

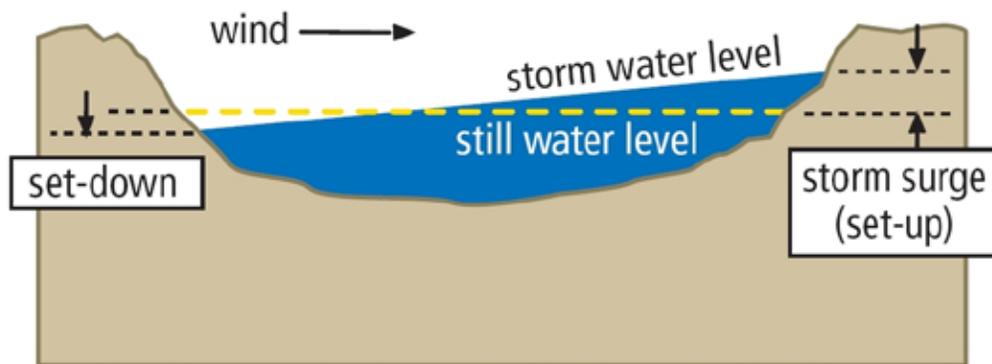
2.8 SEICHE / COASTAL FLOODING

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 magnitude of seiche events is dependent on a number of factors. Wind velocity and barometric pressure are the most obvious contributors to the size of an event. What is not immediately apparent is how the configuration of the water body factors into the event. The larger and shallower the water body is translates into an increase in the magnitude of the seiche. This can have significant effects on artificial bodies of water such as reservoirs.

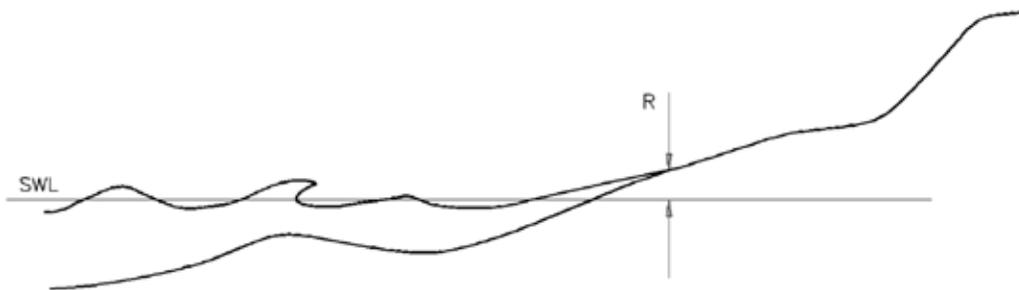
The United States Army Corps of Engineers office in Detroit Michigan developed a profile of seiche as part of a larger work analyzing water levels for the Great Lakes. Figure 2.8.a displays the static impact seiche has on a body of water with water levels rising on the downwind shore and falling along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

Figure 2.8.a



Lake Profile Showing Wind Set-Up

Figure 2.8.b provides a detailed description 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 represents the new increased water level at the shoreline. When winds are generated by severe storms the potential for wave action increases greatly.

Figure 2.8.b

RISK ASSESSMENT

Location

Lake Erie is most notable water body impacted by 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 seiches varies greatly. The central basin, encompassing the area from Ohio's eastern border to Lorain, ranges from 15 to 24 feet deep with a shoreline ranging from sandy beaches to small cliffs. The western basin is much shallower with depths ranging from 10 to 15 feet along with a shoreline of wetlands and estuaries.

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, Lake and Ashtabula. No counties in Region 3 border the lake, as described in Section 1.

Past Occurrences

The NCDRC history of hazardous weather events currently lists only one seiche event which occurred in 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, but it is common for boats to be suctioned to the lake bottom muck and be covered when water returns thus rendering the vessels to remain sunk unless raised by salvage vessels.

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 and lengths from 15 to 100 miles. Seiche waves continued to oscillate from several hours to days.

In addition to the seiche listed by the NCDC are six events classified as storm surge. Reviewing the descriptions provided it was deduced these events were associated with severe summer or winter storms and are clear examples of coastal flooding.

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 flood waters. 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 snow plows 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.

