Digital Shorelines for Boston Harbor

Automatic methods, with some manual intervention, convert images into digital maps more rapidly and portray complex features more accurately than previous methods.

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Computerized digital mapping of coastal waterways and their environmental conditions requires data files that define the coast and provide a frame of reference for other data being mapped. One way to improve the resolution of available digital shoreline data is by unifying data from the most recent National Oceanic and Atmospheric National Ocean Survey (NOAA/NOS) charts.

Shoreline files are in vector format — *i.e.*, they are in the form of sets of data points that define connected line segments. Compiling them might seem a relatively simple and straightforward matter, but the increasing need for digital shoreline data has pointed up variables and problems in their acquisition and use. For example, the definition of the shoreline as the boundary between land and sea poses special problems:

- Which tidal stage is chosen, and with what corrections?
- Should high-water, mean sea level or low-water based datums be used?

The latter will encompass features like sand bars and mudflats that are only intermittently exposed.

In addition, geographical information systems (GIS) and some gridding and mapping systems require completed shoreline "polygons" — *i.e.*, the shoreline must form a closed loop, which lead to another set of problems:

- In the case of streams and canals, how far upstream should artificial closures be drawn?
- How many man-made constructions (like bridges, docks and jetties) should be shown?
- What resolution is needed for given purposes (neither too small nor too great)?

Improved Resolution

Current coastal engineering demands greater resolution (accuracy) for shoreline projects. For example, projects in Boston — including the Central Artery/Tunnel Project — require both the highest resolution possible as well as the ability to easily use the information in digital

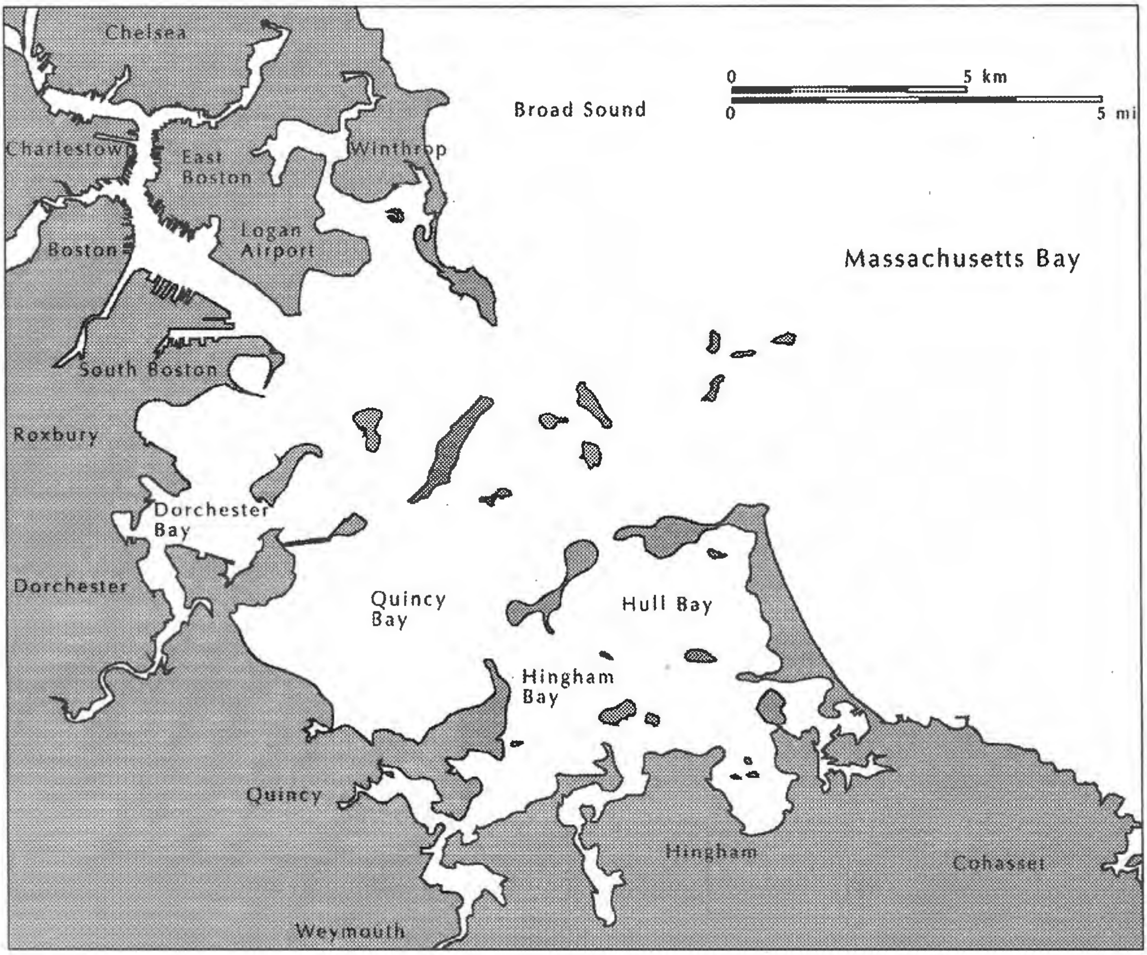

FIGURE 1. Location map for Boston Harbor, modified from the NOAA Massachusetts Bay Nautical Chart.

form. New and existing shoreline data for the greater Boston Harbor area (see Figure 1) have been compiled into a new shoreline file by digitizing and combining the most recent charts. Up-to-date digital shoreline files are required to support coastal GIS displays that combine data from multiple sources. The new Boston Harbor data set can then be compared with earlier shoreline data sets — such as the Massachusetts Coastline (MCOAST) compiled by MassGIS from U.S. Geologic Survey (USGS) digital line graphs (DLGs) with supplementary digitization from USGS topographic maps; NOAA's Medium Resolution Digital Vector Shoreline (NMRDVS); and recent, high-resolution orthophotographic coverage — to reveal changes due to coastal construction as well as discrepancies that need resolution.

NOAA/NOS hydrographic charts of Boston Harbor were used (NOAA/NOS charts #13270 and #12272) to create the new shoreline file.[1,2] The new shoreline data set — hereafter referred to as BHS (Boston Harbor Shoreline) — combines those two charts, the most recent and detailed nautical charts available. These charts are both dated 1996 and have scales of 1:25,000 and 1:10,000 (Inner Harbor), respectively. As is often the case, the chart dates refer to the date of the navigational information. However, the shoreline data are probably older but their actual dates are not stated on the charts.

