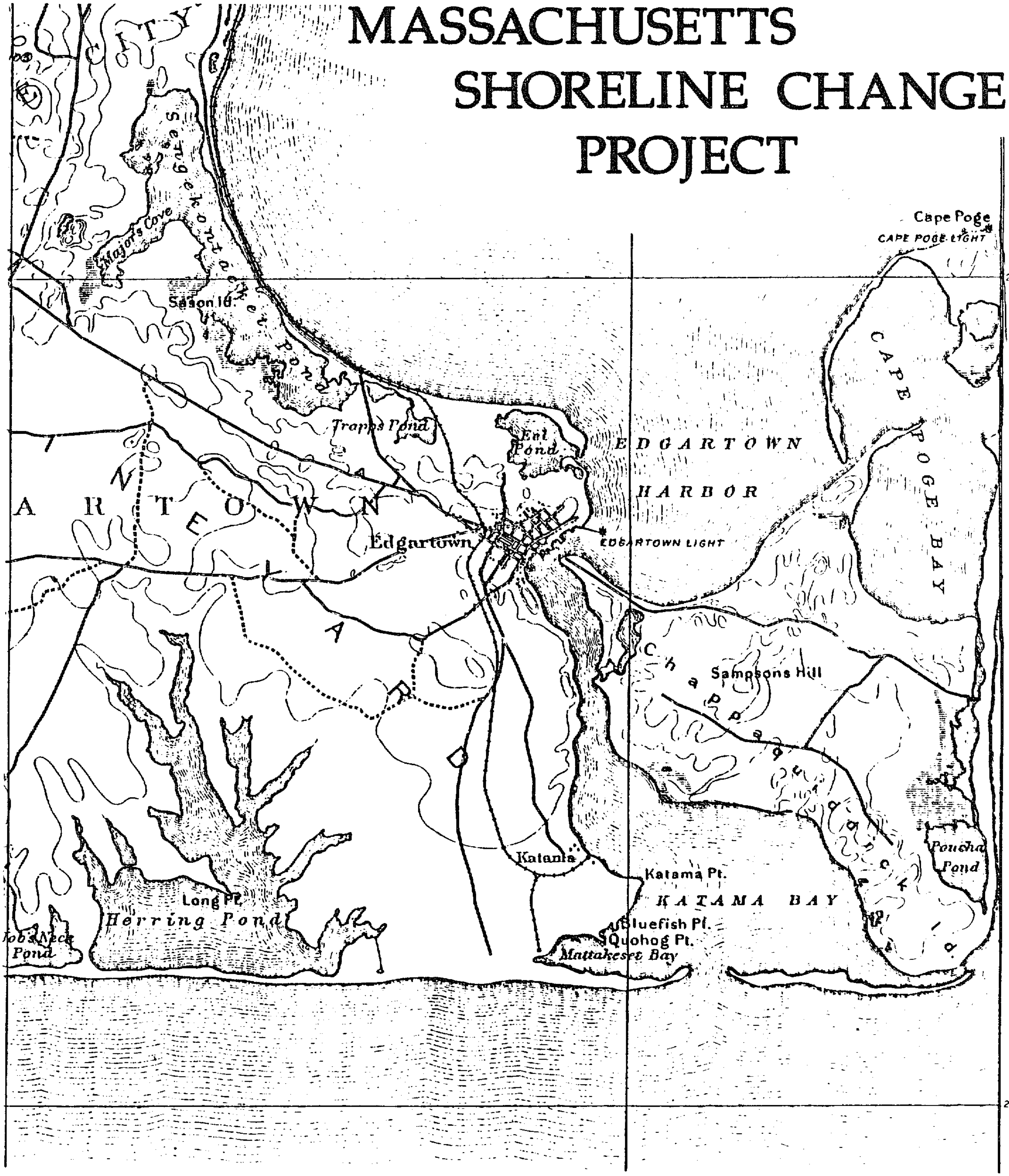
MASSACHUSETTS SHORELINE CHANGE PROJECT



MASSACHUSETTS
COASTAL ZONE
MANAGEMENT

January 1989

MASSACHUSETTS
SHORELINE CHANGE PROJECT

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January 1989

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ACKNOWLEDGEMENTS

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THE MASSACHUSETTS COAST

Introduction

Accurate measurements of shoreline change have become a prerequisite for coastal planning and management. Most U.S., and indeed world, sandy shores are presently eroding (Bird, 1976). It has become apparent that these shoreline changes represent long-term net coastal losses. Even more rapid shore recession is forecast for the future, due to accelerated sea-level rise (Hoffman, et al., 1983; Leatherman, 1983a; Giese, et al., 1987). At the same time, there has been a burgeoning of coastal development, particularly on low-lying, dynamic barrier beaches.

It is apparent that there is a need for accurate shoreline data to serve as a base for predictions of future changes. Presently, there are a number of techniques available that produce historic shoreline change data; the products vary from point measurements along the shoreline (no map product) to computer-generated shoreline change maps.

The Metric Mapping technique is probably the most cost-effective method of generating shoreline change maps that meet or exceed national map accuracy standards (Leatherman and Clow, 1983). This system makes use of the high speed data processing capabilities of a computer to emulate the best photogrammetric techniques. The maps are comparable in accuracy to those produced by a stereoplotter (Kleeger, 1983), yet metric mapping allows more flexibility, uses less expensive equipment, and requires less human effort.

For the Massachusetts shoreline analysis, both recent and historic shoreline maps, as well as aerial photographs, were utilized to generate 231 shoreline change maps.

When aerial photographs were used as data bases, a certain amount of pre-processing was necessary prior to map digitization. The tasks included identifying the mean high water line, which was chosen as the shoreline indicator, and establishing stable man-made structures to be used as coordinate control points. When historic shoreline maps

(T-sheets, or hydrographic charts) were used, certain corrections for geographic positioning had to be applied, especially for those produced during the nineteenth century.

Unfortunately, some of the older historic shoreline maps are dilapidated or have stretched too much over the years to meet National Map Accuracy Standards. With only a few exceptions, maps found to be in error by more than 10 feet were not used. (See Appendix B for a more in-depth discussion on map accuracy.)

This report describes the metric mapping methodology, data interpretation, and, in general terms, the process of map compilation. The report also discusses the difference between various data sources (e.g., maps, charts, and air photos), including their utility and accuracy.

Coastal Zone Geologic Resources

About 15,000 years ago, during the final stage of the last Ice Age (known as the Wisconsin), immense glaciers made their final advance southward, sculpting the northeastern United States. Many of the present-day geomorphic landforms throughout Massachusetts still show the influence of their glacial history. For example, such coastal landforms as the Boston Harbor Islands are remnants of long, narrow glacial till deposits known as drumlins. Further south, coarse debris accumulated by the glacial meltwaters formed an outwash plain, the relic of which is the south shore of Cape Cod. Nantucket, Martha's Vineyard, and the Elizabeth Islands are all examples of huge accumulations of glacial drift deposits known as moraines.

North Shore Geology

Coarse sand beaches dominate the coastline from the Massachusetts/New Hampshire border south to the Merrimack River Inlet. Plum Island, a barrier island, is the prominent depositional landform in this northern section. Southeast of Ipswich Bay to Coffins Beach, beach sediments decrease in size to a fine-medium grained texture.

From Annisquam to Manchester (all of Cape Ann), the coastline is characterized by rocky headlands, with intermittent stretches of sand or gravel "pocket" beaches. The rocky headlands are erosion-resistant and the shoreline has remained virtually stationary through time.

Although Gloucester Harbor is dominated by gravel beaches and rocky shores, Manchester (from Dollivers Neck to Chubb Point) predominantly consists of exposed rocky headlands. From Chubb Point to Beverly Harbor, the beach complexion changes to coarse sand and gravel, with intermittent exposures of rocky headlands.

Swampscott and Nahant beaches consist of fine to medium-sized sand. Nahant Beach, a depositional feature known as a tombolo, connects both the rocky Little Nahant and Nahant "Islands" to the mainland.

From Point of Pines south to Deer Island, man-made structures dominate the coastline with occasional large expanses of tidal flats scattered throughout. The Boston coastline is highly developed; almost the entire shoreline consists of man-made structures (revetments and bulkheads). Therefore, the Boston area was not included in this study.

South Shore Geology

Old Harbor and most of the Boston Harbor Islands are composed primarily of unconsolidated sands and gravels. These whaleback-shaped glacial features are called drumlins. The same holds true for Quincy Bay, although here the beach is flanked by exposed tidal flats.

Most of the coastline of Quincy, Weymouth, Hingham, and Hull Bay is influenced by man-made structures, with occasional limited expanses of gravel beach located throughout. From Pt. Allerton, south along Nantasket Beach, the shoreline consists of sand and gravel beaches. The coastline of Cohasset, however, is predominately rocky headlands which are slowly eroding.

From Scituate to the Marshfield/Duxbury boundary, the shoreline is highly developed and the beaches consist of mixed sand and gravel. Further south lies Duxbury Beach, a barrier beach, connecting a glacial "island" (Gurnet Point) to the mainland. This is another example of a tombolo. The back barrier environment of Duxbury Beach (Duxbury Bay and Kingston Bay) consists of marshes interspersed with extensive tidal flats.

Extensive tidal flats are also found in Plymouth Harbor which is sheltered by Plymouth Beach, a long sandy barrier spit. To the south, the coastal terrain is characterized by numerous glacially-formed small hills and valleys, called knob and kettle terrain. The beach grain size decreases in a southerly direction from gravel at Rocky Point to fine-medium sand at Sagamore Beach.

Cape Cod Geology

Cape Cod, an elongated "arm" stretching seaward from the coast of Massachusetts, is geologically very dissimilar to the mainland. The base-rock of New England is approximately 300 to 500 million years old, whereas the Cape was sculpted by the Pleistocene glaciers, which retreated approximately 10,000 years ago.

The backbone of Cape Cod is an accumulation of glacial drift, including clay, sand, gravel, and boulders. This non-uniform accumulation is known as a moraine. Subsequent melting of the ice front resulted in glaciofluvial deposits. Material was carried away from the moraine and deposited by the melt waters as gently-sloping outwash plains (all of the outer Cape and the south shore along Nantucket Sound).

Almost the entire Cape consists of coarse sand, with a few gravel beaches. Nauset Spit and Monomoy Island, both located on the outer Cape, represent two dynamically unstable barrier beaches that have changed considerably over time.

Islands Geology

Nantucket, Martha's Vineyard and the Elizabeth Islands are largely the remnants of huge moraines. The islands' topography has been influenced in the past by at least five glacial advances during the depositional process, which produced wide variations in the landscape of moraines and outwash plains.

The Elizabeth chain includes Naushon Island, Pasque Island, Nashawena Island, and Cuttyhunk Island. These consist primarily of mixed sand and gravel beaches and wave-cut cliffs.

The east end of Martha's Vineyard (Chappaquiddick Island) is an interesting area from a geomorphological point of view. Chappaquiddick is connected to Martha's Vineyard by a series of barrier beaches (bay-mouth barriers) that join headlands together along the outer reaches of embayments. This entire coastline consists of mixed sand and gravel beaches.

Nantucket Island is another interesting landform. The northeast end consists of a large cape-like feature, the western arm of which (Coatue) has six regularly-spaced triangular projections that point in towards the bay (Nantucket Harbor). These coastal features are known as cuspate spits, and they are comprised primarily of coarse sands. In contrast, the shoreline on the eastern arm is primarily a wave-cut cliff. Of further note is the northern-most tip of the cape. Here, the "Galls" area consists of a thin arm of coarse sand, which reaches out and joins Great Point to form another tombolo.

