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A COASTAL HAZARDS DATA BASE FOR THE U.S. EAST COAST

Contributed by

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

ABSTRACT

GORNITZ, V.M. and T.W. WHITE. 1992. A Coastal Hazards Data Base for the U.S. East Coast, ORNL/CDIAC-45, NDP-043A, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 184 pp.

This document describes the contents of a digital data base that may be used by raster or vector geographic information systems (GIS) and non-GIS data bases to assess the risk of coastlines to erosion or sea level rise. The data base integrates point, line, and polygon data for the U.S. East Coast into 0.25° latitude x 0.25° longitude grid cells. Each coastal grid cell contains data on geology, geomorphology, elevation, wave heights, tidal ranges, shoreline displacement (erosion), and sea-level trends.

To allow for the identification of coastlines at risk from coastal erosion or sea level rise, 7 of the 22 original data variables in this data base were classified and used to create 7 relative risk variables. These relative risk variables may be used to calculate a coastal vulnerability index for each grid cell. The data for the 22 original variables and 7 risk variables, for a total of 29 data variables, have been placed into the following data groups:

(1) Gridded polygon data for the 22 original data variables. Data include elevations, geology, geomorphology, sea-level trends, shoreline displacement (erosion), tidal ranges, and wave heights.

(2) Supplemental data for the stations used in calculating the sea-level trend and tidal range data sets.

(3) Gridded polygon data for the seven classified risk variables. The risk variables are classified versions of the following data variables: mean coastal elevation, geology, geomorphology, local subsidence trends, mean shoreline displacement, maximum tide range, and the maximum significant wave height.

These data are available as a Numeric Data Package (NDP), from the Carbon Dioxide Information Analysis Center, consisting of this document and a set of computerized data files. The documentation contains information on the methods used in calculating each variable, detailed descriptions of file contents and formats, and a discussion of the sources, restrictions, and limitations of the data. The data files are available on magnetic tape, on floppy diskettes, or through INTERNET. This data base consists of several ARC/INFO™ export files and flat ASCII data files (provided to extend the use of the data to non-ARC/INFO™ users) with the data placed into 0.25° x 0.25° grid cells of latitude and longitude. A 1:2,000,000 digitized coastline of the U.S. East Coast, FORTRAN and SAS™ retrieval files, and a descriptive file have also been provided.

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PART 1
INFORMATION ABOUT THE DATA PACKAGE

1. NAME OF THE NUMERIC DATA PACKAGE

A COASTAL HAZARDS DATA BASE FOR THE U.S. EAST COAST

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3. KEYWORDS

Coastal hazards; risk assessment; sea level rise; elevation; geology; geomorphology; coastal landforms; subsidence; erosion; accretion; tide range; wave height; geographic information system.

4. BACKGROUND INFORMATION

Effective coastal management requires the ability to project the response of coastal zones to short- and long-term climate variations, since any change in climatic processes will ultimately affect the coastal zone in some way. For example, 10,500 years ago during the Wisconsin glaciation, the mean global surface air temperature was 5 to 10°C cooler than at present. This reduced global temperature resulted in the growth of continental and alpine glaciers. These glaciers fixed large amounts of water in place (as ice or snow) and resulted in a reduction, from current levels, in the eustatic sea level of 110 to 120 m.

Variations in sea levels and air temperatures of this magnitude can profoundly affect the maximum intensity and frequency of storms and, as a result, increase or decrease erosion rates in coastal areas (Emanuel, 1988). The effects of coastal storms range from accelerated shoreline erosion (Dolan et al., 1988) to loss of life and property (Case and Mayfield, 1990). Added to these concerns is a fear that climatic change, especially that caused by an increase in the world's mean global surface air temperatures (i.e., the greenhouse effect), may cause the world's current rate of sea level rise to increase (Houghton et al., 1990).

The prediction of the future response of coastal zones to changes in sea level or storm intensity requires information on the past and current state of the coast (Smith and Piggott, 1987). In 1987 the U.S. Department of Energy, Atmospheric and Climate Research Division, funded Dr. Vivien M. Gornitz (Goddard Institute for Space Studies) and the *Carbon Dioxide Information and Analysis Research Program: Resource Analysis Project* at Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee, to develop a Coastal Hazards Data Base to provide information on the past and current state of the coast. As envisioned, the data base would contain information on relative sea level trends, elevation, vertical land movements, horizontal displacement (erosion/accretion), coastal geomorphology, and geology. When complete, the data base would be used within a Geographic Information System (GIS) to identify coastal areas of the United States (and possibly Europe, Australia, Mexico, and Canada) that are currently at risk to inundation and erosion, and whose risk would increase if the world's eustatic sea level increased (Department of Energy, 1987; 1988; 1989; 1990; 1991).

The research- and data-acquisition phase of this project ended in 1991. The data gathered over the lifetime of the project are archived at the Carbon Dioxide Information Analysis Center (CDIAC) at ORNL. From this data CDIAC plans to produce a set of Numeric Data Packages (NDPs) for the continental United States. The following NDPs are available, in progress, or planned: U.S. East Coast (NDP-043A, available), U.S. Gulf Coast (NDP-043B, in progress), and U.S. West Coast (NDP-043C, planned) — NDPs for Hawaii, Alaska, and portions of Mexico and Canada may follow. The data for the Gulf and West Coast are still in the process of being statistically analyzed and integrated into the GIS, and need to be documented and quality assured before they are distributed. These data sets will be released through CDIAC as they are completed. The data contained within this data base, for the U.S. East Coast, is the first of these regional data sets to be made available.

The information presented here may be used for calculating the relative vulnerabilities of different areas on the East Coast to projected increases in air and sea temperatures, and sea level. This information will be useful to researchers, government planning agencies, the private sector, or educational institutions which are trying to determine the present and future vulnerability of coastal zones to erosion and sea-level rise.

The data base described here comprises data extracted from a variety of sources, including publications of the National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers, the U.S. Geological Survey (USGS), universities, and other federal and state agencies. Because of the wide variety of data sources used, the scale and form in which data was received varied. To facilitate data analysis, the information was referenced to a grid of 0.25° latitude by 0.25° longitude cells that cover the East Coast (i.e., one grid cell contains four USGS 7.5-minute Topographic Quadrangles). For the purposes of this NDP the East Coast has been defined as extending from the Maine - Canadian border to Key West, Florida.

5. APPLICATIONS OF THE DATA

This coastal hazards data base contains information on elevation (relief), bedrock geology, geomorphology (coastal landforms), sea-level trends, horizontal shoreline displacement (erosion or accretion), tide ranges, and wave heights. These data variables were selected for inclusion in this data base on the bases of the roles they play in determining the vulnerability of coastal areas to variations in sea level and long-term erosion.

When the information in this data base is used in conjunction with appropriate climatological data (e.g., Birdwell and Daniels, 1991), it may be used to identify coastal grid cells that are at greater risk of temporary inundation from coastal storms relative to other areas on the East Coast (Gornitz, 1990). This data base may also be used to identify coastal zones that are at risk from coastal erosion or possible changes in relative sea level in response to predicted global warming and local subsidence (Houghton et al., 1990). This predictive capability will allow the planning process for coastal areas to begin before the effects of climate change are actually felt.

The 29 data variables in this data base effectively measure two basic risk factors, erosion and inundation. The inundation risk of a given grid cell may be estimated based on the sea level trends and elevation data; while the erosion risk may be determined on the basis of historical shoreline displacement trends, resistance to erosion (geomorphology, geology), and ocean forcing factors (tide ranges and wave heights).

6. DEFINITION OF STANDARD TERMS AND CONCEPTS USED IN THE DATA PACKAGE

The large number of data variables within this data base may cause confusion. To help alleviate this problem, the following standard definitions have been adopted:

Data variable - A single, discrete, data item within a data group or set (e.g., data set=elevation, data variable=mean elevation).

System variable - A variable that references or identifies data variables with respect to their geographic location or the physical dimensions of the grid cells or points they represent.

Data set - A collection of data variables that have been derived from a single data source, such as the mean and maximum elevation variables.

Data group - A collection of data variables that have been placed into a single ARC/INFO™ export file and a comparable flat ASCII file.

Data base - All data groups within this NDP.

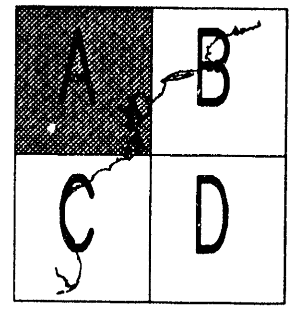
All 29 data variables within this data base have been placed into two primary data groups and one supplemental data group (i.e., the supplemental data group contains the point data used for calculating the sea level trend and tide-range variables). The primary data groups are stored in a grid of 0.25° latitude by 0.25° longitude cells. All three of the data groups are available as ARC/INFO™ export files or flat ASCII files. The data values in the ARC/INFO™ files are point or polygon based. This implies that each grid cell that describes the U.S. East Coast has a total of 29 attribute values. (An auxiliary data file containing a 1:2,000,000 digitized coastline of the East Coast has been included. The data in this file were extracted from a map originally digitized by the USGS.)

To allow these data to be used by a raster GIS, or a non-GIS data base, the data were transformed into a raster format and stored in the flat ASCII data files. The storage format for these flat files uses the same 0.25° latitude by 0.25° longitude grid used in the vector (ARC/INFO™) files. The 0.25° grid covers the East Coast and is defined by the following coordinates: 85°W, 24°N; 85°W, 46°N; 65°W, 46°N; and 65°W, 24°N. The origin of the grid is at 85°W, 24°N and grid identifiers increase from left to right, bottom to top (Figure 1). The data contained within each grid cell is valid for the entire grid cell. The data for a grid cell should not be construed as being representative of a "point" in the cell -be it the lower-left corner, upper-left corner, center, etc.

Of the 29 data variables contained witnin this data set, 9 contain information originally derived from point data. For these variables the actual point data have been provided in the supplemental data group. The supplemental data group includes the following items: station name/number, latitude/longitude location, period-of-record, and the actual values used to derive the relative sea level trend, long-term geologic-trend, corrected sea level trend, local subsidence trend, mean tide range, maximum tide range, and mean tide level variables.

Upon special request a line/arc version of the data used in the creation of this data base is available from CDIAC. If requested, this data will be provided as an exported ARC/INFO™ coverage. This special coverage contains data for line segments, each approximately 4.5 km long, that when plotted are equivalent to those found within the auxiliary file (i.e., a 1:2,000,000 scale coastline map) provided with this database.

Figure 1. Grid cells (0.25° by 0.25°) and identification numbers used in the raster (ASCII) and vector (ARC/INFO) files. The value shown within each cell is the grid cell identification number.



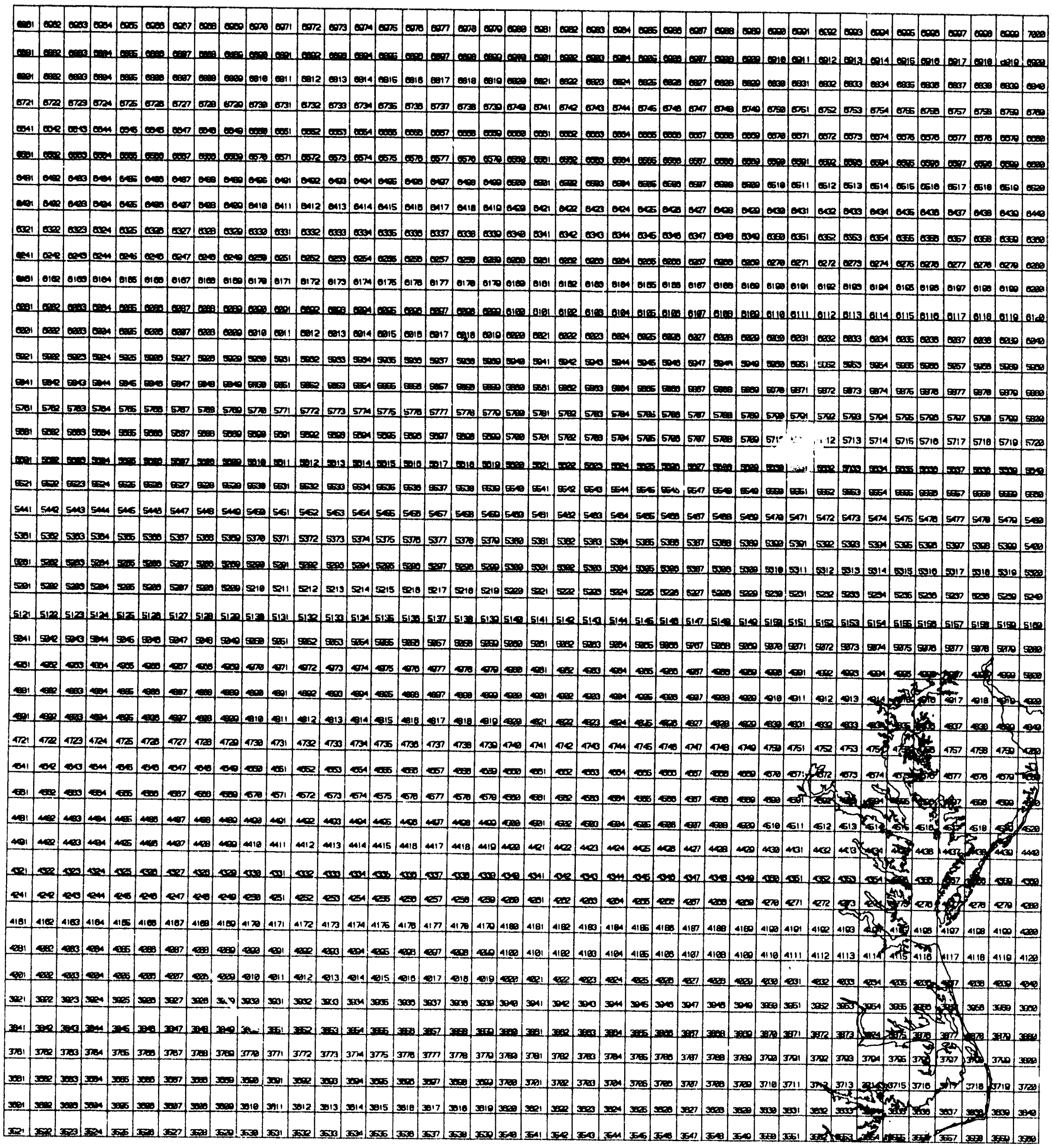
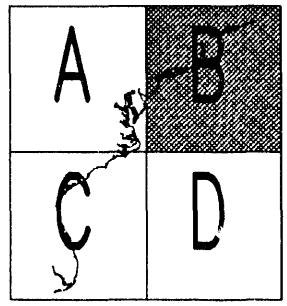
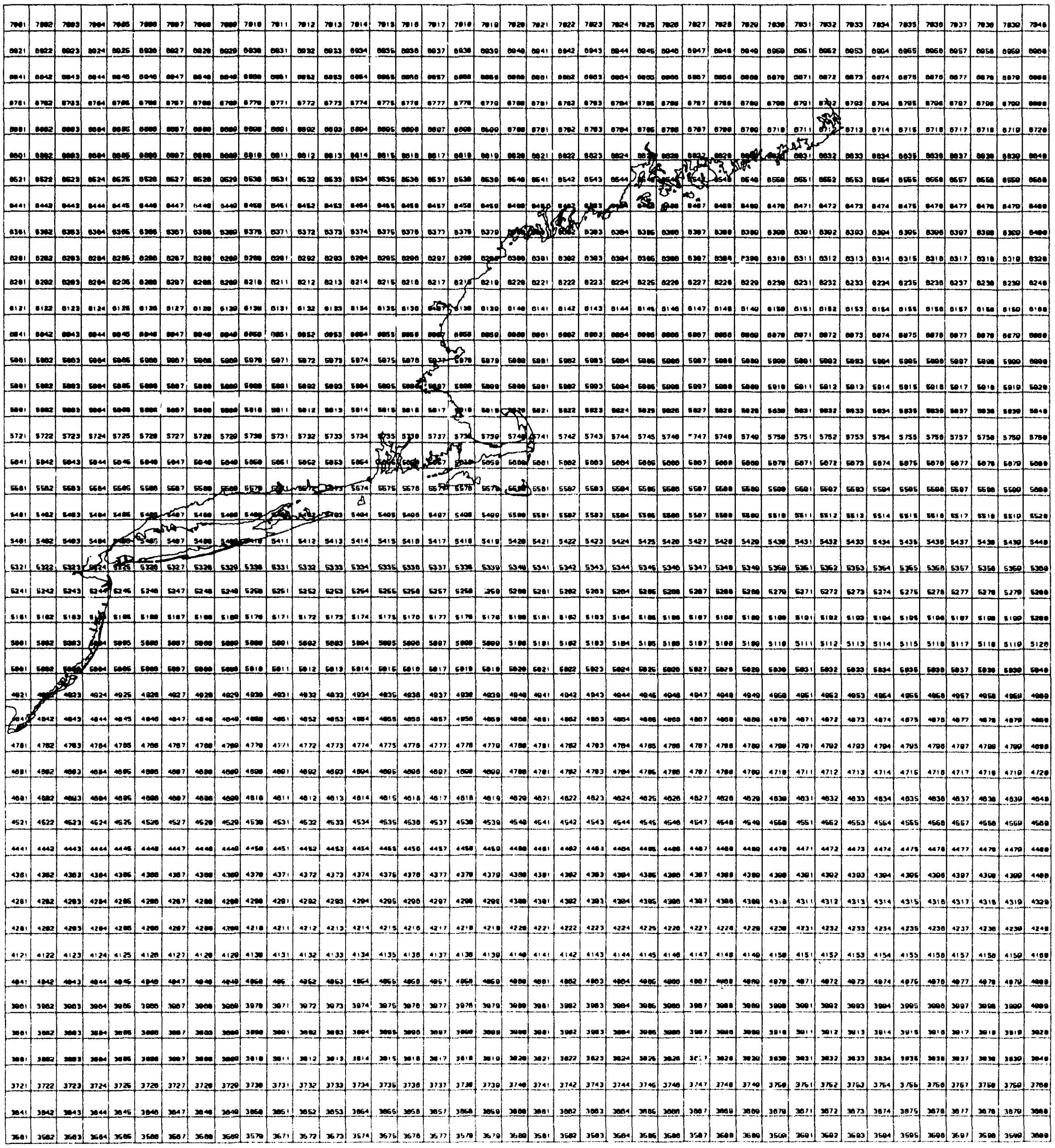


Figure 1. (Continued)





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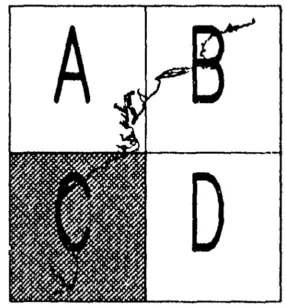

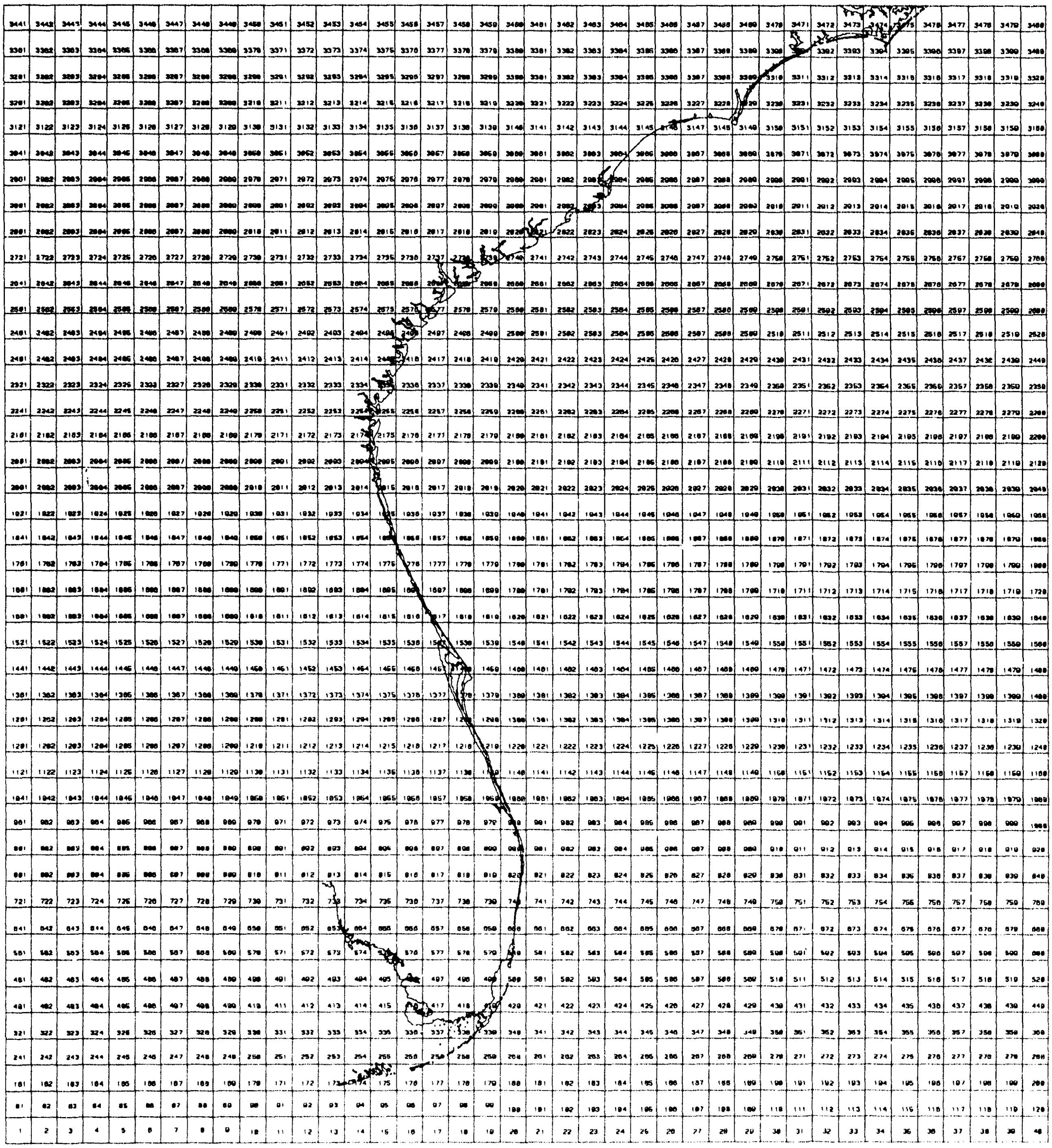

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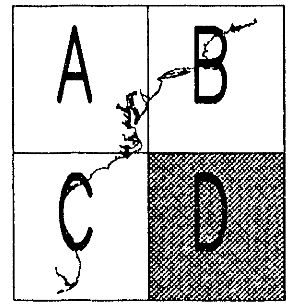

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841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880
761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800
681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720
601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640
521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560
441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480
361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400
281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320
201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240
121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

7. ORIGINAL DATA VARIABLES

The data sets that make up this data base include the following: elevation, geology, geomorphology, sea level trends, shoreline displacement, tide ranges, and wave heights. These data sets were obtained in a variety of scales and formats (e.g., as point, line, or polygon data). Therefore, the methods used to enter the data into the 0.25° grid cells vary by data set. The variable descriptions used in this data base were derived from annual reports delivered on April 30, 1988, November 30, 1988, April 29, 1991; and personal correspondence with the contributors (Gornitz, 1988a; 1988b; 1991). The following subsections provide a brief description of the data sources and the units/classification methods used in compiling each data set.

7.1 Elevation

The elevation data for this data set were obtained from the National Geophysical Data Center (NGDC), Boulder, Colorado, as digitized land elevations (to the nearest meter) for 5' latitude by 5' longitude grid cells. The NGDC grid cells were then grouped into the 0.25° x 0.25° grid cells used in this data base. Minimum, mean, and maximum elevation data for each coastal grid cell are provided. The 0.25° cells used may contain up to nine 5' grid cells, where only the 5' grid cells with nonnegative elevation values (i.e., with land within their borders) have been used in calculating the data variables in this data set (all 5' cells without data contained a value of -1). If only one 5' grid cell within a given 0.25° cell contains a nonnegative data value, then the minimum, mean, and maximum elevation variables will be the same. To calculate and transfer these data to the 0.25° grid used in this data base, the variables were calculated as follows:

1. The number of 5' NGDC grid cells with nonnegative elevation values within each 0.25° grid cell was determined.

2. The minimum elevation for each 0.25° grid cell was assigned by taking the minimum elevation of all the nonnegative 5' grid cells (i.e., from the original data source) within the grid cell.

3. The mean elevation for each 0.25° grid cell was assigned by taking the average of the elevations from all nonnegative 5' grid cells (i.e., from the original data source) within the grid cell.

4. The maximum elevation for each 0.25° grid cell was assigned by taking the maximum elevation of all nonnegative 5' grid cells (i.e., from the original data source) within the grid cell.

Because of the low resolution of the original elevation data files, peninsulas and small islands often were not represented in the NGDC data. Because of this, the 0.25° elevation data were overlaid onto a 1:2,000,000 map of the East Coast. Then, through examination of the overlay, any 0.25° grid cells with land within their boundaries that had a negative elevation value (i.e., indicating that the grid cell contained no land) were assigned an elevation value of 0 m. In this case, the 0 value indicates that the land within the given 0.25° grid cell is less than 1 m above mean sea level. A limitation of this method is produced by cell boundary conditions. For example, an entire 0.25° grid cell is counted as coastal land even when all of the component 5' data cells originally had negative elevation values. This condition appears within the data files as a zero number of 5' cells used in calculating the elevation variables and 0 m minimum, mean, and maximum elevations. These zero values indicate that a 0.25° grid cell had no land above mean sea level within its boundaries, based on the 5' grid cells in the original data source. This situation typically occurred when there was a parallel alignment of the coastline with the source grid system (i.e., the coastline is oriented East-West or North-South).

The distribution of the elevation values within the elevation data revealed important differences among the U.S coasts, primarily because of differences in the geologic history of each coastal region. For example, the East and Gulf coasts are located on the tectonically stable Atlantic Coastal Plain (Graf, 1987). This stability has resulted in relatively small local relief along the East Coast (e.g., 28.3% of the East Coast is ≤ 3.0 m above sea level). This is in marked contrast to the West Coast, where tectonic instability, caused by the collision of the Pacific and American plates, results in only 3.4% of the grid cells having elevation values less than 3 m.

7.2 Geology

The geologic/lithologic variable is present for all coastal grid cells in the data base. By its nature, geological data are a form of nominal data. In this data set the data were classified in terms of an ordinal scale based on the hardness of each mineral. For the East Coast a simplified classification of coastal lithology was derived from state geologic maps ranging in scale from 1:125,000 to 1:2,500,000 with publication dates from 1929 to 1986 (maps used are listed in section 13.2).

The coastal geology classification system used was adapted in part from one used by Dolan et al. (1975). The system contains 5 major groups with 20 subgroups (Table 1). Appendix B contains a glossary of the terms used in the classification system, and Figure 2 shows an example of how the codes derived for the coastline were transferred to the grid cells used in this data base. (Appendix C gives a breakdown of the geology codes that occurred with each grid cell.) The key discriminant between the individual classes identified below is the relative resistance of each rock type to physical and chemical weathering.

Table 1. Coastal geologic classification codes assigned to the coastal geology variable.

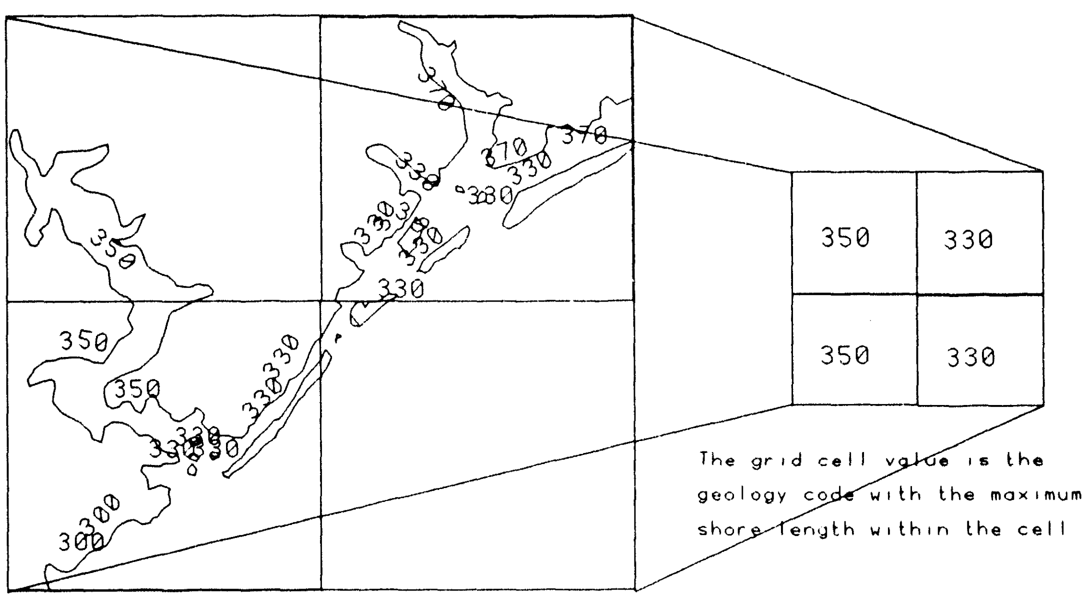
Material description	Code
I. Old Erosion Resistant Rocks (crystallines)	100
1. Igneous, volcanic (basalt, rhyolite, andesite, etc.)	110
2. Igneous, plutonic (granite, granodiorite, etc.)	130
3. Metamorphic (schists, gneisses, quartzite, serpentinite, etc.)	150
II. Sedimentary Rocks	200
1. Shale	210
2. Siltstone	220
3. Sandstone	230
4. Conglomerate	240
5. Limestone	250
6. Eolianite (calcite-sand)	260
7. Mixed or varied lithology	270
III. Unconsolidated Sediments	300
1. Mud, Clay	310
2. Silt	320
3. Sand	330
4. Gravel, conglomerates	340
5. Glacial till	345
6. Glacial drift (fluvial-glacial)	350
7. Calcareous sediment	360
8. Mixed or varied lithology	370
IV. Recent Volcanic Materials	400
1. Lava	410
2. Ash, Tephra	420
3. Composite	430
V. Coral Reef (living)	500

This ranking scheme is generalized; consequently, a wide range of erodibilities exist for each rock type listed. The erodibility of each rock is dependent on the mineral content, cementation (especially for sedimentary rocks), grain size (for unconsolidated sediments), and presence of planar elements (i.e., bedding, schistosity, cleavage, and fractures) within the rock. These risk characteristics cannot be deduced from the geologic maps alone, and field checking would be required to obtain a more detailed classification than that used in this data set.

Based on Table 1 all grid cells that fall on the East Coast have been assigned a data value. The value assigned to each grid cell is the code with the maximum shore length within each cell. For example, if the bedrock geology of a given 0.25° grid cell contained sand (330), gravel (340), and limestone (250) in the percentages 35%:40%:25%, respectively, then the geologic code assigned to the grid cell would be 340 -gravel.

In general the bedrock geology of the East Coast is relatively uncomplicated. The East Coast may be divided into three regions. The Northern region, covering approximately 15% of the coast, extends from Providence, Rhode Island, to the Maine-Canadian border. This region is primarily made up of igneous and metamorphic rocks that are relatively resistant to erosion. The Mid-Atlantic region covers 74% of the East Coast and extends north from Cape Canaveral, Florida, to Cape Cod, Massachusetts. This region is predominantly made up of unconsolidated sediments consisting of sand and other materials with mixed lithologies. The Southern region covers 11% of the East Coast and extends from the Florida Keys to Cape Canaveral. The lithology of this region is made up of limestones and sandstones overlain with recently deposited unconsolidated sediments.

Figure 2. Example of how geologic data codes were transferred to the 0.25° grid cells used in this NDP.



7.3 Geomorphology

The geomorphology variable contains data for all coastal grid cells in the data base. The data values were interpreted and classified from USGS 1:250,000 topographic maps (maps used are listed in section 13.3) and other published sources, such as Shepard and Wanless (1971) and Bird and Schwartz (1985). The landforms identified from the 1:250,000 maps may omit landforms with small spacial extent. The maps used for the East Coast were compiled from 1913 (for Long Island, New York) to 1972, with some revisions as recent as 1987. Most of the maps used, however, were dated 1950 or later.

The classification system used divides the East Coast into two major groups, those formed by erosion and those formed by deposition (Table 2). These two groups are further subdivided into several categories (e.g., marine, non-marine, glacial, non-glacial, and volcanic). Appendix B contains a glossary of the terms used to describe each landform type and Appendix C gives a breakdown of the geomorphic codes that occurred within each cell.

Table 2. Coastal geomorphology classification codes assigned to the coastal geomorphology variable.

