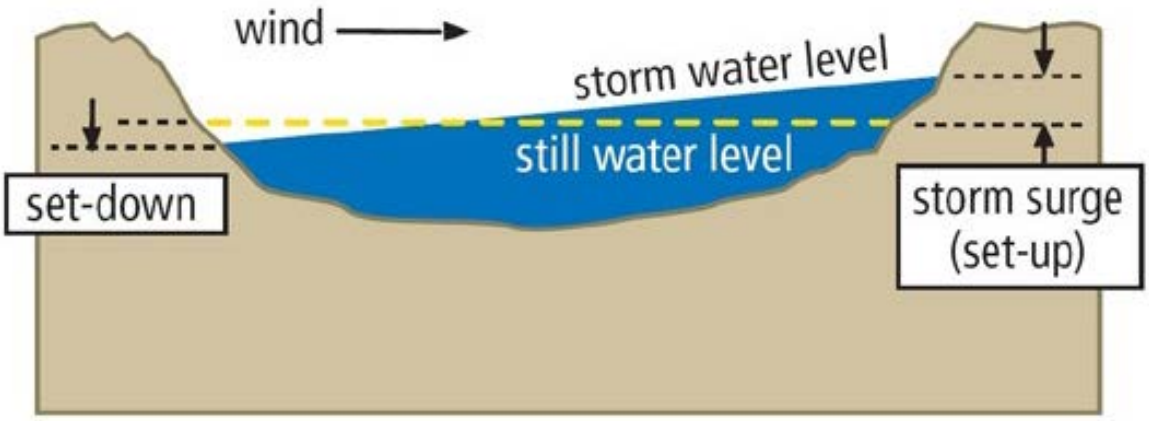
2.8 STORM SURGE / SEICHE / COASTAL FLOODING

When a storm system moves across a lake, typically the temperature drops and the wind changes direction. This disturbs the water in the lake and causes it to move in the same direction the storm is moving. The magnitude of storm surge events is dependent on a number of factors. Wind velocity and barometric pressure are the most obvious contributors to the size of an event. The orientation of the lake with respect to the direction the storm is moving is critical to the wind fetch distance over the lake, which in turn increases wave heights and storm surges. Lake Erie is oriented southwest to northeast, and the lake is shallowest near Toledo. Therefore, storms moving northeast to southwest have the potential to produce higher storm surges.

Seiche can be defined as a standing wave in an enclosed or partially enclosed body of water, which can result in coastal flooding. The most common cause of seiches in Ohio is a strong, constant wind blowing over the surface of the water forcing it to accumulate at the down-wind shore. When the wind diminishes, the water level will begin to return to its original equilibrium though a series of broad oscillations across the entire body. Often referred to as the bathtub effect, seiches cause the water levels to rise and fall along the shorelines repeatedly until equilibrium is restored. Other causes of seiches include earthquakes, changes in barometric pressure or any of a variety of atmospheric changes.

The United States Army Corps of Engineers office in Detroit, Michigan developed a profile of seiche as part of a larger work analyzing water levels for the Great Lakes. Figure 2.8.a displays the static impact storm surge has on a body of water with water levels rising on the downwind shore and falling along the upwind shore.

