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THE GLOBAL COASTAL HAZARDS DATA BASE

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ABSTRACT

A rise of sea level between 0.5 and 1.5 m, caused by predicted climate warming in the next century, could jeopardize low-lying radioactive waste disposal sites near the coast, due to permanent and episodic inundation, increased shoreline retreat, and changes in the water table. The effects of global sea level rise on the shoreline will not be spatially uniform. Therefore, site selection will depend on assessment of these differential vulnerabilities, in order to avoid high-risk coasts. The coastal hazards data base described here could provide an appropriate framework.

The coastal hazards data base integrates relevant topographic, geologic, geomorphologic, erosional and subsidence information in a Geographic Information System (GIS), to identify high-risk shorelines characterized by: 1) low coastal 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.

Data for seven variables relating to inundation and erosion hazards are incorporated into the ORNL ARC/INFO Geographic Information System (GIS). These include: 1) elevation (relief), 2) bedrock geology, 3) geomorphology (coastal landforms), 4) vertical movements (relative sea level changes), 5) horizontal shoreline movements (erosion or accretion), 6) tidal ranges, and 7) wave heights. Data compilation has been completed for the U.S. and is being extended to North America, and ultimately the world. A coastal vulnerability index (CVI) has been designed to flag high risk coastal segments. Each coastal variable is ranked, based on relative risk. The individually ranked components are then overlaid in the GIS, and a composite rank or score determines the final risk factor.

The physical data collected for this study can eventually be integrated with socio-economic factors for policy development on a national to international level. The high-risk coastal segments found here can be used to establish priorities for higher resolution studies.

1. Introduction

The greenhouse climate warming is expected to lead to a sea level rise of between 50 and 150 cm within the next century, at rates exceeding current trends by a factor of 10 (Hoffman et al., 1986; NRC, 1987). The impacts of this accelerated sea level rise (SLR) on radioactive waste disposal sites near the shore arise from inundation, increased shoreline retreat, and changes in the water table. Permanent inundation will affect the coastal zone inland, to an elevation equivalent to the vertical rise in sea level. In addition, episodic flooding from storm waves and high surges could penetrate further inland. Coastal erosion could also leave a waste site under water, or subjected to continual wave attack. Finally, increasing water tables, resulting from the SLR, could threaten containment vessels, by exerting additional hydrostatic pressure.

The effects of the global SLR on the shoreline will be spatially non-uniform because of the presence of local vertical crustal movements, differential resistance to erosion, varying wave climates and longshore currents. In selecting nuclear waste disposal sites near the coast, it is vital to evaluate these differential vulnerabilities, and to avoid high-risk coasts. The coastal hazards data base described below (Gornitz and Kanciruk, 1989) could provide a relevant framework for site selection. Problems of tectonic stability or suitable bedrock geology are addressed indirectly, through consideration of vertical movements, coastal lithology and landforms.

2. Survey of Data Base Components

The coastal hazards data base integrates information on seven variables relating to inundation and erosion hazards, in order to screen out high-risk shorelines characterized by: 1) low coastal 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.

The data are incorporated into the Oak Ridge National Laboratory (ORNL) ARC/INFO Geographic Information System (GIS). Data compilation has been completed for the U.S., with ultimate global coverage planned. Storm frequency data, economic and demographic factors are not presently considered, but can be added later to the GIS.

The variables discussed here are associated with two types of coastal hazard: 1) inundation, both permanent and episodic, and 2) erosion. They include: 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, and 7) wave heights.

Coastal relief, or elevation, provides an indication 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). Worldwide coverage at higher resolution is incomplete.

Lithology, as an indicator of resistance to erosion, is interpreted from geologic maps. A simplified geologic classification differentiates between resistant crystalline rocks, sedimentary rocks, and unconsolidated sediments (Table 1). Each rock type is assigned a 3-digit code.

Coastal landforms are interpreted and classified from topographic maps, generally at a scale of 1:250,000. This scale represents a compromise between completeness of international coverage at a uniform scale, and the ability to identify coastal landforms. The present classification system divides coasts into those formed by erosion (marine, non-marine), and by deposition (marine, non-marine). Each class is assigned a four-digit code (Fig. 1). The last digit designates shore features that exist in to more than one environment (i.e. beach, or salt marsh).

Records of relative 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. The relative sea level change at each locality includes the eustatic component (around 1-2 mm/yr, Gornitz and Lebedeff, 1987; Barnett, 1984; Peltier and Tushingham, 1989), 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).

