

## 2.6 DAM/LEVEE FAILURE

A dam failure is defined as an uncontrolled release of the reservoir. The causes of dam failures can be divided into three groups: dam overtopping, excessive seepage, and structural failure of a component. Despite efforts to provide sufficient structural integrity and to perform inspection and maintenance, problems can develop that can lead to failure. While most dams have storage volumes small enough that failures have little or no repercussions, dams with large storage amounts can cause significant flooding downstream.

Dam failures can result from any one or a combination of the following causes:

- Prolonged periods of rainfall and flooding, which cause most failures;
- Inadequate spillway capacity, resulting in excess overtopping flows;
- Internal erosion caused by embankment or foundation leakage or piping;
- Improper maintenance, including failure to remove trees, repair internal seepage problems, replace lost material from the cross section of the dam and abutments, or maintain gates, valves, and other operational components;
- Improper design, including the use of improper construction materials and construction practices;
- Negligent operation, including the failure to remove or open gates or valves during high flow periods;
- Failure of upstream dams on the same waterway;
- Landslides into reservoirs, which cause surges that result in overtopping;
- High winds, which can cause significant wave action and result in substantial erosion; and
- Earthquakes, which typically cause longitudinal cracks at the tops of the embankments, which can weaken entire structures.

Dams are complicated structures, and it can be difficult to predict how a structure will respond to distress. "... the modes and causes of failure are varied, multiple, and often complex and interrelated, i.e., often the triggering cause may not truly have resulted in failure had the dam not had a secondary weakness. These causes illustrate the need for careful, critical review of all facets of a dam" (*Safety of Existing Dams*, 1983).

The Ohio Department of Natural Resources, Division of Water - Dam Safety Program has the responsibility to ensure that human life, health and property are protected from dam failures. The program achieves its core purpose by performing six main functions:

- *Emergency response* – Assessing the conditions of dams during severe floods and emergency's, taking action to correct dams that pose an immediate threat to public safety, providing timely and best-available

information to other agencies and the public during disasters, and supporting mandate Ohio Revised Code (ORC) Section 1521.062;

- *Construction permits* – Ensuring that dams and levees are designed and constructed in accordance with proper engineering standards and OAC rules, reviews construction plans and specifications, performs calculations and investigations, issues permits, and monitors/approves construction;
- *Repairs and modifications* – Ensuring that dams and levees are repaired in accordance with proper engineering standards and OAC rules, reviews construction plans and specifications, performs calculations and investigations, issues permits, and monitors/approves construction, and supports mandate ORC Section 1521.062;
- *Periodic safety inspections* – Identifying dam deficiencies and direct dam owners to correct said deficiencies, monitors the overall condition of Ohio's dams, provides data for NPDP, supports mandate ORC Section 1521.062, and inspects every jurisdictional dam once every five years;
- *Enforcement* – Requiring dam and levee owners to improve safety when efforts for voluntary compliance have been unsuccessful and focuses on highly deficient Class 1 dams with dense populations downstream; and
- *Public information* – Providing data security for Ohio EMA, USACE, the National Guard, OEPA, as well as state and federal legislature, provides dam and levee owners and engineers with technical information and access to division files, educates the public about dam safety and provides quality data, and gives presentations for EPA, WMAO, and OLCA.

The ORC provides the authority for the program to regulate dam safety and dictates the responsibilities of the program as well as the responsibilities of the dam owners. The program regulates approximately 1,656 dams in Ohio of which 498 are Class I (high hazard).

## **RISK ASSESSMENT**

### **Location**

In Ohio there are 1,656 known dams included in the USACE, national inventory of dams (NID). The volume of water impounded, and the density, type, and value of development downstream determine the potential severity and potential classification of dam failure.

The ODNR - Dam Safety Program classifies the hazard potential for dams as Class I, Class II, Class III, and Class IV dams (*see Table 2.6.a*). All Class I dams are required to have Emergency Action Plans (EAPs), including dam failure inundation mapping.

