Middle States Geographer, 1996, 29:114-122

STARTING POINTS FOR EXAMINING STORM SURGE SEDIMENTATION IN URBANIZED ESTUARIES

Michael Craghan
Department of Geography
Rutgers University
New Brunswick, NJ 08903

ABSTRACT: Storm surges in estuaries may flood urban areas on the estuarine fringe. Flooding on developed shorelines shares some of the characteristics of flooding in fluvial, lake, and salt marsh systems. Comparisons to other environments reveal that urban areas on the estuarine shore should experience minimal deposition and little topographic change following storm surge inundation. Some techniques used in other environments (e.g. water level records, sediment traps, coring to find marker layers, visual observations) can be adapted to study urban flooding; some will not be useful because of the process-response differences between urban areas of estuaries and the other environments.

INTRODUCTION

Estuaries are important recreational, commercial, and aesthetic resources, and have consequently attracted high density development to their shorelines. Urbanization of the estuarine shoreline impacts geomorphic processes and responses. Humans alter the shoreline through bulkheading, paving, installing drainage systems, and erecting buildings. As a result, the ability of other geomorphic agents (gravity, waves, currents, tides) to act has been curtailed. In turn, the mass wasting and erosion/deposition that would be found in a natural system may be absent along a developed shore.

Estuaries are complex environments that can have numerous configurations and can be dominated by either fluvial or tidal forces. The estuarine flooding referred to in this paper occurs in the tidally dominated portion of an estuary and is a result of coastal storm surges that are transferred into the estuary.

The purpose of this paper is to cultivate some research techniques for studying sedimentation along the developed shorelines of estuaries. Three paths are used to achieve that goal. The first is to examine storm surge flooding on estuarine shores. The hazards of storm surges, flooding in salt marsh systems, and some of the impacts of flooding in built areas are reviewed in order to characterize the flooding problem. As a result, some of the flooding processes, and the geomorphic responses in an urban area can be anticipated. The second approach of this paper is to compare and contrast estuarine floods with floods from other environments. Flooding in other systems may share some characteristics with estuarine flooding. Knowledge of similarities and differences among flooding environments can help to conceptualize flooding and sedimentation in developed estuaries. The third approach is to determine if some of the research methodologies used in geomorphological investigations of other flooding environments might be useful for studying floods along urbanized estuarine shores.

STORM SURGES

Storm surges are changes to normal water levels caused by meteorological conditions. Coch (1994) described five factors that affect the height of storm surge: (1) wind speed; (2) central pressure of the atmospheric disturbance; (3) slope and width of the continental shelf; (4) tidal stage; and (5) shoreline configuration. Wind duration and wind direction should be added to Coch's list.

Storm events such as northeasters and hurricanes generate the largest storm surges.

Northeasters are extratropical cyclones that have potentially severe impacts at the coast as a function of their storm tracks. They cause large storm surges because of their low atmospheric pressures, high wind speeds and long durations. In contrast to the duration of the northeasters, relatively fast moving hurricanes generate immense surges due to their very low central pressures and their extremely high winds. The oceanic surges caused by northeasters and hurricanes can be transferred into coastal estuaries where they affect geomorphic processes.

Impacts of Storm Surge Inundation

Storm surges are a hazard on developed shorelines because they are a threat to property and investments, but also because floodwaters can isolate or kill vulnerable people. Increases to water levels due to intense storms have caused substantial damage and loss of life on a worldwide scale. The 1970 Bangladesh cyclone and storm surge killed over 200,000 people, affected 4.7 million others, damaged 400,000 houses, 3,500 schools, and approximately 100,000 fishing boats (Murty, 1984, p. 824). A 1953 storm in the Netherlands flooded 160,000 hectares, killed 1,835 people and 200,000 farm animals, and damaged over 46,000 farms and buildings (Watson and Finkl, 1990). Typhoon Angela's flood waters killed many people, left dozens of villages under water and flooded access highways in the Philippines (Asbury Park Press, 1995). In the United States, FEMA (1994) reports that three storms generated 43,238 claims to the U.S. National Flood Insurance Program. The Halloween storm of 1991 cost NFIP $141 million in New England. The December 1992 storm produced $334 million in claims from New York and New Jersey. The March 1993 storm caused $207 million in losses along the east coast and the west coast of Florida.

