4.3. Hazard Profiles and Vulnerability Analysis
NATURAL HAZARDS

4.3.1. Coastal Erosion

4.3.1.1. Location and Extent

There are two areas in Pennsylvania which are subject to potential coastal erosion hazards; the Lake Erie and Delaware River shorelines (Figure 4.3.1-1). The Lake Erie shoreline in Pennsylvania stretches 76.6 miles across the northern border of Erie County. It includes the highest bluffs anywhere on the Lake Erie shore and Presque Isle, the only significant coastal depositional feature on the south shore of the lake. Presque Isle is a compound re-curved spit made up of beach, dune, and inter-dune-pond features which protects Erie Harbor. Most of the Pennsylvania lake shore consists of narrow beaches in front of bluffs, five to one hundred-eighty feet high (PADEP, 2002). The glaciers that carved out the Great Lakes basin resulted in the deposition of sediments that make up the bluffs. These unconsolidated glacial sediments include sand, gravel and clay, all of which are very vulnerable to erosion when exposed to the forces of direct wave contact, groundwater flows, surface water runoff, ice, wind and rain. In some areas along the Lake Erie coast, the bluffs have a bottom layer of exposed bedrock or shale which is often weathered and undercut over the long-term by wave action.

The Delaware River is tidally influenced from the southern reaches of Delaware County, PA to Trenton, NJ (a distance of approximately 135 miles) and is therefore subject to coastal or wetland erosion. However, the high degree of urbanization along the southeastern Pennsylvania Delaware River shoreline has resulted in a significant amount of shoreline hardening with structures such as bulkheads, piers, and marginal wharves. While detailed structure inventories have not been performed, these structures greatly reduce erosion hazards along most of the Delaware River shoreline. Lake Erie is the area of primary concern for coastal erosion hazards and is therefore the focus of the risk assessment.

Figure 4.3.1-1 Map identifying areas where coastal erosion hazards are present in Pennsylvania (ESRI, 2010).