The southeast and southern sectors of the Nantucket coastline alternate between coarse sand beaches and wave-cut cliffs. These areas are of particular interest because of the large-scale erosion that has occurred over time.

Buzzards Bay Geology

The topography and coastal morphology of Buzzards Bay is very complex and irregular. Glacial outwash valleys and kettle holes create a jagged coast with many estuaries and salt ponds.

The coastline is strung with many rocky shores and headlands, although an extensive barrier beach system does exist in Westport (Horseneck Beach). In addition, numerous marshes and estuarine systems are located in the upper reaches of the embayments scattered throughout the area.

Coastal Processes

Sea levels have been rising since the retreat of the Wisconsin glaciers approximately 15,000 years ago. At that time the sea-level was about 400 feet lower than it is today. Initially, the rate of sea-level rise was very rapid. During the past 5,000 years, these rates have slowed considerably; however, sea-level is still rising in relation to the land at a rate of approximately one foot per century. This rise in sea-level may at first glance seem relatively insignificant, but a small vertical rise in sea-level translates into a much greater horizontal retreat of the shoreline. For example, if a shoreline slope varies from 1:100 to 1:1000, a one foot rise in sea-level spanning a ten year period would result in the submergence of approximately 10 to 100 feet of beach. Over a 100 year period, the shore would move 100 to 1000 feet landward. (Gutman, et. al, 1979).

It has long been known that the fundamental long-term parameter affecting shore retreat is sea-level rise. However, localized climatic episodes such as storms and hurricanes have a more immediate, and sometimes severe, impact on shoreline evolution.

Storms that affect the eastern U.S. coastline fall into two basic categories: northeasters and hurricanes. Northeasters are so named because the strongest winds frequently come from the northeast. These winter storms originate in the mid-latitudes of the U.S., frequently moving offshore at Cape Hatteras, North Carolina, then build in intensity along the coast and move northeastward toward New England.

Some of the most intense storms and greatest coastal damage along the U.S. East Coast have occurred during these nor'easters (such as the February 6-7, 1978 Blizzard). The frequency of northeasters is high, and almost every year several coastal storms of this type affect the shoreline.

One of the most severe storms ever to strike the mid-Atlantic coast occurred on March 5-8, 1962, a result of two low pressure cells converging to form a storm system which extended from Cape Hatteras to Cape Cod. This storm was especially devastating for several reasons. It occurred during spring high tide and strong northeast winds pushed water onshore during five successive high tides. Waves up to 30 feet high breached the dunes, subjecting barrier islands to bayside flooding, massive overwashing, and inlet breaching along much of the shoreline.

Hurricanes affect the East Coast in late summer and early fall, with September being the most active month. Hurricanes that strike the U.S. coastline are born in the tropical and subtropical latitudes, particularly the Atlantic Ocean west of Africa. Beginning as low pressure cells, these small tropical cyclones increase in size and intensity until they become full-fledged hurricanes (defined as maintaining wind speeds in excess of 74 miles per hour). These storms move westward into the Gulf of Mexico or turn northeastward toward the eastern seaboard.

Near the center of a hurricane, winds may gust to more than 200 miles per hour. While intense winds are a serious threat to life and property and do much damage, massive storm surges are by far the greatest cause of death and destruction in low-lying coastal areas. A storm surge is a super-elevated mound of water that sweeps across the coastline near the area where a hurricane passes or makes landfall. Surge and hurricane-driven waves act in deadly combination to hammer the outer shorelines, such as barriers, and other low-lying coastal areas.

Storms are an integral part of the oceanic environment, and records since the 1700s show that hurricanes have seriously impacted the U.S. coastline. There is some indication that hurricanes come in cycles. The last series of major storms along the East Coast occurred during the 1950s. During the past two decades, most hurricanes have entered the Gulf of Mexico rather than travelling up the East Coast. The great Atlantic hurricanes will undoubtedly return. Unfortunately, this unusually calm period has seen widespread construction of housing and commercial establishments along the East Coast.

In summary, a combination of meteorological, oceanographic and geomorphic processes control the evolution of coastal areas. These processes can be either gradual or rapid, acting over the long-or short-term. The effect of rising sea-levels on coastal erosion is gradual, thus the significance of this phenomenon might not be appreciated over the course of a few years. On the other hand, hurricanes are rapid, short-term phenomena that can cause immediate destruction and reconfiguration of the coastline.

Shoreline Protection

There are essentially two options for beach protection and shoreline stabilization: structural or "hard" techniques, such as groins and walls, and non-structural or "soft" techniques, such as artificial beach nourishment.

The rigid devices fall into two basic categories: structures designed to trap longshore transport of sand (e.g., groins and jetties) and structures designed to prevent the erosion of the shoreline (principally seawalls and bulkheads).

Groins are common shoreline protection structures that extend perpendicular to the beach. These structures are often built in a series, known as a groin field, and are intended to widen the beach and retard erosion by trapping sand (littoral drift). Unfortunately, there can be problems associated with their construction. For instance, lack of proper groin spacing can result in the net offshore transport of a high percentage of the littoral drift, thereby depleting a beach's sand supply. Furthermore, the construction of groins does not solve the beach erosion problem, but merely shifts it downdrift where severe erosion often takes place.

Seawalls, bulkheads, and revetments are rigid structures built parallel to the shoreline to serve as barriers to wave attack and storm-surge flooding. Seawalls are quite effective in preventing erosion, at least in the short-term; however, over a longer period, they can have a harmful effect on beaches. During storms these massive, inflexible structures prevent the natural exchange of sand between the dune and the beach. Without beach nourishment, or some other means of sand replenishment, the seawall will eventually collapse when it is undermined during a severe storm.

One of the simplest ways of providing beach protection is the construction or enhancement of coastal dunes. The importance of dunes as a means of natural beach protection has been recognized, and dunes have been found to be an effective barrier against storm waves by reducing the amount of salt spray and preventing overwash. Sand fencing and the planting of beach grass are the primary methods of encouraging dune development.

THE USE OF METRIC MAPS

Reading Metric Maps

The Massachusetts shoreline change maps document the changes in shoreline location during the past 140 years. Current cultural features (roads, boundaries, etc.) have been added to the maps to assist the user in locating a specific location along the coastline.

The state plane coordinate system, with numerous tickmarks drawn on each map, can serve as an accurate baseline for calculating rates and amounts of shoreline change. It should be noted, however, that cultural features should not be used as a baseline for shoreline change measurements, or any other exact form of data computation. The cultural features were digitized from U.S.G.S. 7.5 minute quadrangles drawn at a scale of 1:24,000. Since the shoreline change maps are plotted at a scale of 1:5,000, the cultural features are much less accurate in true position than the shoreline change data. All cultural features are represented by thick black lines (1 mm in width), whereas shorelines digitized from N.O.S. T-sheets and aerial photographs are depicted by thin black lines (0.5 mm in width).

In general, the 231 shoreline change maps contain 2 or 3 historical shorelines, plus the most recent (late-1970s) shoreline. Appendix A contains a full set of Index Maps. Categorization of the historical shorelines of various dates into four different shoreline time periods is intended to be a visual and graphic aid for the user in delineating shoreline trends. The "recent" shoreline (usually based on 1978 aerial photography) is represented by a solid line; the "late" shoreline (usually based on 1938-1955 N.O.S. T-sheets) is depicted by a long-dashed line; the "middle" shoreline (based on 1886-1934 N.O.S. T-sheets) is depicted by a short-dashed line; and the "early" shoreline (based on 1844-1868 N.O.S. T-sheets) is depicted by a dotted line.

Symbols have been included on the maps so that the user can identify the exact year of the data for a particular shoreline type. This information can be used to determine rates of shoreline change over a specified period of time. Not only can the shoreline change rate be generated, but other details such as shoreline change acceleration or deceleration can be inferred. It should be noted that more than one symbol can sometimes be found for each shoreline group on a particular map. This only occurs when data from different years were used to represent a particular shoreline group. For example, Map 0008 North Shore included data digitized from both 1853 and 1855 N.O.S. T-sheets in order to depict an "early" shoreline. The early shoreline is represented by a dotted line pattern throughout, but different symbols were used to differentiate between the 1853 and 1855 shoreline data. (In this case an upside-down triangle represents the 1853 shoreline, and a rightside-up triangle represents the 1855 shoreline.)

It has been known for some time now that many expanses of the Massachusetts shoreline have been undergoing erosion. The erosional "problem-areas" are predominantly confined to those beaches consisting of unconsolidated material (e.g., sand and gravel). Headland areas, such as Cape Ann and Nahant, are composed of erosion-resistant bedrock and thus have experienced little or no change in the shoreline position as documented by the shoreline change maps.

On the other hand, the shoreline change data demonstrate that the sandy beaches have been dynamically unstable over the past 130 years. The following maps illustrate the types of shoreline situations along the Massachusetts coast.

Figure 1 depicts an area near Hummocks Pond on the south shore of Nantucket Island. It is readily apparent that the coastline has been eroding at a high rate. In fact, this area has lost between 1000 and 1500 feet of beach between 1846 and 1978 (measurements taken perpendicular to the shoreline). Therefore, the average annual rate of shoreline retreat since 1848 has been approximately 7.7 to 11.5 feet per year. It should be pointed out that the erosion rates for the south shore of Nantucket Island appear to be among the highest for all of the Massachusetts coastline.

Figure 2 depicts an area near Wellfleet on Cape Cod. This map was chosen because it is a typical representation of the erosion problems afflicting almost the entire outer Cape, where average annual rates of erosion range up to 4 feet per year.