Figure 2.8.a



Lake Profile Showing Wind Set-Up

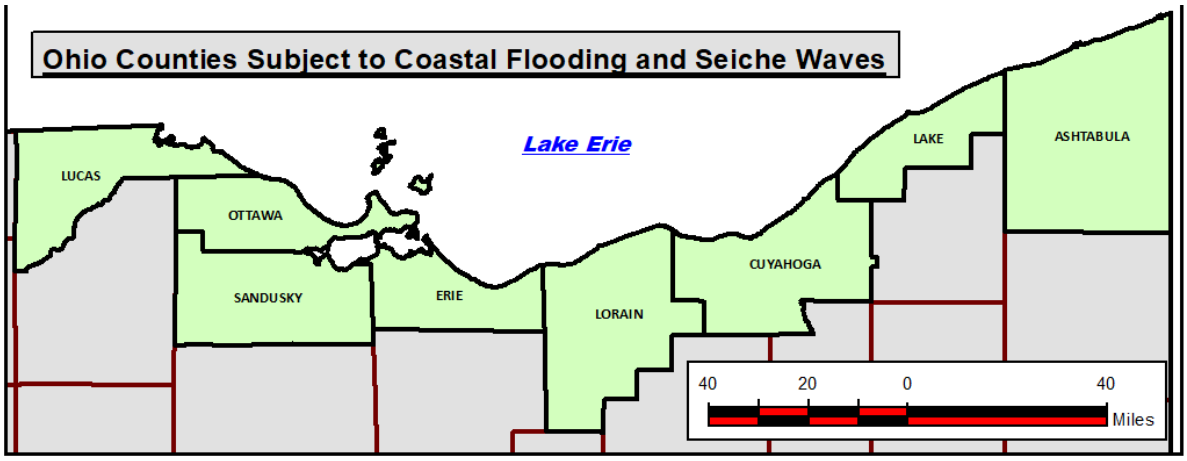
Figure 2.8.b provides a depiction of the combined effect of wind and wave actions. The base water level for the lake is marked as the SWL, or still water level. The position marked R is for run-up, the elevation a wave rises to as it spills on the shore or a structure. When winds are generated by severe storms the potential for wave action increases greatly.

Figure 2.8.b

RISK ASSESSMENT

LOCATION

Lake Erie is the most notable water body impacted by storm surge and seiches in Ohio. Although Lake Erie has 9,940 square miles of surface area implying a large body of water, it is relatively shallow with an average depth of 62 feet. Broken into what is generally referred to as the eastern, central and western basins, Lake Erie's susceptibility to storm surge and seiches varies greatly. The central basin, encompassing the area from Ohio's eastern border to Lorain, ranges from 45 to 65 feet deep with a shoreline that is mostly developed and armored. The western basin is much shallower with a depth averaging about 24 feet. The shorelines in the western basin are former coastal wetlands, many of which have been armored. One of the un-protected areas are the islands off of Ottawa County.



The seiche / coastal flooding hazard exposure is limited to counties adjacent to the south shore of Lake Erie. Region 1 counties impacted by seiche include: Lucas, Ottawa, Sandusky and Erie. Region 2 counties impacted by seiche include: Lorain, Cuyahoga, and Lake. Ashtabula is the only county impacted in Region 3.

PAST OCCURRENCES

The NCDC history of hazardous weather events currently lists only one seiche event, which occurred on November 10, 1998, impacting Erie, Lorain, Lucas and Ottawa counties. The event consisted of southwest storm force winds gusting to 69 miles per hour that pushed water away from the western end of Lake Erie towards the state of New York and Ontario Canada. As the

water level fell to four feet below normal, boats and ferries were left stranded in the mud in marinas from the Maumee River east to the lagoons in Vermilion, while freighters were forced to drop anchor outside Sandusky Bay near Port Clinton. There were no estimates provided for property or other economic losses. Prolonged SW storm events create navigational hazards in the western basin due to the low water level. Put-In-Bay harbor has been near-emptied in this type of event, exposing rock and making the harbor non-navigable.

The earliest recorded seiche wave in Ohio history occurred on the morning of June 23, 1882 when an eight-foot wall of water suddenly crashed into the 9th Street Pier in Cleveland. This wave damaged or destroyed several boats and created a novel fishing experience as it propelled hundreds of fish farther inland from the docks. One fatality resulted from this event as a homeless person was sleeping near the shore and drowned. Other events occurred in May 1942, 1944 and 1948 with waves being recorded anywhere from six to 20 feet high. Seiche waves continued to oscillate from several hours to days.

The NCDC database also contains six days with events described as storm surge. The six descriptions cover a period of nearly record high water level. Lake water level is the most important factor in producing storm surges that cause wave damage and coastal flooding. The NE storms happen every year, but flooding and damage occur when there is high water.

