CONTROLLING AND MONITORING OF COASTAL EROSION, FLOODING AND FLOATING DEBRIS: CURRENT PRACTICES AND NEW SOLUTIONS

C. Vipulanandan, Ph.D., P.E. and B. Basirat

Texas Hurricane Center for Innovative Technology (THC-IT)
Department of Civil and Environmental Engineering
University of Houston, Houston, Texas 77204-4003
Phone: (713) 743-4278 Email: cvipulanandan@uh.edu and bbasirat@uh.edu

Abstract

Coastal erosion and flooding are two of the major disasters in the history of mankind. Coastal erosion is an integrated dynamic physical-biochemical continuous process occurring around the world while the flooding related to coastal areas, rivers and urban areas and are seasonal in nature and is causing billions of dollars in damages just in the United States. Coastal erosion not only results in continuous loss of land but also affecting the bathymetry, sea animals and sea plants. The general coastline for the United States is over 12,830 miles and the tidal shoreline length is over 88,630 miles. Maximum erosion reported in the United States is over 4 m/year. Monitoring erosion along the coast is a challenge and new technologies must be integrated to address the monitoring problems. Also methods to minimize the dynamic physical-biochemical coastal erosion processes must be developed and better quantify erosion must be developed. Damages due to flooding must be minimized by better predicting the flooding areas and also developing temporary storage facilities. Large wooden floating debris is not only causing damages to all the surface infrastructures but also delay in the recovery after flooding. It has been estimated that coastal erosion, flooding and debris management affects the residential and industrial properties, agricultural lands, and recreational areas with protection systems costing billions of dollars yearly around the world.

1. Introduction

With the growth in population together with industrial and recreational activities coastal protection against erosion, flooding and debris management are becoming major issues (Fig. 1). During hurricanes all the three events, coastal erosion, flooding and debris accumulation happen at the same time. On an average about 30 % of the world's population live along the coastline. The dynamic geophysical-biochemical continuous erosion processes along the coastal areas are becoming as major issues because of loss of land and increase flooding due to subsidence of the ground. There are no standards to control or minimize the coastal erosion process. Increased built in areas are part of the problem for urban flooding.

Because of growing concerns regarding the impact of floatable debris, several legislations have been passed and programs implementing the legislations have been established. In October 2000, Congress passed the Beaches Environmental Assessment and Coastal Health (BEACH)

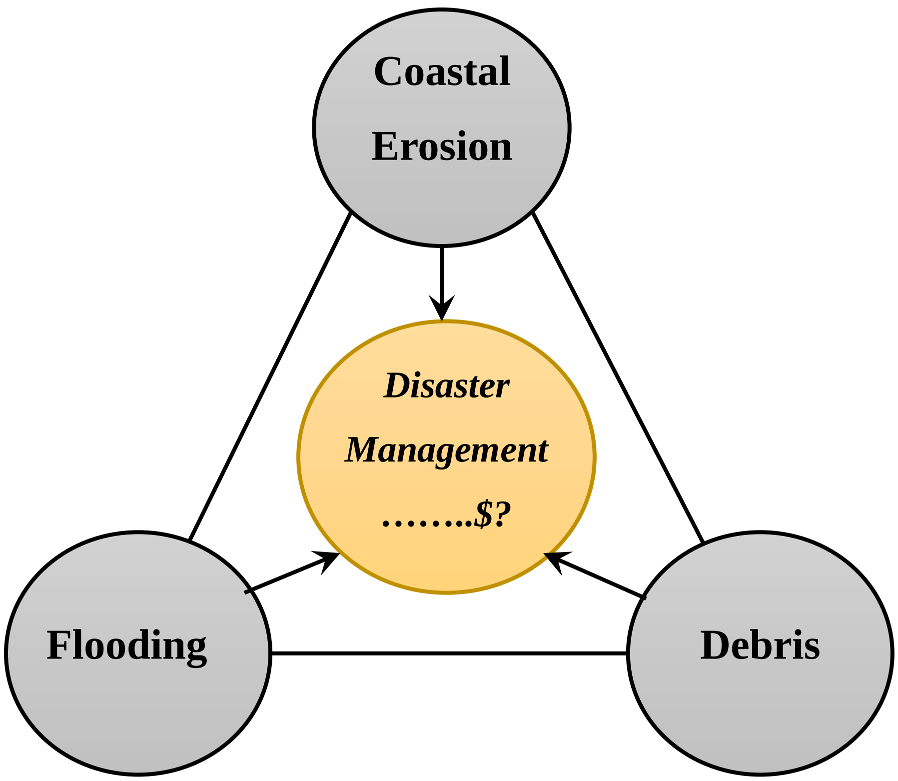

Figure 1. Major Disaster Management Triangle

The BEACH Act, among other things, asked EPA to provide technical assistance to states and local governments in assessing and monitoring their floatable materials. Since then EPA has developed a document on "Assessing and Monitoring Floatable Debris" (USEPA 2002). The purpose of this document was to help states, tribes, and local governments develop programs to assess and monitor their coastal recreation waters for floatable debris. These programs could be used to help identify sources of floatable debris, protect human and animal health and safety in those waters, and restore and preserve the overall coastal watershed and aquatic environment.

2. Objectives

The overall objective was to investigate the issues related to coastal erosion, flooding and floating debris. The specific objectives are as follows:

(1) Characterize the types of coastlines, quantify the erosion and evaluate the coast protection methods.
(2) Characterize the types of inland and coastal flooding, evaluate the monitoring systems, and evaluate the flood protection methods.
(3) Characterize the types of floating debris, evaluate the monitoring systems, and evaluate the debris removal methods.

Also potential for developing new theories to quantify coastal erosion, flooding and floating debris and integration of new technologies will be evaluated.

3. Coastal Erosion

Coast is the interface between the ocean and land and the interaction results in the Coastal erosion. Coastal erosion is a continuous chemo-physical dynamic process of wearing away of the land and the removal of beaches or dune sediments by coastal waves, high winds and flooding. Waves, physical-dynamic processes, are generated by natural disasters such as hurricanes, storms, wind, or manmade disaster like fast moving motor craft, causing the coastal erosion, which may take the form of long-term losses of sediments and rocks, or merely the temporary redistribution of coastal sediments. The pH of the seawater and the contaminations due to oil and chemical spills are the chemo-dynamic process causing erosion. The study of erosion and sediment redistribution is called 'coastal morphodynamics'.