Landform description	Code	Beach	Man modified
I. Erosional Coasts (Scoured, beaches poorly developed)	1000		
A. Marine with wave erosion and cliffs	1100		
1. Low 5- 30 m	1110	1111	1119
2. Medium 30-100 m	1120	1121	1129
3. High >100 m	1130	1131	1139
B. Non-Marine (Land erosion)	1200-1500		
1. Glaciated coast	1210	1211	1219
a. Fjord(drowned valley)	1220	1221	1229
b. Indented Fiard (low-lying inlet)	1230	1231	1239
mud flats	1234		
salt marsh	1235		
c. Rocky glacial coast	1240	1241	1249
Salt Marsh	1245		

Table 2. (Continued)

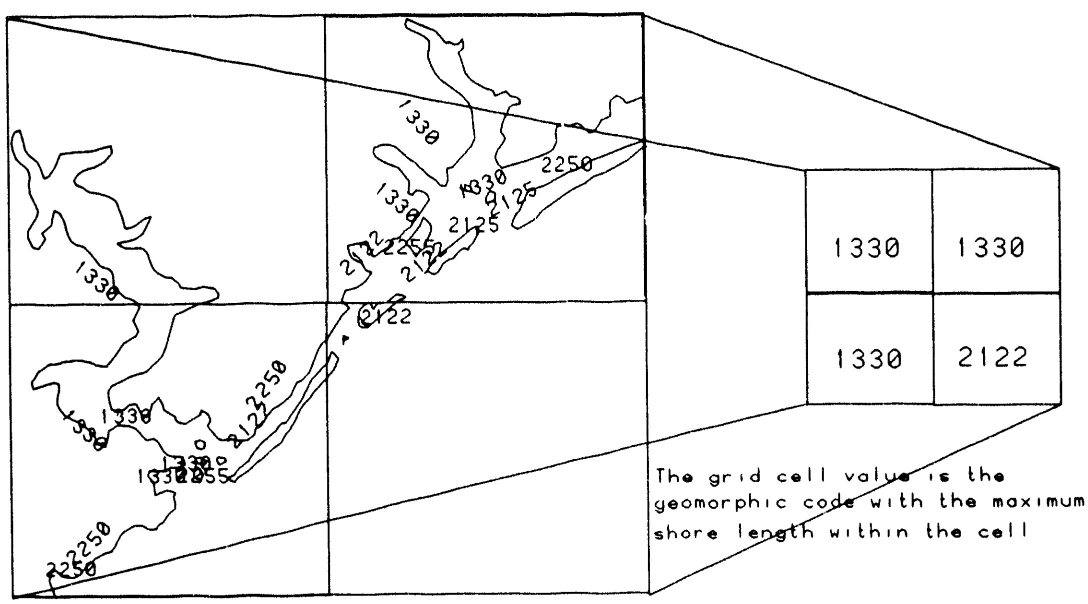
Landform description	Code	Beach	Man modified
2. Non-glacial irregular coast	1300		
a. Strongly embayed, non-rocky coast	1310	1311	1319
b. Strongly embayed, rocky coast	1320	1321	1329
c. Estuaries	1330	1331	1339
mud flats	1334		
salt marsh	1335		
mixed types	1338		
3. Ice coasts	1400		
4. Drowned karst topography	1500		
II. Depositional Coasts (Sediment accumulations and well-developed beaches)	2000		
A. Marine Deposits	2100		
1. Coastal plain beach	2110	2111	2119
salt marsh	2115		
2. Beach rock (beach sediment cemented by carbonates)	2112		
3. Barrier Coast	2120	2121	2129
a. barrier island	2122		
b. bay barrier	2123		
c. mud flats	2124		
d. salt marsh	2125		
e. cuspate foreland	2126		
f. spit	2127		
g. mixed	2128		

Table 2. (Continued)

Landform description	Code	Beach	Man modified
B. River Deposits	2200		
1. Alluvial plain	2210	2211	2219
2. Delta environment	2220	2221	2229
a. mud flats	2224		
b. salt marsh	2225		
c. mixed	2228		
C. Marine/Fluvial Deposits (Lagoonal coast)	2250	2251	2259
1. Mud flats	2254		
2. Marsh/Mangrove	2255		
3. Mixed	2258		
D. Glacial Deposits	2300		
1. Outwash plain	2310	2311	2319
2. Moraine	2320	2321	2329
3. Drumlin	2330	2331	2339
salt marsh	2315		
4. Drift	2340	2341	2349
salt marsh	2345		
5. Composite	2350	2351	2359
E. Biogenic	2400		
1. Reefs (Coral, oysters, algal)			
a. fringing	2410	2411	2419
b. barrier	2420	2421	2429
2. Barrier reef with an associated mangrove swamp	2425		
3. Swamp/Mangrove	2450	2451	2459
F. Volcanic Coasts	2500		
1. Lava flows	2510	2511	2519
2. Tephra, ash	2520	2521	2529
3. Composite/caldera	2530	2531	2539

A few geomorphic features occurred in more than one coastal environment. When this happened, a special digit was added after the three-digit code that identified the feature. The special digit is used to identify areas that are made up primarily of beach or in areas that have been significantly modified by human activities. Thus each geomorphological setting is identified by a four-digit code. An example of how these codes were transferred from a classified coastline to the 0.25° grid used in this data base is shown in Figure 3.

Figure 3. Example of how geomorphic data codes were transferred to the 0.25° grid cells used in this NDP.



7.4 Sea-Level Trends

The sea level trend data set was derived for the U.S. East Coast from 36 long-term tide-gauge stations (Pugh et al., 1987; see Figure 4a) and Holocene paleosealevel indicators (Gornitz and Seeber, 1990). The tide-gauge stations used in this data base have a minimum of 20 years of record (records may contain discontinuities) and were measured in mm/year. The 20 year cutoff was selected to minimize the effects of the 18.6 year lunar nodal cycle and to reduce errors, due to high interannual variability, on the regression line slope. The following variables were derived from the tide-gauge records and Holocene data: a relative sea-level-trend variable, a long-term geological-trend variable, a corrected sea-level-trend variable, a local subsidence variable, and a variable containing the number of years of record used in estimating these values.

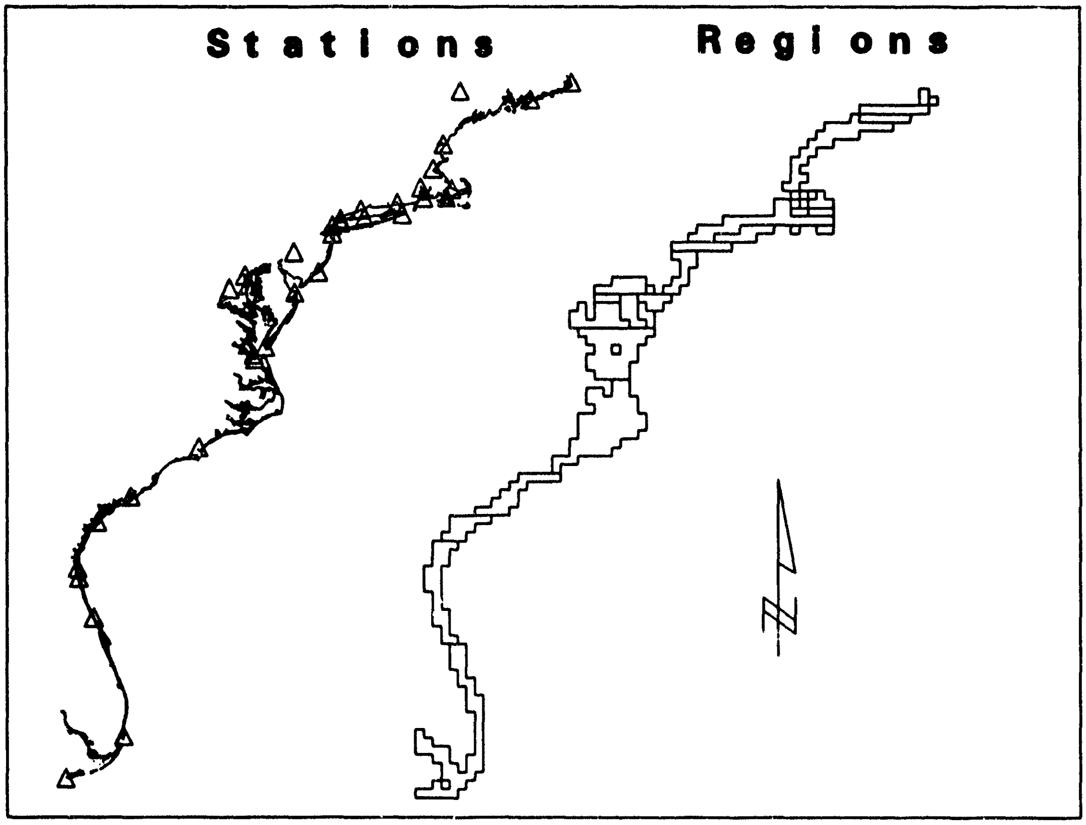
The relative sea-level-trend variable for any given tide-gauge station represents a composite of several components, among these are the global rate of eustatic sea level rise and regional and local subsidence/uplift trends. Along the U.S. East Coast, these land movements are largely caused by glacio-isostatic adjustments in the Earth's crust, in particular, from glacial rebound and bulge collapse, with minor contributions from subsidence due to local groundwater withdrawal, sediment compaction, and possible neotectonism. The relative sea level trend is calculated by a linear least-squares regression fitted to the time-series of mean annual sea level elevations for each of the 36 long-term tide gauge stations (Lyles, et al. 1987; Emery and Aubrey, 1991).

To allow for the correction of the relative sea-level-trend variable for vertical land movements, for each grid cell and tide station, Holocene paleosealevel indicators were used to derive a long-term geological-trend variable for each region on the East Coast. The indicators consisted of coral, shell, wood, and peat materials that lived or formed within $\pm$ 0.5 m of mean sea level within the last 6,000 years (Pardi and Newman, 1987). The paleosealevel data were grouped into regions (Figure 4a) small enough to have undergone a fairly uniform change in sea level but large enough to enclose several data points. Based on the ^{14}C measurements available for the data points within each coastal region the geologic variable was derived by fitting a least-squares regression line, or higher order polynomial, to the ^{14}C indicators as a function of time.

The long-term geological-trend variable was subtracted from the relative sea-level-trend variable to obtain the corrected sea-level-trend variable for each gauge station (Gornitz and Seeber, 1990). The average of the corrected sea level trends for each of the 36 tide stations was then calculated and determined to be 1.25 mm/year. This value, 1.25 mm/year, is the regional eustatic sea level trend for the East Coast.

To determine the relative vulnerability of each station (and by extension the entire coast) a local subsidence variable was calculated by subtracting the regional eustatic sea-level trend (1.25 mm/year) from the relative sea level trend for each station. This variable gives an indication of the relative vulnerability of each 0.25° grid cell, and station, on the East Coast to sea-level rise (i.e., may be used to identify areas that are subsiding faster or slower than the regional average).

Figure 4a. Location of the 36 tide-gauge stations and ^{14}C paleosealevel regions used in the calculation of the sea-level-trend data variables.



The methods discussed above were used to obtain the data variables for each grid cell in which one of the 36 tide-gauge stations fell. To derive a prediction of the relative and corrected sea-level-trend variables and the local subsidence variable for cells without tide-gauge stations, the following steps were taken:

1. The tide-gauge stations and their relative sea level trends were plotted on the coast (Figure 4a), along with the 0.25° grid used in data base.

2. For each coastal grid cell without data, the difference in relative sea levels between the two nearest gauge stations (i.e., occurring north and south of the given grid cell) was calculated.

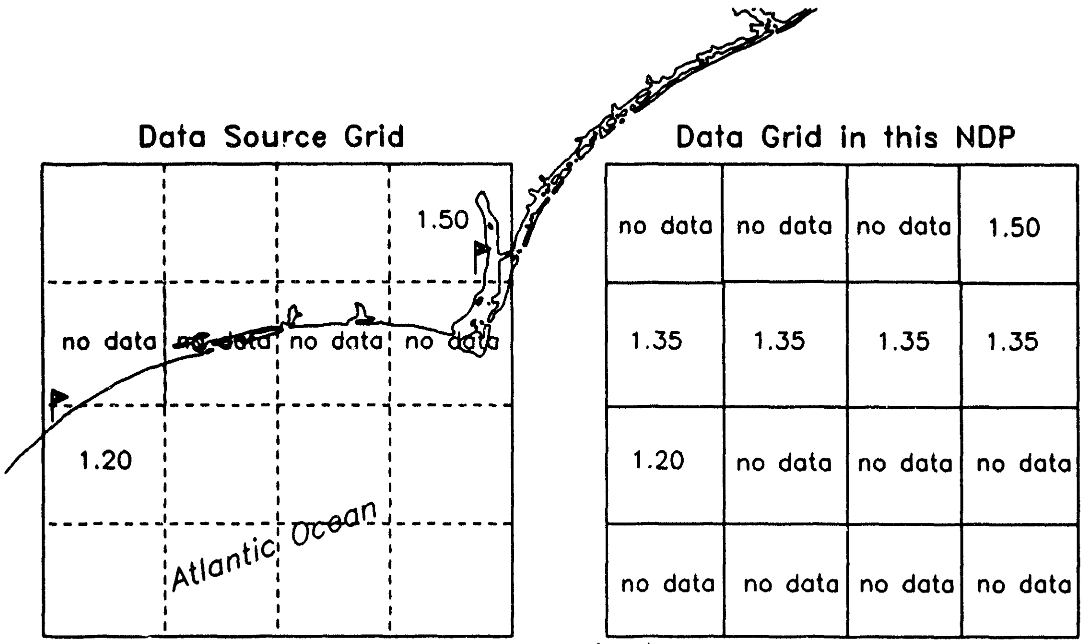
3. The difference between the relative sea levels was then divided by the number of grid rows, plus one, occurring between the grid cells into which the stations fell. This value was called the slope factor.

4. The slope factor was then multiplied by the number of grid rows from the grid cell being calculated to the southernmost station and added to the southern stations' relative sea level trend. This produced the relative sea-level-trend variable for the coastal grid cell of interest (Figure 4b).

The long-term geological-trend variable (from the ^{14}C regions previously described) were subtracted from the relative sea-level trends to obtain the corrected sea-level-trend variable. The regional eustatic sea-level trend (1.25 mm/year) was then subtracted from the relative sea-level-trend variable to obtain the local subsidence variable for each grid cell.

On the basis of the differences between the relative and corrected sea level trend variables, it was determined that from Eastport, Maine, to Key West, Florida, a mean subsidence on the order of 1.46 mm/year was occurring. The maximum rates of subsidence are concentrated in the Mid-Atlantic region surrounding Chesapeake Bay (Gornitz and Lebedeff, 1987), and the minimum is occurring in upper New England and in the Florida Keys.

Figure 4b. Example of how the sea-level-trend data were averaged for areas without data on a fictional coastline and transferred to the 0.25° grid cells used in this NDP.



Data values for relative sea level (SLR) were calculated by row for grid cells without data. To calculate the value a slope factor (SF) was obtained as follows:

SF = (Station2 − Station1) / (Rows between stations +1)

SF = (1.50 − 1.20) / (1 + 1) = 0.15

= Long−term tide−gauge station

7.5 Horizontal Shoreline Displacement (Erosion)

The erosion/accretion data used in the development of the horizontal shoreline displacement data set was extracted and modified from the Coastal Erosion Information System (CEIS) developed by May et al. (1982, 1983) and Dolan et al. (1975, 1983, 1989)[1]. The CEIS data is limited in extent to coastlines that open onto the ocean or large bays (e.g., Chesapeake Bay) and lacks data for the Florida Keys. The displacement data within the CEIS data base was originally obtained from over 500 individuals or organizations with lengths of records from as little as 20 years to as long as 165 years. The majority of the shoreline displacement measurements, however, were made from historic maps and aerial photographs that cover the U.S. East Coast for a minimum of 40-50 years. Most of the information was originally obtained from published reports or from regionally available high resolution data sets (e.g., Dolan et al., 1980). Of the data within CEIS 25% was obtained in raw form and was converted into point measurements of erosion or accretion. In conducting the measurement and data compilation steps of the raw data, May et al. (1982) used the landward limit of wetted sand as the criteria for identifying the shoreline. This definition was selected because it produced the most consistent results in the photo-interpretation process.

By comparing present and past shorelines from maps, aerial photographs, and data from regional studies, May et al. (1982) were able to obtain rates of change, expressed in m/year, for coastal points on the East Coast. May et al. (1982) then averaged and extrapolated the point data into 3' latitude x 3' longitude grid cells (in locations with sparse data 7.5' and 15' grid cells were used) to minimize the problems associated with mapping errors, imprecise shoreline definitions, and poor temporal resolution within the original erosion/accretion data sources. These 3', 7.5', or 15' grid cells were then overlaid onto the 0.25° grid cells used in this data base to derive the following data variables (values in m/year): minimum erosion trend, mean erosion trend, maximum erosion trend, and the number of 3', 7.5', or 15' cells used in deriving the data for each 0.25° grid cell. To transfer this information to the 0.25° grid cells used in this data set, the erosion variables were recalculated as follows:

1. The number of 3', 7.5', or 15' grid cells that occur in a given 0.25° grid cell was determined. These 3', 7.5', or 15' cells were used to calculate the minimum, mean, or maximum erosion rate variables.

2. The minimum erosion rate for a 0.25° grid cell is the minimum erosion rate found in the 3', 7.5', or 15' grid cells within a 0.25° grid cell.

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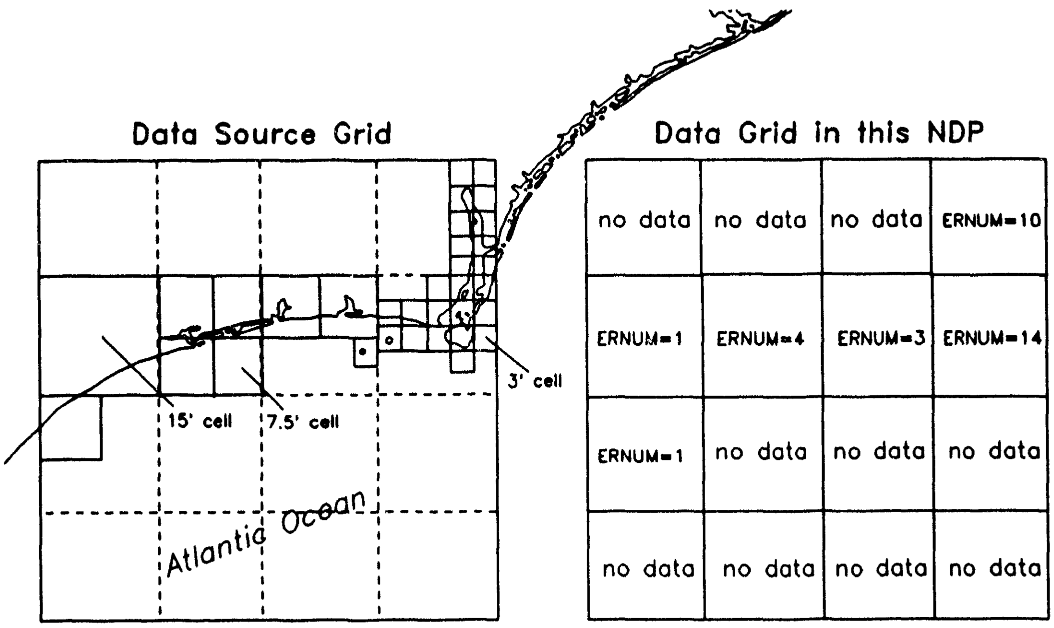
[1] Portions of the CEIS data base used in this NDP are currently being updated by Dolan and others for the U.S. Geological Survey. Partial documentation of these changes may be found in Dolan et al. (1990) and Dolan et al. (1991).

3. The mean erosion rate for a 0.25° grid cell is the average of the erosion rates of all 3', 7.5', or 15' grid within a 0.25° grid cell.

4. The maximum erosion rate for a 0.25° grid cell is the maximum erosion rate found in the 3', 7.5', or 15' grid cells within a 0.25° grid cell.

Figure 5 gives an example of how the overlay process was used to transfer the data values from the 3', 7.5', or 15' grid cells to the 0.25° grid.

Figure 5. Example of how the shoreline displacement data were transferred to the 0.25° grid cells used in this NDP.



ERNUM = the number of "source" grid cells used to obtain the minimum (ERMIN), mean (ERAVG), and maximum (ERMAX) data variables. The mean is the average of the erosion rates that fall in a given grid cell. The minimum is the minimum of all the source grid cells, and the maximum is the maximum of all source grid cells that fall in a given output grid cell

Based on the length of record, from 20 to 165 years depending on location, and the errors inherent in the data, the reported shoreline displacement trends must be seen as average values that are highly variable over time; as such, rates of change less than ± 0.6 m/year are not considered significant. The CEIS data base, however, does indicate that the general pattern of shoreline displacement on the U.S. East Coast is one of erosion. Areas experiencing significant erosion, with rates > 1.5 m/year, occur in Martha's Vineyard and Nantucket in Massachusetts and within Fire Island National SeaShore, New York.

7.6 Tidal Ranges

The tidal range data set was obtained from tide tables published by NOAA's National Ocean Service (NOS) for 1,447 stations located on the East Coast (NOS, 1988). These station data were entered into the ARC/INFO™ GIS as point data and are available in the supplemental data group. The supplemental data group contains the name, identification number, longitude/latitude, mean tide range, maximum tide range, mean tide level for each tide-range station. The data for each station were overlaid onto the 0.25° grid cells used in this data set. The data were then spatially averaged to derive the mean tide range, maximum tide range, mean tide levels, and the number of stations used to calculate each data variable (values expressed in meters) for each coastal grid cell.

The mean tide range at a given tide station in this data set is defined as the difference in height between mean high water and mean low water in 1988 (tide heights vary annually, but their differences are *relatively* constant in relation to each other). The maximum tide range variable contains either the "spring tide range" or "diurnal tide range". The "spring tide range" is defined as the maximum range occurring semimonthly when the Moon is in the full or new phase (in 1988). It is larger than the mean range when the type of tide is either semidiurnal or mixed and is of no practical significance when the dominant tide is diurnal. If the tide in a given area is chiefly of the diurnal type the maximum range variable contains the "diurnal tide range". The diurnal range is defined as the difference in height between mean higher high water and mean lower low water (NOS, 1988). The mean tide level variable is defined as a plane midway between mean low water and mean high water in 1988. This value is reckoned from chart datums.

The chart datums used in the tide tables for the mean tide level variable are the Gulf Coast Low Water Datum (GCLWD) and the Atlantic Coast Low Water Datum (ACLWD). The ACLWD is used for most of the East Coast, with the GCLWD being used only in the Florida Keys. The boundary between these two datums is defined more precisely as extending [definition taken directly from *Tide Tables 1988 -High and Low Water Predictions* (NOS, 1988)]:

1. From the intersection of the most westerly segment of the southern boundary of the Key Biscayne National Monument, Florida, and the land just south of Mangrove Point;

2. then along the southwest segments of the southern boundary of the Monument to Old Rhodes Point on the southeast corner of Old Rhodes Key;

3. then from Old Rhodes Point to the northwest corner of the John Pennekamp Coral Reef State Park;

4. and along the land of the northwestern boundary of the park (with the exception of the coastal indentations of Largo Sound) to the southwest corner (just southwest of Rock Harbor); and

5. then from the southwest corner of John Pennekamp Coral Reef State Park along its southwestern boundary and continuing straight out to sea just south of, and beyond, Molasses Reef.

The boundary described above is graphically represented on the affected nautical charts published by NOS.

The mean-tide-range, maximum-tide-range, and mean-tide-level variables are available for 1,447 tide gauge stations in the supplemental data group. To transfer this information to the 0.25° grid cells used in compiling this coastal hazards data set, the station tide data were overlaid onto the grid and the variables calculated, based on the stations that fell within each grid cell, as follows:

1. The number of tide stations that fell within each 0.25° grid cell was calculated. The stations within each cell were then used to derive the mean tide level, and the mean and maximum tide range for each 0.25° grid cell.

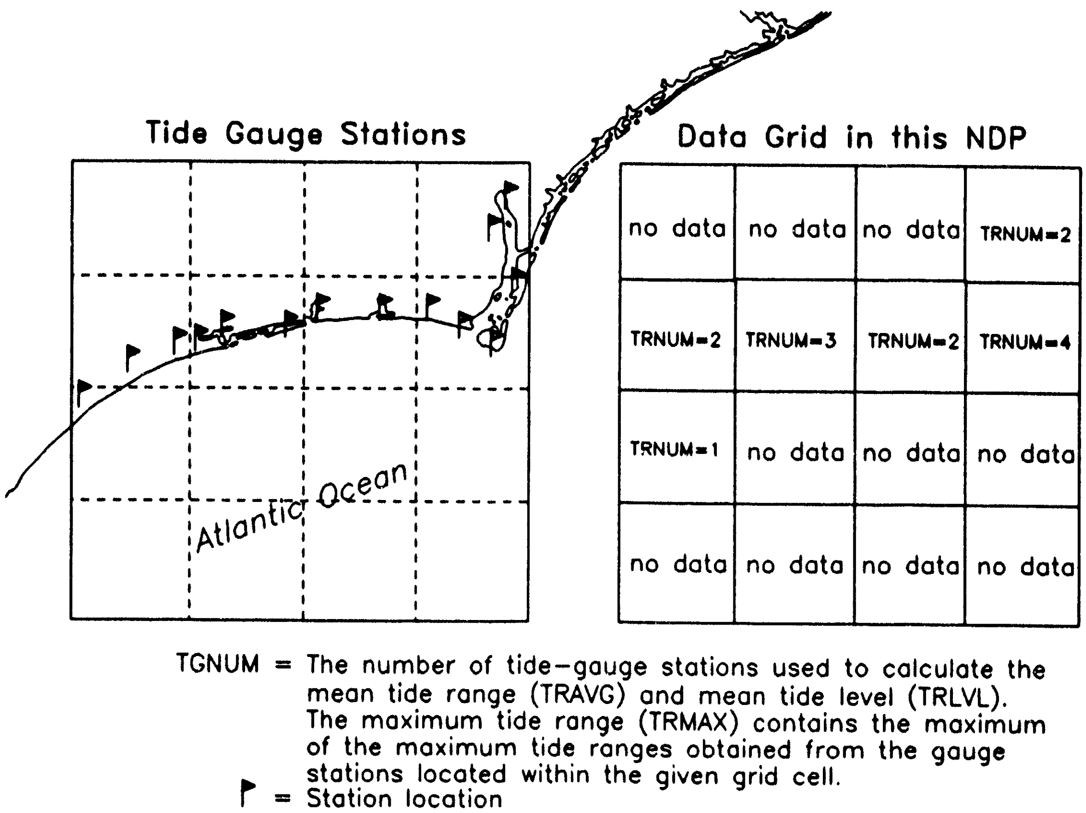
2. The mean tide range for each grid cell is the average of the mean tide ranges of all the stations within a given cell.

3. The maximum tide range for each grid cell is the largest value found within the maximum tide ranges (i.e., spring/diurnal tide range) of all the stations within a given cell.

4. The mean tide level for each grid cell is the average of the mean tide levels of all the stations within a given cell.

Figure 6 gives an example of how this conversion from point data to area data was conducted for the maximum tide-range variable.

Figure 6. Example of how tide-gauge data were transferred to the 0.25° grid cells for the maximum tide-range variable.



The magnitude of the tidal range variables defined above has been linked to both inundation and erosion hazards. Although a large tidal range dissipates wave energy, it also delineates a broad zone of low-lying intertidal wetlands susceptible to inundation. Furthermore, the velocity of tidal currents in estuaries depends on the tide range, as well as the asymmetry of the tidal cycle and channel morphology. Therefore, when holding these other factors constant, high-tide ranges are associated with stronger tidal currents capable of eroding and transporting sediment offshore.

Table 3 provides a statistical summary of the mean tidal ranges along the U.S. East Coast and compares them with tides experienced on the Gulf and West coasts. The table shows that the more sheltered Gulf Coast experiences a lower tidal range than either the East or West Coast. On the East Coast the highest tidal range occurs in New England, near 42°N, and between South Carolina and Georgia. Areas with very low tide ranges include the Chesapeake Bay region and parts of southern Florida.

Table 3. Mean, maximum, and minimum mean tide-range data by U.S. coast.

Region:	East	Gulf	West
Mean tide range (m)	1.37	0.72	1.55
Standard deviation (m)	0.91	0.21	0.57
Maximum (m)	6.10	1.19	3.35
Minimum (m)	0.06	0.15	0.12
Number of stations	1,447	35	373

7.7 Wave Heights

Wave heights and tidal ranges affect the development of coastal landforms; however, these parameters can vary independently of each other. For example, along the U.S. East Coast these variables vary inversely, whereas along the West Coast they vary directly. Thus these two parameters should be treated as independent but complementary variables.

This wave-height data set contains three data variables: the maximum significant wave height, the 20-year mean wave height, and the standard deviation of the mean (all variables expressed in meters). This data set was originally obtained from published documents of the Coastal Engineering Research Center (CERC), U.S. Army Corps of Engineers, *Wave Information Study* (Jensen 1983). In the study CERC calculated wind speeds from station histories, National Weather Service surface charts, surface pressure data, ships-at-sea observations, and monthly air-sea temperature gradients. The estimated wave heights were derived using a three phase process. The first phase hindcasted wind speeds/directions for each 120 nautical-mile-long segment along the East Coast, the second hindcasted wind speeds for a 30 nautical-mile-spacing, and in the third phase, the wind data were input into a transformation model that hindcasted nearshore wave heights for each 10 nautical-mile-segment (18.5 km) of the East Coast (Jensen 1983; Corson et al. 1987). The wave heights forecast within the Wave Information Study are for the open coast and large bays (i.e., Chesapeake Bay). As such, most intracoastal areas (i.e., lagoons) within the data source were missing data.

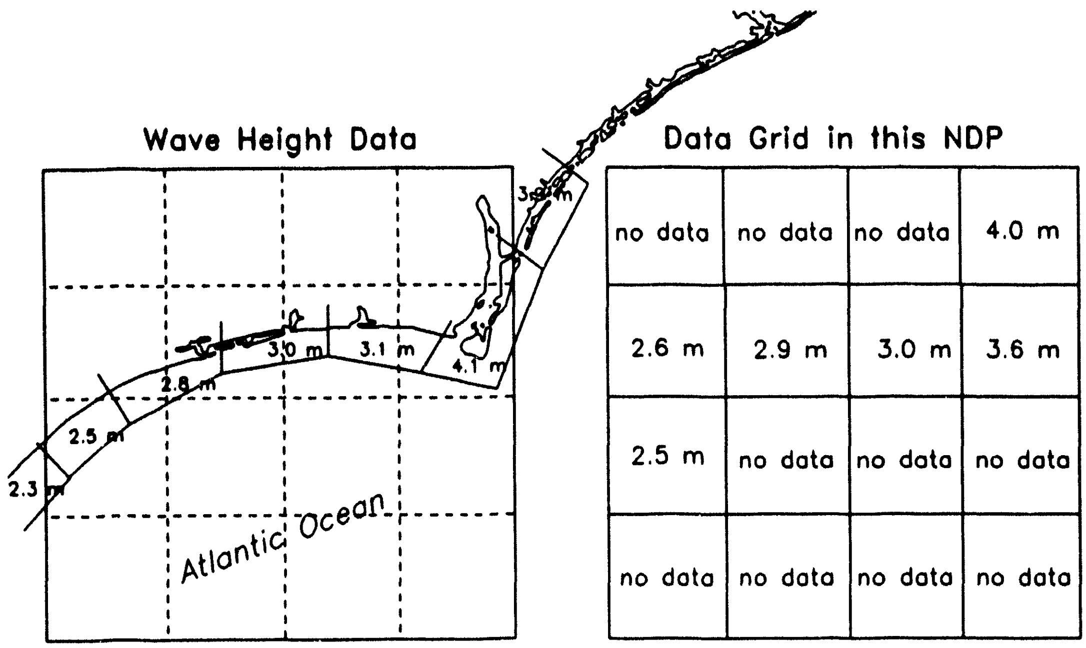
These 10 nautical-mile-segments were then overlaid onto the 0.25° grid cells used within this data base (Figure 7). The data variables (i.e., maximum significant wave height, 20 year mean wave height, and the standard deviation of the mean) were then derived for each cell by averaging the data values associated with the line segments that fell on or within each grid cell (on average a minimum of 2 segments are located within each grid cell).

Table 4 provides a summary of the East Coast wave statistics (using the original data segments) and compares them with similar data available for the Gulf and West coasts. In general, Table 4 indicates that the West Coast has higher maximum wave heights than the East and Gulf coasts. On the East Coast the highest waves are found around Cape Hatteras, North Carolina, and the lowest are found south of Miami, Florida.

Table 4. Statistical summary of maximum significant wave heights for the three U.S. coasts.

Region:	East	Gulf	West
Average maximum wave (m)	4.27	3.67	7.10
Standard deviation (m)	0.63	0.81	0.64
Maximum (m)	5.90	5.80	8.10
Minimum (m)	2.40	2.30	5.00
Number of segments	166	50	143

Figure 7. Example of how the wave-height data were transferred to the 0.25° grid cells used in this NDP.



Data values for 20 year mean wave height (WHAVG), wave standard deviation (WHSD), and the maximum significant wave (WHMAX) were derived from 18.5 km reaches along the coast. The data values for WHAVG and WHMAX were obtained by averaging the data for each reach that fell within a given grid cell.

8. RELATIVE RISK FACTORS

The previous section discussed how the original 22 data variables within this data base were obtained and entered into the GIS (i.e., as point data -sea level trends and tidal ranges; line data -wave heights; or as polygons -elevation, geology, geomorphology, and shoreline displacement. These data were directly digitized from maps or copied from computer tapes and imported into the ARC/INFO^{TM} GIS, where the information was analyzed and the data values were incorporated into the 0.25° grid cells. The entry of these data into a common format (i.e., the grid cell) has made it possible to relate and manipulate the data to identify relationships among the different variables.

