HURRICANE ISABEL AND SHORE EROSION CHESAPEAKE BAY, MARYLAND

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ABSTRACT

Hurricane Isabel resulted in irregular erosion of the Chesapeake Bay shoreline in Maryland. In the aftermath of the storm, the Governor's Chesapeake Bay Cabinet, concerned about environmental degradation due to the influx of sediment into the Bay, requested an estimate of sediment input from shore erosion. The Maryland Geological Survey (MGS) polled local officials and county planners throughout the State and, based on limited quantitative information, endeavored to supply that estimate.

From available photographs, MGS deduced that: (1) erosion was uneven in occurrence and amount, (2) the storm surge afforded two opportunities for erosion, once as water inundated low-lying coast lands and again as floodwaters ebbed, (3) erosion control structures commonly remained intact, but failed to prevent bank erosion, (4) the storm disrupted nearshore sedimentary structures, and (5) not all changes were erosional.

The most extensive assessment of shore erosion was conducted by Baltimore County, using aerial surveys. Erosion occurred along an estimated 18,300 ft of county shoreline, about 1.5% of the county's total shoreline length. No other county prepared as comprehensive an assessment of storm-related erosion.

To approximate the amount of sediment delivered to the Bay as a result of Isabel, MGS used the percentage of affected shoreline in Baltimore County, an assumed mean retreat of 5 ft, and an average bank height of 5 ft to estimate the area and volume of sediment lost. These figures probably overestimate losses, but they provide some indication of the impact of Isabel relative to sediment delivery during other extreme events. Extrapolating Baltimore County shoreline losses to the Western Shore of the Maryland Chesapeake Bay, MGS estimated that 20 acres of land were lost, contributing about 81,000 metric tonnes of fine-grained sediment to the Bay.

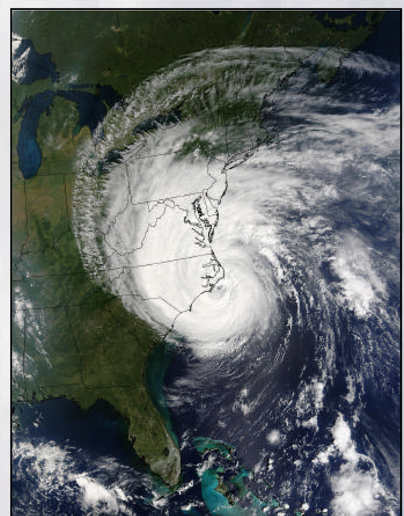
INTRODUCTION

Severe erosion threatens road. Bay Ridge, Chesapeake Bay, Anne Arundel Co. [2]