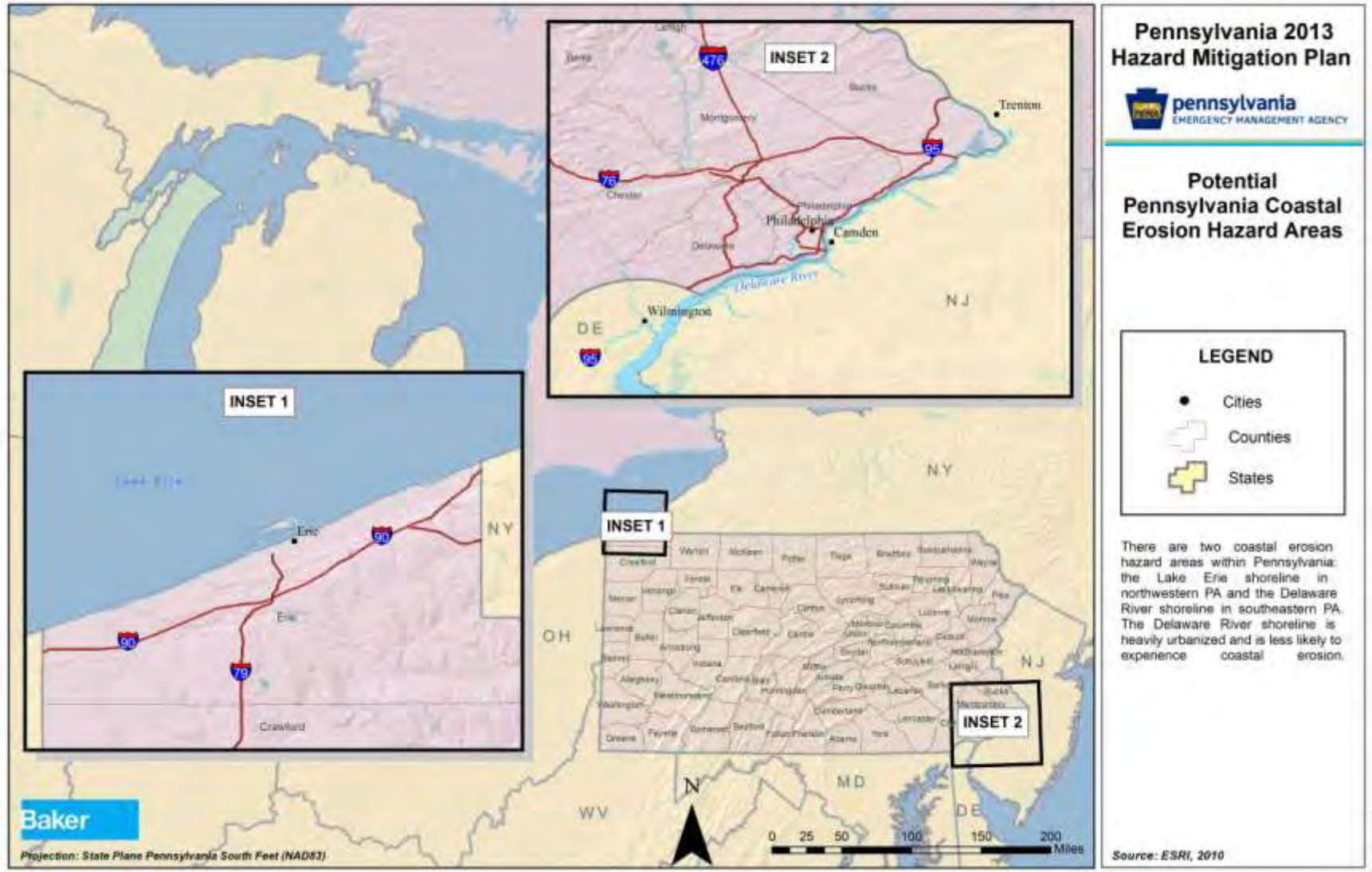
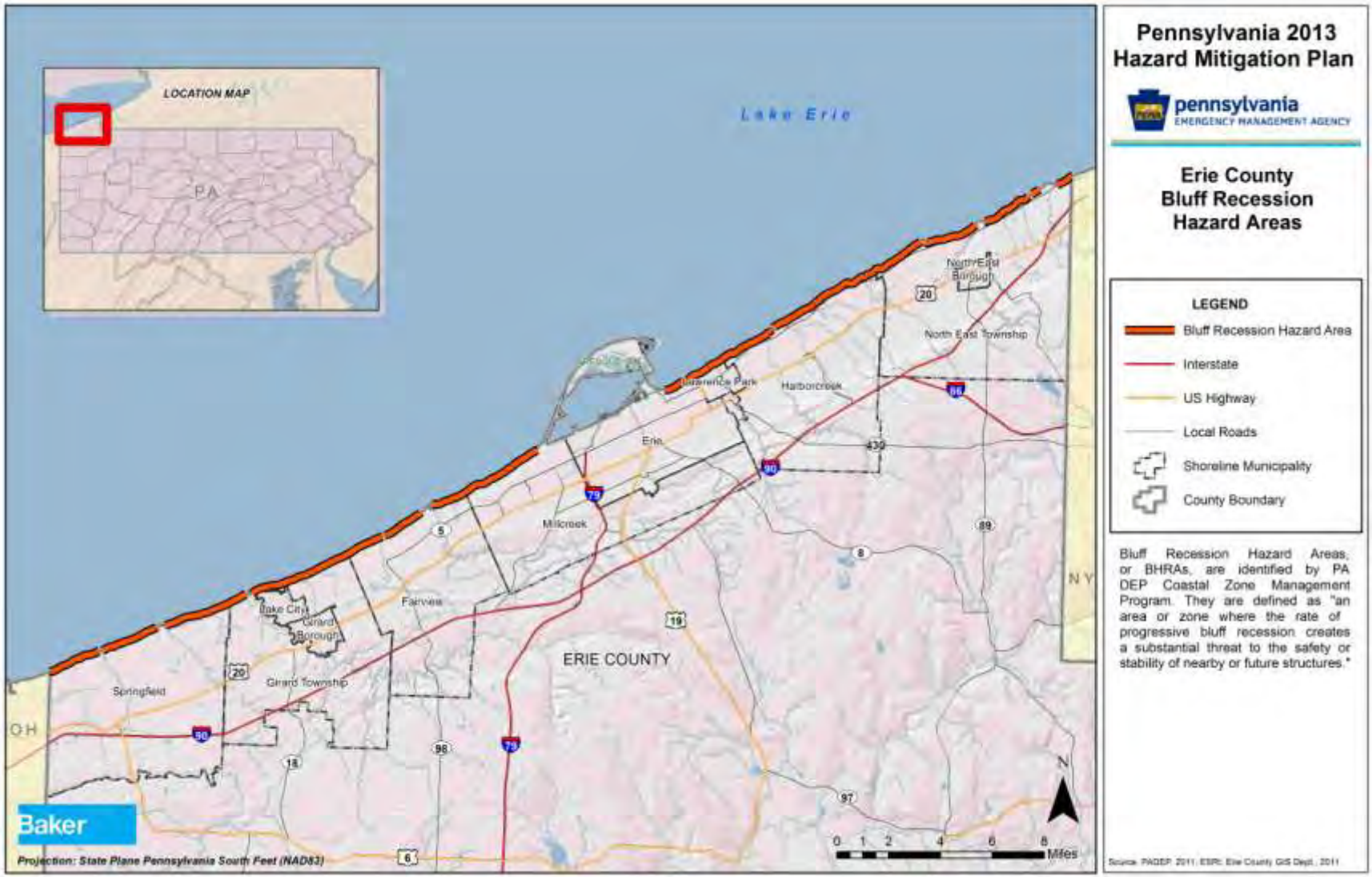