To simplify the manipulation process, seven of the original data variables (mean elevation, local subsidence trend, mean shoreline displacement, mean tide range, maximum significant wave height, geology, and geomorphology) were classified into seven new relative risk variables. These original variables were classified into "risk" variables based on Table 5 (which depicts the categories used for assigning risk values for the five numeric data variables) and Tables 6 and 7 (used for geology and geomorphology). The value assigned to each grid cell, for each risk variable, may be seen as an indicator of the cell's relative risk to erosion or inundation. The rationale for the value assignments used for each relative risk variable has been described in greater detail by Gornitz and Kanciruk (1989) and Gornitz et al. (1991). Reprints of these papers are contained in Appendix D.

Table 5. Assignment of relative risk factors for elevation, local subsidence trend, shoreline displacement, tidal range, and wave height.

Variable:	Very low 1	Low 2	Moderate 3	High very 4	High 5
Mean shoreline displacement (m/year)	> 2.0 Accretion	1.1 to 2.0	-1.0 to +1.0	-1.1 to -2.0	< -2.0 Erosion
local subsidence trend (mm/year)	< -1.0 Land Rising	-1.0 to 1.0	1.0 to 2.0	2.1 to 4.0	> 4.0 Land Sinking
Maximum significant wave height (m)	0.0 to 2.9	3.0 to 4.9	5.0 to 5.9	6.0 to 6.9	> 6.9
Mean elevation (m)	> 30.0	20.1 to 30.0	10.1 to 20.0	5.1 to 10.0	0.0 to 5.0
Mean tidal range (m)	< 1.0 Microtidal	1.0 to 1.9	2.0 to 4.0	4.1 to 6.0	> 6.0 Macrotidal

Table 6. Assignment of relative risk factors for geology.

Rank	Geology values[a]
1	100, 110, 130, 410
2	150
3	200, 210, 220, 230, 240, 250, 260, 270, 400, 430, 500
4	300, 340, 345, 370
5	310, 320, 330, 360, 350, 420

[a] See Table 1 for description of geology values.

Table 7. Assignment of relative risk factors for geomorphology.

Rank	Geomorphology values[a]
1	1130, 1139, 1210, 1219, 1220, 1229, 1230, 1239, 1240, 1249, 1320, 1329, 2510, 2519
2	1120, 1129, 1131, 1211, 1221, 1231, 1234, 1235, 1241, 1245, 1310, 1319, 2511
3	1110, 1119, 1121, 1311, 1321, 1335, 1338, 2112, 2115, 2125, 2225, 2255, 2300, 2315, 2320, 2329, 2330, 2339, 2340, 2345, 2349, 2350, 2359, 2400, 2410, 2419, 2420, 2425, 2429, 2450, 2459, 2500, 2530, 2539
4	1111, 1330, 1339, 2200, 2210, 2219, 2228, 2250, 2258, 2259, 2310, 2319, 2321, 2331, 2341, 2351, 2411, 2421, 2451, 2520, 2529
5	1331, 1334, 2110, 2111, 2119, 2120, 2121, 2122, 2123, 2124, 2126, 2127, 2128, 2129, 2211, 2220, 2221, 2224, 2229, 2251, 2254, 2311, 2521, 2531

[a] See Table 2 for a description of geomorphology values.

9. THE COASTAL VULNERABILITY INDEX

The seven relative risk variables contained within this data base may be combined to obtain an index of coastal vulnerability, where the grid cells with high index values will tend to have low reliefs, erodible substrates, histories of subsidence and shoreline retreat, and high wave and tide energies (Gornitz et al., 1991). Thus an index may be designed, using the risk variables. to identify areas that are at risk of erosion and permanent or temporary inundation. However, when several risk factors for a given area are missing data, then any calculated index will underestimate the risk faced by the area in question. The methods shown below for deriving such an index have been tested on a sample of 93 randomly selected coastal segments and seem to be adequate for the task when the number of risk factors that are missing data, for a given location, is less than three. The addition of new variables to this data base in the future or the use of a different classification system for the risk variables may result in index values that differ significantly from those that would be produced using the formulas shown.

The following six formulas were proposed and tested for the derivation of the Coastal Vulnerability Index (CVI). Of the CVI formulas shown CVI_5 was used in Gornitz et al. (1991).

Product mean:

$$CVI_1 = \frac{(a_1 * a_2 * a_3 * a_4 * \ldots a_n)}{n}$$

Modified product mean:

$$CVI_2 = \frac{[a_1 * a_2 * \frac{1}{2}(a_3 + a_4) * a_5 * \frac{1}{2}(a_6 + a_7)]}{n - 2}$$

Average sum of squares:

$$CVI_3 = \frac{(a_1^2 * a_2^2 * a_3^2 * a_4^2 * \ldots a_n^2)}{n}$$

Modified product mean (2):

$$CVI_4 = \frac{(a_1 * a_2 * a_3 * a_4 * \ldots a_n)}{5^{(n-4)}}$$

Square root of product mean:

$$CVI_5 = [\, CVI_1 \,]^{1/2}$$

Sum of products:

$$CVI_6 = 4a_1 + 4a_2 + 2(a_3 + a_4) + 4a_5 + 2(a_6 + a_7)$$

Where:

n = variables present,	a_1 = mean elevation,
a_2 = local subsidence trend,	a_3 = geology,
a_4 = geomorphology,	a_5 = mean shoreline displacement,
a_6 = maximum wave height,	a_7 = mean tidal range.

The relative risk variables were assigned to one of five classes on the basis of Tables 5, 6, and 7. Errors in the classification of any of the variables could result in a misclassification of up to one risk class for each risk variable. The sensitivity of each of the six CVI formulas to misclassification errors was tested by changing the relative risk factor of 1 to 3 risk variables from high to low (i.e., 5 to 1) while holding the others fixed at a value of 5. The calculated sensitivity is the percentage change from the original CVI (with all variables set to five), such that the greater the value the greater the percent change. For some CVIs a change in two or more variables may result in more than one score; when this occurs only the maximum value is shown (Table 8; Gornitz, 1991).

Table 8. Sensitivity of different Coastal Vulnerability Indices to changes in risk class from high to low assignments for one to three variables.

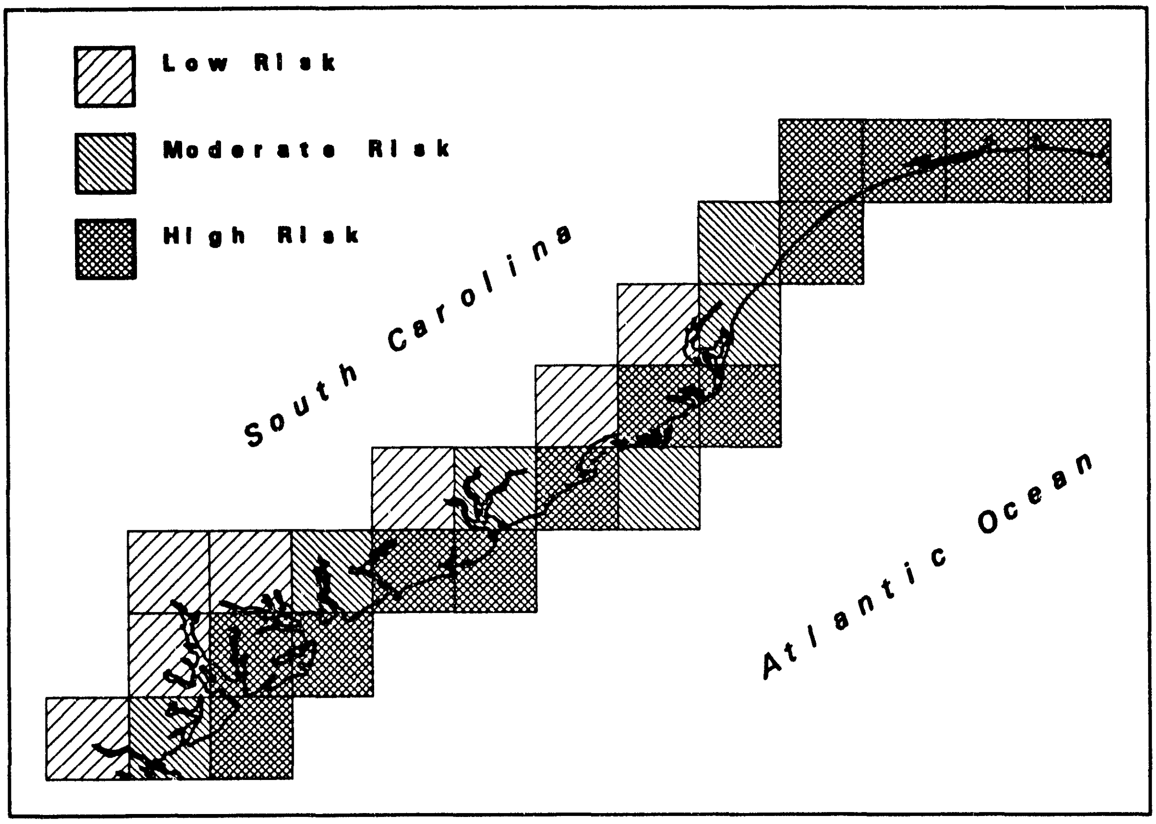
CVI	Number of Variables Changed 1	2	3
CVI_1	80	96	99
CVI_2	80	96	99
CVI_3	14	27	41
CVI_4	80	96	99
CVI_5	56	80	81
CVI_6[a]	16	32	48

[a] CVI_6 was developed after the East Coast was initially analyzed.

This table indicates that CVI_1, CVI_2, and CVI_4 are highly sensitive to variations in the classification of the risk variables, while CVI_3 is insensitive to classification variations. CVI_5 seems to be relatively insensitive to variations in one risk factor, while still being able to produce usable results when differences occur within several factors. CVI_6 minimized the effects of variations in one variable (in the relative risk classification system) while still being sensitive to significant differences in risk factor values. Thus, in future studies CVI_6 may be preferable to CVI_5.

An example of how the CVI, in this case CVI_5, may be used to identify high-risk coastlines is shown in Figure 8. A histogram of the data values from CVI_5 was constructed and three classes were developed (i.e., low-, moderate-, and high-risk), with grid cells at "high-risk" to coastal erosion or sea level rise being defined as having an index greater than 33, moderate-risk, 33 to 20, and low-risk, > 20. Other high-risk coastal grid cells identified using CVI_5 are located in Cape Cod, New Jersey, North Carolina, Georgia, and on the Delmarva Peninsula (i.e., Delaware, Maryland, Virginia).

Figure 8. Example of how the Coastal Vulnerability Index may be used to identify high-risk coastlines in South Carolina.



10. LIMITATIONS AND RESTRICTIONS OF THE DATA

The 29 data variables in this data base contain no known calculation or data entry errors. Because of the spatial extent of this data base the period of record, sampling frequency, and scale of the source documents varied. The use of long-term averages and the choice of the 0.25° grid cell as the spatial scale for these data has minimized the error that may have been introduced into this data base when these data sources were integrated into a single data base with uniform formats and scales.

Of the 29 data variables contained in this data base, only the sea-level-trend variables (derived from long-term tide-gauge records) may have significant error. The tide-gauge records used for calculating the sea level trends on the East Coast were obtained from the records of the *Permanent Service for Mean Sea Level* (Pugh et al., 1987). These records have been examined and contain no identifiable errors, are of very high quality, and have been used in several sea-level-rise studies (Douglas, 1991). The sparse station network, however, has made it necessary to calculate the sea level trend variables for intervening grid cells by calculating a slope line between the two closest adjacent stations. Confidence in the accuracy of the local subsidence variable and the relative and corrected sea-level-trend variables estimated with this method decreases as the distance from grid cells who are missing data and adjacent tide-gauge stations increases. If the distance from a grid cell with no-data to the nearest two long-term gauge stations (i.e., that are North and South of the no-data grid cell) exceeds ≈350 km (i.e., at that distance the r^2 of adjacent stations is 0.717), then the sea-level-trend variable derived for the no-data grid cell may be erroneous.

The coastal hazards data base presented here for the U.S. East Coast omits several factors that may be important when determining the risk of a given area to inundation or erosion. Other variables that may be useful in the risk assessment process are storm surge, storm frequencies, storm intensities, presence of exposed infrastructure, coastal population density, the role of sediment transport, and the risk of saltwater intrusion (Titus et al., 1991; Snedaker and Sylva, 1987). Pilot studies are currently in progress that consider several of these factors in combination with the variables in this data base (i.e., Daniels et al., 1992). These pilot studies use an expanded CVI that is based on the seven relative risk variables in this NDP and six climatic factors derived from Birdwell and Daniels (1991).

11. DATA CHECKS PERFORMED BY CDIAC

An important part of the data packaging process at the CDIAC is the quality assurance (QA) of the data before its distribution. Data received at CDIAC are rarely in perfect condition for immediate distribution, regardless of source. Reviews conducted involve the examination of the data for completeness, reasonableness, and accuracy. The QA process is an important component in the value-added concept of assuring accurate, usable information for researchers. The following summarizes the QA checks performed on the various data groups presented in this document.

1. Data variables obtained from primary data sources were double-entered from data sheets into a VAX mainframe computer. The generated machine readable data files were then printed and compared with the original data sheets by two individuals. All identified discrepancies were corrected.

2. Data variables obtained from maps (e.g., geology) were classified and transferred to coastal segments on working maps of the coastline. The working maps were then digitized, replotted, and compared with the original working maps and data sources. All identified discrepancies were then corrected.

3. Maximum, minimum, and mean values were generated for all data variables and checked for reasonableness.

4. The data values for each data variable were mapped to check for outliers and identify discrepancies. The identified data items were then recalculated, and corrected if necessary.

12. HOW TO OBTAIN THE PACKAGE

This document describes the contents of a coastal hazards data base intended for use by vector or raster GISs or non-GIS data bases. The computerized data are available on 9-track magnetic tapes or IBM DOS-compatible floppy diskettes (high density, 3.5- or 5.25-inch diskettes), and through an anonymous File Transfer Protocol service from CDIAC. Requests for the magnetic tape should include any specific instructions for transmitting the data as required by the user and/or the user's local computer system. Requests not accompanied by specific instructions will be filled on 9-track, 6250 BPI, standard-labeled tapes with characters written in Extended Binary Codes Decimal Interchange Code and formatted as given in Part 2, Section 1. Requests for this data package should be addressed to:

Carbon Dioxide Information Analysis Center
Oak Ridge National Laboratory
Post Office Box 2008
Oak Ridge, Tennessee 37831-6335
U.S.A.

Telephone: (615) 574-0390
FAX: (615) 574-2232
BITNET: CDP@ORNLSTC
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OMNET: CDIAC

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U.S. Geological Survey. 1972. *Bath.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1972. *Beaufort.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1970. *Boston.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1977. *Brunswick.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1984. *Chincoteague.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1980. *Currituck Sound.* 1:250,000 series (topographic), Reston Virginia.

U.S. Geological Survey. 1972. *Daytona Beach.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1956. *Eastport.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1988. *Fort Pierce.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1957. *Fredericton.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1978. *Georgetown.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1975. *Hartford.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1988. *Jacksonville.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1975. *James Island.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1973. *Manteo.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1979. *New York.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1971. *Miami.* 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1969. *Newark.* 1:250,000 series (topographic), Reston Virginia.

U.S. Geological Survey. 1969. *Norfolk*. 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1972. *Orlando*. 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1972. *Portland*. 1:250,000 series (topographic), Reston Virginia.

U.S. Geological Survey. 1969. *Providence*. 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1973. *Richmond*. 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1982. *Rock Moun*. 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1969. *Salisbury*. 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1978. *Savannah*. 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1979. *Washington*. 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1987. *West Palm Beach*. 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1972. *Key West*. 1:250,000 series (topographic), Reston, Virginia.

U.S. Geological Survey. 1972. *Wilmington*. 1:250,000 series (topographic), Reston, Virginia.

PART 2
INFORMATION ABOUT THE COMPUTERIZED DATA FILES

14. CONTENTS OF THE COMPUTERIZED DATA FILES

The following lists the files distributed on the 9-track magnetic tape by the Carbon Dioxide Information Analysis Center (CDIAC) along with this documentation. These files are also available on IBM-formatted floppy diskettes as DOS ASCII text files and through CDIAC's anonymous File Transfer Protocol service.

File number and description	Logical records	Block size	Record length
1. General description information file	557	8000	80
2. FORTRAN IV retrieval program to read and print File 5	51	8000	80
3. SAS™ code to read and print File 5	10	8000	80
4. Gridded data for the 22 original data variables, all 7 data sets (ARC/INFO™ export file)	120,300	8000	80
5. Gridded data for the 22 original data variables, all 7 data sets (flat ASCII file)	14,080	10000	100
6. FORTRAN IV retrieval program to read and print File 9	51	8000	80
7. SAS™ code to read and print File 9	8	8000	80
8. Supplementary point data for the sea-level and tide range data sets (ARC/INFO™ export file)	10,429	8000	80

File number and description		Logical records	Block size	Record length
9.	Supplementary point data for the sea-level and tide range data sets (flat ASCII file)	2,962	10000	100
10.	FORTRAN IV retrieval program to read and print File 13	36	8000	80
11.	SAS™ code to read and print File 13	6	8000	80
12.	Gridded data for the 7 relative risk variables: elevation, geology, geomorphology, sea-level trends, erosion/accretion rates, tidal ranges, and wave heights (ARC/INFO™ export file)	85,086	8000	80
13.	Gridded data for the 7 relative risk variables: elevation, geology, geomorphology, sea-level trends, erosion/accretion rates, tidal ranges, and wave heights (flat ASCII file)	7,040	8000	80
14.	FORTRAN IV retrieval program to read and print File 17	52	8000	80
15.	SAS™ code to read and print File 17	16	8000	80
16.	1:2,000,000 digitized coverage of the U.S. East Coast (ARC/INFO™ export file)	25,180	8000	80

File number and description	Logical records	Block size	Record length
17. 1:2,000,000 digitized coverage of the U.S. East Coast (flat ASCII file)	44,464	2000	20
Total records	310,328		

1. Tapes are 9-track, 6250 BPI, standard-labeled, with all characters written in EBCDIC unless otherwise specified by the requester.

2. All records are stored in a fixed-block record format.

3. ARC/INFO™ export files (Version 6.0.1) are coverages converted to flat ASCII, fixed-block, files for data transfer purposes. The IMPORT command in ARC/INFO™ must be used to enter these files into your system.

4. SAS™ is a registered trademark of the SAS Institute, Inc., Cary, NC 27511-8000.

5. ARC/INFO™ is a registered trademark of the Environmental Systems Research Institute, Inc., Redlands, CA 92372.

15. DESCRIPTIVE FILE ON THE TAPE

The following is a listing of the first file provided on the magnetic tape distributed by CDIAC. This file provides variable descriptions, formats, units, and other pertinent information about each file associated with this coastal hazards data base.

TITLE OF THE DATA BASE

A Coastal Hazards Data Base for the U.S. East Coast

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SCOPE OF THE DATA

The 29 data variables within *A Coastal Hazards Data Base for the U.S. East Coast* are designed for use by coastal planning, research, and management agencies in combination with appropriate climatological data (e.g., Birdwell and Daniels, 1991). The data base may be used to identify coastal zones that are vulnerable to coastal erosion and inundation from sea level rise or storm surge.

This data base is comprised of the following data sets: elevation, bedrock geology, geomorphology, sea level trends, horizontal shoreline movements (erosion/accretion), tidal ranges, and wave heights. For several of these data sets minimum, mean, and maximum data values are available. These data variables may be divided into two basic classes, one that measures erosion potential and one that is related to inundation risk. The inundation risk of a given coastal grid cell may be estimated based on sea level trends and elevations; whereas the erosion risk may be determined based on geology, geomorphology, shoreline displacement, tidal ranges, and wave heights.

Seven of the 29 data variables in this data base are classified versions of other variables within this data base. The seven classified risk variables contain "risk values" of one to five for each coastal grid cell in the data base. These risk variables may be used to calculate a Coastal Vulnerability Index (CVI) that may be used to identify areas on the East Coast that are vulnerable to sea level rise or coastal erosion.

DATA FORMATS

For ease of use, this data base has been divided into four data groups or coverages. The 22 original data variables have been provided in data group ECGRID (Files 4 and 5), the 7 relative risk variables have been provided in data group ECRISK (Files 12 and 13), and the source information for the tide and sea-level-trend data variables have been provided in the supplemental data group ECPOINT (Files 8 and 9). In addition, an auxiliary file with a 1:2,000,000 digitized coastline of the U.S. East Coast has been provided in ECOAST (Files 16 and 17).

For the data groups identified above, two different data formats were used. Each format provides the data registered to a 0.25° latitude by 0.25° longitude grid [or in longitude/latitude coordinates in the case of ECPOINT (Files 8 and 9) and ECOAST (Files 16 and 17)]. The first format is designed for use by the ARC/INFO™ Geographic Information System (GIS). This format stores the data as points, arcs, or polygons (based on the coverage in question). The second format contains comparable data that has been converted into flat ASCII data files for use by raster GISs or non-GIS data base systems.

For the data sets that were originally obtained as point data (i.e., sea level trends and tide ranges) the actual data variables, station names/numbers, record lengths, and latitude/longitude locations have been provided in data group ECPOINT. Within data group ECPOINT, data are provided on the basis of the data point, thus allowing the precise location of each station used in calculating the data for the 0.25° grid cells contained in ECGRID to be determined. A description of the contents of each of the data groups and files included with this data base follows:

(1) **ECGRID:** Gridded polygon data for the 22 original data variables. Data sets contained in this file include elevation, geology, geomorphology, sea level trend, shoreline displacement, tide range, and wave heights.

(2) **ECPOINT:** Point data for the stations used in calculating the sea-level-trend and tide-range data sets. Data include station names/numbers, record length, latitude/longitude location, and mean and maximum data values (when available).

(3) **ECRISK:** Gridded polygon data for the seven classified risk variables. The risk variables are classified versions of the following original variables: mean coastal elevation, geology, geomorphology, local subsidence trend, mean shoreline displacement, mean tidal range, and the maximum significant wave height.

(4) **ECOAST:** 1:2,000,000 digitized coastline of the U.S. East Coast. The coastline was extracted from a digitized map of the United States compiled by the U.S. Geological Survey.

To improve the portability of the information in the data files, FORTRAN IV input/output routines and SAS™ input/output routines have been included with this data base for each of the flat ASCII data files. These input/output routines are intended to be used to read/write the data values contained in the flat ASCII data files [containing the gridded data base, the original point data (for the sea level trend and tide range variables), and the digitized coastline].

The data groups in this data base are available as exported ARC/INFO™ coverages (Version 6.0.1). The export files **must be read into an ARC/INFO™ GIS using the IMPORT command with the COVER option** after uploading the files onto a computer. These files are in a GEOGRAPHIC projection, which means the coverages are projected in a spherical reference grid using latitude and longitude coordinates that are stored in decimal degrees (DD). The flat ASCII files contain an identical version of this data base. The gridding method used in this data base consists of 7,040 0.25° latitude by 0.25° longitude grid cells. These cells cover the area defined by the following coordinates: 85°W, 24°N; 85°W, 46°N; 65°W, 46°N; and 65°W, 24°N. The origin of the grid is at 85°W, 24°N, and grid identifiers increase from left to right, bottom to top. The data contained within each grid cell is valid for the entire grid cell. The data for a grid cell should not be construed as being representative of a "point" in the cell -be it the lower-left corner, upper-left corner, center, etc.

The flat ASCII versions of the files have been provided to allow use of these data by users who do not have access to ARC/INFO™. The format and contents of each of the flat ASCII files are described in the following section (the ARC/INFO™ coverages have the same variables and general format as described herein for the ASCII files).

Upon special request a line/arc version of the data in ECGRID and ECRISK is available from CDIAC. If requested, this data will be provided as an ARC/INFO™ coverage (i.e., ECLINE.E00). Coverage ECLINE contains 29 variables for each line segment in the coverage; these line segments average 4.5 km length, and when plotted, are equivalent to those found within the auxiliary file ECOAST.

DATA GROUP ECGRID:

This data group contains gridded polygon data for the 22 original data variables. These data variables are from the seven data sets and are as follows: minimum, mean, and maximum elevation, and the number of 5' grid cells used in deriving the data values; geology; geomorphology; relative sea level trend, long-term geologic-trend, corrected sea level trend, local subsidence trend, and the years of record of the gauge stations used in calculating these values; mean, minimum, and maximum shoreline displacement, and the number of 3', 7.5', or 15' grid cells used in deriving the data values; mean tide level, mean and maximum tidal range, and the number of tidal stations used in calculating these values; maximum significant wave height and the 20 year mean wave height and its standard deviation.

The names of the ARC/INFO™ coverage and flat ASCII file in which these data variables reside are ECGRID.E00 (File 4) and ECGRID.ASC (File 5), respectively. File 5 is formatted as follows:

```
10  READ (5,100,END=999) ID, WHAVG, WHMAX, WHSD, ERAVG,
   1     ERMAX, ERMIN, ERNUM, ELAVG, ELMAX, ELMIN, ELNUM
    READ (5,110) GM, GL, TRMAX, TRAVG, TRLVL, TRNUM,
   1     SLR, SLG, SLC, SLS, SLYR

100 FORMAT(I5,6F8.2,I4,3F8.2,I4)
110 FORMAT(2I5,3F8.2,I4,4F8.2,I4)
```

The variables in data group ECGRID (File 5) are shown in Table 9 and are listed as they appear in the file.

Table 9. Variable formats for ECGRID.ASC (File 5).

Variable name	Column start	Column end	Variable type	Variable description
ID	1	5	Integer	System variable - grid cell identifier
WHAVG	6	13	Real	Data variable - 20-year mean wave height experienced within each 0.25° grid cell; values in meters

Table 9. Variable formats for ECGRID.ASC (Continued).

Variable name	Column start	Column end	Variable type	Variable description
WHMAX	14	21	Real	Data variable - maximum significant wave height for each 0.25° grid cell; values in meters
WHSD	22	29	Real	Data variable - standard deviation of the 20-year mean wave height experienced within each 0.25° grid cell; values in meters
ERAVG	30	37	Real	Data variable - mean long-term erosion trend for given 0.25° grid cell; values in meters
ERMAX	38	45	Real	Data variable - maximum long-term erosion trend for a given 0.25° grid cell; values in meters
ERMIN	46	53	Real	Data variable - minimum long-term erosion trend for a given 0.25° grid cell; values in meters
ERNUM	54	57	Integer	Data variable - number of 3', 7.5', or 15' grid cells used in calculating ERAVG, ERMIN, and ERMAX for a given 0.25° grid cell
ELAVG	58	65	Real	Data variable - mean elevation of all nonnegative 5' by 5' grid cells within a given 0.25° grid cell; values in meters
ELMAX	66	73	Real	Data variable - maximum elevation of all nonnegative 5' by 5' grid cells within a given 0.25° grid cell; values in meters

Table 9. Variable formats for ECGRID.ASC (Continued).

Variable name	Column start	Column end	Variable type	Variable description
ELMIN	74	81	Real	Data variable - minimum elevation of all nonnegative 5' by 5' grid cells within a given 0.25° grid cell; values in meters
ELNUM	82	85	Integer	Data variable - number of 5' by 5' grid cells used in calculating ELAVG, ELMIN, and ELMAX for a given 0.25° grid cell
--------------- **SECOND LINE READS AS FOLLOWS** -----------------				
GM	1	5	Integer	Data variable - ordinal value indicative of the type and susceptibility of the landforms within a given 0.25° grid cell to inundation and erosion
GL	6	10	Integer	Data variable - ordinal value indicative of the type and resistance of the rocks within a given 0.25° grid cell to erosion
TRMAX	11	18	Real	Data variable - maximum tide range measured for all gauge stations that occurred within a given 0.25° grid cell in 1988 (this value may be the "spring" or "diurnal" tide range, depending on geographic location); values in meters
TRAVG	19	26	Real	Data variable - average of the mean tide range for all the gauge stations that occur within a given 0.25° grid cell (mean tide range is the difference in height between mean high water and mean low water in 1988); values in meters

Table 9. Variable formats for ECGRID.ASC (Continued).

Variable name	Column start	Column end	Variable type	Variable description
TRLVL	27	34	Real	Data variable - the average of the mean tide levels of all the gauge stations that occur within a given 0.25° grid cell (mean tide level is a plane midway between mean low water and mean high water in 1988). Values were reckoned from chart datums (i.e., Gulf Coast Mean Low Water Datum was used for the Florida Keys; the Atlantic Coast Mean Low Water Datum was used for the rest of the East Coast)
TRNUM	35	38	Integer	Data variable - number of tide gauge stations used in calculating TRAVG, TRMAX, and TRLVL for a given 0.25° grid cell
SLR	39	46	Real	Data variable - relative sea level trend within a given 0.25° grid cell; values in mm/year
SLG	47	54	Real	Data variable - long-term geologic-trend derived from ^{14}C data for each 0.25° grid cell; values in mm/year
SLC	55	62	Real	Data variable - corrected sea level trend. Tide-gauge data (i.e., SLR) corrected for geologic trends (i.e., SLG) for each 0.25° grid cell
SLS	63	70	Real	Data variable - the local subsidence trend. Tide-gauge data (i.e., SLR) corrected for the regional eustatic rate of sea level rise (i.e., 1.25 mm/year)
SLYR	71	74	Integer	Data variable - years of record used in estimating the sea level trend for each 0.25° grid cell

Within ECGRID missing data values are indicated as follows:

9999.99 — A grid cell with real data values that is missing data for a given data variable.

9999 — A grid cell with integer data values that is missing data for a given data variable.

A value of 0.0 is a valid value for all variables. For the elevation variables 0.0 m indicates that land occurs within the given grid cell, but the maximum elevation of this land is < 1.0 m. If the data variables in a given data set, such as elevation, contain data and the "number" variable is set to zero (i.e., ELNUM, ERNUM, TRNUM, or SLYR), then the data variables for the given 0.25° grid cell have been estimated based on the methods discussed in Part 1 of this document.

DATA GROUP ECPOINT:

This data group contains the point data for the stations used in calculating the relative sea level trend, long-term geologic-trend, corrected sea level trend, local subsidence trend, mean tide range, maximum tide range, and mean tide level variables contained within data group ECGRID. Data include station names, station number, record length, latitude/longitude location, and data variable values.

The names of the ARC/INFO™ coverage and flat ASCII file are ECPOINT.E00 (File 8) and ECPOINT.ASC (File 9), respectively. A summary of the format used for File 9 follows:

```
10  READ (5,100,END=999) ID, SLLONG, SLLAT, SLR, SLG,
   1     SLC, SLS, SLYR, SLNAME
    READ (5,110) TRLONG, TRLAT, TRAVG, TRMAX, TRLVL,
   1     TRID, TRNAME

100 FORMAT(I5,6F8.2,I4,A38)
110 FORMAT(5F8.2,I5,A45)
```

The variables listed in Table 10 are listed as they appear in data group ECPOINT (File 9).

Table 10. Variable formats for ECPOINT.ASC (File 9).

Variable name	Column start	Column end	Variable type	Variable description
ID	1	5	Integer	System variable - Point identification number
SLLONG	6	13	Real	Data variable - longitude of the tide-gauge station used in determining the sea level trends
SLLAT	14	21	Real	Data variable - latitude of the tide-gauge station used in determining the sea level trends

Table 10. Variable formats for ECPOINT.ASC (Continued).

Variable name	Column start	Column end	Variable type	Variable description
SLR	22	29	Real	Data variable - relative sea level trend measured for each tide-gauge station; values are expressed in mm/year
SLG	30	37	Real	Data variable - long-term geologic-trend derived from C^{14} data; values are expressed in mm/year
SLC	38	45	Real	Data variable - corrected sea level trend. Tide-gauge data (i.e., SLR) corrected for long-term geologic-trends (i.e., SLG); values are expressed in mm/year
SLS	46	53	Real	Data variable - local subsidence trend. Relative sea level trend corrected for the regional eustatic rate of sea level rise (i.e., 1.25 mm/year)
SLYR	54	57	Integer	Data variable - years of record of the tide-gauge station used in determining the sea level trends
SLNAME	58	95	Char	Data variable - name of the tide gauge used for determining the sea level trends
---------------- **SECOND LINE READS AS FOLLOWS** -------------------				
TRLONG	1	8	Real	Data variable - longitude of a tide-gauge station used for determining the tide range variables
TRLAT	9	16	Real	Data variable - latitude of a tide-gauge station used for determining the tide range variables

Table 10. Variable formats for ECPOINT.ASC (Continued).

Variable name	Column start	Column end	Variable type	Variable description
TRAVG	17	24	Real	Data variable - difference between mean high water and mean low water for 1988; values in meters
TRMAX	25	32	Real	Data variable - maximum tide range, maximum measured range for the gauge station in 1988 (this value may be the "spring" or "diurnal" tide range, depending on geographic location); values in meters
TRLVL	33	40	Real	Data variable - mean tide level, a plane midway between mean low water and mean high water in 1988. Values are reckoned from chart datums (i.e., Gulf Coast Mean Low Water Datum is used for the Florida Keys; the Atlantic Coast Mean Low Water Datum is used for the rest of the East Coast)
TRID	41	45	Integer	Data variable - station number (used in the 1988 Tide Tables) of a tide-gauge station
TRNAME	46	90	Char	Data variable - name of a tide-gauge station (from the 1988 Tide Tables)

Within this data file, missing data values are indicated with one of the following values:

> **0.0 or 0** - A tide range or sea-level station that has not been assigned data for the variable in question.