March 13, 1997 Storm Surge - Gale force east winds to 35 knots caused the water level at the west end of Lake Erie to rise to 79 inches above low water datum, around 35 inches above the recent average lake level. Flooding and considerable beach erosion occurred along the lakeshores of Lucas, Ottawa, Sandusky and Erie Counties. In Toledo (Lucas County), roads and a parking lot were inundated, including Monroe and Second Streets, and at Point Place on Maumee Bay. Water also overtopped a road in Jerusalem Township. In Ottawa County, roads were flooded in Port Clinton and sandbagging was performed at some local businesses. Also, on Catawba Island, waves were recorded as overtopping at least one road. At Bayview (Sandusky County), County Road 259 was flooded. Losses approached $50,000 from this coastal event.

June 1, 1997 Storm Surge - Businesses and homes were flooded when strong northeasterly winds and near record high lake levels produced waves of six to eight feet, aggravating shoreline erosion and slowing discharge of stream outflow into Lake Erie. In Erie County, 75 – 100 families evacuated near the Vermilion and Huron Rivers, while those on Mudbrook Road moved to their second floors to escape the floodwaters. Also in Erie County, Riverside Avenue residents were evacuated as well as those in Franklin Flats, Rye Beach and White's Landing. Roads along the shoreline were flooded and covered with so much sand and debris that they had to be cleared with snowplows in Port Clinton and Marblehead. On Catawba Island, rising water flooded buildings and cars were submerged. Charter services cancelled trips and hundreds of travelers were stranded on South Bass Island when most ferry trips were also cancelled. In Erie County, the north end of Jackson Pier collapsed. As the water receded, a large number of fish were left behind in people's yards. Losses were estimated at $525,000 from the event, which encompassed Erie, Lorain, Lucas, Ottawa and Sandusky Counties.

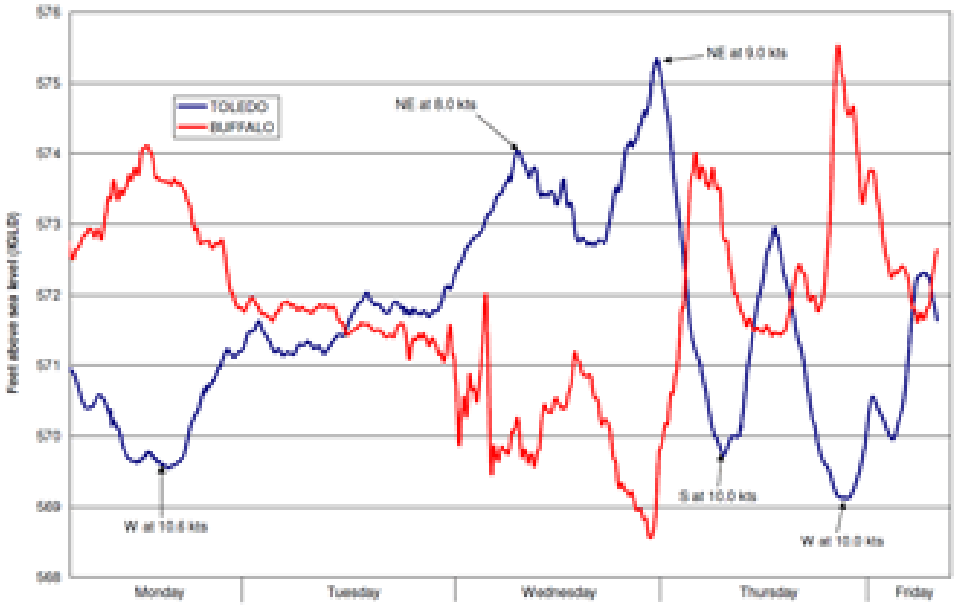
February 4, 1998 Storm Surge - Northeast winds up to 35 miles per hour caused flooding of the immediate lakeshore and beach erosion in Lucas, Erie, and Ottawa Counties. Losses were estimated at $75,000 from the event.