(a) Characterization

The occurrence of coastal erosion is dependent upon the balance between the resistance, or erodibility, of the coastline and strength or the driving force of erosivity of the waves affecting the area. There are number of factors influencing the coastal erosion and erosion rates are as follows: (a) type of geological formations exposed along the coast – natural resistance to erosion (b) waves, wind and local flooding –driving force (c) engineered coastal protections – artificial protections and (d) weather and sea level changes – environmental conditions. Coastal erosion typically results in a landward retreat of the coastline resulting in salt-water into fresh water area.

Based on the geoformation of the coasts, these coasts can be characterized as follows:

Type 1: Rock coastline – Based on the geographical location and geology, rocks will be along the coastline. The rock types can vary from volcanic deposits, sandstone, limestone and shale (Fig. 2).

Figure 2. Type 1 Rock Coastline

Type 2: Rock and Soil coastline – A mix of rocks and soils along the coastline. Generally, the soils will erode faster than the rocks (Fig. 3).

Figure 3. Type 2 Rock and Soil Coastline

Type 3: Soil coastline – A mix of rocks and soils along the coastline. Generally, the soils will erode faster than the rocks (Fig. 4).

Figure 4. Type 3 Soil Coastline

Coastal erosion is most likely to occur in coastal lowland areas and along "soft" sediment coastlines represented by Type 3 coastline. The types of coastlines in the United States are shown in Fig. 5.

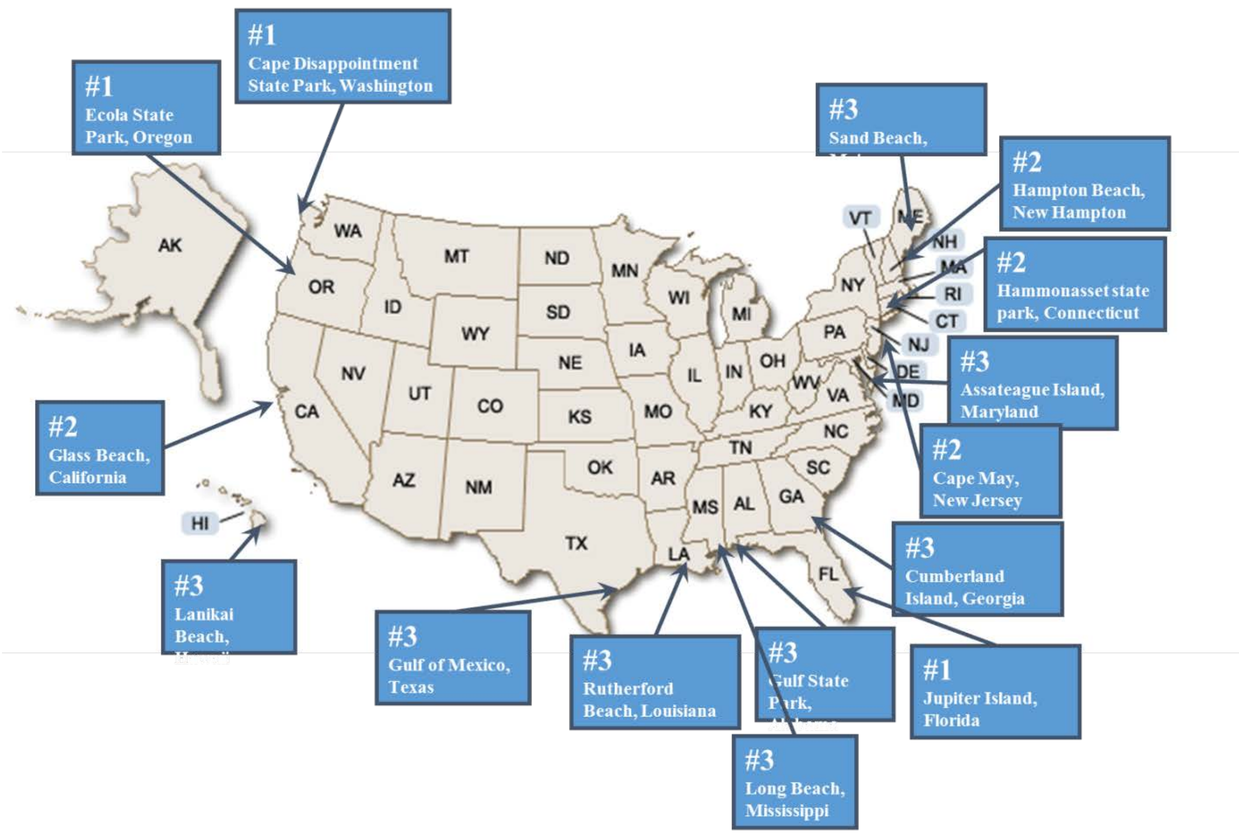

Figure 5. Distribution of Types of Coastlines in the U.S.

(b) Quantification

The general coastline for the United States is over 12,830 miles and tidal shoreline length is over 88,630 miles.

Table 1. General and Tidal Coastal Lengths and Hurricanes

States	General Coastline (miles)	Tidal Shoreline (miles)	Hurricanes/Major (Category $\geq$ 3) (1851 - 2016)	Remarks
Alabama	53	607	26/5	Second lowest tidal shore lines
Florida (Gulf)	770	5,095	?	Second highest tidal shoreline. Highest total but second in major hurricanes
Louisiana	397	7,721	57/18	Highest tidal shoreline. Third highest total and major hurricanes
Mississippi	44	359	20/8	Lowest tidal shoreline
Texas	367	3,359	63/19	Third highest tidal shoreline. Highest in major hurricanes but second highest in total hurricanes.
Regional Coastal Lengths				
Gulf	1,631	17,141	273	Nearly 20% of the tidal shoreline. Has the highest total and major hurricanes
Atlantic	2,069	28,673	101	
Pacific	7,623	40,298		
Arctic	1,060	2,521		
U.S.	12,383	88,633	151*	Number of hurricanes does not directly correlate to the length of tidal shoreline.

* State totals will not be equal to the U.S. total.

Factors that influence erosion rates

Primary factors

The ability of waves to cause erosion of the cliff face depends on many factors. The erosion rates are summarized in Table 2. The hardness (or inversely, the erodibility) of sea-facing rocks is controlled by the rock strength and the presence of fissures, fractures, and beds of non-cohesive materials such as silt and fine sand.