Some of the geomorphic effects of storm surges that are associated with hurricanes and extratropical storms impact natural systems. Flooding has caused salinization in coastal forests (Gardner et al., 1991); relocated wrack (vegetative detritus) in marshes (Hackney and Bishop, 1981); and impacted tree growth (Johnson and Young, 1992). Notwithstanding overwash, which is a surge-enhanced ocean wave process, storm surges also cause deposition in marshes (Stumpf, 1983; Orson and Howes, 1992; Leonard et al., 1995; Nyman et al., 1995). In their study of Hurricane Hugo's impacts to the South Carolina coast, Coch and Wolff (1991) noted mud drapes and deposits; mud stains on objects; wrack in branches; stranded debris (e.g. boats); scour marks on trees; abrasion marks on buildings; and channelization of ebbing flood waters by structures. Coch and Wolff's observations are complemented by a newspaper account of storm surge flooding from the Shrewsbury River (N.J.) during the December 1992 northeaster (Parry, 1992). It was reported that, "Boats were smashed up against houses and each other. Slimy, smelly mud covered floors and walls." At one house, "The raging current blew out his windows and front doors, caked the hardwood floors with mud, ripped away the bottom half of his locked kitchen door, and sucked most of the kitchen furniture out the hole." Those are direct results of storm surge flooding and strong winds. They are not the results of oceanic waves or overwash mechanisms, although those surge enhanced processes can yield similar results (FitzGerald et al., 1994).

Responses in Salt Marshes

High winds and strong rains from a low-pressure storm system, wind generated local waves, ocean waves that enter the system, and high water levels that are transferred inland from oceanic storm surges are characteristics of coastal storms in estuaries. The effects of these processes are manifest in slumping tidal channel walls, flooding wetlands to greater depths than usual, and lateral extension of the estuarine waters' boundaries. All of these processes act to increase sediment transport, and thus affect sediment deposition.

The deposition in marshes is related to the amount of sediment that is being transported within the marsh system. Stumpf (1983) noted that during a northeaster, suspended sediment concentrations in saltmarsh creeks and the backmarsh were much higher than had been previously measured. This is partly attributed to storm surge flooding that exceeded the vegetation canopy, allowing additional turbulence and the formation of waves. Leonard et al. (1995) noted the effects of strong winds on suspended sediment concentrations in a tidal creek and, state that the primary manner in which marsh sediments are recirculated is by slumping of creek walls. In Gulf of Mexico salt marshes, sediments that were deposited during extratropical storms (Leonard et al.) and Hurricane Andrew (Nyman et al., 1995) were determined to be locally derived.

The role of marsh vegetation in trapping suspended material is important in the natural formation of marsh surfaces (Stumpf, 1983). Vegetation also distorts marsh hydraulics (French and Stoddart, 1992). Finally, the ability of salt marshes to maintain themselves against rising sea-levels may be dependent upon the high amounts of sediment deposited during episodic strong storms (Stumpf, 1983; Leonard et al., 1995; Goodbred and Hine, 1995; Nyman et al., 1995).

Urbanized Estuaries

Some of the effects of surges in developed areas and in marshes are similar (e.g. sediment deposits, abrasion and scour marks). However, human alteration to an estuary has been shown to have significant effects on estuarine processes. Nichols and Howard-Strobel (1991) describe changes to the harbor at Norfolk, Virginia that are typical of the way that humans alter the estuarine environment as part of the urbanization process. Bulkheads, piers, docks, dredging, spoils disposal, and land reclamation have extensively altered the estuary. They report, "Today after 100 years of accelerated development little is left of the natural system along the main estuary." Some of the impacts of these changes include a 24% reduction to the estuary's tidal prism as well as changes to bottom current strength and estuarine salinity structure. MacPherson (1979) writes of how later stages of urbanization and the development of storm water collection systems have accompanied a dramatic increase to the tidal prism in a New Zealand estuary. After Hurricane Allen passed Padre Island, Texas, Giardino et al. (1984) reported that the undeveloped lagoon shoreline "experienced a marked amount of change" while the urbanized shore "exhibited a minimum amount of change". This was partly attributed to paved streets that channelized overwash and lagoon side pylons that altered wave characteristics and interrupted longshore transport.