One other application of computerized digital mapping is to aid in the study of chemical contaminants in bottom sediments and contaminant transport in Boston Harbor and adjoining parts of Massachusetts Bay. Active re-

TABLE 1.
Representative Autodigitization/Autovectorization Software Products

Software Product	Notes/Features	Manufacturer
ABICAS	Free-standing system	ITA
ArcScan	Works within ArcInfo system	ESRI
AutoCAD Map	Works within AutoCAD system	AutoDesk
Autotrace	Part of MapInfo GIS system	MapInfo
Infotec, LT4X	Free-standing system	Pace
MapFlex 2000	Free-standing system	Audre
Vectorizer	Part of Microstation GIS system	Integraph
Vtrak	UNIX-based black & white or color system	Laserscan

search in this field is facilitated by digital mapping.[3-5]

Shoreline Definitions & Issues

Shorelines in the United States are a federal responsibility, which for domestic purposes is handled by NOAA/NOS and its contractors.[6] The terms *coastline* and *shoreline* are considered synonymous according to a leading treatise on coastal mapping.[7] Both terms are defined as the line of contact between land and selected water elevations. The term *coastline* occurs in several recent Congressional acts, such as the Coastal Zone Management Act. Most commonly it is often used to signify the permanent high water boundary. For more generalized quantitative measures, *coast* or *coastal zone* tend to be employed, whereas *shoreline* refers to more detailed delineation. *Baseline* is a term used in international law to indicate the reference line from which the marginal sea and other offshore zones are measured. The official U.S. baseline is the mean low water (MLW) line along the coast, which includes tidal flats.

For tidal waters the shoreline is normally mean high water (MHW). For non-tidal waters it is normally the mean water level. MHW and MLW refer to the average high and low tidal levels for a 19-year period, not necessarily the most recent one. Mean lower low water (MLLW) level refers to the lower of the two daily tidal levels in those areas where diurnal tides dominate. A corresponding definition applies to mean higher high water (MHHW). A 1980 international convention has stipulated that *lower low water level* be used as the standard for all soundings on nautical charts, since it provides the lowest water levels likely to be encountered in navigation. (Data on the lower low water level are included in the NOAA/NOS Boston Harbor charts.)

Shoreline data are used for legal, administrative, regulatory/cadastral, as well as state and federal sovereignty purposes (such as determining federal-state boundaries). In addition, they are used to aid maritime navigation (as in nautical charts and bathymetric maps), and to facilitate the assessment of coastal flood zones, erosion and subsidence. They are also needed for military concerns, as well as for the engineering and construction of coastal structures.

Technical aspects that require consideration while preparing shoreline data for digitization include:

- Topological "closing lines";
- Geodetic control reference standards;
- Georectification of orthophoto and satellite imagery;
- Metadata (documentation of the quality, source and other information on the data used);
- Certification and validation; and,
- Attributes.

Attributes refer to the nature or characteristics of shoreline features (such as rocky, sandy and

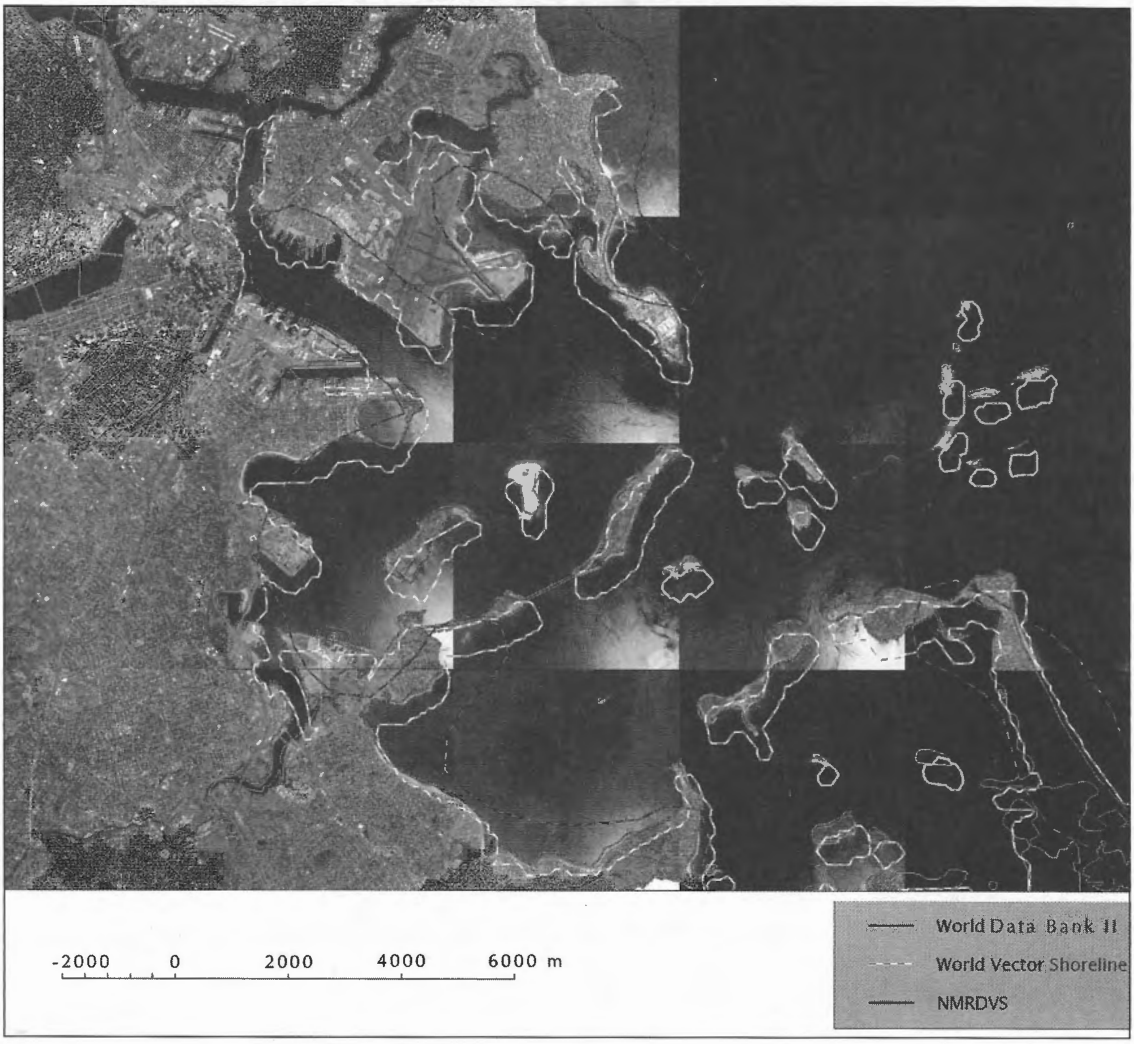

FIGURE 2. Low to medium-resolution shoreline data plotted for Boston Harbor.