Figure 4.3.1-2 identifies Bluff Recession Hazard Areas (BRHAs) identified by the Pennsylvania Department of Environmental Protection Coastal Zone Management Program. BRHAs are defined in Section 3 of the Bluff Recession and Setback Act as "an area or zone where the rate of progressive bluff recession creates a substantial threat to the safety or stability of nearby or future structures or utility facilities." These bluffs are present along the majority of Erie County's border with Lake Erie and present a hazard. Original designations of BRHAs, codified at 25 Pa. Code § 85.26, are based on a 1975 study titled *Shoreline Erosion and Flooding – Erie County* (PADEP, 2004). Current designations were established in 2009 based on a 2004 study titled, *Study to Tentatively Designate Bluff Recession Hazard Areas*. All BHRAs were first established in 1980 except for the BRHA within the City of Erie, which was established during the 2009 update (PADEP, 2011).

The BRHAs determine where along the shoreline development will be subject to Minimum Bluff Setback Distances. Sections of shoreline which are not identified as a BRHA (e.g. beach and dune areas, headlands, armored shorelines, etc…) may not be subject to bluff recession, but remain vulnerable to shoreline erosion.

Figure 4.3.1-2 Bluff Recession Hazard Areas along the Lake Erie Shoreline (PADEP, 2011)

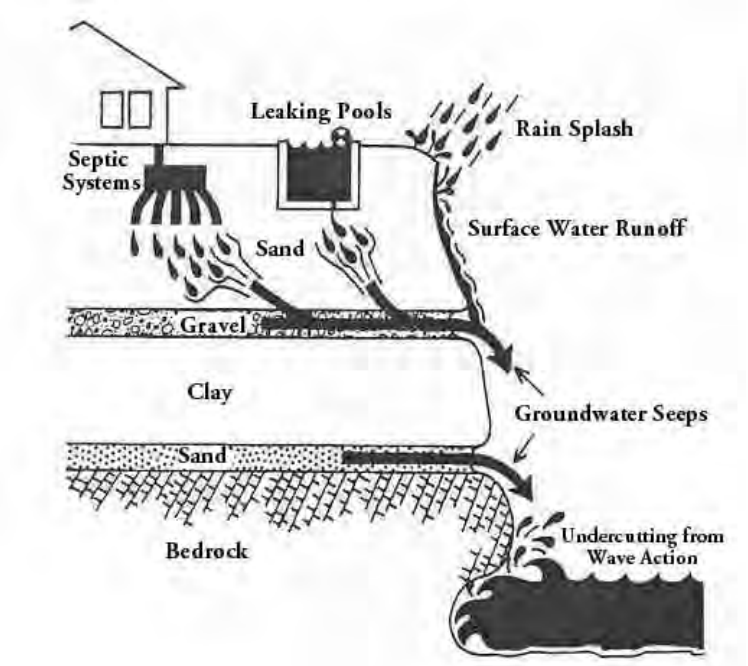


4.3.1.2. Range of Magnitude

Bluff recession and shoreline erosion events can take place gradually over decades or abruptly during a single storm event. The magnitude of bluff recession and shoreline erosion events depends greatly on fluctuating lake levels and the amount of beach material along the shoreline, but other factors that affect rate of change include surrounding land use, storm impacts, vegetative cover, soil type, depth of unconsolidated soils, hydrology, bedrock geology, slope gradient, offshore bathymetry and human activity. Figure 4.3.1-3 illustrates both the natural and human-induced processes which influence bluff recession rates of change.

Bluff instability often occurs as a result of erosion of foreshore beach materials and the undercutting of bluffs by wave attack. However, slumping and mass-wasting of the bluff face can also occur without the presence of direct wave attack. Erosion of the bluffs may be accelerated by groundwater seepage, surface water runoff, and human activity or changes in land use that would alter the hydrology or vegetation on a site.

Figure 4.3.1-3 Diagram showing many of the natural and human-induced processes which influence result in coastal erosion along the Lake Erie shoreline.



In beach and dune areas such as Presque Isle, wind-driven waves, especially during periods of high lake levels, can inundate natural protective beaches and allow water and damaging waves to reach the back beach areas. During prolonged periods of inundation, large quantities of beach material can be moved offshore. It is during these periods that the greatest threat of property damage and site instability occurs.

