Where's the Shoreline? Sources of Historical High Water Lines Developed in the Context of Massachusetts Coastal Regulations[1]

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SUMMARY

The identification and location of natural ambulatory features have traditionally presented unique challenges to coastal surveyors and cartographers charged with the accurate depiction of shoreline position on maps or plans. From a legal and regulatory perspective, time specific comparisons of reliable shoreline position frequently form the basis for establishing title to valuable waterfront property and defining the geographic scope of jurisdiction of coastal regulations. As important planning and design considerations for waterfront projects, such comparisons are equally significant to coastal engineers and scientists seeking to identify and restore areas of filled salt marsh; characterize coastal processes affecting past, present, and future shoreline movement; and determine rates of shoreline change and potential impacts of relative sea level rise. Finally, accurate historical coastal maps are used by coastal managers to document cultural and land use patterns of coastal communities and by historians and archeologists concerned with the identification and preservation of maritime-related cultural resources.

Beginning in 2003, the Massachusetts Office of Coastal Zone Management (CZM) began a historical shoreline mapping project[2] to facilitate determinations of state jurisdiction related to the protection of the public's rights in filled and flowed tidelands of the Commonwealth. Plans and maps were identified through a rigorous research program that included the archives of local historical societies; state agencies, registries, and repositories; public and private cartographic collections; and federal agencies. Based on this research, a carto-bibliography of in excess of 2,600 plans was developed, including digital copies of historical plans and maps produced as early as the mid-1700s. The foundation of the project was built on mid-19th century Topographic Sheets (T-Sheets) and Hydrographic Sheets (H-Sheets) of the U.S. Coast Survey. This work is considered to be one of the most reliable and reproducible sources of early waterfront conditions and shoreline position. Recognizing the multi-disciplinary potential for such a large cartographic dataset, this paper discusses the maps acquired for the project; the nature of the shoreline information depicted on them; the methodologies used in the transformation of earlier mapping

[1] The views and conclusions expressed in this paper are the authors' and are in no way to be considered an official position or policy of the Massachusetts Office of Coastal Zone Management or other Commonwealth agencies.
[2] The Massachusetts Historical Shoreline Mapping Project.

efforts to a common contemporary datum; and the results of quantitative, period-specific assessments of spatial accuracy.

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INTRODUCTION

The accurate identification, location, and cartographic representation of historical natural features, such as shorelines, are subjects of much debate in current scientific journals. Varying spatially at several time scales (*e.g.*, daily, yearly, geologic time scales) and subject to episodic and chronic movement in response to waves, tides, storms, relative sea-level rise, and human alteration, shoreline positions are valid for only discrete time periods (Donovan, et al, 2002). Indeed, this spatial variability in three dimensions has historically presented unique challenges to surveyors and cartographers charged with mapping the coast.

In addition to the natural spatial variability associated with an ambulatory feature over multiple temporal scales, the mapped position of shorelines also relates directly to the nature of the surveying effort. Indeed, cartographic representations of shorelines, and the spatial accuracies associated with them, are dependent on many factors including the purpose of the survey; the scale at which data was compiled and depicted on the final plan; the natural variations inherent in the mapped feature(s); the quality of instrument(s) used in measuring and recording horizontal and vertical positional data; the surveying principles, methods, and standards commonly practiced at the time measurements were made; and the competence of individual surveyors.

Generally recognized as the intersection of the land with the water surface, the positions of present and former shorelines are often fundamental to contemporary legal, regulatory, scientific, and engineering considerations associated with coastal development. While over 300-years of coastal mapping efforts provide today's historians, scientists, engineers, and land surveyors with rich and valuable historical (and historic) coastal and waterfront information, the use of multiple and disparate definitions of shoreline can make historical and contemporary comparisons of time-specific positions difficult, frequently resulting in misleading or incorrect conclusions. For surveyors, engineers, and scientists documenting historical shoreline position, therefore, an understanding of the shoreline definition is fundamental, particularly when assessments of mapping accuracy and the reliability of plan information are necessary to support claims of tidelands ownership and regulatory jurisdiction within the coastal zone.