muddy). Horizontal accuracy is referenced to the National Map Accuracy Standard.[8] The vertical standard is referenced to tidal data measured by NOAA/NOS. Numerous sources present discussions of the accuracy of elevation contours and datum references.[7,9-13]

Digitization Methods

A traditional, and still common, method of preparing digital files is by using a digitizing tablet with a "hockey puck" digitizer to encode data points. The source map, or *orthophoto*, is registered geographically, and the data points can then be defined relative to this system. Manual digitization is slow and is being widely supplanted by autodigitization and vectorization techniques. A number of software programs running on a range of computer platforms is available today for automatic vectorization. Table 1 (on page 37) presents some of the more common software automatic digitization and/or vectorization programs. These progams are commonly referred to as raster-to-vector conversion systems, or intelligent document conversion systems.

The software system chosen to perform the work on the Boston Harbor charts utilized an autovectorization system that operated on scanned and projected raster images. If the source material was in multiple parts (for example, adjacent aerial photographs or maps that were too large to be scanned in one piece),

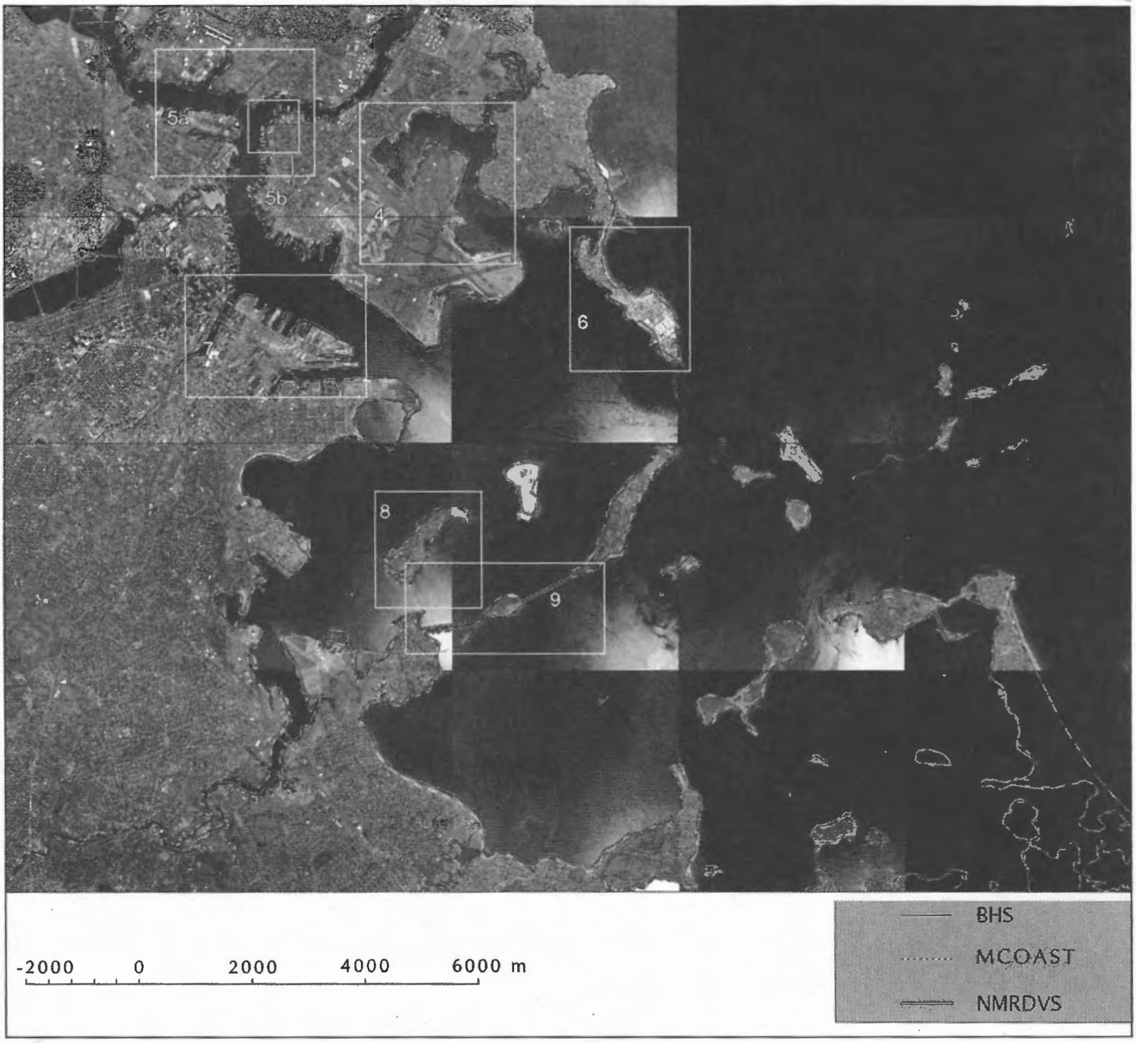

FIGURE 3. Medium to high-resolution shoreline data plotted for Boston Harbor

images were scanned in sections, georeferenced by use of locations at corners and then tiled together. All processing was performed on desktop computers.

