Restoring Water Quality in Greenwich Bay: A Whitepaper Series

Paper 2: Greenwich Bay and Its Watershed: Spacial Data for Planning and Environmental Management

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Sea Grant Rhode Island

Greenwich Bay Initiative Warwick, R.I. Bring Back The Bay

Greenwich Bay and Its Watershed: Spatial Data for Planning and Environmental Management

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Introduction

It is impossible to make responsible land management decisions without current and accurate data about the environment. In a municipal planning context, the fundamental unit of land management is the individual parcel of property defined by plat and lot boundaries. Land use activities on individual parcels can collectively cause significant impact to the environment. For example, leachate emanating from failed septic systems on individual parcels contributes to the nutrient enrichment of Greenwich Bay. The slow incursion of development on individual parcels nibbles away at forest and wetland habitats that support biodiversity. For informed and effective decision-making, the land manager must have an integrated picture of how individual parcels of land are used, their geomorphological setting (soil, slope, aspect), and the legal and environmental constraints to potential land uses. The information management technology that is used to integrate and assess spatial (map) data are geographic information systems (GIS) (Burrough and McDonnell, 1998). The baseline data required to develop a land management system of parcel-level accuracy are not, however, readily available. The objectives of our project were to (1) design and develop a prototype GIS database that would give planners, environmental scientists, and engineers information with sufficient breadth and detail to make informed decisions for land use management; and (2) assess the strengths and weaknesses of the prototype database and recommend a data system that could be implemented for the city of Warwick, R.I.

In April 1996, the Rhode Island AquaFund program in the R.I. Department of Environmental Management, the city of Warwick, and the University of Rhode Island (URI) natural resources science department formed a partnership to develop a prototype parcel-based information system for a 15 square kilometer (5.8 square mile) region of the Greenwich Bay watershed between Greenwich Bay and T.F. Green Airport (Figure 1). This area was chosen as the study site for a number of reasons. Land use in this region is believed to be a significant contributor of nutrients and pollutants to Greenwich Bay. The area contains land uses representative of coastal Rhode Island communities. The Warwick Sewer Authority is planning on expanding the municipal sewer system in this area and this affords the opportunity to assess the utility of the large-scale GIS database for engineering applications.

The city of Warwick had spatial data resources typical of a Rhode Island community. There was a substantial GIS database available from the Rhode Island GIS (RIGIS) program (August et al., 1995) and this included information on soils, land use, wetlands, geology, infrastructure, and more. However, these data were developed primarily from 1:24,000 scale sources and did not have the resolution required of a parcel-based information system. The RIGIS wetlands data, for example, had a resolution of 0.1 hectare (0.25 acre). The RIGIS land use data had a spatial resolution of 0.2 hectare (0.5 acre). Although the RIGIS data strive to adhere to National Map Accuracy Standards (Thompson, 1987) for positional accuracy, lines and boundaries could still deviate from their true location by as much as 12.2 meters (40 feet). This is an unacceptable level of error in a parcel-based information system. The RIGIS data would be a valuable supplement to the parcel-based information system but did not have the accuracy or resolution to serve as the foundation of the database.

The parcel data for the city of Warwick consisted of 186 map sheets of lot delineations mapped at 1:1,200 scale. The drawings do not have a reference system of geographic coordinates printed on the maps. The parcel maps appeared to have acceptable spatial accuracy *relative* to the locations of lots and plats to one another. But, without a geographic reference system indicated on the maps, there was no way to ascertain the *absolute* accuracy of the lot lines, and therefore could not be used as the plani-

Figure 1. *Location of the study area in Warwick, R.I.*

metric basis for the GIS database (August et al., 1990). So we chose to develop a new planimetric base map based on digital orthophotography and this would serve as the foundation of the Warwick prototype GIS database.

Digital orthophotography is aerial photography that has been scanned into a computer and manipulated to remove the distortions caused by airplane tilt, optical aberrations in the camera, and scale variation caused by irregular topography (Bolstad, 1992). The photogrammetric processing of the scanned photograph to create the orthophoto requires accurate elevation data for the region and well-surveyed ground control points that are readily identifiable in the photo images. The process of converting the aerial photograph to an orthophoto adjusts the location and spectral content of individual pixels in the digital image to match their true location based on the ground control points and the terrain model (Hohle, 1996). The final product is a digital image that has the clarity and resolution of the original aerial photograph, is free of distortion, and is stored in the computer in a geographic coordinate system. Large-scale digital orthophoto data have all the characteristics required of a planimetric base for a detailed parcel-based GIS.

The workplan for the development of the Warwick large-scale GIS database consisted of the following steps:

1) Create an orthophoto planimetric base map.
2) Convert parcel data to digital form using the orthophoto as a spatial reference.
3) Develop collateral data for planning and environmental management applications.
4) Consolidate spatial data into a single GIS system.
5) Install GIS systems at various municipal offices in Warwick and provide training in their use to land managers.
6) Evaluate the utility of the GIS prototype database and develop a recommendation for a citywide parcel-based information system.