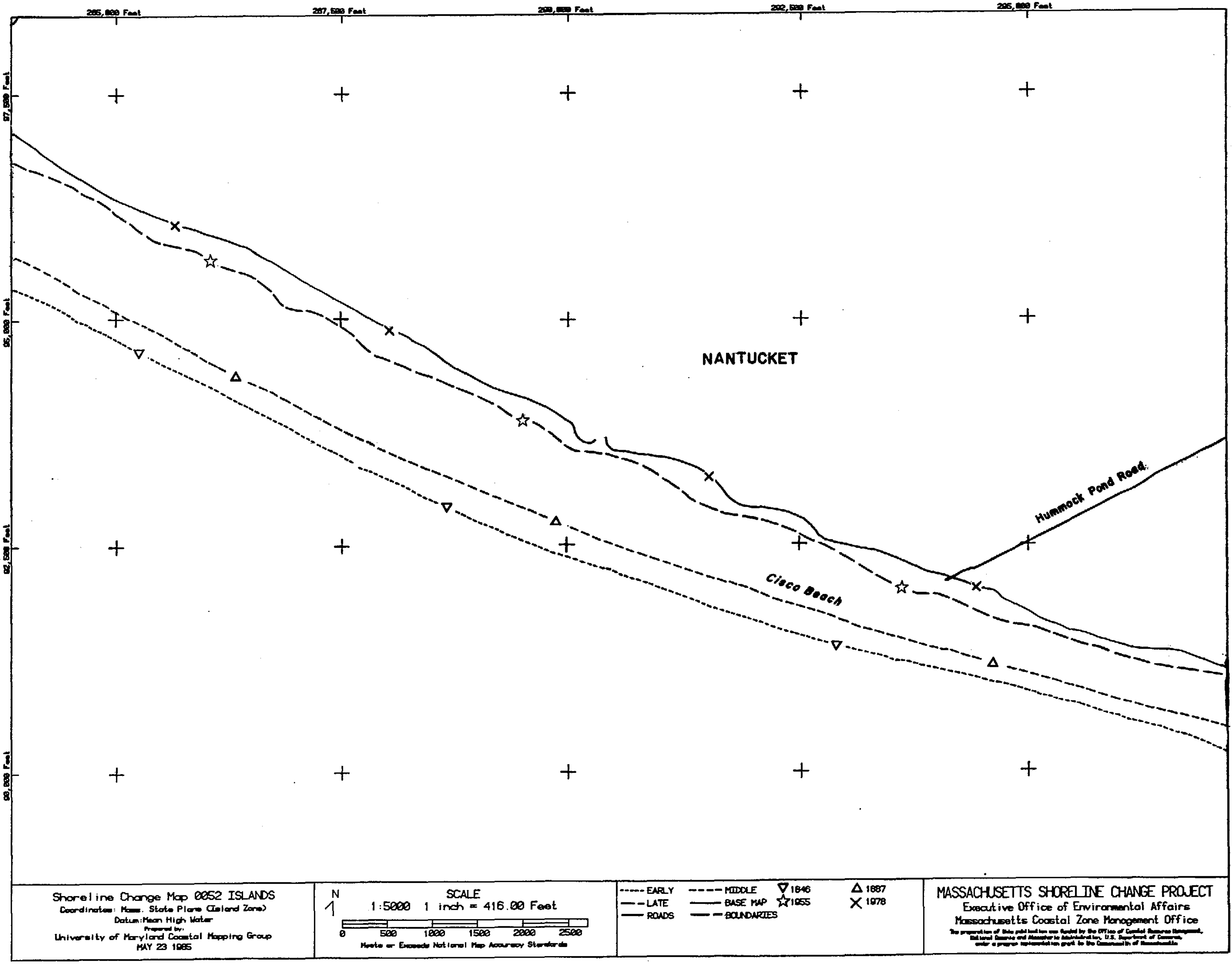

Fig.1. Shoreline Change map of Hummock Pond, Nantucket

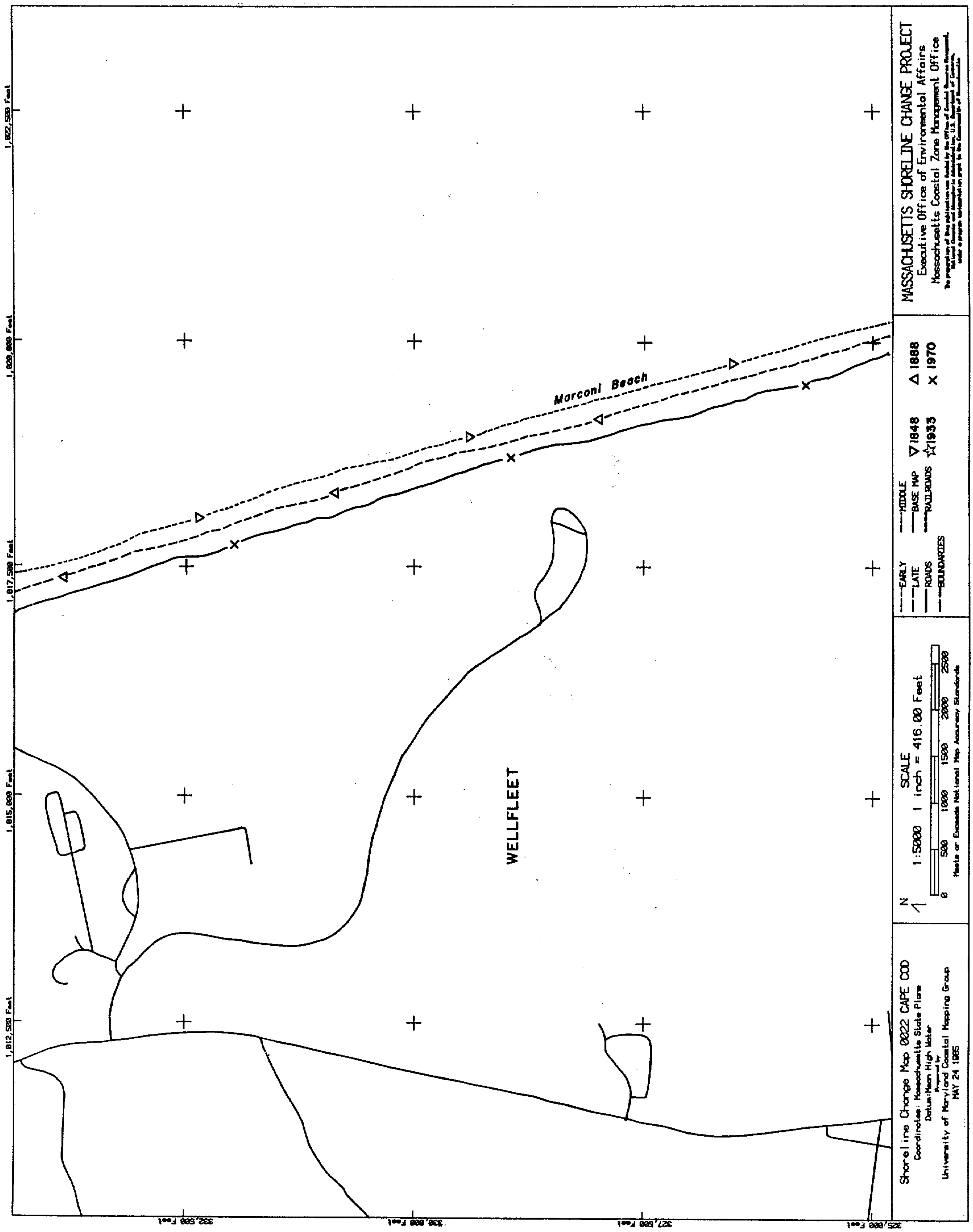

Fig. 2. Shoreline Change map of Wellfleet

Map Analysis

When first starting the evaluation of a map, it is recommended to familiarize oneself with the historic shoreline change data presented on the map. It is also convenient to color code the historic shorelines represented on each map (i.e., red = early, green = middle, blue = late, and orange = recent). Change in shore location over time can be measured with the use of transects. The transects are drawn on a paper map copy, perpendicular to the shorelines at 300-foot intervals along the coast. The quickest and easiest method of setting up transect locations is to lay a flexible rule, marked with the scaled 300-foot spacings, along the coastline and mark off the appropriate distances on the map. Transects are drawn "most" perpendicular to all of the shoreline change data represented. Where parallelism divergence occurs between plotted historic shorelines, and a transect cannot be drawn most perpendicular to all of the data, a shift in the transect location is made to a point ± 100 feet from the original proposed transect location. Each transect is labled with the map number and transect number, i.e., 35-1, on each working map (See Figure 3a).

Data tables, such as Table 1, can now be set up to show the time periods covered by the historic shorelines and the transect locations. The distances (in feet) between the historical shorelines is extracted from the maps manually. This entails measuring the distance between shorelines with the use of a good drafting divider. The distance between divider needle points is determined by holding the divider to a engineer's rule. Discernable measurements can be made to 1/60 of an inch using this method. Each 1/60 of an inch represents 6.93 feet of change. When possible, distances can be read from the rule between the 60th divisions. All measurements in inches are recorded in working data tables under the appropriate time interval and at each transect location. A (+) or (-) is recorded to indicate seaward advance (+) or landward retreat (-) of the shoreline. Measurements can then be converted to feet of shoreline change values for each transect, since each time period between shorelines is presented in an individual map data table (Table 1).

A histogram of the shoreline change between the earliest and latest time periods represented by the data can be produced for selected transects (Figure 3b). These are very useful graphs for determining areas