Much of Lake Erie and its beaches and bluffs are frozen during winter, inhibiting the formation of storm waves and reducing erosion. However, during ice formation in early winter and during the spring thaw, ice processes can accelerate erosion and recession. The spring rains, snowmelt,

and low evaporation rates cause Lake Erie's average water level in June to be more than 30 centimeters above the typical January level. Several years of above-normal precipitation, as in the mid-1980s, can cause Lake Erie's water level to rise significantly above its long-term average, increasing the likelihood of erosion.

Lake Erie is the shallowest of the Great Lakes, reaching a maximum depth of 210 feet in the eastern basin. The lake topography coupled with changing water levels can have extreme effects on the shoreline. Because the lake is shallow, the effects of storm driven waves are amplified. The axis of the lake runs from southwest to northeast, corresponding to the direction of prevailing winds. Strong winds can push water toward one end of Lake Erie (setup) and may create a difference in elevation of over 15 feet. When the wind stops, the water will rebound creating a seiche effect which causes the water to move back and forth across the lake. Strong winds or northeasters can also be a problem, driving storm waves opposite of their normal path. Elevated water levels associated with these seiche events can result in significant erosion events.

The impacts of bluff recession and shoreline erosion may be minimal in areas where buildings and infrastructure have been constructed at an adequate setback distance or erosion mitigation measures have been employed. However, development within and south of designated hazard areas can result in damage or complete destruction of property and public infrastructure as well as threats public health and safety. A worst-case scenario for coastal erosion would be if coastal erosion from a strong storm occurred, causing a slumping or mass-wasting of a bluff and numerous homes on the bluff to collapse. This could result in not only property damage, but loss of life or injuries if the homes are occupied at the time of the slope collapse. Figure 4.3.1-4 shows an example of a building imminently threatened by significant bluff recession, dating back to the 1970s. Figure 4.3.1-5 shows an example of a collapsed retaining structure.

Figure 4.3.1-4 Photograph of large avulsive event along the Lake Erie, PA shoreline (USGS, 2009 and the Pennsylvania Coastal Resource Management Program.

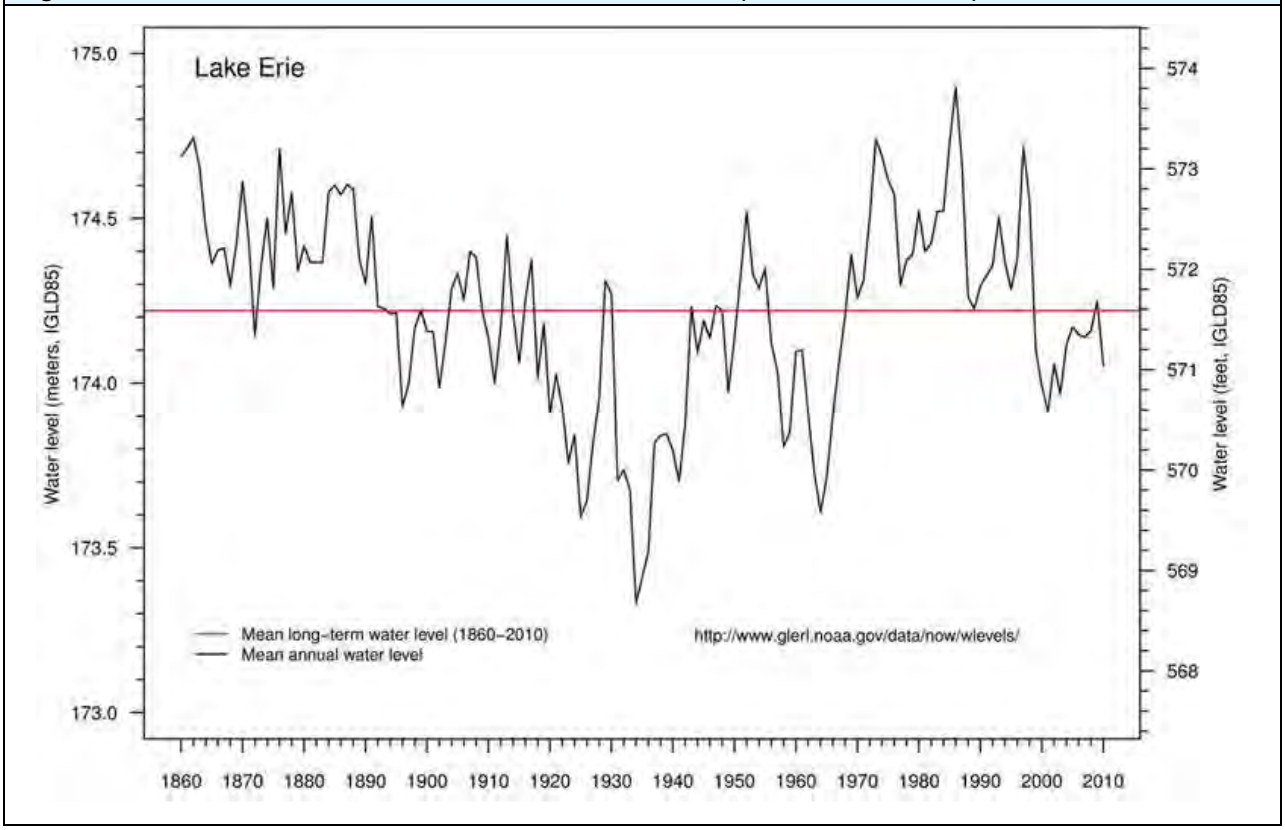
Figure 4.3.1-5 Photograph of collapsed retaining wall structure along the Lake Erie, PA shoreline (PADEP, 2011).