The scanned images were saved as 24-bit Targa files and then converted to the vectorizing software's proprietary file format. The images were processed to reduce the amount of dithering and the pixilation of colors. The user then selected a color to follow and clicked two points on a line of that color. If the option to use a completely automatic trace method was chosen, the software followed the line until it came to a dead end or the edge of the screen, at which point the user could accept or reject the line. If the option to use a semi-automatic trace method was chosen, the software would prompt the user to accept or reject each point as it was added. The semi-automatic method could be quite useful if the line being digitized crosses other lines of the same color or had many tight bends. When using semi-automatic mode, the user could interrupt the tracing to add points manually (for example, to take a coastline past a bridge or to close off a river mouth in a coastline).

The orthophotos used as the background for comparing shoreline files had a ground resolution of 0.5 by 0.5 meter, obtained from aerial photography at a negative-equivalent scale of 1:30,000. The image files were downloaded from their source at the Massachusetts Institute

FIGURE 4. The northern part of Logan Airport and adjacent waterways. Shoreline delineation is strongly affected by tidal levels in the very shallow waters and marshes in the northwest sector but, with few exceptions, the agreement is good.

of Technology (the MassGIS web site). The orthophoto images were resampled to reduce the number of pixels by a factor of 4, which resulted in a file with a ground resolution of 2.0

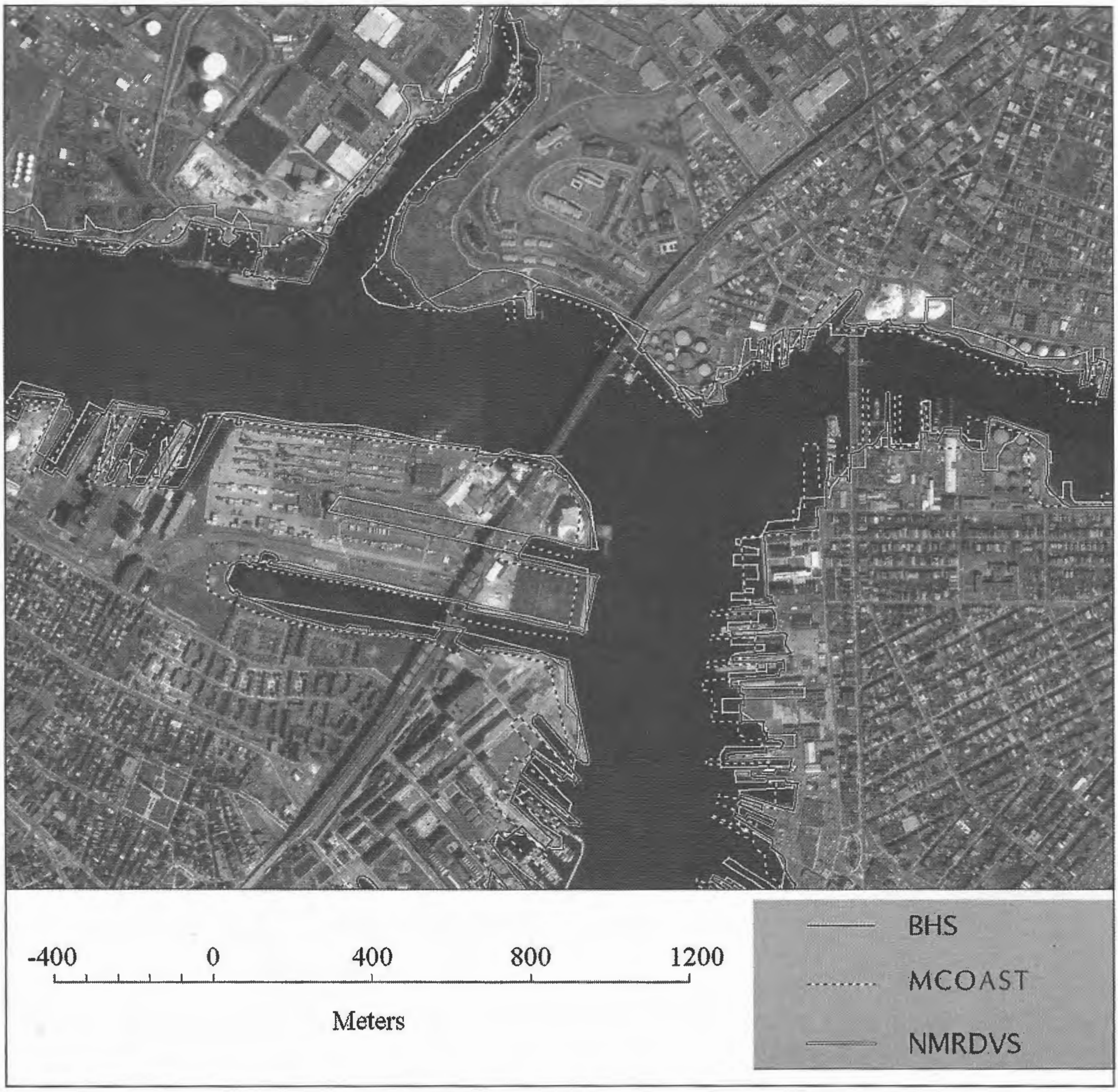

FIGURE 5A. The confluence of the Inner Harbor with the Chelsea and Mystic Rivers. This figure has the same scale as Figures 4, 6, 7, 8 and 9. Greater resolution for the complex, man-made shorelines in the inner harbor area is provided by Figure 5b.

by 2.0 meters. The images had been rectified to Massachusetts State Plane, North American Datum (NAD83). To tile the images together, the state plane coordinates were first converted to decimal latitudes and longitudes. This conversion was accomplished using software released by the U.S. Army Corps of Engineers.[14] All sources of information (except MCOAST) were based on NAD83. The original topographic map data upon which the USGS DLG data are based were derived from 1978 overflights.

