National Estuarine Inventory

Shoreline Modification, Dredged Channels and Dredged Material Disposal Areas in the Nation's Estuaries

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NOAA's National Estuarine Inventory

The National Estuarine Inventory (NEI) is a series of related activities of the Office of Oceanography and Marine Assessment (OMA), National Oceanic and Atmospheric Administration (NOAA) to develop a national estuarine data base and assessment capability. The NEI was initiated in June 1983 as part of NOAA's program of strategic assessments of the Nation's coastal and oceanic resources. No comprehensive inventory or data base of the Nation's estuaries could be found prior to the NEI in spite of the high value, intense use, frequent overuse, and thousands of scientific studies related to various aspects of estuaries. Without this fundamental set of information developed for the NEI, it is impossible to analyze or compare the estuaries that make up the Nation's estuarine resource base.

The cornerstone of the NEI is the *National Estuarine Inventory Data Atlas.* Volume 1, completed in November 1985, identifies 92 of the most important estuaries and subestuaries of the contiguous USA; presents information through maps and tables on physical and hydrologic characteristics of each estuary; and specifies a commonly derived spatial unit for all estuaries, the estuarine drainage area (EDA), for which data are compiled. These estuaries represent approximately 90 percent of the estuarine water surface area and 90 percent of the freshwater inflow to estuaries of the East Coast, West Coast, and Gulf of Mexico. Volume 2, Land Use, presents area estimates for seven categories and 24 subcategories of land use as well as 1970 and 1980 population estimates. Land use data are compiled for three spatial units: (1) the estuarine drainage area; (2) U.S. Geological Survey hydrologic cataloging units; and (3) counties that intersect EDAs. Population estimates are compiled for EDAs only. With these two volumes, the NEI represents the most consistent and complete set of data ever developed for the Nation's estuarine resource base.

The data base and assessment capability under development for the NEI are part of a dynamic and evolving process. Other estuaries and subestuaries have been added to the NEI from the West Coast and will be added to the Gulf of Mexico. Refinements are being made to physical and hydrologic data estimated in Volume 1. Attributes such as volume and flushing rates have been added to the data base. Other NOAA projects whose data and information will be included in the NEI are: the distribution of estuarine-dependent living marine resources; characterization of estuarine shoreline modification, navigational channels, and dredged material disposal areas; the National Coastal Wetlands Data Base; the *National Shellfish Register* and related projects; the National Coastal Pollutant Discharge Inventory; and the Inventory of Outdoor Coastal Recreation Facilities.

Additional information on NOAA's National Estuarine Inventory is available from:

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This paper presents estimates of shoreline modification, dredged navigational channels, and dredged material disposal areas within the 92 estuaries included in NOAA's *National Estuarine Inventory Data Atlas* (NEI). The estimates, developed from NOAA nautical charts, represent the first consistent and comprehensive inventory of these features for the Nation's estuaries. They are a first step toward assessing whether these changes to estuaries might represent a problem nationwide. When combined with other components of the NEI, they will complement capabilities already developed to assess the characteristics and environmental quality of the Nation's estuaries. The information developed for each estuary includes: 1) length of estuarine perimeter, 2) length of estuarine shoreline, 3) length of modified shoreline, 4) length and surface area of dredged channels, and 5) area of dredged material disposal sites.

Background

Increasingly, estuaries are being altered to accommodate industrial operations requiring access to water transportation, navigable channels to commercial centers and port facilities, and living space and recreational areas for human populations. When the level of these activities in an estuary was relatively small, overall impacts were also relatively small. But, as development pressures and uses of estuaries have continued to increase in the last few decades, concern has risen over the *cumulative* effects of these changes.

The major impact of shoreline modification may be the extent to which it affects intertidal areas that are vital components of the estuarine ecosystem. Intertidal areas include wetlands and tidal flats, the vegetated and non-vegetated areas innundated or exposed throughout a tide cycle. These areas store energy for the system, trap pollutants and sediments, and provide shoreline stabilization and valuable habitat. However, despite their ecological importance, intertidal areas exhibit the most visible shoreline modification. For example, wetlands have been routinely drained and cleared of vegetation for expansion of residential or resort communities. Such alterations threaten critical habitat areas, eliminate the buffering capacity of the natural environment, and frequently result in serious shoreline erosion. To counteract shoreline erosion, bulkheads, groins, and jetties are constructed, but these often increase erosion of shoreline elsewhere.

A major impact of dredged navigation channels and dredged material disposal is the extent to which they alter the bottom of the estuary by disturbing vegetation and benthic communities. In addition, because most estuaries become increasingly shallow as sediments settle to the bottom, routine dredging is necessary to maintain navigational channels for commercial and private use. Routine dredging results in repeated disruption of the benthic habitat – sediments and sediment-bound toxins are resuspended, turbidity increases, and light penetration decreases – adversely affecting many fish and invertebrate species within estuaries.

Increasingly, legislators and public interest groups have come to recognize that the many, small individual decisions to modify a length of shoreline, dredge a channel, or deposit dredged material may result in serious cumulative consequences throughout the Nation's estuaries. An example of this increasing recognition is the recent State of Maryland legislation protecting "critical areas" within the watershed of the Chesapeake Bay and its tributaries. This measure restricts development within 1,000 feet of the shoreline to preserve undisturbed areas and to protect those areas already altered by earlier development. Another example is Section 404 of the Clean Water Act requiring the U.S. Army Corps of Engineers, the lead Federal agency for dredging activities, to consult with numerous Federal and state agencies and local interest groups, before it conducts or approves dredging activities.

An important first step in understanding the *cumulative* effects of estuarine modification nationwide is to develop a clear, consistent, and comprehensive quantification of the potential problem. Although efforts have been made in the past to quantify the extent of estuarine alteration for some estuaries, this project is the first to provide ***baseline estimates*** for estuaries across the USA. As other data become available that describe physical and biological consequences of estuarine modification, the potential impacts can be more accurately assessed and informed decisions more readily made.

Developing the Data

Information related to estuarine modification exists for some estuaries, although varying scales, time increments, and levels of detail prohibit data synthesis and analysis nationwide. Development of this data base required complete and consistent map coverage for 92 estuaries, for a recent "snapshot" in time, and at a scale that allowed the information to be digitized with a reasonable degree of accuracy.

NOAA nautical charts are the *only* data source to provide this coverage for the Nation's estuaries. Because they were originally designed to promote safe and efficient navigation, those chart features most critical to the mariner are the most accurate. Consequently, features such as modified shoreline, navigational channels, and dredged material disposal sites are among the most accurate depicted on the charts because they relate directly to navigation. Data sources, methods of interpretation, and frequency of chart revisions were discussed in detail with NOAA's Charting Division to derive maximum benefit from the charts. Figure 1 illustrates shoreline and channel features depicted on the nautical charts that were digitized.

Digitizing the Data. Data base development required four steps: 1) developing functional definitions of the shoreline and dredging features (Table 1); 2) establishing criteria for consistent data synthesis; 3) color-coding modified shoreline, navigational channels, and dredged material disposal sites to simplify the digitizing process, and 4) quantifying estimates of length and area by using a digitizing routine on a microcomputer.

Table 1. Definitions of shoreline and dredging features.

