of the United States population.[4] In the prototype developed, users can query the database clicking on a map, entering an address, or searching by keywords (structures built, public benefits, date). Database search capabilities on the web site are designed to answer questions from Permit Applicants ("What permits have been issued at my address?"), DEP or other agencies ("What structures have been licensed on the Boston harbor?"), and from Researchers ("How did human activities changed the coastline? Where were industrial activities located in the early 20th century? How have waterfronts developed?"). Together with a multimedia cartography product (briefly described later) the web site will facilitate the study of the impact of the program over time: a task very difficult to accomplish now.
Before proceeding to describe the project in more detail and discussing its components, I will present a brief overview of the history of New Bedford, the area chosen for the pilot project. The Chapter 91 database reflects quite well the different stages of the city's history, and can be used to study the spatial and temporal evolution of its coastal development.

3. New Bedford

3.1. Historical background

New Bedford has played an important role in the history of New England, with a long tradition of tolerance, dating back from its beginnings in the 17th century. The first settlers came from Plymouth looking for religious freedom and later the city was a station on the Underground Railroad for runaway slaves (Frederick Douglass spent two years here). Many—if not most—of today's citizens are of Portuguese and Cape Verdean descent, and the city has Portuguese-language newspapers and a Cape Verdean historical society.
New Bedford also has an interesting economic and social history. Writing at the time of the "golden age of whaling" (mid 19th century), Melville could so describe the city in *Moby Dick*: "Nowhere in all America will you find more patrician-like houses, parks and gardens more opulent, than in New Bedford." All this wealth was due to the whaling industry, that made of New Bedford the fourth tonnage district in the United States in 1845, behind only New York, Boston, and New Orleans (Pease 1918: p. 37). In 1918, "those who visit New Bedford to-day will see such a city as Melville saw not ... The city has made the land tributary to her wealth ... The old ships that crowded the wharves have gone. So have the industries allied to whaling ... A new city has been builded (*sic*)" (p. 7). The new city based its economic prosperity on the textile industry, which had developed starting in the last decades of the 19th century. But this new prosperity was to be short-lived. In 1937, at the peak of the Depression, New Bedford's 32% unemployment rate was the second highest of any city in the United States (Georgianna and Aaronson, 1993: p. 147). Population fell from over 120,000 in 1920 (the record year for the city) to 110,000 in 1940 (Gibson 1988). The city has never really recovered from economic depression: in a recent report, the United States Department of Housing and Urban Development (HUD) identified New Bedford as one of the "places left behind in the new economy" (1999), one of only fifteen "doubly burdened" cities in the Northeast. The "burdens," in the New Bedford case, were high unemployment rate (8.1% in 1998) and persistently high poverty rate (estimated to be 20.1% in 1995). The city has also continued losing population (from 99,922 in 1990 to 93,768 in 2000, according to the U.S. censuses), following a trend that dates back several decades.

4: As of March 2000, the Internet penetration rate in the United States was equal to 42%, and has increased since (United States Internet Council).

3.2. Chapter 91 in New Bedford

The first permit issued in New Bedford and contained in the Chapter 91 prototype digital database dates back to 1883. It was granted to the "Philadelphia and Reading Coal and Iron Company" for the extension of a wharf. As already mentioned, these are the years of economic boom for the city, a boom in large part due to the development of the textile mill industry (cotton, especially) that started in the second half of the 19th century, and peaked in the 1910s and very early 1920s. Railroads developed, banks opened and textile companies flourished. The database reflects this development: 110 permits were issued in the years between 1883 and 1925, mostly to private companies and mostly between 1905 and 1925.

Competition from the Southern states, obsolescence of equipment, and unprogressive management brought the textile industry's expansion to a halt in the early 1920s. The Great Depression gave a final blow to the industry and to the city. It brought about two decades of recession, approximately from 1925 to the end of World War II. Most licenses in this period are issued to the government or to private individuals, very few to private companies.

In the last fifty or so years, several attempts have been made to recover from the recession, and the city's economy is now much more diversified than it used to be. The construction of a hurricane barrier in the 1960s and of new terminals, aimed at revitalizing the city's maritime tradition, has contributed to the redevelopment of the fishing industry. A business park has been built and is now a major economic resource. Starting in the last few years, the city has also marketed itself as a cultural tourism destination. The waterfront area has been extensively renovated, and in 1996 thirteen blocks adjacent to the waterfront were designated as the "New Bedford Whaling National Historical Park," in an attempt to capitalize on the golden age of the city. The Chapter 91 database shows the city's attempts at redeveloping the waterfront. Permits were issued in equal parts to individuals, private companies, and the government, for activities ranging to the construction of a new marina to the renovation of the waterfront and the redevelopment of the harbor.

All this information can be easily extracted from a simple database of Chapter 91 data in New Bedford. As I will show, a geographical database adds the possibility of spatially based explorations, and a multimedia cartography product can effectively combine space and time for additional insights into the data. Putting these applications on the Internet allows for easy dissemination of the information, and let the general public explore the data following a personal itinerary.