February 17, 1998 Storm Surge - Northeast winds up to 40 miles per hour increased the water level at the Toledo Coast Guard Station (Lucas County) to around seven feet above low water datum. Waves of seven to ten feet caused major flooding and beach erosion along the western shoreline of Lake Erie, particularly at Crystal Rock and Whites Landing (Erie County), where homes and yards were flooded. Losses were estimated at $700,000 from the event, which impacted Erie, Lucas and Ottawa Counties.

March 20, 1998 Storm Surge - North to northeast gales of 35 knots, with higher gusts, produced 11 to 14 foot waves on Lake Erie. Also, the water level at Toledo (Lucas County) was seven feet above low water datum. This combination resulted in major flooding and beach erosion. Many streets were flooded around Sandusky Bay (Ottawa, Sandusky, and Erie Counties) and Maumee Bay (Lucas County) and flooding had progressed further inland in some areas. In Sandusky and Huron (Erie County), several streets were flooded. At Beachwood Cove in Huron, the 30-foot high breakwall was destroyed and just a few feet of land separated the homes from the lake. Losses were estimated at $400,000 from the event, which impacted Sandusky, Lorain, Ottawa, Erie and Lucas counties.

April 9, 1998 Storm Surge - Northeast gales of 35 knots and water levels that peaked just below 100 inches above low water datum produced 10 to 14 foot waves, which caused major damage along the lakeshore. Many lakeshore roads were not only flooded, but also covered with rocks and other debris that, in some places, had to be removed by bulldozers. In Ottawa County, ten houses were destroyed and over 200 others were damaged, streets in downtown Port Clinton were flooded and the dike system and gravel roads in the Ottawa National Wildlife Refuge were badly damaged. Some evacuations took place at Whites Landing in Erie and Sandusky Counties and also at Wightmans Grove and Memory Marina in Sandusky County. A State of Emergency was declared and standing floodwater persisted for several days in some areas. Losses were estimated at $3,700,000 from the event, which impacted Erie, Ottawa, Lucas and Sandusky Counties.

October 17 to 21, 2011 Seiche Event - The graph below traces a recent Lake Erie seiche. From October 17 to 21, 2011, the wind shifted widely, from out of the west to out of the northeast, and to eventually out of the west again. The lines on the graph show the response of the water levels at Buffalo (red) and Toledo (blue) to these shifts. The greatest difference in water level was about 7 feet, and as the up-and-down swings of the lines show, the lake never settled to an equilibrium state over these several days.



Source: Ohio Dept. of Natural Resources, Division of Geological Survey

April 15, 2018 Storm Surge – High water, strong NE winds and rain combine to cause storm surge and flooding in Lucas, Ottawa, Erie and Sandusky Counties. Water levels within 6 inches of 1985's all-time record high, hours of 40-plus knot gale force winds from the east and 1 ½ inches of rain combined resulting in 13-15 foot waves. The municipalities of Marblehead, Port Clinton, Oak Harbor, Bayshore, Woodville, Toledo, Curtice, Point Place and Luna Pier (MI) were issued flood warnings. Damage was reported to structures in Port Clinton. Flooding inundated many farms, roads, businesses and homes on the west end of Lake Erie. State Route 2 was closed between S.R. 590 and Camp Perry, along with many other state routes along the north shore. The high water and waves caused $10-11 Million in damages to outer dikes protecting several of Lake Erie's marshes at Ottawa National Wildlife Refuge, Magee Wildlife Area, and Metzger's Marsh. There was also damage to docks and fishing piers in the area.

PROBABILITY OF FUTURE EVENTS

It is clear storm surge, coastal flooding, and seiche waves have a significant impact in Ohio. Based on the event profiles, it is possible for these events to occur between two and five times in a given year. Based on twelve events over 136 years, there is an 8.82% chance of a storm surge event significant enough to cause coastal flooding happening on any given year. The only seasonal limitation to events on Lake Erie would be during the height of winter when portions of the water surface can be covered by ice. It should be noted that ice coverage on Lake Erie varies from year to year, making it impossible to indicate any definitive time period when events cannot occur.