Feature	Definition
Perimeter	A relative measure of the boundary enclosing the water of an estuary at mean lowest low water. This estimate includes four components: 1) modified and unmodified shoreline; 2) the ocean boundary at the mouth of the estuary; 3) the non-tidal fresh-water boundary at the head of an estuary; and 4) other boundaries defined in the NEI, Volume 1, such as the transect where the mouth of the Susquehanna River enters the head of the Chesapeake Bay.
Shoreline	A subset of the perimeter that refers only to a relative measure of the estuarine land boundary exposed at mean lowest low water and does not include the ocean boundary or "other" boundaries included in the NEI, Volume 1.
Modified Shoreline	Any length of shoreline within an estuary that is artificially adjusted or modified from its naturally occurring state and is readily apparent on nautical charts. This includes piers, when present in a concentration of three or more within 180 meters, as well as wharfs, docks, bulkheads, dams, groins, jetties, and similar structures. Modified shoreline does not include beach nourishment or intricate, developed canal systems such as those in Florida and the Gulf of Mexico that are inland and have a limited connection to the estuary.
Estuarine Surface Area	Defined at mean lowest low water and enclosed by the boundaries delineated in the NEI, Volume 1.
Channel Length	The length of a line longitudinally bisecting a marked dredged channel. Total channel length consists of the sum of lengths of all dredged channels within an estuary.
Dredged Material Disposal Sites	The area enclosed within the marked boundaries for the disposal site. The area estimate for a designated site is a measure of the target area for the dumping of dredged material and does not account for displacement of the material after dumping.

A total of 205 nautical charts were digitized defining over 68,000 km of total estuarine shoreline, nearly 5,000 km of modified shoreline, over 5,400 km of dredged navigational channels, and almost 1,000 km^2 of dredged material disposal sites. The data were entered into an RBase 5000 data base management system to provide summaries by nautical chart and by estuary. Using OAD's geographical information system (GIS), color maps portraying the digital data can be plotted by chart or for any combination of charts. This digital data base is a fundamental component of NOAA's GIS for estuaries. Figure 2 illustrates the data base developed for Tampa Bay.

Figure 1. Examples of shoreline and modification features that appear on NOAA charts.

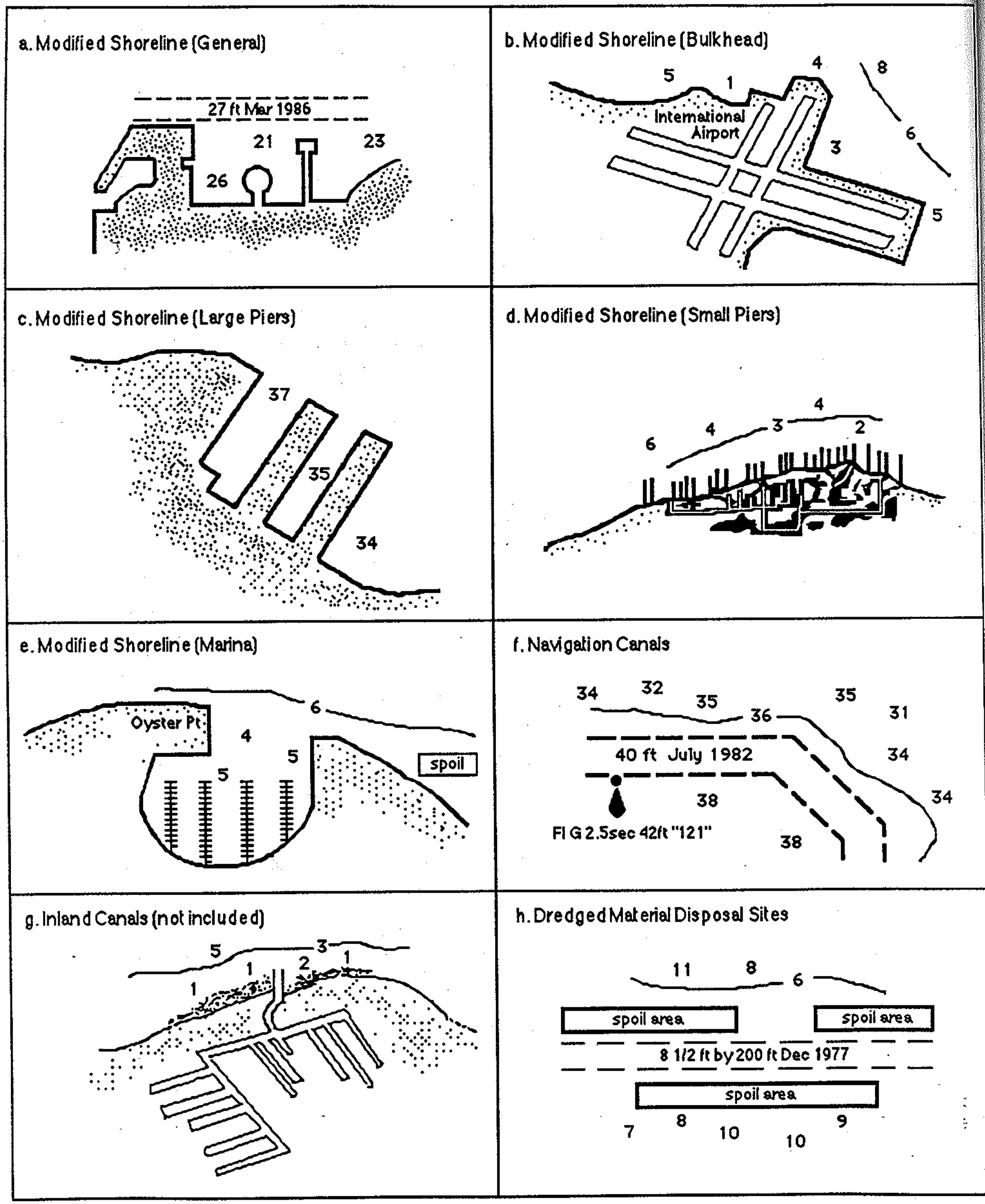
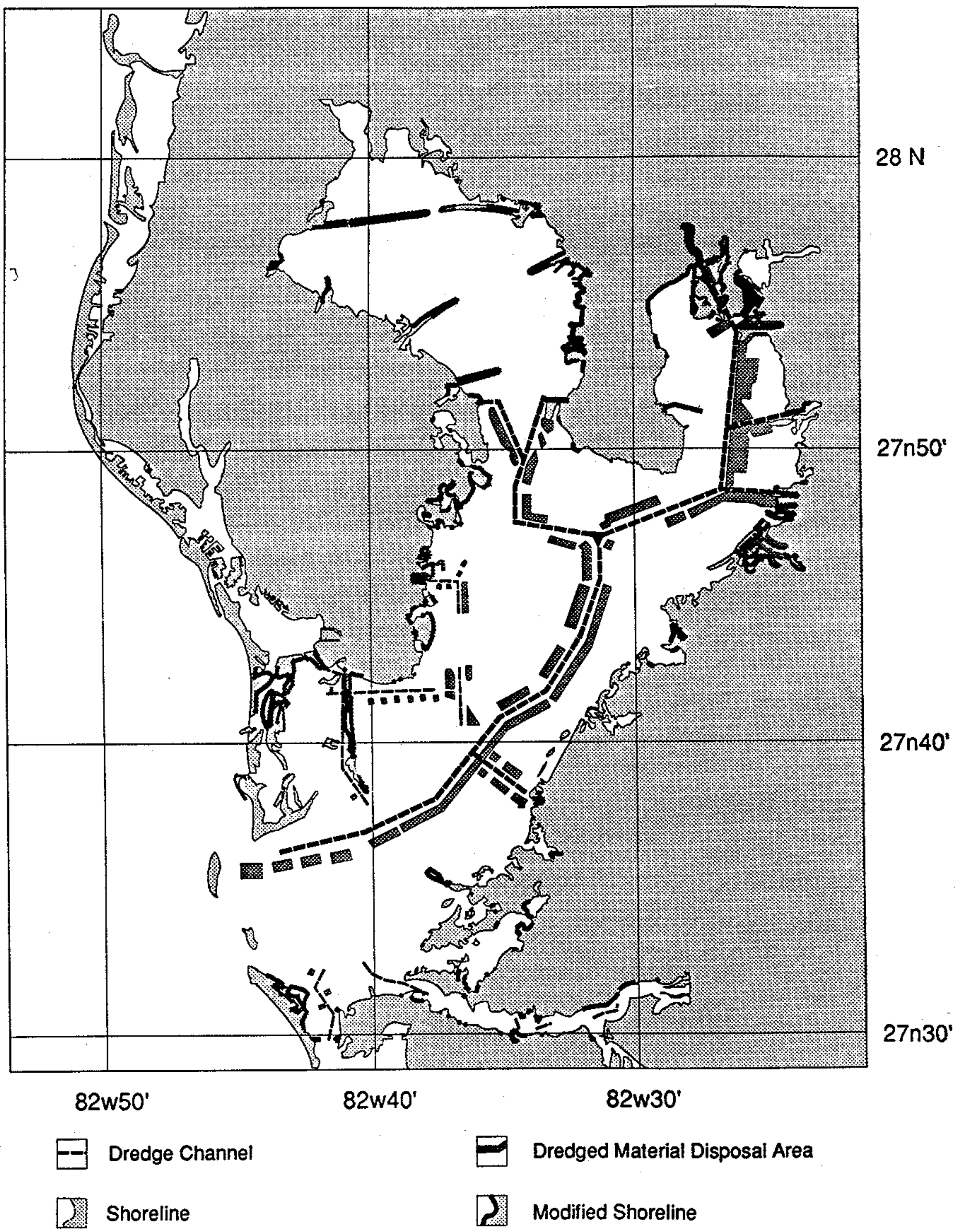