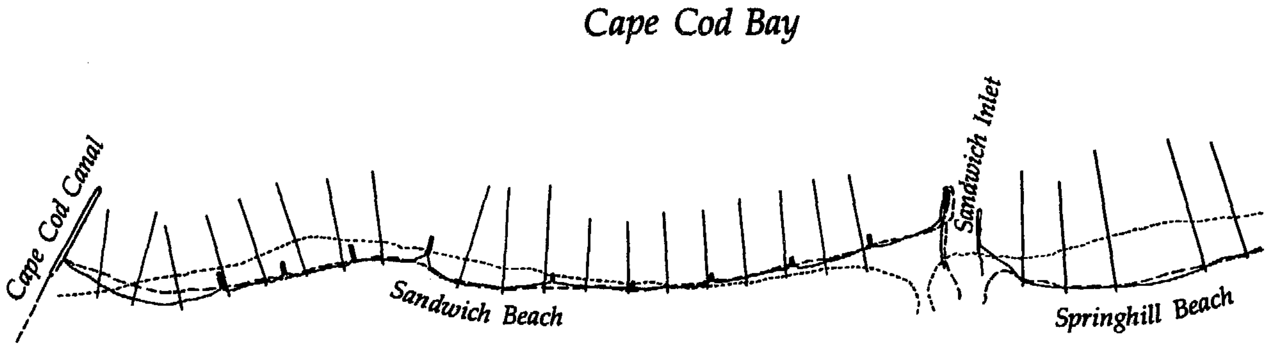

Fig. 3a. Shoreline Change Map 0035 - Cape Cod with transect locations

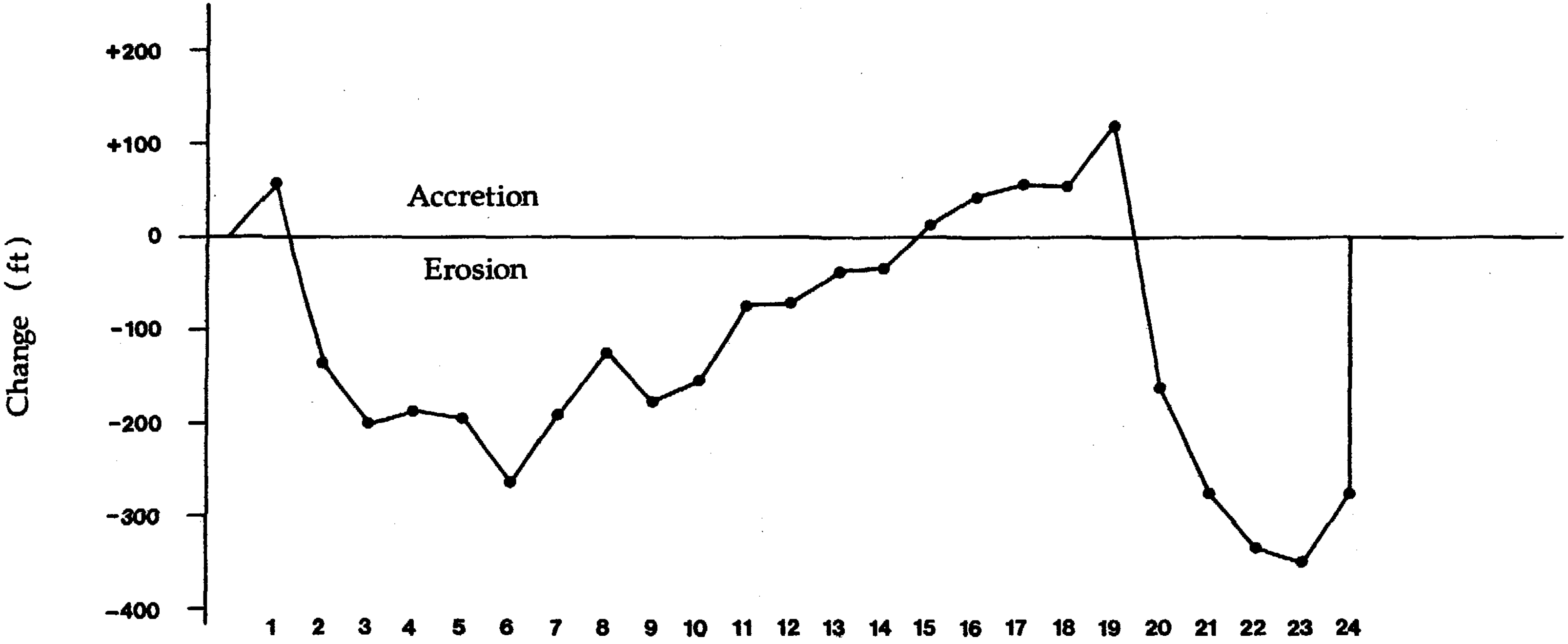

Fig. 3b. Histogram of net shoreline change 1860 - 1978

TABLE 1

SHORELINE CHANGE DATA

LOCATION: SANDWICH **MAP: 0035 CAPE COD**

SHORELINE INTERVALS

TRANSECT	1860 - 1952 CHANGE		1952 - 1978 CHANGE		1860 - 1978 CHANGE	
	MEASURED	FEET	MEASURED	FEET	MEASURED	FEET
35-1	+20.0	+138.6	-12.5	- 86.6	+ 8.0	+ 55.4
35-2	-5.0	- 34.7	-15.0	-104.0	-20.0	-138.7
35-3	-17.5	-121.3	-11.5	- 79.7	-29.0	-201.0
35-4	-21.5	-149.0	- 5.0	- 34.7	-26.5	-183.7
35-5	-23.0	-159.4	- 5.0	- 34.7	-28.0	-194.1
35-6	-35.0	-242.6	- 3.5	- 24.3	-38.5	-266.9
35-7	-24.0	-166.3	- 3.5	- 24.3	27.5	-190.6
35-8	-17.0	-117.8	- 1.5	- 10.4	-18.5	-128.2
35-9	-23.5	162.9	- 1.0	- 6.9	-24.5	-169.8
35-10	-23.0	-159.4	+ 1.0	+ 6.9	-22.0	-152.5
35-11	-15.0	-104.0	+ 3.5	+ 24.3	-11.5	- 79.7
35-12	-10.0	- 69.3	0.0	0.0	-10.0	- 69.3
-5-13	- 6.0	- 41.6	+ 0.5	+ 3.5	- 5.5	- 38.1
35-14	- 4.5	- 31.2	- 0.5	- 3.5	- 5.0	- 34.7
35-15	+ 4.0	+ 27.7	- 2.0	- 13.9	+ 2.0	+ 13.8
35-16	+ 5.5	+ 38.1	0.0	0.0	+ 5.5	+ 38.1
35-17	+ 8.5	+ 58.9	0.0	0.0	+ 8.5	+ 58.9
35-18	+12.0	+ 83.2	- 4.5	- 31.2	+ 7.5	+ 52.0
35-19	+18.0	+124.7	- 0.5	- 3.5	+17.5	+121.2
35-20	-21.0	-145.5	- 3.0	- 20.8	-24.0	-166.3
35-21	-39.0	-270.3	- 0.5	- 3.5	-39.5	-273.8
35-22	-49.0	-339.6	- 0.5	- 3.5	-49.5	-343.1
35-23	-47.0	-325.7	- 3.5	- 24.3	-50.5	-350.0
35-24	-42.0	-291.1	+ 0.5	+ 3.5	-41.5	-287.6

along the coast which have been subjected to the greatest change. Histograms visually present a measure of the shoreline change and indicate stable areas as well as areas along the coast that are more vulnerable to erosion. Rates of shoreline change between the earliest and latest shorelines for each transect can be listed on the shoreline change map at each transect location.

Conclusion

The methods used in long-term historical monitoring are obviously not without fault. Rates of change are, to some degree, less accurate than trends or direction of change, but when an analysis can be documented for shoreline change data spanning a 100-year time frame, the significance of the data is well founded. Thus, the method of using topographic charts and aerial photographs represents the best method available for investigating long-term trends in shoreline changes (Morton and Pieper, 1977).

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APPENDIXES

A. Index Maps

B. Data Sets

C. Metric Mapping Procedures

D. List Of N.O.S. T-sheets Used In The Massachusetts Shoreline Change Project

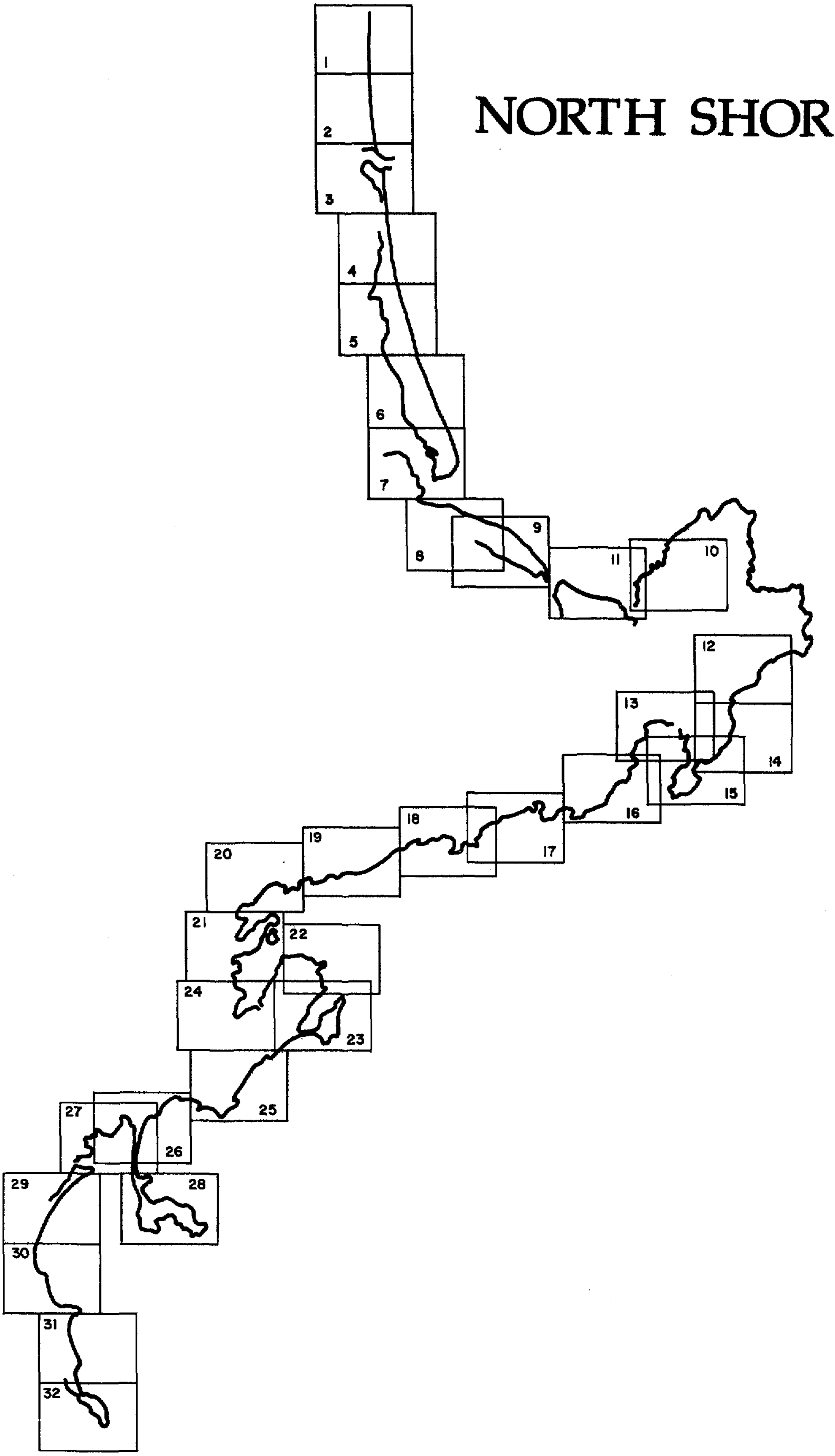
E. List of N.O.S. T-sheets Not Acceptable For Use In The Massachusetts Shoreline Change Project