The rate at which cliff fall debris is removed from the foreshore depends on the power of the waves crossing the beach. This energy must reach a critical level to remove material from the debris lobe. Debris lobes can be very persistent and can take many years to completely disappear. Beaches dissipate wave energy on the foreshore and provide a measure of protection to the adjoining land.

Once stable, the foreshore should widen and become more effective at dissipating the wave energy, so that fewer and less powerful waves reach beyond it. The provision of updrift material coming onto the foreshore beneath the cliff helps to ensure a stable beach.

The adjacent bathymetry, or configuration of the seafloor, controls the wave energy arriving at the coast, and can have an important influence on the rate of cliff erosion. Shoals and bars offer protection from wave erosion by causing storm waves to break and dissipate their energy before reaching the shore. Given the dynamic nature of the seafloor, changes in the location of shoals and bars may cause the locus of beach or cliff erosion to change position along the shore.

Analytical approach for erosion quantification

Erosion can be quantified analytically. The impact of the waves in the coastal area leads to the erosion and if the shear stress between the sea water and the coast of the beach reaches to the critical shear stress the erosion initiates. Shear Stress in Vipulanandan form can be defined as Eq. (1) as shown in Fig. 5.

$$\tau = \tau_o + \frac{\dot{\gamma}}{A + B\dot{\gamma}} \quad \textbf{(1)}$$

At critical strain rate the Vipulanandan shear stress is shown in Eq. (2)

$$\tau = \tau_o + \frac{\dot{\gamma}_c}{A + B\dot{\gamma}_c} \quad \textbf{(2)}$$

The impact of the waves can be expressed as the energy rate which is defined as Eq. (3). Energy rate per unit volume $\dot{E}\left(\frac{Pa}{s}\right)$ is the summation of the area under the curve in Fig. 5.

$$\dot{E} = \int d\dot{E} = \int \tau d\dot{\gamma} \quad \textbf{(3)}$$

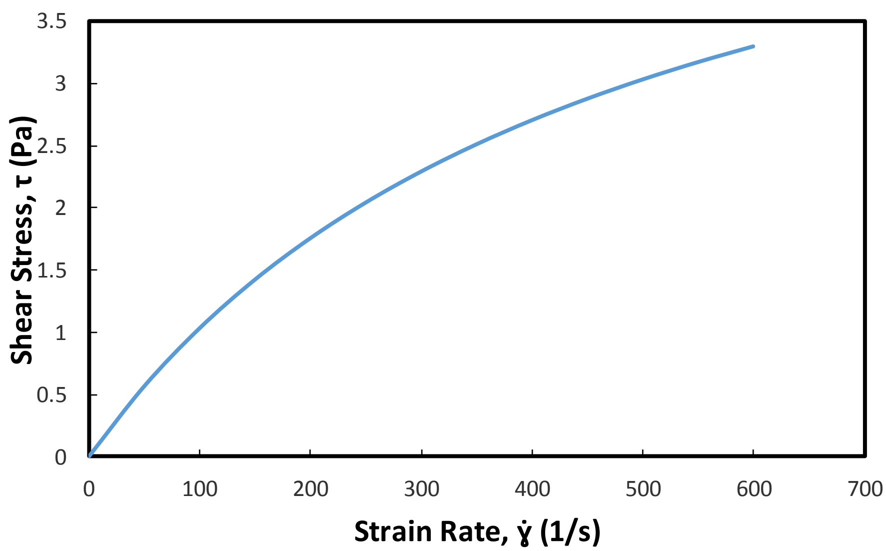

Figure 5. Shear stress versus strain rate

Substituting shear stress Eq. (1) in Eq. (3) and taking the integration, the energy rate will be derived as Eq. (4). Therefore, at the critical strain rate and the critical shear stress the energy rate reaches to the impact required by the wave to erode the coastal area.

$$\dot{E} = \frac{-A\, ln|A + B\dot{\gamma}|}{B^2} + \frac{\dot{\gamma}}{B} + C\tau_o \qquad \textbf{(4)}$$

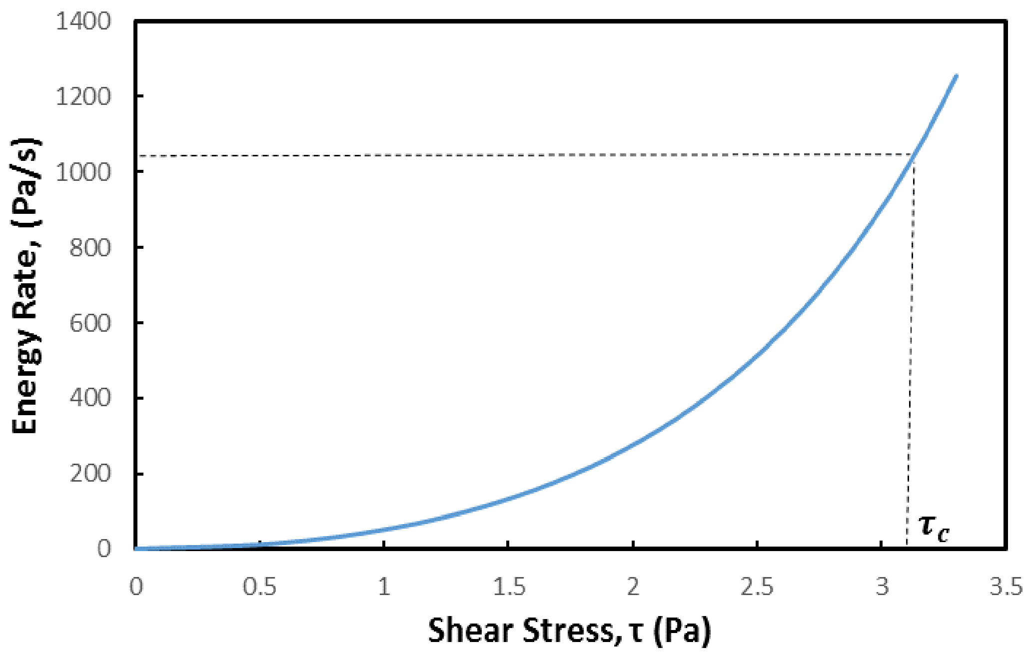

Figure 6. Energy rate versus shear stress

Coastal erosion has been greatly affected by the rising sea levels globally. There have been great measures of increased coastal erosion on the Eastern seaboard of the United States. Locations such as Florida have noticed increased coastal erosion. In reaction to these increases Florida and its individual counties have increased budgets to replenish the eroded sands that attract visitors to Florida and help support its multibillion-dollar tourism industries.