By examining salt marshes and contrasting them with the built environment it is possible to anticipate how urbanized areas will react differently to storm surge flooding. The importance of vegetation, mudflats, and tidal channels in saltmarsh sedimentation suggest that in urban environments where they are not found, sedimentation will be different than in the undisturbed salt marshes. In a salt marsh slumping of channel walls is an important process in supplying sediment for redeposition on the marsh. The larger waves that are present during storms (due to increased wind energy, deeper water from the surge, and increased fetch caused by flooding of the adjacent uplands) also act to mobilize bottom sediments. In contrast, for developed systems part of the estuary bottom is out of reach of even the larger waves because of dredging for navigation purposes. Furthermore sediment is immobilized by bulkheads that line the shorelines and tidal channels. In a salt marsh the role of vegetation in trapping sediment is very important and vegetation also acts to retard the flow of waters on the ebb tide. In a developed system there is minimal tall vegetation, and removal of water is accelerated by the prevalence of impervious surfaces and engineered storm drainage systems.

Urbanization and alteration of the terrain on a developed shoreline limit the effectiveness of geomorphic processes. Human impacts in developed areas go beyond circumscribing geomorphic processes. People also reverse the responses to any flooding processes that are still competent (Williams and Costa, 1988; Nordstrom and Jackson, 1995). In a short period of time (hours to weeks) following a storm, debris and flotsam is collected and removed (often a great distance to a landfill); streets are cleaned; sediment deposited in buildings or other places is removed; the effects of salinization are fought with lime; sewer systems are flushed; and damages to facilities are repaired.

FLOODING

Because urban shorelines are expected to respond differently than salt marshes to storm surge flooding, a different approach to the analysis of an urbanized estuarine system may be in order. Flooding, which occurs in places as divergent as mountain streams and ocean beaches, is a geomorphic process that acts differently in different environments. This paper reviews some of the characteristics of flooding in fluvial, lake, ocean shoreline, and tidal environments in order to better understand estuarine floods that are caused by oceanic storm surges.

Stream Flooding

Flood studies in geography are strongly associated with fluvial systems (Baker et al., 1988; Nanson and Croke, 1992). Many of the processes that occur as a stream rises and overflows its banks also occur in estuaries. Zwolinski, (1992) identified a sequence of events (quoted below) for river overflow onto floodplains:

(1) Rising of water stage and bank modification
(2) Floodplain inundation and initial deposition
(3) Flood peaks and widespread transport and deposition
(4) Falling of water stages and high intensity deposition
(5) Cessation of overbank flow and final deposition
(6) Post-flood transformation of overbank forms and deposits

This sequence is also applicable to estuarine flooding. Zwolinski's six stages can be seen in investigations of tidal creek dynamics and marsh surface deposition (Hackney and Bishop, 1981; Stumpf, 1983; Swenson and Turner, 1987; French and Stoddart, 1992; Reed, 1992; Goodbred and Hine, 1995; Leonard et al., 1995; Nyman et al., 1995). Additionally, the sizes of sediment particles and the quantity of material that are deposited on floodplains have been found to vary with distance from the channels in both fluvial (Kesel et al., 1974; Pizzuto, 1987; Marriott, 1992; Zwolinski, 1992; Asselman and Middelkoop, 1995) and salt marsh studies (Stumpf, 1983; Reed, 1992; Goodbred and Hine, 1995).

Despite their similarities, a large difference between fluvial and estuarine flooding occurs once the floodplain is inundated. Water flow on a stream's floodplain is governed by the hydraulic gradient of the stream. That is, on the floodplain, water will continue to flow in a downstream direction. In an estuary, flooding of adjacent uplands involves movement by waters that rise out of the open water of the estuary. When those lands are inundated, the movement of flood waters is controlled by the water level in the estuary. The energy gradient is onshore-offshore, not alongshore as on a stream's floodplain.

Stream flooding is also different from its estuarine counterpart in terms of frequency. Overbank flooding in a fluvial system generally occurs every year or two. In the salt marshes of estuaries, water levels regularly exceed the channel boundaries. Waters typically flow out of the channels onto the marsh surface every day at high tide (or at least several times a month during spring tides).