Recent worldwide coastline erosion trends have been summarized (Bird, 1985). For most places, only qualitative information exists. Quantitative data for most of the U.S., at 3' resolution are incorporated into the CEIS Data Base (Dolan et al., 1983). Coastal Zone '89 presents additional measurements for the U.S. The CORINE project has assembled qualitative erosion data for 11 European community countries (Quelennec, 1989).

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. Phase II data, at 30 n. mi spacing, exist for Southern California (Corson et al., 1987), and the Gulf of Mexico (Hubertz and Brooks, 1989). Phase III data (~10 mi) exist for 166 stations along the East Coast, and 134 stations along the West Coast (Jensen, 1983). The calculated 20 yr mean significant heights and maximum wave heights are used for these stations. Internationally, offshore wave data are available from the Summary of Synoptic Meteorological Observations (SSMO), Naval Weather Service, Washington, D.C.

The data base components occur 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 ARC/INFO GIS software can relate and manipulate these various formats. Each component forms a feature class (coverage), which can be displayed graphically. Different spatial projections can be transformed to the same format, individual feature classes can be superposed, and areas with a common set of attributes can be identified.

3. The Coastal Vulnerability Index

A vulnerable coastline exhibits low relief, erodible lithology or mobile landform, history of erosion, subsidence, high wave energies and/or tide ranges.

Each variable for each coastal segment is ranked from 1 to 5, with 5 representing the most vulnerable class. The rationale for the ranking scheme for each variable is now briefly reviewed (Table 2).

a. Relief (elevation) -- inundation risk

Projected sea level rise within the next 100 yrs is estimated to range between 0.5-1.5 m (NRC, 1987). Clearly, this elevation zone faces the highest probability of permanent inundation. Thus, the coastal strip within 5 m of present MSL lies at very high risk to permanent inundation, as well as above normal tides from severe storm surges. The next 10 m may be vulnerable to extreme storm events. The hazard decreases progressively for higher average elevations (Table 2).

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

The relative resistance of rocks to erosion depends on a number of factors. As a rule, consolidated sedimentary rocks are more erodible than crystalline rocks. Unconsolidated sediments show the least resistance 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.

c. Landform (geomorphology) -- erodibility risk

Landforms are the product of weathering of geologic structures. High risk landforms are mobile or unstable, hence underlain by unconsolidated material, at 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).

d. Vertical land movement (from relative sea level change) -- inundation risk

Relative SL change at each locality can be compared with the eustatic trend of 1-2 mm/yr. Stable regions have trends within 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).

e. Shoreline displacement -- erodibility risk.

Rates within ± 1m can be considered relatively 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 correspondingly higher risk (Table 2).

f. 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).

g. Wave heights -- erodibility risk

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

After each variable has been ranked, as described above, the ranks can be combined into a coastal vulnerability index, CVI. A preliminary version of the CVI is presented for the mid-Atlantic region of eastern U.S., from Long Island south to Chesapeake Bay. It provides a demonstration of the approach, rather than a final assessment. Four variables (relief, lithology, landform and shoreline change) are illustrated individually in Fig. 2 for the two highest risk categories of Table 2. The composite risk map is shown in Fig. 3.

The very high risk category (#5) comprises mean coastal relief between 0-5m, a mud, clay, silt, and sand substrate, 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 (#4) includes relief between 5-10m, consists of gravels, conglomerates, glacial till, and mixed or varied sediments, and landforms such as pebble or cobble beach, estuaries and lagoons. Mean erosion rates fall between -2.0 and -1.1 m/yr.

4. Preliminary Results

Geologically, the mid-Atlantic coastal region consists of still mostly unconsolidated Tertiary and Quaternary sediments. The ocean-facing coast is flanked by barrier island systems. This stretch of coast is indented by two major estuaries: the Delaware and Chesapeake Bays. Elevations, in general, are fairly low. Erosion rates are relatively high (Fig. 2). When these four variables are overlaid in the GIS, using the criteria discussed above, the composite map (Fig. 3) indicates very high risk areas on Fire Island, NY, parts of the New Jersey and Delaware-Virginia coasts, and segments of Chesapeake Bay.

Methods of averaging or smoothing data over longer segments are being implemented. Although implementation of the CVI is still incomplete, preliminary results for the U.S., from consideration of risk factors for individual variables, indicate 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 inland, is near sea level, and is connected to San Francisco Bay by the Sacramento and San Joaquin Rivers, and by canals. Even if protected from inundation by dikes, the agricultural potential of this valley could be negatively impacted by salinization of the groundwater.