7) Use the World Wide Web (WWW) to distribute a sample of the prototype database to the GIS and environmental management community for assessment and evaluation.

Development of Large Scale Digital Orthophotos

The digital orthophotos of the project area needed to serve many functions. They had to be of sufficient positional accuracy to serve as the planimetric base-map for the GIS data system. They had to have sufficient spatial and spectral resolution to discern various land cover classes (e.g., wetland boundaries, houses, parking lots) that we knew would be important to planners and environmental scientists. The resulting computer files representing the orthophoto had to be small enough to store on a personal computer and work in a responsive manner with off-the-shelf GIS software. It was unclear to us what the optimal film for the imagery would be. Black-and-white (single spectral band) imagery would have the smallest file sizes and perform most efficiently on a PC platform. Color infrared imagery would be best for discerning different vegetation types. True color imagery would be easiest to interpret for nontechnical users of the data. We chose to create orthophotography in all three film types (black-and-white, color infrared, and natural color) so we could evaluate which one would serve the greatest number of users. We developed the technical specifications for the orthophotography (Table 1) and hired a consultant to obtain the aerial photography and create the digital imagery. Copies of the request for proposals for this work can be obtained at *http://www.edc.uri.edu/warwick.*

The digital orthophotography was received from the contractor in September 1996. We specified that the imagery exceed the American Society of Photogrammetry and Remote Sensing accuracy standards for large-scale maps (ASPRS, 1987) and well-defined points ($\pm$30 cm at 1:1,200 scale). To check the positional accuracy of the digital

Table 1. *Technical specifications for the aerial photography and digital orthophotography.*

Product	Specification
Aerial Photography	
Film Type	Black-and-white, natural color, color infrared
Altitude	1,100 m (3,600 feet) above sea level
Print Scale	1:7,200
Forward Overlap	80%
Sidelap	40%
Sheet-Centered	Yes
Season	Leaf off; no snow, ice, or cloud shadows
Digital Orthophotography	
File Format	TIF
Scale	1:1,200
Pixel Size	15.2 cm (6 inches)
Scene Size	3,300 square feet (approx. 1 square km)
File Size per Scene	42 MB for panchromatic, 130 MB for natural color or color infrared
No. of Scenes	15
Positional Accuracy	30 cm (1 foot)
Spectral/Band Types	Panchromatic (black-and-white, single band), natural color (3 bands, RGB), color infrared (3 bands, RGB)
Datum	NAD 1983
Coordinate System	Rhode Island State Plane

orthophotography, we used survey-grade global positioning system (GPS) technology (LaBash et al., 1997) to obtain centimeter-level accurate coordinates for 36 well-defined points in the project area. Well-defined points are those features that could be sharply identified as discrete points in the imagery. Details of how the analysis was conducted are given in Barrette (1997). We found that the mean deviation (±1 standard deviation) between coordinates obtained from the orthophotography and the 36 verification sites was 27±22 cm (10.6±8.7 inches, on-the-ground distance). This was well within the 30 cm positional accuracy we required for the study.

All three sets of orthophotography showed excellent detail and resolution (Figure 2). The color infrared aerial photography was obtained when some of the tree species had begun to develop leaf or flower buds. Although this makes it possible to identify individual crowns of specific tree species in the forest canopy, it also obscured the ground and made it difficult to see colors and textures indicative of saturated (wet) soils, an important signature for wetland delineation. The natural color aerial photography was obtained two weeks prior to the color infrared photography when leaf buds were not present. Understory vegetation and patterns of soil saturation were clearly evident in the natural color orthophotography. We therefore chose to use the natural color imagery for land-cover mapping (Barrette, 1997).

Accurate topographic information is required to make the orthophoto, and one of the useful by-products of the process is a computer file (called a digital terrain model, DTM) of detailed elevation data over the study area (digital mapping citation). This, in itself, is a very valuable dataset. Along with the digital orthophotos, we received topographic contours of the project area at 0.6 m (2 foot) intervals. These data were accurate to within ±20 cm (8 inches) and were the most detailed elevation data available for a large area within the city.

Development of a Digital Parcels Database

Conversion of the 35 individual plat maps from hardcopy to digital form was relatively simple. We used the location of granite bounds (survey reference points) from existing survey and subdivision plans as registration points (TICs). We manually digitized all the lot boundaries from the original stable-based mylars of the 35 plat sheets. The resulting polygon GIS coverage of all the individual lots on each plat sheet was stored in a “digitizer inches” coordinate system. Each map sheet contained an average of 300 lots and required approximately 15 hours to digitize, edit, encode (assign plat and lot numbers to each polygon), georeference (see below), and edgematch (align with neighboring plat maps).