F. Glossary of Technical Terms

APPENDIX A

Index Maps

NORTH SHORE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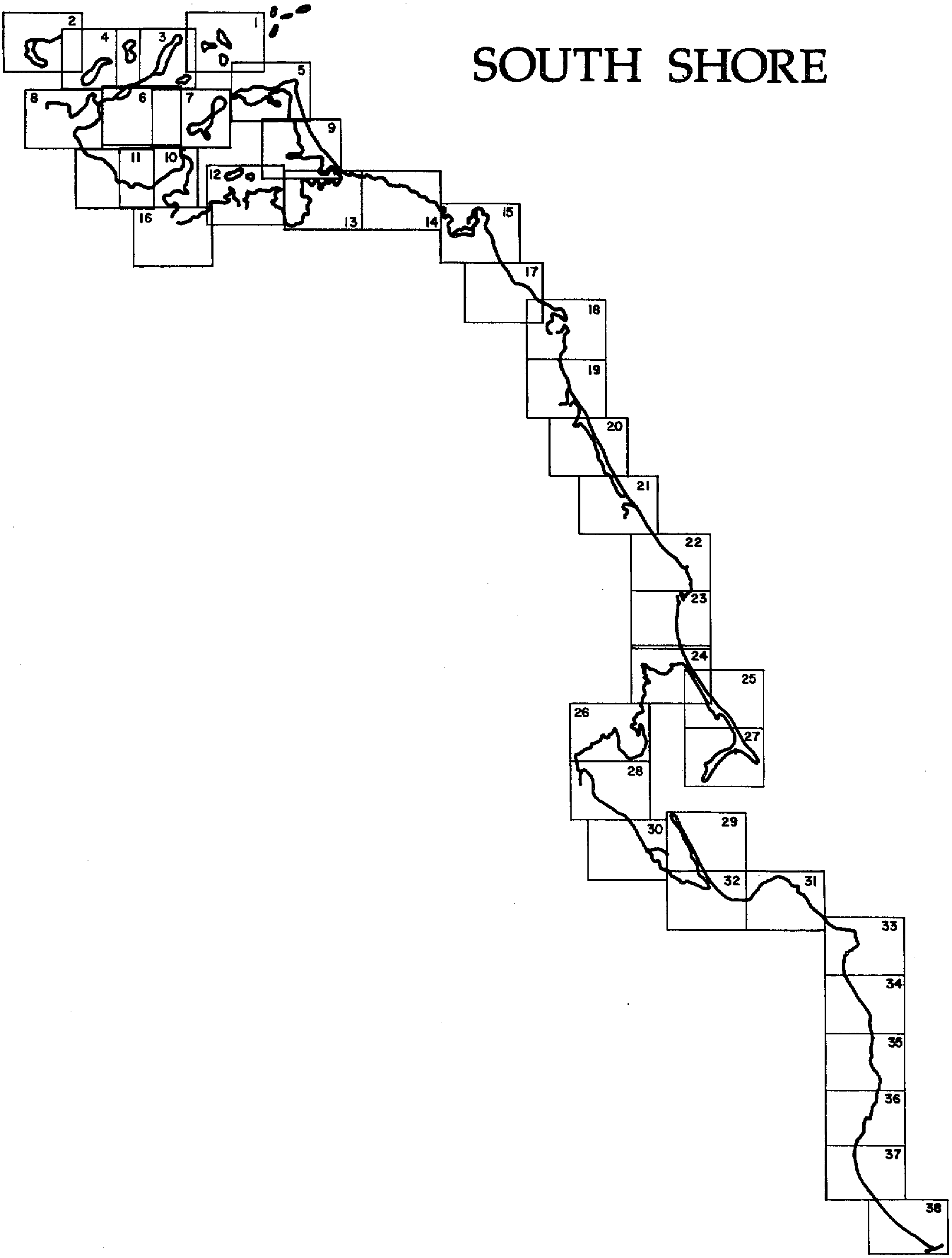
SOUTH SHORE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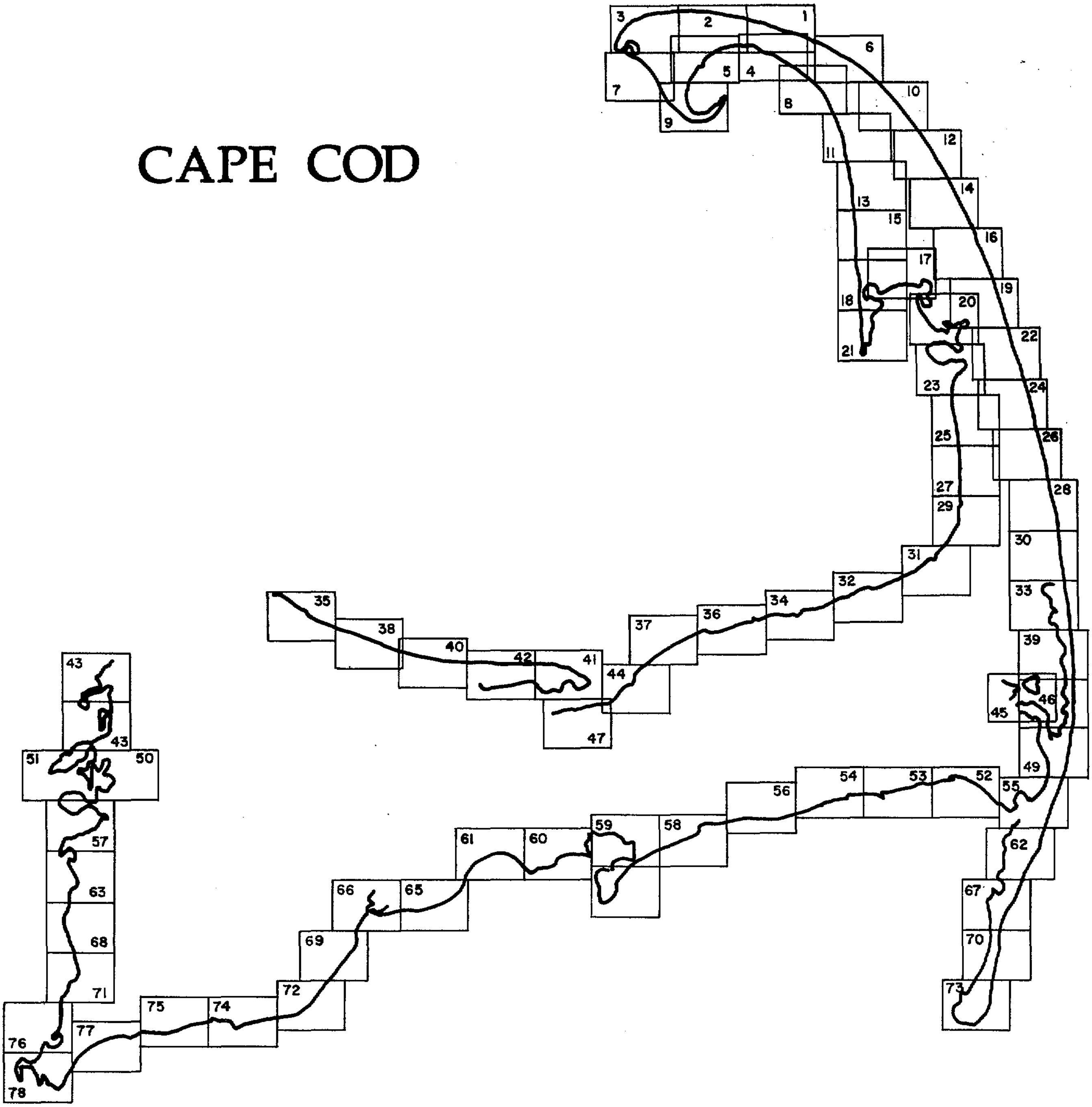
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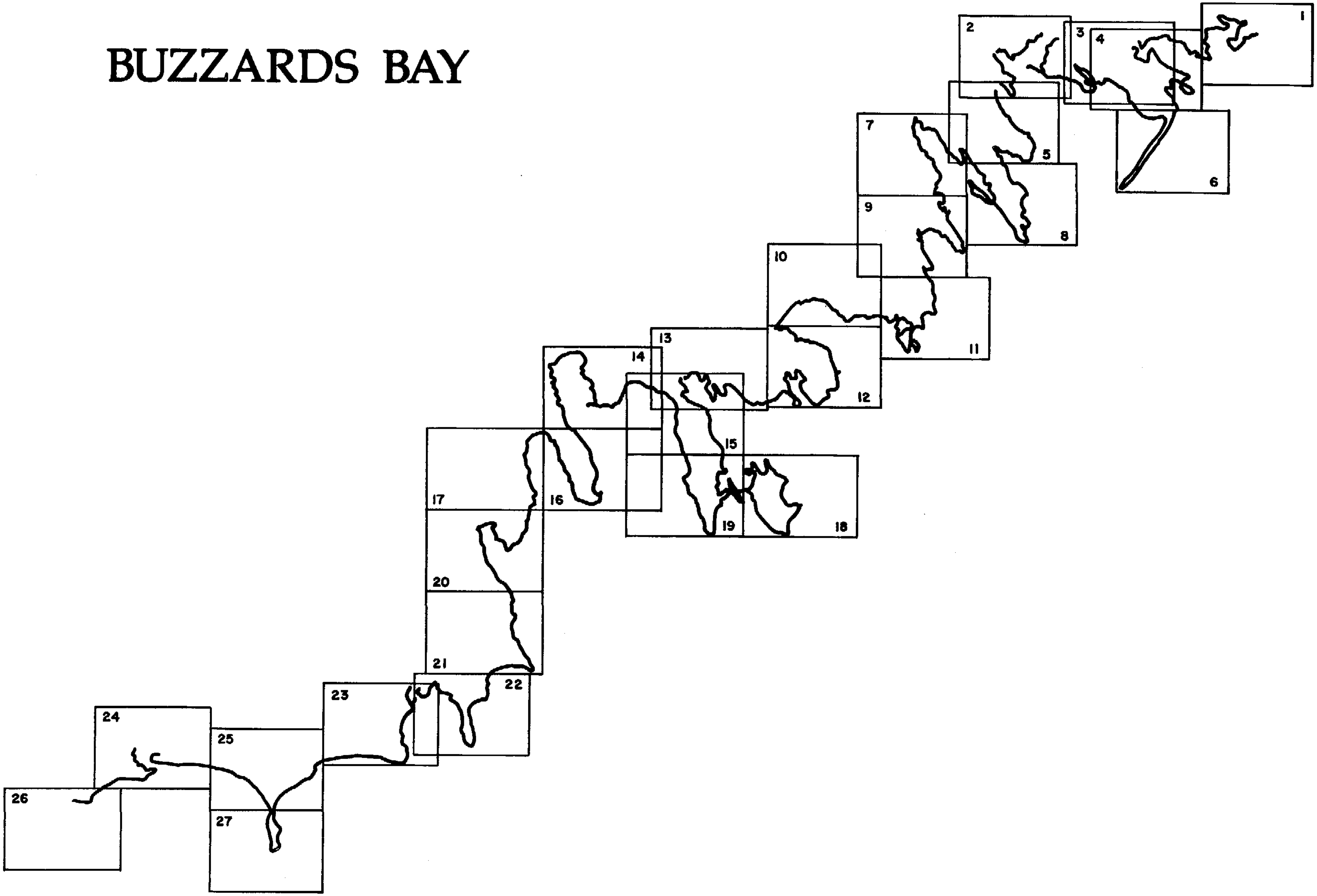
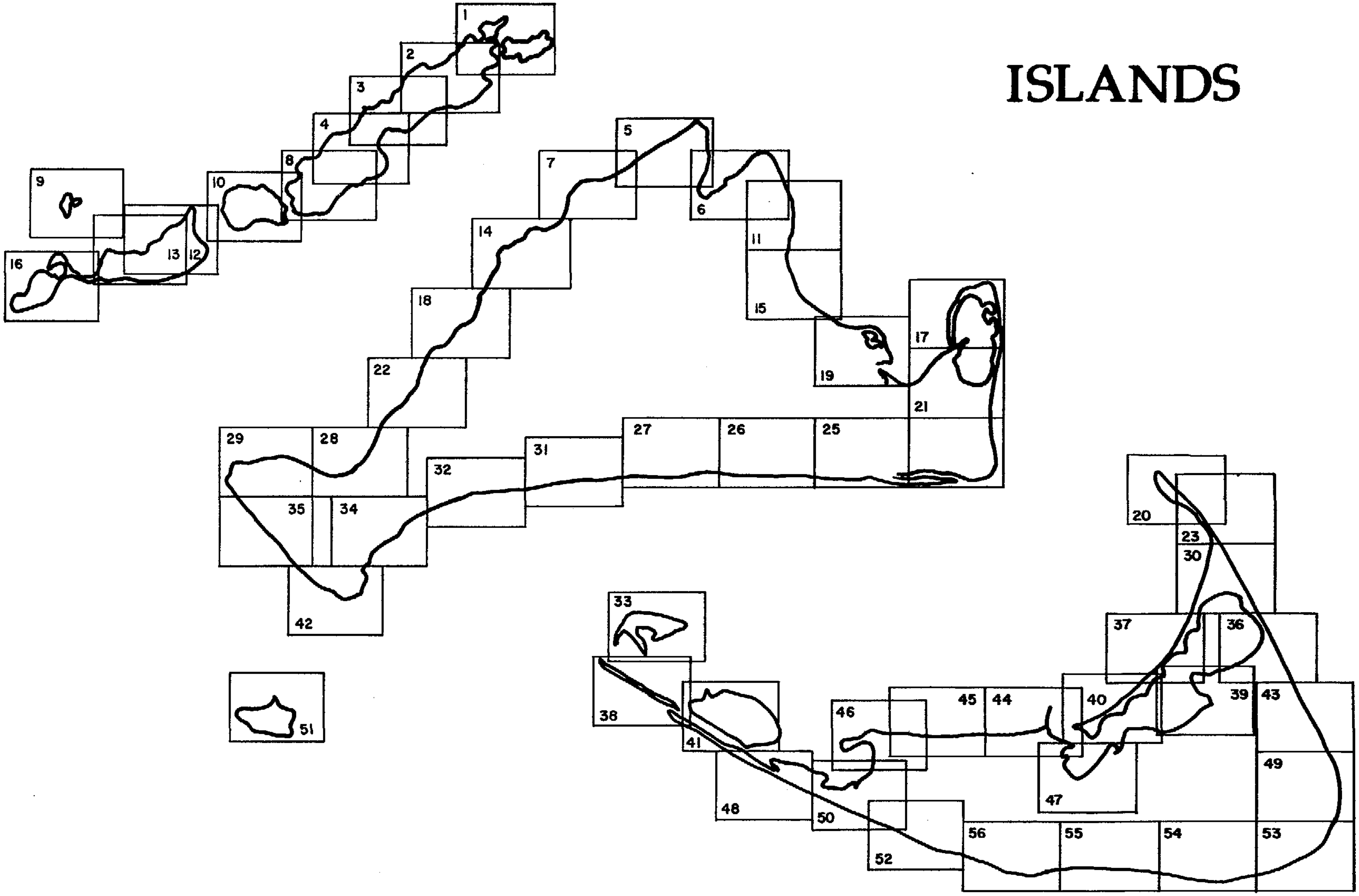
BUZZARDS BAY



ISLANDS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APPENDIX B

Data Sets

DATA SETS

Introduction

Six different varieties of map sets were used as the data base for the Massachusetts shoreline change mapping project. These sets include National Ocean Survey (N.O.S.) topographic maps (T-sheets), hydrographic maps, Flood Insurance Study (FIS) topographic maps (produced for FEMA by various contractors), orthophotos, aerial photographs, and U.S.G.S. Quadrangles. The insurance maps, orthophotos, and aerial photographs served as the data base for the most recent (1970s) shoreline. The earlier (1850-1950) shorelines were digitized exclusively from T-sheets and hydrographic charts. Cultural features were digitized from the U.S.G.S. Quadrangles.