For the case of contemporary mapping efforts seeking to establish a "true" shoreline position, project-specific requirements typically define the shoreline or reference feature of interest,

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including minimum equipment specifications and agreement on the methodologies necessary to achieve project accuracies. Significantly, the standards developed by the U.S. Coast Survey for its coastal mapping work continue to yield reliable depictions of shoreline position and represent one of the best available sources of information for the position of historical shorelines. With mapping begun in earnest in New England in the early 1840s, the standards associated with Topographic (T) and Hydrographic (H) Sheets produced by this government agency, and its successors the U.S. Coast & Geodetic Survey, the National Ocean Survey and the National Ocean Service, facilitate quantifiable assessments of plan reliability necessary to evaluate 19th century shoreline positions. Prior to such standardization of coastal mapping methodologies, procedures, and cartographic symbologies, the mapping standards of early surveys were often subjective with the reliability of depicted shoreline positions related directly to the professional standards of the individual in charge of the mapping effort (Anders and Byrnes, 1991). As a result, the cumulative effects of natural spatial variability, surveying and mapping accuracy, and inconsistent shoreline definition of many early surveys can be difficult to quantify making assessments of the reliability of early mapped shoreline position for the mapping project both an art and a science.

SHORELINES: AN ELUSIVE NATURAL FEATURE

Although shorelines appear prominently on most coastal maps, not all shorelines are created equally. Defined generally as the intersection of the land with the water surface (NOAA, 2000), a multiplicity of shoreline definitions are used to satisfy coastal mapping applications. Coastal scientists and engineers investigating past, present, and potential future shoreline movement, for example, may use a variety of shoreline indicators or shoreline reference features (SRFs) to serve as proxies for the "true" shoreline position. (Moore, 2000, Ruggiero et al, 2003, and O'Connell, 1999 and 2005.) Indeed, in excess of 40 shoreline indicators relied on to portray shoreline position have been identified (Boak and Turner, 2005).

Typically, shoreline indicators are represented by physical features that exist consistently at all locations within the scope of the study; that are sufficiently defined to ensure consistent interpretation by individual mappers (i.e., repeatable); and that provide consistent representation of shoreline position (i.e. reliable) (Pajak and Leatherman, 2002). In addition to traditional datum-referenced shorelines such as the mean high water (MHW), these features often include the tops of coastal bluffs; the toes of coastal dunes; the most seaward vegetation line; the most recent high water line (HWL); coastal beach and berm crests; the vegetation change between Spartina patens in the upper marsh and Spartina alterniflora in the lower marsh; the wrack line; the wet-dry line; the algal line on rocky outcrops; and the interface between vertical seawalls/bulkheads and open water. (Boak and Turner, 2005, O'Connell, 2005, Thieler, et al, 2001).

From the standpoint of professionals such as coastal managers, surveyors, and, hydrographers, who are concerned with producing nautical charts for safe navigation and establishing legal lines of geopolitical, private property, or regulatory boundaries, the use of a uniform and consistent definition of shoreline and associated mapping standards is essential. For contemporary applications, the shoreline is typically defined to be the line of contact between the land and a selected water elevation referenced to an accepted vertical datum (NOAA, 2000). For marine and coastal applications, base elevations typically refer to local tidal datums that are defined in terms of specific tidal phases (NOAA, 2000.) Calculated as the average or mean of a specified tidal height, tidal datums vary locally in response to local topographic and hydrographic characteristics such as the geometry of the landmass, the depth of nearshore waters, and the distance of a location from the open ocean (Cole, 1997). To account for short-term meteorological effects associated storms and long-term astronomical effects related to the 18.6-year cycle of the lunar nodes and the annual variation in solar declination, a tidal datum is calculated by taking the average of the height of a specific tidal phase over a 19-year period referred to as a tidal epoch. (Marmer, 1951.) NOAA's National Ocean Survey (NOS) periodically adopts and publishes values for datums calculated for specific 19-year periods, referred to as a National Tidal Datum Epoch (NTDE). The present NTDE, published in April 2003, is for the period 1983-2001. Although significant differences can exist between published NTDE datum values and values calculated for the most recent 19-years, legally accepted values for most boundary determinations are those referenced to the most current NTDE (Cole, 1997.)

Common tidal datums include mean higher high water (MHHW) – the average of the highest high water (or single high water) of each tidal day observed at a specific location over the NTDE; mean high water (MHW) – the average of all high water heights observed at a specific location over the NTDE; mean sea level (MSL) – the arithmetic mean of hourly tidal heights for a specific location observed over the NTDE; mean tide level (MTL) – the arithmetic mean of mean high and mean low water calculated for a specific location; mean low water (MLW) - the average of all low water heights observed at a specific location over the NTDE; and mean lower low water (MLLW) – the average of the lowest low water (or single low water) of each tidal day observed at a specific location over the NTDE (NOAA, 2000.) Frequently, tidal datum elevations are correlated to a fixed reference adopted as a standard geodetic datum such as the North American Vertical Datum of 1988 (NAVD88) or the National Geodetic Vertical Datum of 1929 (NGVD29.)