Table 2. Erosion Rates and Cost in the U.S.

<table>
<tr><th rowspan="3" colspan="2">Shorelines</th><th colspan="6">Coastal Erosion,
Erosion Rate (m/Year)</th><th rowspan="3">Cost (Millions of Dollars)</th></tr>
<tr><th colspan="2">Long Term</th><th colspan="2">Mean</th><th colspan="2">Range</th></tr>
<tr></tr>
<tr><td rowspan="5">Gulf Coast</td><td>Florida</td><td rowspan="5">N/A</td><td>-0.1 ± 0.1 [1]</td><td rowspan="5">-1.8 [4]</td><td>-0.4 [4]</td><td rowspan="5">8.8/- 15.3 [4]</td><td>8.8/-4.5 [4]</td><td rowspan="5">$100–$200 [5]</td></tr>
<tr><td>Alabama</td><td>-0.4 ± 0.8 [1]</td><td>-1.1 [4]</td><td>0.8/-3.1 [4]</td></tr>
<tr><td>Louisiana</td><td>-7.1 ± 4.5 [1]</td><td>-4.2 [4]</td><td>3.4/-15.3 [4]</td></tr>
<tr><td>Mississippi</td><td>-2.3 ± 1.9 [1]</td><td>-0.6 [4]</td><td>0.6/-6.4 [4]</td></tr>
<tr><td>Texas</td><td>-0.7 ± 1.7 [1]</td><td>-1.2 [4]</td><td>0.8/-5.0 [4]</td></tr>
<tr><td colspan="2">Atlantic Coast</td><td colspan="2">-0.6 ± 0.1 [2]</td><td colspan="2">-0.8 [4]</td><td colspan="2">25.5/-24.6 [4]</td><td>$1,700-$2,700 [5]</td></tr>
<tr><td colspan="2">Pacific Coast</td><td colspan="2">0.9 ± 0.07 [3]</td><td colspan="2">-0.005 – 0 [4]</td><td colspan="2">10.0/-4.2 [4]</td><td>$900–$1,000 [5]</td></tr>
<tr><td colspan="2">U.S.</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td>$3,300–$4,800 [5]</td></tr>
</table>

[1]. Morton, R. A., Miller, T. L. and Moore, L. J., (2004), "National Assessment of Shoreline Change: Part 1 Historical Shoreline Changes and Associated Coastal Land Loss Along the U.S. Gulf of Mexico", U.S. Geological Survey Center for Coastal and Watershed Studies.

[2]. Hapke, Ch. J., Himmelstoss, E. A., Kratzmann, M. G., List, J. H. and Thieler, E. R., (2011), "National Assessment of Shoreline Change: Historical Shoreline Change along the New England and Mid-Atlantic Coasts", U.S. Geological Survey Woods Hole Coastal and Marine Science Center.

[3] Ruggiero, P., Kratzmann, M. G., Himmelstoss, E. A., Reid D., Allen, J. and Kaminsky G., (2012), "National Assessment of Shoreline Change: Historical Shoreline Change Along the Pacific Northwest Coast", U.S. Geological Survey Woods Hole Coastal and Marine Science Center.

[4] Pilkey, O. H., Jr and Thieler, E. R., (1992), "Erosion of the United States Shoreline", Quaternary Coasts of the United States: Marine and Lacustrine Systems. SEPM (Society for Sedimentary Geology) Special Publication No. 48

[5] The H. John Heinz III Center for Science, Economics and the Environment (2000), "Evaluation of Erosion Hazards", for Science, Economics and the Environment.

(c) Monitoring

The Global Position System (GPS) and terrestrial Light Detection and Ranging (LiDAR) surveys are used to measure the costal profile changes. The terrestrial LiDAR surveys provide perhaps the most accurate measurement of coastal profile change. Three-dimensional (3D) numerical models of the coastline can be produced and volumetric change calculated. Aerial photographs and historic maps can also provide information on variation in coastal position, although attention should be paid to the definition of the coastline provided in these data sources. The land-water interface detailed in aerial photography is tide height dependent and hence the information on the tide state must also be collected. Quantitative video monitoring of the coastline is also increasingly being employed.

There are no real-time monitoring tools available for coastal erosion monitoring, where not only the location but also the material losses have to be quantified.

(d) Protection

There are few common forms of coastal erosion control methods. These include: soft-erosion controls, hard-erosion controls, and others.

Long-term erosion controls

Long-term erosion control methods provide a more permanent solution than soft-erosion control methods. Seawalls, dikes, wave breakers and groynes serve as semi-permanent infrastructure. These structures are not immune from normal wear-and-tear and will have to be refurbished or rebuilt. It is estimated the average life span of a seawall is 50–100 years and the average for a groyne is 30–40 years. Because of their relative permanence, it is assumed that these structures can be a final solution to erosion. Seawalls can also deprive public access to the beach and drastically alter the natural state of the beach. Groynes also drastically alter the natural state of the beach. Some claim that groynes could reduce the interval between beach nourishment projects though they are not seen as a solution to beach nourishment.

Natural forms of hard-erosion control include planting or maintaining native vegetation, such as mangrove forests and coral reefs.

Short-term erosion controls

Short term erosion strategies refer to temporary options of slowing the effects of erosion. These options, including sandbags and beach nourishments which are not intended to be long term solutions or permanent solutions. Another method, beach scraping or beach bulldozing allows for the creation of an artificial dune in front of a building or as means of preserving a building foundation. However, there is a U.S. federal moratorium on beach bulldozing during turtle nesting season, 1 May – 15 November. One of the most common methods of short-term erosion control is beach nourishment projects. These projects involve dredging sand and moving it to the beaches as a means of reestablishing the sand lost due to erosion.

New Technologies

In order to minimize the physical dynamic processes, artificial islands with sea plants, geosynthetic covers and buried shutters with energy production are being developed. The artificial islands will be shaped to reduce the wave speeds to minimize erosion. Geosynthetic covers are being developed to reduce the erosion. Buried shutter are being develop to brake the under current, reduce erosion and protect the bathymetry. Drones technology can be developed for real-time monitoring of the coastal region.