4. Project implementation

The implementation of the Chapter 91 project will be described only in its main stages in this paper, but will be discussed thoroughly in my oral presentation. The topics discussed here are intended to provide background information concerning especially the historical parts, the rational for the project, and the design phases of the prototype.

4.1. General remarks

From an operational point of view, the main difficulty we encountered in completing the project concerned the graphic part of the licenses (the large-scale maps). As already mentioned, each license is composed of textual information and of a series of maps at different scales; the maps show the location of the structure being licensed, a sketch of the surrounding area, and engineering drafts complete with precise measures and detailed plans of the structure to be built. In order to convert this information into digital data, text and maps needed to be treated differently from each other. As far as the maps are concerned, most problematic were the earlier licenses. Until about the 1920s, there were no general guidelines for designing the maps: several

of the maps pre-dating this period are in color, of various size, and often in poor conservation state. Since the 1920s, all maps are in black and white and in a standard Letter format (8.5 by 11 inches). This makes for often drab designs, but certainly facilitates digital conversion. However, in the city chosen for the pilot project—New Bedford—many licenses were issued before the standardization of the format.
Another issue is the poor state of conservation of several of the USGS maps, that have been used for decades and can today be handled only with extreme care (some are even under glass). A digital database could solve the serious conservation problems of both the text and graphic parts of the licenses, while also eliminating the need for the paper USGS maps.

In addition to its obvious relevance to DEP, a statewide Chapter 91 database could be very useful to environmental policy researchers, government agencies, non-profit organizations, and the public at large, as a tool to evaluate the effects of over 100 years of coastal environmental policies in the Commonwealth of Massachusetts. To give just an example, much of what is today's Boston used to be under water in areas that have been filled over the course of the last few centuries. Starting with 1866, these activities can be documented and studied using the Chapter 91 licenses; a digital statewide database would facilitate this study, which is now difficult because of the conservation status of the licenses and because of the obsolete recording system.
But why a *geographic* database? Because the entire licensing process is geographically-based, and so are to a great extent the outcomes of the decision-making process: what is already at a certain location, in terms of natural or built environment, largely determines what can be built or what can be done at that location. The digital database needs therefore to be geographical. The obvious solution is of course to build a GIS, and indeed we created and put on the Internet one. The GIS, however, is limited in its dealing with the temporal dimension of geographic information. In order to study the dynamics of the development of coastal New Bedford, we integrated the GIS with a multimedia cartography product, which uses cartographic animation, images, old and new maps, graphs and charts to provide the interested researcher with the additional necessary information.
The next section describes the six principal phases of the project.

4.2. Project phases

Phase 1 – Quality control

This stage required preparation of a document detailing quality control procedures for the capture of the textual and graphical part of the licenses at DEP, the GPS fieldwork, and the creation of the geographical database for use in the GIS and in the web site. The only factor that needs to be mentioned here concerns the horizontal accuracy requirements for the project. To be consistent with statewide GIS data (*www.state.ma.us/mgis*), the RMS error had to be within 3-5 meters. This implied the use of differential GPS, discussed in the next paragraph.

Phase 2 – Global Positioning System (GPS)

One of the main challenges of the pilot project was to georeference the structures or activities described in the Chapter 91 permits. Over the course of a century, the city of New Bedford has dramatically changed: new roads have been built, structures have been demolished, and areas have been filled. To identify the location of certain structures using the maps in the licenses, and thus reconstruct the history of coastal development in New Bedford, proved at times very difficult. Another serious problem derives from the fact that each map is, especially until the 1920s, a substantially unique specimen: dimensions varies widely, some maps are nothing more than a sketch, positional accuracy is often very poor, and several maps have no scale at all. Even in more recent years, DEP standardization efforts notwithstanding, it is often difficult to identify the exact location of many structures, especially the smaller ones. In order to georeference the licenses, we then decided to use differential GPS. This decision was based on three main factors:

- At the beginning of our work, we learned that the DEP GIS office had already georeferenced some of the Chapter 91 permits on an ArcInfo database. However, the data entry recorded the residence of the permit applicant, which often did not correspond to the location of the licensed structure—and of course correspondence was even more infrequent in the case of private companies or government agencies. The result was that the DEP GIS database was virtually useless: each license had to be georeferenced on a case-by-case basis;
- Only visual inspection could be used for the very old licenses, because the city had greatly changed. Visual clues in the contemporary landscape made it possible to locate several, although not all, of the old structures;
- In the hypothesis of a statewide extension of the pilot project, half-a-meter resolution orthophotos could be used as an alternative to the GPS. These orthophotos, produced by the Massachusetts State's GIS office (MassGIS), can be freely downloaded from the MassGIS web site (*www.state.ma.us/mgis*). But the feasibility of using orthophotos instead of a much more expensive GPS fieldwork needed to be tested. Our sample of 300 licenses indicate that probably 80-90% of them can be located using the orthophotos, but that for the oldest licenses fieldwork is required.