The emerging interest in the development of marine cadastral information systems reinforces the need to clearly define shorelines of interest so that the complex language of coastal and marine boundary delimitation and demarcation can be applied consistently and accurately. With most maritime, coastal, and real property boundaries located seaward of the coast, accurate mapping of a dynamic shoreline is often necessary to establish the spatial extents of a range of interests – from those of waterfront property owners and private property rights, to those of municipal and state political and jurisdictional boundaries, to those of national security and the determination of the extent of U.S. maritime rights, and finally to the allocation of international rights (Fowler and Treml, 2001). In the context of coastal and marine boundaries several shoreline definitions, referenced to specific tidal datums, are typically used to describe and locate boundaries. For example, in the absence of a baseline decree by the U.S. Supreme Court, the shoreline (or coast line) used to administer the Submerged Lands Act (Public Law 31) and to establish the limits of the Territorial Sea (or the federal/state boundary) and other offshore or marine boundaries is defined as a low water tidal datum, the mean lower low water line (NOAA, 2000).

By contrast, the seaward extent of private ownership in the coastal zone is frequently limited by a high water shoreline defined as the intersection of mean high water or mean higher high water with the land surface. Along the waterfront, tidal datums have historically been used to determine the location and extent of individual property lines and the extent and nature of public rights in areas of both present and former tidelands. Indeed, in most coastal states, the mean high water shoreline establishes the seaward limit of private ownership. Historically, recognizing the ambulatory nature of the mean high water line, the horizontal position of this shoreline was frequently approximated to depict the seaward extent of private ownership (Cole, 1997.) Increasingly, however, with the escalation of waterfront property values juxtaposed against competing claims of public rights to vanishing coastal resources, determining the seaward extent of private property based on datum–referenced shorelines such as the MHW line have taken on an added significance (Morton & Speed, 1998.) In response to this increasing competition between public and private rights, the Commonwealth of Massachusetts has conducted a historical shoreline mapping project that, when completed, will provide more certainty to the orientation of overlapping public and private interests in the coastal zone.

COMPETING RIGHTS ALONG THE MASSACHUSETTS SHORELINE: PUBLIC RIGHTS VERSUS PRIVATE OWNERSHIP IN THE COASTAL ZONE

The early colonization of Massachusetts began in 1620 with the settling of what is now known as Plymouth by a group of religious outcasts from England. Initially, under a charter from the British Crown, the colonial government was given absolute ownership of the land within the limits of the colony, the power to make the laws of the colony, and full dominion over the seashore and coastal waters, to the same extent as previously held by the King (Archer, et al, 1994.) Under the common law of the new colony, the rights of the sovereign in coastal waters extended landward to the high water mark, so that "[the] shore, which is the space between [the] high-water and low-water mark[s], belong[ed] to the sovereign" with the property of the owner of the upland bounding on tide waters extending seaward only to the high water mark (*Storer*, 1810.) Private title to land bounding on tidewaters remained limited by the high water mark until legislation was enacted in the 1640's.

In 1641, the Massachusetts Bay Colony exercised its sovereignty over the sea and adjacent tidelands by enacting an ordinance, the first codification of the public trust doctrine in America. The purpose of the ordinance was "to declare a great principle of public right, to abolish the forest laws, the game laws and the laws designed to secure several and exclusive fisheries, and to make them all free" (*Alger*, 1851.) With the passage of this ordinance, the colonial legislature expressly extended this right to all tidelands. In 1647, however, recognizing a need to stimulate commerce and a struggling maritime economy, the colonial government amended the 1641 ordinance and extended private ownership of property bounding on tidal waters to the low tide line "…where the sea doth not ebb above a hundred rods (approximately 503 meters), and not more wheresoever it ebbs farther." The purpose of this amendment was to encourage the building of wharves and docks by private interests, something the fledgling colony could not afford to undertake (*Alger,* 1851; *Charlestown,* 1822; *Storer,* 1810; and; *Adams*, 1807.) While this amendment granted shorefront proprietors ownership of the tidelands adjacent to their upland property, it continued to respect the traditional nature of the public trust doctrine and reserved the public rights of fishing, fowling, and navigation between high and low water (*Opinion*, 1974.)