Lake Flooding

In many ways the inundation of an estuarine shore is similar to flooding from lakes. Rising levels in the basin cause a shore-perpendicular movement of water onto the adjacent, normally dry, lands. Evidence of flooding from lakes is found in wrack and debris lines, gravel beaches and ridges, and erosional steps on shorelines. The impact of flood waters can sometimes be discerned by plant zonation or by vegetation kills (Atwood, 1994). Lake flooding comes about in three main ways: from changes in water levels caused by climate fluctuations (these can be either long term or seasonal); from seiches; and from processes similar to those of an ocean shoreline.

Geomorphic activity can be initiated in lakes by strong storms. If a lake is large enough, a storm will impact it in much the same way that an oceanic storm affects the open coast. The increase in water level from flooding increases the available fetch and wave energy. Waves will strike the shoreline and move sediment on- or offshore, much like on an ocean beach. Similarly offshore bars can form and longshore currents can develop (Gracia-Prieto, 1995). A storm surge of water moved by atmospheric forces can also pile up on the windward shore. Those accumulations of water can be released as seiches. Seiches tend to have small amplitudes and their effects are not well documented, although Carter (1988, pp. 196-198) reports that seiches can cause the landward transport of sediment as water level rises.

Ocean Shoreline Surges

On the open ocean shoreline, flooding occurs in two ways: from storm surges, and from tsunamis. The origins of storm surges have been discussed. Tsunamis are long period waves that are generated from an underwater disturbance, in particular, earthquakes.

Previous research into the storm surge hazard in developed areas has concentrated on oceanic surge and its impact to other shoreline processes. Much effort has been directed towards prediction of surge height (Murty, 1984; USACE, 1984; Pugh, 1987; Murty and Flather, 1994) because higher water levels enhance other destructive elements of a storm. The extension of the vertical and horizontal reach of storm waves, overwash from the beach to inland areas, and ebb surge returning to the ocean (Coch and Wolff, 1991; Coch, 1994; Bush and Pilkey, 1994) are all effects of coastal storm surge.

On the open coast, tsunamis are another source of flooding. Water levels become elevated because of the long periodicity (10's-100's of minutes) of the wave, and several cycles of inundation are possible. The ability of a tsunami to move and deposit sediments is well known, however tsunami deposits can be indistinguishable from deposits laid down during intense coastal storms (Foster et al., 1991; Dawson, 1994).

The Role of Tides

One characteristic that separates estuarine flooding from all of the other types of flooding (except open ocean storm surge) is the presence of tides. Since any flooding that fails to exceed the spring tide high water level may have no effect, the interaction of surge and tide will be of some importance.

Water levels during a coastal flood will fluctuate with the tidal cycle. So a coastal flood could have several cycles of rising and lowering due to tidal influences. Alternatively a short duration surge (say 3-8 hours) might not have any unusual impact on water levels if it arrives on the ebb tide. Tides and surges also interact hydraulically, especially in shallow water. The highest surge is likely to occur on the rising tide (Pugh 1987, Chapter 7:8; Murty 1984, Chapter 5.3).

WORKING MODEL OF URBAN FLOODING IN ESTUARIES

Developed shorelines in estuaries might be expected to react to storm surge flooding in much the same way that salt marshes do. The processes (i.e. rain, strong winds, waves, tides, storm surge) and environmental setting (low lying coastal lands bordering open water) are similar. However, some of the important geomorphic characteristics of marshes (vegetation, mud flats, tidal channels) are absent or recast in developed areas.

Flooding in other environments also shares some of the characteristics of estuarine flooding. The systematic variation of water level and sediment transport found in fluvial systems, the onshore-offshore gradient found in lakes, and the high energy inputs and tidal characteristics of coastal flooding are all characteristics found in estuaries. In contrast, the alongshore current of fluvial systems, the long time periods involved with fluctuating lake levels, and the dynamic response to ocean processes are all factors that distinguish estuarine flooding from the other environments.

The characteristics of urban areas will also influence the response to any flooding. Building, paving, bulkheading, and dredging (1) will limit the amount of sediment that is available, and (2) are resistant to topographic changes. Engineered drainage systems also accelerate the removal of water from built areas.

