HURRICANE ISABEL AND EROSION OF CHESAPEAKE BAY SHORELINES, MARYLAND

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ABSTRACT

Hurricane Isabel resulted in spotty, uneven erosion of the Chesapeake Bay shoreline in Maryland. In the aftermath of the storm, the Maryland Geological Survey (MGS) polled local officials and county planners throughout the state and estimated the amount of sediment contributed by shore erosion to the Bay based on limited quantitative information. In Maryland, erosion was largely limited to the Bay's western shore. Among the affected counties, Baltimore County conducted the most extensive assessment of shore erosion, using aerial surveys. To approximate the area and volume of sediment lost, the authors extrapolated Baltimore County shoreline losses to the western shore of the Maryland Chesapeake Bay and assumed a value of 5 ft (1.5 m) for both shoreline retreat and average bank height. In sum, Isabel washed away approximately 20 acres (8 hectares) of coastal uplands and contributed about 81,000 metric tonnes of fine-grained sediment to the Bay.

From photographs, MGS deduced that: 1) erosion varied 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.

INTRODUCTION

In the early afternoon of 18 September 2003, Isabel—a tropical cyclone—made landfall as a Category 2 hurricane in the vicinity of Drum Inlet on the Outer Banks of North Carolina. The storm then tracked northwestward through North Carolina and Virginia, west of the Chesapeake Bay. Within 24 hours after landfall, the storm had dissipated, but not before ravaging coastal communities all along the western shore of Maryland's Chesapeake Bay. In addition to extensive property damage, shoreline erosion was an unmistakable and widely reported effect of Isabel's passage over Maryland. State officials estimated the cost to repair damaged shoreline structures, primarily piers and bulkheads, 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 shoreline erosion. The Maryland Geological Survey (MGS) endeavored to supply that estimate. Relying on others' photographs and firsthand observations, MGS: 1) examined the effects of the storm on the shoreline to understand the processes responsible for erosion; and 2) estimated the length of affected shoreline, the area of land lost, and the volume of fine-grained sediment delivered to the Bay as a result of the storm.

BACKGROUND

The Storm

Hurricanes are distinguished by their most damaging forces, operating singly or in combination. In Maryland, Isabel will be remembered, not for her intensity or heavy rains, but for the size of her wind field and especially her high storm surge. At landfall, the radius of hurricane-force winds extended 115 miles (185 km) from the eye; tropical storm-force winds extended 345 miles (555 km). Although wind speeds gradually diminished after landfall, the radius of the wind field remained unchanged for almost as long as Isabel remained a tropical cyclone [2]. Maximum sustained winds and wind gusts measured in the vicinity of the Maryland Bay were all of tropical storm force: 39–73 mph (63–117 $km \cdot hr^{-1}$[3].

The storm surge, a bulge of water generated by the hurricane's swirling winds and low pressure within the eye, 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 in the right front quadrant of the storm, as defined by the direction of the storm's forward motion. As the storm, with its enormous wind field, tracked north-northwest and to the west of the Chesapeake Bay, the right-front-quadrant winds blew from the south-southeast, pushing the storm surge up the Bay and piling water onto the western shore.

Output from the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) computer model, run with actual storm data, depicted probable maximum water levels reached over the course of the surge [4]. Along the western shore, highest maximum levels occurred along the main Bay shorelines of Baltimore and Harford counties, the headward reaches of the Patuxent and Potomac rivers, and minor tributaries draining the north shore of the Potomac River. For 88 better-than-poor-quality, coastal, high-water marks (e.g., mud lines, debris lines, eyewitness accounts) surveyed in western shore counties following Isabel, flood elevations ranged from 0.9–2.4 m (3.0–7.9 ft) and averaged 2.0 m (6.5 ft) (NAVD 88) [5].