Figure 2. Shoreline modification, dredged navigational channels, and dredged material disposal areas for Tampa Bay.



Interpreting the Data. Interpretation of the data was based upon: 1) functional definitions of shoreline and dredging features (Table 1), 2) identification of regional-specific characteristics that affect how features are portrayed on charts, and 3) identification of data gaps that must be considered when making estuarine comparisons.

Criteria were developed to establish consistent application of these definitions and to treat situations unique to regions of the country. Probably the single most important factor for consistent data interpretation was map scale. Regional differences in coastal geomorphology dictate varying degrees of shoreline complexity which, depending on map scale, may have affected linear estimates of shoreline length. For instance, shorelines of glaciated estuaries in the Northeast are generally distinct and well defined in contrast to low energy regions of the Southeast, where estuaries have large fringing marshes that create complex and less clearly defined shorelines. To minimize scale differences, charts at a scale of 1:40,000 were used where available. Where not available, charts of other scales were used (Table 2).

Table 2. NOAA nautical charts used to measure shoreline and modification features.

Region	Number of Charts	Map Scale (in thousands)					
		10 to 15	20 to 25	40	50	80	175 to 200
Northeast	81	5	19	50	0	7	0
Southeast	41	0	6	28	0	7	0
Gulf of Mexico	50	2	3	24	4	15	2
West Coast	33	2	9	17	1	2	2
Total	205	9	37	119	5	31	4

Chart features were evaluated at scales of 1:20,000, 1:40,000, and 1:80,000 to compare consistency of the linear measurements. Water surface area, channel dimensions, and dredged material disposal areas were nearly identical at these scales. Estuarine perimeter, shoreline length, and modified shoreline features varied somewhat between scales. Greatest sensitivity to scale was exhibited for low energy marsh areas and deltaic formations characteristic of the Southeast and Gulf of Mexico. In this instance, as map scale increases (e.g., from 1:80,000 to 1:20,000), intertidal zones not apparent at smaller scales, increased estimates of shoreline length as resolution increased. In a similar sense, modified shoreline estimates generally increased with increasing map resolution. Important features that affect the interpretation in specific regions are listed below.

<u>Southeast</u>

- Because estuaries were digitized at mean lowest low water, extensive tidal flats in Bogue Sound masked modified reaches of shoreline that are actually modified at high tide.

- Some dredged material disposal sites were referenced on the charts without specific boundaries. These sites were not included in the data base.

Gulf of Mexico

- The Mississippi River-Gulf Outlet canal was judged to be cut through land. Therefore, it is not included in the Mississippi Delta totals.

- The portion of the Intra-Coastal Waterway that cuts through land was not included. The portion that extended into the estuarine water boundaries defined in the National Estuarine Inventory was included.

- Numerous canals exist within the Mississippi Delta region as a result of petroleum exploration and onshore piping from platforms and were not included.

- In cases where continual disposal of dredged material has resulted in the development of an island, only the portions of these areas that are completely submerged are identified as disposal areas. This is most apparent in Galveston Bay.

- For some dredged material disposal areas in the Mississippi Delta region, boundaries were not clearly defined by the NOS charts and had to be inferred using bathymetric information.

- For Laguna Madre, the regions labelled "area subject to innundation" were treated as land to maintain consistency with shoreline at mean lowest low water.

West Coast

- The Klamath and Eel rivers were included on nautical charts at a scale of approximately 1:200,000. Therefore, estimates of total shoreline and modified shoreline length may be conservative. Channels and dredged material disposal sites, if present, could not be determined.

For some estuaries, portions of shoreline were not included on the NOS charts and, therefore, are not included in the estuary totals (Table 3).

Data Quality. Chart revisions are frequent and reflect shoreline alterations, based on recent aerial photography as well as changes to channels and disposal site dimensions as permitted by the U.S. Army Corps of Engineers. More than 80 percent of all nautical charts are revised on a four-year schedule. Approximately 50 percent (those areas subject to greater change and use) are revised at least every two years. Heavily traveled waterways are revised every six to twelve months to capture recent modifications of importance to navigation. Coastline stability associated with different regions of the country also dictates frequency of chart revisions and the extent to which charts reflect existing conditions within the estuary. For example, the Northeast and West Coast shorelines are generally bounded by steep bluffs that are not readily inundated at high tide, nor likely to expose tidal flats at low tide. In contrast, the coast of

Louisiana is less stable due to the effects of heavy storms, hurricanes, and subsidence on the extensive marsh regions. More frequent revisions may be necessary for these unstable regions.

Table 3. Estuaries without complete coverage by NOS nautical charts.

Estuary	Area
Narragansett Bay	Taunton River, five-mile reach below head of tide.
Connecticut River	Connecticut River, eight-mile reach below head of tide.
Hudson/Raritan Bays	Hudson River, fifteen-mile reach below head of tide.
North/South Santee Rivers	Santee River, thirty-five mile reach below head of tide.
Altamaha River	Altamaha River, two-mile reach below head of tide.
Corpus Christi Bay	Approximately half of Nueces Bay, west of 97°28'30".
Lake Calcasieu	Part of West Cove.
Sabine Lake	Keith Lake.
Aransas Bay	Parts of Mission Bay, Aransas River, and St. Charles Bay.
Coos Bay	Part of South Slough.

Summary

The data base developed provides the first comprehensive quantification of estuarine shoreline and bottom modification throughout the USA (Appendix 1). It enables simple comparisons to be made among estuaries and across the Nation and may help provide a basis for investigating further nationwide policies and programs that affect estuarine modification.