Although the enactment of the Colonial Ordinances of 1641-47 resulted solely from the actions of Massachusetts Bay Colony legislature, it has been a long and well settled principle of law that the extension of private title to low water applies to all coastal landowners in the Commonwealth and to those of Maine when it became a separate state in 1820 (*Weston,* 1851; *Barker*, 1832; and *Alger,* 1851.) Significantly, the enactment of these ordinances, representing a marked departure from the English common law public trust doctrine, still serves as the point of reference for all Massachusetts' intertidal law (Connors and Krumholz, 1990) Under the colonial ordinances, which have been treated as settling the common law of the Commonwealth, private ownership was extended to the low water mark or 100 rods from the high water mark, whichever is farther landward, subject to the public rights of fishing, fowling and navigation (*Michaelson,* 1933 and *Home for Aged Women,* 1909.) The waters and the land under them beyond the line of private ownership are held by the State, both in fee and as the sovereign. The right of the legislature regarding the area beyond private ownership is paramount to all private rights and subject only to the authority of the U.S. government to act in the interest of interstate or foreign commerce. Further, as a property- or ownership-based doctrine, based on the property law of the Commonwealth of Massachusetts, the geographic scope of the public trust doctrine also migrates in the same manner as those lines, represented by high or low water, that define the limits of private littoral ownership (Mague, 1999.)

Until the 1860's Massachusetts courts, as the sole interpreter of the colonial ordinances, adhered strictly to the central purpose of the ordinances with decisions encouraging and facilitating the building of wharves for the benefit of commerce (Archer et al, 1990.) Infringement of public rights in tidelands escalated in the mid-1800's as the Massachusetts legislature enacted hundreds of special "wharfing statutes" authorizing and encouraging private parties to construct and maintain wharves seaward of the low water line. Following a number of amendments to the original Act establishing a temporary Board of Harbor Commissioners in 1837, the Massachusetts legislature created a permanent Board in 1866. Broader in scope than its predecessor, the new Board was charged with protecting the public interest in tidelands and with regulating Massachusetts' waterfront development through the administration of a tidelands licensing program – known today as the Chapter 91 license program (Lahey, 1985.)

In 1979, development issues concerning the public trust doctrine re-emerged when the Massachusetts Supreme Judicial Court (SJC) considered a dispute involving Lewis Wharf on the Boston Harbor waterfront and revisited “the allocation of rights among private parties, the Commonwealth, and the public to use, own and enjoy one of the Commonwealth’s most precious natural resources, its shore” (*Boston Waterfront Development Corp.*, 1979.) In *BWDC*, the SJC rejected the claim that a wharfing statute had conveyed an absolute fee simple title to property located seaward of low water, holding that title conveyed by such a statute was subject to an “implied condition subsequent” that the property, below low water, be used only for the public purpose for which it was granted (*BWDC*, 1979.) Future uses that did not comply with the public purpose intended by such grants, could result in the state reclaiming the land, even if the land had been *filled* by the grantee.

Because of the uncertainties arising out of the *BWDC* decision, particularly as it affected the title to and the nature of public rights in the significant filled tideland areas of Boston Harbor, new legislation was proposed in 1981 and amendments to M.G.L. Chapter 91 were adopted by the Legislature in 1983 (and again in 1986 and 1990.) After considerable public debate, the Department of Environmental Protection (DEP) Waterways Program promulgated new licensing regulations in 1990 that promoted and protected the public rights inherent in both flowed and formerly flowed (i.e., *filled*) tidelands.

Today, the Waterways Regulations define tidelands as “present and former submerged lands and tidal flats lying between the present or *historic high water mark*, whichever is farther landward, and the seaward limit of state jurisdiction” (310 CMR 9.02.) Significantly, in response to the 1979 *Boston Waterfront Development Corp.* decision, both *flowed tidelands*, defined as present submerged lands and tidal flats which are subject to the action of the tides, and *filled tidelands*, defined as former submerged lands and tidal flats which are no longer subject to tidal action because they have been filled, are included within this definition. Consequently, even if tidal flats were filled years ago, the geographic area is still impressed with public rights (Mague, 1999.) The ability to reliably determine the position of the *historic high water mark* as the landward boundary of regulated tideland, therefore, is fundamental to the c.91 licensing process.

THE MASSACHUSETTS HISTORCAL SHORELINE MAPPING PROJECT

The development history of many of the Commonwealth’s urban waterfronts and ports includes extensive filling of former tideland areas. In the context of the Massachusetts Supreme Judicial Court’s 1979 *BWDC* decision, therefore, the identification of reliable and reproducible historical high water lines in filled tideland areas, in addition to contemporary high lines in flowed tideland areas, is the initial step for determining the geographic scope of the Chapter 91 licensing process. Defined by regulation as the mark that “existed prior to human alteration of the shoreline by filling, dredging, excavation, impounding, or other means”, the historic[al] high water line is presumed to be “the farthest landward former shoreline, which can be ascertained with reference to topographic or hydrographic surveys, previous license plans, and other historical maps or charts, which may be supplemented as appropriate by soil logs, photographs, and other documents, written records, or information sources of the type on which reasonable persons are accustomed to rely in the conduct of serious business affairs" (310 CMR 9.02.)