LHMP DATA

Cuyahoga County – Seiche. The Countywide All Natural Hazards Mitigation Plan states their northern coastline has a high frequency of seiche with a moderate vulnerability. The roads and highways along the coast can become flooded due to seiche waves. Most damage caused by seiche involves boat docks, low-lying areas along the lake shore, and river inlets to Lake Erie. The most severe seiche that hit the Cleveland area was an eight-foot seiche in the early 1990s.

Lucas County – Coastal Flooding. The Plan states that lake surges (also referred to as storm surges) are associated with extreme weather events and are responsible for coastal flooding and erosion (along

Lake Erie within Lucas County). The storms that generate large waves and lake surges can develop year-round, however within Lucas County, these events have typically occurred in the early spring and late fall months. Storm surges inundate coastal floodplains by dune over wash, the rise in water levels in inland bays and harbors, and backwater flooding through river mouths. Storm systems also generate large waves that run up and flood coastal beaches. The problem of lake surges and associated inland flooding is compounded by adjacent low-lying floodplains. The plan's history provides information that lake surges cause coastal flooding in the cities of Toledo, Oregon, the Village of Harbor View and the unincorporated Jerusalem Township. The total damages attributed to lake surges are $665,981.92, which equates to approximately $110,996.99 per event. There are limited data to calculate the probability of occurrence; however, records indicate multiple occurrences during the early spring and late fall months. It is fair to assume that future events would likely result in localized property damage to only specific areas within Lucas County, and that there is only a small potential for future events to result in injuries or deaths.

SHARPP. See section 4.3 for an analysis of SHARPP data in Ohio's coastal counties.

VULNERABILITY ANALYSIS & LOSS ESTIMATION

METHODOLOGY

Loss estimates for Ohio's coastal flooding hazard were developed using FEMA's hazard analysis and loss estimation software HAZUS-MH MR3 coastal flooding application within the flood module. This application was updated in HAZUS-MH MR3 to reflect the unique issues associated with the Great Lakes. Still water lake elevations for each county were taken from the US Army Corps of Engineers report *Revised Report on Great Lakes Open-Coast Flood Levels* published April 1988.

HAZUS-MH MR3 analysis was run for each county bordering Lake Erie based on a 100-year return event. Each run was specifically adjusted to take into consideration the type of shoreline associated with each county. Sandusky County could not be analyzed due to the software failing to recognize any coastal exposure. Upon closer review, the exposure, which does exist within the county, was assessed as part of the two neighboring county evaluations.

RESULTS

Region 1 exposure to coastal flooding is limited to the coastal counties of Erie, Lucas, Ottawa and Sandusky. The total building exposure is estimated at $8,743,489,700. The numbers of impacted structures by percent of the structure damaged are estimated to be: 1 to 10 percent damaged at 455, 11 to 20 percent damaged at 2,184, 21 to 30 percent damaged at 1,476, 31 to 40 percent damaged at 1,059, 41 to 50 percent damaged at 309 and substantially damaged at 914. There are an estimated four essential facilities, which will experience at least moderate damage. According to Table 2.8.a, estimates for business interruption and building losses are $8,560,000 and $974,880,000, respectively.

Table 2.8.a

Estimate of Potential Losses to Coastal Flooding Region 1											
County	Population	Building Exposure Value	1-10% Damage Count	11-20 % Damage Count	21-30% Damage Count	31-40% Damage Count	41-50% Damage Count	Substantial Damage Count	Essential Facilities Count	Estimate Business Interrupt	Estimated Property Loss
Erie	79,321	$4,150,287,000	159	372	175	28	5	40	1	$2,070,000	$132,210,000
Lucas	454,029	$2,545,448,000	113	395	840	932	227	189	3	$3,260,000	$548,900,000
Ottawa	41,036	$2,047,754,700	183	1,417	461	99	77	685	0	$3,230,000	$293,770,000
TOTAL	**574,386**	**$8,743,489,700**	**455**	**2,184**	**1,476**	**1,059**	**309**	**914**	**4**	**$8,560,000**	**$974,880,000**

The majority of building loss is associated with Lucas County as a result of inland backup flooding of the Maumee River. HAZUS-MH MR3 profiles for the remaining counties do not indicate riverine backup flooding to a significant extent.