In this data group the sea level variables and tide range variables are mutually exclusive (i.e., if tide-range data are present, then the sea-level data are missing or vice versa).

DATA GROUP ECRISK:

This data group contains gridded polygon data for the seven classified risk variables. The risk variables are classified versions of the following original variables: mean coastal elevation, geology, geomorphology, local subsidence trend, mean shoreline displacement, mean tidal range, and maximum significant wave height.

The names of the ARC/INFO™ coverage and flat ASCII file are ECRISK.E00 (File 12) and ECRISK.ASC (File 13), respectively. A summary of the format used in File 13 follows:

```
10    READ(5,100,END=999) ID,
   1    ERR, LSR, WHR, ELR, GMR, GLR, TRR

100   FORMAT(I5,7I4)
```

The variables in data group ECRISK, listed in Table 11, are shown as they appear in File 13.

Table 11. Variable formats for ECRISK.ASC (File 13).

Variable name	Column start	Column end	Variable type	Variable description
ID	1	5	Integer	System variable - grid cell identifier
ERR	6	9	Integer	Data variable - classified version of the mean erosion/accretion variable (i.e., ERAVG)
LSR	10	13	Integer	Data variable - classified version of the local subsidence trend variable (i.e., SLS)
WHR	14	17	Integer	Data variable - classified version of the maximum significant wave-height variable (i.e., WHMAX)

Table 11. Variable formats for ECRISK.ASC (Continued).

Variable name	Column start	Column end	Variable type	Variable description
ELR	18	21	Integer	Data variable - classified version of the mean elevation variable (i.e., ELAVG)
GMR	22	25	Integer	Data variable - classified version of the geomorphology variable (i.e., GM)
GLR	26	29	Integer	Data variable - classified version of the geology variable (i.e., GL)
TRR	30	33	Integer	Data variable - classified version of the mean tide range variable (i.e., TRAVG)

Values of **Zero** are used in risk variables to identify grid cells that are missing data for a given data variable. If several "no data" values occur within the same grid cell, then any calculated coastal vulnerability index that uses these relative risk factors may not accurately represent the risk of the given coastal area to sea level rise or coastal erosion (unless some type of corrective action is taken). Grid cells that are not in the coastal zone, or are totally ocean bound, have values of **zero** for all seven derived risk variables.

AUXILIARY DATA GROUP, ECOAST:

Auxiliary data group ECOAST (Files 16 and 17) contains a 1:2,000,000 digitized coastline of the U.S. East Coast. Data in this coverage were extracted from a digitized map of the United States (originally compiled by the U.S. Geological Survey). This coastline may be overlaid onto any of the three data groups previously discussed to provide locational information when plotting any or all of the data variables.

Unlike the other data groups within this data base, this coverage contains line segments (or arcs) that describe the U.S. East Coast. The coastline provided has no attribute values associated with the line segments. However, such overlay commands as UNION, INTERSECT, and IDENTITY in ARC/INFO™ (or other GISs) may be used to transfer the gridded data values to the coastal segments, thus simplifying the interpretation of any derived indices.

The name of the ARC/INFO™ coverage where the coastline resides is ECOAST.E00 (File 16), and the flat ASCII data file with this same information is in ECOAST.ASC (File 17). Since this file is line based, the data values in ECOAST.ASC contain the line segment name, and a listing of the points that describe each line, for all 934 line segments that define the East Coast.

The flat ASCII version of this file contains a listing of the line segments (or arcs) that describe the coast. An example of the format for this file is shown in Table 12.

Table 12. Sample of the vector format used for ECOAST.ASC (File 17).

Name, Number of points	
"1", -5	-Vector 1 uses 5 points to describe the line
-71.0812,45.1245	-Start at 71.08°W Longitude, 45.30°N Latitude
-70.6414,45.4167	
-70.9824,45.5545	
-71.0035,45.6234	
-71.0334,45.7834	-End of arc
"2", -13	-Vector 2 uses 13 points to describe the line
-71.0334,45.7834	-Start of next line
-71.2267,45.7734	
-71.2946,45.7948	
...	-Continued

16. LISTING OF THE FORTRAN 77 DATA RETRIEVAL PROGRAMS

What follows is a listing of the four FORTRAN 77 data retrieval programs provided by CDIAC on magnetic tape, floppy diskette, or through CDIAC's anonymous FTP service with this data base. Each program is designed to read and write the contents of one of the four flat ASCII data files.

The first program (File 2 on the magnetic tape) is designed to read and print the file ECGRID.ASC (File 5).

```
C*************************************************************
C* FORTRAN PROGRAM TO READ AND PRINT ECGRID.ASC (FILE 5) *
C*************************************************************
      INTEGER NLIN
      INTEGER ID, ERNUM, ELNUM, GM, GL, TRNUM, SLYR
      REAL    WHAVG, WHMAX, WHSD, ERAVG, ERMAX, ERMIN
      REAL    ELAVG, ELMAX, ELMIN, TRMAX, TRAVG, TRLVL
          REAL    SLR, SLG, SLC, SLS
C*************************************************************
C* INITIALIZE A COUNTER AND OPEN FILES FOR INPUT/OUTPUT   *
C*************************************************************
      NLIN=0
      OPEN(UNIT=5,FILE='ECGRID.ASC',READONLY,STATUS='OLD')
      OPEN(UNIT=6,FILE=SYS$OUTPUT,STATUS='NEW')
C*************************************************************
C*   READ AND PRINT GRID CELL ID AND 22 DATA VARIABLES     *
C*************************************************************
   10 READ (5,100,END=999) ID, WHAVG, WHMAX, WHSD, ERAVG,
     1     ERMAX, ERMIN, ERNUM, ELAVG, ELMAX, ELMIN, ELNUM
      READ (5,110) GM, GL, TRMAX, TRAVG, TRLVL, TRNUM,
     1     SLR, SLG, SLC, SLS, SLYR

      IF (NLIN.GT.32) NLIN=0
      IF (NLIN.EQ.0) WRITE(6,120)
      IF (NLIN.EQ.0) WRITE(6,130)
      NLIN=NLIN+1

      WRITE(6,105) ID, WHAVG, WHMAX, WHSD, ERAVG,
     1     ERMAX, ERMIN, ERNUM, ELAVG, ELMAX, ELMIN, ELNUM
      WRITE(6,115)  GM, GL, TRMAX, TRAVG, TRLVL, TRNUM,
     1     SLR, SLG, SLC, SLS, SLYR
   20 CONTINUE
      GO TO 10
C
  100 FORMAT(I5,6F8.2,I4,3F8.2,I4)
  105 FORMAT(1X,I5,6F8.2,I4,3F8.2,I4)
  110 FORMAT(2I5,3F8.2,I4,4F8.2,I4)
  115 FORMAT(1X,2I5,3F8.2,I4,4F8.2,I4)
```

```
 120 FORMAT(1X,3X,'ID',3X,'WHAVG',3X,'WHMAX',4X,'WHSD',
    1     3X,'ERAVG',3X,'ERMAX',2X,'ERMIN ','ERNUM',2X,
    1     'ELAVG',3X,'ELMAX',2X,'ELMIN ','ELNUM')
 130 FORMAT(1X,2X,'GM',3X,'GL',3X,'TRMAX',3X,'TRAVG',
    1      2X,'TRLVL ','TRNUM',4X,'SLR',5X,'SLG',5X,'SLC',
    1      5X,'SLS ','SLYR')
C*********************************************************
C*          CLOSE FILES AND EXIT GRACEFULLY              *
C*********************************************************
 999 CLOSE(UNIT=5)
     CLOSE(UNIT=6)
     STOP
     END
```

The second FORTRAN 77 program (File 6 on the magnetic tape) is designed to read and print the file ECPOINT.ASC (File 9).

```
C***********************************************************
C* FORTRAN PROGRAM TO READ AND PRINT ECPOINT.ASC (FILE 9)*
C***********************************************************
      INTEGER NLIN
      INTEGER ID, TRID, SLYR
      REAL    SLLONG, SLLAT, SLR, SLG, SLC, SLS
      REAL    TRLONG, TRLAT, TRAVG, TRMAX, TRLVL
      CHARACTER SLNAME*38, TRNAME*45
C***********************************************************
C* INITIALIZE A COUNTER AND OPEN FILES FOR INPUT/OUTPUT   *
C***********************************************************
      NLIN=0
      OPEN(UNIT=5,FILE='ECPOINT.ASC',READONLY,STATUS='OLD')
      OPEN(UNIT=6,FILE=SYS$OUTPUT,STATUS='NEW')
C***********************************************************
C*READ AND PRINT POINT ID, SEA-LEVEL, AND TIDE VARIABLES *
C***********************************************************
   10 READ (5,100,END=999) ID, SLLONG, SLLAT, SLR, SLG,
     1     SLC, SLS, SLYR, SLNAME
      READ (5,110) TRLONG, TRLAT, TRAVG, TRMAX, TRLVL,
     1     TRID, TRNAME

      IF (NLIN.GT.32) NLIN=0
      IF (NLIN.EQ.0) WRITE(6,120)
      IF (NLIN.EQ.0) WRITE(6,130)
      NLIN=NLIN+1

      WRITE(6,140) ID, SLLONG, SLLAT, SLR, SLG, SLC, SLS,
     1     SLYR, SLNAME
      WRITE(6,150) TRLONG, TRLAT, TRAVG, TRMAX, TRLVL,
     1     TRID, TRNAME

   20 CONTINUE
      GO TO 10
C
  100 FORMAT(I5,6F8.2,I4,A38)
  110 FORMAT(5F8.2,I5,A45)
  120 FORMAT(1X,3X,'ID',2X,'SLLONG',3X,'SLLAT',5X,'SLR',
     1     5X,'SLG',5X,'SLC',5X,'SLS',1X,'SLYR',15X,'SLNAME')
  130 FORMAT(1X,2X,'TRLONG',3X,'TRLAT',3X,'TRAVG',3X,
     1     'TRMAX',3X,'TRLVL',' TRID',15X,'TRNAME')
  140 FORMAT(1X,I5,6F8.2,I4,A38)
  150 FORMAT(1X,5F8.2,I5,A45)
```

```
C***********************************************************
C*           CLOSE FILES AND EXIT GRACEFULLY               *
C***********************************************************
 999 CLOSE(UNIT=5)
     CLOSE(UNIT=6)
     STOP
     END
```

The third FORTRAN 77 program (File 10 on the magnetic tape) is designed to read and print the file ECRISK.ASC (File 13).

```
C***********************************************************
C* FORTRAN PROGRAM TO READ AND PRINT ECRISK.ASC (FILE 13)*
C***********************************************************
     INTEGER NLIN
     INTEGER ID, ERR, LSR, WHR, ELR, GMR, GLR, TRR
C***********************************************************
C* INITIALIZE A COUNTER AND OPEN FILES FOR INPUT/OUTPUT  *
C***********************************************************
     NLIN=0
     OPEN(UNIT=5,FILE='ECRISK.ASC',READONLY,STATUS='OLD')
     OPEN(UNIT=6,FILE=SYS$OUTPUT,STATUS='NEW')
C***********************************************************
C* READ AND PRINT GRID CELL ID AND SEVEN RISK VARIABLES  *
C***********************************************************
  10 READ(5,100,END=999) ID,
    1     ERR,LSR,WHR,ELR,GMR,GLR,TRR

     IF (NLIN.GT.65) NLIN=0
     IF (NLIN.EQ.0) WRITE(6,110)
     NLIN=NLIN+1

     WRITE(6,105) ID,ERR,LSR,WHR,ELR,GMR,GLR,TRR
  20 CONTINUE
     GO TO 10
C
 100 FORMAT(I5,7I4)
 105 FORMAT(1X,I5,7I4)
 110 FORMAT(1X,3X,'ID',1X,'ERR',1X,'LSR',1X,'WHR',1X,
    1     'ELR',1X,'GMR',1X,'GLR',1X,'TRR')
C***********************************************************
C*           CLOSE FILES AND EXIT GRACEFULLY               *
C***********************************************************
 999 CLOSE(UNIT=5)
     CLOSE(UNIT=6)
     STOP
     END
```

The last FORTRAN 77 program (File 14 on the magnetic tape) is designed to read and print the file ECOAST.ASC (File 17).

```
C**********************************************************
C* FORTRAN PROGRAM TO READ AND PRINT ECOAST.ASC (FILE 17)*
C**********************************************************
      CHARACTER  NAME*6, ALLNAME*7
      CHARACTER  COMMA
      INTEGER I, NUM, NLIN
      REAL     X, Y
C**********************************************************
C*                OPEN FILES FOR INPUT/OUTPUT              *
C**********************************************************
      OPEN(UNIT=5,FILE='ECOAST.ASC',READONLY,STATUS='OLD')
      OPEN(UNIT=6,FILE=SYS$OUTPUT,STATUS='NEW')
C**********************************************************
C* READ AND PRINT LINE NAME AND NUMBER OF POINTS IN LINE *
C**********************************************************
   10 NLIN=0
      READ(5,100,END=999) NAME,COMMA,NUM
      IF (COMMA.EQ.'-') NUM=NUM*-1
      IF (COMMA.EQ.',') THEN
         ALLNAME=NAME//','
      ELSE
         ALLNAME=NAME//' '
          END IF
      WRITE(6,130)
      WRITE(6,110) ALLNAME,NUM
C**********************************************************
C*      READ AND PRINT X,Y COORDINATES FOR THE LINE        *
C**********************************************************
      DO 20 I = 1,NUM*-1
        IF (NLIN.GT.77) NLIN=0
        IF (NLIN.EQ.0) WRITE(6,140)
        NLIN=NLIN+1
        READ (5,120) X,COMMA,Y
        WRITE(6,120) X,COMMA,Y
   20 CONTINUE
      GO TO 10
C
  100 FORMAT(A6,A1,I6)
  110 FORMAT(A7,I6)
  120 FORMAT(F8.4,A1,F7.4)
  130 FORMAT(1X,'NAME    ,NUMBER')
  140 FORMAT(1X,'X       ,Y ')
```

```
C*******************************************************
C*          CLOSE FILES AND EXIT GRACEFULLY            *
C*******************************************************
 999  CLOSE(UNIT=5)
      CLOSE(UNIT=6)
      STOP
      END
```

17. LISTING OF THE SAS™ DATA RETRIEVAL PROGRAMS

The following pages list the four SAS™ data retrieval programs provided by CDIAC with this data base. Each program is designed to read and write the contents of one of the four flat ASCII data files.

The first program (File 3 on the magnetic tape) is designed to read and print the file ECGRID.ASC (File 5).

```
DATA ECGRID;
INFILE IN;
INPUT ID 1-5 WHAVG 6-13 WHMAX 14-21 WHSD 22-29 ERAVG 30-37
      ERMAX 38-45 ERMIN 46-53 ERNUM 54-57 ELAVG 58-65
      ELMAX 66-73 ELMIN 74-81 ELNUM 82-85;
INPUT GM 1-5 GL 6-10 TRMAX 11-18 TRAVG 19-26
      TRLVL 27-34 TRNUM 35-38 SLR 39-46
      SLG 47-54 SLC 55-62 SLS 63-70 SLYR 71-74;
PROC PRINT;
RUN;
```

The second SAS™ program (File 7 on the magnetic tape) is designed to read and print the file ECPOINT.ASC (File 9).

```
DATA ECPOINT;
INFILE IN;
INPUT ID 1-5 SLLONG 6-13 SLLAT 14-21 SLR 22-29 SLG 30-37
      SLC 38-45 SLS 46-53 SLYR 54-57 SLNAME $ 58-94;
INPUT TRLONG 1-8 TRLAT 9-16 TRAVG 17-24 TRMAX 25-32
      TRLVL 33-40 TRID 41-45 TRNAME $ 46-89;
PROC PRINT;
RUN;
```

The third SAS™ program (File 11 on the magnetic tape) is designed to read and print the file ECRISK.ASC (File 13).

```
DATA ECRISK;
INFILE IN;
INPUT ID 1-5 ERR 6-9 LSR 10-13 WHR 14-17
      ELR 18-21 GMR 22-25 GLR 26-29 TRR 30-33;
PROC PRINT;
RUN;
```

The last SAS™ program (File 15 on the magnetic tape) is designed to read and print the file ECOAST.ASC (File 17).

```
DATA ECOAST;
FILE PRINT;
INFILE IN DLM=',';
INPUT NAME $ NUM;
PUT 'NAME ,  NUMBER OF POINTS';
PUT NAME $ NUM;
LENGTH DEFAULT=4;
NUM2 = NUM * -1;
ARRAY X{466};
ARRAY Y{466};
PUT 'X        ,Y';
DO I = 1 TO NUM2;
   INPUT X{I} Y{I};
   PUT   X{I} Y{1};
   END;
RUN;
```

18. PARTIAL LISTINGS OF THE FLAT ASCII DATA FILES

What follows is a sample listing of the first 15 lines in each of the four flat ASCII data files provided with this data base.

Sample listing of ECGRID.ASC (File 5).

```
  ID    WHAVG    WHMAX     WHSD    ERAVG    ERMAX  ERMIN ERNUM  ELAVG    ELMAX    ELMIN ELNUM
  GM    GL    TRMAX    TRAVG  TRLVL TRNUM    SLR      SLG      SLC      SLS  SLYR

   1 9999.99 9999.99 9999.99 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99    0
9999 9999 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99 9999.99   0
   2 9999.99 9999.99 9999.99 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99    0
9999 9999 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99 9999.99   0
   3 9999.99 9999.99 9999.99 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99    0
9999 9999 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99 9999.99   0
   4 9999.99 9999.99 9999.99 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99    0
9999 9999 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99 9999.99   0
   5 9999.99 9999.99 9999.99 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99    0
9999 9999 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99 9999.99   0
   6 9999.99 9999.99 9999.99 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99    0
9999 9999 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99 9999.99   0
   7 9999.99 9999.99 9999.99 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99    0
9999 9999 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99 9999.99   0
   8 9999.99 9999.99 9999.99 9999.99 9999.99 9999.99    0 9999.99 9999.99 9999.99    0
...
```

Sample listing of ECPOINT.ASC (File 9).

```
  ID  SLLONG    SLLAT     SLR      SLG      SLC     SLS SLYR                SLNAME
 TRLONG    TRLAT   TRAVG   TRMAX   TRLVL  TRID                    TRNAME

   1    0.00    0.00    0.00    0.00    0.00    0.00   0'                         '
 -66.98   44.90    5.61    6.37    2.80  597                             EASTPORT'
   2    0.00    0.00    0.00    0.00    0.00    0.00   0'                         '
 -67.05   44.97    5.61    6.37    2.80  599'     GLEASON COVE- WESTERN PASSAGE'
   3    0.00    0.00    0.00    0.00    0.00    0.00   0'                         '
 -67.10   45.08    5.85    6.64    2.93  601'                          ROBBINSTON'
   4    0.00    0.00    0.00    0.00    0.00    0.00   0'                         '
 -67.13   45.13    5.97    6.80    2.99  603'                    ST. CROIX ISLAND'
   5    0.00    0.00    0.00    0.00    0.00    0.00   0'                         '
 -67.28   45.18    6.10    6.95    3.05  605'                              CALAIS'
   6    0.00    0.00    0.00    0.00    0.00    0.00   0'                         '
 -67.02   44.90    5.70    6.49    2.83  607'               DEEP COVE- MOOSE ISLAND'
   7    0.00    0.00    0.00    0.00    0.00    0.00   0'                         '
 -67.12   44.93    5.82    6.64    2.90  609'                            EAST BAY'
   8    0.00    0.00    0.00    0.00    0.00    0.00   0'                         '
...
```

Sample listing of ECRISK.ASC (File 13).

```
  ID ERR LSR WHR ELR GMR GLR TRR

   1  0   0   0   0   0   0   0
   2  0   0   0   0   0   0   0
   3  0   0   0   0   0   0   0
   4  0   0   0   0   0   0   0
   5  0   0   0   0   0   0   0
   6  0   0   0   0   0   0   0
   7  0   0   0   0   0   0   0
   8  0   0   0   0   0   0   0
   9  0   0   0   0   0   0   0
  10  0   0   0   0   0   0   0
  11  0   0   0   0   0   0   0
  12  0   0   0   0   0   0   0
  13  0   0   0   0   0   0   0
  14  0   0   0   0   0   0   0
  15  0   0   0   0   0   0   0
 ...
```

Sample listing of ECOAST.ASC (File 17).

```
"29", -42      -Vector 29 uses 42 points to describe the arc
-67.0226,44.9002
-67.0179,44.9023
-67.0151,44.9039
-67.0077,44.9008
-67.0011,44.8964
-66.9978,44.8962
-66.9938,44.8978
-66.9911,44.8986
-66.9884,44.9003
-66.9878,44.9057
-66.9880,44.9099
-66.9903,44.9132
-66.9944,44.9166
-67.0013,44.9192
...
```

19. VERIFICATION OF DATA TRANSPORT: FLAT ASCII DATA FILES

The gridded coastal hazards data base and the original point data may be read using the FORTRAN 77 or SAS™ input/output routines provided. After these files are loaded onto the system it should be verified that the files have not been corrupted during transport. To do this, some or all of the statistics or characteristics presented in the following tables should be generated. These statistics were obtained for ECGRID, ECPOINT, and ECRISK using the SAS™ statistical package (i.e., with PROC MEANS); however, these statistics may be duplicated using other statistical packages or computer languages.

The information shown for ECOAST was obtained using operating system commands. If the file sizes differ from those presented in Table 16 by > 1 byte or the number of rows differs from the number of rows shown, then the flat ASCII file may have been corrupted in transport.

These statistics are presented only as a tool to ensure proper reading of the four flat ASCII data files and should not be construed as either a summary of the data or as an indicator of trends in the data.

Table 13. Statistical characteristics of the numeric variables in ECGRID.ASC (File 5)

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
ID	7040	3520.50	2032.42	1.00	7040.00
WHAVG	7040	9819.60	1330.97	0.23	9999.99
WHMAX	7040	9819.67	1330.47	2.40	9999.99
WHSD	7040	9819.60	1330.98	0.36	9999.99
ERAVG	7040	9801.11	1396.32	-7.82	9999.99
ERMAX	7040	9801.14	1396.09	-6.40	9999.99
ERMIN	7040	9801.08	1396.55	-24.60	9999.99
ERNUM	7040	0.07	0.55	0.00	6.00
ELAVG	7040	9483.46	2212.24	0.00	9999.99
ELMAX	7040	9483.78	2210.87	0.00	9999.99
ELMIN	7040	9483.14	2213.62	0.00	9999.99
ELNUM	7040	0.22	1.20	0.00	9.00
GM	7040	9607.43	1757.68	1230.00	9999.00
GL	7040	9538.68	2062.81	110.00	9999.00
TRMAX	7040	9554.04	2064.09	0.06	9999.99

Table 13. (Continued)

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
TRAVG	7040	9554.03	2064.16	0.03	9999.99
TRLVL	7040	9554.00	2064.30	0.02	9999.99
TRNUM	7040	0.21	1.29	0.00	36.00
SLR	7040	9521.43	2134.47	1.80	9999.99
SLG	7040	9521.36	2134.76	0.43	9999.99
SLC	7040	9521.36	2134.75	0.04	9999.99
SLS	7040	9521.37	2134.73	0.55	9999.99
SLYR	7040	0.27	4.12	0.00	130.00

Table 14. Statistical characteristics of the numeric variables in ECPOINT.ASC (File 9)

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
ID	1481	754.49	457.95	1.00	2036.00
SLLONG	1481	-1.82	11.56	-81.81	0.00
SLLAT	1481	0.93	5.94	0.00	44.90
SLR	1481	0.07	0.43	0.00	4.30
SLG	1481	0.04	0.24	0.00	2.35
SLC	1481	0.03	0.23	0.00	3.10
SLS	1481	0.04	0.25	0.00	3.05
SLYR	1481	1.33	9.03	0.00	130.00
TRLONG	1481	-73.64	12.22	-82.87	0.00
TRLAT	1481	36.71	7.57	0.00	45.18
TRAVG	1481	1.34	0.93	0.00	6.10
TRMAX	1481	1.56	1.06	0.00	6.95
TRLVL	1481	0.67	0.46	0.00	3.05
TRID	1481	1965.81	866.06	0.00	3449.00

Table 15. Statistical characteristics of the numberic variables in ECRISK.ASC (File 13)

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
ID	7040	3520.50	2032.42	1.00	7040.00
ERR	7040	0.07	0.49	0.00	5.00
LSR	7040	0.10	0.44	0.00	3.00
WHR	7040	0.04	0.30	0.00	3.00
ELR	7040	0.23	0.99	0.00	5.00
GMR	7040	0.16	0.78	0.00	5.00
GLR	7040	0.19	0.87	0.00	5.00
TRR	7040	0.05	0.25	0.00	4.00

Table 16. Characteristics and size, in bytes and 512-byte blocks, of ECOAST.ASC (File 17)

Number of lines/arcs	Number of rows	Size in bytes	Size in blocks
934	44,464	889,280	1465

20. VERIFICATION OF DATA TRANSPORT: ARC/INFO™ EXPORT FILES

The four ARC/INFO™ export files were created in ARC/INFO™, Version 6.0.1, using the EXPORT command with the COVER and NONE options. Each export file contains an entire coverage and its associated INFO data files in a fixed-length, uncompressed format.

The exported coverages are in a GEOGRAPHIC projection, which is a spherical reference system that locates positions using latitude and longitude coordinates that are stored in decimal degrees. As a result of this, the reference grids in which the data are stored are *not* uniform in size or area.

After loading the ARC/INFO™ export files onto a system, the user should verify that the files have been correctly transported. To verify the integrity of the files, the size of the export files and (after importing the data into ARC/INFO™) the total number of INFO data records in each coverage should be compared with those presented in Table 17. If the file sizes differ from those presented by > 1 byte or the number of INFO data records do not match those shown in Table 17, then the coverage may have been corrupted in transport. Importation of the ARC/INFO™ E00 files into the user's ARC/INFO™ system can be accomplished using the IMPORT command with the COVER option. The IMPORT command will automatically recognize that the export file is in an uncompressed format (files should be EXTERNALED after being imported [e.g., ARC> external ECGRID]).

Table 17. File size, in bytes and 512-byte blocks, and the number of INFO data records in each ARC/INFO™ export file

Export file name	Tape file number	File size (bytes)	File size (blocks)	ARC/INFO™ data type	Number of ARC/INFO™ records
ECGRID.E00	4	7,534,005	14715	Pat	7041
ECPOINT.E00	8	722,941	1412	Pat	1481
ECRISK.E00	12	4,822,332	9419	Pat	7041
ECOAST.E00	16	1,451,541	2836	Aat	934

APPENDICES

APPENDIX A

THE DATA GROUPS: A QUICK REFERENCE

THE DATA GROUPS: A QUICK REFERENCE

The following provides a listing and description of the data variables and other pertinent information for each of the three data groups and one auxiliary data file. In the ARC/INFO™ version of these files, each data group contains several additional system variables. These system variables are AREA; PERIMETER; an internal point, polygon, or line segment number (e.g., ECGRID#); and an external point, polygon, or line segment identifier (e.g., ECGRID-ID). The external grid cell identifier is present in both the export (.E00) and ASCII (.ASC) files and is used to identify the 0.25° by 0.25° grid cell, point, or line segment to which the data record belongs.

(1) **DATA GROUP ECGRID:** Gridded polygon data for 22 data variables from the following data sets: elevation, geology, geomorphology, sea level trend, shoreline displacement, tidal range, and wave heights. (A value of 9999.99 or 9999 indicates no data are available for the given data cell for a given data variable.)

Data Variables

WHAVG - 20-year mean wave height calculated for each 0.25° grid cell: values expressed in meters.

WHMAX - Maximum significant wave height for each 0.25° grid cell; values expressed in meters.

WHSD - Standard deviation of the mean wave heights experienced within each 0.25° grid cell; values expressed in meters.

ERAVG - Average of the mean long-term erosion trend values for a given 0.25° grid cell; values expressed in meters.

ERMAX - Maximum of the mean long-term erosion trends for a given 0.25° grid cell; values expressed in meters.

ERMIN - Minimum of the mean long-term erosion trends for a given 0.25° grid cell; values expressed in meters.

ERNUM - Number of 3', 7.5', or 15' grid cells (i.e., format of original data source) used in calculating ERAVG, ERMIN, or ERMAX for a given 0.25° grid cell.

DATA GROUP ECGRID:
Data Variables (Continued)

ELAVG - Average elevation calculated from all nonnegative 5' by 5' grid cells within a given 0.25° grid cell; values expressed in meters.

ELMAX - Maximum elevation of all the nonnegative 5' by 5' grid cells for a given 0.25° grid cell; values expressed in meters.

ELMIN - Minimum elevation of all the nonnegative 5' by 5' grid cells for a given 0.25° grid cell; values expressed in meters.

ELNUM - Number of 5' by 5' grid cells used in calculating ELAVG, ELMIN, and ELMAX for a given 0.25° grid cell.

GM - Ordinal value indicating the type and susceptibility of the landforms within a given 0.25° grid cell to inundation and erosion.

GL - Ordinal value indicating the type and resistance of the rocks within a given 0.25° grid cell to erosion through physical and chemical weathering.

TRMAX - Maximum tide range measured for all gauge stations that occurred within a given 0.25° grid cell in 1988 (this value may be the "spring" or "diurnal" tide range, depending on geographic location). Data values are expressed in meters and are based on the point data in data group ECPOINT.

TRAVG - Average of the mean-tide-range values for all tide stations occurring within a given 0.25° grid cell in 1988 (the mean tide range is the difference in height between mean high water and mean low water for 1988). Data values are expressed in meters and are based on the point data in data group ECPOINT.

TRLVL - Average of the mean-tide-level values for all tide stations occurring within a given 0.25° grid cell in 1988 (the mean tide level is a plane midway between mean low water and mean high water in 1988). Values are reckoned from chart datum, are expressed in meters, and are based on the point data in data group ECPOINT. (The Gulf Coast Mean Low Water Datum was used for the Florida Keys, and the Atlantic Coast Mean Low Water Datum was used for the rest of the East Coast.)

DATA GROUP ECGRID:
Data Variables (Continued)

TRNUM - Number of tide-gauge stations used in calculating TRAVG, TRMAX, and TRLVL for a given 0.25° grid cell. Data values are based on the point data in data group ECPOINT.

SLR - Relative sea level trend within a given 0.25° grid cell; values are expressed in mm/year. Data values are based on the point data in data group ECPOINT.

SLG - Long-term geologic-trend derived from ^{14}C data for each 0.25° grid cell; values are expressed in mm/year. Data values are based on the point data in data group ECPOINT.

SLC - Corrected sea level trend derived from tide-gauge data (i.e., SLR) and corrected for geologic trends (i.e., SLG) for each 0.25° grid cell; values are expressed in mm/year. Data values are based on the point data in data group ECPOINT.

SLS - Local subsidence trend derived from tide-gauge data (i.e., SLR) and corrected for the regional eustatic sea level trend (i.e., 1.25); values are expressed in mm/year. Data values are based on the point data in data group ECPOINT.

SLYR - Number of years of record used in estimating the sea level trend for each 0.25° grid cell (grid cells in which tide-gauge stations do not occur have been assigned a zero value.) Data values are based on the point data in data group ECPOINT.

Data Format - ARC/INFO™ coverage and flat ASCII file with data values for each 0.25° latitude by 0.25° longitude grid cell on the U.S. East Coast.

File Storage- ARC/INFO™ coverage name is ECGRID.E00 (File 4) ASCII file name is ECGRID.ASC (File 5).

(2) **DATA GROUP ECPOINT:** Point data for the stations used in constructing the sea level trend and tidal range data sets. (Missing data values are indicated by the value 0.0 for real numbers, 0 for integers, and blank spaces [i.e., ' '] for station names.)

Data Variables

SLLONG - Longitude of the tide-gauge station used for determining the sea-level-trend variables.

SLLAT - Latitude of the given tide-gauge station used for determining the sea-level-trend variables.

SLR - Relative sea level trend for the tide-gauge station; values expressed in mm/year.

SLG - Long-term geologic-trend derived from ^{14}C data; values expressed in mm/year.

SLC - Corrected sea level trend derived from tide-gauge data (i.e., SLR) and corrected for geologic movements (i.e., SLG); values expressed in mm/year.

SLS - Local subsidence trend derived from tide-gauge data (i.e., SLR) and corrected for the regional eustatic sea level trend (i.e., 1.25 mm/year); values are expressed in mm/year.

SLYR - Period of record in years of the tide-gauge station used for determining the sea-level-trend variables.

SLNAME - Station name of the tide-gauge station used for determining the sea level trend variables.

TRLONG - Longitude of the tide-gauge station used for determining the tide-range variables.

TRLAT - Latitude of the given tide-gauge station used for determining the tide-range variables.

TRAVG - Difference (i.e., range) in height between mean high water and mean low water in 1988; values expressed in meters.

DATA GROUP ECPOINT:
Data Variables (Continued)

TRMAX - Difference (i.e., range) in height between the highest high tide and the lowest low tide in 1988 (this value may be the "spring" or "diurnal" tide range, depending on geographic location); values expressed in meters.