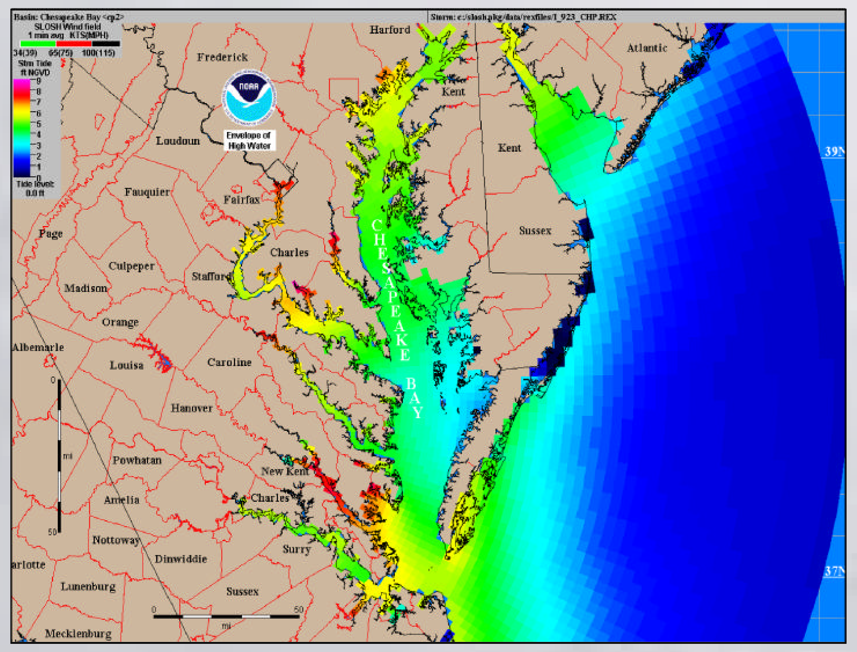
On September 18, 2003, a tropical cyclone, Isabel, made landfall as a Category 2 hurricane along the North Carolina coast. The storm then weakened and accelerated. Within 24 hours Isabel had dissipated, but not before ravaging coastal communities all along the Western Shore of Maryland's Chesapeake Bay. Shore erosion was an unmistakable and widely reported effect of Isabel's passage over the State. Damage to shoreline structures alone was assessed at $84 million [1]. Government agencies and citizens groups were concerned about the possible deleterious effects of an influx of suspended sediments and nutrients on the Bay ecosystem, particularly given the near-record extent of the summer's anoxic "dead zone." The Governor's Chesapeake Bay Cabinet requested an estimate of sediment input contributed by shore erosion. The Maryland Geological Survey (MGS) endeavored to supply that estimate.

The Storm

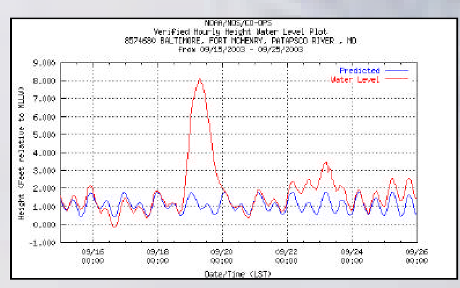
Hurricanes are distinguished by their most damaging forces, operating singly or in combination. In Maryland, Isabel will be remembered, not for its intensity or heavy rains, but for the height of its storm surge. A bulge of water generated by the hurricane's swirling winds and low pressure within the eye, the storm surge made its way from the Atlantic Ocean into the Chesapeake Bay. In the Northern Hemisphere, winds associated with tropical cyclones, including tropical storms and hurricanes, rotate counterclockwise. The most damaging winds are those found in the right front quadrant of the storm, as defined by the direction of the storm's forward movement. As Isabel, with its enormous wind field, tracked north-northwest, to the west of the Chesapeake Bay, right front quadrant winds blew from the south-southeast, pushing the storm surge up the Bay and piling it onto the Western Shore. For 88 coastal high water marks surveyed in Western Shore counties following Isabel, surge elevations ranged from 3.0 to 7.9 ft, averaging 6.5 ft [3].



Isabel at landfall. The radius of tropical storm force winds extended 345 miles from the eye [4].



Maximum water levels reached throughout the Bay over the course of the storm surge. Output from the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) computer model, run with actual storm data [5].



The storm tide exceeded 8 ft in Baltimore Harbor [6].

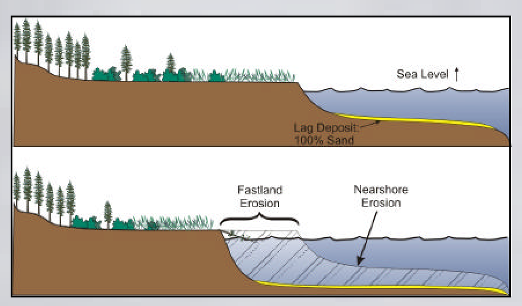
Storm surge flooding. St. George Island, Potomac R., St. Mary's Co. [7]