Since the beginning of tidelands licensing in 1866, the Waterways Program has issued approximately 20,000 Chapter 91 licenses regulating various coastal development activities. Licenses for projects located on filled tidelands, however, were not issued until the promulgation of new regulations in 1990 in response to the *BWDC* decision. Typically, jurisdictional determinations for filled tidelands have been conducted on a site-by-site basis, relying on a variety of historical shoreline information submitted by license applicants (BSC Report, 2007). Further, many of the historical plans and maps used in these determinations are geo-referenced to local datums and, due to a lack of geographic features, difficult to register to contemporary geodetic datums.

Beginning in 2003, the Massachusetts Office of Coastal Zone Management (CZM) contracted with The BSC Group, Inc., a professional land surveying firm headquartered in Boston Massachusetts, to initiate the Massachusetts Historical Shoreline Mapping Project (the mapping project) for the entire Massachusetts coast. Recognizing the significance of such work to both public and littoral property owners, the goal of this project was to develop a GIS-based mapping product grounded in the best available historical plans and shoreline information that would facilitate accurate depictions of historical tidal boundaries as defined by the Waterways regulations. When completed, the project will provide the DEP Waterways Program, the state agency authorized by the Legislature to regulate activities on public trust lands and waters, with a comprehensive, reliable, and searchable digital database that identifies the best available historical shoreline information upon which to base its jurisdictional determinations.

HISTORICAL PLANS AND SHORELINES

Fixing the horizontal location of natural features is particularly challenging in the high energy and dynamic environment of the coast. Recognizing that even spatial depictions of contemporary high water shorelines are representative only for a discrete period of time, factual determinations of historical shoreline position most often must rely on the *best evidence* possible, even though fixing the location may be arbitrary, tainted with uncertainties and inconsistent with other evidence (CSO, 1997.) Further, what constitutes the *best evidence* will vary with the topography, hydrography, and stability of the site; the type, amount and purpose of the data and other records; and the state of the art and science of surveying at the time the measurement was made" (CSO, 1997.) In the case of filled tidelands, where the high water boundary line was moved seaward, a primary source of best evidence is typically found in the form of historical plans, maps, and charts of coastal areas.

Plans and maps for the mapping project were identified through a rigorous research program that included the archives of local historical societies; state agencies, registries of deeds; public and private cartographic collections; and federal agencies. As discussed below, the early Topographic Sheets (T-Sheets) and Hydrographic Sheets (H-Sheets) of the U.S. Coast Survey were confirmed to be one of the most reliable and reproducible extant sources of early waterfront conditions in the United States. In addition, the accuracy of this work makes it a valuable primary source from which to establish historical shoreline positions. Indeed, the courts have repeatedly recognized this work as the best available evidence of the condition of the coastline a hundred or more years ago (Shalowitz, 1964.) Further, grounded in survey methodologies utilizing advanced principles of geodetic control to produce solid triangulation networks that facilitate registration to contemporary datums, these U.S. Coast Survey field sheets constitute period-specific base maps that can be used to evaluate earlier mapping efforts.

All plans obtained during the research were evaluated against initial screening criteria developed to identify promising sources of historical shoreline information for georeferencing and further evaluation (BSC Report, 2007.) Based on these criteria, the plans, where possible, should:

- Exhibit spatial integrity, i.e. the geographic relationship between prominent features (man-made or natural) should generally represent real world positions,
- Reflect information acquired from actual surveys,
- Depict shorelines associated period-specific tidal data
- Depict shoreline conditions prior to filling or alteration,
- Reflect data acquired using state-of-the art survey methods and equipment,
- Contain sufficient detail to allow registration of plans to a known horizontal datum,
- Display standardized or recognizable cartographic symbology, and
- Reflect a compilation scale that facilitates reliable placement of lines on the ground.

Since the filling of many Massachusetts tideland in the commercial port areas such as Boston, Salem, and Newburyport began early in 17th century and escalated during the 18th and 19th centuries, reliable plans from actual surveys of unaltered shoreline conditions often proved difficult to locate. Of the surveys, maps, and charts identified during the research, those of the *Atlantic Neptune* and the U.S. Coast Survey proved to be particularly useful sources of shoreline information for the historical analysis component of the mapping project.