4. Flooding

A flood is an overflow of water that submerges land which is usually dry. Some of the billion dollar damged flooding is summarized in Table 3. Flooding may occur as an overflow of water from water bodies, such as a river, lake, or ocean, in which the water overtops or breaks levees, resulting in some of that water escaping its usual boundaries, or it may occur due to an accumulation of rainwater on saturated ground in an areal flood. While the size of a lake or other body of water will vary with seasonal changes in precipitation and snow melt, these changes in size are unlikely to be considered significant unless they flood property or drown domestic animals. Floods can also occur in rivers when the flow rate exceeds the capacity of the river channel, particularly at bends or meanders in the waterway. Floods often cause damage to homes and businesses if they are in the natural flood plains of rivers. While riverine flood damage can be eliminated by moving away from rivers and other bodies of water, people have traditionally lived and worked by rivers because the land is usually flat and fertile and because rivers provide easy travel and access to commerce and industry. Some floods develop slowly, while others such as flash floods, can develop in just a few minutes and without visible signs of rain. Additionally, floods can be local, impacting a neighborhood or community, or very large, affecting entire river basins.

4a. Characterization

Areal

Floods can happen on flat or low-lying areas when water is supplied by rainfall or snowmelt more rapidly than it can either infiltrate or run off. The excess accumulates in place, sometimes to hazardous depths. Surface soil can become saturated, which effectively stops infiltration, where the water table is shallow, such as a floodplain, or from intense rain from one or a series of storms. Infiltration also is slow to negligible through frozen ground, rock, concrete, paving, or roofs. Areal flooding begins in flat areas like floodplains and in local depressions not connected to a stream channel, because the velocity of overland flow depends on the surface slope. Endorheic basins may experience areal flooding during periods when precipitation exceeds evaporation.

Table 3. Billion Dollar Flooding Events in the U.S.

Event	Impacted Areas	Affected Population	Losses	Remarks
Gulf States Storms and Flooding December 1982-January 1983	TX, AR, LA, MS, AL, GA, and FL	45 deaths	$3.6 billion	Severe storms and flooding, especially in the states of TX, AR, LA, MS, AL, GA, and FL
Southern Flooding May 1990	TX, OK, LA, and AR	13 deaths	$1.8 billion	Torrential rains cause flooding along the Trinity, Red, and Arkansas Rivers in TX, OK, LA, and AR
Texas Flooding October 1994	Southeast Texas	19 deaths	$1.6 billion	Torrential rain (10-25 inches in 5 days) and thunderstorms cause flooding across much of southeast Texas
Texas Flooding October 1998	Texas	31 deaths	$1.4 billion	Severe flooding in southeast Texas from 2 heavy rain events, with 10-20 inch rainfall totals.
Texas and Oklahoma Flooding and Severe Weather† May 2015	Texas and also other states (KS, CO, AR, OH, LA, GA, SC)	31 deaths	$2.5 billion	A slow-moving system caused tremendous rainfall and subsequent flooding to occur in Texas and Oklahoma. The Blanco river in Texas swelled from 5 feet to a crest of more than 40 feet over several hours causing considerable property damage and loss of life. The city of Houston also experienced flooding which resulted in hundreds of high-water rescues. The damage in Texas alone exceeded $1.0 billion.
Texas and Louisiana Flooding† March 2016	Texas and Louisiana	5 deaths	$1.3 billion	Multiple days of heavy rainfall averaging 15 to 20 inches led to widespread flooding along the Sabine River basin on the Texas and Louisiana border. This prompted numerous evacuations, high-water rescues and destruction, as more than 1,000 homes and businesses were damaged or destroyed.
Houston Flooding† April 2016	Houston	8 deaths	$1.2 billion	A period of extreme rainfall up to 17 inches created widespread urban flooding in Houston and surrounding suburbs. Over 1,000 homes and businesses were damaged in addition to more than 1,800 high water rescues. This represents the most widespread flooding event to affect Houston since Tropical Storm Allison in 2001.

http://www.ncdc.noaa.gov/billions/events

Riverine (Channel)

Floods occur in all types of river and stream channels, from the smallest ephemeral streams in humid zones to normally-dry channels in arid climates to the world's largest rivers. When overland flow occurs on tilled fields, it can result in a muddy flood where sediments are picked up by run off and carried as suspended matter or bed load. Localized flooding may be caused or exacerbated by drainage obstructions such as landslides, ice, debris, or beaver dams.

Slow-rising floods most commonly occur in large rivers with large catchment areas. The increase in flow may be the result of sustained rainfall, rapid snow melt, monsoons, or tropical cyclones. However, large rivers may have rapid flooding events in areas with dry climate, since they may have large basins but small river channels and rainfall can be very intense in smaller areas of those basins.

Rapid flooding events, including flash floods, more often occur on smaller rivers, rivers with steep valleys, rivers that flow for much of their length over impermeable terrain, or normally-dry channels. The cause may be localized convective precipitation (intense thunderstorms) or sudden release from an upstream impoundment created behind a dam, landslide, or glacier. In one instance, a flash flood killed 8 people enjoying the water on a Sunday afternoon at a popular waterfall in a narrow canyon. Without any observed rainfall, the flow rate increased from about 50 to 1,500 cubic feet per second (1.4 to 42 m^3/s) in just one minute. Two larger floods occurred at the same site within a week, but no one was at the waterfall on those days. The deadly flood resulted from a thunderstorm over part of the drainage basin, where steep, bare rock slopes are common and the thin soil was already saturated.

Flash floods are the most common flood type in normally-dry channels in arid zones, known as arroyos in the southwest United States and many other names elsewhere. In that setting, the first flood water to arrive is depleted as it wets the sandy stream bed. The leading edge of the flood thus advances more slowly than later and higher flows. As a result, the rising limb of the hydrograph becomes ever quicker as the flood moves downstream, until the flow rate is so great that the depletion by wetting soil becomes insignificant.

Estuarine and coastal

Flooding in estuaries is commonly caused by a combination of sea tidal surges caused by winds and low barometric pressure, and they may be exacerbated by high upstream river flow.

Coastal areas may be flooded by storm events at sea, resulting in waves over-topping defenses or in severe cases by tsunami or tropical cyclones. A storm surge, from either a tropical cyclone or an extratropical cyclone, falls within this category. Research from the NHC (National Hurricane Center) explains: "Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tides. Storm surge should not be confused with storm tide, which is defined as the water level rise due to the combination of storm surge and the astronomical tide. This rise in water level can cause extreme flooding in coastal areas particularly when storm surge coincides with normal high tide, resulting in storm tides reaching up to 20 feet or more in some cases."