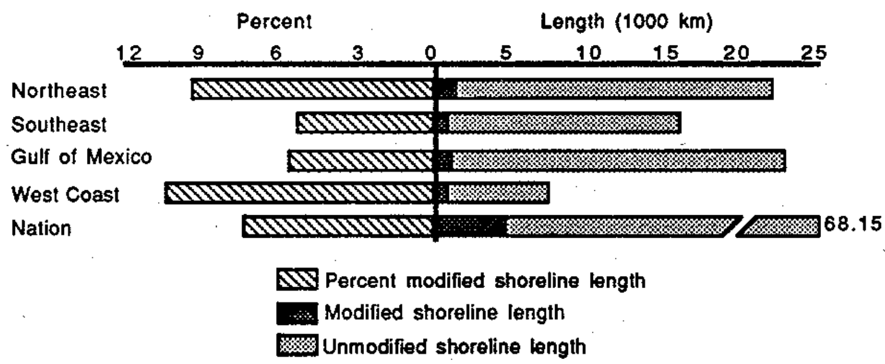
Shoreline. At the simplest level, the data support conventional thinking about relationships between shoreline and geomorphology. For example, in the *Northeast* (Maine through Virginia) two unique geological zones exist. From Passamaquoddy Bay south to Long Island Sound, estuaries were created by glaciation. These estuaries are relatively small with rocky shorelines and are often bounded by steep cliffs defining shorelines that are relatively easy to interpret from nautical charts. A second geologic zone exists from Long Island Sound through Chesapeake Bay where rising sea levels resulting from melting glaciers drowned the mouths of ancient rivers extending across the continental shelf. Tidal flats and marshes are more abundant in these estuaries such that shoreline length and complexity is increased when compared to the relatively linear characteristics of the systems along the coast of Maine. For example, the Chesapeake Bay and its tributaries account for almost 50 percent of the total shoreline for the *Northeast* region.

In the *Southeast* (North Carolina through Florida), shoreline is characterized by lagoonal systems in North Carolina and Florida while tributaries meander through the low-lying marshes of South Carolina and Georgia. Albemarle and Pamlico Sounds plus their tributaries contain nearly one-third of the total shoreline for the Southeast.

The *Gulf of Mexico* region is characterized by flat coastal plains and high sediment deposition. Marshes dominate the region between Florida and Mississippi, whereas deltaic formations dominate the coast of Louisiana. In southwest Florida, shoreline estimates for Ten Thousand Islands and Charlotte Harbor account for 15 percent of the Gulf total. By itself, the Mississippi River, as defined by the NEI, represents nearly 80 percent of Louisiana's shoreline and almost one-third of the total for the Gulf of Mexico. In dramatic contrast, lagoonal estuaries in Texas are dominated by tidal flats resulting in less complex, easily defined shorelines.

The *West Coast* of the United States is characterized by uniformly uplifted, resistant rock except for parts of the Oregon and Washington coasts that have become coastal flats due to erosion of sedimentary rock. The shoreline of California and southern Oregon is generally stable and easily defined, except within the marsh regions of Suisun Bay. Glacier activity in Puget Sound produced a steep-sided, rocky, and well-defined shoreline similar to estuaries along the coast of Maine. *West Coast* estuaries account for only 10 percent of the Nation's shoreline (Figure 3). Of this total, Suisun Bay, Columbia River, and Puget Sound (including subsystems) comprise almost two-thirds. The relatively small shoreline length in this region is due to fewer estuaries and a high energy environment that maintains their rocky and stable structure.

Figure 3. Modification of estuarine shoreline by region.



Modified Shoreline. Shoreline modification features were defined in Table 1. These features, although definable, were not as readily quantifiable as dredged channels or disposal areas. As discussed previously, chart scale and data interpretation produced some variance in the ability to define precise linear estimates of each modification type. The data, therefore, should not be interpreted in their strictest sense, but rather as a relative measure that suggests which estuaries may have problems and that provides a basis for management strategies. The data can be used to address questions such as:

1. To what extent have the Nation's estuaries been modified?
2. Which estuaries appear to be most sensitive to modification?
3. Should strategies to reduce modification or minimize its consequences be targeted at specific estuaries, groups of estuaries, or across all estuaries?

Initially, data results revealed few surprises. The greatest length of modified shoreline appears in the Northeast and Gulf of Mexico regions. Analysis of these conditions suggests a strong correlation between shoreline modification and existing urban areas, specifically large cities originally established as port facilities. Table 4 shows those estuaries that rank highest for shoreline modification. These include Chesapeake Bay, Hudson/Raritan Bays, Tampa Bay, Galveston Bay, and Long Island Sound. In most instances, shoreline modification of these estuaries was due to construction of bulkheads and earthen piers to support commercial activities.

Shoreline modification is not limited to estuaries having large urban areas. For example, about half of the total shoreline modification for the Gulf of Mexico can be attributed to factors other than industrialized centers. Due in part to its moderate climate, the Gulf of Mexico region has experienced dramatic population growth that has increased demands on shorefront development. Residential areas (especially retirement communities) have crowded the Florida shoreline. Numerous and extensive canal systems have been constructed to provide water access through these communities. A similar situation is developing within some Southeast estuaries. St. John's River, Indian River, and Biscayne Bay account for approximately two-thirds of total shoreline modification in this region.

A different situation exists for the West Coast from central Washington to northern California. Shoreline modification is generally due to physical processes that occur along the coast and within the estuaries. Jetties, groins, and bulkheads are constructed to minimize erosional processes that endanger existing shoreline development or threaten to close entrance channels to the estuary.

Dredging Activities. Dredging activities, as reflected by channel length and surface area, are necessary to increase or maintain the controlling depth of the waterbody and often coincide with shoreline modifications. For example, dredging of harbor areas is necessary to accommodate commercial operations in the metropolitan areas of the Northeast and the heavily industrialized areas of the Gulf of Mexico. One-third of the Nation's channel length and channel area were found within these estuaries. Similarly, access to residential and recreational areas within estuaries of Florida and Texas accounts for one-third of the Nation's channel length.

Disposal of dredged material occurs most often within the estuaries from which it was dredged and may cover considerable portions of estuarine bottoms. The bulk of dredge disposal (75 percent) occurs in the Gulf of Mexico where sediment deposition is high. Ninety percent of this total occurs within estuaries between Mobile Bay and Laguna Madre. Another 20 percent of the Nation's dredged material is disposed within Long Island Sound, Chesapeake Bay (including subsystems), and Albemarle/Pamlico Sounds. Figure 4 shows that portion of the estuarine bottom surface area modified by channels and dredged disposal areas.

Table 4. "Top-Ten" rankings for selected shoreline and modification features.