TRLVL - Mean tide level is a plane midway between mean low water and mean high water in 1988; values expressed in meters. Values are reckoned from chart datums (i.e., Gulf Coast Mean Low Water Datum is used for the Florida Keys; the Atlantic Coast Mean Low Water Datum is used for the rest of the East Coast).

TRID - Station number (as given in the 1988 Tide Tables) of the given tide gauge station used in determining the tide-range variables.

TRNAME - Station name (as given in the 1988 Tide Tables) of the given tide gauge station used in determining the tide-range variables.

Data Format - ARC/INFO™ coverage and flat ASCII file with data values for each point (i.e., station) on the U.S. East Coast.

File Storage- ARC/INFO™ coverage name is ECPOINT.E00 (File 8) ASCII file name is ECPOINT.ASC (File 9).

(3) **DATA GROUP ECRISK:** Gridded polygon data for the seven classified risk variables. The risk variables contain values ranging from 0 to 5. A value of zero indicates no data are available for a given data variable, for a given grid cell. When the value for a given variable is greater than zero, the value indicates the relative risk of each 0.25° grid cell to inundation or erosion, with 5 indicating the greatest risk.

Data Variables

ERR - Classified version of the mean erosion/accretion data variable (i.e., ERAVG).

LSR - Classified version of the local subsidence trend data variable (i.e., SLS).

WHR - Classified version of the maximum significant wave-height variable (i.e., WHMAX).

ELR - Classified version of the mean elevation data variable (i.e., ELAVG).

GMR - Classified version of the geomorphology data variable (i.e., GM).

GLR - Classified version of the geology data variable (i.e., GL).

TRR - Classified version of the mean-tide-range data variable (i.e., TRAVG).

Data Format - ARC/INFO™ coverage and flat ASCII file with data values for each 0.25° latitude by 0.25° longitude grid cell on the U.S. East Coast.

File Storage- ARC/INFO™ coverage name is ECRISK.E00 (File 12) ASCII file name is ECRISK.ASC (File 13).

(4) **AUXILIARY DATA GROUP ECOAST:** 1:2,000,000 digitized coastline of the U.S. East Coast.

Data Variables

Unlike the other data groups within this data base, this coverage contains line segments (or arcs) that are used to describe the U.S. East Coast. The coastline provided has *no data variables* associated with the line segments. However, simple overlay commands (such as UNION, INTERSECT, IDENTITY) in ARC/INFO™ may be used to transfer the gridded data values to the coastal segments, thus simplifying the interpretation of any derived indices.

Data Format - ARC/INFO™ coverage and flat ASCII file containing the latitude-longitude coordinates of line segments that describe the U.S. East Coast.

File Storage- ARC/INFO™ coverage name is ECOAST.E00 (File 16) ASCII file name is ECOAST.ASC (File 17).

APPENDIX B

GLOSSARY OF TERMS

GLOSSARY OF TERMS USED IN THE GEOLOGIC CLASSIFICATION

What follows are a listing and definitions of the terms that appear in the geologic classification system shown in Table 1. The codes used in the classification system are shown in parentheses. When the classification number given contains an "X" (e.g., 1XX) it is implied that the definition is valid for all subsets of the given geologic feature. This list defines only those rock types mentioned within Table 1 and should not be construed as a comprehensive set of geologic definitions.

IGNEOUS ROCK (1XX) - Rock that has crystallized from a silicate melt at high temperatures (i.e., 900 to 1600°C).

VOLCANIC (EXTRUSIVE) ROCK (OLD=11X) (NEW=4XX) - Igneous rock that has reached the Earth's surface as a result of eruptive processes in a molten or partially molten state. Since these rocks tend to cool rapidly they are usually fine-grained.

ANDESITE (110) - Grayish fine-grained volcanic rock composed of oligoclase/andesine (plagioclase feldspar), with lesser amounts of hornblende, biotite, or pyroxene. Potassium feldspar and quartz compose less than 10% of the total mineral content (plutonic equivalent is quartz diorite).

BASALT (110) - Dark fine-grained volcanic rock consisting of labradorite (plagioclase feldspar) and augite (pyroxene), with minor olivine (plutonic equivalent is gabbro).

RHYOLITE (110) - Light fine-grained volcanic rock composed essentially of alkali feldspar and quartz, with minor biotite occasionally present (plutonic equivalent is granite).

PLUTONIC (INTRUSIVE) ROCK (13X) - Igneous rock which has crystallized from molten material (magma) at depth and has reached the Earth's surface through uplift and erosion. Because cooling is generally slower, these rocks are coarser-grained than their volcanic equivalents.

METAMORPHIC ROCK (15X) - Rock derived from preexisting materials (either igneous, sedimentary, or metamorphic) when recrystallization occurs under higher temperatures, pressures, and shear stresses than normally exist at the Earth's surface.

GNEISS (150) - Metamorphic rock that exhibits alternating bands of lighter minerals (quartz, feldspars) and darker minerals (biotite, hornblende, pyroxene).

QUARTZITE (150) - Metamorphic rock composed essentially of quartz. It results from high-grade metamorphism of a quartz-rich sandstone in which recrystallization of silica has produced a tough, hard rock with interlocking quartz grains.

SCHIST (150) - Metamorphic rock characterized by a layered or foliated appearance (schistosity) cause by the planar alignment of platy minerals, such as mica together with quartz, and minor amounts of other minerals, like garnet.

SERPENTINITE (150) - Green to greenish-yellow rock composed chiefly of the mineral serpentine, derived from metamorphism of iron-magnesium-rich igneous rocks.

SEDIMENTARY ROCK (2XX) - Rock consisting of weathered or eroded fragments of preexisting rocks that have been cemented together as a result of chemical cementation, compression, or precipitation.

SHALE (210) - Sedimentary rock consisting of very fine-grained particles ($\leq$ 0.004 mm) composed chiefly of clay minerals. It is distinguished from mudstone, by its ability to split into thin layers.

SILTSTONE (220) - Sedimentary rock consisting of fine-grained particles in the size range of 0.004 to 0.062 mm. Composed chiefly of clays and fine-grained quartz with mica.

SANDSTONE (230) - Fine to medium-grained sedimentary rock with particles in the size range between 0.062 to 2.0 mm. Typically composed of quartz, feldspars, and rock fragments, which are cemented together by silica, calcite, iron oxide, or clay. The hardness or strength of this rock depends largely on the nature and extent of the cement.

CONGLOMERATE (240) - Coarse-grained sedimentary rock composed of boulders to granule-sized particles ($>$2.0 mm), which are cemented together by silica, calcite, iron oxide, or clay. The hardness or strength of this rock depends largely on nature of the cement.

LIMESTONE (250) - Carbonate rock that can consist either of fragmental material, including fossils, pellets, etc., or a chemical precipitate.

EOLIANITE (260) - Layer of wind-blown beach sand often cemented by deposition of calcium carbonate. Tends to occur above the mean tide level in warm climates.

UNCONSOLIDATED SEDIMENTS (3XX) - Fragmented materials that are derived from the chemical and mechanical weathering process or from chemical precipitation and that have not yet undergone cementation and induration into a consolidated rock.

MUD, CLAY (310) - Very fine-grained particles ($\leq$ 0.004 mm) of clay and quartz.

SILT (320) - Fine-grained particles ($\leq$ 0.062 mm) of clay, quartz, and mica.

SAND (330) - Fine- to medium-grained particles (2.0 to 0.062 mm) of quartz, feldspar, other heavy minerals, and rock fragments.

GRAVELS, CONGLOMERATES (340) - Coarse-grained rock fragments (> 2.0 mm), usually rounded to some degree, depending on the amount of transportation before the fragments came to rest.

GLACIAL TILL (350) - Unsorted materials, ranging in size from fine-grained "rock flour" to large boulders, deposited by glaciers (also known as glacial drift).

CALCAREOUS SEDIMENT (360) - Very fine-grained to fine-grained carbonate sediment, which can be fragmental or chemically precipitated.

LAVA (410) - Geologically recent volcanic rock that has formed by extrusion of molten magma to the Earth's surface as a sheet or flow.

ASH, TEPHRA (420) - Tephra is the general term for all fragmental volcanic materials ejected through a surface-reaching vent. Ash is unconsolidated, fine-grained ejected material (coarser-grained fragments are called bombs, scoria, pumice, etc.).

CORAL REEF (500) - Mass of calcareous material consisting of the skeletal structures of corals, growing in situ, as well as coralline debris and chemically precipitated material. Reefs are generally built of coral, but calcareous algae and shells contribute to the reef structure in many areas.

GLOSSARY OF TERMS USED IN THE GEOMORPHOLOGIC CLASSIFICATION

What follows is a list of landform definitions and their associated classification values (shown in Table 2 on page 15). The terms are defined on the basis of the descriptions found in Bird (1984), Pethick (1984), Ritter (1986), Schwartz (1982), and Shepard and Wanless (1971). When the actual classification number contains an "X" (e.g., 222X) in the last digit, it is implied that the description is valid for all subsets of the given feature.

ALLUVIAL PLAIN SHORELINE (221X) - Intersection of broad alluvial slope, located at the base of a mountain range, with the ocean. These alluvial plains may also occur on delta coasts (222X) or outwash plains (231X).

BARRIER COASTS (212X) - In its most general sense, a barrier refers to accumulations of sand or gravel lying above high tide along a coast. These barriers may be partially or fully detached from the mainland. A barrier beach (2121) is a narrow strip of beach with a single ridge and often foredunes. A barrier island (2122) is completely surrounded by water and usually has multiple ridges, dunes, and salt marshes on the landward side of the island. It usually encloses a body of water known as a lagoon. Although barrier islands are the most common feature off the U.S. East and Gulf coasts, they constitute 10% - 15% of the rest of the world's shorelines. A bay barrier (2123) is a beach barrier built across an embayment and is found in areas with low tide ranges, and high to moderate wave energies.

BEACH (21XX) - A beach is generally made up of sand, cobbles, or boulders and is defined as the portion of the coastal area that is directly affected by wave action and that is terminated inland by a sea cliff, a dune field, or the presence of permanent vegetation and seaward at the breaker/plunge point (the active portion of this zone varies based on wave and tide conditions).

BEACH ROCK (2112) - Cementation of beach sand by $CaCO_3$ in intertidal zones. Confined to warm climates.

CLIFFED COASTS (11XX) - Coasts with cliffs and other abrupt changes in slope at the ocean land interface. Cliffs indicate marine erosion and imply that the sediment supply of the given coastal segment is low. The cliffs height depends upon the topography of the hinterland, lithology of the area, and climate.

COASTAL PLAIN (211X) - Sedimentary deposits formed on a trailing-edge coast. Trailing-edge coasts are often associated with barrier beach systems and are commonly subject to subsidence.

CORAL REEF COASTS (241X, 242X) - Shoal water area built up by secretions of $CaCO_3$ by coral, marine algae, and other marine organisms. Reefs may form either fringing reefs that surround the shore or barrier reefs that grow at some distance from the coast and protect the coast from large waves.

CUSPATE FORELAND (2126) - Seaward projection of accumulated unconsolidated marine sand or gravel, bounded on both sides by wave-dominated coasts (indicates convergence of currents in a low-tide environment).

DELTA (222X) - Accumulations of fine-grained sedimentary deposits at the mouth of a river. The sediment is accumulating faster than wave erosion and subsidence can remove it. These are associated with mud flats (2224) and salt marshes (2225).

DROWNED KARST (1500) - Terrain with distinctive characteristics of relief and drainage arising from a high degree of rock solubility that was submerged at the end of the Wisconsin glaciation period (i.e., geologic substrate that is made of highly soluble, usually carbonate, rock).

ESTUARY COAST (133X) - Tidal mouth of a river or submerged river valley. Often defined to include any semi-enclosed coastal body of water diluted by freshwater, thus includes most bays. The estuaries are subjected to tidal influences with sedimentation rates and tidal ranges such that deltaic accumulations are absent. Also, estuaries are associated with relatively low-lying hinterlands, mud flats (1334), and salt marshes (1335).

FJORD (122X) - Narrow steep-walled, U-shaped, partially submerged glacial valley.

FIARD (123X) - Glacially eroded inlet located on low-lying rocky coasts (other terms used include sea inlets, fjardur, and firth).

ICE COAST (1400) - Coast bordered by glaciers.

LAGOON (225X) - A shallow water body separated from the open sea by sand islands (e.g., barrier islands) or coral reefs.

MANGROVE SWAMP (245X) - Coasts with tree vegetation of subtropical/tropical origin located on muddy, peaty substrates. Occur in coastal regions with low wave energies that are located in tropical and subtropical climates (occupies same ecological niche as salt marsh in temperate zones).

MUD FLATS - Located in areas with fine-grained sediments at low ends of the intertidal zone and are exposed at low tide. Found in estuaries (1334), deltaic environments (2224), and areas with marine/fluvial deposits (2254).

OUTWASH PLAIN (231X) - A river deposition coast. Deposits are derived from meltwater from the front of a glacier. Grades from gravel near the glacier edge to sand farther away. Other types of glacial deposits include moraines (2320), composed of poorly sorted till, and drumlins (2330), hills sculpted by glaciers, that are composed of well-sorted till.

SALT MARSH - Salt-tolerant vegetation that colonizes the intertidal zones of estuaries (1335), deltas (2225), and lagoons (2255). Located on slightly higher elevations than mud flats, and vegetation zonation reflects subtle changes in elevation.

SPIT (2127) - Curved or hooked depositional feature formed by longshore drift. Often has salt marshes on landward side and beach ridges marking former positions of the shoreline. Very mobile landform.

VOLCANIC COASTS (25XX) - Coasts dominated by volcanic landforms. The coasts may be built up of lava flows (251X), ash flows (252X), peninsular and island volcanoes, or calderas (253X). Often may be flanked by coral reefs (241X) if the volcano has become submerged.

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APPENDIX C

DATA LISTING OF GEOLOGIC AND GEOMORPHIC DATA

DATA LISTING OF THE GEOLOGIC DATA FOR LINE SEGMENTS THAT OCCURRED WITHIN A COASTAL GRID CELL

The geologic data contained within this data base were originally obtained from coastal line segments. These segments averaged 4.5 km in length. As a result, more than one line segment may occur within each grid cell contained in the data base. The geologic code assigned to each coastal grid cell was from the geologic classification code with the longest total shore length within each grid cell. For example, if grid cell 416 contained two classification codes and one occurred over 76% of the coastline and the other occurred over 24%, then the geologic code and geologic risk value for the code with the largest percentage were assigned to grid cell 416.

To help the data user determine how this selection process may have affected the gridded data, the following table was constructed. This table shows each geologic code (Table 1 on page 13) that occurred in each coastal grid cell along with the shore length of each code, percentage of total shore length (in the cell), and the risk value associated with each geologic code.

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
173	250	12323.30	100.00	3
174	250	141635.18	100.00	3
175	250	156516.44	100.00	3
176	250	44346.69	100.00	3
177	250	6893.82	100.00	3
255	250	13776.66	100.00	3
257	250	42652.21	100.00	3
258	250	57032.94	100.00	3
336	250	48145.89	100.00	3
337	250	89270.18	100.00	3
338	250	158958.47	100.00	3
339	250	154455.27	100.00	3
416	370	26126.38	23.84	4
416	250	83469.64	76.16	3
417	250	41405.19	100.00	3
419	250	79488.76	100.00	3
420	250	35458.22	100.00	3
495	370	42332.99	100.00	4
496	370	139053.01	100.00	4
499	250	29673.70	100.00	3
500	250	16730.12	36.33	3
500	350	29321.35	63.67	5
573	330	1819.98	100.00	5
574	250	23845.44	14.06	3
574	330	64627.12	38.11	5
574	370	81089.34	47.82	4

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
575	370	116248.88	100.00	4
576	370	4709.21	100.00	4
580	250	31470.42	37.34	3
580	350	52806.85	62.66	5
653	250	32387.22	46.09	3
653	330	37885.34	53.91	5
654	330	1494.36	7.91	5
654	250	17386.82	92.09	3
660	350	28520.77	43.94	5
660	250	36386.55	56.06	3
733	330	16821.55	27.47	5
733	250	44425.36	72.53	3
740	350	40772.63	48.06	5
740	250	44071.36	51.94	3
820	250	28023.17	34.04	3
820	350	54304.21	65.96	5
900	350	49551.83	47.28	5
900	250	55259.55	52.72	3
979	250	28121.32	100.00	3
980	250	49794.64	45.73	3
980	350	59105.36	54.27	5
1059	250	26310.03	37.94	3
1059	350	43040.31	62.06	5
1060	250	4117.34	12.27	3
1060	350	29430.69	87.73	5
1139	250	30551.33	32.25	3
1139	350	64169.17	67.75	5
1218	350	13642.03	43.43	5
1218	250	17772.21	56.57	3
1219	250	20041.75	27.55	3
1219	350	52695.06	72.45	5
1298	250	31104.71	26.77	3
1298	350	85081.52	73.23	5
1377	250	9200.43	100.00	3
1378	330	13873.82	8.45	5
1378	250	23411.67	14.26	3
1378	350	126932.74	77.30	5
1457	250	29634.16	46.97	3
1457	350	33459.75	53.03	5
1458	330	58572.35	36.88	5
1458	350	100244.62	63.12	5
1537	330	3746.18	3.45	5
1537	9999	5250.14	4.83	0
1537	250	17655.71	16.25	3
1537	350	81995.13	75.47	5
1538	350	244.46	1.39	5

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
1538	330	17365.52	98.61	5
1616	350	8548.31	47.80	5
1616	250	9336.49	52.20	3
1617	250	24534.46	25.76	3
1617	350	70693.60	74.24	5
1696	350	45395.26	47.41	5
1696	250	50363.38	52.59	3
1775	250	724.71	100.00	3
1776	350	36639.17	39.65	5
1776	250	55772.12	60.35	3
1855	310	10759.18	11.83	5
1855	330	17010.43	18.70	5
1855	250	28859.59	31.72	3
1855	350	34353.94	37.76	5
1856	350	4681.67	100.00	5
1935	310	30607.94	34.08	5
1935	330	59192.64	65.92	5
2015	310	35832.30	29.65	5
2015	330	85028.58	70.35	5
2094	330	56360.75	100.00	5
2095	310	1809.25	1.67	5
2095	330	106291.07	98.33	5
2174	330	25417.46	29.48	5
2174	310	60802.16	70.52	5
2175	310	40225.12	40.19	5
2175	330	59855.76	59.81	5
2254	310	67957.48	100.00	5
2255	330	39568.65	26.64	5
2255	310	108958.72	73.36	5
2335	300	5216.98	3.34	4
2335	330	12129.32	7.76	5
2335	310	138924.95	88.90	5
2336	330	11130.40	100.00	5
2415	300	60536.30	100.00	4
2416	330	22980.92	18.74	5
2416	300	99653.16	81.26	4
2495	300	34485.43	100.00	4
2496	320	10986.60	6.23	5
2496	330	11941.04	6.77	5
2496	300	153496.45	87.00	4
2497	330	22506.50	41.91	5
2497	300	31193.53	58.09	4
2576	300	33371.22	100.00	4
2577	330	9604.71	6.73	5
2577	300	133065.36	93.27	4
2578	300	830.77	4.72	4

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
2578	330	16771.88	95.28	5
2657	300	108278.75	100.00	4
2658	9999	325.66	0.20	0
2658	330	19863.79	12.04	5
2658	300	144773.69	87.76	4
2659	330	19694.41	26.52	5
2659	300	54557.56	73.48	4
2737	300	13593.93	100.00	4
2738	300	52645.50	100.00	4
2739	330	4856.85	4.30	5
2739	300	108124.21	95.70	4
2740	330	32902.73	35.69	5
2740	300	59292.21	64.31	4
2741	330	13930.41	42.01	5
2741	300	19229.58	57.99	4
2820	300	5296.79	100.00	4
2821	330	10653.98	7.80	5
2821	300	125883.36	92.20	4
2822	300	28036.16	48.48	4
2822	330	29790.37	51.52	5
2823	300	1039.78	29.33	4
2823	330	2505.20	70.67	5
2902	300	15754.23	100.00	4
2903	330	56092.58	45.10	5
2903	300	68294.78	54.90	4
2904	300	12273.83	32.13	4
2904	330	25931.39	67.87	5
2983	300	42615.96	100.00	4
2984	330	40412.73	40.85	5
2984	300	58516.48	59.15	4
3064	330	10154.79	100.00	5
3065	330	27048.51	100.00	5
3145	330	5970.85	100.00	5
3146	300	20191.19	33.86	4
3146	330	39432.16	66.14	5
3147	300	10847.07	17.24	4
3147	330	52085.40	82.76	5
3148	300	10227.30	22.27	4
3148	330	35695.68	77.73	5
3149	330	65657.13	100.00	5
3229	370	7758.89	5.13	4
3229	340	27596.50	18.24	4
3229	300	33409.61	22.08	4
3229	330	82560.38	54.56	5
3309	330	6411.43	39.44	5
3309	300	9844.43	60.56	4
3310	300	40798.40	32.89	4

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
3310	330	83255.18	67.11	5
3311	300	6866.46	21.73	4
3311	330	24733.46	78.27	5
3391	9999	828.83	0.50	0
3391	300	8433.50	5.12	4
3391	330	61937.70	37.62	5
3391	350	93427.72	56.75	5
3392	350	8941.01	7.59	5
3392	370	34761.91	29.52	4
3392	330	74055.68	62.89	5
3393	300	8177.01	11.25	4
3393	370	17890.93	24.62	4
3393	330	46595.82	64.13	5
3394	300	65353.72	49.67	4
3394	330	66219.13	50.33	5
3395	300	1707.06	5.63	4
3395	330	28622.93	94.37	5
3471	350	304.84	100.00	5
3472	370	5719.34	100.00	4
3473	300	32122.22	37.59	4
3473	370	53320.79	62.41	4
3474	300	140628.96	100.00	4
3475	330	59941.07	28.83	5
3475	300	147976.45	71.17	4
3476	300	11686.18	28.34	4
3476	330	29549.06	71.66	5
3552	370	13183.98	24.72	4
3552	350	40156.43	75.28	5
3553	300	7558.22	15.86	4
3553	370	40093.62	84.14	4
3554	300	185289.58	100.00	4
3555	300	69220.97	100.00	4
3556	330	38615.06	100.00	5
3557	330	62258.49	100.00	5
3558	330	40551.84	100.00	5
3632	300	8513.28	100.00	4
3633	300	116663.48	100.00	4
3634	300	223926.17	100.00	4
3635	300	152395.67	100.00	4
3636	300	56812.36	100.00	4
3637	300	5650.59	100.00	4
3638	330	49539.02	100.00	5
3639	330	30685.42	100.00	5
3712	370	18070.16	47.70	4
3712	300	19815.86	52.30	4
3713	300	3411.04	100.00	4
3714	300	71085.90	100.00	4

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
3715	300	24250.86	100.00	4
3716	300	49940.58	100.00	4
3717	300	64738.83	100.00	4
3718	330	10871.41	38.16	5
3718	300	17614.93	61.84	4
3719	330	52434.68	100.00	5
3794	370	17994.01	46.91	4
3794	300	20365.99	53.09	4
3795	300	41887.24	100.00	4
3796	300	102363.15	100.00	4
3797	300	109918.08	100.00	4
3798	300	12173.30	8.05	4
3798	330	138970.25	91.95	5
3873	370	13295.92	100.00	4
3874	300	19904.13	27.27	4
3874	370	53091.62	72.73	4
3875	300	108179.19	100.00	4
3876	300	88233.56	100.00	4
3877	330	42389.22	33.89	5
3877	300	82681.76	66.11	4
3878	330	58847.00	100.00	5
3953	370	35981.47	100.00	4
3954	370	30689.69	100.00	4
3956	300	45545.43	100.00	4
3957	330	95262.68	49.05	5
3957	300	98961.76	50.95	4
4036	300	24327.68	100.00	4
4037	300	13146.62	23.15	4
4037	330	43644.00	76.85	5
4114	350	45785.15	100.00	5
4115	350	22441.64	17.67	5
4115	330	104539.14	82.33	5
4116	330	86730.92	100.00	5
4117	330	20576.85	100.00	5
4193	330	41904.23	100.00	5
4194	330	10768.50	10.50	5
4194	350	91797.41	89.50	5
4195	350	12348.40	7.87	5
4195	330	144553.04	92.13	5
4196	330	8650.90	100.00	5
4197	330	127486.82	100.00	5
4273	330	21301.83	100.00	5
4274	350	30291.36	49.35	5
4274	330	31094.57	50.65	5
4275	350	3647.97	1.60	5
4275	330	223906.97	98.40	5
4276	330	30982.90	100.00	5

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
4277	330	244989.34	100.00	5
4278	330	78137.58	100.00	5
4354	330	63135.51	100.00	5
4355	350	23767.04	11.20	5
4355	330	188355.10	88.80	5
4357	330	144982.63	100.00	5
4358	330	172683.51	100.00	5
4433	370	8846.00	34.48	4
4433	330	16809.56	65.52	5
4434	330	71636.29	100.00	5
4435	330	175116.54	100.00	5
4436	330	45297.20	100.00	5
4437	330	130340.29	100.00	5
4438	330	147335.43	100.00	5
4439	330	157691.67	100.00	5
4512	370	254.31	100.00	4
4513	330	1641.14	3.18	5
4513	370	50030.28	96.82	4
4514	370	44879.70	32.04	4
4514	330	95188.39	67.96	5
4515	330	9554.02	7.59	5
4515	370	116369.81	92.41	4
4516	330	98609.43	100.00	5
4517	370	16274.89	9.71	4
4517	330	151418.46	90.29	5
4518	330	871.05	100.00	5
4519	330	69646.52	100.00	5
4520	370	12568.74	15.23	4
4520	330	69962.74	84.77	5
4591	330	30165.17	44.94	5
4591	370	36957.47	55.06	4
4592	330	44197.32	40.70	5
4592	370	64386.19	59.30	4
4593	370	95003.82	100.00	4
4594	370	96858.64	100.00	4
4595	310	4201.41	3.13	5
4595	330	24179.80	18.04	5
4595	370	105652.28	78.83	4
4596	370	15483.83	12.66	4
4596	330	106795.58	87.34	5
4597	370	24448.40	30.90	4
4597	330	54682.40	69.10	5
4600	370	9288.20	6.58	4
4600	330	131794.39	93.42	5
4671	370	26876.50	100.00	4
4672	370	71302.77	100.00	4
4674	370	10689.28	35.55	4

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
4674	310	19379.21	64.45	5
4675	310	695.05	0.70	5
4675	330	4016.21	4.06	5
4675	370	94133.85	95.23	4
4676	370	245328.63	100.00	4
4679	330	6354.95	100.00	5
4680	370	2998.07	2.28	4
4680	330	128223.59	97.72	5
4754	310	3017.48	3.88	5
4754	330	9496.14	12.22	5
4754	370	65205.43	83.90	4
4755	330	3459.35	1.86	5
4755	370	182569.37	98.14	4
4756	370	207982.63	100.00	4
4759	330	16626.74	100.00	5
4760	370	12133.38	44.86	4
4760	330	14911.13	55.14	5
4761	330	66123.89	100.00	5
4834	330	11196.13	10.82	5
4834	370	92232.40	89.18	4
4835	330	1549.88	1.11	5
4835	370	137716.61	98.89	4
4836	370	152927.65	100.00	4
4839	330	32323.68	100.00	5
4840	370	30576.44	100.00	4
4841	370	21559.36	28.65	4
4841	330	53692.81	71.35	5
4842	330	80045.55	100.00	5
4914	370	19790.16	100.00	4
4915	370	147987.18	100.00	4
4916	370	148468.07	100.00	4
4917	370	99808.59	100.00	4
4918	330	15125.61	41.45	5
4918	370	21365.41	58.55	4
4919	330	18129.20	34.47	5
4919	370	34470.21	65.53	4
4920	370	7908.62	100.00	4
4922	330	62351.14	100.00	5
4923	330	124318.02	100.00	5
4996	130	8366.81	33.27	1
4996	370	16783.68	66.73	4
4997	370	58323.45	100.00	4
4998	370	8847.48	13.32	4
4998	310	19258.03	28.99	5
4998	330	38327.33	57.69	5
4999	330	3189.00	100.00	5
5003	330	65917.61	100.00	5

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
5004	330	92227.18	100.00	5
5084	330	129643.57	100.00	5
5164	310	1344.62	1.47	5
5164	330	90084.08	98.53	5
5165	310	3205.55	100.00	5
5243	370	20165.61	100.00	4
5244	370	5203.62	10.18	4
5244	310	13251.38	25.93	5
5244	330	32643.16	63.88	5
5245	310	4250.97	8.15	5
5245	330	47936.36	91.85	5
5323	370	4731.56	100.00	4
5324	270	13392.04	15.45	3
5324	345	13991.00	16.14	4
5324	150	17257.07	19.91	2
5324	370	42025.18	48.49	4
5325	150	6033.80	5.95	2
5325	345	10654.86	10.51	4
5325	370	84660.46	83.53	4
5326	370	69127.33	100.00	4
5327	370	75251.25	100.00	4
5328	370	77805.17	100.00	4
5329	370	40088.74	100.00	4
5405	370	14170.59	25.80	4
5405	150	17158.34	31.24	2
5405	345	23589.10	42.95	4
5406	345	39711.61	45.23	4
5406	370	48089.02	54.77	4
5407	370	65788.24	100.00	4
5408	370	58297.97	100.00	4
5409	370	59522.96	100.00	4
5410	370	89400.41	100.00	4
5411	370	75572.16	100.00	4
5412	370	22821.72	100.00	4
5486	345	5182.19	20.09	4
5486	150	20614.15	79.91	2
5487	150	30640.24	100.00	2
5488	150	42424.37	100.00	2
5489	230	516.42	5.54	3
5489	130	3519.96	37.76	1
5489	150	5285.40	56.70	2
5490	150	1948.84	16.66	2
5490	370	9748.22	83.34	4
5491	370	131659.59	100.00	4
5492	370	76903.04	100.00	4
5493	370	34397.82	100.00	4
5494	345	29130.00	100.00	4

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
5497	330	1855.74	100.00	5
5500	330	13769.01	100.00	5
5501	330	865.27	36.41	5
5501	345	1510.93	63.59	4
5569	130	4538.62	15.45	1
5569	150	8832.08	30.06	2
5569	230	16012.89	54.50	3
5570	130	7710.23	29.74	1
5570	150	18218.55	70.26	2
5571	130	12359.18	22.11	1
5571	9999	18930.14	33.87	0
5571	150	24606.09	44.02	2
5572	130	570.64	1.01	1
5572	370	5507.40	9.70	4
5572	9999	11544.74	20.34	0
5572	150	39135.48	68.95	2
5573	370	4434.02	9.64	4
5573	130	5687.03	12.36	1
5573	9999	12838.96	27.91	0
5573	150	23037.20	50.08	2
5574	130	35959.03	100.00	1
5575	240	270.16	0.48	3
5575	150	11029.29	19.59	2
5575	130	20685.18	36.74	1
5575	230	24319.08	43.19	3
5576	230	1011.09	3.48	3
5576	150	1675.27	5.76	2
5576	240	3870.91	13.31	3
5576	130	22528.87	77.46	1
5577	345	28757.64	36.60	4
5577	330	49820.55	63.40	5
5578	345	23619.42	29.35	4
5578	330	56849.63	70.65	5
5579	330	36145.92	100.00	5
5580	345	8262.83	12.94	4
5580	330	55598.31	87.06	5
5581	330	3803.18	31.94	5
5581	345	8104.93	68.06	4
5655	130	5202.62	3.57	1
5655	230	140664.87	96.43	3
5656	150	2345.75	2.03	2
5656	240	18908.20	16.37	3
5656	130	43647.95	37.80	1
5656	230	50574.29	43.80	3
5657	150	24933.09	26.69	2
5657	130	68483.11	73.31	1
5658	330	21508.16	19.98	5

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
5658	130	23098.74	21.45	1
5658	345	63060.55	58.57	4
5659	340	4334.41	6.08	4
5659	320	11285.75	15.82	5
5659	330	55702.20	78.10	5
5660	370	565.04	1.45	4
5660	330	38421.08	98.55	5
5661	9999	4421.08	6.67	0
5661	320	10554.71	15.92	5
5661	370	14886.55	22.45	4
5661	330	36434.40	54.96	5
5735	230	30600.09	100.00	3
5736	240	7122.86	39.32	3
5736	230	10991.88	60.68	3
5738	130	1968.47	4.29	1
5738	330	7839.10	17.10	5
5738	300	36045.31	78.61	4
5739	330	5842.01	100.00	5
5740	330	62254.18	100.00	5
5741	320	3655.60	7.73	5
5741	370	19243.25	40.71	4
5741	330	24364.45	51.55	5
5817	130	8831.36	39.00	1
5817	270	13811.39	61.00	3
5818	270	11405.73	18.65	3
5818	330	18578.28	30.38	5
5818	130	31172.90	50.97	1
5819	330	1916.66	100.00	5
5820	330	46990.32	100.00	5
5896	270	33955.01	100.00	3
5897	130	27053.82	28.35	1
5897	270	68386.88	71.65	3
5977	110	9231.04	14.67	1
5977	130	53673.83	85.33	1
5978	130	58978.78	100.00	1
6057	110	4252.36	8.40	1
6057	150	11813.91	23.33	2
6057	130	34566.22	68.27	1
6137	130	1333.57	2.43	1
6137	150	53656.97	97.57	2
6138	130	2431.53	4.70	1
6138	150	49337.36	95.30	2
6218	150	14308.59	100.00	2
6219	130	7083.00	23.17	1
6219	150	23484.61	76.83	2
6299	130	6376.65	23.35	1
6299	110	8620.11	31.56	1

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
6299	150	12315.76	45.09	2
6300	130	9440.94	15.40	1
6300	150	13257.63	21.63	2
6300	110	38603.94	62.97	1
6301	130	3323.44	14.68	1
6301	150	19321.37	85.32	2
6380	110	55178.84	100.00	1
6381	110	31741.35	16.64	1
6381	150	159026.33	83.36	2
6382	150	213378.67	100.00	2
6383	130	18109.48	24.57	1
6383	150	55595.98	75.43	2
6384	150	10597.16	48.87	2
6384	130	11086.45	51.13	1
6461	150	6594.11	28.15	2
6461	110	16829.36	71.85	1
6462	150	20279.74	100.00	2
6463	150	444.98	1.34	2
6463	130	32741.26	98.66	1
6464	370	13171.98	16.23	4
6464	130	23805.46	29.33	1
6464	150	44193.35	54.44	2
6465	150	28130.37	28.84	2
6465	130	29628.00	30.37	1
6465	370	39788.10	40.79	4
6466	150	14713.25	15.93	2
6466	130	77619.67	84.07	1
6467	110	16125.90	25.31	1
6467	130	47580.70	74.69	1
6468	110	1947.25	100.00	1
6544	150	3437.69	100.00	2
6545	130	5242.48	3.31	1
6545	370	18792.17	11.88	4
6545	110	45775.19	28.94	1
6545	150	88377.96	55.87	2
6546	110	34592.33	27.98	1
6546	150	42866.89	34.67	2
6546	130	46182.92	37.35	1
6547	9999	709.06	0.40	0
6547	110	5274.98	3.00	1
6547	130	83155.20	47.25	1
6547	150	86868.05	49.35	2
6548	110	2973.22	2.80	1
6548	370	5179.43	4.88	4
6548	150	9664.06	9.10	2
6548	130	88341.75	83.22	1
6549	370	12861.57	15.13	4

GRID ID	GEOLOGY CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
6549	130	72162.89	84.87	1
6550	150	16175.61	100.00	2
6625	130	2435.24	4.15	1
6625	150	56203.32	95.85	2
6626	130	1814.89	37.69	1
6626	150	3000.36	62.31	2
6627	150	14593.42	100.00	2
6628	130	644.61	8.63	1
6628	150	6825.43	91.37	2
6629	130	65825.27	100.00	1
6630	110	7575.28	7.72	1
6630	150	15465.09	15.76	2
6630	370	16272.56	16.58	4
6630	130	58811.59	59.94	1
6631	9999	487.69	0.51	0
6631	130	12827.71	13.53	1
6631	110	33638.18	35.47	1
6631	370	47870.51	50.48	4
6632	370	1174.28	4.32	4
6632	130	26011.58	95.68	1
6712	150	4876.08	3.49	2
6712	370	6275.53	4.49	4
6712	130	9395.13	6.72	1
6712	110	119262.80	85.30	1
6713	110	3562.84	21.45	1
6713	370	5586.85	33.63	4
6713	130	7463.37	44.92	1
6792	150	4329.22	30.74	2
6792	370	9752.05	69.26	4

DATA LISTING OF THE GEOMORPHIC DATA FOR LINE SEGMENTS THAT OCCURRED WITHIN A COASTAL GRID CELL

The geomorphic data contained within this data base were originally obtained for coastal line segments that averaged 4.5 km in length. As a result, more than one line segment may occur within each grid cell contained in the data base. The geomorphic code assigned to each coastal grid cell was from code with the greatest total shore length (derived from the coastal line segments). For example, if grid cell 416 contained two geomorphic codes and one covered 70% of the shore and the other 30%, then the geomorphic code and geomorphic risk value for the code with the greatest percentage were assigned to grid cell 416.