The coordinates of the points surveyed in New Bedford were collected using a Trimble GeoExplorer II Receiver/Datalogger, and differentially corrected using Trimble Pathfinder Office v. 2.70 with base files downloaded from the University of Rhode Island GPS station (*www.edc.uri.edu/rigps*). The points were chosen on the basis of one criteria: to be easily identifiable both on the field and on the licenses. Some points are associated to several permits, because—as already mentioned—more than one license is often issued at the same location over the course of the years. Finally, during the survey we took pictures of the sites and the structures using a digital camera, and used the pictures in the multimedia presentation.
The accuracy of the points surveyed, between 1 and 2 meters, fell well within the required standards (3-5 meters). It should be noted that such a high level of accuracy is unnecessary given the quality characteristics of the maps contained in the Chapter 91 project. But high accuracy is required of any GPS data to be included in the State's GIS system, and therefore we complied with it.

Phase 3 - Geographic Information System (GIS)

The location of the GPS points surveyed on the field was subsequently exported to ArcView 3.2 for the creation of the GIS database. The contents of the GIS will be shown and discussed during the presentation, but briefly, they include digital orthophotos, USGS 1:24,000 base maps, and the city's road network. The most important component is, of course, the point coverage containing the location of the licenses, which are georeferenced using the Massachusetts-Mainland State Plane coordinates. Associated to each point there also is a scanned image of the large-scale map included in each permit. Finally, some of the structures (the largest ones) were digitized and represented in the GIS as they appear on the licenses.
The database created contains information on the applicant, the date the permit was issued, the activity performed (construction, maintenance, etc.), and the type of structure (pier, wharf, etc.).

Phase 4 – Data conversion

The conversion of the graphical and textual components of the permits from paper to a digital format was handled as follow:

- *Textual materials*. The text of the permits was captured in two formats, as a scanned image and as Word file. The Word file is to be utilized on the web site to search by keywords (e.g., type of structure built). The scanned images can be viewed and downloaded from the web site;
- *Graphic materials*. The maps in the standard Letter size (8.5" by 11") were scanned using readily available flat scanners. The larger plans, above these sizes, were imaged using large-scale scanners.

Phase 5 – Web site

The web site was built using ArcIMS. The site contains the GIS database, and the scanned images and text files described in the preceding section. At this point (May 2001), the information is stored on an Oracle database, and is maintained on a server at the University of Massachusetts at Boston. As already mentioned, the database can be searched by keywords (structures built) and geographically.

In addition, the web site provides data on the "public benefits" associated with some licenses. This is information that is not explicitly contained in the permits, but was gathered by DEP for a sample of the most recent licenses. Public benefits include activities such as walkways, benches, public restrooms, facilities of public accommodation, restaurants, conference rooms, etc.. Screenshots from the web site will be shown during my presentation, together with a discussion of the stages of its creation.

Task 6 – Multimedia Cartography

The final part of the project consisted in the completion of a multimedia cartography product, created using Macromedia Flash 5. The main feature of the multimedia is the cartographic animation of coastal development in New Bedford. The animation is multiscale, in two ways. Because development has occurred mostly on the waterfront, this area is shown at a larger scale than the rest of the city. And the animation is multiscale because it shows both the large-scale maps and, for some of the licenses, the engineering plans describing the structure to be built. The location of the structures was digitized and animated to show when and where the largest structures were built. The large-scale maps give an overview of the shape of the coast at particular times, like snapshots of New Bedford at the time the license applications were presented. Together, the animations provide information on where development occurred at particular times in the history of the city.

The multimedia includes also a series of graphs and charts that the viewer can interactively explore to study the database (i.e., what structures have been built when, who are the applicants), an introduction to Chapter 91, an overview of the history of New Bedford, a series of pictures taken at the GPS survey sites, and scanned maps from the licenses. The multimedia is available both on the Internet and as a stand–alone CD-ROM.

5. Conclusions

The Chapter 91 pilot project tested the feasibility of transferring a paper archive—an historical database of construction permits—to a digital format. From the point of view of DEP, a statewide digital geographic database of licenses will serve the public better and will also facilitate the decision-making process for the agency officials.

From a research point of view, the project involved the integration of different geographic information technologies: GPS, GIS, and multimedia cartography. The design of a web site with geographic search capabilities completed the project. The most interesting part was to integrate the GIS with the multimedia. The lesson we learned is that together the two provide a formidable suite of tools: the geographic query capabilities of the GIS, coupled with cartographic animations, images, pictures, and videos, can help researcher gain additional insights into the study of historical databases. On a negative note, however, the integration must be done totally from scratch. Today's GIS is not ready to deal with multimedia applications.

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