1. Surface Water Area at Mean Lowest Low Water

	Estuary	10 sq. km
1	Chesapeake Bay	823
2	Mississippi Delta	817
3	Albemarle/Pamlico Sounds	713
4	Long Island Sound	325
5	Mississippi Sound	219
6	Delaware Bay	201
7	Lake Pontchartrain	193
8	Atchafalaya/Vermilion Bay	183
9	Puget Sound	147
10	Cape Cod Bay	133

2. Shoreline Length

	Estuary	10 km
1	Mississippi Delta	761
2	Chesapeake Bay	634
3	Albemarle/Pamlico	344
4	Ten Thousand Islands	205
5	Columbia River	154
6	St. Catherines/Sapelo Sound	146
7	Hudson/Raritan Bay	146
8	Long Island Sound	133
9	Puget Sound	132
10	Indian River	131

3. Channel Length

	Estuary	10 km
1	Galveston Bay	32
2	Chesapeake Bay	32
3	Hudson/Raritan Bay	30
4	Laguna Madre	30
5	Columbia River	26
6	Delaware Bay	24
7	Indian River	22
8	Albemarle/Pamlico	19
9	James River	18
10	Mississippi Sound	16

4. Percent of Shoreline Modification

	Estuary	Percent
1	San Pedro Bay	79
2	San Diego Bay	44
3	Tampa Bay	34
4	Boston Bay	29
5	San Francisco Bay	26
6	Caloosahatchee River	24
7	Hudson/Raritan Bay	23
8	Santa Monica Bay	23
9	Biscayne Bay	23
10	Barnegat Bay	21

5. Estuary Volume at Mid-Tide Level

	Estuary	cu. km
1	Puget Sound	95
2	Long Island Sound	62
3	Chesapeake Bay	61
4	Santa Monica Bay	52
5	Monterey Bay	42
6	Cape Cod Bay	33
7	Albemarle/Pamlico Sounds	28
8	Hood Canal	26
9	Skagit Bay	26
10	Mississippi Delta	22

6. Modified Shoreline Length

	Estuary	10 km
1	Chesapeake Bay	48
2	Hudson/Raritan Bay	34
3	Tampa Bay	30
4	Indian River	23
5	Galveston Bay	19
6	San Francisco Bay	18
7	Long Island Sound	18
8	St. Johns River	16
9	San Pedro Bay	16
10	Great South Bay	15

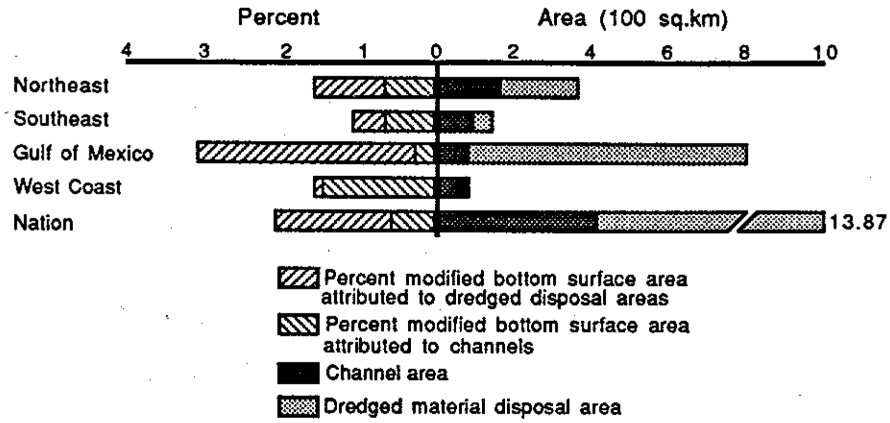
7. Dredged Material Disposal Area

	Estuary	10 km
1	Mississippi Delta	19
2	Mobile Bay	12
3	Long Island Sound	8
4	Mississippi Sound	7
5	Laguna Madre	7
6	Chesapeake Bay	7
7	Galveston Bay	5
8	Tampa Bay	4
9	Matagorda Bay	4
10	Sabine Lake	2

8. Percent of Modified Bottom Surface Area

	Estuary	Percent
1	Cape Fear River	39.2
2	San Diego Bay	18.1
3	Coos Bay	12.9
4	Mobile Bay	11.3
5	Charleston Harbor	11.3
6	Calcasieu Lake	10.8
7	Sabine Lake	10.7
8	Winchester Bay	10.0
9	Laguna Madre	8.9
10	Columbia River	8.7

Figure 4. Modification of estuarine bottom surface area by region



Preliminary Comparisons

One way to compare estuarine features nationwide is to "normalize" the data developed for each estuary according to another parameter that may provide insight into how significant each feature can be within an estuary. Several ratios have been developed to provide preliminary nationwide comparisons (Appendix 2).

Ratio of shoreline length to surface area. This ratio may indicate the complexity of the shoreline configuration. For example, the relatively simple geometry of Delaware Bay results in a shoreline-to-surface area ratio of about 0.5. In contrast, the winding, complex shoreline of St. Catherine/St. Sapelo Sounds produces a ratio of nearly 7.5. Therefore, as this ratio increases, the intertidal habitat susceptible to modification probably increases. This implies that small estuaries bordered by a lengthy shoreline may be most sensitive to modification. These include the marshy, riverine systems of the Southeast and central West Coast.

Ratio of modified shoreline length to surface area. This ratio, when considered with the ratio above, can identify "susceptible" estuaries that are being modified. Large amounts of modified shoreline exist per estuarine water surface area for estuaries where large industrial or population centers exist. In addition, Barnegat Bay, Charleston Harbor, Indian River, Caloosahatchee River, Coos Bay, and several Texas estuaries identified as susceptible exhibit dramatic shoreline modification. Furthermore, San Pedro and San Diego bays, although not originally selected as potentially sensitive estuaries, show extensive shoreline modifications compared to the size of the estuary. In contrast, many Southeast estuaries that appeared susceptible are not subject to extensive shoreline modification.

Ratio of channel area and disposal area to bottom surface area. This ratio indicates the approximate percentage of estuarine bottom modification and totals slightly more than two percent nationally. Although small, this percentage represents a surface area slightly larger than Galveston Bay. Furthermore, modification is concentrated among relatively few estuaries in which over 10 percent of the bottom surface area has been altered. As expected, bottom modification is highest for estuaries adjacent to industrial centers as well as for estuaries in the Southeast, Gulf of Mexico, and central Pacific. The estuary subject to the greatest percentage of bottom modifiction is the Cape Fear River where significant dredging is necessary to provide access to the city of Wilmington, North Carolina.

Concluding Remarks

Shoreline modification and dredging activities are only two of the many human activities that affect estuaries. Increasing demand on the coastal regions has resulted in modifications that directly influence many physical, biological, and chemical processes. In some estuaries, commercial, industrial, and residential pressures have already had significant impacts. The Gulf of Mexico region, in particular, has already been significantly impacted and consequences are well documented. One effort to reconcile this situation is to dispose of dredged material outside the Gulf estuaries.

Projected population increases in coastal areas presents a tremendous challenge to government agencies, academic institutions, and the public to develop strategies that address estuarine resource conflicts and minimize adverse environmental effects. The information compiled in this report, may help provide additional insights to develop regional and nationwide strategies to address shoreline and bottom modification activities throughout the Nation's estuaries.

Appendix 1. Shoreline and dredging characteristics for estuaries of USA.