To help the data user determine how this selection process may have affected the gridded data, the following table was constructed. This table shows, for each grid cell with data, the grid cell identification number, the geomorphic codes that occur (Table 2 on page 15) within the cell, the total shore length (in meters) for each code, and the percentage of the total shore length in the grid cell that is in each geomorphic code.

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
173	2459	12323.30	100.00	3
174	2459	1217.98	0.86	3
174	2450	140417.20	99.14	3
175	2425	19933.86	12.74	3
175	2450	136582.58	87.26	3
176	2425	44346.69	100.00	3
177	2425	6893.82	100.00	3
255	2450	13776.66	100.00	3
257	2450	4614.30	10.82	3
257	2425	38037.91	89.18	3
258	2450	1044.58	1.83	3
258	2425	55988.36	98.17	3
336	2255	15848.32	32.92	3
336	2450	32297.57	67.08	3
337	2255	31772.13	35.59	3
337	2450	57498.05	64.41	3
338	2425	13898.01	8.74	3
338	2255	60976.74	38.36	3
338	2450	84083.72	52.90	3
339	2450	269.73	0.17	3
339	2255	70489.97	45.64	3
339	2425	83695.57	54.19	3
416	2450	32714.41	29.85	3
416	2255	76881.61	70.15	3
417	2255	41405.19	100.00	3

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
419	2450	39507.33	49.70	3
419	2425	39981.43	50.30	3
420	2425	35458.22	100.00	3
495	2255	4736.76	11.19	3
495	2122	12044.29	28.45	5
495	2450	25551.94	60.36	3
496	2122	8347.09	6.00	5
496	2450	18628.20	13.40	3
496	2255	112077.72	80.60	3
499	2259	4157.86	14.01	4
499	2450	25515.84	85.99	3
500	2425	6637.35	14.41	3
500	2259	11879.99	25.80	4
500	2129	27534.13	59.79	5
573	2122	1819.98	100.00	5
574	2122	4495.38	2.65	5
574	2127	6828.20	4.03	5
574	2255	29519.72	17.41	3
574	2450	128718.60	75.91	3
575	2122	8164.80	7.02	5
575	2255	22208.56	19.10	3
575	2450	85875.52	73.87	3
576	2255	4709.21	100.00	3
580	2259	27244.24	32.33	4
580	2129	57033.03	67.67	5
653	2255	15817.72	22.51	3
653	2122	25821.11	36.74	5
653	2121	28633.73	40.75	5
654	2122	1494.36	7.91	5
654	2255	17386.82	92.09	3
660	2129	13373.00	20.60	5
660	2259	23013.55	35.46	4
660	2122	28520.77	43.94	5
733	2121	9098.21	14.85	5
733	2255	52148.70	85.15	3
740	2122	41607.99	49.04	5
740	2259	43236.00	50.96	4
820	2122	11002.02	13.36	5
820	2129	21986.71	26.71	5
820	2259	49338.65	59.93	4
900	2129	1342.04	1.28	5
900	2259	15415.29	14.71	4
900	1330	22484.78	21.45	4
900	2122	24909.15	23.77	5
900	2250	40660.12	38.79	4
979	1330	28121.32	100.00	4
980	2125	9001.36	8.27	3

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
980	1330	20164.92	18.52	4
980	2122	29477.21	27.07	5
980	2250	50256.51	46.15	4
1059	2122	14730.27	21.24	5
1059	2250	26077.58	37.60	4
1059	2125	28542.49	41.16	3
1060	2250	4117.34	12.27	4
1060	2125	13225.35	39.42	3
1060	2122	16205.34	48.30	5
1139	2250	29319.29	30.95	4
1139	2122	29398.02	31.04	5
1139	2125	36003.19	38.01	3
1218	2126	3683.28	11.72	5
1218	2125	8473.80	26.97	3
1218	2250	19257.16	61.30	4
1219	2122	9637.30	13.25	5
1219	2126	14062.99	19.33	5
1219	2250	20041.75	27.55	4
1219	2125	28994.77	39.86	3
1298	2125	17991.93	15.49	3
1298	2126	37427.26	32.21	5
1298	2250	60767.04	52.30	4
1377	2250	9200.43	100.00	4
1378	2126	72631.08	44.23	5
1378	2250	91587.15	55.77	4
1457	2259	1722.71	2.73	4
1457	2255	28896.00	45.80	3
1457	2250	32475.20	51.47	4
1458	2255	10357.49	6.52	3
1458	2126	66591.26	41.93	5
1458	2250	81868.22	51.55	4
1537	9999	1542.42	1.42	0
1537	2255	9061.95	8.34	3
1537	2250	9651.43	8.88	4
1537	2259	38429.74	35.37	4
1537	2126	49961.62	45.99	5
1538	2126	17609.98	100.00	5
1616	2250	3089.43	17.27	4
1616	2259	6247.06	34.93	4
1616	2122	8548.31	47.80	5
1617	2259	19313.58	20.28	4
1617	2126	19410.23	20.38	5
1617	2250	23326.02	24.49	4
1617	2122	33178.23	34.84	5
1696	2259	15648.62	16.34	4
1696	2250	22291.01	23.28	4
1696	2122	57819.01	60.38	5

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
1775	2250	724.71	100.00	4
1776	2250	41068.75	44.44	4
1776	2122	51342.54	55.56	5
1855	2255	3439.11	3.78	3
1855	2125	8995.64	9.89	3
1855	2259	18244.02	20.05	4
1855	2122	25406.65	27.92	5
1855	2250	34897.72	38.36	4
1856	2250	1317.07	28.13	4
1856	2122	3364.60	71.87	5
1935	2122	28820.51	32.09	5
1935	2125	30372.13	33.82	3
1935	2255	30607.94	34.08	3
2015	1335	16104.37	13.32	3
2015	2255	20303.75	16.80	3
2015	2125	33639.14	27.83	3
2015	2122	50813.62	42.04	5
2094	1335	15125.35	26.84	3
2094	9999	41235.40	73.16	0
2095	9999	14233.55	13.17	0
2095	1335	29258.91	27.07	3
2095	2122	29661.28	27.44	5
2095	2125	34946.58	32.33	3
2174	9999	395.81	0.46	0
2174	2125	1384.77	1.61	3
2174	1335	84439.04	97.93	3
2175	9999	3332.04	3.33	0
2175	2122	27550.75	27.53	5
2175	2125	32845.92	32.82	3
2175	1335	36352.17	36.32	3
2254	1335	67957.48	100.00	3
2255	1339	5418.49	3.65	4
2255	2125	23902.96	16.09	3
2255	2122	41501.23	27.94	5
2255	1335	77704.69	52.32	3
2335	2122	13154.84	8.42	5
2335	1335	143116.41	91.58	3
2336	2122	11130.40	100.00	5
2415	1335	60536.30	100.00	3
2416	2122	25688.28	20.95	5
2416	1335	96945.80	79.05	3
2495	1335	34485.43	100.00	3
2496	2122	11941.04	6.77	5
2496	1335	164483.05	93.23	3
2497	2122	22098.78	41.15	5
2497	1335	31601.25	58.85	3
2576	1335	33371.22	100.00	3

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
2577	1334	10091.04	7.07	5
2577	2122	14857.31	10.41	5
2577	1335	117721.72	82.51	3
2578	1335	1214.68	6.90	3
2578	1334	6766.77	38.44	5
2578	2122	9621.20	54.66	5
2657	1330	6100.38	5.63	4
2657	1335	102178.37	94.37	3
2658	2121	1472.51	0.89	5
2658	2122	8390.13	5.09	5
2658	1334	10592.15	6.42	5
2658	2255	33079.62	20.05	3
2658	1335	111428.73	67.55	3
2659	2125	1806.69	2.43	3
2659	2255	18792.61	25.31	3
2659	1335	24939.08	33.59	3
2659	2122	28713.59	38.67	5
2737	1335	13593.93	100.00	3
2738	1335	52645.50	100.00	3
2739	2125	4856.85	4.30	3
2739	1335	108124.21	95.70	3
2740	2125	11988.13	13.00	3
2740	2122	17061.98	18.51	5
2740	1335	63144.83	68.49	3
2741	2122	14128.89	42.61	5
2741	1335	19031.10	57.39	3
2820	1339	5296.79	100.00	4
2821	1330	10196.97	7.47	4
2821	1335	27820.25	20.38	3
2821	2122	46451.31	34.02	5
2821	1339	52068.81	38.14	4
2822	2255	28036.16	48.48	3
2822	2122	29790.37	51.52	5
2823	2122	451.45	12.73	5
2823	1335	1039.78	29.33	3
2823	2121	2053.75	57.93	5
2902	2255	15754.23	100.00	3
2903	2255	1722.08	1.38	3
2903	1330	6303.56	5.07	4
2903	2122	8302.37	6.67	5
2903	2121	10451.24	8.40	5
2903	2125	23365.14	18.78	3
2903	1335	74242.97	59.69	3
2904	2125	5315.26	13.91	3
2904	1335	15010.13	39.29	3
2904	2122	17879.83	46.80	5
2983	9999	1657.51	3.89	0

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
2983	1330	14720.44	34.54	4
2983	1335	26238.01	61.57	3
2984	1330	3110.27	3.14	4
2984	2121	6307.83	6.38	5
2984	2122	8884.24	8.98	5
2984	2125	9238.86	9.34	3
2984	9999	14107.07	14.26	0
2984	2111	16209.29	16.38	5
2984	1335	41071.65	41.52	3
3064	2111	3796.94	37.39	5
3064	2121	6357.85	62.61	5
3065	2111	27048.51	100.00	5
3145	2111	5970.85	100.00	5
3146	2122	4531.97	7.60	5
3146	2121	8894.76	14.92	5
3146	2111	11986.39	20.10	5
3146	2251	16883.83	28.32	5
3146	1330	17326.40	29.06	4
3147	2111	9267.41	14.73	5
3147	2122	14103.40	22.41	5
3147	1330	14801.65	23.52	4
3147	2251	24760.01	39.34	5
3148	9999	2032.09	4.42	0
3148	2125	4149.26	9.04	3
3148	2126	5302.34	11.55	5
3148	2121	7209.50	15.70	5
3148	2111	12055.12	26.25	5
3148	1330	15174.67	33.04	4
3149	2121	3038.96	4.63	5
3149	1330	13963.82	21.27	4
3149	2125	23787.38	36.23	3
3149	2126	24866.97	37.87	5
3229	9999	2092.56	1.38	0
3229	1339	6288.04	4.16	4
3229	2121	6825.71	4.51	5
3229	2126	12173.08	8.04	5
3229	2122	26238.03	17.34	5
3229	2250	28682.43	18.95	4
3229	1330	30342.37	20.05	4
3229	2255	38683.16	25.56	3
3309	2122	988.52	6.08	5
3309	2255	5082.34	31.26	3
3309	2250	10185.00	62.65	4
3310	2124	9928.83	8.00	5
3310	2255	36063.22	29.07	3
3310	2122	36123.74	29.12	5
3310	2250	41937.79	33.81	4

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
3311	2250	6866.46	21.73	4
3311	2122	11100.31	35.13	5
3311	2124	13633.15	43.14	5
3391	9999	779.70	0.47	0
3391	2124	4505.84	2.74	5
3391	2125	10253.71	6.23	3
3391	2255	11580.06	7.03	3
3391	2122	16508.51	10.03	5
3391	2250	20757.45	12.61	4
3391	1330	100242.48	60.89	4
3392	9999	531.51	0.45	0
3392	2255	8385.63	7.12	3
3392	2250	17343.61	14.73	4
3392	2122	20946.57	17.79	5
3392	2125	27571.68	23.41	3
3392	1330	42979.60	36.50	4
3393	1330	1323.71	1.82	4
3393	2125	5120.12	7.05	3
3393	2250	24744.23	34.05	4
3393	2122	41475.70	57.08	5
3394	2122	13828.35	10.51	5
3394	1330	24913.62	18.94	4
3394	2250	38532.21	29.29	4
3394	2126	54298.67	41.27	5
3395	2250	1707.06	5.63	4
3395	2126	28622.93	94.37	5
3471	1330	304.84	100.00	4
3472	1330	5719.34	100.00	4
3473	1330	85443.01	100.00	4
3474	2250	6317.90	4.49	4
3474	1335	15635.15	11.12	3
3474	1330	118675.91	84.39	4
3475	2122	7896.24	3.80	5
3475	1330	8669.87	4.17	4
3475	2250	29820.14	14.34	4
3475	2255	39351.99	18.93	3
3475	2126	52044.83	25.03	5
3475	1335	70134.45	33.73	3
3476	1335	11686.18	28.34	3
3476	2122	29549.06	71.66	5
3552	1335	12423.63	23.29	3
3552	1339	15632.85	29.31	4
3552	1330	25283.93	47.40	4
3553	1330	23664.21	49.66	4
3553	1335	23987.63	50.34	3
3554	1330	81584.15	44.03	4
3554	1335	103705.43	55.97	3

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
3555	1330	1621.80	2.34	4
3555	1335	67599.17	97.66	3
3556	2122	38615.06	100.00	5
3557	2126	895.59	1.44	5
3557	2122	61362.90	98.56	5
3558	2126	40551.84	100.00	5
3632	1335	1725.11	20.26	3
3632	1330	6788.17	79.74	4
3633	1335	42563.78	36.48	3
3633	1330	74099.70	63.52	4
3634	1330	44830.64	20.02	4
3634	1335	179095.53	79.98	3
3635	1335	152395.67	100.00	3
3636	1335	14216.67	25.02	3
3636	2255	42595.69	74.98	3
3637	2255	5650.59	100.00	3
3638	2126	49539.02	100.00	5
3639	2126	30685.42	100.00	5
3712	1339	4968.30	13.11	4
3712	1330	8062.19	21.28	4
3712	1335	24855.53	65.61	3
3713	1330	1588.82	46.58	4
3713	1335	1822.22	53.42	3
3714	1335	71085.90	100.00	3
3715	1335	24250.86	100.00	3
3716	1335	49940.58	100.00	3
3717	1335	1610.55	2.49	3
3717	2250	8662.34	13.38	4
3717	2255	54465.94	84.13	3
3718	2250	3157.72	11.09	4
3718	2126	10871.41	38.16	5
3718	2255	14457.21	50.75	3
3719	2126	52434.68	100.00	5
3794	1331	7953.37	20.73	5
3794	1330	11948.40	31.15	4
3794	1335	18458.23	48.12	3
3795	1330	11788.04	28.14	4
3795	1335	30099.20	71.86	3
3796	1335	102363.15	100.00	3
3797	2255	4292.79	3.91	3
3797	2250	8959.50	8.15	4
3797	1335	96665.79	87.94	3
3798	2250	6145.44	4.07	4
3798	2126	8827.85	5.84	5
3798	2122	62208.31	41.16	5
3798	2255	73961.95	48.93	3
3873	1335	3499.01	26.32	3

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
3873	1330	9796.91	73.68	4
3874	1335	5075.77	6.95	3
3874	1330	67919.98	93.05	4
3875	1330	108179.19	100.00	4
3876	1330	88233.56	100.00	4
3877	2125	1071.46	0.86	3
3877	1335	8286.61	6.63	3
3877	2254	10862.86	8.69	5
3877	2255	22983.32	18.38	3
3877	2122	30454.90	24.35	5
3877	1330	51411.83	41.11	4
3878	2125	4935.38	8.39	3
3878	2122	53911.62	91.61	5
3953	1330	14331.03	39.83	4
3953	1335	21650.44	60.17	3
3954	9999	740.91	2.41	0
3954	1330	14091.05	45.91	4
3954	1335	15857.73	51.67	3
3956	1335	2308.15	5.07	3
3956	2255	12263.84	26.93	3
3956	1330	30973.44	68.01	4
3957	1330	12270.72	6.32	4
3957	2125	16437.89	8.46	3
3957	1335	17440.02	8.98	3
3957	2254	25984.58	13.38	5
3957	2122	49907.05	25.70	5
3957	2255	72184.18	37.17	3
4036	2255	24327.68	100.00	3
4037	2125	10322.83	18.18	3
4037	2255	17214.51	30.31	3
4037	2122	29253.28	51.51	5
4114	1330	45785.15	100.00	4
4115	1335	3888.79	3.06	3
4115	1330	31402.59	24.73	4
4115	1339	91689.40	72.21	4
4116	2122	1706.49	1.97	5
4116	1339	85024.43	98.03	4
4117	2122	20576.85	100.00	5
4193	1339	3602.92	8.60	4
4193	1330	38301.31	91.40	4
4194	1339	4835.55	4.71	4
4194	1330	97730.36	95.29	4
4195	1339	1041.27	0.66	4
4195	1330	76163.55	48.54	4
4195	1335	79696.62	50.79	3
4196	1330	8650.90	100.00	4
4197	1330	12833.76	10.07	4

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
4197	2122	20578.84	16.14	5
4197	2125	41324.31	32.41	3
4197	2255	52749.91	41.38	3
4273	1330	21301.83	100.00	4
4274	1330	61385.93	100.00	4
4275	1335	39744.58	17.47	3
4275	1330	187810.36	82.53	4
4276	1335	4721.72	15.24	3
4276	1330	26261.18	84.76	4
4277	2122	10957.98	4.47	5
4277	2125	11895.74	4.86	3
4277	1330	74187.49	30.28	4
4277	2255	147948.13	60.39	3
4278	2122	33945.58	43.44	5
4278	2255	44192.00	56.56	3
4354	1330	63135.51	100.00	4
4355	1330	212122.14	100.00	4
4357	2255	2592.05	1.79	3
4357	1335	2952.19	2.04	3
4357	1330	139438.39	96.18	4
4358	2125	7656.30	4.43	3
4358	2122	20753.57	12.02	5
4358	2255	144273.64	83.55	3
4433	1330	25655.56	100.00	4
4434	1330	71636.29	100.00	4
4435	1330	175116.54	100.00	4
4436	1335	2264.34	5.00	3
4436	1330	43032.86	95.00	4
4437	1331	8179.54	6.28	5
4437	1330	8584.58	6.59	4
4437	1335	113576.17	87.14	3
4438	2125	9423.62	6.40	3
4438	2255	38188.79	25.92	3
4438	1335	99723.02	67.68	3
4439	2125	14506.83	9.20	3
4439	2127	17845.25	11.32	5
4439	2122	19432.43	12.32	5
4439	2255	105907.16	67.16	3
4512	1331	254.31	100.00	5
4513	1330	17780.07	34.41	4
4513	1331	33891.35	65.59	5
4514	1330	52993.20	37.83	4
4514	1331	87074.89	62.17	5
4515	1331	6698.08	5.32	5
4515	1330	119225.75	94.68	4
4516	1335	10609.25	10.76	3
4516	1330	88000.18	89.24	4

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
4517	1331	4493.10	2.68	5
4517	1330	4755.63	2.84	4
4517	1335	158444.62	94.48	3
4518	1335	871.05	100.00	3
4519	2122	2660.91	3.82	5
4519	2125	7762.60	11.15	3
4519	2255	59223.01	85.03	3
4520	2255	20839.54	25.25	3
4520	2122	25941.00	31.43	5
4520	2125	35750.94	43.32	3
4591	1331	14763.32	21.99	5
4591	1330	52359.32	78.01	4
4592	1331	5492.98	5.06	5
4592	1330	103090.53	94.94	4
4593	1331	2467.62	2.60	5
4593	1330	92536.20	97.40	4
4594	1330	96858.64	100.00	4
4595	9999	4201.41	3.13	0
4595	1331	14019.59	10.46	5
4595	1330	115812.49	86.41	4
4596	1330	43869.34	35.88	4
4596	1335	78410.07	64.12	3
4597	1335	79130.80	100.00	3
4600	2123	5367.94	3.80	5
4600	2122	8486.07	6.01	5
4600	2121	15539.62	11.01	5
4600	2255	18605.18	13.19	3
4600	2125	29030.76	20.58	3
4600	1335	64053.02	45.40	3
4671	1330	26876.50	100.00	4
4672	1330	71302.77	100.00	4
4674	9999	4770.36	15.86	0
4674	1330	12221.43	40.65	4
4674	1331	13076.70	43.49	5
4675	9999	695.05	0.70	0
4675	1330	98150.06	99.30	4
4676	1339	10389.88	4.24	4
4676	1330	234938.75	95.76	4
4679	1330	6354.95	100.00	4
4680	2111	3893.47	2.97	5
4680	2123	7731.46	5.89	5
4680	2121	18909.39	14.41	5
4680	1330	48591.07	37.03	4
4680	2250	52096.27	39.70	4
4754	1330	77719.05	00.00	4
4755	1331	27894.23	14.99	5
4755	1330	158134.49	85.01	4

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
4756	1330	207982.63	100.00	4
4759	1335	16626.74	100.00	3
4760	2127	4964.33	18.36	5
4760	2111	5323.73	19.69	5
4760	1331	7369.34	27.25	5
4760	1335	9387.11	34.71	3
4761	2129	7274.00	11.00	5
4761	2122	11837.11	17.90	5
4761	1330	12993.44	19.65	4
4761	2125	14359.59	21.72	3
4761	2255	19659.75	29.73	3
4834	1339	48272.77	46.67	4
4834	1330	55155.76	53.33	4
4835	1331	30655.11	22.01	5
4835	1339	37226.58	26.73	4
4835	1330	71384.80	51.26	4
4836	1330	152927.65	100.00	4
4839	1335	32323.68	100.00	3
4840	1335	30576.44	100.00	3
4841	2122	3798.75	5.05	5
4841	1330	8436.30	11.21	4
4841	2125	16852.43	22.39	3
4841	1335	20569.09	27.33	3
4841	2255	25595.60	34.01	3
4842	2125	22126.86	27.64	3
4842	2122	26849.33	33.54	5
4842	2255	31069.36	38.81	3
4914	1339	19790.16	100.00	4
4915	1339	41531.88	28.06	4
4915	1330	106455.30	71.94	4
4916	1330	148468.07	100.00	4
4917	1330	99808.59	100.00	4
4918	1330	10871.26	29.79	4
4918	1335	25619.76	70.21	3
4919	1335	52599.41	100.00	3
4920	1335	7908.62	100.00	3
4922	2129	2755.38	4.42	5
4922	2120	5950.46	9.54	5
4922	2122	6583.36	10.56	5
4922	2125	14546.10	23.33	3
4922	2255	32515.84	52.15	3
4923	2129	15218.69	12.24	5
4923	2122	17685.40	14.23	5
4923	2250	23347.12	18.78	4
4923	2255	29577.64	23.79	3
4923	2120	38489.17	30.96	5
4996	1330	25150.49	100.00	4

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
4997	1330	58323.45	100.00	4
4998	1339	12360.36	18.61	4
4998	1335	13223.77	19.91	3
4998	1330	40848.71	61.49	4
4999	1330	3189.00	100.00	4
5003	2122	2674.60	4.06	5
5003	2120	4980.82	7.56	5
5003	2250	6931.69	10.52	4
5003	2255	51330.50	77.87	3
5004	2121	6956.23	7.54	5
5004	2250	12631.43	13.70	4
5004	2122	20553.34	22.29	5
5004	2255	24770.00	26.86	3
5004	2120	27316.18	29.62	5
5084	2250	14262.94	11.00	4
5084	2121	27953.73	21.56	5
5084	2120	30295.74	23.37	5
5084	2255	57131.16	44.07	3
5164	2121	9495.89	10.39	5
5164	2120	11739.85	12.84	5
5164	2119	22730.28	24.86	5
5164	2255	47462.68	51.91	3
5165	2119	3205.55	100.00	5
5243	2329	2119.60	10.51	3
5243	2119	4263.90	21.14	5
5243	1339	13782.11	68.34	4
5244	2127	4209.50	8.24	5
5244	1119	6472.50	12.67	3
5244	2119	19362.67	37.89	5
5244	1339	21053.49	41.20	4
5245	1119	1571.38	3.01	3
5245	2121	8234.96	15.78	5
5245	1339	13013.36	24.94	4
5245	2127	13801.34	26.45	5
5245	2119	15566.29	29.83	5
5323	2329	1503.53	31.78	3
5323	1339	3228.03	68.22	4
5324	2129	3004.12	3.47	5
5324	2349	16430.88	18.96	3
5324	1129	17806.08	20.55	2
5324	2329	49424.21	57.03	3
5325	2122	948.30	0.94	5
5325	1129	6033.80	5.95	2
5325	2329	8369.83	8.26	3
5325	2255	11357.75	11.21	3
5325	2319	32586.65	32.15	4
5325	2129	42052.79	41.49	5

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
5326	2319	12652.04	18.30	4
5326	2125	14733.13	21.31	3
5326	2315	17902.33	25.90	3
5326	2122	23839.83	34.49	5
5327	2315	6537.43	8.69	3
5327	2319	16865.51	22.41	4
5327	2125	22066.28	29.32	3
5327	2122	29782.03	39.58	5
5328	2125	1473.49	1.89	3
5328	2315	30063.97	38.64	3
5328	2122	46267.71	59.47	5
5329	2315	4110.85	10.25	3
5329	2122	35977.89	89.75	5
5405	2340	1902.22	3.46	3
5405	1249	6015.51	10.95	1
5405	1129	16526.40	30.09	2
5405	2329	30473.90	55.49	3
5406	2329	432.80	0.49	3
5406	2127	7463.05	8.50	5
5406	2321	9579.50	10.91	4
5406	2320	14162.23	16.13	3
5406	1249	15840.27	18.04	1
5406	2340	40322.78	45.93	3
5407	2321	7665.03	11.65	4
5407	2127	27498.77	41.80	5
5407	2320	30624.44	46.55	3
5408	2315	680.50	1.17	3
5408	2321	13176.26	22.60	4
5408	2127	44441.21	76.23	5
5409	2122	11287.80	18.96	5
5409	2321	21148.39	35.53	4
5409	2315	27086.77	45.51	3
5410	2321	14434.75	16.15	4
5410	2315	16463.68	18.42	3
5410	2320	25772.63	28.83	3
5410	2121	32729.35	36.61	5
5411	2321	2666.58	3.53	4
5411	2123	4499.13	5.95	5
5411	2311	9680.23	12.81	5
5411	2121	13469.69	17.82	5
5411	2310	14827.58	19.62	4
5411	2320	30428.95	40.26	3
5412	2321	1291.11	5.66	4
5412	2311	21530.61	94.34	5
5486	1249	25796.34	100.00	1
5487	1245	3048.17	9.95	2
5487	1241	9599.85	31.33	2

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
5487	1249	17992.22	58.72	1
5488	1330	2201.34	5.19	4
5488	1245	3712.66	8.75	2
5488	1241	6943.52	16.37	2
5488	1249	7247.38	17.08	1
5488	1339	8958.01	21.12	4
5488	2121	13361.46	31.49	5
5489	2341	4036.38	43.30	4
5489	1249	5285.40	56.70	1
5490	1240	1948.84	16.66	1
5490	2321	9748.22	83.34	4
5491	2121	11643.58	8.84	5
5491	2321	16845.87	12.80	4
5491	2320	103170.14	78.36	3
5492	2121	1587.68	2.06	5
5492	2311	1677.44	2.18	5
5492	2321	13239.66	17.22	4
5492	2320	60398.26	78.54	3
5493	2311	1078.75	3.14	5
5493	2321	33319.07	96.86	4
5494	2320	29130.00	100.00	3
5497	2321	1855.74	100.00	4
5500	2341	870.11	6.32	4
5500	2311	12898.90	93.68	5
5501	2341	2376.20	100.00	4
5569	1249	2761.79	9.40	1
5569	1339	11420.05	38.87	4
5569	2341	15201.75	51.74	4
5570	1240	1984.62	7.65	1
5570	2345	5264.31	20.30	3
5570	2341	18679.85	72.04	4
5571	1240	6740.19	12.06	1
5571	2341	23094.64	41.32	4
5571	1330	26060.58	46.62	4
5572	1330	6514.03	11.48	4
5572	1241	7422.15	13.08	2
5572	2320	9439.34	16.63	3
5572	1339	12435.87	21.91	4
5572	1240	20946.87	36.91	1
5573	2127	4232.74	9.20	5
5573	2121	10912.27	23.72	5
5573	2320	15239.50	33.13	3
5573	1240	15612.70	33.94	1
5574	1330	13711.35	38.13	4
5574	2121	22247.68	61.87	5
5575	2121	1124.79	2.00	5
5575	1249	8380.04	14.88	1

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
5575	1241	11976.40	21.27	2
5575	1240	34822.48	61.85	1
5576	1330	947.85	3.26	4
5576	2121	6228.61	21.41	5
5576	1240	10830.35	37.24	1
5576	2123	11079.33	38.09	5
5577	2320	29405.77	37.42	3
5577	2321	49172.42	62.58	4
5578	2311	7169.95	8.91	5
5578	2123	7765.24	9.65	5
5578	2321	13713.83	17.04	4
5578	2310	23513.92	29.22	4
5578	2320	28306.11	35.18	3
5579	2310	1189.99	3.29	4
5579	2121	2528.90	7.00	5
5579	2122	5972.13	16.52	5
5579	2127	6495.79	17.97	5
5579	2311	19959.11	55.22	5
5580	2321	8655.52	13.55	4
5580	2311	20708.31	32.43	5
5580	2127	34497.31	54.02	5
5581	2127	2122.00	17.82	5
5581	2341	9786.11	82.18	4
5655	1249	4443.95	3.05	1
5655	1339	49672.11	34.05	4
5655	1240	91751.43	62.90	1
5656	2123	2997.75	2.60	5
5656	2121	4168.85	3.61	5
5656	1339	5853.70	5.07	4
5656	1249	13245.39	11.47	1
5656	1330	37509.26	32.48	4
5656	1240	51701.24	44.77	1
5657	2121	5196.62	5.56	5
5657	1239	28268.52	30.26	1
5657	1230	59951.06	64.18	1
5658	2320	3253.82	3.02	3
5658	2321	5150.22	4.78	4
5658	2311	23093.84	21.45	5
5658	2350	35414.40	32.89	3
5658	1230	40755.17	37.85	1
5659	2121	6132.79	8.60	5
5659	2341	7309.15	10.25	4
5659	2125	7516.44	10.54	3
5659	2111	7771.98	10.90	5
5659	2255	10837.34	15.19	3
5659	2311	31754.66	44.52	5
5660	2315	565.04	1.45	3