Shoreline Comparison

A selection of existing low- and medium-resolution shoreline files is displayed in Figure 2 (on page 38). Scales for the files are 1:2,000,000 for World Data Bank II, 1:250,000 for World Vector Shoreline (Defense Mapping Agency) and 1:80,000 for NMRDVS. Medium- and high-resolution shoreline files are shown in Figure 3 (on page 39). Scales for the files are 1:80,000 for NMRDVS, 1:24,000 for MCOAST, and 1:25,000 and 1:10,000 for BHS. Data from NMRDVS are

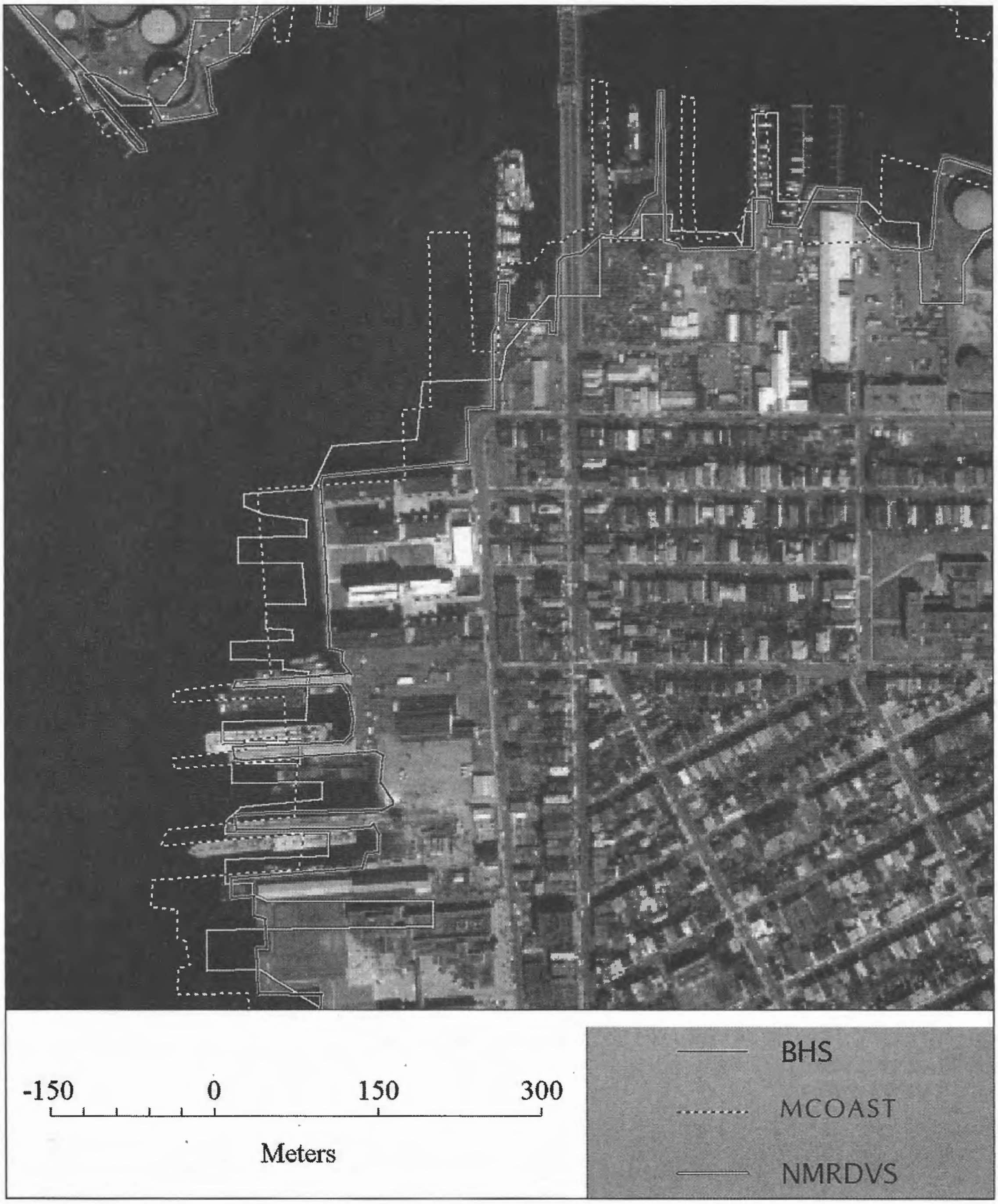

FIGURE 5B. The confluence of the Inner Harbor with the Chelsea and Mystic Rivers (an enlargement of the subarea shown in Figure 5a). The 1:80,000 resolution of the NMRDVS is not sufficient or probably intended to resolve the complex features. A higher resolution is needed to depict the shore for engineering development, or for the location of sediment samplings for dredging or environmental purposes.

common to both. Whereas the NOAA shoreline has a variable scale (with an average scale for the entire NMRDVS of approximately 1:70,000), the chart used for Boston Harbor