The work of J.F.W. DesBarres, a British Army engineer and surveyor whose mid- to late-18th century charts of the North American coasts were recognized as the standard of accuracy against which all United States mapping efforts were compared as late as the 1830s (Guthorn, 1984), provides an excellent early record of pre-filled shoreline conditions for many harbors along the Massachusetts coast. Produced at relatively small scales (i.e., > 1:20,000), these early plans compiled in his *Atlantic Neptune*[4] were one of the first efforts to employ triangulation and plane table surveying techniques, however, the focus of his efforts appears to have been on the location of low water for navigators and no documentation of the actual shoreline that was mapped

[4]Due to a lack of funding on the part of the Royal Navy, Desbarres paid for the publication of his charts of the North American Atlantic Coast in a compendium entitled The *Atlantic Neptune*.

appears to exist. With contemporary computer registration or geo-referencing techniques, DesBarres plans did support useful "first-cut" evaluations of the extent of filling.

In 1834, in response to the demands of a flourishing maritime commerce, the U.S. Coast Survey began triangulation work to control the first large-scale, comprehensive survey of the American coast for the purpose of producing accurate nautical charts (Cajori, 1980).[5] Topographic (T-) and Hydrographic (H-) sheets, the original field sheet manuscripts of plane table and soundings surveys used in the compilation of these charts, were typically produced at scales on the order of 1:5,000 to 1:20,000. Significantly, one of the most prominent features depicted on the T- and H-sheets, developed with an eye to the mariner using the finished chart, were the high and low water lines. In 1840, Ferdinand Hassler, the first Superintendent of the U.S. Coast Survey, emphasizing the importance of these lines, issued the earliest known agency instructions for the topographic work and shoreline mapping of the Survey stating in part:

> On the sea shore and the rivers subject to the tides, the high and low water lines are to be surveyed accurately; … The survey must always be conducted with the chain, and the "Method of intersections," and sketching by the eye the contours of shore lines, marshes, etc. must never be resorted to except where it is not possible to get along with the chain, or where a large extent of straight sandy or marshy sea coast exists and then the points fixed by intersections should not exceed 400 metres when the scale of the survey is 1/10,000, and the like ratio inversely for all other scales… (Shalowitz, 1964.)

The work of the U.S. Coast Survey also represents the first scientifically based effort to continuously record daily tidal observations at various locations along the United States' east and west coasts for the purpose of standardizing, as close as possible, its cartographic representation of the shoreline to reflect mean high water (Shalowitz, 1964.) Based on this information, the nature of the shoreline to be located was defined for the first time in the U.S. Coast Survey instructions issued in 1898 as that resulting from the "careful location of the mean high water line - not considering storm-high water" (Shalowitz, 1964.) As a matter of practice, however, locating the mean high water line precisely can only be accomplished with datum referenced surveying techniques that could not be not justified for the compilation of nautical charts and survey crews delineated the line more from the physical appearance of the beach and from the markings left on the beach by the last preceding high water, barring the drift cast up by storm tides (Shalowitz, 1964.) Although a legally accepted definition of mean high water did not emerge until the 1935 *Borax* case,[6] Shalowitz concludes that, based on the 1898 Instructions, the intention on all U.S. Coast Survey topographic surveys was to delineate the line of mean high water, as accurately as possible without recourse to leveling.

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[5] The U.S. Coast Survey (later the U.S. Coast and Geodetic Survey and today NOAA's, National Ocean Survey) was established by President Thomas Jefferson in 1807 with the naming of Ferdinand Hassler as the first Superintendent. For various reasons, including a lack of dedicated funding and the War of 1812, actual survey work did not begin in earnest for several decades.

[6] Today, as a result of the Supreme Court's decision in *Borax, (*1935), mean high water at any place is "defined simply as the average height of the high waters at that place over a period of 19 years" (Marmer, 1951.)

Prepared at the relatively large scale of 1:10,000, T-sheets provide exceptional period-specific shoreline detail for all of the Massachusetts ocean-facing coast and most of its more inland estuaries and fresh water tributaries. By the latter part of the 1800s, the U.S. Coast Survey had completed mapping most of the New England coast using sophisticated (for the period) plane table surveying techniques and instrumentation and begun the process of updating and expanding its plane table surveys. This process of updating and expanding ground surveys continued through the 1920s until the emergence of aerial photogrammetry (Collier, 2002.) Significantly, the exacting work of the U.S. Coast Survey can be translated to a contemporary horizontal datum with little or no reduction in accuracy, facilitating the development of an accurate and historical base map. This base map can, in turn, be used to register earlier non- U.S. Coast Survey plans since T-sheets depict numerous geographic features or registration points that were mapped on earlier plans for which little or no accurate, extant positional data exists. Indeed, the consistency of registration results associated with the U.S. Coast Survey's T-sheets and the ability to conduct quantifiable accuracy assessments contributed to the decision to develop a project-wide mid-1800s base map (Mague, 2006.)