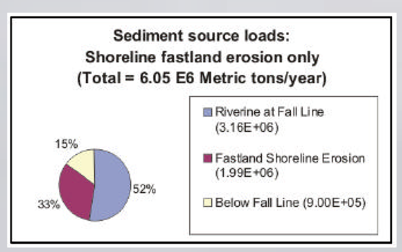
Shore Erosion in Chesapeake Bay

For its size, Maryland has an inordinately long shoreline, with 6,776 miles bordering the Chesapeake Bay and its tributaries. Based on changes in shoreline position over a recent 50-year period, the 2,182 miles of shoreline along the Bay's Western Shore retreat at an average annual rate of 0.52 ft/yr. The Western Shore thus loses about 137 acres/year to shore erosion.

The effects of long- and short-term climatic changes and events drive shore erosion. Over the long-term, fluctuations in sea level establish the water level at which erosive forces operate. Over the short-term, winds, particularly those associated with storms, propel the waves that impinge on the shore. Tied to storms, erosion is episodic. Unlike open ocean coastlines, the Bay shoreline tends not to recover from these events.

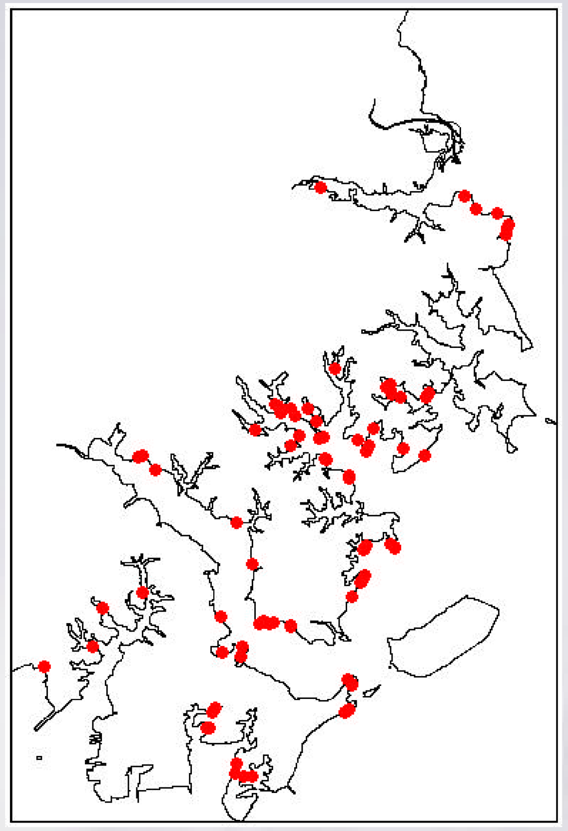
Shoreline change occurs, not just at the line of contact between land and water, but within a broader zone that extends for some distance both offshore and onshore. In addition to wearing away fastland, shore erosion operates in the nearshore to the base of wave action, that is, at water depths up to about 8 ft. In any given year, an estimated 2.0 million metric tonnes of sediment are eroded from fastland bordering the Maryland Chesapeake Bay [8].





STORM-INDUCED EROSION

Shoreline Vulnerability



Baltimore County issued nearly 100 permits to replace or repair destroyed or damaged erosion control structures [9].

Given the elevation of the storm surge, much of the Western Shore shoreline was vulnerable to erosion. Baltimore County reissued permits for erosion control structures, primarily bulkheads, that had been damaged or destroyed by the storm. Assuming that bulkhead damage and erosion were linked, MGS mapped the sites for which those permits had been reissued. The map, biased in favor of densely developed, protected shoreline, confirms the long reach of the storm surge. Bulkheads built within the normally quiet coves of minor tributaries were damaged, as well as those lining more exposed reaches of shoreline.

Despite widespread storm surge flooding, shore erosion was irregular. Seemingly identical reaches of shoreline behaved differently. Some were unaffected. Others experienced greater or lesser sediment losses.