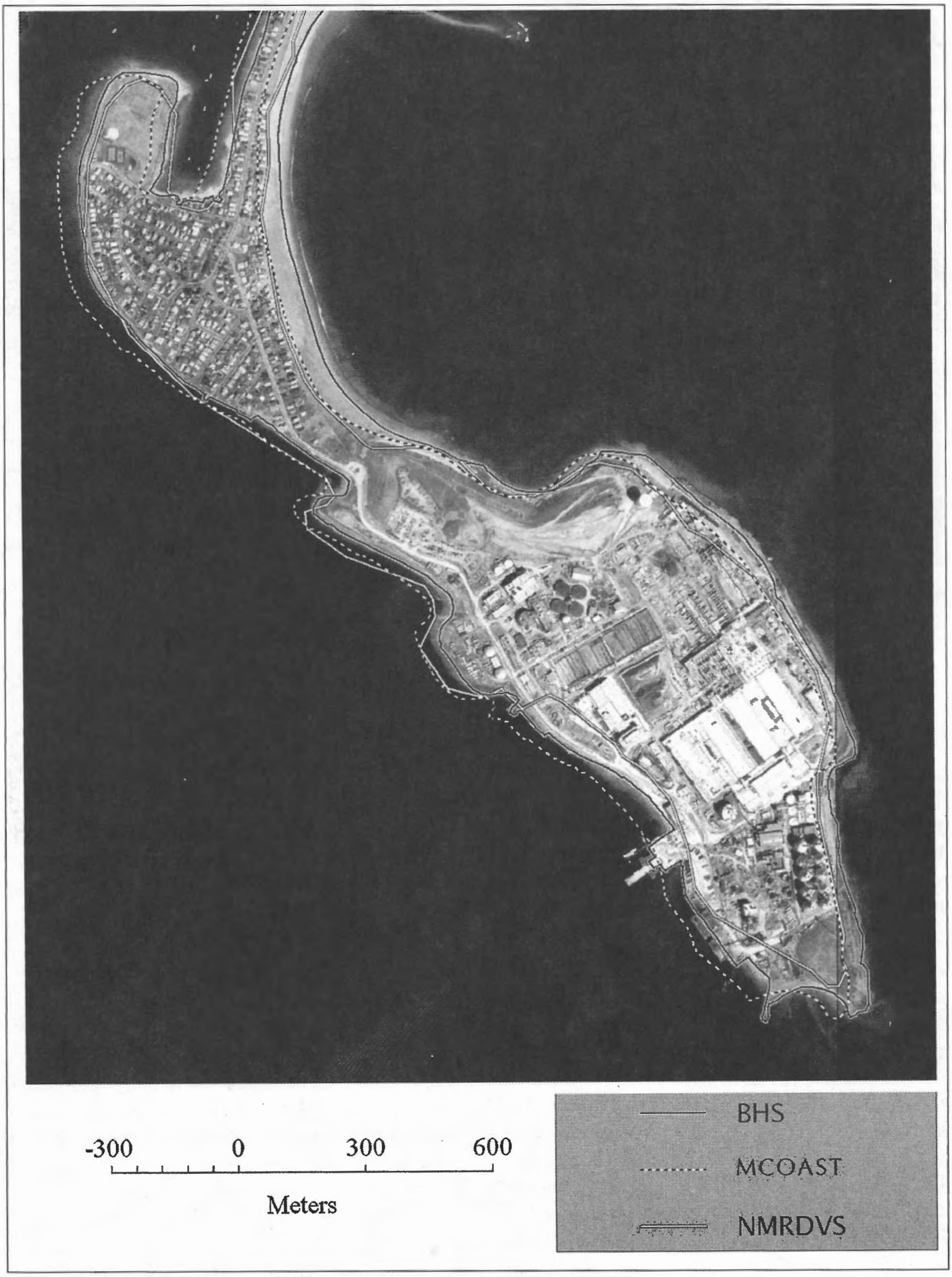

FIGURE 6. Up to 100-meter departures between the NMRDVS and BHS shorelines can be observed on the eastern and southwestern shores of Deer Island. The NMRDVS shows a prominent inland offset in the northeastern part of the peninsula.

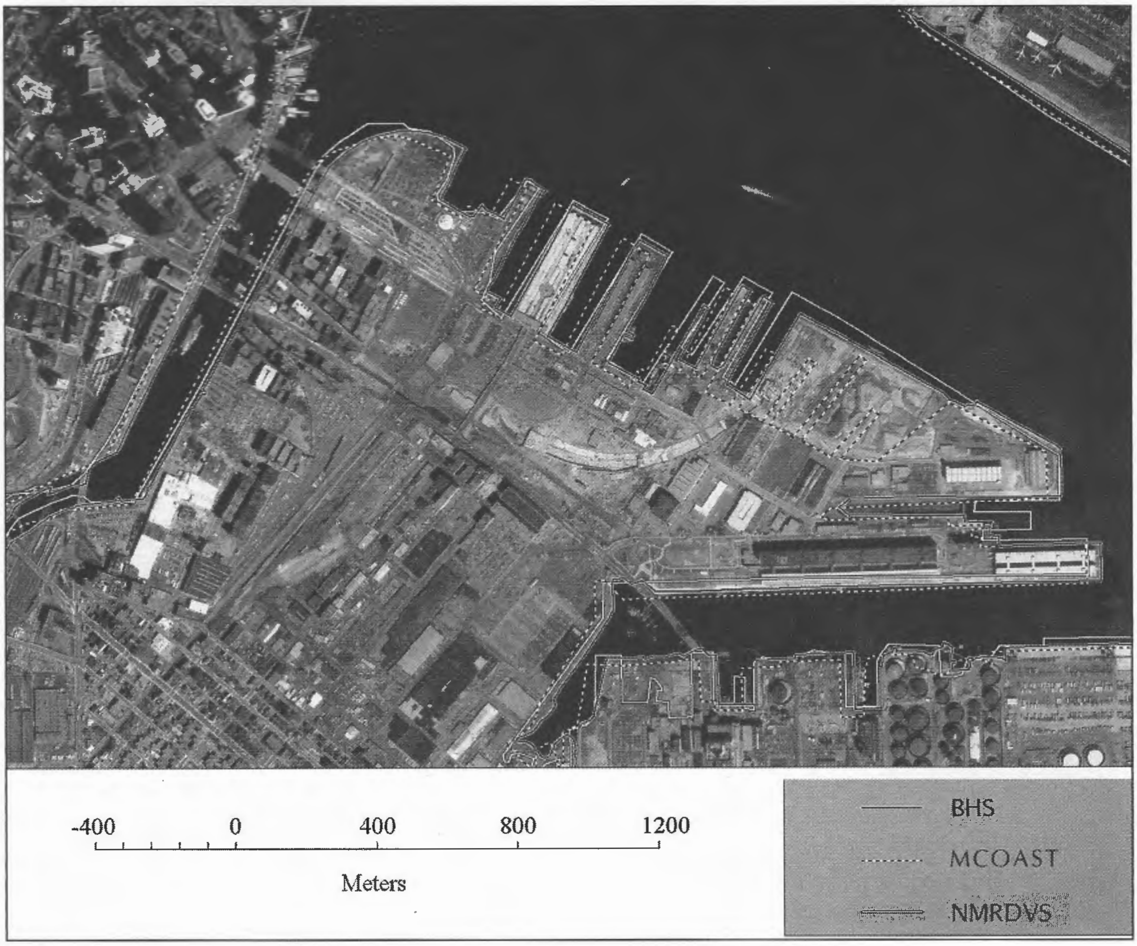

FIGURE 7. The MCOAST shoreline clearly shows older harbor areas in the eastern segment of the Inner Harbor north of the Reserved Channel. Their filling in is reflected in the newer shorelines. Except for a difference in the southwestern margin of the Reserved Channel, the other two shorelines agree quite closely.

(#13267) is 1:80,000. On a page-sized diagram of Boston Harbor as a whole, the differences between the three latter files are not great. Agreement is good in many of the outer and middle-harbor areas. However, comparisons between the shoreline files and recent orthophotos show significant local differences particularly in the Inner Harbor and the Mystic River confluence. In these areas the NMRDVS lacks sufficient detail to effectively delineate the shoreline at high resolution.