Shoreline Erosion in Chesapeake Bay

For its size, Maryland has an inordinately long shoreline, of which 10,905 km (6,776 miles) border the Chesapeake Bay and its tributaries. Based on changes in shoreline position over a 50-year period ending between 1988 and 1995, the 3,511 km (2,182 miles) of shoreline bordering the Bay's western shore retreat at an average annual rate of 0.16 $m \cdot yr^{-1}$ (0.52 $ft \cdot yr^{-1}$) [6].

Both long- and short-term climatic changes and events drive shoreline erosion. Over the long-term—on the order of centuries or millennia—fluctuations in sea level establish the water level at which erosive forces operate. Over the short-term (daily, monthly, or yearly) winds, particularly those associated with storms, propel the waves that impinge on the shore. The energy of the attack depends on wind speed and duration, water depth, and fetch, or the distance the wind blows over water. Tied to storms, particularly nor'easters in the winter and hurricanes in the summer and fall, erosion is episodic. Unlike open ocean coastlines, the Bay shoreline tends not to recover from these events; once fastland sediments are eroded, they are seldom replaced [7].

Finally, 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, shoreline erosion also operates in the nearshore to the base of wave action [8]. For any given year, an estimated 1.99 million metric tonnes of sediment are eroded from fastland bordering the Maryland Chesapeake Bay, and an estimated 2.95 million metric tonnes are eroded from the nearshore.

METHODS

In the months following Isabel, MGS contacted coastal managers, planners, and engineers in most of the counties bordering the Maryland Chesapeake Bay and requested an account of local shoreline losses due to Isabel. County contacts confirmed that damage to shorelines was largely restricted to the western shore. All willingly shared available information. That information, however, was largely qualitative, mostly in the form of photographs and firsthand anecdotal accounts. Only Baltimore County had quantitative data. The county's Department of Environmental Protection and Resource Management (DEPRM) had: reissued permits to rebuild or replace damaged or destroyed structures, including bulkheads, seawalls, etc.; and estimated the length of eroded shoreline for 60% of the county's shoreline.

Assuming that wherever an erosion control structure had been damaged or destroyed, sediment had washed away, MGS reviewed DEPRM's Hurricane Isabel Building Permit Log and constructed a database of locations where such damage had occurred. Within days after the storm, DEPRM surveyed the county's shoreline by plane and estimated that roughly 3,350 m (11,000 ft) of shoreline had undergone erosion [9]. DEPRM, however, made direct observations of only 60% of the county's shoreline. Adjusting for the eroded length of the unobserved (40%) shoreline, MGS calculated the total length of eroded shoreline in Baltimore County as 18,300 ft (5.6 km or 3.5 miles).

Several years before the storm, MGS had updated shoreline change information for the state's tidal water bodies. One phase of the project entailed acquiring a modern, digital representation of the shoreline based on photo interpretation of 1988–1995 orthophotography [10]. From that digital shoreline, MGS determined the length of tidal shoreline bordering Baltimore County: 367 km (228 miles). Of that total, 5.6 km (3.5 miles), or 1.5%, experienced erosion during Isabel. Applying that percentage to the total length of shoreline bordering western shore coastal counties, MGS calculated that approximately 53 km (33 miles) of shoreline eroded during the storm.

In terms of its track and the magnitude of its storm surge, Hurricane Isabel has been compared to the Chesapeake-Potomac Hurricane of 1933. Following that storm, the most severely damaged shorelines comprised a total of 23 km (14 miles or 74,700 ft) in Anne Arundel, Calvert, and St. Mary's counties [11]. The definition of "severe damage" is unclear. Nonetheless, for both storms, the estimated length of affected shoreline is of the same order of magnitude.