The Louisiana-Texas coast is additionally vulnerable to flooding because of anomalously high subsidence rates (~ 10 mm/yr) caused by subsurface fluid withdrawal, and sediment deprivation due to construction of dams, levees, and channels. These factors, in turn, have led to extreme beach erosion rates (EPA, 1987). 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 may not be eroding as rapidly as other areas because of the protective mangrove vegetation (Kelletat, 1989), and the low wave-energy and microtidal environment. These preliminary findings suggest that application of the CVI to low elevation areas should enable further discrimination based upon these various factors.

5. 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. Because of the intended global coverage, the resolution is relatively coarse. However, the data base should be suitable for regional planning, providing an estimate of the magnitude of the problems and suggesting policies needed to mitigate these problems.

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7. References

Barnett, T.P., 1984: The estimation of "global" sea level change: a problem of uniqueness. J. Geophys. Res., 89, 7980-7988.

Bird, E.C.F., 1985: Coastline Changes - A Global Review, J. Wiley and Sons, Chichester, 219p.

COASTAL ZONE '89, 1989: Proc. 6th Symp., Coastal and Ocean Management, Am. Soc. Civil Eng., New York, 4971 pp.

Corson, W.D., Abel, C.E., Brooks, R.M., Farrar, P.D., Groves, B.J., Payne, J.B., McAreny, D.S. and Tracy, B.A., 1987: Pacific Coast Hindcast Phase II Wave Information. WIS Report 16, USAE, CE, Vicksburg, MS.

Dolan, R., Hayden, B. and May, S., 1983: Erosion of the U.S. shorelines, in: CRC Handbook of Coastal Processes and Erosion. P.D. Komar, ed., Chap 14, 285-299, CRC Press, Inc. Boca Raton, FL.

Environmental Protection Agency, 1987: Saving Louisiana's coastal wetlands: The need for a long-term plan of action: Report of the Louisiana Wetland Protection Panel, U.S. EPA 230-02-87-026, 109 pp.

Gornitz, V. and Kanciruk, P., 1989: Assessment of global coastal hazards from sea level rise. COASTAL ZONE '89, Proc. 6th Symp. Coastal and Ocean Management/ASCE, July 11-14, 1989, Charleston, SC, 1345-1359.

Gornitz, V. and Lebedeff, S., 1987: Global sea level changes during the past century, in Nummedal, D., Pilkey, O.H.,and Howard,J.D., eds., Sea Level Fluctuation and Coastal Evolution. SEPM Spec. Pub. No. 41, 3-15.

Hoffman, J.S., Wells, J.B. and Titus, J.G., 1986: Future global warming and sea level rise, in: G. Sigbjarnarson, ed., Proc. Iceland Coastal and River Symposium '85. Reykjavik: National Energy Authority, 245-266.

Hubertz, J.M. and Brooks, R.M., 1989: Gulf of Mexico hindcast wave information. WIS Report 18, U.S. Army Corps Engineers, Vicksburg, MS.

Jensen, R.E., 1983: Atlantic Coast hindcast, shallow water, significant wave information. WIS Report 9, USAE, WES, CE, Vicksburg, MS.

Kelletat, D., 1989: The question of "zonality" in coastal geomorphology - with tentative application along the East Coast of the USA. J. Coast. Res., 5(2), 329-344.

National Research Council, 1987: Responding to Changes in Sea Level. Engineering Implications. Washington, D.C., 148 pp.

National Ocean Service, 1988: Tide Tables 1988. NOAA, U.S. Govt. Printing Office, Washington, D.C.

Peltier, W.R. and Tushingham, A.M., 1989: Global sea level rise and the greenhouse effect: might they be connected? Science, 244, 806-810.

Pugh, D.T., Spencer, N.E. and Woodworth, P.L., 1987. Data Holdings of the Permanent Service for Mean Sea Level. Bidston Observatory, England.

Quelennec, R.E., 1989: The CORINE "Coastal Erosion Project": Identification of coastal erosion problems and data base of the littoral environment of eleven European countries. COASTAL ZONE '89, Proc. 6th Symp. Coastal and Ocean Management/ASCE, 4594-4601.

Figure Captions

Figure 1. Schematic classification of shorelines

Figure 2. Very high and high risk coastal segments for four individual variables, along the mid-Atlantic coast from Long Island, New York, south to Chesapeake Bay.