As a consequence of the above, two geomorphic results of storm surge flooding in urban areas can be anticipated. The first is that there will be little sedimentation. The sediment sources that are available in salt marshes (reactivated muds from channels and mudflats) are absent or armored in developed systems. The tall marsh vegetation that is an important trapping mechanism is absent. In addition, there is no upstream source of sediment as in a fluvial system because the flooding comes from the open water of the estuary. The other anticipated result of storm surge flooding is that there will be little topographic change. Sealing the ground with pavement, bulkheads, and buildings precludes erosion. And, as explained above, deposition is expected to be minimal.

GEOMORPHOLOGICAL INVESTIGATION OF URBAN FLOODS

The conceptual model of storm surge flooding in urban areas suggests that sedimentation and topographic changes will be minimal. A geomorphological investigation will have to address those expectations and the severe meteorological conditions that are necessary to cause storm surge flooding.

Changes to water level are very important and should be documented. Since it is the increase in water elevation that actually causes flooding, recording water levels allows the temporal and spatial extent of flooding to be known. Water levels can also be used to determine the relative magnitude of a storm by calculating its recurrence potential. As in studies of fluvial and salt marsh floods (Stumpf, 1983; Gretener and Stromquist, 1987; French and Stoddart, 1992), the duration and magnitude of a flood is best measured with a gauge. Because of the tidal component, water levels will fluctuate up and down throughout the event (storm surge can be separated from the tidal signature by subtracting the predicted times and heights of tides), therefore heights must be frequently monitored. Furthermore, the severe weather that is likely to occur argues for an automated device. Dangerous winds and/or icy cold waters make manual measurement too risky.

The minimal amount of sedimentation that is expected requires methods that can resolve very low quantities of material. Sedimentation measurements using mats (Gretener and Stromquist, 1987; Asselman and Middelkoop, 1995) surface grab samples (Cooper et al., 1990; Marriott, 1992; Goodbred and Hine, 1995; Leonard et al., 1995) and cores (often with marker layers) (Alther and Wyeth, 1980; Stumpf, 1983; Reed, 1992; Goodbred and Hine, 1995; Nyman et al., 1995) have been used to document deposition in salt marshes and fluvial systems. They may be able to distinguish the small amount of sedimentation expected on developed shorelines.

Just as sedimentation is expected to be very low, topographic changes as a result of storm surge inundation are also expected to be minimal. Techniques such as topographic surveys or profiling that are used in other systems will probably be of little use. They will be incapable of resolving the minimal amount of geomorphic response that is anticipated.

Visual observation of the flood's effects will also be an important method of evaluation (Williams and Costa, 1988). Observation is likely to reveal high-water levels, whether currents were channelized by landscape elements, and where any sediment transport or deposition took place. This information can be used to extrapolate any sedimentation data to larger areas, and will also provide direction for future investigations.

Finally, some geomorphological methods will be unsatisfactory for studying storm surge inundation. Techniques like aerial photography, dye traces, and current metering will be of limited value due to the bad weather during severe coastal storms and the turbulence from waves, tides, and wind-caused circulation.

CONCLUSION

The behavior of floods in streams, lakes, and ocean environments provides clues when trying to understand flooding on the urban shores of estuaries. However, while other types of flooding may provide starting points, storm surge flooding in estuaries will also need to be considered as a special case. The features of urban shorelines (paving, buildings, bulkheads, storm sewers) and the environmental characteristics of estuaries (waves, tides, hydraulic gradients, storm conditions) lead to expectations of negligible geomorphic response, even to extensive flooding.

The expectations of minimal change require geomorphological techniques that can show the potential for change (e.g. water level records) while also revealing that little change has taken place (e.g. sediment traps, coring to find marker layers, and visual observations) Other methods (e.g. topographic surveys, dye tests, aerial surveys) that are used in more responsive environments or under calm weather conditions, will not be useful.

Urbanizing an estuarine shoreline appears to affect sedimentation within the developed zone. Minimal sedimentation within an urban area contrasts with the vertical accumulation that occurs in estuarine salt marshes. Accretion is the only way that salt marshes can survive rising sea-level conditions. Thus, the prevention of geomorphic process and response in a built area may (by preventing vertical accretion), over time, leave the high density development on estuary shorelines even more vulnerable to the hazard of storm surge flooding.