Topographic Maps and Hydrographic Charts

Shoreline change maps can only be as accurate as the base maps from which the data were digitized. With respect to historic accuracy, topographic sheets (T-sheets) and hydrographic maps produced by the U.S. Coast and Geodetic Survey are the earliest surveys available that are recognized to be accurate and justifiable for use in quantitative studies. In fact, the courts have repeatedly recognized the competency of these maps in depicting the coastline as it appeared more than one hundred years ago (Shalowitz, 1964).

Maps produced before 1929 contain obsolete geographic data (latitude/longitude grids) that are usually in error by at least 60 feet when compared to the modern, North America 1929 datum. Fortunately, data on almost all of the early, pre-1929 maps can be converted to modern data by the use of triangulation stations.

Triangulation stations are survey stations for which exact geographic coordinates are known. Generally, early maps contain at least one station, usually more. Over the years, the geographic coordinates of the stations (current listings of which can be obtained from the National Geodetic Survey), have been modernized. Thus, it is a fairly easy (albeit time-consuming) task to convert obsolete geographic data to more accurate modern data.

Experience proves that there are occasional historic maps containing inaccurate geographic data. This problem is usually confined to those maps produced during the nineteenth century. Such inaccuracies can either be attributed to original misplacement of triangulation stations on the map sheet or distortion of the manuscript due to stretching and shrinking over the years.

Fortunately, the metric mapping package can detect inaccurately placed triangulation stations. When one or more stations were determined to be inaccurate (greater than 10-foot error), other, more accurate, stations were searched for and used instead. In general, maps were not used when the corrected data were found to be off by more than 10 feet (see Quality Control).

The shoreline plotted on T-sheets and hydrographic charts coincides with the mean high water line. This line represents the shape and extent of the shoreline at average high tide and was preferred by the early surveyors over other shore/sea boundaries such as the mean low water line.

From the surveyor's standpoint, the high-water line is the only demarcation line visible at all times, regardless of the height of the tide. At high tide, the high water line is easily determined; at low tide the boundary can be closely approximated by observing the visible signs of high tide, such as the discoloration of sand and rocks and driftwood deposits. Thus, the mean high water (MHW) line served as the base from which all shorelines were digitized (Shalowitz, 1964).

Almost all T-sheets and hydrographic charts are scaled at 1:10,000. Occasionally maps scaled at either 1:5,000 or 1:20,000 were used.

Flood Insurance Topographic Maps

Topographic maps were produced by various contractors for FEMA and used in flood insurance studies in coastal communities of Massachusetts. All of these topographic maps meet or exceed National Map Accuracy Standards and are generally scaled at 1:5,000. Unfortunately, the mean high water line was not delineated on any of the maps. However, through the use of tide tables and map contour lines, and by knowing the time and day that the original imagery was taken (the topographic maps were based upon aerial photographs), calculations were made which enabled the high water line to be placed on the maps with a high degree of accuracy.

Orthophoto Maps

Orthophoto maps can be described as photomaps (Lillesand and Kiefer, 1979). They are generated from overlapping conventional photos in a process called differential rectification. This process eliminates photo scale variation and image displacement resulting from relief and tilt. Like photographs, these maps show the terrain in actual detail (Lillesand and Kiefer, 1979).

The orthophotos used in the Massachusetts shoreline change study were produced primarily for delineating wetlands. Unfortunately, the MHW lines are not delineated on any of the maps, although this line can often be determined directly from the orthophoto by delineating the wetted boundary (dark-toned sand). The same visible signs of high tide that made the MHW line convenient for the early surveyors to map can usually be observed directly from the orthophotos.

Orthophotos were scaled at 1:5,000 and 1:7,500. The Nantucket shoreline, part of Buzzards Bay (Marion, Mattapoisett, Wareham), and part of the North Shore were all digitized from orthophotos made in the 1970s.

Aerial Photographs

Vertical aerial photographs were digitized and used exclusively to fill gaps in the recent (1970s) data. These gaps resulted from the lack of adequate and/or accurate maps for some areas along the Massachusetts coastline. The western half of Martha's Vineyard, the south shore of Massachusetts and parts of Cape Cod were digitized from air photos.

The annotation, data selection, and digitization of air photos followed a slightly different procedure than was used for topographic maps. Since air photos do not contain labelled tickmarks or triangulation stations (collectively known as primary control points), secondary control points had to be selected. These points were obtained by comparing maps (usually the 1950s vintage NOS T-sheets) with corresponding airphotos and identifying stable features that appear on both data sets (e.g., corners of buildings, road intersections). These features (or points) were used as secondary control points. The selected points (minimum of 4) were marked on both photograph and map and given a unique identification number. Both primary and secondary control points were then digitized from the map. The primary control points were used by a computerized transformation subroutine to change the secondary control points from digitizer coordinates to state plane coordinates. The control points, thus corrected, were subsequently used in the photogrammetric transformation of the photograph.

Occasionally airphotos and/or the corresponding topographic maps are almost completely devoid of corresponding permanent features, thereby precluding the location of four secondary control points. Aerial photographs such as these were not used. Therefore, there are occasional gaps in the 1970s vintage shorelines.

The location of the mean high water (MHW) line was determined by identifying the wetted boundary under stereoscopic viewing. The MHW line was undeterminable on some photographs; these were not used for the mapping project.

Since air photos do not contain latitude/longitude lines or other convenient "match lines", the exact joining of the MHW line from one airphoto to the next was often very difficult, if not impossible. For this reason, shorelines digitized from air photos were not "tied" together; therefore, small gaps (less than 1/3 inch in length) exist after mapping of the data. (These abrupt breaks in the shoreline should not be confused with landward curving breaks that indicate inlets.)

U.S.G.S. Quadrangles

Cultural features, such as roads, railroads and corporate boundaries, were digitized exclusively from U.S.G.S. 7.5-minute quadrangles. These features were added so that the map-user could easily locate the shoreline section in question and ascertain the general aspect of the area (e.g., quick identification of land vs. water bodies).

The cultural data are not as accurate as the shoreline change data. The quadrangles (from which the cultural features were digitized) are printed at a scale of 1:24,000. The N.O.S. T-sheets, orthophotos, and aerial photographs were usually scaled at 1:10,000 or less. Since the shoreline change maps were plotted at a scale of 1:5,000, any inherent mapping or digitizing errors are increased five-fold. For this reason the cultural features should only be used to assist the user in locating the area of interest.

Not all roads were digitized from the quadrangles. Many minor roads are not shown on the shoreline change maps; however, most major roads were digitized along with most city/town boundaries. Minor roads were digitized only when deemed necessary; representation increased with proximity to the coastline.

APPENDIX C

Metric Mapping Procedures

METRIC MAPPING PROCEDURES

Techniques used for map-making have changed considerably over the last 150 years. The earliest maps that are of sufficient accuracy to permit quantitative comparisons were derived from careful ground measurements. The U.S. Coast & Geodetic Survey relied upon the laborious alidade and planetable techniques to obtain ground survey data. The data thus obtained, along with free-hand sketches between survey points, were used to draw a map (Shalowitz, 1964).

Through time, triangulation techniques improved the accuracy of field survey methods and new instruments improved the speed at which a survey could be conducted. Map-making, however, was still a time and labor-intensive process. With the invention of the airplane and refinements in the photographic process, came the possibility of using vertical aerial photography for creating maps. The development of modern photogrammetric techniques has made map-making from vertical aerial photography very accurate and, as compared to ground surveys, cost-effective.

There are a number of problems with aerial photographs related to the camera and the irregularity of the flight line of the plane used to take the photographs. One major problem with aerial photography arises from the inability of an airplane to fly in a perfectly straight line at a constant altitude. Changes in altitude cause the scale to vary from one photograph to the next, and the camera is very rarely oriented exactly vertical with respect to the ground at the moment that the shutter is opened. Virtually all aerial photographs are slightly tilted, with 1-degree being common but usually not exceeding 3-degrees (Lillesand and Keifer, 1979).

Another problem introduced by the camera is radial lens distortion. Lens distortion varies as a function of radial distance from the photo isocenter. Thus, the center of the image is relatively distortion-free but, as the angle of view increases, distortions become more pronounced. While this was a significant source of error in earlier photography, it has become less of a problem with refinements in lens manufacturing techniques.

The technology most often employed by professional photogrammetrists and federal agencies (e.g., N.O.S. and U.S.G.S.) to construct maps is the stereoplotter. This instrument has the ability to make corrections for lens and atmospheric distortions as well as for irregularities in the airplane flight line. The stereo projection allows the operator to trace the contours of the ground onto a topographic map. This method, while it is very accurate (meets or exceeds National Map Accuracy Standards), requires the use of sophisticated and expensive equipment and is labor intensive. A number of other techniques have been used previously by coastal scientists, but these methods yield much less accurate maps (Leatherman, 1983a).

The metric mapping technique makes use of the high speed data processing capabilities of a computer to emulate the best photogrammetric techniques. Several statistical techniques have been employed to filter inherent imaging distortion beyond that of simple planar rectification.

Many of the techniques of photogrammetry have mathematical origins and can be programmed into a computer. Thus, the development of this package of programs was initiated as an attempt to develop a system which maintains the accuracy of standard photogrammetric techniques but allows more flexibility, uses less expensive equipment, requires less human effort, and is therefore more cost effective in producing accurate map products.

The package of computer programs used in this project is written in Fortran 77 for a Prime computer. This system can be divided into 4 distinct tasks: (1) annotation and data selection, (2) digitization and transformation, (3) data adjustment, and (4) map plotting.

The abilities of the package include simple transformation of original maps to state plane coordinates, space resection of photographs to correct for distortions introduced by irregularity in the flight path, and a method for drawing the data on paper to produce final maps. Data are input through an X-Y coordinate digitizer and finally drawn by a computer-driven plotter.

Although the computer does much of the work, a certain amount of manual pre-processing is required. The steps done by hand include selection of stable control points, data annotation and node point selection. The maps and photographs are digitized and the output is fed directly into the host computer. The computer is used to correct the photographs for various distortions, to adjust the data at joints between adjacent photographs, and finally to plot onto a map.

Annotation and Data Selection

Selection of control points and annotation of desired features must take place prior to actual line digitization. A control point is a location visible on both the map and photograph for which the geographic coordinates are known. These points are used in the transformation process to calculate the transformation necessary to correct for such error factors as scale and rotation. The lines to be digitized are annotated at the same time that the control points are selected. Annotation is often not necessary on maps because the features are usually clearly marked. On a photograph, however, a magnifying stereoviewer (6X) is used to determine exactly where the lines are to be drawn. Selected features are "annotated" with a fine-line technical pen to make them easily visible to the naked eye.