Shore erosion was spotty and irregular. Chesapeake Bay, Anne Arundel Co. [2]

Storm Surge Flood and Ebb

Along shorelines eroded by the action of wind-generated waves, the main effect of the storm surge was to expand the zone of wave influence, both vertically and laterally. Along high banks and bluffs, the surge elevated wind waves, extending the line of wave attack progressively higher up, and then down, the bluff face. At the base of the bluff, any protection, manmade or natural (e.g., a narrow beach at the base of the bluff), was overtopped. Laterally, the waves reached much further inland than normal. Upland reaches not usually subject to wave attack were eroded during Isabel.

Once the storm surge had peaked, floodwaters drained back into the Bay. This storm surge ebb produced uncommon effects. Receding floodwaters scoured fastland sediment. Freestanding structures, like sheds, obstructed the ebbing flow. Along protected reaches, the ebb resulted in selective failure of erosion control structures that had been overtopped by the flood. Bulkheads and similar structures failed from behind. Once a structure was breached, water channeled through the opening, commonly scouring a semi-conic section -- wider at the top and narrower at the base -- from the exposed bank.

Bank erosion due to vertical expansion of zone of wave influence. St. Clements I., Potomac R., St. Mary's Co. [10]

Erosion of inland bank due to lateral expansion of zone of wave influence. Anne Arundel Co. [2]

Bulkhead failure and fastland scour associated with storm surge ebb. Chesapeake Bay, Baltimore Co. [11].

Effects of storm surge flood (cinder blocks carried inland) and ebb (collapse of block wall; scour near motor boat). Middle R., Baltimore Co. [11]

Uprooted Trees

Some of the most dramatic examples of storm-induced erosion involved the uprooting of trees. Generally, the extensive root systems of large trees stabilize the upper parts of a slope, until the root mat is undermined. When a tree falls, it pulls away as much as 5-10 m^3 of bank material. During the storm, other factors may have contributed to the collapse of trees along the shoreline: (1) the high soil moisture, due to above average precipitation in 2003, (2) the sail effect produced by trees in full canopy catching tropical storm force winds, and (3) on the shoreward side, the absence of shielding afforded by neighboring trees. For a while, the downed trees and eroded sediment will protect newly exposed banks from wave erosion. Once the eroded sediment washes away and the trees disintegrate or float away, direct wave attack will resume. Longer term, the effects of brackish water flooding and spray on trees growing near the shore may lead to their premature demise and collapse.

Slope undercut by floodwaters overtopping 2-3 ft stone wall and undermining mature trees. Gibson I., Chesapeake Bay, Anne Arundel Co. [2]

Estimated 65x25 ft section of shoreline washed away, toppling trees. Fairhaven, Chesapeake Bay, Anne Arundel Co. [2]

Sediment Redistribution

The forces responsible for erosion operate beyond the shoreline, within the broader coastal zone. In addition to actively eroding upland sediments, those forces, magnified by the storm, were directly responsible for extensive reconfiguration of the Bay margin, redistributing sediments temporarily stored on beaches and in shallow nearshore waters.

Bulldozers removed several feet of sand transported from the beach to a nearby road. Piney Pt., Potomac R., St. Mary's Co. [10]

Pre- and post-storm photos showing the disruption of nearshore bars and the effectiveness of sand-trapping groins (above) and the reconfiguration of Point No Point, an incipient cuspate foreland (below). Chesapeake Bay, St. Mary's Co. [10]