In addition to shoreline length, one or two other linear measures are needed to determine the area and volume of sediment lost: shoreline retreat and height of the eroded bank. These two varied widely from site to site. For example, in November 2003, MGS conducted a GPS survey of a 283.5-m (930-ft) stretch of shoreline at Todds Point on the Choptank River. Compared to a pre-storm survey in October 2002, shoreline retreat at the site averaged about 2.4 m (8 ft), ranging up to 6.1 m (20 ft). Considering such variability, MGS assigned an approximate value of 1.5 m (5 ft) to both shoreline retreat and bank height. That is, MGS assumed that along eroded reaches, a 1.5-m high bank retreated 1.5 m. Based on that assumption, the area of eroded sediment roughly equaled 20 acres, and the volume of eroded sediment was 122,000 m^3 (4.3 x 10^6 ft^3).

In 2003, Hill and others evaluated shoreline erosion as a source of sediments and nutrients to the Maryland Chesapeake Bay [12]. Field crews sampled 12 bluff sites on the western shore, in Baltimore, Anne Arundel, Calvert, and St. Mary's counties. They collected sediment samples from the beach and from each of the visually distinctive horizons on the bluff face and subsequently analyzed them for dry bulk density and grain size. Based on site descriptions, the authors of this report extracted a total of 35 bluff samples, averaged results for replicate samples, and calculated mean bulk density and the mean percentage of the various grain size classes.

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 for western shore bluff samples. A total of 159,000 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 to this study.

Of the 159,000 metric tonnes of eroded sediment, 51% (81,000 metric tonnes) is the estimated suspended sediment load contributed by storm-induced shore erosion to the Bay.

RESULTS AND DISCUSSION

Shoreline Vulnerability

Given the storm surge elevation, virtually the entire western shore shoreline was vulnerable to erosion. In Baltimore County, DEPRM reissued permits for erosion control structures 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 (Figure 1). The map, biased in favor of densely developed, protected shorelines, confirmed the long reach of the surge. Erosion control structures built in the normally quiet coves of minor tributaries were damaged, not just those lining more exposed reaches of shoreline.

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

Processes of Erosion

Along shorelines eroded by the action of wind-generated waves, the storm surge's main effect was to expand the zone of wave influence both vertically and laterally (Figures 2a and 2b). 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 bluff's base, both manmade and natural protection (e.g., a narrow beach at the bluff base) were overtopped. Laterally, the waves reached much further inland than normal. Upland areas not usually subject to wave attack were eroded during Isabel. Flooding also increased fetch.

Once the storm surge had peaked, floodwaters flowed back into the Bay. This storm surge ebb produced uncommon effects. Receding floodwaters scoured fastland sediment. Small freestanding structures, such as sheds, obstructed the ebbing flow. Along protected reaches, the ebb produced selective failure of erosion control structures that had been overtopped by the flood (Figure 2c).