A cycle of bluff erosion generally begins with high lake levels and direct wave erosion of the base of the bluff. This steepens the total bluff profile, and a variety of mass movement processes lead to progressive failure of the upper bluff face. These are basically landslide processes and include topple and fall of blocks of jointed diamict, liquefaction and flow of well-sorted silts and sands, and slump of blocks of sediment held together by tree roots. Groundwater seepage from the face of the bluff is an important factor in many of the bluff-face processes. Grain-by-grain erosion of sand and silt in some cases leads to development of large soil pipes. These can be twenty feet in diameter and can extend into the bluff face for tens of feet. When the roof of a pipe collapses, large embayments in the top of the bluff result.

Accumulation of material at the toe of the bluff provides some protection from further retreat at the toe, but the colluvial sediment can be quickly removed by storm waves at times of high lake level. Significant erosional waves typically occur during spring and fall storms. Winter storms may have more energy, but ice build-up protects the shore from erosion.

Lake levels significantly influence erosion and bluff recession rates. Periods of rising lake levels resulted in increased erosion rates. Glacial isostatic rebound may still be a small factor in changing lake levels, but most modern lake-level changes are attributable to climatic factors. Long-term changes are caused by variations in precipitation and evapo-transpiration rates. Figure 4.3.1-6 shows average annual lake levels for the period 1860-2010. Lake levels have varied on the order of five feet over this time period. The droughts of the 1930's and 1960's are clearly reflected in the lake levels. Between 1987 and 1989, the lake level dropped to near its long-term average. An annual cycle and short-term changes related to weather also affect the lake level.

Figure 4.3.1-6 Lake Erie water levels between 1860 and 2009 (NOAA GLERL, 2011).



The most severe erosion events occur when lake levels are at their highest. This is reflected in the fact that 1987 and 1998 erosion events referenced in Section 4.3.1.3 correspond with lake level peaks shown in Figure 4.3.1-6. The worst-case scenario for an erosion event would be an abrupt increase in lake levels of up to one meter lasting for several years in succession.

4.3.1.3. Past Occurrence

The long-term average recession rate based on 125 fix control point monuments for the Pennsylvania Lake Erie Coastal Zone is 0.75 ft/yr; however, during the past two decades of monitoring, losses of up to twenty feet in a single year have been observed (Hapke et al., 2009 and Pennsylvania Sea Grant, 2002). Figure 4.3.1-4 displays historical bluff recession rates along the Pennsylvania Lake Erie shoreline. Erosion and recession rates are spatially variable and temporally episodic. This is evident by the fact that very low retreat rates have been measured at certain control points, while rates in immediately adjacent areas are much higher. A study performed by the U.S. Geological Survey in cooperation with the Pennsylvania Coastal Resources management Program divided the Pennsylvania Lake Erie shoreline into two areas along which recession rates were calculated (Hapke et al., 2009). Using data from 1938-2006, the study area extending southwest of Presque Isle had an average rate of recession of 0.98 +/- 0.33 ft/yr. Using data from 1938-1998, the study area extending northeast of Presque Isle had an average rate of recession of 0.66 +/- 0.33 ft/yr. A maximum rate of 3.28 +/- 0.33 ft/yr was measured in each study area, both occurring in predominantly agricultural areas.

Figure 4.3.1-7 Historical erosion rates along the Pennsylvania Lake Erie Shoreline (PADEP, 2007).

Record high lake-levels caused significant erosion events on the Lake Erie shoreline in 1987 and 1998 (Malone, 2010). Table 4.3.1-1 shows the results of a damage assessment that was completed for these events by the DEP, Coastal Resources Management Program (PA DEP, 1987). This data is from 1987 and a more recent study is not available at this time. No significant long-term trends or short-term erosion events have been identified for the Delaware River shoreline.

Table 4.3.1-1 Summary of the impact of damages caused by high water levels on the Pennsylvania Coastal Zone in Erie County, 1985-1987 (PA DEP 1987).