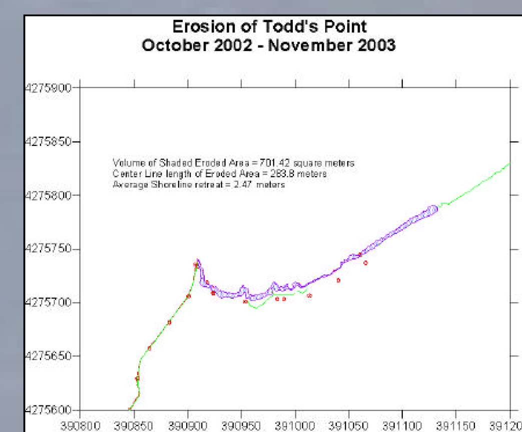
ESTIMATED SEDIMENT LOSSES

Within days after the storm, Baltimore County surveyed its shoreline by plane. Erosion had occurred along roughly 3.5 linear miles, or 1.5% of the total length of the county's shoreline. Applying that percentage to the length of shoreline bordering Western Shore coastal counties, MGS calculated that approximately 32.7 miles of shoreline experienced erosion during Isabel.

Two other variables needed to determine area and volume losses, shoreline retreat and bank height, varied widely from site to site. MGS assigned a value of 5 ft to both variables. That is, MGS assumed that along eroded reaches, a 5-ft high bank retreated 5 ft. Based on that assumption, the area of fastland eroded by Isabel equaled about 20 acres, and the volume of eroded sediment, 4.3 million ft^3 (122,000 m^3). On average, those 20 acres, lost in a single day, account for about 15% of the acreage lost from the Western Shore in any given year.

To convert the volume of eroded sediment to sediment mass, MGS multiplied sediment volume (m^3) by 1.30 metric tonnes/m^3, the mean dry bulk density measured previously for Western Shore bluff samples [12]. A total of 158,8000 metric tonnes of sediment were eroded during the storm.

Generally, when fastland sediments erode, only the finer-grained constituents (silt and clay) remain suspended in the water column. Coarser-grained sands and gravels form a lag deposit near the toe of the bluff. The average Western Shore bluff consists of nearly equal parts fine-grained (51%) and coarse-grained (49%) sediments [12]. The fine-grained fraction is of particular interest. Of the 158,800 metric tonnes of eroded sediment, 51%, or 81,000 metric tonnes, is the estimated suspended sediment load contributed by storm-induced erosion of the Western Shore. As a point of comparison, during Hurricane Agnes (1972), a storm noted for torrential rainfall in the Bay watershed, the Susquehanna River alone discharged over 31 million tonnes of suspended sediment into the Bay [13].



MGS surveyed a reach of shoreline at the mouth of the Choptank R. a year before and immediately after Isabel. Erosion rates varied. Todds Pt., Choptank R., Dorchester Co.

Based in part on images like this, MGS assumed that, along eroded shorelines, a 5-ft high bank retreated 5 ft. Annapolis Roads, Chesapeake Bay, Anne Arundel Co. [2]

CONCLUSIONS

- The Western Shore of Maryland's Chesapeake Bay lost about 20 acres of fastland to erosion during Isabel -- a total of 158,800 metric tonnes of sediment. The influx of suspended sediment (silt and clay) from Western Shore erosion amounted to about 81,000 metric tonnes. Compared to the 31 million metric tonnes delivered by the Susquehanna River during Hurricane Agnes, Isabel's contribution, though substantial, was not overwhelming.
- Generally, when coastal researchers and planners consider the future, they recognize two main scenarios: continued erosion of the shoreline in the face of sea level rise and permanent inundation of low-lying shoreline. Given the effects of Isabel, the first of these scenarios must include episodes of erosion due to short-lived storm surge flooding and, particularly, ebbing.
- Severe as it was, erosion might have been worse. Given storm surge elevation, virtually the entire Western Shore was vulnerable. However, only 1.5% of the total shoreline length experienced erosion.
- Destructive as it was, Isabel might have been worse. Had the hurricane been stronger at landfall, the storm surge generated in the Chesapeake Bay might have been higher. Had Isabel stalled along its path and lingered through several tidal cycles, prolonged surge conditions, exacerbated by high winds, might have caused more severe erosion. Had rainfall been higher, bank erosion due to slope failure might have been more common, particularly given the wetter than normal months that preceded the hurricane.

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