Estuary	Surface Area MLLW 10 sq. km	Estuary Volume MTL cu. km	Perimeter Length km	Shoreline Total Length km	Shoreline Modified Length km	Shoreline Percent Modified	Channel Length km	Channel Surface Area sq. km	Dredge Disposal Area sq. km	Percent Modified Surface Area
NORTHEAST										
1.01 Passamaquoddy Bay	40	9	485	473	3	1	0	0	0	0
1.02 Englishmans Bay	19	2	303	275	0	0	0	0	1	1
1.03 Narraguagus Bay	16	2	348	320	1	0	5	0	0	0
1.04 Blue Hill Bay	29	7	354	340	0	0	2	0	0	0
1.05 Penobscot Bay	92	21	836	796	12	2	3	0	5	1
1.06 Muscongus Bay	19	2	331	309	1	0	0	0	0	0
1.07 Sheepscot Bay	25	3	779	750	17	2	6	0	0	0
1.08 Casco Bay	40	5	603	566	12	2	14	2	5	2
1.09 Saco Bay	4	0	71	63	2	4	0	0	0	0
1.10 Great Bay	3	0	206	203	7	4	11	1	0	2
1.11 Merrimack River	1	0	72	72	2	3	0	0	0	0
1.12 Boston Bay	17	1	320	308	89	29	57	10	0	6
1.13 Cape Cod Bay	133	33	401	371	10	3	11	0	6	0
1.14 Buzzards Bay	59	6	388	374	30	8	31	4	11	2
1.15 Narragansett Bay	41	4	506	484	56	11	67	12	1	3
1.16 Gardiners Bay	50	3	483	464	34	7	41	0	0	0
1.17 Long Island Sound	325	62	1351	1325	175	13	142	8	81	3
1.17a Connecticut River	4	0	294	292	8	3	36	0	0	0
1.18 Great South Bay	38	1	842	838	152	18	84	1	0	0
1.19 Hudson/Raritan Bay	75	5	1472	1461	340	23	301	63	1	8
1.20 Barnegat Bay	31	0	535	527	111	21	16	1	0	0
1.21 Delaware Bay	201	13	987	968	138	14	235	36	10	2
1.22 Chincoteague Bay	33	1	425	424	7	2	23	2	1	1
1.23 Chesapeake Bay	823	61	6388	6338	483	8	315	14	66	1
1.23a Potomac River	123	8	1303	1284	114	9	29	0	1	0
1.23b Rappahannock River	38	2	693	686	42	6	16	0	0	0
1.23c York River	20	1	525	520	20	4	10	0	0	0
1.23d James River	59	3	1130	1124	141	13	182	3	20	4
TOTAL	2,359	255	22,431	21,953	2,009	---	1,635	156	209	---
SOUTHEAST										
2.01/2.02 Albemarle/Pamlico Sound	713	28	3471	3437	67	2	192	12	21	0
2.02a Pamlico /Pungo Rivers	44	1	681	672	44	7	57	3	1	1
2.02b Neuse River	45	2	549	540	20	4	29	1	0	0
2.03 Bogue Sound	25	0	984	978	37	4	95	4	1	2
2.04 New River	9	0	241	240	4	2	31	1	5	7
2.05 Cape Fear River	9	0	390	387	6	2	75	17	17	39
2.06 Winyah Bay	8	0	391	388	6	2	26	2	0	3
2.07 Charleston Harbor	10	1	699	692	40	6	72	11	1	11
2.08 North/South Santee Rivers	2	n/a	152	150	0	0	2	0	0	0
2.09 St. Helena Sound	20	1	772	757	2	0	5	0	0	0
2.10 Broad River	29	2	1074	1059	14	1	24	2	1	1
2.11 Savannah River	9	0	450	439	14	3	46	7	0	8
2.12 Ossabow Sound	9	0	470	464	8	2	1	0	0	0
2.13 St. Catherines/Sapelo Sound	20	1	1472	1464	5	0	16	0	0	0
2.14 Altamaha River	4	0	285	280	0	0	9	0	0	1
2.15 St. Andrew/St. Simons Sound	17	1	978	971	7	1	30	2	0	1
2.16 St. Johns River	61	2	997	994	162	16	120	12	3	2
2.17 Indian River	74	1	1313	1309	227	17	222	10	3	2
2.18 Biscayne Bay	80	2	687	659	149	23	84	3	1	0
TOTAL	1,188	43	16,055	15,878	811	---	1,134	87	53	---

Estuary	Surface Area MLLW 10 sq. km	Estuary Volume MTL cu. km	Perimeter Length km	Shoreline Total Length km	Shoreline Modified Length km	Shoreline Percent Modified	Channel Length km	Channel Surface Area sq. km	Dredge Disposal Area sq. km	Percent Modified Surface Area
GULF OF MEXICO										
3.01 Ten Thousand Islands	49	1	2125	2048	9	0	7	0	0	0
3.02 Charlotte Harbor	71	2	1313	1291	85	7	107	1	10	1
3.02a Caloosahatchee River	7	0	129	125	30	24	30	0	3	5
3.03 Tampa Bay	89	3	909	892	300	34	146	8	43	6
3.04 Suwanee River	12	0	440	400	1	0	11	0	0	0
3.05 Apalachee Bay	42	1	455	415	6	1	16	0	0	0
3.06 Apalachicola Bay	58	2	582	558	23	4	59	1	6	1
3.07 St. Andrew Bay	25	1	445	442	26	6	25	1	0	0
3.08 Choctawhatchee Bay	33	1	289	289	26	9	16	1	0	0
3.09 Pensacola Bay	37	1	311	307	33	11	52	4	9	3
3.10 Perdido Bay	12	0	273	272	19	7	15	0	1	1
3.11 Mobile Bay	107	3	633	624	75	12	126	5	116	11
3.12 Mississippi Sound	219	8	1036	972	57	6	156	4	73	4
3.12a Lake Borgne	71	2	245	231	2	1	31	1	11	2
3.12b Lake Pontchartrain	193	6	417	413	46	11	13	0	1	0
3.13 Mississippi Delta	817	22	7972	7613	112	1	96	5	188	2
3.14 Atchafalaya/Vermilion Bay	183	4	850	794	2	0	19	1	9	1
3.15 Calcasieu Lake	25	1	371	364	23	6	82	6	21	11
3.16 Sabine Lake	25	1	237	235	45	19	59	4	23	11
3.17 Galveston Bay	131	3	1206	1197	190	16	317	12	48	5
3.18 Brazos River	1	0	86	85	1	1	0	0	0	0
3.19 Matagorda Bay	97	2	761	750	13	2	142	6	38	5
3.20 San Antonio Bay	56	1	607	604	18	3	37	1	6	1
3.21 Aransas Bay	48	1	485	478	20	4	72	2	15	4
3.22 Corpus Christi Bay	48	1	458	451	63	14	124	5	25	6
3.23 Laguna Madre	90	1	673	664	42	6	298	11	69	9
3.23a Baffin Bay	21	0	243	234	6	2	0	0	0	0
TOTAL	2,567	68	23,549	22,749	1,271	---	2,057	81	713	---
WEST COAST										
4.01 San Diego Bay	4	0	110	109	48	44	31	8	0	18
4.02 San Pedro Bay	6	1	219	201	159	79	15	1	0	2
4.03 Santa Monica Bay	58	52	162	119	27	23	3	0	0	0
4.04 Monterey Bay	55	42	116	81	6	7	2	0	1	0
4.05 San Francisco Bay	87	7	698	693	179	26	96	12	1	2
4.05a Suisun Bay	22	1	1168	1165	60	5	84	7	0	3
4.06 Eel River	2	n/a	142	142	0	0	0	0	0	0
4.07 Humboldt Bay	3	0	178	177	8	5	17	2	0	7
4.08 Klamath River	1	n/a	65	64	0	0	0	0	0	0
4.09 Coos Bay	2	0	166	164	12	7	27	3	0	13
4.10 Winchester Bay	1	n/a	102	101	6	6	21	1	0	10
4.11 Columbia River	49	4	1551	1545	103	7	257	41	1	9
4.12 Willapa Bay	18	1	522	511	5	1	19	1	0	1
4.13 Grays Harbor	10	1	450	447	15	3	32	3	0	3
4.14 Puget Sound	147	95	1338	1323	139	10	33	2	1	0
4.14a Hood Canal	37	26	348	342	6	2	2	0	0	0
4.14b Skagit Bay	56	26	393	387	11	3	14	1	0	0
TOTAL	558	257	7,729	7,570	785	---	650	83	5	---
NATIONAL TOTAL	6,672	625	69,764	68,150	4,876	---	5,476	407	980	---

Appendix 2. Ratio of modification characteristics for estuaries of USA.