With few exceptions, registration of most U.S. Coast Survey T-sheets (and H-sheets) to the project datum - North American Datum of 1983 (NAD83) - was accompanied by low residual values, indicating reliable registration solutions.[7] Non- U.S. Coast Survey plans generally exhibited higher registration solutions, in part due to the somewhat less sophisticated methods and equipment available to 18th century surveyors. Georeferencing of project plans was achieved using one of three types of registration points (BSC Report, 2007).

– Triangulation stations: Typically, T-sheets (and H-sheets) depict numerous primary control stations from the original triangulation network. NAD83 coordinate values for most of these stations are available from the National Geodetic Survey (NGS), facilitating the direct referencing of the sheets to the project datum.
– Latitude/longitude graticules: Most T-sheets also depicted graticules (latitude/longitude) based on survey datums in use during the 19th century. Graticules for early U.S. Coast Survey datums were translated to the NAD83 project datum using a statistical comparison of obsolete and NAD '83 coordinate values to provide a registration framework for individual T-sheets.
– Physical features: Where geodetic control points or graticules were not available, as for many early non- U.S. Coast Survey plans, discrete physical features such as church spires, building corners, etc. that also appeared on the historical or ortho-image base maps were used as registration points.

While the registration process provides a quantitative measure of registration accuracy, georeferencing reliability was also assessed by comparing the coordinate values of well-defined points on registered plans with values for the same points obtained from a source of higher accuracy. T-Sheets evaluated under this process proved to be extremely accurate with test

[7] The average of all residuals for 281 U.S. Coast Survey plans was 2.77 meters (standard deviation, 0.58 meters.)

results typically in the two (2) to five (5) meter range (BSC Report, 2007.) This assessment comports well with other published results assessing T-sheet accuracy and supports conclusions that T-sheet accuracy is largely controlled by mapping scale and not document age or surveying techniques (Daniels and Huxford, 2001) and that the T-sheets of the U.S. Coast Survey typically meet the United States National Map Accuracy Standard for 1:10,000 mapping,[8] and, in many cases, exceed it (Crowell, et al 1991.) Non-U.S. Coast Survey plans were similarly tested and although the results varied, most fell within acceptable limits for the era in which the maps were produced (BSC Report, 2007.)

PRELIMINARY PROJECT RESULTS AND FINDINGS

After four years of intensive of work, the Massachusetts Historical Shoreline Mapping Project is presently undergoing final review. As a contemporary characterization of the public/private nature of the tidelands along the Massachusetts coast, particularly in highly developed waterfront areas, the project methodology, developed to contemporary standards of care for this type of mapping work, relied on careful inquiry and professional assessment of multiple local and regional historical plans and maps depicting historical high and low water lines. Indeed, the searchable, digital project database includes scans of 2,638 historical plans and maps produced as early as the late 17th century. Sources of historical plans identified during the research phase of the project are summarized in Table-1. Of the plans included in this database, 281 U.S. Coast Survey T- and H-sheets, and 66 Non- U.S. Coast Survey plans, covering 75 coastal communities, were geo-referenced to the project datum.

In addition to the digital carto-bibliography, project deliverables will also include an interactive GIS data management querying tool, developed for the project as an ArcGIS extension, which will allow users to simultaneously view and compare the digitized position of the most landward historical shorelines with multiple registered images and the historical and ortho-image base maps used for the project (BSC Report, 2007.) Designed to integrate cartographic database records with spatial information, when a historical shoreline segment is selected, the querying tool will also document decisions that went into the development of the most landward former shoreline by providing the user with the following information:

- Shoreline vector data defining the most landward shoreline,
- A database record documenting the cartographic source of the line,

[8] In 1941, the U.S. Bureau of the Budget issued the United States National Map Accuracy Standards (NMAS), applicable to all Federal agencies producing maps. The standards were revised several times with the most recent version issued in 1947. Pursuant to these standards, for maps published at scales larger than 1:20,000, not more than 10 percent of the well-defined points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50 inch. Well-defined points are those that are easily visible or recoverable on the ground, such as: property boundary monuments; intersections of roads and railroads; corners of large buildings or structures or the center points of small buildings (U.S. Bureau of Budget, June 17, 1947) For maps such as T-sheets produced at a scale of 1:10,000 to meet NMAS, therefore, not more than 10 percent of the points tested shall be in error by more than 8.5 meters.