Region 2 exposure to coastal flooding is limited to the coastal counties of Cuyahoga, Lake and Lorain. The total building exposure is estimated at $2,396,004,000. The numbers of impacted structures by percent of the structure damaged are estimated to be: 1 to 10 percent damaged at 82, 11 to 20 percent damaged at 260, 21 to 30 percent damaged at 278, 31 to 40 percent damaged at 91, and 41 to 50 percent damaged at 20 and substantially damaged at 12. There are no essential facilities estimated as impacted. Estimates for business interruption and building loss are $500,000 and $82,690,000 respectively (see Table 2.8.b).

Table 2.8.b

Estimate of Potential Losses to Coastal Flooding Region 2											
County	Population	Building Exposure Value	1-10% Damage Count	11-20 % Damage Count	21-30% Damage Count	31-40% Damage Count	41-50% Damage Count	Substantial Damage Count	Essential Facilities Count	Estimated Business Interrupt	Estimated Property Loss
Cuyahoga	1,384,252	$1,033,868,000	2	19	16	0	2	0	0	$110,000	$10,410,000
Lake	227,324	$671,888,000	55	159	206	89	12	12	0	$240,000	$43,840,000
Lorain	285,798	$450,219,000	25	82	56	2	6	0	0	$150,000	$28,710,000
TOTAL	**1,897,374**	**$2,396,004,000**	**82**	**260**	**278**	**91**	**20**	**12**	**0**	**$500,000**	**$82,960,000**

Region 3 exposure to coastal flooding is limited to the coastal county of Ashtabula. The total building exposure is estimated at $240,290. The numbers of impacted structures by percent of the structure damaged are estimated to be: 1 to 10 percent damaged at 3, 11 to 20 percent damaged at 12, 21 to 30 percent damaged at 8, 31 to 40 percent damaged at 1, and 41 to 50 percent damaged at 0 and substantially damaged at 1. There are no essential facilities estimated as impacted. Estimates for business interruption and building loss are $80,000 and $5,280,000 respectively (see Table 2.8.c).

Table 2.8.c

Estimate of Potential Losses to Coastal Flooding Region 3											
County	Population	Building Exposure Value	1-10% Damage Count	11-20 % Damage Count	21-30% Damage Count	31-40% Damage Count	41-50% Damage Count	Substantial Damage Count	Essential Facilities Count	Estimated Business Interrupt	Estimated Property Loss
Ashtabula	102,729	$240,029,000	3	12	8	1	0	1	0	$80,000	$5,280,000

GREAT LAKES COASTAL FLOOD STUDY

The FEMA has initiated a coastal analysis and mapping study to produce updated Digital Flood Insurance Rate Maps (DFIRMs) for coastal counties around the Great Lakes. This storm surge study is one of the most extensive coastal storm surge analyses to date, encompassing coastal floodplains in eight states. Ultimately, the study will update the coastal storm surge elevations for all of the U.S. shoreline of the Great Lakes. This new coastal flood hazard analyses will utilize updated 1-percent-annual chance stillwater elevations obtained from a comprehensive storm surge study conducted by the U.S. Army Corps of Engineers.

The effort to produce these maps for all the Great Lakes states began in 2012 and is expected to be completed in Ohio in 2020. The resulting DFIRMs will introduce VE Zones to Ohio and the Great Lakes Region. A VE Zone is used on a DFIRM to differentiate coastal high hazard areas from the rest of the 1%-annual-chance flood hazard area (100-year floodplain). The Zone VE designation indicates that during the 1%-chance-annual flood, wave hazards are expected to be particularly strong and have the potential to cause structural damage.