Selection of the control points is straightforward in the case of a map since geographic coordinates are always indicated. These geographic coordinates are called primary control points. A minimum of 4 points is required, to ensure accuracy and aid in error analysis.

Each feature on the map or photograph is digitized separately, allowing maps displaying only particular features to be drawn. Points where boundaries meet and where features are broken by the edge of the photograph or map are identified. These "node" points are later used to identify boundary lines and to allow a data-smoothing program to recognize boundary lines to be tied together. These node points are also sufficient for creating polygons from the data, although this feature has not been used to date.

Digitization

The first step in the computer mapping process is to convert features depicted on a map or photograph into numerical data that can be easily handled by a computer. This process, known as digitization, involves converting an image into a list of X-Y coordinate pairs. An arc, composed of a series of these X-Y coordinates connected by straight lines, may describe a shoreline, a road, a pond, or any other feature. A collection of these line segments, when drawn together, can be used to create a map with as much detail as desired.

Arcs, representing particular historic shorelines or other physical features, are distinguished from each other in two primary ways:

1) the year in which the map was drawn or the photograph was taken; or
2) an artificial data type, hereinafter referred to simply as type, which denotes what sort of feature is described by the line (e.g., type 1 = shoreline, type 2 = roads). The two groupings impose a structure on the data, allowing easy selection of features which are to be drawn on the final map.

Data is collected by the digitizer, which uses essentially arbitrary units in its coordinate system. The only requirement is that its coordinate system be rectilinear (orthogonal with scale equivalence in both directions) and accurate within 0.005".

The arbitrary digitizer coordinates must be transformed into a recognized coordinate system; the easiest coordinate system to use is known as the "state plane" coordinate system. This system is convenient because it is rectilinear and based on common units (feet). There are actually many such systems, each with a different origin, for different parts of the United States.

Transformation

The metric mapping system implements data transformations during digitization. The operator provides a list of control points to be used for each map or photograph. This may be done either by entering state plane or latitude-longitude coordinates directly (latitude-longitude coordinates are immediately converted to state plane coordinates) from the terminal or by requesting that the program read this information from a previously prepared file. The operator then provides the coordinates of these points in the digitizer coordinate system. With the coordinates of control points known in both coordinate systems, parameters are computed to transform digitizer coordinates into state plane coordinates.

The process of transforming data from digitizer coordinates to state plane coordinates is different for maps than it is for photographs. The maps must be corrected only for scale, location, and rotation. In other words, there is a direct relationship between digitizer coordinates and state plane coordinates once the map has been properly oriented and the relationship between the origins determined.

The transformation program uses the primary control points to find a "least squares" solution to the scaling and rotation transformation. For photographs, however, there is a different set of problems introduced by the fact that airplanes cannot fly perfectly straight or level. In particular, beyond the obvious factors of scale and location, photographs must be corrected for tilt, tip, and yaw. These are side-to-side swings, front-to-back motion, and deviation with respect to north or with respect to the flight line if the plane was in a crosswind. Thus, the photographs require a three-dimensional transformation, which is inherently more complicated than the two-dimensional one, and there is no closed-form solution possible.

The two-dimensional tranformation involves one rotation, scaling, and translation. The scaling factor is computed first by determining the distances between control points. The distance between any two control points must be the same on the map as it is between known state plane coordinates of those points. Next the rotation is computed by comparing the angles between control points and the vertical axis. Finally, the translation is computed by determining the distance between the center of the controls on the map and the center of the known control. Throughout this process, averages are used to ensure the best fit for all of the control points. The transformation program forces the use of at least four control points, one more than is necessary for a unique solution, to ensure that the transformation is correct.

The three-dimensional tranformation is considerably more complicated. The photogrammetric method of space resection is employed to compute a transformation matrix. This method, which is discussed by

Keller and Tweinkel (1966), was specifically developed by the U.S. Geological Survey for determination of the three angles, flying height and coordinates of the camera at exposure time. The transformation matrix is used for changing digitizer coordinates into the correct state plane coordinates. A true space resection makes use of not only the ground coordinates of control points but also of their elevation. Elevation can be an important factor if the study area has a great deal of relief. For our application, this has not been a concern since natural relief is quite low on the Massachusetts coastline. The program is, however, capable of including elevation in the computations for areas where there is significant natural relief or if the tops of tall man-made structures are used as control points.

The digitizing program requires that there be at least 4 control points on each photograph or map. In the case of a planar transformation, this is one more point than is necessary to ensure a unique solution. For space resection, 4 points are required to guarantee uniqueness. Four control points were typically used in this application; however, up to 6 were included in some instances.

The transformation subroutines display a table that summarizes the results of the transformation process. Included in the information given by the subroutine is a list of residual errors or differences between known geographic coordinates at control points and transformed coordinates of digitized control points. The magnitude of residuals is dependent on map scale and accuracy with which the control points have been digitized. For example, a 10-foot residual on a map of 1:24,000 scale corresponds to only 0.005" on the map. Thus the residuals provide a good check on digitizing accuracy. If the values are large, then the control points were either digitized out of sequence, coordinates were keyed incorrectly, or the control points were incorrectly placed on the map. The space resection subroutine also outputs location and altitude of the camera as well as tip, tilt, and yaw angles as a further check on transformation accuracy. Of course, the operator must have some prior knowledge of the photography in use, such as approximate heading and altitude of the flight line and focal length of the camera. Upon examination of the residuals, the operator is given the opportunity to go back and re-enter control point information and redigitize control points in order to correct large residual errors.

The transformation subroutines are designed to convert one photograph or map at a time. The digitizing program reads in the control points, calls the appropriate subroutine to calculate the transformation, and then converts the data points as digitized. This "one photograph at a time" method has the advantage of simplicity of digitization and program operation. There are two disadvantages; namely, this method requires a great deal of ground control (at least 4 points for each plate) and it ignores the fact that aerial photography is taken in strips which can be an advantage when joining photographs together.

The single photograph method has worked well under most circumstances. Modern aerial photography is usually of sufficient quality that, given good ground control, photographs will fit together very well once they have been separately "tied" to the ground. This is, however, not always true since some imagery is almost completely devoid of ground control, thereby precluding their use for mapping purposes.

Once the transformation has been computed for the map or photograph, the actual data may be digitized. The operator keys in the node IDs and the data type of each arc to be digitized. Having checked that this information is correct, the arc is then digitized either in a continuous mode where the digitizer transmits a point each time the cursor has been moved by some pre-specified distance, or with the elapse of some time interval. Alternatively, the digitizer may be used in single point mode for less complex features. The program also draws the arcs on a graphics terminal as digitization proceeds to give visual confirmation that the data have been digitized correctly.

Clearly, the digitizing process is the most crucial step in the entire metric mapping process. The system builds as many checks into this process as possible to guarantee that accuracy is maintained.

Data Adjustment

After the data have been transformed into state plane coordinates, smoothing is sometimes required. Digitizing errors must be corrected and line segments describing a continuous feature must be adjusted so that end points match.

The problem of inexact matching of data segments stems from the fact that the study area is covered by many photographs, all of which are digitized and transformed individually. To address this issue, two approaches have been taken. One method is to adjust all of the line segments in a batch, i.e., try to ensure that all segments of a particular type and year match up to form a continuous line. The other approach is to manually adjust segments and/or blocks of segments. These two techniques are implemented through two separate programs. The first program is a type of block adjustment, the latter program is an interactive editor which allows the user to visually correct data.

The first data adjustment program applied is named "TIE". This program is designed to correct a large number of small data problems in a batch-type environment. In particular, this program uses the node IDs discussed earlier to check the distance between the end of one arc and the beginning of another. If this distance is found to be less than some specified tolerance level (usually 20 feet or less), the gap will be bridged in one of two ways, depending on whether the arcs were digitized from the same plate. If the arcs were digitized from the same plate, the end point of each arc is simply moved to the halfway point in the gap. This procedure works well if there is no overlap between the two arcs and is based on the assumption that the data gap was introduced by operator error in the digitizing procedure.

Arcs that meet at the joint between two plates are handled somewhat differently. In this case, the arcs are subjected to a linear transformation that rotates the arcs about their opposite ends and applies a scaling factor so that the two arcs meet at the halfway point between the two end points. This procedure is based on the assumption that the data gap is due to slight errors in the transformations at adjoining plates rather than to operator error.

The second technique for data correction is a program using an interactive editor. It is similar to a text editor in that it takes commands from the user and modifies a file to reflect changes made by these commands; however, it operates on graphic data, rather than text.

The program makes use of an interactive graphics terminal that allows the user to display line segments and alter them with direct visual confirmation.

It has been found that good original maps and photographs require very little editing once they have been subjected to the TIE program. Conversely, poor aerial photography (which some argue should not be used in the first place) can require extensive changes to achieve a map in completed form. In some sense, the editor provides a function quite analogous to manual controls on optical photogrammetric devices. The operator can adjust the photograph so that it fits nicely with its neighbors before hand drawing the map. The editor is merely working on individual line segments instead of an entire photograph. The fact that data can be altered in non-exact ways is analagous to what a cartographer does when he draws features in an idealized form.

Map Plotting

The primary objectives for the plotting program include the ability to draw the data to scale with state plane reference marks, to distinguish different years and types for time series studies, and to select a subset of a file for a particular application. The program takes advantage of the hierarchical data structure to allow subsets of the data to be drawn. The program has been designed to provide a great deal of flexibility while maintaining ease of operation.

When operating the plotting program, the user is able to select a subset of the data to be used by type, year, and geographical area. The program allows the user to choose dash patterns and in-line symbols to differentiate lines. It also has facilities for automatically sectioning maps for areas that are too large to be shown on one map sheet. The program will work either with an interactive graphics terminal or with a pen plotter. If the plotter is on-line, the user may switch back and forth between the two types of output devices.

Quality Control

Mapping techniques are subject to a variety of error sources, introduced either by the source materials or by human factors.

The National Ocean Survey (N.O.S.) T- sheets are the most accurate maps commonly available for the coastal zone. Stable points located on these maps are accurate to within 0.3 mm of their actual position at the scale of the map (1:10,000). The smallest field distance measurable is between 7 and 16 feet (Ellis, 1978).

Some inherent error exists in the original topographic surveys conducted by the U.S. Coast Survey (U.S. Coast and Geodetic Survey, now called National Ocean Survey). Shalowitz (1964) stated that the degree of accuracy of the early surveys depended on many factors including the purpose of the survey and the importance of the area surveyed. However, there is little doubt that these coastal surveys are on a large enough scale and in sufficient detail to justify their use for quantitative study (Shalowitz, 1964).

Considerable experience was gained working with the N.O.S. T- sheets from the Massachusetts and other shoreline change projects. In a few cases the T/- sheets were not immediately acceptable for digitizing. As technological advancements allow for a more accurate determination of triangulation station coordinates, the National Geodetic Survey will publish the updated data, the use of which greatly improves the accuracy of the older T/- sheets. It is important to note that the original N.O.S. shoreline manuscripts have been subject to a some amount of shrinkage and stretch, which may be sources of error. For instance, it was found that some 1800s vintage N.O.S. T/- sheets were actually at a scale of 1:10,015 and not 1:10,000 as printed on the map. These errors were discovered by computing the stated and actual distance between control points. While these errors are extremely small, it was necessary to make corrections to the maps in question before digitizing.

Another potential problem is radial lens distortion with older aerial photography. There appears to be no way to correct for this problem without knowing the make and model of the lens which was used. Fortunately, modern lenses are relatively free from this problem, and only recent photography (1978) was used in this project.