- A listing of all registered and non-registered plans in the area of interest along with the archived location of the scanned image,
- The ability to view all images of historical maps and plans that were registered to the project datum within an ArcGIS project in their real world positions,
- Residual values for all registered plans and maps, and
- Metadata, including the reasons for selection of a historical plan as the best source for the most landward shoreline in a particular area

When completed, approximately 1,244 miles (approximately 2,002 km) of historical high water shoreline, of the approximately 4,476 miles (approximately 7,203 km) of estuarine and ocean-facing shoreline included within the geographic scope of the project, will have been mapped to delineate areas of formerly flowed tidelands. Further preliminary analysis indicates that approximately 13,601 acres (approximately 5,504 hectares) of present-day Massachusetts coastal upland area consists of formerly flowed tidelands. Not surprisingly, almost 60% (3,238 hectares) of this total is located within present or former commercial port areas of the Commonwealth,[9] with over 2,226 hectares (40%) alone found in the city of Boston.

The historical shorelines identified by the project represent the best compilation of former shoreline conditions that can be documented by the extensive database developed as part of the mapping project. While the database is extensive, it is clearly possible that additional plans or information may be recovered that, subject to critical review and analysis, would support modification to the most landward former shorelines defined by project data sets. For this reason, the historical shorelines that define state tidelands jurisdiction are presumptive and subject to change should additional and better evidence be provided. Notwithstanding this possibility, it is clear that this rich, comprehensive cartographic database will prove to be a reliable source of information to state agencies and landowners, contributing to greater certainty and consistency in jurisdictional determinations that profoundly impact the nature and extent of the public's rights to and along the waterfronts of the Commonwealth of Massachusetts.

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[9] These ports include Boston, Salem, New Bedford, Lynn, Fall River, Plymouth, Nantucket, Newburyport, Gloucester, Beverly, Provincetown, Tisbury, and Barnstable.

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BIOGRAPHICAL NOTES

Stephen T. Mague is a Project Manager for the Massachusetts Office of Coastal Zone Management. Mr. Mague received an M.S. in Environmental Science from the University of Massachusetts Boston and a B.A. in Environmental Studies from Colby College in Waterville, Maine and has over 20 years experience as a Senior Project Manager with a land surveying and civil engineering consulting firm. Over the past 8 years, he has served as CZM's project manager for the Massachusetts' Historic Shoreline Mapping Project, the South Coastal Hazards Mapping Project, and the 2001 Shoreline Change Mapping Project and as technical advisor to the state's Department of Environmental Protection concerning the mapping of tidelands jurisdiction and the Massachusetts Highway Department concerning alterations to the state's seaward boundary in Nantucket Sound. He is a member of the American Congress on Surveying and Mapping, The Massachusetts Association of Land Surveyors and Civil Engineers, and the Canadian Institute of Geomatics. He has published articles dealing with shoreline issues in ACSM's *Surveying and Land Information Systems* and *Environment Cape Cod* - a science based management journal addressing environmental issues on Cape Cod – and presented at conferences sponsored by the Massachusetts Historical Society, the Massachusetts Audubon Society, the Northeast Shore and Beach Association, and the Massachusetts Association of Land Surveyors and Civil Engineers.

Robert W. Foster is a Registered Professional Engineer and a Registered Professional Surveyor with over 40 years experience in private practice. He received a Bachelor of Science degree in civil engineering from the University of Vermont in 1955. He provides consulting services in engineering for local towns and lending institutions and offers professional consulting services nationally in dispute resolution and litigation involving civil engineering and surveying issues. He is a past president of the International Federation of Surveyors (FIG), is a past president of the American Congress on Surveying and Mapping (ACSM), and has served on the Board of Trustees of The Engineering Center Education Trust (Boston). He is also a member of the Boston Chapter of the American Society of Civil Engineers, the New England Land Title Association, the Massachusetts Association of Land Surveyors and Civil Engineers (MALSCE), and the Massachusetts Conveyancers Association (MCA) Dispute Resolution Register, and served on CZM's Peer Review Committee for the Massachusetts Historical Shoreline Mapping Project. Mr. Foster has provided testimony in litigation involving property disputes, appeals for permit denials, eminent domain proceedings, and professional negligence. He has testified before the United States Congress and the Massachusetts Legislature on pending legislation and budgetary matters. He has conducted numerous seminars on the subjects of planning and zoning, professional practice issues and ethics, and professional standards. Mr. Foster is author of *The Liability Environment*, a compendium of his columns appearing in the ACSM *Bulletin.* He has written several papers and articles on the global positioning system (GPS), ethics, professional practice, public relations, mapping the wetlands of Massachusetts, and the need for a land data system in New England, has written for the monthly *Civil Engineering News* and is a Contributing Editor for *P.O.B. Magazine*, a publication of Business News Publishing Company.

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