REFERENCES

Alther, G.R. and Wyeth, R.K. 1980. A Test Utilizing Sediment Traps, Survey Rods, and Radiographs to Monitor Sediment Accumulation from a Dredging Disposal Operation. *Environmental Geology* 3:97-105.

Asbury Park Press 1995. Typhoon Death Toll Reaches 250. Asbury Park Press, November 5, 1995, p. A26.

Asselman, N.E.M. and Middelkoop, H. 1995. Floodplain Sedimentation: Quantities, Patterns and Processes. *Earth Surface Processes and Landforms* 20:481-499.

Atwood, G. 1994. Geomorphology Applied to Flooding Problems of Closed-basin Lakes... Specifically Great Salt Lake, Utah. *Geomorphology* 10:197-219.

Baker, V.R., Kochel, R.C. and Patton, P.C. (Eds.). 1988. *Flood Geomorphology*. New York: John Wiley & Sons,. 503 pages.

Bush, D.M. and Pilkey, O.H. 1994. Mitigation of Hurricane Property Damage on Barrier Islands: A Geological View. *J. Coastal Research,* Special Issue No. 12:311-326.

Carter, R.W.G. 1988. *Coastal Environments*. London: Academic Press, 617 pages.

Coch, N.K. 1994. Geologic Effects of Hurricanes. *Geomorphology* 10:37-63.

Coch, N.K. and Wolff, M.P. 1991. Effects of Hurricane Hugo Storm Surge in Coastal South Carolina. *J. Coastal Research* Special Issue No. 8: 201-226.

Cooper, J.A.G., Mason, T.R., Reddering, J.S.V. and Illenberger, W.K. 1990. Geomorphological Effects of Catastrophic Flooding on a Small Subtropical Estuary. *Earth Surface Processes and Landforms* 15:25-41.

Dawson, A.G. 1994. Geomorphological Effects of Tsunami Run-up and Backwash. *Geomorphology* 10:83-94.

Federal Emergency Management Agency 1994. Mitigation of Flood and Erosion Damage to Residential Buildings in Coastal Areas. FEMA 257/October 1994.

FitzGerald, D.M., van Heteren, S. and Montello, T.M. 1994. Shoreline Processes and Damage Resulting from the Halloween Eve Storm of 1991 along the North and South Shores of Massachusetts Bay, U.S.A. *J. Coastal Research* 10:113-132.

Foster, I.D.L., Albon, A.J., Bardell, K.M., Fletcher, J.L., Jardine, T.C., Mothers, R.J. Pritchard, M.A. and Turner, S.E. 1991. High Energy Coastal Sedimentary Deposits: An Evaluation of Depositional Processes in Southwest England. *Earth Surface Processes and Landforms* 16:341-356.

French, J.R. and Stoddart, D.R. 1992. Hydrodynamics of Salt Marsh Creek Systems: Implications for Marsh Morphological Development and Material Exchange. *Earth Surface Processes and Landforms* 17:235-252.

Gardner, L.R., Michener, W.K., Blood, E.R., Williams, T.M., Lipscomb, D.J. and Jefferson, W.H. 1991. Ecological Impact of Hurricane Hugo - Salinization of a Coastal Forest. *J. Coastal Research*, Special Issue No. 8:301-317.

Giardino, J.R. and Isett, P.E. 1984. Impact of Hurricane Allen on the Morphology of Padre Island, Texas. *Environmental Geology* 6:39-43.

Goodbred, S.L., Jr. and Hine, A.C. 1995. Coastal Storm Deposition: Salt-marsh Response to a Severe Extratropical Storm, March 1993, West-central Florida. *Geology* 23:679-682.

Gracia Prieto, F.J. 1995. Shoreline Forms and Deposits in Gallocanta Lake (NE Spain). *Geomorphology* 11:323-335.

Gretener, B. and Stromquist, L. 1987. Overbank Sedimentation Rates of Fine Grained Sediments. A Study of the Recent Deposition in the Lower River Fyrisan. *Geografiska Annaler* 69A:139-146.

Hackney, C.T. and Bishop, T.D. 1981. A Note on the Relocation of Marsh Debris During a Storm Surge. *Estuarine, Coastal and Shelf Science* 12:621-624.