**Table 2.6.a**

| <b>Ohio and Federal Dam Classification Systems</b> |                                                                                                                                                                                   |                                             |
|----------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|
| <b>Ohio Hazard Classification</b>                  | <b>Description</b>                                                                                                                                                                | <b>Corresponding Federal Classification</b> |
| Class I                                            | Probable loss of life, serious hazard to health, structural damage to high value property (i.e., homes, industries, major public utilities)                                       | High                                        |
| Class II                                           | Flood water damage to homes, businesses, industrial structures (no loss of life envisioned), damage to state and interstate highways, railroads, only access to residential areas | High                                        |
| Class III                                          | Damage to low value non- residential structures, local roads, agricultural crops and livestock                                                                                    | Significant                                 |
| Class IV                                           | Losses restricted mainly to the dam                                                                                                                                               | Low                                         |

Source: [www.dnr.stat.oh.us/water/dsafety/whatdam.htm](http://www.dnr.stat.oh.us/water/dsafety/whatdam.htm)

In Ohio, there are 498 high, 541 significant, and 639 low hazard potential dams. This assessment will primarily focus on the top ten dams in Ohio whose failure could have catastrophic consequences:

- Salt Fork Dam – Guernsey County – Region 3
- Hoover Dam – Franklin County – Region 2
- O’Shaughnessy Reservoir Dam – Delaware County – Region 2
- Indian Lake Dam – Logan County – Region 1
- Grand Lake St. Mary’s Dam – Auglaize County – Region 1
- Mineral Ridge Dam – Trumbull County – Region 2
- Lake Milton Dam – Mahoning County – Region 2
- Bridge Creek Dam – Geauga County – Region 2
- Rocky Fork Lake Dam – Highland County – Region 3
- Wolf Run Lake Dam – Noble County – Region 3

There are a total of 264 dams within Region 1, which is the least number of dams among the regions. Out of those there are 92 high hazard dams and 69 significant hazard dams. Within Region 1, Huron County has the largest number of dams for a total of 24, of which 17 are high hazard or significant hazard dams.

There are a total of 707 dams within Region 2 registered with NID. Out of those, there are 190 high hazard dams and 212 significant hazard dams. The largest concentration of dams within Region 2 is in Medina County. Medina County has the second highest number of high hazard and significant hazard dams in the county.

Region 3 has the second highest number of dams registered with NID for a total of 685 structures. Of these, 216 are high hazard and 238 are significant hazard dams which creates a higher vulnerability in the region than in region 2 where the total number of dams is higher, but the number of high hazard or significant hazard dams is lower. Within Region 3 Muskingum County has the largest total number of dams (66). Muskingum County, has the largest number of significant hazard dams (27) and the largest number of low hazard dams (30). However, Perry County has the largest number of high hazard dams (17).

### Past Occurrences

The National Performance of Dams Partnership, a cooperative effort of engineers and dam safety professionals in the U.S., retrieve, archive, and disseminate information on dam performance, reports nine failures in regulated and unregulated dams in the State of Ohio between 1950 and 2003 (see Table 2.6.b). Of these events, only one failure was associated with one of the top 10 high hazard dams in Ohio (Wolf Creek Dam).

According to ODNR - Dam Safety Program, there has been little property damage that has resulted from a dam failure alone. However, there has been property damage that was a combination of downstream flooding due to excessive precipitation and dam failure. Unfortunately, it is difficult to assess which property damage was a direct result of the dam failure and which damage was a result of downstream flooding due to excessive precipitation. There has been some infrastructure loss in terms of roads washing away, but there has been no loss of critical facilities due to dam failure.

**Table 2.6.b**

| <b>Ohio Dam Failures/Near Failures From 1950 to 2003</b> |               |              |                      |                                                                                                                                                                                                            |
|----------------------------------------------------------|---------------|--------------|----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Dam Name</b>                                          | <b>County</b> | <b>State</b> | <b>Incident Date</b> | <b>Incident Description</b>                                                                                                                                                                                |
| Morgan County Dam (Wolf Creek Dam)                       | Morgan        | OH           | 1950                 | Heavy rainfall and flooding; downstream property damage.                                                                                                                                                   |
| Lake Logan Dam                                           | Hocking       | OH           | 1950                 | The dam was breached due to inadequate design and construction and the lake was forcibly drained.                                                                                                          |
| Ashland Reservoir Dam                                    | Ashland       | OH           | 1969                 | Failed by overtopping. There were no details on the failure in the file.                                                                                                                                   |
| Greenwich Reservoir Dam                                  | Huron         | OH           | 1969                 | There was a partial failure of the dam in 1969. There were no details of the failure in the file.                                                                                                          |
| Houston Lake Dam                                         | Holmes        | OH           | 1969                 | The dam completely washed out in the 1969 flood. There are no specific details on the failure in the file.                                                                                                 |
| Athens Fish and Game Club Lake Dam                       | Athens        | OH           | 1975                 | The dam was breached in 1975 due to seepage seen in three areas and a slide approximately 15-feet wide and about 10-feet above the toe. There was no downstream property damage as a result of the breach. |
| Bloomington South Lake Dam                               | Jefferson     | OH           | 1997                 | The spillway failed and the dam breached itself. There were no reported property damages down stream.                                                                                                      |
| Brimfield Lake Dam                                       | Portage       | OH           | 1979                 | Storms from a hurricane caused the dam to overtop.                                                                                                                                                         |