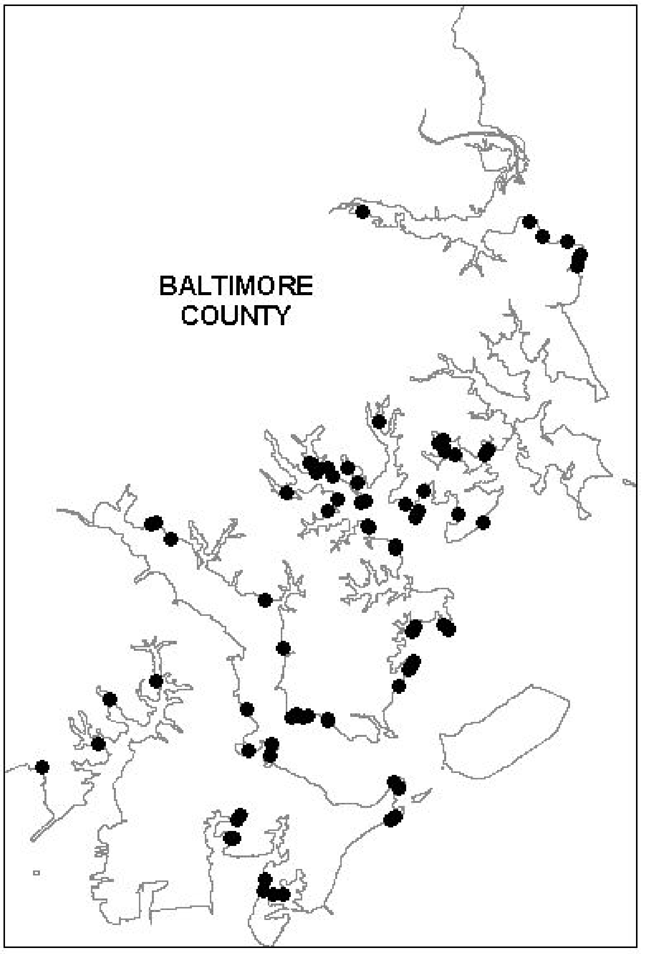

Figure 1. Baltimore County issued nearly 100 permits to replace or repair destroyed or damaged erosion control structures.

Although many erosion control structures remained intact after the storm, most were overtopped by the surge. Bulkheads and similar structures constructed higher than the land surface failed selectively from behind as the surge ebbed. 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. During the storm surge flood, structures backed by higher banks or bluffs directed the wave attack higher up the bluff face; sediments were gouged from there, rather than from the toe of the slope.