Urban flooding

Urban flooding is the inundation of land or property in a built environment, particularly in more densely populated areas, caused by rainfall overwhelming the capacity of drainage systems, such as storm sewers. Although sometimes triggered by events such as flash flooding or snowmelt, urban flooding is a condition, characterized by its repetitive and systemic impacts on communities, that can happen regardless of whether or not affected communities are located within designated floodplains or near any body of water. Aside from potential overflow of rivers and lakes, snowmelt, stormwater or water released from damaged water mains may accumulate on property and in public rights-of-way, seep through building walls and floors, or backup into buildings through sewer pipes, toilets and sinks.

In urban areas, flood effects can be exacerbated by existing paved streets and roads, which increase the speed of flowing water.

The flood flow in urbanized areas constitutes a hazard to both the population and infrastructure. Some recent catastrophes include the inundations of Nîmes (France) in 1998 and Vaison-la-Romaine (France) in 1992, the flooding of New Orleans (USA) in 2005, and the flooding in Rockhampton, Bundaberg, Brisbane during the 2010–2011 summer in Queensland (Australia). Flood flows in urban environments have been studied relatively recently despite many centuries of flood events. Some recent research has considered the criteria for safe evacuation of individuals in flooded areas.

Catastrophic

Catastrophic riverine flooding is usually associated with major infrastructure failures such as the collapse of a dam, but they may also be caused by drainage channel modification from a landslide, earthquake or volcanic eruption. Examples include outburst floods and lahars. Tsunamis can cause catastrophic coastal flooding, most commonly resulting from undersea earthquakes.

4b. Quantification

Flooding is another major disaster caused mainly by hurricanes and storms. A series of annual maximum flow rates in a stream reach can be analyzed statistically to estimate the 100-year flood and floods of other recurrence intervals there. Similar estimates from many sites in a hydrologically similar region can be related to measurable characteristics of each drainage basin to allow indirect estimation of flood recurrence intervals for stream reaches without sufficient data for direct analysis.

Physical process models of channel reaches are generally well understood and will calculate the depth and area of inundation for given channel conditions and a specified flow rate, such as for use in floodplain mapping and flood insurance. Conversely, given the observed inundation area of a recent flood and the channel conditions, a model can calculate the flow rate. Applied to various potential channel configurations and flow rates, a reach model can contribute to selecting an optimum design for a modified channel. Various reach models are available as of 2015, either 1D models (flood levels measured in the channel) or 2D models (variable flood depths measured across the extent of a floodplain). HEC-RAS, the Hydraulic Engineering Center model, is among the most popular software, if only because it is available free of charge. Other models such as TUFLOW combine 1D and 2D components to derive flood depths across both river channels and the entire floodplain.

Physical process models of complete drainage basins are even more complex. Although many processes are well understood at a point or for a small area, others are poorly understood at all scales, and process interactions under normal or extreme climatic conditions may be unknown. Basin models typically combine land-surface process components (to estimate how much rainfall or snowmelt reaches a channel) with a series of reach models. For example, a basin model can calculate the runoff hydrograph that might result from a 100-year storm, although the recurrence interval of a storm is rarely equal to that of the associated flood. Basin models are commonly used in flood forecasting and warning, as well as in analysis of the effects of land use change and climate change.

Primary effects

The primary effects of flooding include loss of life, damage to buildings and other structures, including bridges, sewerage systems, roadways, and canals. Floods also frequently damage power transmission and sometimes power generation, which then has knock-on effects caused by the loss of power. This includes loss of drinking water treatment and water supply, which may result in loss of drinking water or severe water contamination. It may also cause the loss of sewage disposal facilities. Lack of clean water combined with human sewage in the flood waters raises the risk of waterborne diseases, which can include typhoid, giardia, cryptosporidium, cholera and many other diseases depending upon the location of the flood.

Damage to roads and transport infrastructure may make it difficult to mobilize aid to those affected or to provide emergency health treatment.

Flood waters typically inundate farm land, making the land unworkable and preventing crops from being planted or harvested, which can lead to shortages of food both for humans and farm animals. Entire harvests for a country can be lost in extreme flood circumstances. Some tree species may not survive prolonged flooding of their root systems.

Secondary and long-term effects

Economic hardship due to a temporary decline in tourism, rebuilding costs, or food shortages leading to price increases is a common after-effect of severe flooding. The impact on those affected may cause psychological damage to those affected, in particular where deaths, serious injuries and loss of property occur.

Urban flooding can lead to chronically wet houses, which are linked to an increase in respiratory problems and other illnesses. Urban flooding also has significant economic implications for affected neighborhoods. In the United States, industry experts estimate that wet basements can lower property values by 10-25 percent and are cited among the top reasons for not purchasing a home. According to the U.S. Federal Emergency Management Agency (FEMA), almost 40 percent of small businesses never reopen their doors following a flooding disaster. In the United States, insurance is available against flood damage to both homes and businesses.

Benefits

Floods (in particular more frequent or smaller floods) can also bring many benefits, such as recharging ground water, making soil more fertile and increasing nutrients in some soils. Flood waters provide much needed water resources in arid and semi-arid regions where precipitation can be very unevenly distributed throughout the year and kills pests in the farming land. Freshwater floods particularly play an important role in maintaining ecosystems in river corridors and are a key factor in maintaining floodplain biodiversity. Flooding can spread nutrients to lakes and rivers, which can lead to increased biomass and improved fisheries for a few years.

For some fish species, an inundated floodplain may form a highly suitable location for spawning with few predators and enhanced levels of nutrients or food. Fish, such as the weather fish, make use of floods in order to reach new habitats. Bird populations may also profit from the boost in food production caused by flooding.

Periodic flooding was essential to the well-being of ancient communities along the Tigris-Euphrates Rivers, the Nile River, the Indus River, the Ganges and the Yellow River among others. The viability of hydropower, a renewable source of energy, is also higher in flood prone regions.

4c. Monitoring

At the most basic level, the best defense against floods is to seek higher ground for high-value uses while balancing the foreseeable risks with the benefits of occupying flood hazard zones. Critical community-safety facilities, such as hospitals, emergency-operations centers, and police, fire, and rescue services, should be built in areas least at risk of flooding. Structures, such as bridges, that must unavoidably be in flood hazard areas should be designed to withstand flooding. Areas most at risk for flooding could be put to valuable uses that could be abandoned temporarily as people retreat to safer areas when a flood is imminent.