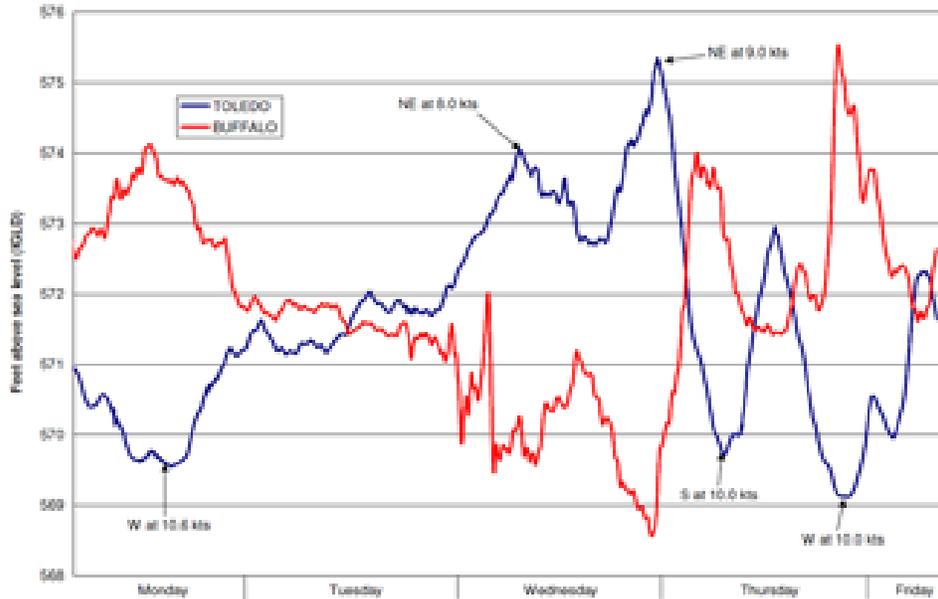
February 4, 1998 Storm Surge - Northeast winds up to 35 miles per hour caused flooding of the immediate lakeshore and beach erosion in Lucas, Erie, and Ottawa Counties. Losses were estimated at \$75,000 from the event.

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.

November 11, 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 flood water 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 Wave - 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

There are two observations which can be made reviewing the NCDC data. First, none of the events impacted Region 2 counties. This could be due to size of the area impacted by the wind or due to the type of shoreline for those counties. Second, the only seiche event noted depicts a westerly wind lowering the water level in the western basin. It can be speculated that the displaced water was moved to the eastern basin which is beyond the Ohio and Pennsylvania border. This could be an additional factor resulting in Region 2 counties having no record of seiche or storm surge impacts.

Probability of Future Events

It is clear seiche and storm surge coastal flooding 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 eleven events over 132 years, there is an 8.34% chance of a seiche wave to happen on any given day. 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. Hazard identification data were queried from SHARPP to evaluate each hazard and its frequency. There are limited data to evaluate in SHARPP concerning this hazard since not all coastal counties have their HIRA populated. For those coastal counties reporting HIRA data, a couple incorporated seiche into their flood hazard identification and risk assessment. However, for those responding specifically to this hazard, seiche/coastal flooding ranked very low for all factors evaluated. This could be related to the difficulty in differentiating between riverine and coastal flooding given large events impacting these counties. These and additional HIRA data queried from SHARPP can be found in Appendix J.

VULNERABILITY ANALYSIS & LOSS ESTIMATION

Methodology

Loss estimates for Ohio's seiche 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 seiche 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 4 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 Seiche / 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	Estimated Business Interup	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 of the Maumee River. HAZUS-MH MR3 profiles for the remaining counties do not indicate riverine backup to a significant extent.

Region 2 exposure to seiche is limited to the coastal counties of Ashtabula, 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 85, 11 to 20 percent damaged at 272, 21 to 30 percent damaged at 286, 31 to 40 percent damaged at 92, 41 to 50 percent damaged at 20 and substantially damaged at 13. There are no essential facilities estimated as impacted. Estimates for business interruption and building loss are \$580,000 and \$88,240,000 respectively (see Table 2.8.b).

Table 2.8.b

Estimate of Potential Losses to Seiche / 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 Interup	Estimated Property Loss
Ashtabula	102,729	\$240,029,000	3	12	8	1	0	1	0	\$80,000	\$5,280,000
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	85	272	286	92	20	13	0	\$580,000	\$88,240,000

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.c 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.c

Estimated Losses from Seiche/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