Item	Number Affected (Total)	# Affected by Flooding	# Affected by Shoreline Erosion	# of People Affected
PUBLIC FACILITIES				
Water Plants	1	1	0	0
Sewage Plants	0	0	0	0
Marinas, Decks	12	12	0	300
Parks/Beaches	12	12	11	0
Roadways	6	6	0	0
Hospitals	0	0	0	0
Schools	0	0	0	0
Sewer Facilities Systems	3	3	0	0
Airports	0	0	0	0
Sanitary Landfills	0	0	0	0
PRIVATE FACILITIES				
Commercial	7	3	5	15
Industrial	0	0	0	0
Residential	180	136	144	474
Power Plants	0	0	0	0
OTHER				
Seasonal Residences	31	14	20	65
Boathouses	5	0	5	37
Bathhouse/Comfort Stations	3	3	0	0 (other facilities available)

Various studies, notably those developed by the U.S. Army Corps of Engineers (Buffalo District) and the Pennsylvania Coastal Resources Management Program, have assessed shoreline damage statistics and the costs of protection. Shore structure inventories have also been prepared in recent years, some of which are ongoing. These documents provide useful information for measuring losses and recording efforts made to mitigate damage. However, studies more recent than the 1987 damage assessment are not currently available.

The long-term average historical recession rate based on 130 fixed control point monuments for the Pennsylvania Lake Erie Coastal Zone is 1.0 ft/yr. Figure 4.3.1-6 displays historical long-term bluff recession rates along the Pennsylvania Lake Erie shoreline as of 2007. Field surveys are being performed through 2011 to update the control point monument data; this data is expected to be ready for release in 2014.

Due to excessive precipitation in the spring of 2011, several lakefront properties experienced significant bluff recession. One of the properties affected by this event receded approximately 100 ft. (ECDPS, 2011).

Historical recession data is valuable for long-term planning purposes. However, historical rates are spatially variable and temporally episodic. During the past two decades of monitoring, losses of up to twenty feet in a single year have been observed (Hapke *et al.*, 2009). In addition, low retreat rates have been measured at certain control points, while rates in immediately adjacent areas are much higher. Therefore, the limitations of historical rates must be recognized and data must be used appropriately for purposes of evaluating risk.

4.3.1.4. Future Occurrence

The geological processes along the Lake Erie shoreline are continuous, but rates of change vary as a result of the natural and human-caused influences previously described. Future shoreline erosion and bluff recession can be considered *highly likely*; as defined by the Risk Factor Methodology probability criteria. However, rates of change will vary over time, primarily as a function of changing lake levels. Historical rates described in Section 4.3.1.3 serve as best estimates of future changes. Additionally, FEMA is in the process of completing a Great Lakes Coastal Flood Study which will also address coastal erosion as it relates to flood hazards for the Lake Erie Coastline in Pennsylvania. The estimated completion date of this study is 2016.

4.3.1.5. Environmental Impacts

In the absence of development, the environmental impacts of coastal erosion are minimal. It is a geological process through which shorelines naturally evolve. However, if erosion occurs in the vicinity of development or infrastructure, impacts may include the release of chemically hazardous (e.g. heating fuels) or biohazardous materials (e.g. sewage), or contamination of beaches with construction materials (i.e. asphalt, siding, lumber, shingles, etc…).

4.3.1.6. Jurisdictional Vulnerability Assessment

As previously mentioned, Erie County is the only jurisdiction in the Commonwealth which is significantly threatened by coastal erosion. Since passage of the Bluff Recession and Setback Act in 1980, structures are required to be set back from areas determined to be hazardous as a result of bluff recession and coastline erosion. The PADEP Coastal Resources Management Program has calculated bluff recession rates to determine setback distances and periodically recommends setback modifications to municipalities along Lake Erie.

Within Erie County, Springfield Township has the highest average bluff recession rate (1.27 ft/yr) among all jurisdictions monitored (PADEP, 2007). However, it is important to note that vulnerability is ultimately dependent on development density in the vicinity of receding shorelines. For more information on vulnerability for specific municipalities, see *Tentative Bluff Recession Hazard Area Designations* at: http://www.dep.state.pa.us/river/reference/brha.htm.

One out of 67 counties in Pennsylvania (Erie County) identifies coastal erosion as a hazard. The Erie County HMP has not calculated a risk factor value for coastal erosion at this time. The State Risk Factor for Coastal Erosion is 2.2 while the Pennsylvania THIRA ranks coastal

erosion as a 3 out of 10. For more details on the State Risk Factor and THIRA rankings, please see Section 4.1.

4.3.1.7. State Facility Vulnerability Assessment

No state facilities fall within 500 feet of the Lake Erie shoreline or within the BHRA for Lake Erie, so the vulnerability impact is low. However, Presque Isle State Park is located on Lake Erie's Shoreline. In 2008, PA DCNR was awarded an L-PDM grant to undergo flood mitigation and coastal erosion mitigation in the Park. This investment of $990,000 has reduced the overall vulnerability of this unique state park and recreation space.