| Ohio Dam Failures/Near Failures From 1950 to 2003 |              |       |               |                                                                                                                                                                                                                            |
|---------------------------------------------------|--------------|-------|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Dam Name                                          | County       | State | Incident Date | Incident Description                                                                                                                                                                                                       |
|                                                   |              |       |               | There were no reported damages to downstream property.                                                                                                                                                                     |
| Lexington Glen Dam                                | Delaware     | OH    | 1987          | The dam failed in 1987 due to erosion on the emergency spillway and four erosion rills on the downstream slope.                                                                                                            |
| Chopper's Lake Dam                                | Washington   | OH    | 1994          | Heavy rainfall leading to dam overtopping and erosion of earth adjacent to spillway                                                                                                                                        |
| Ivex of Ohio Upper Lake Dam                       | Cuyahoga     | OH    | 1994          | Heavy rain leading to dam breaching itself causing significant sediment to be released into the lake. There is no record of downstream property damage as a result of the breach.                                          |
| Thomas Pond Dam                                   | Adams        | OH    | 1997          | Heavy rain led to dam overtopping and breach; spillway clogged with debris; foundation poorly constructed; downstream damage included road underground power lines being destroyed and three homes receiving flood damage. |
| Cecil Hollow Lake Dam                             | Not recorded | OH    | 1997          | Lack of spillway system lead to dam being overtopped and breached; downstream residents flooded.                                                                                                                           |
| Green Acres Levee                                 | Not recorded | OH    | 1997          | 100-Year flood; levee overtopped; several homes flooded.                                                                                                                                                                   |
| Bookhamer Lake Dam                                | Madison      | OH    | 1998          | Flooding affected spillway in poor condition spillway, leading to breach; no downstream damage.                                                                                                                            |
| Lower Hickory Hills Lake Dam                      | Meigs        | OH    | 1998          | There was a breach due to overtopping and severe erosion. The road downstream was washed out and overtopping contributed to trailers floating away.                                                                        |
| Beldon Pond Lake Dam                              | Tuscarawas   | OH    | 1999          | Piping corroded leading to slow, continuous breach; no property damage.                                                                                                                                                    |
| Pischieri Pond Dam                                | Medina       | OH    | 1999          | The dam was breached when an inspection found a void in the dam. The downstream property owner was upset that the dam was breached across his property but suffered no structural damage to personal property.             |
| Crown City Mining Pond No. 24 Dam                 | Lawrence     | OH    | 1999          | Dam breached; no downstream damage.                                                                                                                                                                                        |
| Polecat Lake Dam                                  | Lawrence     | OH    | 2001          | The dam was found to have extreme seepage in 2001 and was breached in 2001. There was no reported property damage down stream.                                                                                             |
| Rustic Hills Lake Dam                             | Medina       | OH    | 2003          | The emergency spillway failed causing overtopping. This overtopping severely eroded the downstream slope.                                                                                                                  |

Source: National Performance of Dams, Dam Incident Notification Database and ODNR – Dam Safety Program

## Probability of Occurrence

For reasons previously mentioned and uncontrollable by humans, it is highly possible a dam can fail at any time, given the right circumstances. However, the probability of future occurrence is reduced due to proactive preventative action on the part of ODNR – Dam Safety Program. As previously discussed in this section,

the ODNR – Dam Safety Program provides oversight to dam/levee repairs, oversees and issues construction permits, enforces safety standards and mandates, conducts periodic safety inspections, and provides public information to levee owners, engineers, and the general public. This proactive approach to managing dam safety in Ohio reduces the number of losses to property and life as a result of dam failure or near failure. Table 2.6.c provides specific information on the events affecting the top ten high hazard dams in the state.