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
5660	2255	1315.96	3.38	3
5660	2341	3435.10	8.81	4
5660	2122	5771.88	14.80	5
5660	2319	7397.55	18.97	4
5660	2111	7922.30	20.32	5
5660	2311	12578.29	32.26	5
5661	2311	9599.76	14.48	5
5661	2315	12308.24	18.57	3
5661	2121	22117.03	33.36	5
5661	2122	22271.71	33.59	5
5735	1339	30600.09	100.00	4
5736	1339	1320.79	7.29	4
5736	1330	16793.95	92.71	4
5738	2111	3919.45	8.55	5
5738	1240	7348.94	16.03	1
5738	2127	10891.85	23.75	5
5738	2321	23692.64	51.67	4
5739	2111	5842.01	100.00	5
5740	2111	15759.55	25.31	5
5740	2341	21991.98	35.33	4
5740	2127	24502.65	39.36	5
5741	2315	4775.60	10.10	3
5741	2121	11499.93	24.33	5
5741	2341	14341.89	30.34	4
5741	2345	16645.88	35.22	3
5817	1241	8831.36	39.00	2
5817	2359	13811.39	61.00	3
5818	2255	6503.81	10.63	3
5818	1241	8183.03	13.38	2
5818	2121	10975.66	17.95	5
5818	1240	12785.85	20.91	1
5818	2127	22708.56	37.13	5
5819	2127	1916.66	100.00	5
5820	2341	8071.32	17.18	4
5820	2127	38919.00	82.82	5
5896	2359	33955.01	100.00	3
5897	1249	544.62	0.57	1
5897	1241	4045.30	4.24	2
5897	1230	9183.59	9.62	1
5897	2127	16661.61	17.46	5
5897	2359	65005.58	68.11	3
5977	1230	3346.51	5.32	1
5977	1240	7954.24	12.64	1
5977	2121	7953.88	12.64	5
5977	1249	16958.81	26.96	1
5977	2255	26691.43	42.43	3
5978	2121	2883.99	4.89	5

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
5978	1240	4249.95	7.21	1
5978	2255	7692.47	13.04	3
5978	1230	44152.37	74.86	1
6057	1339	5682.33	11.22	4
6057	1330	9555.85	18.87	4
6057	1241	12269.90	24.23	2
6057	2121	23124.41	45.67	5
6137	1241	574.60	1.04	2
6137	1330	54415.94	98.96	4
6138	1241	11143.49	21.53	2
6138	1330	17488.38	33.78	4
6138	1240	23137.02	44.69	1
6218	1241	14308.59	100.00	2
6219	1241	2048.62	6.70	2
6219	2111	4641.98	15.19	5
6219	2127	9286.27	30.38	5
6219	1240	14590.74	47.73	1
6299	1241	3496.75	12.80	2
6299	1249	6376.65	23.35	1
6299	2111	7699.26	28.19	5
6299	1240	9739.86	35.66	1
6300	1249	12935.50	21.10	1
6300	1240	22072.77	36.01	1
6300	1230	26294.24	42.89	1
6301	1230	22644.81	100.00	1
6380	1240	18985.12	34.41	1
6380	1230	36193.72	65.59	1
6381	1330	34396.24	18.03	4
6381	1230	156371.44	81.97	1
6382	1330	40380.98	18.92	4
6382	1230	172997.69	81.08	1
6383	1230	73705.46	100.00	1
6384	1230	21683.61	100.00	1
6461	1330	23423.47	100.00	4
6462	1330	20279.74	100.00	4
6463	1230	33186.24	100.00	1
6464	1230	81170.79	100.00	1
6465	1230	97546.47	100.00	1
6466	1230	92332.92	100.00	1
6467	1235	2979.36	4.68	2
6467	1230	60727.24	95.32	1
6468	1235	1947.25	100.00	2
6544	1230	3437.69	100.00	1
6545	1230	158187.80	100.00	1
6546	1231	4883.02	3.95	2
6546	1234	8253.74	6.68	2
6546	1230	110505.38	89.38	1

GRID ID	GEOMORPHIC CODE	LENGTH (m)	COASTLINE PERCENTAGE	RISK VALUE
6547	1235	2954.03	1.68	2
6547	1231	5327.52	3.03	2
6547	1220	16838.74	9.57	1
6547	1230	150887.00	85.73	1
6548	1234	3893.79	3.67	2
6548	1230	102264.67	96.33	1
6549	1235	5728.10	6.74	2
6549	1234	17234.50	20.27	2
6549	1230	62061.86	72.99	1
6550	1230	16175.61	100.00	1
6625	1230	21665.93	36.95	1
6625	1330	36972.63	63.05	4
6626	1330	1676.87	34.82	4
6626	1230	3138.38	65.18	1
6627	1230	5467.30	37.46	1
6627	1231	9126.12	62.54	2
6628	1230	7470.04	100.00	1
6629	1230	20319.91	30.87	1
6629	1234	45505.36	69.13	2
6630	1235	10730.61	10.94	2
6630	1234	31287.37	31.89	2
6630	1230	56106.54	57.18	1
6631	1231	5618.36	5.93	2
6631	1235	11618.81	12.25	2
6631	1234	23569.53	24.86	2
6631	1230	54017.39	56.97	1
6632	1231	2288.89	8.42	2
6632	1230	24896.97	91.58	1
6712	1231	464.12	0.33	2
6712	1230	139345.42	99.67	1
6713	1231	5275.72	31.76	2
6713	1230	11337.34	68.24	1
6792	2122	586.72	4.17	5
6792	1230	13494.55	95.83	1

APPENDIX D

REPRINTS OF PERTINENT LITERATURE

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ASSESSMENT OF GLOBAL COASTAL HAZARDS FROM SEA LEVEL RISE

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ABSTRACT

A global coastal hazards data base that contains topographic, geologic, geomorphic, erosional and subsidence information is being developed in order to predict the coastal segments at greatest risk to a rise in sea level caused by future climate warming. High risk areas are characterized by low coastal relief, an erodible substrate, past and present evidence of subsidence, extensive shoreline retreat and high wave/tide energies. Data have been assembled for the U.S.A. and are being extended to the rest of North America. Several high risk areas have been tentatively identified and include the central Gulf Coast, South Florida, the North Carolina Outer Banks, southern Delmarva peninsula, and the San Francisco Bay area.

INTRODUCTION

Recent studies predict that global climate warming caused by accumulation of "Greenhouse" gases in the atmosphere could lead to a sea level rise of between 50 and 150 cm within the next century (Ramanathan, 1988; NAS, 1987). Such a rise would endanger human populations, cities, ports and wetlands in low-lying coastal areas. It becomes important, therefore, to classify and map the coastal areas that will be most vulnerable to future rise in sea level, and to select high-risk shorelines for more detailed studies.

The coastal data base described here contains relevant topographic, geologic, geomorphologic, erosional and subsidence information, which are integrated into a Geographic Information System (GIS), to screen out high-risk shorelines. These latter areas are characterized by one or more of the following conditions: 1) low coastal

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relief, 2) an erodible substrate (e.g. sand, unconsolidated sediment), 3) present and past evidence of subsidence, 4) extensive shoreline retreat, and 5) high wave/tide energies.

Information on at least eight variables relating to the coastal zone is being compiled and entered into the ORNL ARC/INFO Geographic Information System (GIS). These variables include the following: 1) relief (elevation), 2) lithology (rock type), 3) coastal landforms (geomorphology), 4) vertical land movements (relative sea level changes), 5) horizontal shoreline changes (erosion or accretion), 6) tidal ranges, 7) wave heights, and 8) storm frequencies and intensities.

Data compilation for the first seven variables has been completed for the U.S. and is being extended to North America, with ultimate global coverage planned. Storm frequency data are being collected, for a related study, by others.

In this paper, we briefly describe the components of the data base, treatment of data, entry into the GIS, and development of a Coastal Vulnerability Index. Procedures are still under development, and the outline presented here provides a demonstration of the approach rather than a final assessment. Preliminary results are given for individual variables in the U.S., and an overlay is shown of several components for a section of the U.S. East Coast.

DEVELOPMENT OF THE GLOBAL COASTAL HAZARDS DATA BASE

Survey of Data Base Components

Coastal hazards, in the context of rising sea levels, fall into two major categories: 1) inundation, both permanent and episodic, and 2) erosion. Among the variables considered here, relief and vertical land movements (particularly subsidence) provide a direct measure of inundation risk, the other factors contribute to the erodibility risk. Bedrock lithology, shore materials and coastal landforms vary substantially in their resistance to erosion. Tidal currents and wave action can erode and modify the shoreline. Important coastal processes, outside the scope of the present study, include the sediment budget, and storm surges and frequencies, which contribute to episodic flooding. (The latter data are being compiled by others in a related study). Economic and demographic factors are not presently considered, but can be added later to the GIS.

Coastal relief, or elevation, provides a first order approximation of the extent of inundation. Global digital elevation data exists at 5' latitude-longitude resolution (ETOPO5 Gridded World Elevations, National Geophysical Data Center, Boulder, CO). Higher resolution coverage (such as the U.S.G.S. DEM) is incomplete, worldwide. A measure of relief should extend beyond the immediate shoreline. In this study, the measure of relief used is the average elevation of 5' land data points, grouped into 1/4 degree coastal cells. The absence of globally uniform map scales and contour intervals render unsatisfactory alternate indices, such as elevation at a fixed distance inland, or distance inland to a fixed contour.

Lithology is interpreted directly from geologic maps. A simplified geologic classification is used (modified from Dolan et al., 1975), which differentiates between resistant crystalline rocks, sedimentary rocks and unconsolidated sediments (Table 1). Each rock type is assigned a 3-digit code.

Table 1. Coastal Geologic Classification

I. OLD, RESISTANT ROCKS (crystallines)

- A. Igneous, volcanic (basalt, rhyolite, andesite, etc.)
- B. Igneous, plutonic (granite, granodiorite, etc.)
- C. Metamorphic (schists, gneisses, quartzites, serpentinite, etc.)

II. SEDMENTARY ROCKS, CONSOLIDATED

- A. shale
- B. siltstone
- C. sandstone
- D. conglomerate
- E. limestone
- F. eolianite (calcite cemented sand)
- G. mixed or varied lithology

III. SEDIMENTS, UNCONSOLIDATED

- A. mud, clay
- B. silt
- C. sand
- D. gravels, conglomerates
- E. glacial till
- F. calcareous sediment (includ. coquina)
- G. mixed or varied lithology

IV. VOLCANIC, Quaternary

- A. lava
- B. ash, tephra
- C. composite

V. CORAL REEF (living)

Coastal landforms are interpreted and classified from the U.S. Geological Survey 1:250,000 topographic map series. This scale represents a compromise between completeness of international coverage at a uniform scale, and the ability to identify coastal landforms. Coastlines are divided here into those formed primarily by erosion (marine, non-marine), and by deposition (marine, non-marine), and assigned a four-digit code (Fig. 1). The last digit designates shore features that occur in more than one environment (i.e. beach, or salt marsh).

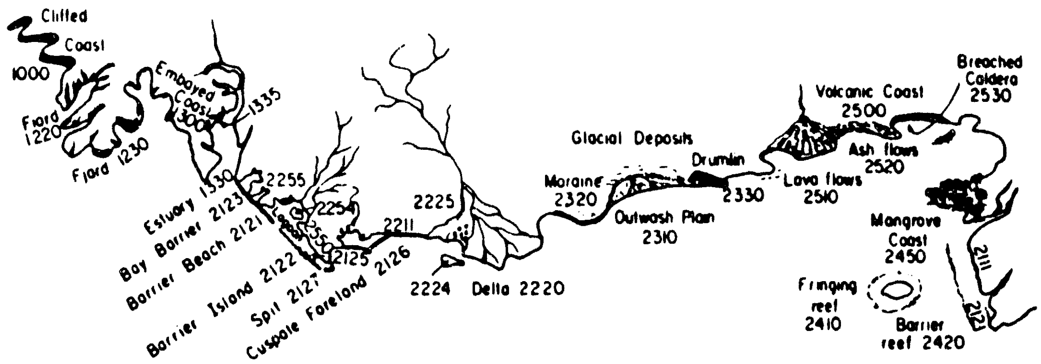

Figure 1. Schematic classification of shorelines.

Records of sea level (SL) change are obtained from a worldwide network of ~1000 tide-gauge stations (Pugh et al., 1987), of which around 300 have usable record lengths greater than 20 years (Gornitz and Lebedeff, 1987). U.S. tide-gauge data are given in Lyles et al. (1987). The relative sea level change at each locality includes the eustatic component (around 1-1.5 mm/yr, Gornitz and Lebedeff, 1987; Barnett, 1983, 1984), as well as glacio isostatic, neotectonic and local subsidence components. Subsiding areas (RSL ≥ 2 mm/yr), regardless of ultimate cause, are subject to greater inundation hazards (see below).

Historical U.S. shoreline changes have been digitized and averaged into 3' cells (CEIS data base; Dolan et al., 1983). Continuous coverage extends from Long Island to Key West, and from Apalachicola, FL to Mexico border, with some gaps in New England, West Florida and the Pacific Coast. No CEIS data are currently available for Alaska and Hawaii.

Worldwide tide range data for around 6,000 stations are listed in the annual Tide Tables (NOS, 1988). Both mean and spring tide ranges are given.

U.S. wave data come from the Wave Information Study (WIS) conducted by the Coastal Engineering Research Center (CERC), U.S. Army Corps of Engineers. Only Phase I deep-water coverage (120 n.mi) exists for the Gulf of Mexico, which does not accurately represent the near shore environment. Phase II data, at 30 n. mi spacing, exist for Southern California (Corson et al., 1987), and Phase III data (30 n. mi) for 166 stations along the East Coast, and 134 stations along the West Coast (Jensen, 1983). The calculated 20 yr mean and maximum wave heights are used for these stations.

Data entry into the Geographic Information System (GIS)

The seven components of the coastal hazards data base discussed above include data in a variety of formats and spatial resolutions: 1) Point data (e.g. tide-gauge stations), 2) Line or arc data (lithology, landforms, waves), 3) Polygons or cells (relief, shoreline displacements). The data are entered into the ARC/INFO (ESRI, Inc.) GIS at ORNL.

The ARC/INFO GIS software can relate and manipulate point, line and polygon data at different scales. Each of the coastal components forms a feature class (coverage), encoded within ARC/INFO, which can be displayed graphically. After each coverage has been formed, the various classes can be overlaid and areas with a common set of attributes can be identified. Various modules within ARC/INFO allow transformation of different spatial projections to a common format and superposition of the various individual feature classes. A major advantage of the GIS is the ability to display spatially-referenced data graphically, highlighting relationships among the different variables, comprising the individual data sets.

Some of the data sets are continuous, whereas others are point data that must be averaged or interpolated to eliminate discontinuities. For the conterminous U.S. at least, all the variables, except for sea level trends, are continuous, or nearly so. The high spatial variability present in the CEIS shoreline displacement data can be reduced by using 3-5 point running means. Sensitivity tests can be made to establish optimum values.

Sea level trends, which are point data can be averaged over coastal segments of uniform geology or tectonic setting, and where stations are closely spaced. Alternatively, in regions with fairly good coverage, or where variability of sea level trends is not too great (as along the East Coast), best-fit linear interpolations can be made in a straight line between stations, with the value projected to the nearest location along the coast. Geologically significant systematic variations in sea level trends could be lost by averaging schemes. However, different approaches may be required for different regions.

Development of a Coastal Vulnerability Index

A coastline vulnerable to sea level rise exhibits one or more of the following characteristics. 1) low relief, 2) an erodible substrate, 3) present or past history of subsidence, 4) history of shoreline erosion, 5) high wave energies and/or tide ranges. A coastal vulnerability index (CVI) can be derived that will comprise some combination of the inundability variables (relief, subsidence) and erodibility variables (lithology, landform, wave height, tide range).

Each variable is assigned a rank, from 1 to 5, with 5 the most vulnerable class. The rationale for the ranking scheme for each variable is now briefly reviewed (summarized in Table 2).

1. Relief (elevation)-- inundation risk

Projected sea level rise within the next 100 yrs is estimated to range between 0.5-1.5 m (NAS, 1987). Clearly, this elevation zone faces a high probability of permanent inundation. The coastal strip within 5 m of present MSL lies at high risk to higher than normal tides, or storm surges. The next 10 m may show some increased vulnerability to extreme storm events. The hazard decreases progressively for higher average elevations (Table 2).

2. Lithology (geologic rock type) -- erodibility risk

The relative resistance of rocks to erosion depends on the chemical and physical breakdown of rocks (weathering), which in turn depends on mineral composition, rock texture (grain size), fabric (presence of planar elements), cementation, climate (especially precipitation and temperature), and finally removal of weathering products. A rock weathering sequence has been adapted from the mineral sequence (Berner and Berner, 1987, p.153), and consideration given to responses under different climatic regimes (Loughnan, 1969; Carroll, 1970). As a rule, consolidated sedimentary rocks are more erodible than crystalline rocks. Unconsolidated sediments are the least resistant to erosion -- the finer-grained sediments the least so. The presence of a pronounced layered structure (bedding, slaty cleavage, or schistocity) and jointing also facilitates erosion. Chemical weathering, and removal of weathering products is accelerated in hot, humid climates. A generalized sequence of rock resistance to erosion is shown in Table 2.

3. Landform (geomorphology) -- erodibility risk

Landforms are the resultant of weathering processes acting upon topography and geology. In general, high risk landforms are mobile or unstable, hence underlain by unconsolidated material. In addition, these usually show low relief (e.g. barrier coasts, estuaries, lagoons, deltas, etc.) At less risk are landforms with harder substrates and higher relief. (e.g. fiords, rocky coasts; Table 2).

4. Vertical land movement (relative sea level change) -- subsidence risk (inundability)

Relative SL change at each locality can be compared with the eustatic trend of 1-1.5 mm/yr (Gornitz and Lebedeff, 1987; Barnett, 1983, 1984). Stable regions have trends close to the eustatic range. Subsiding areas have SL trends > 2.0 mm/yr (high risk), while uplifting areas experience SL trends of <1.0 mm/yr (low risk, Table 2).

5. Shoreline displacement -- erodibility risk.

Rates within ± 1m lie within the measurement error. Such shorelines can be considered stable. Shores with displacement rates greater than +1m/yr are accreting, and are thus at relatively low risk. Conversely, shores with rates of -1m/yr or less are eroding, and are at relatively higher risk (Table 2).

6. Tidal ranges - erodibility risk

Coasts with a tidal range of < 2m (microtidal) are at low risk, while those with ranges over 4m (macrotidal) face a higher risk (Table 2).

7. Wave heights -- erodibility risk

The ranks shown in Table 2 are based on maximum wave heights.

After each variable, for each portion of coastline, has been ranked, as described above, the ranks can be combined into a coastal vulnerability index, CVI, which is the product of the inundability and erodibility variables. A simple method of determining high risk coastlines is to flag the high and very high risk classes (Table 2), for each individual component, separately. Then the various components are overlaid in the GIS, and shore segments identified for which four or more of the components fall into the high and very high risk categories. An application of the procedure to the U.S. East Coast is shown below.

PRELIMINARY RESULTS

Individual components

Differences in plate tectonic settings among the U.S. coasts exert a strong influence on the regional variations in average values of several of the data base components (Inman and Nordstrom, 1971).

Table 2. Coastal Vulnerability Index

RANK	Very Low	Low	Moderate	High	Very high risk
VARIABLE	1	2	3	4	5
Relief (m)	≥ 30.1	20.1-30.0	10.1-20.0	5.1-10.0	0-5.0
Rock type (relative resistance to erosion)	Plutonic Volcanic (lava) High-medium grade metamorphics	Low-grade metamor. Sandstone and conglomerate (well-cemented)	Most sedimentary rocks	Coarse and/or poorly-sorted unconsolidated sediments	Fine unconsolidated sediment Volcanic ash
Landform	Rocky, cliffed Coasts Fiords Fiards	Medium cliffs Indented coasts	Low cliffs Glacial drift Salt marsh Coral Reefs Mangrove	Beaches (pebbles) Estuary Lagoon Alluvial plains	Barrier beaches Beaches (sand) Mudflats Deltas
Vertical movement (Relative Sea Level change) (mm/yr)	≤ -1.1 Land rising	-1.0 - 0.99	1.0 - 2.0 within range of eustatic rise	2.1 - 5.0	≥ 5.1 Land sinking
Shoreline displacement (m/yr)	≥ 2.1 Accretion	1.0 - 2.0	-1.0 - +1.0 Stable	-1.1 - -2.0	≤ -2.0 Erosion
Tidal Range, m (mean)	≤ 0.99 Microtidal	1.0 - 1.9	2.0 - 4.0 Mesotidal	4.1 - 6.0	≥ 6.1 Macrotidal
Wave height, m (maximum)	0 - 2.9	3.0 - 4.9	5.0 - 5.9	6.0 - 7.9	≥ 7.0

The East and Gulf Coasts are on trailing plate edges. The West Coast, on the other hand, undergoes plate convergence, north of the Mendocino triple junction, and transcurrent motion along the San Andreas fault system, to the south.

Thus, the East and Gulf Coasts are generally low-lying, as shown by the % of coastal elevation points within the first 10 m of MSL (from the digitized ETOPOS data set): 55.6% and 82.0% respectively (Table 3). By contrast, on the West Coast, only 6.8% of the elevations are ≤ 10 m. Southern Alaska lies near the intersection of three major plates. Much of the coast consists of steep fiords; only 2.7% of the elevations lie within 10 m. The corresponding figure for Southern Alaska is 10.3%. On the other hand, the western and northern coasts of Alaska lie on trailing plate edges, with largely deltaic, coastal plains and barrier island landforms. In these two regions, 16.7% and 21.1% of the coastal elevations, respectively fall within 10 m or less (Table 3). Hawaii consists of a group of volcanic islands, that have been eroded to varying degrees. Although beaches are widespread, the coast is cliffed in any places. Thus, only 9.4% of coastal elevations are 10m or less.

Both East and Gulf Coasts are subsiding (Table 4). Anomalously high subsidence in the Gulf Coast, west of the Florida panhandle (6.68 ± 4.30 mm/yr, Table 4) is caused by high sedimentation/compaction rates at the Mississippi delta, and oil/gas withdrawal (Gabrysch, 1984).

The average sea level change for the West Coast (1.04 ±1.07mm/yr, Table 4) reflects the prevalence of subsidence in the vicinity of most tide-gauges with some localized uplift. This stands in contrast to long-term (late Quaternary-Holocene) evidence for regional uplift based on raised marine terraces (West and McCrumb, 1986; Lajoie, 1986). Negative sea level trends at Neah Bay, WA; Astoria, OR and Crescent City, CA indicate ongoing uplift. Further inland, subsidence is demonstrated by positive (rising) SL trends at Friday Harbor and Seattle, WA (Lyles et al., 1987).

Table 3. Summary of Elevation Data

REGION	% ELEVATION ≤ 10m	% ELEVATION ≤ 100m
East Coast	55.6	98.5
Gulf Coast	82.0	100.0
West Coast	6.8	34.5
SE Alaska	2.7	12.8
South Alaska	10.3	30.2
Aleutian Is.	12.6	37.3
West Alaska	16.7	62.4
North Slope, AK	21.1	84.3
Hawaii	9.4	22.6

Although deformation in southeast Alaska is largely NNW right lateral motion, uplift also occurs, as shown by raised and warped beach terraces (Plafker et al., 1980, Molnia 1985), and unusually negative SL trends: Juneau -12.4 mm.yr; Skagway -17.3 mm/yr, Yakutat, -4.6 mm/yr, and Sitka -2.2 mm/yr (Lyles et al; 1987). However, some of this uplift may be caused by isostatic rebound from glacial retreat within the last 100 years (Shepard and Wanless, 1971).

Erosion is predominant along the East and Gulf Coasts. Areas experiencing significant erosion rates over 2m/yr include Martha's Vineyard, Nantucket, Fire Island, much of the mid-Atlantic Coast, the southern Delmarva peninsula, South Carolina to Georgia.

The central Gulf Coast region (Louisiana and parts of Texas) has the highest average erosion rates in the U.S. Furthermore, the area is characterized by anomalously high subsidence (see above). These factors, coupled with very low-lying topography and an erodible substrate (unconsolidated alluvium or sand) make it one of the most vulnerable regions in the conterminous U.S.

Table 4. Regional Average Sea-Level Trends
(from Lyles et al., 1987)

REGION	Average Sea-level Change, mm/yr	σ	N
East Coast	2.69	0.78	33
Gulf Coast	6.68	4.30	12
West Coast	1.04	1.07	13
Alaska	-6.49	6.09	8
Hawaii	1.40	1.60	5

Along the West Coast, erosion rates are generally lower, and some areas of accretion can be identified, often associated with influx of river sediments. The contrast in shoreline displacements along East and West coasts is another indication of fundamental geologic and tectonic differences (Inman and Nordstrom, 1971).

The South Alaska coast, a glacial outwash coast, is accretionary in general, despite intensive wind and wave erosion, because of tectonic uplift, glacioisostatic rebound, and an abundant sediment supply from glacial meltwater and rivers. Erosion has been recorded for several areas, including the upper Cook Inlet and the northwest coast of Kodiak Island. Shoreline displacements for other parts of Alaska are sparsely documented (National Shoreline Study, 1971).

In general, mean and maximum wave heights are higher along the West Coast than along the East Coast. However, variable, but below average wave heights for the West Coast are concentrated between San Francisco (37°N) and Pismo Beach (35°N). Along the East Coast, the highest wave heights are associated with the exposed Cape Hatteras; the lowest waves appear in Southern Florida (south of Miami) (Fig. 2).

On the East Coast, macrotidal conditions occur north of 42°N (especially Maine). South Carolina and Georgia also have relatively high tidal ranges, whereas Florida and the Gulf Coast are microtidal. The maximum tide ranges on the West Coat are found in the Puget Sound and San Francisco Bay. Much of the Alaska coast is mesotidal to macrotidal, except within a microtidal environment (NOS, 1988).

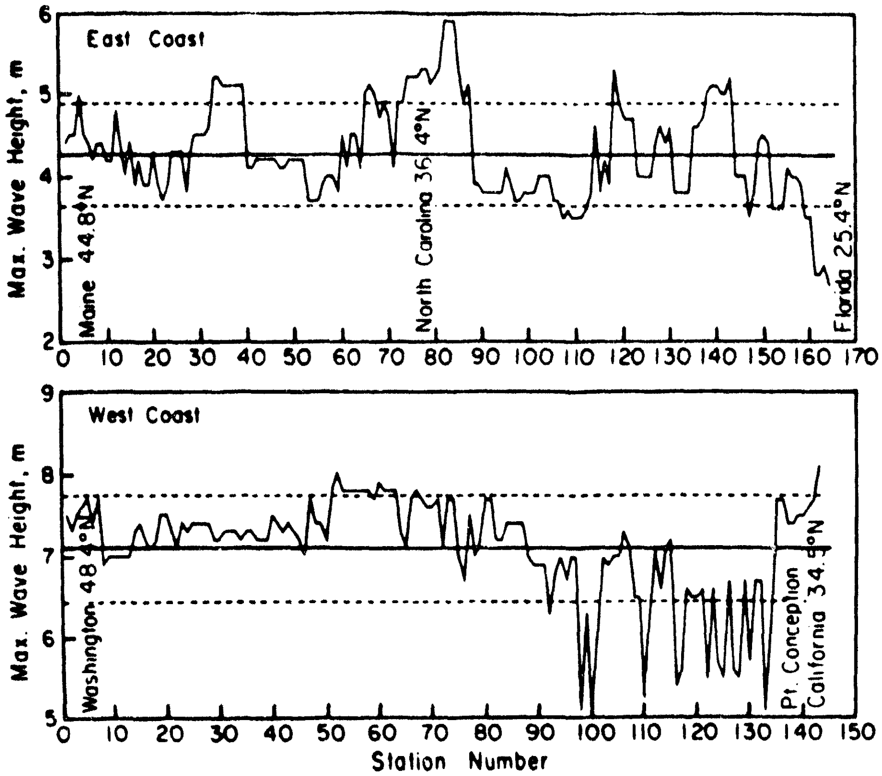

Figure 2. Regional variations in maximum wave heights, East and West Coasts. Heavy lines are the regional means, dashed lines are ± 1 σ.

Overlay of several components

This section illustrates the GIS overlay approach to the determination of high-risk coastal segments for the U.S. East Coast. Variables considered here include relief, lithology, landform and shoreline change.

The very high risk category, for the present demonstration, comprises shore segments that have mean coastal relief between 0-5m, consist of mud, clay, silt, and sand, and located on coastal plains beaches, barrier beaches (including spits, barrier islands), mud flats and deltas. Mean erosion rates exceed -2m/yr. The high risk category includes relief between 5-10m, consists of gravels, conglomerates, glacial till, and mixed or varied sediments, and landforms such as pebble or cobble beach, and more sheltered environments such as estuaries and lagoons. Mean erosion rates fall between -2.0 and -1.1 m/yr.

An example of the GIS overlay for four components is illustrated for the southern half of Chesapeake Bay (Fig. 3). The barrier islands of the southern Delmarva

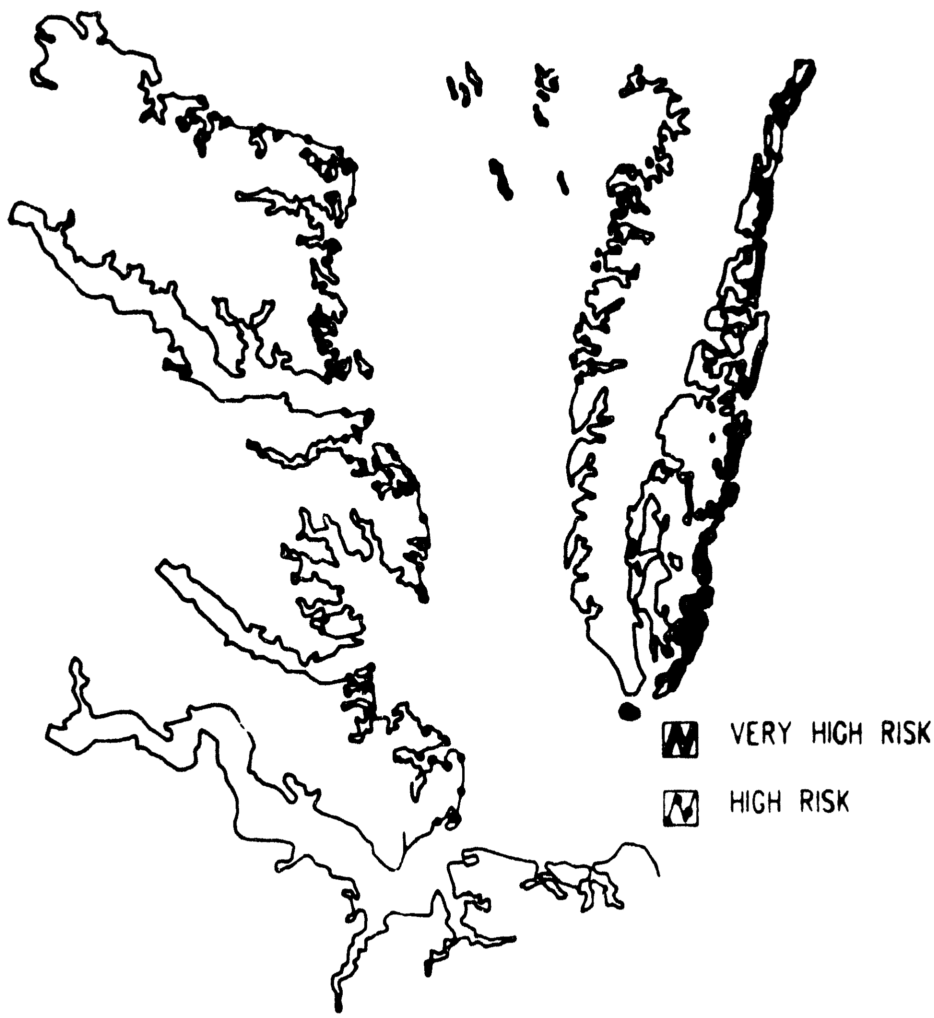

Figure 3. The southern half of Chesapeake Bay, showing very high and high risk coastal segments, based upon the criteria discussed in the text for four components of the data base.

Peninsula fall into the very high risk category, as defined above. The southwest shore of Chesapeake Bay, to Northumberland Co., VA; Tangier Island, and Crisfield, MD are all at high risk. Other very high risk shorelines along the East Coast (not illustrated) include southern NJ, Cape Hatteras and the outer banks of NC, portions of the South Carolina-Georgia coast, Jupiter Island, FL and parts of South Florida.