Zone VE is mapped for areas that meet one of more of the following criteria:

1. Wave runup depth exceeds 3 feet relative to the ground,
2. Wave overtopping rate exceeds 1cfs/ft.,
3. Wave heights exceed 3 feet in areas of overland wave propagation, or
4. The primary frontal dune.

Figure 2.8c illustrates wave runup and overtopping as well as overland wave propagation.

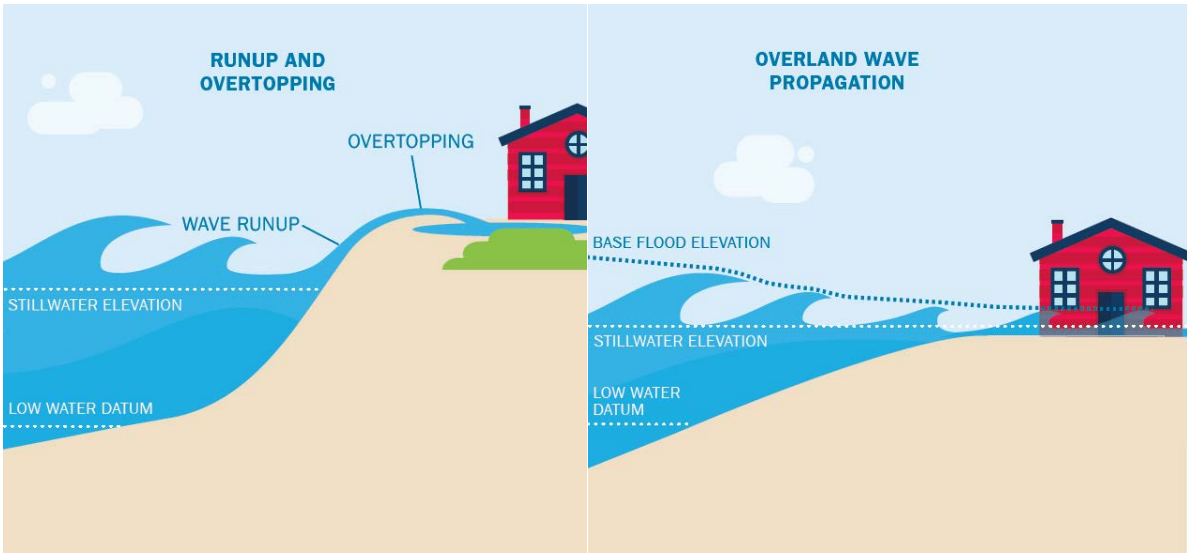


Figure 2.8d illustrates how the VE Zone designations on the FIRM relate to the wave risk.