**Table 2.6.c**

| <b>Events for Top Ten High Hazard (Class 1) Dams in Ohio</b> |             |                                                                                |
|--------------------------------------------------------------|-------------|--------------------------------------------------------------------------------|
| <b>Dam</b>                                                   | <b>Date</b> | <b>Event</b>                                                                   |
| Salt Fork Lake Dam                                           | 1968        | Dam Constructed                                                                |
|                                                              | 1978        | Phase I investigation completed                                                |
|                                                              | 1980        | Phase II investigation completed                                               |
|                                                              | 1985        | Outlet channel repaired and seepage control added                              |
|                                                              | 1985        | ODNR-DOW dam safety inspection                                                 |
|                                                              | 2000        | Last ODNR-DOW dam safety inspection                                            |
| Hoover Dam                                                   | 1956        | Dam Constructed                                                                |
|                                                              | 1974        | First ODNR-DOW dam safety inspection                                           |
|                                                              | 1979        | USACE Phase I inspection was performed by ODNR-DOW                             |
|                                                              | 1986        | Second ODNR-DOW dam safety inspection                                          |
|                                                              | 1992        | Lake drains were rehabilitated                                                 |
|                                                              | 1994        | Concrete repair was made on spillway, sidewall and groin gutters               |
|                                                              | 1998        | Bascule gates were rehabilitated                                               |
|                                                              | 2000        | Third ODNR-DOW dam safety inspection                                           |
| O'Shaughnessy Reservoir Dam                                  | 1925        | Dam Constructed                                                                |
|                                                              | 1980        | USACE Phase I inspection                                                       |
|                                                              | 1999        | 5-Year inspection of structure by private consultant                           |
| Indian Lake Dam                                              | 1852        | Dam Constructed as a feeder lake to the Miami-Erie Canal                       |
|                                                              | 1978        | USACE Phase I inspection                                                       |
|                                                              | 1986        | First ODNR-DOW dam safety inspection                                           |
|                                                              | 1995        | Replace lake drain                                                             |
|                                                              | 1996        | Widened the crest                                                              |
|                                                              | 2000        | Second ODNR-DOW dam safety inspection                                          |
| Grand Lake St. Mary's Dam (West Embankment)                  | 1837-1841   | Dam was constructed as a feeder lake to the Miami-Erie Canal                   |
|                                                              | 1978        | USACE Phase I inspection                                                       |
|                                                              | 1997        | New Spillway and level crest to increase discharge/storage capacity            |
|                                                              | 2000        | ODNR-DOW dam safety inspection                                                 |
| Mineral Ridge Dam                                            | 1932        | Dam constructed                                                                |
|                                                              | 1978        | Phase I inspection                                                             |
|                                                              | 1983        | First ODNR-DOW dam safety inspection                                           |
|                                                              | 1994        | Raised crest and normal pool, and added emergency spillways                    |
|                                                              | 1997        | Second ODNR-DOW dam safety inspection                                          |
|                                                              | 2003        | Third ODNR-DOW dam safety inspection                                           |
| Lake Milton Dam                                              | 1916        | Dam constructed                                                                |
|                                                              | 1930's      | Significant repairs, upgrades, and maintenance on dam                          |
|                                                              | 1969        | Distress on upstream slope and crest of the west embankment is noticed         |
|                                                              | 1970        | Seepage and evidence of instability on the downstream west abutment is noticed |