4.3.1.8. Jurisdictional Loss Estimation

The Bluff Recession and Setback Act was passed in 1980 and requires that new residential, commercial and industrial structures will be constructed landward of Minimum Bluff Setback Distances (MBSD). Such setbacks protect the health and safety of residents, as well as property investments. The statutory authority of the Act only applies to Lake Erie. There are nine municipalities along Pennsylvania's Lake Erie coast that have designated BRHAs and enacted ordinances. Table 4.3.1-2 provides a summary of the life span used to calculate MBSDs based on structure type, where:

Bluff Recession Rate (ft/yr) x Appropriate Life Span of Structure (yrs) = MBSD (ft)

Table 4.3.1-2 Summary of life spans used to calculate Minimum Bluff Setback Distances for development in Lake Erie Bluff Recession Hazard Areas.

TYPE OF STRUCTURE	APPROPRIATE LIFE SPAN (YEARS)
Residential	50
Commercial	75
Industrial	100

Note: MBSDs are determined by and currently set in 25 Pa. Code § 85.26(c). Some municipalities have enacted setback requirements which are greater than the MBSDs published in Chapter 85. For example, Girard Township (200 ft.), Lake City Borough (150 ft.), and Fairview Township (100 ft.) (ECDPS, 2011).

For purposes of this risk assessment, an investigation of properties located within a 100-year bluff recession hazard area was performed. Based on nearby historical recession rates, properties located within BRHAs that are considered at risk from bluff recession over the next 100 years were identified. A planning horizon of 100 years was used since it is the longest of the three life spans used to calculate Minimum Bluff Setback Distances under the Bluff Recession and Setback Act. Using building footprints provided by the Erie County Planning Department, the distance of each structure was measured from the approximate bluff edge. The current approximate setback distance was then divided by a representative historical erosion rate (see Figure 4.3.1-7) to determine which buildings are located along areas of the Lake Erie shoreline expected to erode over the 100 years. A summary of these buildings is provided in Table 4.3.1-3 by municipality, along with total building value information. Building location and building value information is based on 2011 tax assessment data provided by Erie County.

The following assumptions should be considered when interpreting assessment results:

- Long-term bluff recession rates were used to determine setback life. Natural (e.g. changing lake level) or human influences (e.g. construction of shore protection structures) which will alter future recession rates are not considered.
- Control point monuments are typically located every 1,650 ft. along the Lake Erie shoreline. The recession rate from the nearest control point monument was applied to each structure; however this monument may not always be most representative of erosion risk for a given structure.
- Only buildings located adjacent to the BRHAs were included in this assessment. Additional buildings which may be at risk (e.g. buildings located between breaks in BRHA or in non-bluff areas) were not included. While the number of excluded buildings potentially at risk is considered to be relatively small compared to overall assessment results, it is worth noting since results likely serve as conservative estimates of properties at risk over the next 100 years.
- Setback measurements used in the assessment are determined based on the distance of a given building footprint to the approximate bluff edge. The property a building is located on as well as surrounding infrastructure are likely at risk prior to damage to the building itself.
- By regulation, MBSDs are measured from the bluff crest, which due to its dynamic nature, is determined on a case by case basis through field surveys. For purposes of this assessment, a delineation of the bluff edge was created based on the most recent aerial imagery available from the ESRI World Imagery dataset. While this delineation is reasonably accurate, it was not verified with topographic data or field survey data and should therefore be considered approximate.
- New or future development is not accounted for; this assessment is based on present development only.

Table 4.3.1-3 Buildings identified in 100-yr Erosion Hazard Area by community with associated building and land value data.

MUNICIPALITY	NO. OF BUILDINGS IN 100-YR EROSION HAZARD AREA (PERCENT OF TOTAL BUILDINGS THROUGHOUT COUNTY IN 100-YR EROSION HAZARD AREA)	TOTAL BUILDING VALUE	TOTAL LAND VALUE	TOTAL LAND & BUILDING VALUE
Erie City	25 (9.4%)	$316,540	$3,340,650	$3,657,190
Fairview Township	11 (4.2%)	$4,039,100	$2,647,700	$6,686,800
Girard Township	14 (5.3%)	$1,165,600	$6,349,200	$7,514,800
Harborcreek Township	51 (19.2%)	$4,249,070	$8,166,500	$12,415,570
Lake City Borough	0 (0.0%)	$0	$0	$0
Lawrence Park Township	3 (1.1%)	$281,000	$333,200	$614,200
Millcreek Township	111 (41.9%)	$8,842,640	$10,030,000	$18,872,640
North East Township	33 (12.5%)	$2,446,500	$3,240,300	$5,686,800