Figures 2 and 3 display shoreline files superimposed on a mosaic created from a set of orthophotos based on recent aerial photographic coverage of the greater Boston area.[15] The differences between NMRDVS (1:80,000 scale), the MCOAST (1:24,000 scale), and the new BHS file (1:25,000 and 1:10,000 scale) emerge at larger scale, as depicted in Figures 4 through 9. MCOAST is an earlier high-resolution shoreline file and there is often a systematic deviation between MCOAST and the other lines. Some differences are clearly due to changes in the harbor since the data in the original topographic maps were compiled. Others may originate in differing tidal levels, or in processing. Figure 3 also shows the locations of Figures 4 through 9 within the Boston Harbor area.

In general, all three files — BHS, MCOAST and NMRDVS — tend to show a systematic westward offset with a mean of about 30 meters from the orthophotos for both the Outer

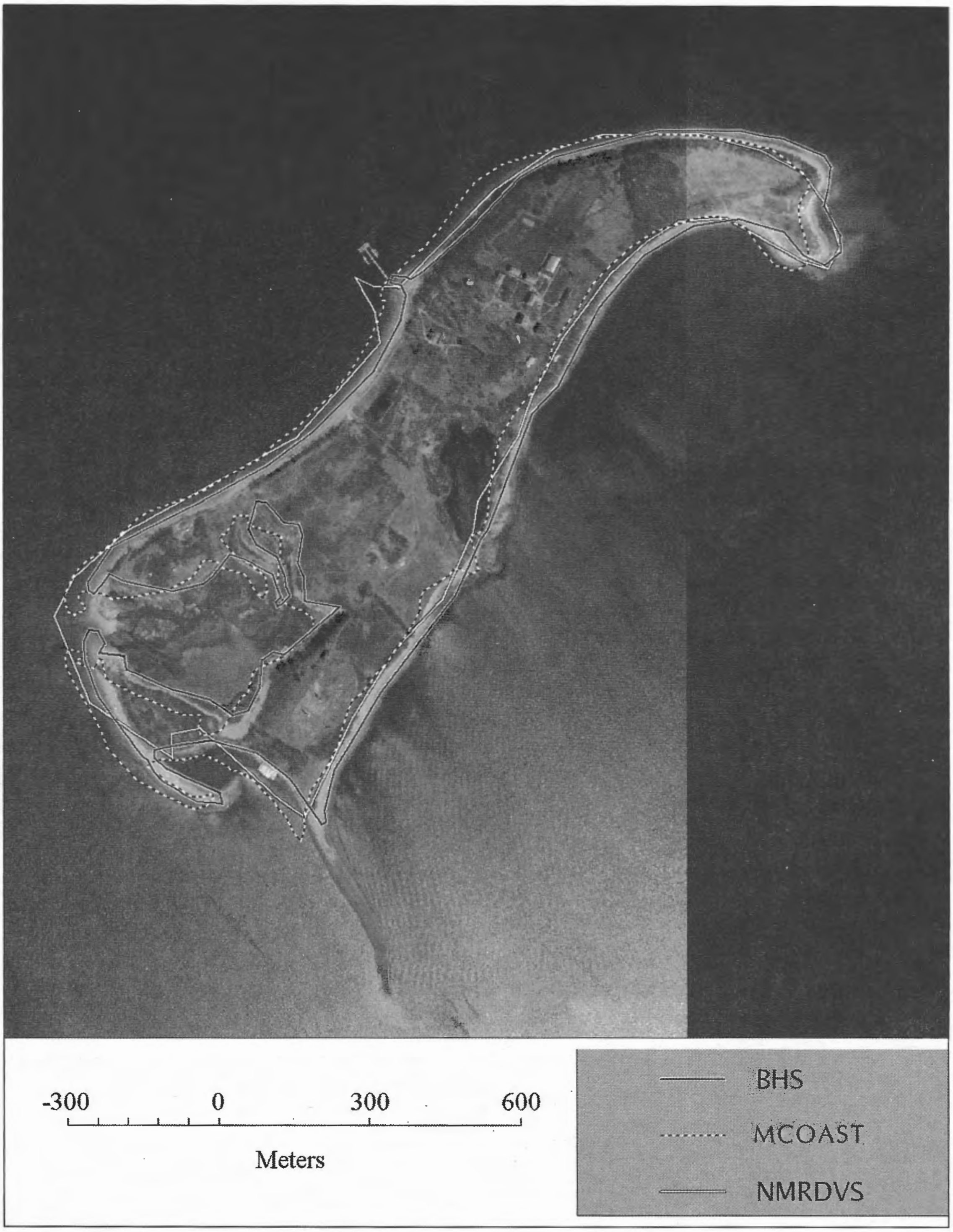

FIGURE 8. Thompson Island. The southwestern margin demonstrates a closed contour in the NMRDVS, whereas the BHS shows an embayment.

Harbor and Inner Harbor areas. The source or sources of this systematic offset could not be identified at this time. It is suggested that this offset be considered and resolved in future