A basic characteristic of a GIS database is the numeric coordinate system that is used to identify the location of points, lines, and areas. There are many different coordinate systems used in GIS. We chose the Rhode Island State Plane (feet) coordinate system referenced to the North American Datum of 1983 (NAD 83) (Schwartz, 1989) for the Warwick database because it is the standard for the engineers and planners in the city. Transformation of the digital parcel map sheets from “digitizer inches” to the Rhode Island State Plane coordinate system was a delicate process. We obtained the geographic coordinates of granite bound survey markers using a GPS capable of sub-meter accuracy. We supplemented these “known” reference points with geographic coordinates we obtained from the digital orthophotography. The TRANSFORM utility in the GIS software was used to convert the coordinate system from digitizer inches to State Plane feet. The parcel boundaries were then viewed against the digital orthophoto to check the accuracy of the transformation. If obvious errors were found in the transformed parcel coverage—for example lot boundaries bisecting buildings—we added known registration points and repeated the transformation process.

The GIS polygon representation of each individual lot was encoded with its plat and lot number obtained from the assessor’s map. Plat and lot number are used by the city departments to identify property. It was then possible to take existing digital databases of relevant information about each lot (see Figure 3) and merge them with the GIS coverage. Valuable property data on water use, sewer, and assessors information could be readily linked with the digital parcel maps. The ability to merge different datasets from one source to another is critical to a GIS database. We now had the ability to ask questions of the many different attributes for each lot and receive an answer as a map image. For example, we could ask the computer to identify all the sub-

(a)

(b)

(c)

Figure 2. *Representative images from the (a) panchromatic, (b) natural color, and (c) color infrared orthophotography.*

standard, undeveloped, unsewered lots within 0.25 mile of Greenwich Bay. The result would be a map image of all the individual lots meeting this query.

Development of a Comprehensive GIS Database

In addition to the parcel data, we developed zoning map and sewer data layers. We also consolidated existing GIS information for the project area. The RIGIS database provided excellent supplemental information on soils, wetlands, geology, and more. We also created a number of new datasets by "heads up" digitizing features directly off the digital orthophoto image on the computer screen (Figure 3). For example, an important factor in modeling water runoff in the Greenwich Bay watershed is the amount of land surface covered by impervious surfaces, such as roads, buildings, and parking lots. We were able to locate impervious areas on the orthophoto image and trace their outlines into the GIS. Barrette (1997) conducted a detailed study of the accuracy of wetland boundaries delineated from the digital orthophotos. He found that wetland boundaries identified from the digital image were just as accurate ($\pm$3.3 m (11 feet)) as boundaries measured using traditional photo interpretation methods. However, it was significantly faster to delineate wetlands using the orthophotography, compared to traditional methods using aerial photographs.

Spreading the Word

An important dimension to the Warwick GIS database prototype project was to disseminate the results of this research to as many interested people as possible. To this end, we created a WWW page that describes the project and provides access to sample imagery and GIS data. Furthermore, we have made available all the technical reports and requests for proposals (for the aerial photography and orthophotography). The Web site is located at *http://www.edc.uri.edu/warwick.*

System Evaluation

The best of GIS data systems is of little value if the decision-makers requiring the information do not have access to the technology or know how to use it. To evaluate the utility of the database, we purchased three PCs and installed on each of them a user-friendly, yet reasonably powerful, GIS software system (ArcView, Environmental Systems Research