Estuary	Shoreline Length to Estuarine Water Surface Area	Modified Shoreline Length to Estuarine Water Surface Area	Channel Area plus Disposal Area to Estuarine Water Surface Area	Disposal Area to Channel Length	Disposal Area to Channel Area
Passamaquoddy Bay	1.2	0.0	0.00	0.00	0.00
Englishmans Bay	1.5	0.0	0.01	0.00	0.00
Narragaugus Bay	2.0	0.0	0.00	0.00	0.00
Blue Hill Bay	1.2	0.0	0.00	0.00	0.00
Penobscot Bay	0.9	0.0	0.01	1.65	0.00
Muscongus Bay	1.7	0.0	0.00	0.00	0.00
Sheepscot Bay	3.1	0.1	0.00	0.00	0.00
Casco Bay	1.4	0.0	0.02	0.35	2.33
Saco Bay	1.5	0.1	0.00	0.00	0.00
Great Bay	6.3	0.2	0.02	0.00	0.00
Merrimack River	5.8	0.2	0.00	0.00	0.00
Boston Bay	1.8	0.5	0.06	0.00	0.00
Cape Cod Bay	0.3	0.0	0.00	0.50	0.00
Buzzards Bay	0.6	0.1	0.02	0.35	2.81
Narragansett Bay	1.2	0.1	0.03	0.02	0.12
Gardiners Bay	0.9	0.1	0.00	0.00	0.00
Long Island Sound	0.4	0.1	0.03	0.57	10.68
Connecticut River	7.2	0.2	0.00	0.00	0.00
Great South Bay	2.2	0.4	0.00	0.00	0.00
Hudson/Raritan Bay	1.9	0.5	0.08	0.00	0.02
Barnegat Bay	1.7	0.4	0.00	0.02	0.29
Delaware Bay	0.5	0.1	0.02	0.04	0.29
Chincoteague Bay	1.3	0.0	0.01	0.04	0.58
Chesapeake Bay	0.8	0.1	0.01	0.21	4.77
Potomac River	1.0	0.1	0.00	0.03	2.92
Rappahannock River	1.8	0.1	0.00	0.02	0.00
York River	2.6	0.1	0.00	0.00	0.00
James River	1.9	0.2	0.04	0.11	7.36
Albemarle/Pamlico Sound	0.5	0.0	0.00	0.11	1.74
Pamlico /Pungo Rivers	1.5	0.1	0.01	0.02	0.51
Neuse River	1.2	0.0	0.00	0.00	0.00
Bogue Sound	3.9	0.1	0.02	0.01	0.34
New River	2.7	0.0	0.07	0.16	4.66
Cape Fear River	4.4	0.1	0.39	0.22	0.96
Winyah Bay	4.8	0.1	0.03	0.00	0.00
Charleston Harbor	6.9	0.4	0.11	0.01	0.07
North/South Santee Rivers	7.5	0.0	0.00	0.00	0.00
St. Helena Sound	3.8	0.0	0.00	0.00	0.00
Broad River	3.6	0.0	0.01	0.04	0.58
Savannah River	5.0	0.2	0.08	0.00	0.00
Ossabow Sound	5.2	0.1	0.00	0.00	0.00
St. Catherines/Sapelo Sound	7.4	0.0	0.00	0.00	0.00
Altamaha River	7.2	0.0	0.01	0.03	0.00
St. Andrew/St. Simons Sound	5.6	0.0	0.01	0.00	0.00
St. Johns River	1.6	0.3	0.02	0.02	0.23
Indian River	1.8	0.3	0.02	0.01	0.26
Biscayne Bay	0.8	0.2	0.00	0.01	0.23

Estuary	Shoreline Length to Estuarine Water Surface Area	Modified Shoreline Length to Estuarine Water Surface Area	Channel Area plus Disposal Area to Estuarine Water Surface Area	Disposal Area to Channel Length	Disposal Area to Channel Area
Ten Thousand Islands	4.1	0.0	0.00	0.00	0.00
Charlotte Harbor	1.8	0.1	0.01	0.09	12.96
Caloosahatchee River	1.9	0.5	0.05	0.09	7.29
Tampa Bay	1.0	0.3	0.06	0.30	5.42
Suwanee River	3.4	0.0	0.00	0.00	0.00
Apalachee Bay	1.0	0.0	0.00	0.00	0.00
Apalachicola Bay	1.0	0.0	0.01	0.09	4.95
St. Andrew Bay	1.8	0.1	0.00	0.00	0.00
Choctawhatchee Bay	0.9	0.1	0.00	0.00	0.00
Pensacola Bay	0.8	0.1	0.03	0.16	1.93
Perdido Bay	2.4	0.2	0.01	0.06	5.40
Mobile Bay	0.6	0.1	0.11	0.93	21.65
Mississippi Sound	0.4	0.0	0.04	0.47	16.36
Lake Borgne	0.3	0.0	0.02	0.35	8.18
Lake Pontchartrain	0.2	0.0	0.00	0.08	2.70
Mississippi Delta	0.9	0.0	0.02	1.97	39.04
Atchafalaya/Vermilion Bay	0.4	0.0	0.01	0.47	6.01
Calcasieu Lake	1.4	0.1	0.11	0.26	3.59
Sabine Lake	1.0	0.2	0.11	0.39	5.81
Galveston Bay	0.9	0.1	0.05	0.15	4.02
Brazos River	13.8	0.1	0.00	0.00	0.00
Matagorda Bay	0.8	0.0	0.05	0.27	6.86
San Antonio Bay	1.1	0.0	0.01	0.17	8.37
Aransas Bay	1.0	0.0	0.04	0.21	6.93
Corpus Christi Bay	0.9	0.1	0.06	0.20	5.40
Laguna Madre	0.7	0.0	0.09	0.23	5.97
Baffin Bay	1.1	0.0	0.00	0.00	0.00
San Diego Bay	2.6	1.1	0.18	0.00	0.00
San Pedro Bay	3.2	2.5	0.02	0.00	0.00
Santa Monica Bay	0.2	0.0	0.00	0.00	0.00
Monterey Bay	0.1	0.0	0.00	0.47	0.00
San Francisco Bay	0.8	0.2	0.02	0.01	0.11
Suisun Bay	5.2	0.3	0.03	0.00	0.00
Eel River	6.9	0.0	0.00	0.00	0.00
Humboldt Bay	5.7	0.3	0.07	0.00	0.00
Klamath River	8.9	0.0	0.00	0.00	0.00
Coos Bay	7.7	0.6	0.13	0.00	0.00
Winchester Bay	7.3	0.4	0.10	0.00	0.00
Columbia River	3.2	0.2	0.09	0.01	0.03
Willapa Bay	2.9	0.0	0.01	0.00	0.00
Grays Harbor	4.5	0.2	0.03	0.00	0.00
Puget Sound	0.9	0.1	0.00	0.03	0.42
Hood Canal	0.9	0.0	0.00	0.00	0.00
Skagit Bay	0.7	0.0	0.00	0.00	0.00