Figure 3. Very high and high risk coastal segments for the mid-Atlantic coast; composite risk map based on GIS overlay of the four individual variables shown in Fig. 2.

Tables

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

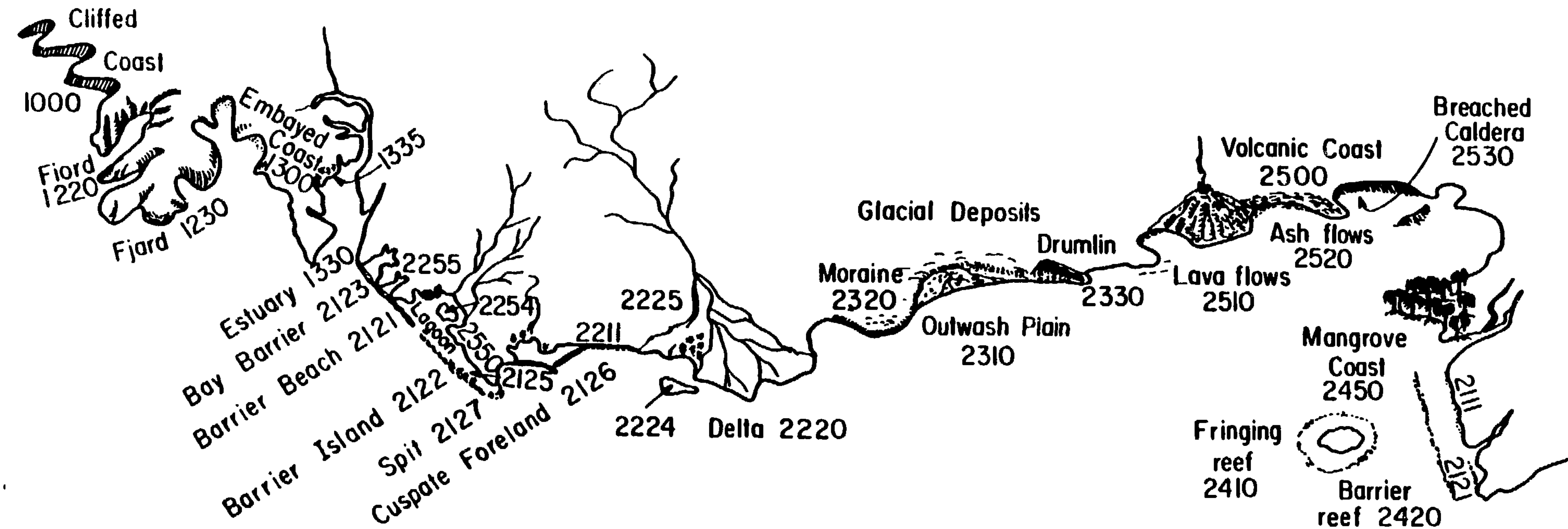
IV. VOLCANIC, Quaternary

A. Lava
B. Ash, tephra
C. Composite

V. CORAL REEF (living)