Table 4.3.1-3 Buildings identified in 100-yr Erosion Hazard Area by community with associated building and land value data.				
MUNICIPALITY	**NO. OF BUILDINGS IN 100-YR EROSION HAZARD AREA (PERCENT OF TOTAL BUILDINGS THROUGHOUT COUNTY IN 100-YR EROSION HAZARD AREA)**	**TOTAL BUILDING VALUE**	**TOTAL LAND VALUE**	**TOTAL LAND & BUILDING VALUE**
Springfield Township	17 (6.4%)	$5,619,500	$4,635,300	$10,254,800
TOTAL	**265**	**$26,959,950**	**$38,742,850**	**$65,702,800**

Based on results from this assessment, 265 structures along the Lake Erie shoreline are considered at risk of significant damage or complete destruction from coastal erosion over the next 100 years. These buildings are spread across eight municipalities with over 40% of them located in Millcreek Township. Based on 2011 tax assessment data provided by Erie County, these 265 buildings have a total value of $26,959,950. In addition, the total value of land associated with these properties and potentially at risk from coastal erosion losses equals $38,742,850.

It is imperative that residents living near the shoreline are well-educated on shoreline erosion and bluff recession hazards. Appropriate mitigation measures also need to be put into place to help lessen the impact of shoreline erosion, bluff recession, and flooding on coastal structures, residents, land, and wildlife.

In addition, because Lake Erie bluffs are reshaped daily by the natural forces of gravity, water, and wind, through proper land-use management practices, bluff recession can be slowed, but not prevented. Since the majority of bluff recession-related problems start at the base of the bluff as a result of wave damage, the following measures can be used to stabilize the shoreline. Note that recent events have shown these measures to be relatively ineffective in protecting bluff areas from groundwater-induced recession:

- Revetments: concrete blocks placed on banks to absorb the energy of incoming waves. These structures protect only the land immediately behind them, not adjacent areas.
- Groins: concrete structures that extend perpendicular from the shore. Groins interrupt the natural wave movement of beach sediment by trapping and retaining sand on the up drift side of the groin.

Once the shoreline is secured, the following bluff face re-contouring and stabilization practices can be undertaken:

- Biotechnical slope protection: combines the use of biodegradable wood cribbing and appropriate vegetation. The structure provides support for the bluff at a groundwater seepage area, while the vegetation absorbs the groundwater, eventually stabilizing the bluff face.

- Dewatering**:** intercepts groundwater before it reaches the bluff face. Wells and groundwater trenches collect groundwater and re-channel it through pipes over the bluff face to the base of the bluff.
- Vegetation: naturally and inexpensively protects the bluffs. Root systems absorb groundwater and hold the soil together. Leaves intercept the impact of raindrops and transfer water absorbed by the root systems into the atmosphere through evapo-transpiration.

The PADEP Coastal Zone Management Program provides funding as well as technical assistance for projects located within the 76.6 miles of coastline and landward to the Lake Erie watershed boundary. Grant funds can be used for many types of projects including education, construction, research, planning, acquisition, and design. The program's main goal is to balance coastal land use with conservation and protection of water-related resources.

4.3.1.9. State Facility Loss Estimation

No state facilities fall within 500 feet of the Lake Erie shoreline, so potential loss estimates are low. However, degradation of Presque Isle State Park due to coastal erosion could lead to losses related to tourism dollars and incalculable damage to the unique natural environment there.

4.3.2. Drought

4.3.2.1. Location and Extent

The current climate in Pennsylvania, when compared to many other states across the U.S., is generally water-rich. However, like all other states, Pennsylvania is subject to periodic droughts that impact the Commonwealth's ability to meet its water needs. Droughts are regional climatic events which can impact large areas ranging from several counties in Pennsylvania to the entire mid-Atlantic region. While large geographic areas can be impacted by a given drought, areas with extensive agricultural land use can experience particularly significant impacts.

4.3.2.2. Range of Magnitude

Droughts can have varying effects, depending upon what month they occur, severity, duration and location. Some droughts may have their greatest impact on agriculture and even short term droughts, when coupled with extreme temperatures can be devastating. Others may impact water supply or other water use activities such as recreation. Most droughts cause direct impacts to aquatic resources. Drought events are defined by rainfall amounts, vegetation conditions, soil-moisture conditions, water levels in reservoirs, stream flow, agricultural productivity, or economic impacts.

Hydrologic drought events result in a reduction of stream flows, reduction of lake/reservoir storage, and reduced groundwater levels. These events have a significant adverse impact on public water supplies for human consumption, rural water supplies for livestock consumption and agricultural operations, water quality, natural soil water or irrigation water for agriculture, soil moisture, conditions conducive to wildfire events and water for navigation and recreation. PEMA has primary responsibility for managing droughts with direct support from PADEP. According to *Drought Management in Pennsylvania* (2102), PEMA and PADEP use the