| Events for Top Ten High Hazard (Class 1) Dams in Ohio |           |                                                                                                                        |
|-------------------------------------------------------|-----------|------------------------------------------------------------------------------------------------------------------------|
| Dam                                                   | Date      | Event                                                                                                                  |
|                                                       | 1974      | ODNR-DOW orders City of Youngstown to breach dam after a review of inspection findings                                 |
|                                                       | 1975      | Ogee weir stabilized with rock anchors. Stabilizing berm and relief wells placed along tow of east embankment section. |
|                                                       | 1980      | USACE inspection to determine the adequacy of structural and hydraulic components                                      |
|                                                       | 1984      | First ODNR-DOW dam safety inspection                                                                                   |
|                                                       | 1987-1988 | Significant repairs, upgrades, and maintenance on dam                                                                  |
|                                                       | 1998      | Second ODNR-DOW dam safety inspection. Slide noted on downstream slope of the east embankment. Slide repaired.         |
|                                                       | 2000      | Problem with gate #4 noted.                                                                                            |
|                                                       | 2003      | Third ODNR-DOW dam safety inspection                                                                                   |
| Bridge Creek Dam                                      | 1961      | Dam constructed                                                                                                        |
|                                                       | 1978      | Phase I inspection                                                                                                     |
|                                                       | 1983      | First ODNR-DOW dam safety inspection                                                                                   |
|                                                       | 1991      | Second ODNR-DOW dam safety inspection                                                                                  |
|                                                       | 2001      | Third ODNR-DOW dam safety inspection                                                                                   |
| Rocky Fork Lake Dam                                   | 1952      | Dam constructed                                                                                                        |
|                                                       | 1978      | Phase I inspection                                                                                                     |
|                                                       | 1984      | First ODNR-DOW dam safety inspection                                                                                   |
|                                                       | 1995      | Large boulders fell from left abutment                                                                                 |
|                                                       | 1998      | Second ODNR-DOW dam safety inspection                                                                                  |
|                                                       | 2003      | Third ODNR-DOW dam safety inspection                                                                                   |
| Wolf Run Lake Dam                                     | 1966      | Dam constructed                                                                                                        |
|                                                       | 1980      | USACE Phase I inspection                                                                                               |
|                                                       | 1985      | First ODNR-DOW dam safety inspection                                                                                   |
|                                                       | 1994      | Second ODNR-DOW dam safety inspection                                                                                  |
|                                                       | 1998      | Principal spillway pipe inspected after the 1998 flood                                                                 |
|                                                       | 2001      | Third ODNR-DOW dam safety inspection                                                                                   |
|                                                       | 2004      | Widened emergency spillway, groin drains, developed draft EAP with inundation map                                      |

Source: ODNR, Division of Water – Dam Safety Program

## Environmental Impacts

Dam or levee failures can have a greater environmental impact than that associated with a flood event. Large amounts of sediment from erosion would alter the landscape changing the ecosystem. Hazardous materials are carried away from flooded out properties and distributed throughout the floodplain. Industrial and agricultural chemicals and wastes, solid wastes, raw sewage, and common household chemicals comprise the majority of hazardous materials spread by flood waters along the flood zone, polluting the environment and contaminating everything they come in contact with, including the community's water supply.

The soil loss from erosion and scouring would be significantly greater because of a large amount of fast moving water affecting a small localized area, which would likely change the ecosystem.

## **VULNERABILITY ANALYSIS & LOSS ESTIMATION**

### **Methodology**

Assessing the hazard that a dam poses to downstream areas can be divided into three analyses: (1) analysis of an uncontrolled release of the reservoir, (2) analysis of the inundation from the uncontrolled release, and (3) analysis of the consequence of the release. In other words, a dam fails, the failure causes flooding downstream, and the flooding has negative impacts on people or property. Each of these analyses includes substantial uncertainty. Legitimate estimates of discharge from a breach can differ by over 200%. Discharge from a dam breach is usually several times the 1% chance flood, and, therefore, typical flood studies are of limited use in estimating the extent of flooding. Dam failure inundation studies require specialized hydraulic modeling software and experience. Determining the impact of flooding is also difficult to accomplish, especially for estimating loss of life. Loss of life is a function of the time of day, warning time, awareness of those affected, and particular failure scenario. Many dam safety agencies have used “population at risk”, a more quantifiable measurement of the impact to human life, rather than “loss of life”. Population at risk is the number of people in structures within the inundation area that would be subject to significant personal danger, if they took no action to evacuate.

The impacts of a dam failure are contingent on many factors and, therefore, cannot be concisely described. The assessments below are very rough estimates based on experience with flood modeling, other inundation studies, best available information, preliminary calculations, and flood insurance rate maps. Loss of water supply due to failure of the dam is not specifically addressed; refer to OEPA for this information. Unless otherwise noted, the assumed failure scenario is rapid breach of the dam during an elevated pool.

- All distances are approximated
- 1% flood = a flood that has a 1% chance of being equaled or exceeded in any given year = 100-year flood
- Comparisons to the 1% chance flood are made for perspective – flood waves diminish as they move downstream
- Vulnerable population and structures are estimated
- Dam failure discharge is estimated
- Multiples of discharge don’t necessarily correspond to multiples of depth

### **Results**

For this particular vulnerability analysis and loss estimation, the top 10 high hazard dams discussed.