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	≥ 8.0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2254
2550
2125
2211
2225
2224
Delta 2220
Glacial Deposits
Moraine 2320
Outwash Plain 2310
Drumlin
2330
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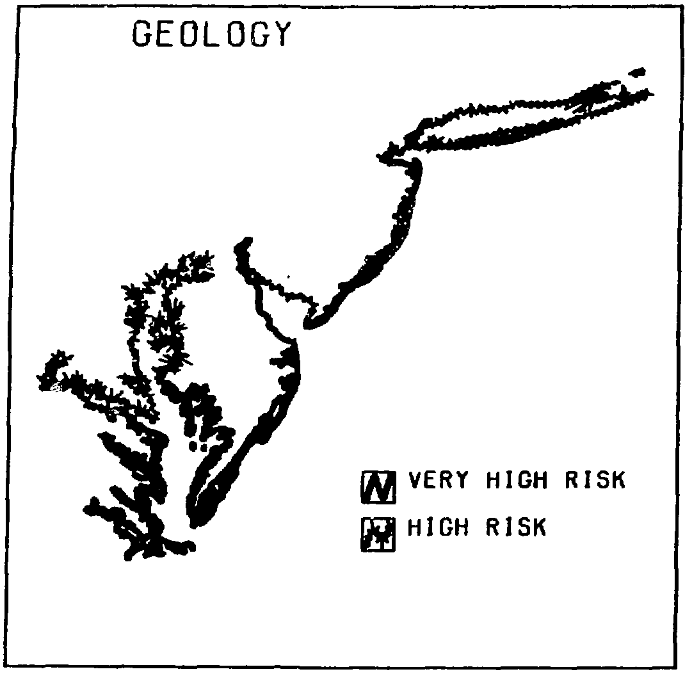
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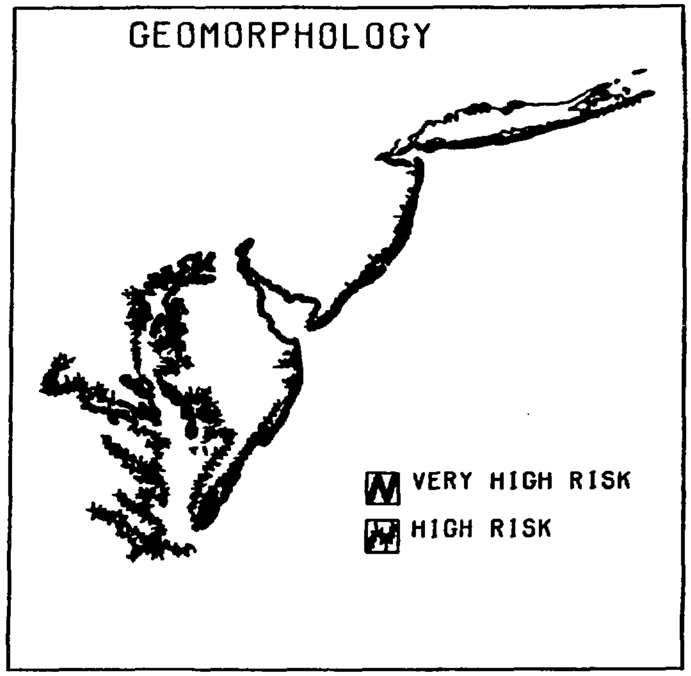