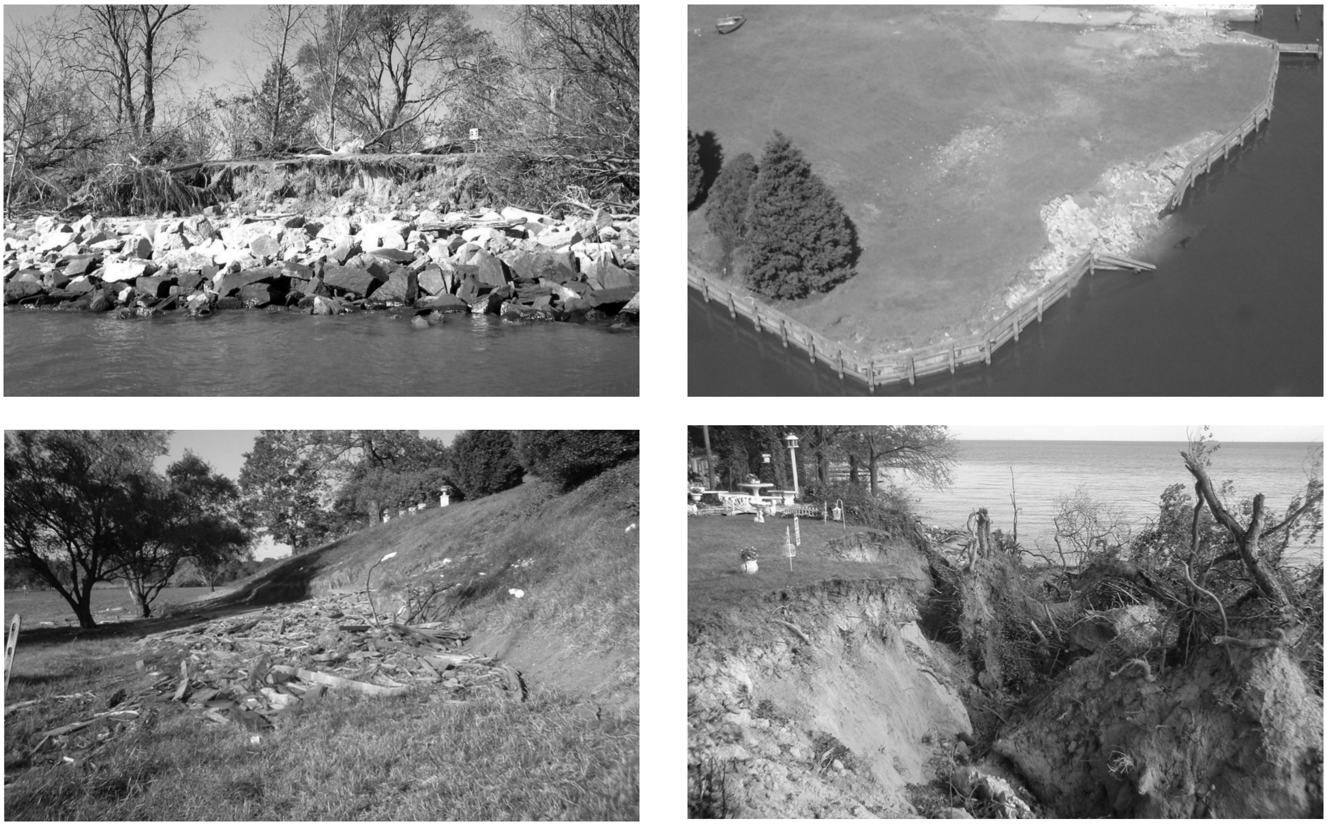

Figure 2. Processes of erosion. Bank erosion due to: a) vertical and b) lateral expansion of zone of wave influence; c) bulkhead failure and fastland scour associated with storm surge ebb; and d) undermining of mature trees. (Photos courtesy of Scott Alexander, St. Mary's County Dept. of Public Works (a); Jim Stein, Anne Arundel Soil Conservation District (b & d); Candy Croswell, Baltimore County DEPRM (c))

Some of the most dramatic examples of storm-induced erosion involved the uprooting of trees (Figure 2d). Generally, the extensive root systems of large trees stabilize the upper part of a slope, until the root mat is undermined. When a tree falls, it can pull away as much as 5–10 m^3 of bank material [13]. During the storm, other factors may have contributed to the collapse of trees along the shoreline: the high soil moisture due to above average precipitation in 2003; the sail effect produced by trees in full canopy acting like sails to catch the tropical-storm-force winds; and, on the shoreward side, the absence of shielding that would have been afforded by neighboring trees. For a while, the downed trees and the mounds of eroded sediment will shield newly exposed banks from wave erosion. Once the eroded sediment washes away and the trees disintegrate or float away, though, 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 eventual demise. To the extent that dead trees are more likely to fall than live ones, Isabel may have a long-lasting (decadal) effect on shoreline erosion [14].

The forces responsible for coastal erosion operate beyond the shoreline in a 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. Redistribution of sediment, often sand, took several forms. Observing the exposed roots of marsh vegetation, Baltimore County reported a foot of sand removed from the surface of Pleasure Island [9]. In Anne Arundel County, the entire beach at Herrington Harbor South washed away [15]. At Piney Point, along the Potomac River in St. Mary's County, bulldozers were brought in to remove several feet of sand transported from the beach to a nearby road. In the same county, along the western shore of the Bay, nearshore bars parallel to the shoreline appear to have been disrupted by the storm, and sand-trapping groins seem to have garnered additional sand set in motion by the storm [16].

Estimated Quantity of Eroded Sediment Delivered to the Chesapeake Bay

From a rough approximation of the length of Baltimore County shoreline eroded by Isabel, MGS extrapolated the length of shoreline affected along the entire western shore. In all, about 53 km (33 miles) of shoreline experienced erosion, resulting in a worst-case estimate of 8 hectares (20 acres) of land lost from the western shore.

Isabel resulted in the erosion of about 159,000 metric tonnes of sediment from western shore shorelines. Of that, 81,000 metric tonnes were fine-grained sediment (silt and clay). As a point of comparison, during Hurricane Agnes (1972)—a storm characterized by torrential rainfall in the Bay watershed—the Susquehanna River alone discharged over 31 million metric tonnes of suspended sediment into the Bay, about 30 times the annual average input [17].

Severe as it was, erosion might have been worse. Given the storm surge elevation, the entire western shore was potentially vulnerable. Had the hurricane been stronger at landfall, the storm surge generated in the Chesapeake Bay might have been larger. 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, as was the case during Hurricane Agnes, bank erosion caused by slope failure might have been more common [18], particularly given the wetter than normal months that preceded the hurricane.

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