### *Salt Fork Lake Dam*

Salt Fork Lake Dam is located on Salt Fork Creek near Cambridge. Salt Fork Creek joins Wills Creek 1 mile downstream of the dam. Wills Creek flows generally to the west and meets Wills Creek Dam 32 miles downstream of the Salt Fork Lake Dam. Wills Creek Dam is a flood-control structure regulated by the US Army Corps of Engineers and normally has about 37 feet of flood storage in its reservoir (flood pool). Flood pool at Wills Creek Dam would inundate a portion of the downstream side of Salt Fork Lake Dam. Communities and their distances downstream include Kimbolton at 8 miles and Plainfield at 23 miles. Discharge from failure of Salt Fork Lake Dam is estimated to be at least 9 times the 1% flood discharge. The 1% flood in Cambridge, 9 miles upstream of Salt Fork Lake Dam on Wills Creek, is about 35 feet deep. The impacts of failure of Salt Fork are relatively uncertain because of the complexity of flood elevations on Wills Creek due to storage behind Wills Creek Dam and natural flooding on Wills Creek. Inundation would damage several homes, local roads, and an interstate highway, and would cause a significant rise in the pool behind Wills Creek Dam. The impact on Wills Creek Dam is unknown but would be dependent on flooding conditions at the time of failure. It appears that during a dry period, Wills Creek Dam would safely pass the flood from Salt Fork. Floodwater from failure of Salt Fork Lake Dam would likely flow upstream to Cambridge. Table 2.6.3.2.a displays the total vulnerable population, structures and EPL for the estimated inundation area of Salt Fork Dam.

Salt Fork Lake Dam does not have a detailed emergency action plan or inundation mapping.

### *Hoover Dam*

Hoover Dam is located on Big Walnut Creek on the northeast side of Columbus. Big Walnut Creek flows along the east side of Columbus, joins the Scioto River south of Columbus, and then flows to Circleville. Discharge from failure of the dam is estimated to be at least 10 times greater than the 1% flood discharge. Communities and their distances downstream include Gould Park at 4 miles, Gahanna at 7 miles, Whitehall at 10 miles, and Columbus at 12 miles. Inundation is expected to be noticeable in Circleville 30 miles downstream. Damage is expected to be extensive and would include many residential structures, state routes, local roads, interstate highways, and businesses. Table 2.6.3.2.a displays the total vulnerable population, structures and estimate of potential loss for the inundation area of Hoover Dam.

Hoover Dam has a working emergency action plan (EAP), and inundation mapping is being developed. The Division of Water has not approved either document. The assessment provided above was partially based on inundation mapping for Alum Creek Reservoir Dam. Alum Creek Reservoir Dam and Hoover Dam are of similar size and construction, which allows for some comparison of the expected extent of inundation. Alum Creek Reservoir Dam is located north of Columbus and is regulated by the US Army Corps of Engineers.

### *O'Shaughnessy Reservoir Dam*

O'Shaughnessy Reservoir Dam is located on the Scioto River on the northwest side of Columbus. The Scioto River flows south through urban areas of Columbus, meets the Olentangy River 15 miles downstream, and continues south. Julian Griggs Dam is located 11 miles downstream. Discharge from failure of the dam is estimated to be at least 5 times greater than the 1% flood discharge. Inundation would damage many residential structures, a state route, a local road, I-270, and the road across the dam. The population at risk is 85. Failure of O'Shaughnessy is not expected to cause failure of Julian Griggs Dam. Significant impact from failure of O'Shaughnessy Reservoir Dam, while at normal pool level, would likely terminate before the Olentangy River. Flooding downstream of Griggs may cause problems but it is not estimated to put any population at risk. Impact could extend farther downstream if the dam failed during a significant flood event. Table 2.6.3.2.a displays the total vulnerable population, structures and EPL for the estimated inundation area of O'Shaughnessy Reservoir Dam.

O'Shaughnessy Reservoir Dam has a detailed EAP and inundation mapping. The inundation mapping provided the basis for much of the information above. The Division of Water has approved both documents.

### *Indian Lake Dam*

Indian Lake Dam is located on the Great Miami River near Logan. The Great Miami River flows south and west toward Sidney. Dam failure inundation would be relatively long in duration, shallow in depth, and far in extent because of the low height and high storage of the dam. DeGraff is 12 miles downstream and is the only community located along the Great Miami River that would likely be affected. Inundation would damage several habitable structures, local roads, and state routes. The population at risk is estimated to be 20 and mostly located near the dam. Table 2.6.3.2.a displays the total vulnerable population, structures and EPL for the estimated inundation area of Indian Lake Dam.