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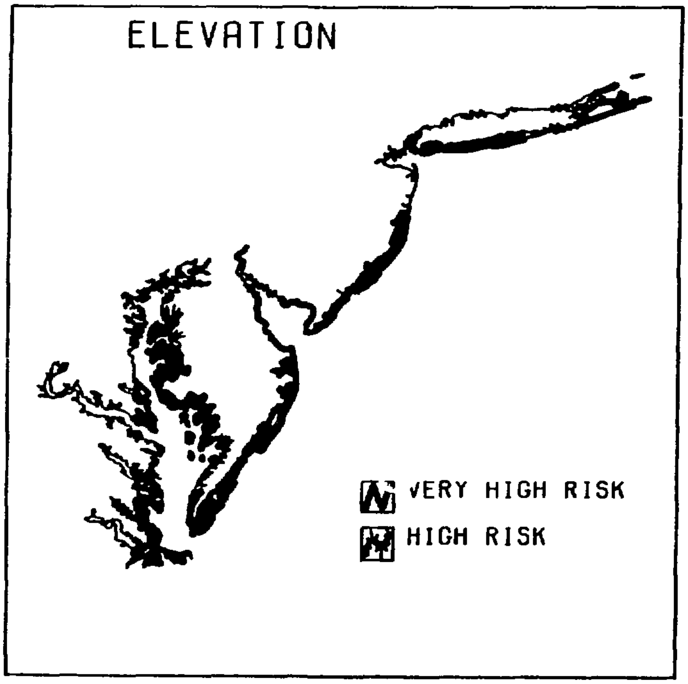
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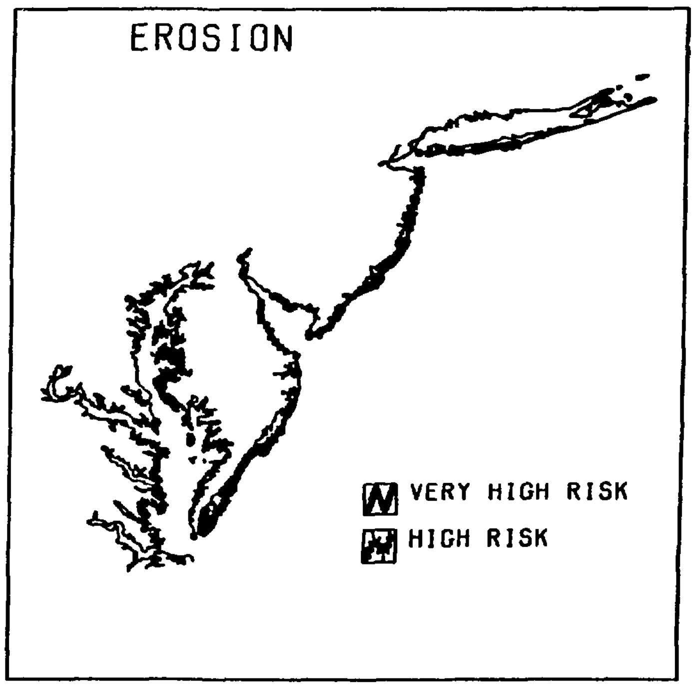
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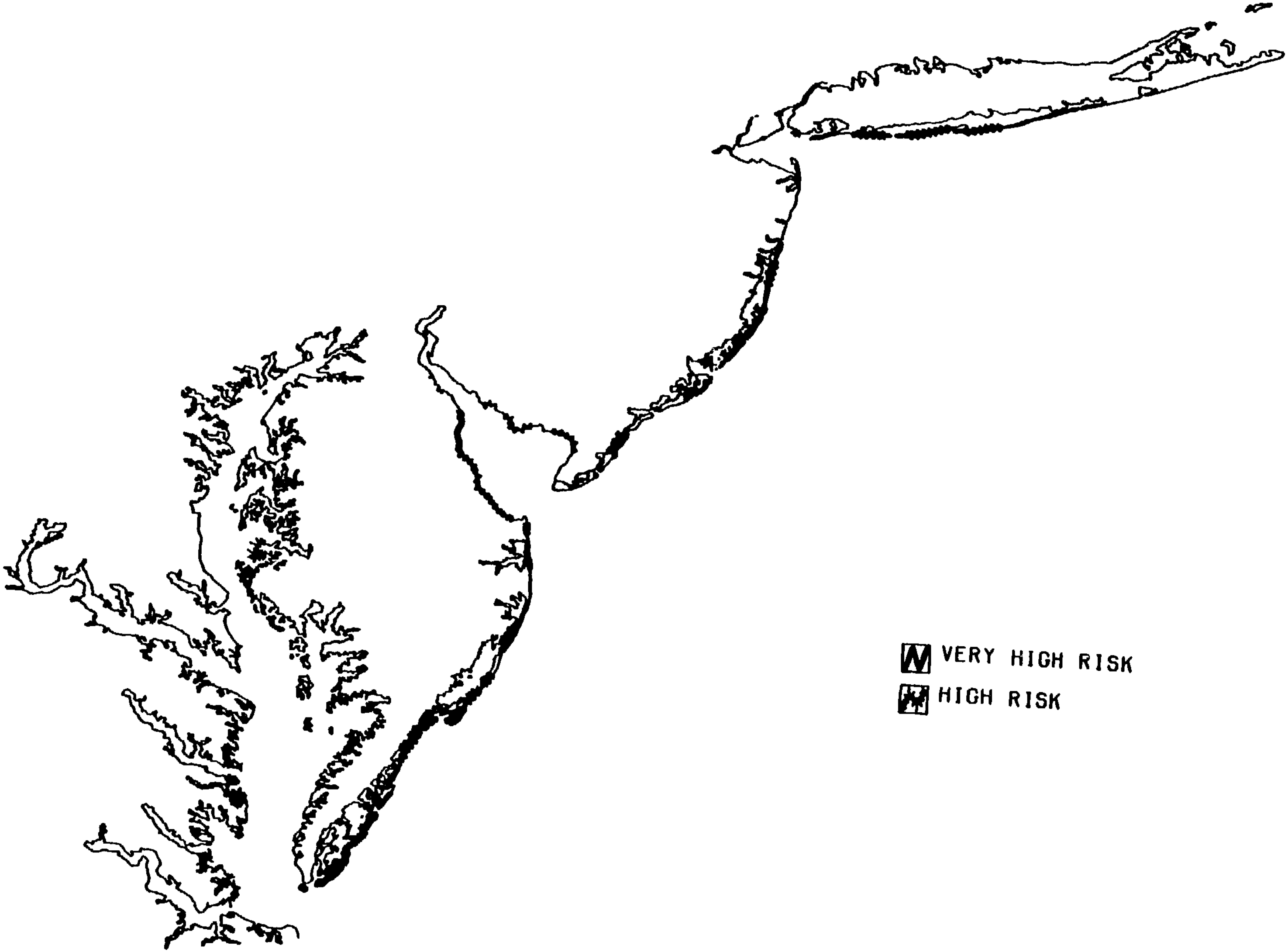
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