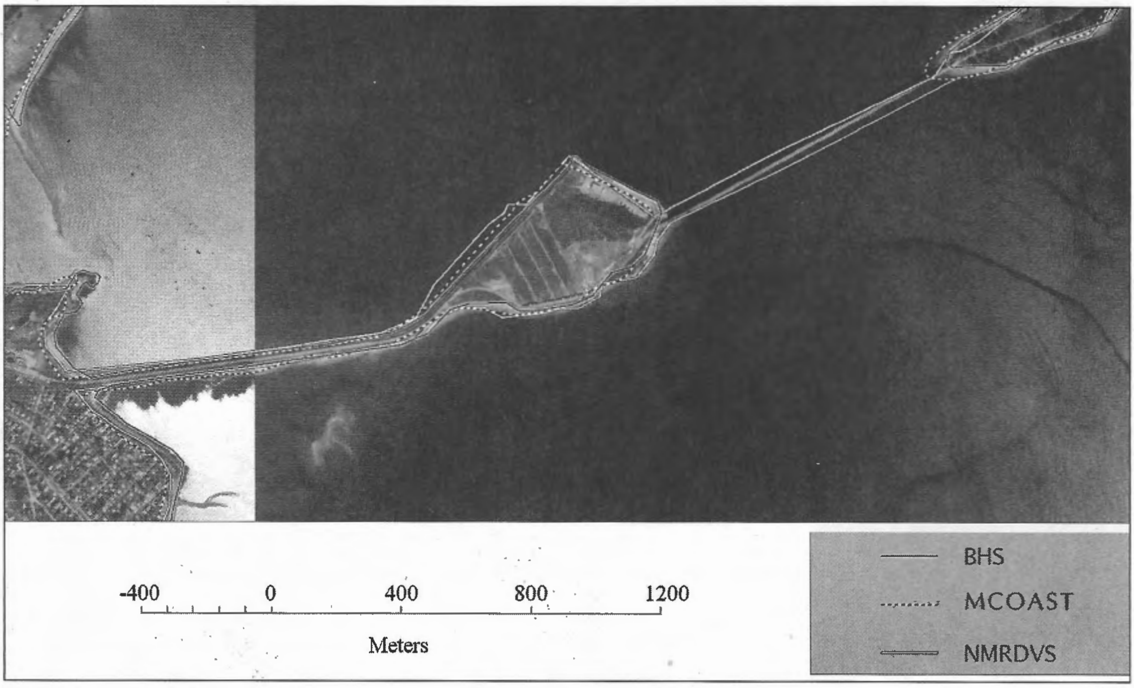

FIGURE 9. Moon Head and Squantum Head. The causeway between the two islands, to the west, is shown as land on all the shorelines, whereas the bridge between Moon Island and the larger Long Island (eastern sector) is shown as water in the MCOAST shoreline.

map additions or GIS treatments of Boston Harbor.

In Figures 2 and 3 and the enlarged insets there can be seen shadowy reflections from the water itself. In some areas, such as near the shore of Hingham Bay, these "reflections" may outline shallow mudflat areas, but elsewhere they may be due to surface reflections of various origins.

Data Sources

The following items include the data sources used in this study as well as some others that are included for completeness:

- *Massachusetts Institute Technology & MassGIS Digital Orthophoto Project.* Jointly sponsored by the Planning Support Systems Group, Department of Urban Studies and Planning, Massachusetts Institute of Technology, and MassGIS. Its web site, entitled "Tools to Facilitate Access to Digital Orthophotos," is a node on the National GeoSpatial Data Clearinghouse. Web site: ortho.mit.edu/nsdi/.
- *Massachusetts Geographic Information System (MassGIS).* Part of the Commonwealth of Massachusetts Executive Office of Environmental Affairs. Its web site has no data online, but has product descriptions and order data. MassGIS developed MCOAST, a complete Massachusetts shoreline file originally created combining data from USGS 1:24,000 scale DLGs and digitized shorelines of topographic maps where DLGs were not available. The original topography is mainly based on aerial photography taken in 1978. Web site: www.magnet.state.ma.us/mgis/massgis. htm.
- *NOAA Medium Resolution Digital Vector Shoreline (NMRDVS).* The NOAA/National Geophysical Data Center web site is: www.ngdc.noaa.gov/mgg/shorelines/.
- *NOAA Office of Ocean Resources Conservation & Assessment (ORCA).*
- *Digital coastline segments* (digital t-sheets and documentation) are available from this web site: seaserver.nos.noaa.gov/projects/shoreline/shoreline.html.

- *U.S. Army Corps of Engineers, Topographic Engineering Division.* Software for converting coordinates to and from geographic, state plane and universal transverse mercator projections is available for downloading from: ftp://survey1.tec.army.mil/pub/software/corpscon.410/v41xzip.
- *USGS Coastline Extractor.* The 1:2,000,000 scale World Data Bank II/CIA global and 1:250,000 scale World Vector Shoreline global data sets also include the NMRDVS (1:70,000 scale) data set, as well as a link to the primary NOAA web site. Web site: crusty.er.usgs.gov/coast/getcoast.html.
- *USGS Boston Harbor Ecosystems.* This source includes figures from this article and BHS digital files in downloadable format. Web site: coast-enviro.er.usgs.gov/boseco/.
- *USGS/National Mapping Division (NMD).* This source provides DLGs and other map information. Other scales available range from 1:10,000 to 1:1,000,000 from USGS quadrangle maps. Web site: edcwww.cr.usgs. gov/glis/glis.html.

Conclusions

There are a number of benefits to using newer automated digitization methods:

- A new digital shoreline file for Boston Harbor has unified the two existing harbor charts (NOAA/NOS charts #13270 and #12272).
- Digitization by the newer autovectorization techniques can be completed more rapidly and also more accurately than by manual digitization techniques. The scanning and processing can be applied to a map of any size and performed on desktop computers. Manual intervention is needed to take into account shoreline indentations like rivers and canals and may be needed for complex inner-harbor features.
- Comparison of the new digital file with existing digital files shows that the new file is distinctly superior to the standard 1:80,000-scale file in the more complex Inner Harbor areas. Systematic shifts in the harbor maps of up to 30 meters, and local shifts (for example, at Deer Island) as great as 100 meters in comparison with recent orthophoto coverage should be resolved in preparing future harbor charts.

NOTES — *The new data set presented here represents the most detailed delineation currently available. It may be downloaded from the web site: coast-enviro.er.usgs.gov/boseco/. The ABICAS software system was used for vectorization in this study. CorpsCon software, available from the U.S. Army Corps of Engineers, was used to convert coordinates to and from geographic, state plane and universal transverse mercator projections. Reference to any specific commercial product, or trade name does not imply its endorsement by the U.S. Geological Survey or the Boston Society of Civil Engineers Section/ASCE.*

ACKNOWLEDGMENTS — *Millington Lockwood, at the National Oceanic and Atmospheric Administration/National Ocean Survey (NOAA/NOS), gave permission to use a briefing report, and provided valuable supplementary information. Christian Jacqz, at the Data Center for the Executive Office of Environmental Affairs (MassGIS), transferred to the authors the Massachusetts digital shoreline derived from USGS topographic maps, and provided information on the recent cooperative orthophoto coverage of Boston Harbor. Norman Vine, of Woods Hole, Mass., cooperated in the earlier data transfers.*

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15. The Planning Support Systems Group at the Massachusetts Institute of Technology (MIT) Department of Urban Studies and Planning, the MIT Department of Urban Studies and Planning, and MassGIS supply tools to facilitate access to digital orthophotos. Web site: ortho.mit.edu/.