Planning for flood safety involves many aspects of analysis and engineering, including:

- observation of previous and present flood heights and inundated areas,
- statistical, hydrologic, and hydraulic model analyses,
- mapping inundated areas and flood heights for future flood scenarios,
- long-term land use planning and regulation,
- engineering design and construction of structures to control or withstand flooding,
- intermediate-term monitoring, forecasting, and emergency-response planning, and
- short-term monitoring, warning, and response operations.

Each topic presents distinct yet related questions with varying scope and scale in time, space, and the people involved. Attempts to understand and manage the mechanisms at work in floodplains have been made for at least six millennia.

In the United States, the Association of State Floodplain Managers works to promote education, policies, and activities that mitigate current and future losses, costs, and human suffering caused by flooding and to protect the natural and beneficial functions of floodplains - all without causing adverse impacts. A portfolio of best practice examples for disaster mitigation in the United States is available from the Federal Emergency Management Agency.

Flood forecasting

Anticipating floods before they occur allows for precautions to be taken and people to be warned so that they can be prepared in advance for flooding conditions. For example, farmers can remove animals from low-lying areas and utility services can put in place emergency provisions to re-route services if needed. Emergency services can also make provisions to have enough resources available ahead of time to respond to emergencies as they occur. People can evacuate areas to be flooded.

In order to make the most accurate flood forecasts for waterways, it is best to have a long time-series of historical data that relates stream flows to measured past rainfall events. Coupling this historical information with real-time knowledge about volumetric capacity in catchment areas, such as spare capacity in reservoirs, ground-water levels, and the degree of saturation of area aquifers is also needed in order to make the most acrate flood forecasts.

Radar estimates of rainfall and general weather forecasting techniques are also important components of good flood forecasting. In areas where good quality data is available, the intensity and height of a flood can be predicted with fairly good accuracy and plenty of lead time. The output of a flood forecast is typically a maximum expected water level and the likely time of its arrival at key locations along a waterway, and it also may allow for the computation of the likely statistical return period of a flood. In many developed countries, urban areas at risk of flooding are protected against a 100-year flood - that is a flood that has a probability of around 63% of occurring in any 100-year period of time.

According to the U.S. National Weather Service (NWS) Northeast River Forecast Center (RFC) in Taunton, Massachusetts, a rule of thumb for flood forecasting in urban areas is that it takes at least 1 inch (25 mm) of rainfall in around an hour's time in order to start significant ponding of water on impermeable surfaces. Many NWS RFCs routinely issue Flash Flood Guidance and Headwater Guidance, which indicate the general amount of rainfall that would need to fall in a short period of time in order to cause flash flooding or flooding on larger water basins.

In the United States, an integrated approach to real-time hydrologic computer modelling utilizes observed data from the U.S. Geological Survey (USGS), various cooperative observing networks, various automated weather sensors, the NOAA National Operational Hydrologic Remote Sensing Center (NOHRSC), various hydroelectric companies, etc. combined with quantitative precipitation forecasts (QPF) of expected rainfall and/or snow melt to generate daily or as-needed hydrologic forecasts. The NWS also cooperates with Environment Canada on hydrologic forecasts that affect both the USA and Canada, like in the area of the Saint Lawrence Seaway.

The Global Flood Monitoring System, "GFMS," a computer tool which maps flood conditions worldwide, is available online. Users anywhere in the world can use GFMS to determine when floods may occur in their area. GFMS uses precipitation data from NASA's Earth observing satellites and the Global Precipitation Measurement satellite, "GPM." Rainfall data from GPM is combined with a land surface model that incorporates vegetation cover, soil type, and terrain to determine how much water is soaking into the ground, and how much water is flowing into streamflow.

Users can view statistics for rainfall, streamflow, water depth, and flooding every 3 hours, at each 12 kilometer gridpoint on a global map. Forecasts for these parameters are 5 days into the future. Users can zoom in to see inundation maps (areas estimated to be covered with water) in 1 kilometer resolution.

4d. Protection

In many countries around the world, waterways prone to floods are often carefully managed. Defenses such as detention basins, levees, bunds, reservoirs, and weirs are used to prevent waterways from overflowing their banks. When these defenses fail, emergency measures such as sandbags or portable inflatable tubes are often used to try to stem flooding. Coastal flooding has been addressed in portions of Europe and the Americas with coastal defenses, such as sea walls, beach nourishment, and barrier islands.

In the riparian zone near rivers and streams, erosion control measures can be taken to try to slow down or reverse the natural forces that cause many waterways to meander over long periods of time. Flood controls, such as dams, can be built and maintained over time to try to reduce the occurrence and severity of floods as well. In the United States, the U.S. Army Corps of Engineers maintains a network of such flood control dams.

In areas prone to urban flooding, one solution is the repair and expansion of man-made sewer systems and stormwater infrastructure. Another strategy is to reduce impervious surfaces in streets, parking lots and buildings through natural drainage channels, porous paving, and wetlands (collectively known as green infrastructure or sustainable urban drainage systems (SUDS)). Areas identified as flood-prone can be converted into parks and playgrounds that can tolerate occasional flooding. Ordinances can be adopted to require developers to retain stormwater on site and require buildings to be elevated, protected by floodwalls and levees, or designed to withstand temporary inundation. Property owners can also invest in solutions themselves, such as re-landscaping their property to take the flow of water away from their building and installing rain barrels, sump pumps, and check valves.

5. Floating Debris

Urban and river flooding can carry street litter, fallen trees and damaged infrastructure debris into the nearby storm water drainage systems and rivers causing several problems. Coastal flooding can carry sea weeds, large bolder and also sea animals causing challenging problems. Typical floatables street litter will include cigarette butts, filters, and filter elements, medical items (syringes), resin pellets, food packaging, beverage containers, and other material that might have been washed down a storm drain or ditch or run off from land (Perham 1988; Battelle 1993; Gaugler 1999; Lagasse 2010). There is increasing concern about the large wood floatable debris in the storm water drainage systems, combined sewer systems and rivers causing several problems including undermining bridge structures and blocking highways, rail tracks and river navigation. Coastal flooding can result in large volumes of sea weeds accumulation and deposint of large rocks and boulders.