SUMMARY AND CONCLUSIONS

This report has outlined the preliminary stages in the compilation and development of a global coastal hazards data base, designed to identify high risk shorelines in the face of future sea level rise, in terms of vulnerability to both inundation and erosion, and to establish priorities for more detailed studies at higher resolution. Furthermore, this data can contribute to programs monitoring global environmental change, such as the International Geosphere-Biosphere Program. Because of the intended global coverage, the resolution is relatively coarse. However, the approach outlined here can be adapted to serve local planners by scaling to higher resolution.

Summaries are presented for coastal relief, lithologic types and landforms, relative sea level changes, tide ranges and wave heights. Mean differences in these coastal properties, for the U.S., are attributed to fundamental differences in plate tectonic settings (Inman and Nordstrom, 1971). Mean elevations, even at the relatively coarse spatial resolution of 0.25' vary sufficiently to distinguish among geomorphologic/geologic environments.

Methods of averaging or smoothing data over longer segments are being implemented. Each variable is assigned a rank, ranging from 1 to 5, based on the relative risk factor. These risk factors are then combined into an overall coastal vulnerability index, CVI. Although implementation of the CVI is still incomplete, preliminary results, from consideration of individual variables suggest that the areas most subject to inundation in the U.S. include: 1) the Louisiana-Texas Coast, 2) southern Florida-Everglades, 3) portions of Chesapeake Bay and the North Carolina Outer Banks, 4) the North Slope of Alaska, and 5) the Stockton-Sacramento area, east of San Francisco Bay, CA. The latter area, although situated well inland, is at or close to sea level, and is connected to San Francisco Bay by the Sacramento and San Joaquin Rivers, and by canals. Even if not directly inundated, the agricultural potential of this valley could be adversely impacted by increased salinization due to salt water intrusion.

Of the areas at high risk to inundation because of low relief, the Louisiana-Texas coast is additionally vulnerable because of anomalously high subsidence rates in part due to oil, gas, groundwater withdrawal (Garbysch, 1984), and to high beach erosion rates. The Cape Hatteras area is additionally at risk to erosion because of relatively high wave heights. The Everglades, although very low-lying, are not subsiding substantially. Furthermore, they can be expected to undergo less erosion because of the protective mangrove vegetation (Kelletat, 1989), and the low wave-energy and microtidal environment. As these preliminary findings suggest, application of the CVI to low elevation areas should enable further discrimination based upon these other factors.

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VULNERABILITY OF THE U.S. TO FUTURE SEA LEVEL RISE

Vivien Gornitz,[1] Tammy W. White,[2] Robert M. Cushman[3]

ABSTRACT

The differential vulnerability of the conterminous United States to future sea level rise from greenhouse climate warming is assessed, using a coastal hazards data base. This data base contains information on seven variables relating to inundation and erosion risks. High risk shorelines are characterized by low relief, erodible substrate, subsidence, shoreline retreat, and high wave/tide energies.

Very high risk shorelines on the Atlantic Coast (Coastal Vulnerability Index ≥ 33.0) include the outer coast of the Delmarva Peninsula, northern Cape Hatteras, and segments of New Jersey, Georgia and South Carolina. Louisiana and sections of Texas are potentially the most vulnerable, due to anomalously high relative sea level rise and erosion, coupled with low elevation and mobile sediments. Although the Pacific Coast is generally the least vulnerable, because of its rugged relief and erosion-resistant substrate, the high geographic variability leads to several exceptions, such as the San Joaquin-Sacramento Delta area, the barrier beaches of Oregon and Washington, and parts of the Puget Sound Lowlands.

INTRODUCTION

Projected sea level rise, based on models of greenhouse climate warming, could reach 0.66 m by the year 2100 (Warrick and Oerlemans, 1990), which would represent an increase of up to 7 times present rates. Locally, increases could be still greater, depending on land subsidence factors.

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Potential impacts of this accelerated sea level rise (SLR) include inundation, increased shoreline retreat, and saltwater intrusion into coastal aquifers and estuaries. The coastal zone will be permanently inundated to an elevation equivalent to the vertical rise in sea level. However, episodic flooding from storm waves and high surges could penetrate much further inland. Enhanced erosion rates would threaten beaches and coastal structures. Finally, increasing salinization of coastal aquifers, and upstream penetration of saltwater resulting from the SLR, could contaminate drinking water supplies and adversely affect agriculture. The effects of the global SLR on the shoreline will be spatially nonuniform because of the presence of local vertical crustal movements, differential resistance to erosion, varying wave climates and longshore currents.

The coastal hazards data base is designed to evaluate the differential vulnerability of shorelines to inundation and erosion, on regional to global scales, and to classify and map the spatial distributions of high-risk coasts, in order to screen out targets for more detailed study.

The data base integrates information on seven variables, including: (1) relief (elevation), (2) lithology (rock type), (3) coastal landforms geomorphology, (4) vertical land movements (relative sea level changes), (5) horizontal shoreline changes (erosion and accretion), (6) tidal ranges, and (7) wave heights. Although not specifically dealt with here, data on storm frequency and intensity have been compiled independently (Birdwell and Daniels, 1991). Storm surges and sediment transport, although also important factors, have not been included at the present time. However, as the data are incorporated into a Geographic Informations System (GIS), these layers can be added as information becomes available. The GIS approach also allows eventual integration with other climatological and socioeconomic data sets.

Climate change will also affect such variables as winds, waves and storm surges. For example, hurricane intensity may increase in a double - CO_2 world (Emanuel, 1987). Because of the complexity of modeling the response of these variables to climate change, the determination of their effects on the relative vulnerability of coastal areas lies outside the scope of this paper. However, any detrimental consequences will only be exacerbated by rising sea levels.

This paper briefly discusses the development of the data base for the conterminous United States. Results for the individual variables are summarized for each coast. The application of the Coastal Vulnerability Index (CVI) to the U.S. Atlantic Coast is illustrated as a test case. Extension of the CVI analysis to the Gulf and Pacific Coasts is still in progress, and the procedures are being refined. Thus the outline presented here serves as a demonstration of the approach rather than a final assessment.

DATA BASE COMPONENTS AND RISK CLASSES

A vulnerable coastline is characterized by low coastal relief, an erodible substrate (e.g. sand, unconsolidated sediment), present and past evidence of subsidence, extensive shoreline retreat and high wave/tide energies. The rationale for the ranking scheme is summarized in the following paragraphs.

Among the variables considered here, relief and vertical land movements (particularly subsidence), are primarily indicators of inundation risk. The average elevation of 5' latitude-longitude land data points (from ETOPO5 Gridded World Elevations, National Geophysical Data Center, Boulder, CO) aggregated into 1/4° coastal cells, provides an approximate measure of inundation, appropriate for a global scale. While the elevation zone within 1 m faces the highest probability of permanent inundation, the coastal strip within 5 m of present SL is also at high risk to above normal tides from severe storm surges. The hazard decreases progressively for higher average elevations (Table 1).

Table 1. Coastal Risk Classes

RANK	Very Low	Low	Moderate	High	Very high risk
VARIABLE	1	2	3	4	5
Relief (m)	≥ 30.1	20.1-30.0	10.1-20.0	5.1-10.0	0-5.0
Rock type (relative resistance to erosion)	Plutonic Volcanic (lava) High-medium grade metamorphics	Low-grade metamor. Sandstone and conglomerate (well-cemented)	Most sedimentary rocks	Coarse and/or poorly-sorted unconsolidated sediments	Fine unconsolidated sediment Volcanic ash
Landform	Rocky, cliffed Coasts Fiords Fiards	Medium cliffs Indented coasts	Low cliffs Glacial drift Salt marsh Coral Reefs Mangrove	Beaches (pebbles) Estuary Lagoon Alluvial plains	Barrier beaches Beaches (sand) Mudflats Deltas
Vertical movement (RSL change) (mm/yr)	≤ -1.1 Land rising ←	-1.0 - 0.99 ———	1.0 - 2.0 within range of eustatic rise	2.1 - 4.0 — Land sinking —	≥ 4.1 ——→
Shoreline displacement (m/yr)	≥ 2.1 Accretion ←	1.0 - 2.0 ———	-1.0 - +1.0 Stable	-1.1 - -2.0 ———	≤ -2.0 → Erosion
Tidal Range m (mean)	≤ 0.99 Microtidal ←	1.0 - 1.9 ———	2.0 - 4.0 Mesotidal	4.1 - 6.0 ———	≥ 6.1 → Macrotidal
Wave height, m (max.)	0 - 2.9	3.0 - 4.9	5.0 - 5.9	6.0 - 6.9	≥ 7.0

Vertical land movements for the U.S. are deduced from relative sea level trends, from a network of 76 stations (Lyles et al., 1987; Pugh et al., 1987). The relative sea level (RSL) change at each locality is a composite of the eustatic component (1-2 mm/yr; Gornitz and Lebedeff, 1987; Peltier and Tushingham, 1989), as well as other vertical land motions. Subsiding areas, or those with RSL in excess of the eustatic range (>2 mm/yr), regardless of ultimate cause, face greater inundation hazards (Table 1).

The other variables of the data base are associated with erodibility risk. Bedrock lithology, shore materials, and coastal landforms vary substantially in their resistance to erosion. A generalized scale of lithologic and geomorphologic resistance to erosion is discussed in Gornitz and Kanciruk (1989). Because these factors are difficult to quantify, they are ranked into classes of increasing risk (Table 1).

Digitized historical U.S. shoreline changes, are derived from the CEIS data base (Dolan et al., 1983, 1990). Rates within ± 1 m lie within the measurement error and are considered at relatively low risk. Shores with rates of - 1 m/yr or less (more negative) are eroding, and at relatively higher risk (Table 1). Conversely, shores with rates > + 1 m/yr are accreting, and at correspondingly low risk.

Waves and tidal currents actively transform the shoreline. Wave heights are proportional to the square root of wave energy, which is a measure of the capacity for erosion. U.S. wave data come from the Wave Information Study (WIS), U.S. Army Corps of Engineers (Jensen, 1983; Corson et al., 1987; Hubertz and Brooks, 1989). (The ranks assigned in Table 1 are based on maximum significant wave heights).

The tidal range is linked to both inundation and erosion hazards. Although a large tidal range dissipates wave energy, limiting active erosion to high tide, it also delineates a broad intertidal zone, susceptible to permanent inundation following SLR. Furthermore, the velocity of tidal currents in estuaries is proportional to the tidal range (Pethick, 1984). Therefore, other factors remaining constant, high tidal range is associated with stronger tidal currents, capable of eroding and transporting sediment. Therefore, macrotidal coasts (>4 m) will be more vulnerable than those with lesser ranges (Table 1). Tide range data are listed in the annual Tide Tables (NOS, 1988).

COASTAL VULNERABILITY INDEX

Because the data base comprises qualitative, as well as quantitative information, at different scales and units, each variable for each coastal segment has been assigned a rank from 1 to 5, with 5 representing the most vulnerable class (highest risk; Table 1). These individual risk classes can then be combined into a Coastal Vulnerability Index, CVI which can be computed as either the sum or product of the variables. The product has the advantage of expanding the range of values. On the other hand, it may be quite sensitive to small changes in individual ranking factors. Therefore, it may be necessary to introduce a factor to dampen the extreme range. For the purposes of this paper, the CVI is taken as the square root of the geometric mean, or the square root of the product of the ranking factors, divided by the number of variables present.

$$CVI = [1/n\ (a_1 \times a_2 \times ...a_n)]^{1/2} \qquad (1)$$

where a_i = variable and n = total number of variables present.

The total range of CVI was divided into four equal parts, and the upper quarter, or CVI ≥ 33.0 was taken as "very high risk coastline."

DATA ENTRY INTO THE GEOGRAPHIC INFORMATION SYSTEM (GIS)

The ARC/INFO GIS (ESRI, Inc.) software at ORNL can relate and manipulate data in various formats and spatial resolutions, such as (1) point data (e.g. tide-gauge stations), (2) line or arc data (lithology, landforms, waves), (3) polygons or cells (relief, shoreline displacements; Gornitz and Kanciruk, 1989). Each variable forms a feature class (coverage), which can be displayed graphically. Individual feature classes can be superposed, and areas with a common set of attributes can be identified.

COMPARISON OF U.S. COASTS

Atlantic Coast

Elevations along the Atlantic Coast range from 144 m in Maine to ~0 m along barrier beaches. Around 33.0% of the land lies within 5 m of sea level, and 55.6% lies within 10 m* (Table 2).

Table 2. Summary of Elevation Data for the U.S.

Relief (m)	≥ 30.1	20.1-30.0	10.1-20.0	5.1-10.0	0-5.0
East Coast	19.3%	10.0	15.1	22.6	33.0
Gulf Coast	4.2	4.0	9.8	23.9	58.1
West Coast	85.3	4.2	3.6	2.6	4.2

*In terms of the population of 5' cells

Estuaries represent the dominant landform along the Atlantic Coast (41.9% of the shorelength), followed by barrier coasts (18.2%) and lagoons (15.3%). Rocky, glaciated coasts occupy 12.3% of the shore, while glacial deposits form 6.0% (Gornitz, 1990). The East Coast, south of New England, lies on poorly consolidated to unconsolidated Mesozoic to Holocene Coastal Plains sediments. Long Island, like Cape Cod, is formed largely of glacial moraine and outwash deposits. While unconsolidated sediments underlie only 24% of the New England shoreline, they constitute ~90% of the Coastal Plains, south of New England (the remainder is mainly limestone, in Florida).

Around two-thirds of the Atlantic Coast is relatively stable (shoreline displacement within ± 1 m), with 25.2% eroding and 7.7% accreting (based upon shorelength for which data are available). However, erosion rates are extremely variable, particularly near tidal inlets. High erosion (more than 2 m/yr) affects parts of Long Island, New York, central New Jersey, and especially the Atlantic shore of Maryland-Virginia, where several barrier islands are retreating at rates exceeding 10 m/yr. Other highly eroding coasts include northern Cape Hatteras and parts of Georgia South Carolina (Gornitz, 1990; Dolan et al., 1989). In contrast, erosion rates in South Florida are relatively low, except between the St. Lucie and Jupiter Inlets (average erosion rate - 1.8 m/yr).

The entire Atlantic Coast is subsiding. Rates of relative sea level rise exceeding 2 mm/yr affect 89.0% of the region. The mid-Atlantic region is characterized by above average rates of sea level rise (> 3 mm/yr). These rates are 1.5-2 times the global eustatic range of 1-2 mm/yr. Around half of the sea level rise can be attributed to continuing glacial-isostatic subsidence of the peripheral bulge (Peltier, 1986, Gornitz and Seeber, 1990).

Mean tidal ranges decrease progressively southward from northern Maine to Chesapeake Bay. The Chesapeake Bay estuary lies in a microtidal (<2 m) environment, in spite of the highly indented shoreline. Mesotidal (2-4 m) conditions prevail in Georgia, becoming microtidal further south, especially in southern Florida.

The highest regional maximum significant wave heights occur on the exposed Cape Hatteras (5.9 m), southern Cape Cod (5.2 m) and the southern Delmarva Peninsula (5.2 m). The lowest waves appear south of Miami, Florida (2.4 m).

The Coastal Vulnerability Index, CVI, is calculated for the Atlantic Coast, according to (1). Values of CVI for the East Coast range between 1.79 and 46.29. Around 4% of the East Coast shoreline, predominantly along the outer barriers, has a CVI score of 33.0 or greater ("very high risk" coastline). The median value is 10.12, while the upper and lower quartiles are 15.12 and 6.87, respectively. Figure 1a-d shows the distribution of CVI values ≥ 33.0 for four representative areas of the East Coast (Cape Cod, the mid-Atlantic region, Cape Hatteras, and southern Florida). Other "very high risk" coasts, not shown in Fig. 1 include Jones Beach, Long Island, and segments of the coast between Wilmington, North Carolina, south to Jacksonville, Florida.

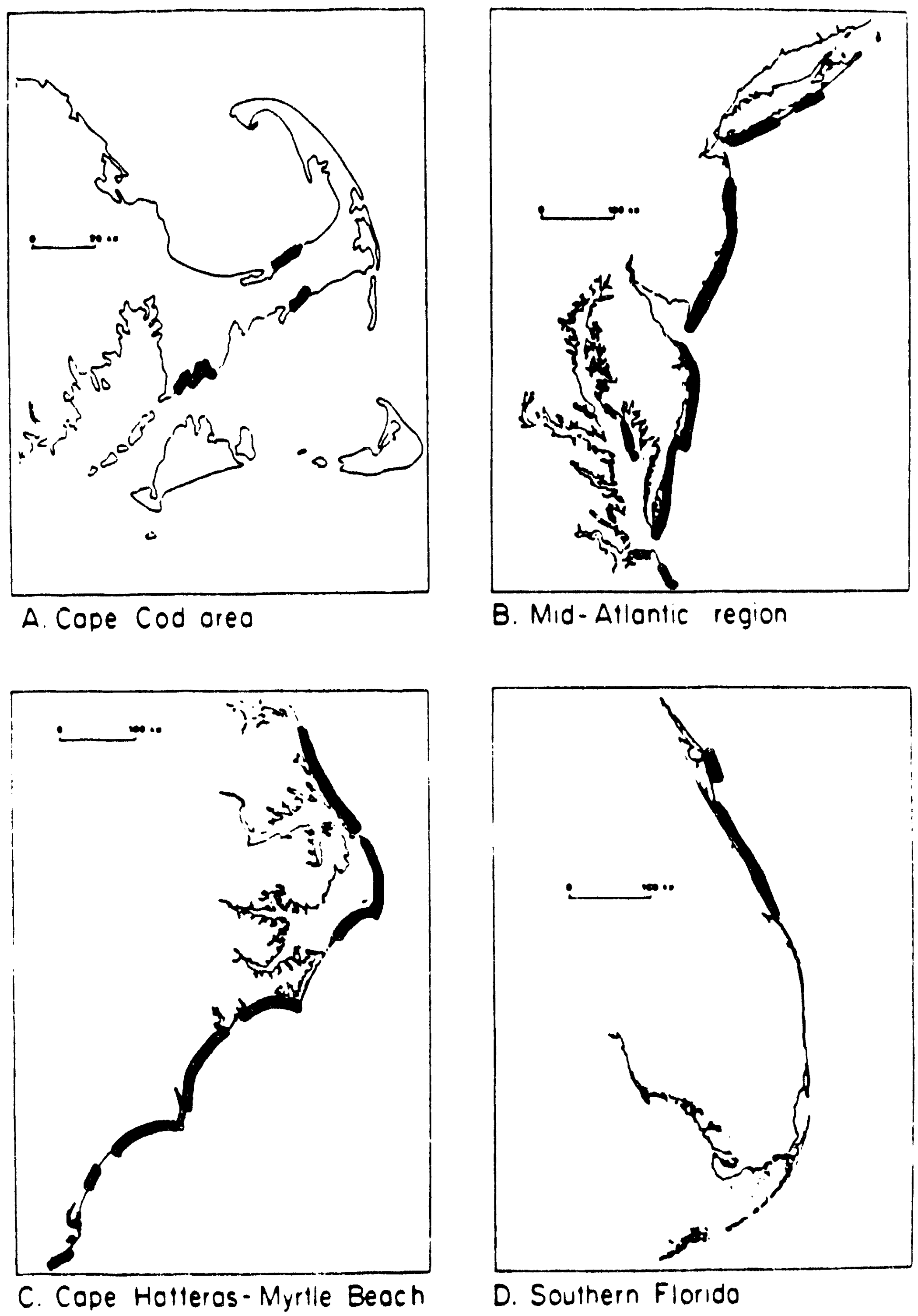

Figure 1. Distribution of CVI values greater than or equal to 33.0 (heavy line).

Gulf Coast

The Gulf Coast is generally low-lying. The maximum elevation is 90 m. Around 58% of the coast lies within 5 m, and 82% within 10 m of sea level (Table 2).

The Texas coast is characterized by barrier-lagoon complexes, including estuarine bays. The chenier plains of western Louisiana grade eastward into deltaic plains, with some outlying barrier islands that are the eroded remnants of abandoned and submerged deltaic lobes (Penland et al., 1981). Eastward, barrier-lagoon complexes extend into northwest Florida. The west coast of Florida includes mangroves, reefs, as well as barrier systems. With the exception of some limestone outcrops in Florida, the rest of the Gulf Coast is underlain by Quaternary to Holocene unconsolidated sediments. In terms of the risk classification (Table 1), all Gulf landforms fall into classes 3-5, and rock types in classes 4-5, with a fairly high proportion, in each case, lying in class 5.

Nearly half of the Gulf Coast is eroding, with 40% retreating at rates greater than 2 m/yr. Around 47% is stable, and only 4% accreting. The most severe erosion (rates > 8 to 10 m/yr) occurs on the Louisiana barrier islands (see also Ritchie and Penland, 1989; Dolan et al., 1985). Other areas of high erosion include the coast northeast of Galveston Bay, southwest of Freeport, Texas and also south Padre Island, Texas.

The Gulf Coast west of the Florida Panhandle, displays the highest rates of relative sea level rise in the U.S. (Fig. 2). Sea level trends over the period 1931-1988 for 20 U.S. Army Corps of Engineers tide-gauge stations in Louisiana range between 3.4 to 17.7 mm/yr, with an average value of 8.1 mm/yr. The highest rates are associated with the delta plains (Penland and Ramsey, 1990). Rates in excess of 2 mm/yr represent land subsidence. Based on regional sea level trends (Fig. 2), nearly the entire coast falls into risk classes 4 and 5 (Table 1).

Mean tidal ranges throughout the Gulf Coast are microtidal (< 2 m), falling into risk classes 1 and 2 (Table 1). Average significant wave heights are generally under 1 m, except along the Texas coast. The regionally highest maximum significant wave heights (5.5-5.8 m) lie off the Mississippi Delta; the regionally lowest values cluster off northwest Florida. Thus wave heights fall into classes 1-3 (Table 1).

Pacific Coast

The Pacific Coast undergoes plate convergence north of the Mendocino triple junction, and transcurrent motion along the San Andreas fault, to the south. As a consequence of this tectonic activity, the relief is much greater than on either Atlantic or Gulf Coasts. Maximum elevations, near the coast, attain 1250 m (48° N, 124° W; Olympic Mts., Washington). Only 4.2% of the shore lies within 5 m of sea level; and only 6.8% lies within 10 m (Table 2).

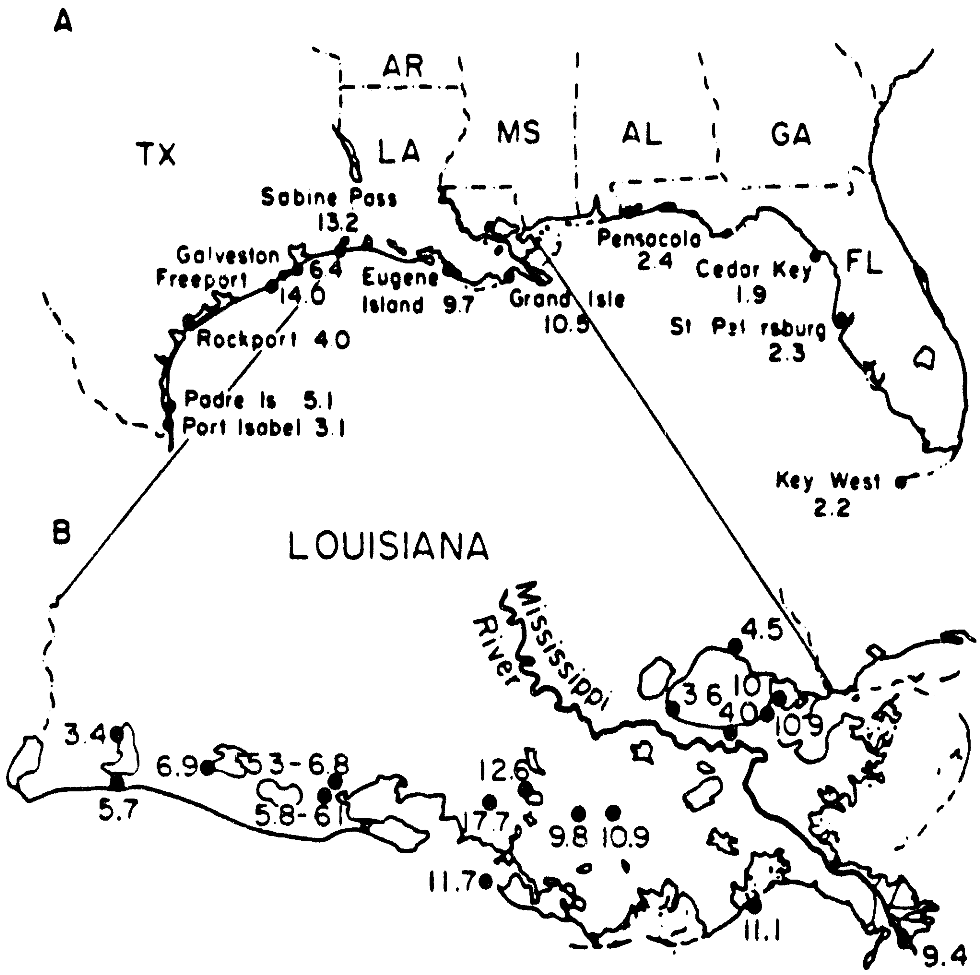

Figure 2(A). Sea level trends in mm/yr, for tide-gauge stations along the Gulf of Mexico (after Lyles et al., 1987; Pugh et al., 1987). (B). Sea level trends in mm/yr for tide-gauge stations in Louisiana (from the U.S. Army Corps of Engineers network; based on Penland and Ramsey, 1990).

Rocky or cliffed coasts, with pocket or fringing beaches, constitute the predominant landforms on the Pacific Coast. Coastal plains deposits outcrop in the Los Angeles, Ventura areas, around Monterey Bay and near Eureka, California. In the Pacific Northwest, several low-lying areas interrupt the generally cliffed coast. These include the stretch between Coos Bay and the Siuslaw River, Oregon, and Tillamook Head, northern Oregon to the Copalis River, Washington. These areas have the longest extent of barriers and lagoons on the Pacific Coast. The Puget Sound Lowlands are underlain mainly by glacial drift, and thus are potentially vulnerable to erosion (Table 1).

In view of the generally high relief and prevalence of consolidated rocks, around 83% of the Pacific Coast is relatively stable, 5.6% eroding and 11.6% accreting. In contrast to the Atlantic and Gulf Coasts, most of the barrier beaches in the Pacific Northwest, are either accreting or stable. However, pockets of intense erosion are associated with barriers or spits at Tillamook Bay (5 m/yr), Columbia Beach, Oregon (2 m/yr), Westport, Grays Harbor, Washington (3.9 m/yr). The shore between the Quinault River to Hoh Head, Washington is retreating at an average rate of 1.1 m/yr. It consists of low to medium cliffs cut into Tertiary continental and marine sediments, overlain by Quaternary glacial deposits. South of the Mendocino triple junction, sea levels are generally rising at rates comparable to the eustatic rise (av. 1.5 ± 0.5 mm/yr, N=8). To the north, negative sea level trends along the outer coast (Crescent City, CA to Neah Bay, WA) indicate land emergence, while positive trends (Seattle, 2 mm/yr; Friday Harbor, 1.4 mm/yr) show submergence of the Puget Lowland. Sea level data are consistent with eastward tilting of the Oregon and Washington Coast Ranges, attributed to continuing subduction of the Juan de Fuca plate (Ando and Balazs, 1979). However, more recent geodetic leveling surveys suggest a more complex situation. Although the area around Neah Bay, Washington (west) is uplifting with respect to Seattle (east), the outer coast subsides toward the south, around Grays Harbor WA, and then rises further south toward Astoria (Holdahl et al., 1989; Shipman, 1990).

Microtidal environments (< 2 m mean tidal range) are prevalent along the open coast. However, in major embayments, such as Puget Sound, the mean tidal range can exceed 3 m. In general, maximum wave heights are greater that along either the Atlantic or Gulf Coasts. The coast between southern Oregon and Pt. Delgada, CA has maximum wave heights over 7.5 m.

DISCUSSION

Examination of individual data base components suggests that Louisiana and parts of Texas, on the Gulf Coast, will rank among the most highly vulnerable shorelines in the conterminous United States. Most of the Gulf Coast is characterized by low elevation (Table 2), presence of unconsolidated sediments, and unstable landforms. Around 40% of the Coast is retreating at rates greater than 2 m/yr, with the most severe erosion concentrated along the Louisiana barrier islands. These barrier islands are not just migrating landward; they are decreasing in area as well. For example, between 1890 and 1979, the Louisiana barriers decreased in area by 37%, from 92 to 58 square kilometers. Between 1887 to 1985, the Isles Dernieres, along the central Louisiana coast, shrank by 63%, from 48 to 18 square kilometers (Sallenger et al., 1987).

Louisiana is also subject to the highest rates of relative sea level rise in the nation (Figure 2). The state-wide average sea level rise of 8 mm/yr can be attributed to a combination of factors in addition to the eustatic rise, including compaction of Holocene deltaic sediments, subsurface fluid withdrawal (oil, gas, water), sediment deposition in upstream dams, and channel dredging (Penland and Ramsey, 1990; Boesch et al., 1983). The anomalous subsidence is largely anthropogenic in origin: late Holocene (< 3000 years BP) rates average ~3 mm/yr; the phase of rapid increase only began around 150 years ago (see Fig. 57, Penland et al., 1988). The high subsidence and erosion rates have resulted in land loss rates of over 102 km^2/yr in the Mississippi delta plain (Gagliano et al., 1981).

Extensive portions of the Atlantic Coastal Plains, particularly along the outer barriers, are also highly vulnerable (Fig. 1; also parts of South Carolina - Georgia; not illustrated). In South Florida, however, the combination of relatively low erosion rates, microtidal and low wave energy environments leads to an apparently lower vulnerability rating than for the above-mentioned areas.

Incorporation of information on storm frequencies or surges, and population densities into the CVI could lead to revision of this vulnerablility assessment. For example, southern Florida has a 12-14% probability of experiencing a hurricane (winds > 119 km/yr) in any given year, as compared to a 12-16.5% probability along Cape Hatteras. While these probabilities are roughly comparable, the area at risk is much more extensive in southern Florida (Birdwell and Daniels, 1991). Florida has the highest shoreline density (coastal population of each state divided by the tidal shorelength) south of New Jersey (Culliton et al., 1990; Table 3). Thus, if these two additional risk factors are included, Florida could rank ahead of the other high risk areas on the East Coast. California, because of the high degree of urbanization, also ranks high in terms of exposed population (Table 3).

Table 3. Coastal Population Density per Shoreline Length

State or Region	Population Density/Shoreline Mile	Population Density/ Shoreline Kilometer
ATLANTIC COAST		
New England (av.)	2,306	1,433
New York	6,738	4,188
New Jersey	3,898	2,423
Delaware	1,733	1,077
Maryland	1,027	638
Virginia	1,133	704

North Carolina	202	126
South Carolina	303	188
Georgia	158	98
Florida	2,075	1,290
WT. AV.	2,330	1,448
GULF COAST		
Florida	1,064	661
Alabama	800	497
Mississippi	928	577
Louisiana	352	219
Texas	1,517	943
WT. AV.	820	510
PACIFIC COAST		
California	6,551	4,071
Oregon	1,140	709
Washington	1,163	723
WT. AV.	3,191	1,983

The Pacific Coast is the least vulnerable, because of its high relief (only 6.8% less than 10 m), resistant lithologies, cliffs, low erosion rates, and moderately low to negative sea level trends. However, the relief and relative resistance to erosion are highly variable, because of the complex tectonic history. Low-lying areas, such as the San Joaquin-Sacramento Delta, east of San Francisco Bay, face potential inundation hazards, if sea level rises. In addition, the agricultural potential of this valley could be adversely affected by increased salinization due to saltwater intrusion. Although the barrier beaches of Oregon and Washington are for the most part either stable or accreting, at present, these areas risk future inundation and increased erosion.

SUMMARY AND CONCLUSIONS

The differential vulnerability of the conterminous United States to future sea level rise is assessed. Highly vulnerable sections of the U.S. Atlantic Coast (CVI $\geq$ 33.0, "very high risk") include the outer coast of the Delmarva Peninsula, northern Cape Hatteras, parts of New Jersey (Fig. 1), Georgia and South Carolina. The apparently lower vulnerability rating of south Florida could increase if additional risk factors, such as storm frequency and population diversity were considered.

Louisiana and parts of Texas are potentially the most vulnerable shorelines in the United States. In this region, at least five out of the seven variables considered here fall into the "high" to "very high" risk classes. In particular, Louisiana is characterized by anomolously high rates of relative sea level rise (Fig. 2; Penland and Ramsey, 1990). The state-wide average sea level rise of 8 mm/yr is close to that projected globally for year 2100 due to greenhouse-induced climate warming (Warrick and Oerlemans, 1990). Therefore, the present situation in Louisiana anticipates conditions that could occur worldwide along highly vulnerable coastlines in the near future.

Although the rugged relief, and erosion-resistant substrate reduce the overall vulnerability rating of the Pacific Coast, the highly variable topography and geologic/geomorphologic setting provide numerous exceptions. Some examples include the low-lying San Joaquin-Sacramento Delta area, some deltas and estuaries in the Puget Sound Lowlands, and the barrier beaches of Oregon and Washington.

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