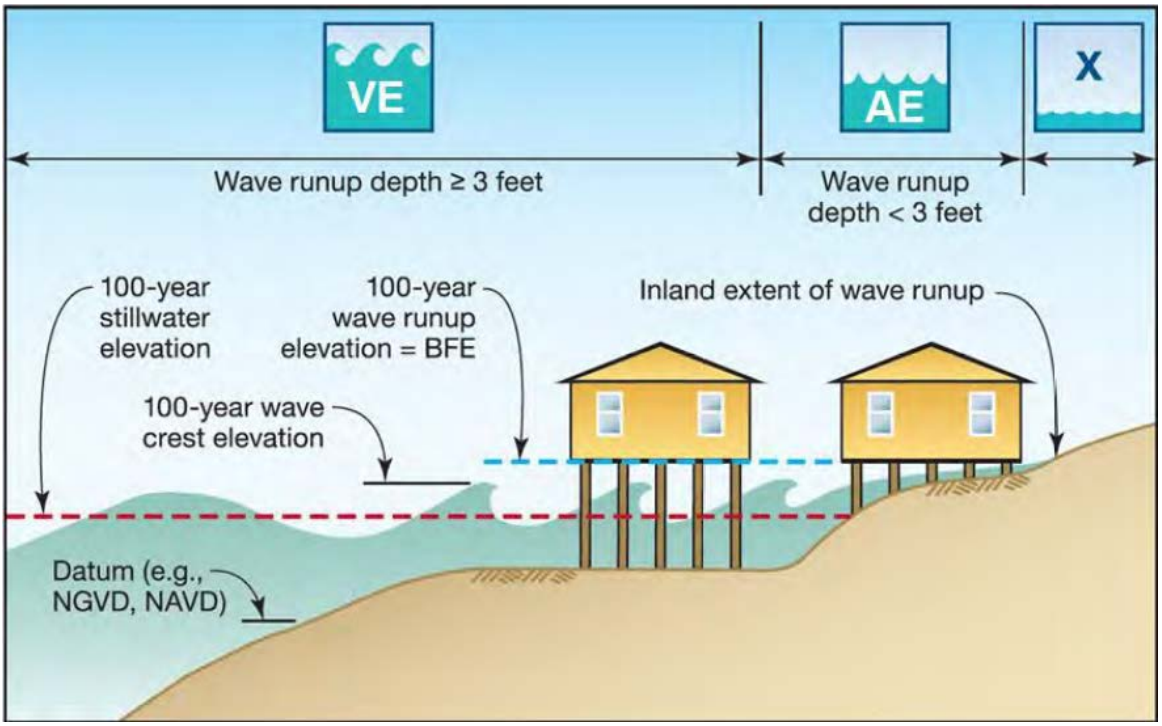


Table 2.8c summarizes building exposure based on analysis performed by the ODNR Office of Coastal Management using Preliminary DFIRM data and county auditor data. The results of this analysis will change as the Preliminary DFIRMs are reviewed and undergo the appeals period.

Table 2.8.c

County	Total Coastal Parcels	Parcels in V-Zone	Parcels with Buildings in V-Zone
Lucas	590	333	1
Ottawa	2,511	1,675	111
Erie	1,982	1,212	20
Lorain	962	1,019	28
Cuyahoga	899	875	24
Lake	1,111	1,070	20
Ashtabula	792	818	29
Total	**8847**	**7002**	**233**

* Sandusky County does not have identified V Zones

STATE-OWNED AND STATE-LEASED CRITICAL FACILITIES VULNERABILITY ANALYSIS & LOSS ESTIMATION

Using HAZUS-MH MR3 results and the FIRMs for the coastal counties, state- owned and state-leased facilities were evaluated for their involvement with seiche/coastal hazards. While all eight coastal counties were evaluated, only three of those contained facilities that could be at risk of flooding via seiche or coastal flooding, and all three are in Region 1. Table 2.8.d lists the results of this analysis.

One state-owned critical facility was located in the hazard area in Lucas County, which represents $153,000 at risk. While this facility is operated by the ODNR, it is a watercraft office that would be crucial to immediate response and rescue necessities. In terms of non-critical facilities, over 90 percent of those identified are located in Lucas County, and the majority of those involve state park facilities. Only one state-leased non-critical facility was noted to be at risk, and it is located in the City of Sandusky, Erie County, representing over $80,000 in annual rent at risk. It should be noted that no state-leased critical facilities were determined to be at risk to this hazard.

Table 2.8.d

Estimated Losses from Coastal Flooding for State-Owned and State-Leased Facilities						
County	**State-Owned Critical Facility Count**	**State-Owned Critical Facility Value**	**State-Owned Non-Critical Facility Count**	**State-Owned Non-Critical Facility Value**	**State-Leased Non-Critical Facility Count**	**State-Leased Non-Critical Facility Rent**
Erie	0	$0	5	$674,495	1	$82,131
Lucas	1	$153,000	33	$24,256,560	0	$0
Ottawa	0	$0	0	$0	0	$0
Sandusky	0	$0	6	$799,680	0	$0
TOTAL	**1**	**$153,000**	**44**	**$25,730,735**	**1**	**$82,131**