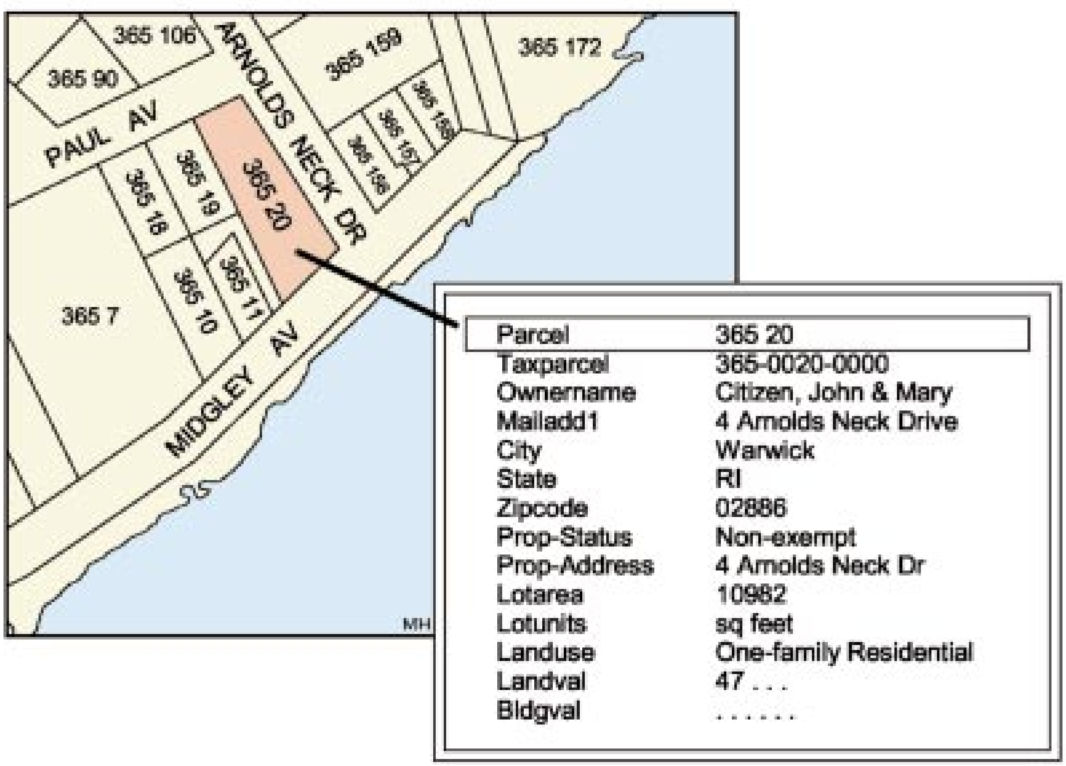

Figure 3. *Descriptive attributes for each lot and their association with the GIS representation of the lot poygon in the GIS.*

Institute, Redlands, California). We transferred the complete GIS database for the project area on each PC and set them up in the Warwick Planning Department, the Public Works (Engineering) Department, and the Warwick Sewer Authority. We provided training to the personnel at each site on how to use the GIS system and database. Three months later we interviewed the personnel at all three sites to determine how they used the technology, how useful were the datasets we created, and what could be done to improve the system.

Each of the departments utilized the technology and datasets in differing ways. For example, the planning department found the orthophotos, parcels data, and topographic information valuable for performing site plan review of new development and as an information tool at public workshops and meetings. The sewer authority, on the other hand, tracked septic system pump-outs within the pilot area and used the GIS to support the preparation of work orders. All of the departments found that the GIS could greatly improve the way they access, use, maintain, store, and share spatial information. Access to the same map data across departments was important, as well as data that had not been previously available at this scale and detail (e.g., 0.6-m (2-foot) contours). In all, 30 or so vector data layers were provided for the prototype, enabling the city staff to widely explore GIS capabilities and applications. Further, the size of the pilot area was large enough to be representative, but small enough to be manageable for the prototype database.

After careful evaluation, Warwick decided to develop a comprehensive GIS database for the whole community using the 1:1,200 scale natural color digital orthophotography as a foundation. Most users of the prototype GIS database found that the 1:1,200 scale orthophotography had the resolution and positional accuracy they required, for both planning and engineering applications. Larger scale orthophotography (e.g., 1:600) would add considerable cost to a citywide database and require significant computer resources to store and display. Smaller scale data (e.g., 1:2,400) would be too coarse for many municipal applications.

Citywide Implementation

In 1997 the city began development of a framework and approach for the strategic planning of a citywide GIS. There was an emphasis on education and awareness, early implementation planning, and discussions around the use and maintenance of the GIS. A committee consisting of a representative from every department met to address and define how GIS capabilities can and will be integrated into the day-to-day operations and service delivery of the municipality. Prominent among the many GIS applications that were identified were land use planning, utility management, and public safety. The essential GIS data to serve multiple departments and users were identified.

Color aerial photography with similar specifications to the prototype model was taken in April 1998. Development of digital orthophotos, 1:1,200 scale photogrammetric mapping of planimetric features (e.g., buildings, curbs, utility poles, fire hydrants), and 0.6-m (2-foot) contours is ongoing. Conversion of the remaining 151 parcel maps is also planned as part of this phased approach.

Conclusions

We learned many valuable lessons on this project.

- For large and complex GIS system development projects, such as building an information system for Warwick, a prototype study is extremely helpful. The technical specifications of the city-wide database are much more refined because of what we learned in the pilot project.
- True color orthophoto imagery serves the information needs of the greatest diversity of users. From the true color imagery we can extract panchromatic (black-and-white) images for use when performance is also an issue.
- The 1:1,200 scale, 15.2-cm (6-inch) pixel size, 30-cm (1-foot) positional accuracy, and elevation data accurate to $\pm$20 cm (8 inches) appears to be a satisfactory scale for most users of the database.
- Digital plat and lot data are widely used by all departments within the city and are a critical element of the database.
- In a municipal context, the GIS is used many ways: simple queries of large, complex databases; records management; basic map-making; emergency management and public safety activities; and relatively complex spatial analyses.

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