5a. Characterization

Because of growing concerns regarding the impact of floatable debris, several legislations have been passed and programs implementing the legislations have been established. In 1987, Congress approved ratification of Annex V of the MARPOL treaty and enacted domestic legislation known as the Marine Plastic Pollution Research and Control Act, which prohibits any ship in U.S. waters from dumping plastics (USEPA 1990; Lagasse 2010). Other floatable debris-related legislation includes the Shore Protection Act of 1988; the Marine Protection, Research, and Sanctuaries Act; and the Clean Water Act, as amended by the Water Quality Act of 1987. In October 2000, Congress passed the BEACH Act. The BEACH Act authorized the U.S. Environmental Protection Agency (EPA) to award program development and implementation grants to eligible states, territories, tribes, and local governments to support microbiological testing and monitoring of coastal recreation waters that are adjacent to beaches or similar points of access used by the public (USEPA 2002). It also tasks EPA to provide technical assistance to states and local governments in establishing assessment and monitoring programs for floatable materials. The BEACH Act defines floatable materials as any foreign matter that may float or remain suspended in the water column. The term included plastic, aluminum cans, wood products, bottles, and paper products.

Floatables Action Plan for New York and New Jersey Waters

The Floatables Action Plan was developed in 1989 by an interagency work group addressing ocean beach closings in New York and New Jersey waters due to debris washing onto the beaches. This plan was designed to reduce the number of such ocean beach closings. Implementation of the plan was facilitated by the use of helicopter and vessel surveillance, cleanup vessels, volunteers, and prison inmates.

(i) Goals

The Floatables Action Plan was designed to accomplish the following objectives:

(a) Minimize the amount of floatable debris escaping the Harbor Complex.

(b) Maintain an effective communication network to coordinate floatable debris removal activities and to respond to the spotting of slicks.

(c) Ensure timely notification of beach operators of potential wash-ups of floatable debris.

(d) Minimize beach closings due to floatable debris.

The plan defined floatable debris as waterborne waste material that is buoyant. Examples include wood, beach litter, aquatic vegetation, street litter, sewage-related wastes, fishing gear, and medical wastes. A number of agencies are implementing the plan.

(ii) Methodology

The plan calls for the use of skimmer vessels to contain and remove floatable debris before it escapes from the harbor; helicopter flyovers, which provide aerial surveillance to potentially reduce the impact of debris slicks spotted off the coasts; and the use of prison inmates to remove shoreline debris.

(iii) Unique Characteristics

The success of the Floatables Action Plan was due to the partnership involving New York, New Jersey, and local municipalities. The plan used multimedia approaches, such as aerial surveillance, coastal cleanup of the beaches by volunteers, and containing and removing debris from areas around storm water and CSO dischargers, to reduce the impact of debris on the coasts.

5b. Quantification

Natural disasters such as hurricanes and flooding cause major floating debris problems.

Table 4. Quantities of Debris After the Three Worst Hurricanes in the U.S.

Event	Types of Debris	Quantity of Debris	Cost of Removal	Remarks
Hurricane Katrina (August 23, 2005)	Curbside Debris, White Goods, Freon removal, Electronic Goods, Waste Containers, Hazardous waste Nonhazardous waste	3.4 million CY in Alabama! 45.8 million CY in Mississippi! 64.3 million CY in Louisiana!	$3.4 billion	Katrina disaster recovery presents the most massive clean-up in America's history.
Hurricane Ike (September 13, 2008)	Trees, White Goods, Hazardous waste Nonhazardous waste	5.0 million CY	$697.1 million	Total 1.2 million CY of sand was removed to a 12-inch depth.
Hurricane Sandy (October 22, 2012)	construction & demolition, Hazardous waste Nonhazardous waste	6.2 million CY	$675.5 million	Waterway debris More than 100,000 CY construction & demolition debris, 195 cars & vessels, 4 houses, 400,000 CY sediment

5c. Monitoring

Some of the plans call for the use of skimmer vessels to contain and remove floatable debris before it escapes from the harbor. Also helicopter flyovers, which provide aerial surveillance to potentially reduce the impact of debris slicks spotted off the coasts. There are no real-time monitoring methods in place for monitoring of the floating debris. Hence there is a need to develop monitoring systems to characterize the storm water drainage systems, including rivers, based on the geographical location, volume of flow, surrounding environment (trees, accessibility, industry, residents) and past history of floatable debris problems. Local survey and national survey (selected cities) documents should be developed focused on collecting information on the causes, effects and mitigation methods for floatable debris in the storm water drainage systems.

5d. Protection

Preliminary studies have shown that there are different methods that are being used to mitigate the floating debris problems. But there is need to develop new methods using sustainable engineering and green technologies. The initial focus will be on minimizing the floatables debris getting into the storm water drainage systems. Cost effective and sustainable protective systems need to be developed outside the open drainage channels to prevent the floatable debris getting into the system. Also new protective systems must be developed within the open drainage channels and rivers to limit the movement of the floatable debris. Also the cleaning of the channels and rivers will be made easier with the protective systems in-place. Various methods of removing and possibly recycling the floatable debris from the drainage systems needs to be investigated.

6. Conclusions

The coastal erosion, flooding and floating debris are three major events that requires better monitoring, control and developing effective protection systems.

7. Acknowledgement

The study was supported by the THC-IT with funding from Texas Department of Transportation. Sponsors are not responsible for any of the findings.

8. References

Oldale, Robert N. "Coastal Erosion on Cape Cod: Some Questions and Answers". U.S. Geological Survey. Retrieved 11 September 2009.

Dean, J. "Oceanfront Sandbag Use in North Carolina: Management Review and Suggestions for Improvement" (PDF). Nicholas School of the Environment of Duke University. Retrieved 11 October 2013.

Knapp, Whitney. "Impacts of Terminal Groins on North Carolina's Coast" (PDF). Nicholas School of the Environment of Duke University. Retrieved 15 October 2013.

"Coastal Hazards & Storm Information: Protecting Oceanfront Property from Erosion". North Carolina Division of Coastal Management. Retrieved 17 September 2013.

McPherson, M. "Adaptation to Sea-Level Rise in North Carolina" (PDF). Nicholas

School of the Environment of Duke University. Retrieved 25 October 2013.

KUENZER, C., OTTINGER, M., LIU, G., SUN, B., DECH, S., 2014: Earth Observation-based Coastal Zone Monitoring of the Yellow River Delta: Dynamics in China's Second Largest Oil Producing Region over four Decades. Applied Geography, 55, 72-107