Mobile Bay
AL

PHYSICAL AND HYDROLOGIC CHARACTERISTICS

PHYSICAL

Surface Areas (mi^2)	
Fluvial Drainage	39,725
Estuarine Drainage	4,875
Estuarine Zones	
Tidal Fresh	29
Mixing Zone	327
Seawater	63
Total	409
Dimensions	
Length (mi.)	128.0
Width (mi.) Average	13.8
Minimum	8.0
Maximum	23.6
Average Depth (ft.)	9.6
Average Depth to Width Ratio	$1.3x10^4$
Stratification Classification	
3-Month High Flow	HS
3-Month Low Flow	MS

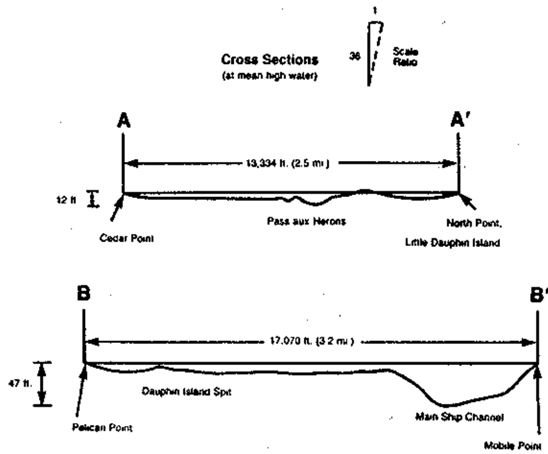
FRESHWATER INFLOW

Flow Rates (1000 cfs)		
Period of Record		1975-1982
Long Term Average Daily		79.3
Long Term Average Monthly	J 129.8	J 32.3
	F 120.7	A 29.4
	M 161.4	S 29.9
	A 179.4	O 36.9
	M 83.3	N 43.4
	J 44.5	D 64.0
7-Day, 10-Year Low Flow		7.6
50-Year Flood		595.7
100-Year Flood		653.0
Flow Ratios		
Average Annual		0.449
High Flow Period		0.670
Low Flow Period		0.173

TIDAL DATA

Prevailing Tide: Diurnal		
Tidal Prism (cf)		$1.58x10^{10}$
Phase Range of Tide (ft.)		
Map Key	Station	Range
A	3194	1.3
B	3197	1.4
C	3198	1.4
D	3199	0.8

Abbreviations: Vertically Homogeneous, VH; Moderately Stratified, MS; Highly Stratified, HS



Notes:
Approximately 40% of Estuarine Drainage Area is shown on map.

References:
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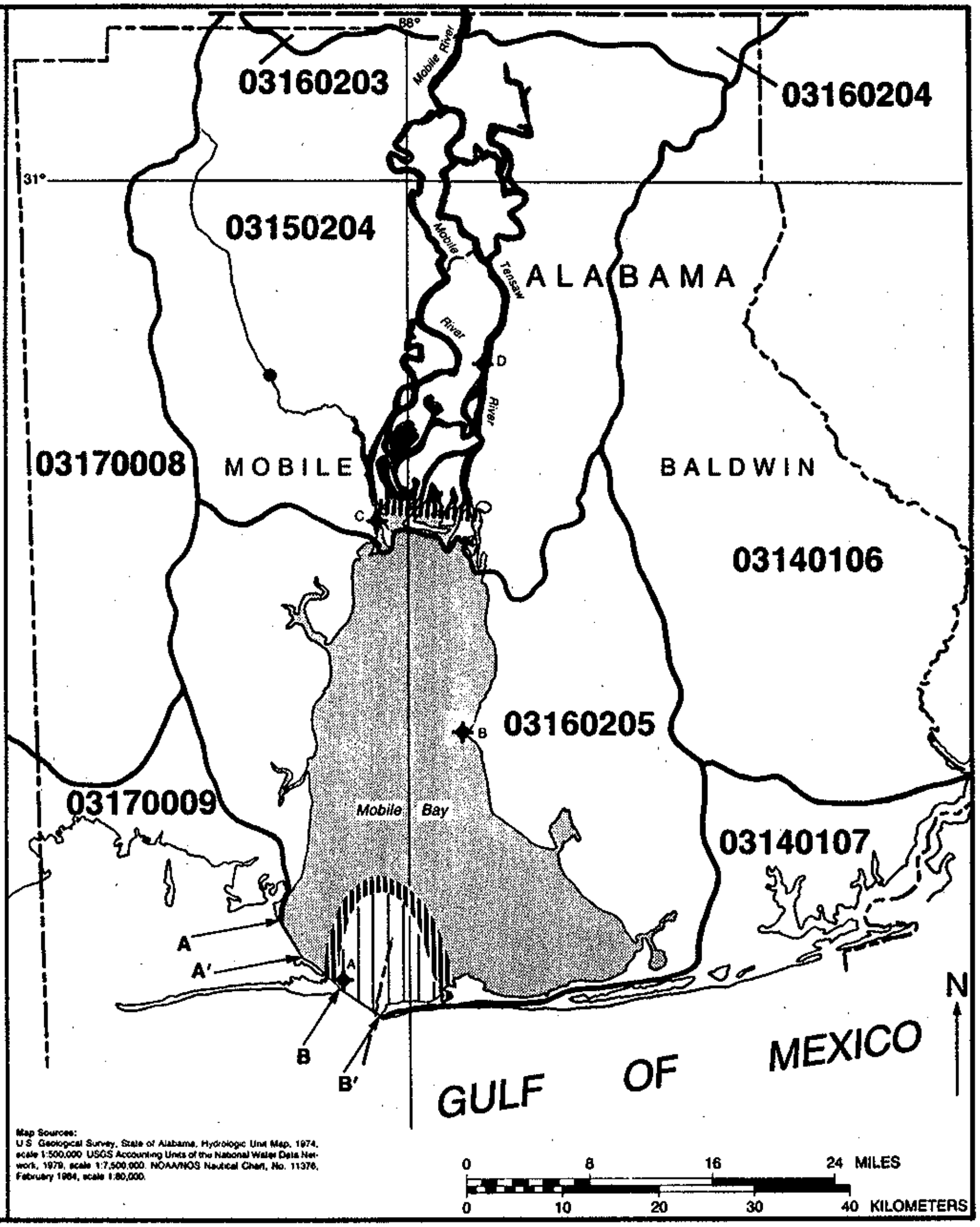
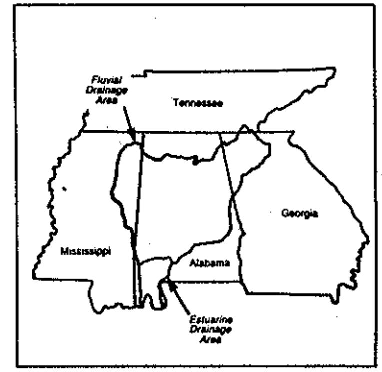


Map Sources:
U.S. Geological Survey, State of Alabama, Hydrologic Unit Map, 1974, scale 1:500,000. USGS Accounting Units of the National Water Data Network, 1979, scale 1:7,500,000. NOAA/NOS Nautical Chart, No. 11376, February 1984, scale 1:80,000.



- Tide Gage
- Flow Gage
- Head of Tide
- Estuarine Drainage Area (EDA)
- Tidal Fresh Zone
- Mixing Zone
- Seawater Zone
- Hydrologic-Cataloging Unit Boundary
- County Boundary
- Salinity Zone Boundary - Low Variability
- Salinity Zone Boundary - Moderate Variability
- Salinity Zone Boundary - High Variability

Strategic Assessment Branch
Ocean Assessments Division
Office of Oceanography and Marine Assessment
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