Johnson, S.R. and Young, D.R. 1992. Variation in Tree Ring Width in Relation to Storm Activity for Mid-Atlantic Barrier Island Populations of Pinus taeda. *J. Coastal Research* 8, 99-104.

Kesel, R.H., Dunne, K.C., McDonald, R.C., Allison, K.R. and Spicer, B.E. 1974. Lateral Erosion and Overbank Deposition on the Mississippi River in Louisiana Caused by 1973 Flooding. *Geology* 2:461-464.

Leonard, L.A., Hine, A.C., Luther, M.E., Stumpf, R.P. and Wright, E.E. 1995. Sediment Transport Processes in a West-central Florida Open Marine Marsh Tidal Creek; the Role of Tides and Extra-tropical Storms. *Estuarine, Coastal and Shelf Science* 41:225-248.

Macpherson, J.M. 1979. Response to Urbanization of the Avon-Heathcote Estuary, Christchurch, New Zealand. *Environmental Geology* 3:23-27.

Marriott, S. 1992. Textural Analysis and Modelling of a Flood Deposit: River Severn, U.K. *Earth Surface Processes and Landforms* 17:687-697.

Murty, T.S. 1984. Storm Surges - Meteorological Ocean Tides. (Canadian Bulletin of Fisheries and Aquatic Sciences 212) Department of Fisheries and Oceans, Ottawa. 897 pages.

Murty, T.S. and Flather, R.A. 1994. Impact of Storm Surges in the Bay of Bengal. *J. Coastal Research*, Special Issue No. 12:149-161.

Nanson, G.C. and Croke, J.C. 1992. A Genetic Classification of floodplains. *Geomorphology* 4:459-486.

Nichols, M.M. and Howard-Strobel, M.M. 1991. Evolution of Urban Estuarine Harbor: Norfolk, Virginia. *J. Coastal Research* 7:745-757.

Nordstrom, K.F. and Jackson, N.L. 1995. Temporal Scales of Landscape Change Following Storms on a Human-altered Coast, New Jersey, USA. *J. Coastal Conservation* 1:51-62.

Nyman, J.A., Crozier, C.R. and DeLaune, R.D. 1995. Roles and Patterns of Hurricane Sedimentation in an Estuarine Marsh Landscape. *Estuarine, Coastal and Shelf Science* 40:665-679.

Orson, R.A. and Howes, B.L. 1992. Salt Marsh Development Studies at Waquoit Bay, Massachusetts: Influence of Geomorphology on Long-Term Plant Community Structure. *Estuarine, Coastal and Shelf Science* 35:453-471.

Parry, W. 1992. *River Leaves Neighborhood in Ruins*. Asbury Park Press, December 15, 1992, p. B1.

Pizzuto, J.E. 1987. Sediment Diffusion During Overbank Flows. *Sedimentology* 34:301-317.

Pugh, D.T. 1987. *Tides, Surges and Mean Sea-Level*. Chichester: John Wiley & Sons, 472 pages.

Reed, D.J. 1992. Effect of Weirs on Sediment Deposition in Louisiana Coastal Marshes. *Environmental Management* 16:55-65.

Stumpf, R.P. 1983. The Process of Sedimentation on the Surface of a Salt Marsh. *Estuarine, Coastal and Shelf Science* 17:495-508.

Swenson, E.M. and Turner, R.E. 1987. Spoil Banks: Effects on a Coastal Marsh Water-Level Regime. *Estuarine, Coastal and Shelf Science* 24:599-609.

U.S. Army Corps of Engineers 1984. Shore Protection Manual, 4 ed. Department of the Army: Washington.

Watson, I. and Finkl, C.W., Jr. 1990. State of the Art in Storm-Surge Protection: The Netherlands Delta Project. *J. Coastal Research* 6:739-764.

Williams, G.P. and Costa, J.E. 1988. Geomorphic Measurements After a Flood. Chap. 4. In: *Flood Geomorphology*, eds. V.R. Baker, C.R. Kochel and P.C. Patton, New York: John Wiley & Sons, 65-77.

Zwolinski, Z. 1992. Sedimentology and Geomorphology of Overbank Flows on Meandering River Floodplains. *Geomorphology* 4:367-379.