Other sources of error in the metric mapping procedure are due, primarily, to human factors. These include problems with map and photograph interpretation and digitizing errors. Photographic interpretation is aided by the use of magnifying stereo viewers, but it is sometimes difficult to accurately determine features such as the mean high water line. The digitizing process is greatly enhanced by an operator with a steady hand, a backlit digitizer table, and a magnifying loupe in the cursor.

Table C-1 is a listing of the metric mapping procedure and quality control steps. Maps generated by this technique are comparable in accuracy to those produced by a stereoplotter (Kleeger, 1983), yet the metric mapping technique allows more flexibility, uses less expensive equipment, and requires less human effort. Therefore, this technique produces less expensive, but still accurate map products (Leatherman and Clow, 1983; Clow and Leatherman, 1984).

TABLE C-1

METRIC MAPPING PROCEDURE AND QUALITY CONTROL STEPS

I. Annotation
   a. Use 6X stereoscope for viewing aerial photography.
   b. Use fine line pen for annotation. (Annotation should not obscure features to be digitized, especially control points.)

II. Control point selection
   a. Always use hard control points (such as easily identified buildings or structures).
      i. Failing that, use permanent, distinguishable natural features.
      ii. Avoid natural features that are subject to change.

III. Digitization of data and secondary controls from base maps
   a. Check tolerance of residual errors in transformation.
   b. Visually inspect instant feedback on graphics screen.
   c. Plot data to scale and overlay on original.

IV. Digitization of photos
   a. Check tolerance of residual errors in transformation,
   b. Visually inspect feedback on graphic screen. (Tip, tilt, and swing make overlay verification impossible.)

V. Combine data from all plates for one year into one data set.
   a. Draw shorelines on paper to check for completeness and possible inconsistencies.
      i. Scale must be at least as large as the original.
      ii. Boundaries between plates are given special scrutiny to check for data overlap and/or data gaps.
   b. Examine plates that do not match up to determine if problem exists with ground control or base map interpretation or if digitizer operator introduced errors.
   c. Based on (b), the plate is either redigitized or rejected. (Note that some plates are kept because data completeness is important; these areas are carefully noted as being less reliable.)

VI. Use TIE program to check for consistency and correct small errors (Review inconsistencies as in part V. above and determine cause; redigitize if necessary.)

VII. Plot all data to visually check the consistency from one year to the next
   a. Hardened features can be expected not to move.
   b. Apparent catastrophic changes are checked with historical records.

VIII. Measure shoreline changes with Transect program and plot histograms
   a. Transects are drawn on overlay map so that results from automatic shoreline measurement can be verified manually.
   b. Transects that are obviously misleading are removed from further consideration.

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APPENDIX D

List of N.O.S. T-sheets Used in the Massachusetts Shoreline Change Project

LIST OF N.O.S. T-SHEETS USED IN THE MASSACHUSETTS SHORELINE PROJECT

North Shore -- Early

T-234	1847 Parts 1 & 2
T-303 bis	1849
T-304 bis	1850
T-340	1851
T-397	1851 Parts 1 & 2
T-396	1852
T-467	1853
T-559	1854
T-556	1855

South Shore -- Early

T-227	1847 Part 1
T-238	1847 Part 2
T-236 bis	1847
T-237	1847
T-612	1848
T-425	1853
T-455	1853
T-719	1858
T-1063	1866
T-1062	1867

Cape -- Early

T-191	1845 Parts 1 & 2
T-192	1845 Part 1
T-289	1846

T-290	1846
T-318	1846
T-259	1848 Parts 1 & 2
T-260	1848 Parts 1 & 2
T-616 bis	1848 Part 1
T-368	1851
T-553	1855
T-579	1856
T-901	1860 Part 1 & 2
T-1077	1868 Parts 1 & 2
T-1078	1868
T-1085	1868
T-1088	1868
T-1090	1868

Islands -- Early

T-192	1845 Parts 1, 2 & 3
T-203	1845 Part 2
T-362	1845 Parts 1 & 2
T-204	1846
T-206	1846 Parts 1 & 2
T-205	1846 Parts 1, 2, 3, & 4

Buzzards Bay -- Early

T-193	1844
T-183	1844 Part 2
T-196	1845 Parts 1 & 2

North Shore -- Middle

T-2146	1893	
T-559	1912	Part 1
T-3766	1919	
T-3767	1919	
T-4394	1928	
T-4395	1928	
T-4396	1928	
T-4426	1928	

South Shore -- Middle

T-2114	1892	
T-2115	1892	
T-2155	1893	Part 1
T-2161	1893	
T-2183	1894	
T-2154	1895	
T-1062	1909	
T-4062	1924	

Cape -- Middle

T-1683	1886
T-1704	1886
T-1705	1886
T-1706	1886
T-1902	1888
T-1997	1890
T-1998	1890
T-1999	1890

T-2039	1890
T-2227	1895
T-2228	1895
T-1077	1909
T-6033	1933
T-6034	1933
T-6112	1934
T-6113	1934
T-6114	1934
T-6122	1934
T-6123	1934

Islands -- Middle

T-1785	1887
T-1814	1887
T-1815	1887
T-1818	1887
T-1845	1888
T-1846	1888
T-1856	1888
T-1937	1889
T-1938	1889
T-1939	1889
T-2299	1897
T-2390	1897
T-2391	1897

Buzzards Bay -- Middle

T-2212	1895
T-2215	1895
T-2216	1895
T-2217	1895
T-2220	1895

T-2221	1895
T-2253	1896

North -- Late

T-5773	1938
T-5774	1938
T-9079	1952
T-11151	1952
T-11152	1952
T-11153	1952
T-11154	1952
T-11155	1952
T-11156	1952
T-11484	1954
T-11483	1954
T-11487	1954

South -- Late

T-5771	1938
T-5772	1938
T-5775	1938
T-5776	1938
T-9512	1950
T-9513	1950
T-11173	1951
T-11174	1951
T-11177	1951
T-11178	1951
T-11180	1951
T-11169	1952
T-11170	1952
T-11182	1952
T-11185	1952
T-11186	1952

Cape -- Late

T-5609	1938
T-5610	1938
T-5732	1938
T-5735	1938
T-5738	1938
T-5739	1938
T-5740	1938
T-5741	1938
T-5743	1938
T-5744	1948
T-11171	1951
T-11175	1951
T-11176	1951
T-11179	1951
T-11181	1951
T-11183	1951
T-11186	1951
T-11187	1951
T-11188	1951
T-11192	1951
T-11193	1951
T-11194	1951
T-11196	1951
T-11203	1951
T-11208	1951

Islands -- Late

T-5744	1948
T-5745	1948
T-5746	1948

T-10641	1955
T-10642	1955
T-10643	1955
T-11212	1955
T-11213	1955
T-11214	1955
T-11215	1955
T-11216	1955
T-11217	1955
T-11218	1955
T-11219	1955
T-11220	1955
T-11221	1955
T-11222	1955
T-11223	1955

Buzzards Bay -- Late

T-5602	1934
T-5603	1934
T-5604	1934
T-5609	1938
T-5610	1938

APPENDIX E

List of N.O.S. T-sheets Not Acceptable for Use in the Massachusetts Shoreline Change Project

LIST OF N.O.S. T-SHEETS NOT USED IN THE MASSACHUSETTS SHORELINE CHANGE PROJECT (These maps are either duplicates of other data or they have been shown to be inaccurate for mapping purposes. Errors for some selected maps in the Cape Cod area have been indicated.)

North Shore -- Early

T-1023
T-835
T-355
T-341
T-235
T-230
T-233 bis
T-229

South Shore -- Early

T-229
T-231
T-232 bis
T-831
T-832
T-833
T-829
T-612
T-1530
T-901

Cape -- Early

T-1530
T-795a
T-645
T-424
T-402
T-356
T-437

Islands -- Early

T-202

North -- Middle

T-2177
T-2147
T-2235
T-2190
H-2156
T-1023a
T-4424
T-355a
T-467b
T-467a
T-556a
T-341a
T-396a
T-397a
T-340a
T-2603

South Shore -- Middle

T-2204
T-2191
T-2180
T-1251a
T-2208
T-2096
T-2097
T-2183a
T-2208a
T-719a
T-612a
T-425a
T-455a
T-1063a
T-901a

Cape -- Middle

T-1088
T-1078
T-1077
H-2019
T-1982
T-1982
H-1903
T-1090
T-441 bis
T-1085a
T-1085b
T-1858
T-901a
T-795a

T-901b
T-795b
T-1088a
T-1088b
T-1078a
T-259b
T-259a
T-616a
T-260b
T-260a
T-1077b
T-2604
T-2393
T-4623
T-6621

Islands and Buzzards Bay -- Middle

H-2209
H-2168
T-1702
T-2388
T-2389
T-1844
T-1802
T-6358
T-6357
T-6356
T-6355
T-6374
T-4612
T-6120
T-4427
T-1818a

T-2597

North -- Late

T-11148
T-11149
T-8534
T-8533
T-11150
T-11485
T-11486
T-5770

South -- Late

T-9512a
T-11169
T-11170
T-11172
T-5611

Cape -- Late

T-5611
T-5734 (off by 38 ft.)
T-5733 (off by 21 ft.)
T-5731 (off by 26 ft.)
T-11189
T-5736 (off by 26 ft.)
T-5737 (off by 24 ft.)

T-5742 (off by 27 ft.)
T-11336
T-5745
T-5746

Islands and Buzzards Bay -- Late

T-11429
T-11431
T-11435
T-11430
T-11434
T-11336
T-9080
T-10641
T-9082
T-9081
T-8204

APPENDIX F

Glossary of Technical Terms

GLOSSARY OF TECHNICAL TERMS

Digitization - a technique of using a precision coordinate digitizer that continuously records the (x,y) location of a movable cursor on a table. A data map is mounted on the digitizer table, and shorelines are traced by an operator. A mini-computer transforms the input values into map coordinates and records them onto magnetic tape for computational purposes.

National Map Accuracy Standards - the standard for horizontal accuracy requires that no more than 10 percent of the well-defined map points tested be in error by more than 0.02 inches at the publication scale. Map accuracy is closely related to map scale; the tolerance corresponds to 40 feet on the ground for 1:24,000 scale maps.

Orthogonal -literally means perpendicular to, but for maps refers to no variation in scale or distortion in the X-Y plane.

Photogrammetry - science, art, and technology of obtaining reliable measurments from maps and photographs.

Shoreline - boundary between land and water, taken as the mean high water line for photogrammetric purposes.

Space Resection - a mathematical procedure for removing distortions from vertical aerial photographs due to tilt, tip, yaw, and radial lens distortion.

State Plane Coordinates - a system, one for each state, for use in defining positions in terms of plane rectangular coordinates.

Stereo projection - three-dimensional viewing of an area on adjacent, overlapping aerial photographs. When images forming a stereo pair (adjacent pairs of overlapping air photos) are viewed through a stereoscope, the result is the perception of a 3-D stereo model.

Stereoplotter - an instrument for the preparation of topographic maps (from aerial photographs) without distortion. In operation, rays from the photographs in stereo pairs (in the same relative orientation in which they were taken) are projected to form a greatly reduced scale model of the terrain in the overlapping area. The model can be viewed and measured in 3-D and can be projected orthographically to a map sheet.

Tilt, Tip, and Yaw - distortions in a "vertical" aerial photograph due to the camera taking a picture when the airplane is tilted (side to side) from horizontal, tipped up or down (nose to tail), into the wind at some angle or along a flight path, respectively.

Transformation - changing the digitized data from one coordinate system (that of the digitizer) to that of true ground location (such as State Plane Coordinate System or Longitude-Latitude).

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