Indian Lake Dam does not have a detailed emergency action plan or inundation mapping. A brief EAP has been established.

### *Grand Lake St. Mary's Dam*

Grand Lake St. Mary's Dam is located near St. Mary's and has an east and west embankment to impound the reservoir. Discharge from the east embankment would flow east to the St. Mary's River, north into St. Mary's, and then west-northwest toward Indiana (36 miles downstream). Communities along the St. Mary's River and their distances downstream include St. Mary's at 3 miles, Mendon at 18 miles, and Rockford at 26 miles. Dam failure inundation would be relatively long in duration, shallow in depth, and far in extent because of the low height and high storage of the dam. Dam failure inundation would damage habitable structures, local roads, state routes, and a railroad.

Discharge from the west embankment would flow into Beaver Creek and then into the Wabash River. The Wabash River enters Indiana 10 miles downstream. No

communities are located in Ohio along Beaver Creek or Wabash River downstream of the dam. The discharge from failure of the dam is estimated to be at least 6 times greater than the 1% flood discharge. Several local roads and state routes would be damaged. The inundation would be relatively long in duration and shallow in depth and far in extent because of the low height and high storage of the dam. Dam failure inundation would damage habitable structures, local roads, and state routes. The west embankment is about 1 mile long and has several habitable structures located along it. There is potentially population at risk in this area depending upon the location of a dam breach. Table 2.6.3.2.a displays the total vulnerable population, structures and EPL for the estimated inundation area of Grand Lake St. Mary's Dam.

Grand Lake St. Mary's Dam does not have a detailed emergency action plan or inundation mapping.

#### *Mineral Ridge Dam*

Mineral Ridge Dam is located on Meander Creek near Niles. Meander Creek joins the Mahoning River 2 miles downstream, which flows toward Youngstown and eventually into Pennsylvania. Discharge from failure of the dam is estimated to be at least 10 times greater than the 1% flood discharge. Communities located along Meander Creek and the Mahoning River and their distances downstream include Niles at 1 mile, Girard at 3 miles, Youngstown at 10 miles, Campbell at 14 miles, Struthers at 15 miles, and Lowellville at 17 miles. The farthest extent of flooding downstream is not known but would likely be noticeable in Pennsylvania. Flooding would extend upstream along the Mahoning River toward Warren. Dam failure inundation would damage habitable structures, local roads, state routes, industrial properties, and railroads. Table 2.6.3.2.a displays the total vulnerable population, structures and EPL for the estimated inundation area of Mineral Ridge Dam.

Mineral Ridge Dam has an extensive EAP but does not have detailed inundation mapping. The Division of Water has not approved either document.

#### *Lake Milton Dam*

Lake Milton Dam is located on Mahoning River near Newton Falls. The Mahoning River flows north and northeast toward Newton Falls and then southeast toward Pennsylvania. Berlin Lake Dam is located directly upstream and regulates flow into Lake Milton. The US Army Corps of Engineers regulates Berlin Lake Dam. Discharge from failure of the dam is estimated to be at least 20 times greater than the 1% flood discharge. The communities and their distances downstream include Pricetown at 1 mile, Newton Falls at 6 miles, Leavitsburg at 17 miles, and Warren at 21.5 miles downstream. The extent of dam failure inundation is not known but would be expected to extend beyond Warren. Dam failure losses would be devastating. Dam failure inundation would damage habitable structures, local roads, state routes, industrial properties, and railroads. Table 2.6.3.2.a displays the total vulnerable population, structures and EPL for the estimated inundation area of Lake Milton Dam.

Lake Milton Dam does not have a detailed emergency action plan or inundation mapping.

### *Bridge Creek Dam*

Bridge Creek Dam is located on Bridge Creek near Burton. Bridge Creek flows northeast and joins the Cuyahoga River 2 miles downstream. The Cuyahoga River flows south and southwest toward Akron. Discharge from failure of the dam is estimated to be at least 16 times greater than the 1% flood discharge. Communities and their distances downstream include Hiram Rapids at 8 miles and Mantua at 12 miles, and Kent at 23 miles. Lake Rockwell Dam is located on the Cuyahoga River 21 miles downstream. Dam failure inundation would damage habitable structures, local roads, state routes, an interstate highway, industrial properties, and railroads. The population at risk between Bridge Creek Dam and Lake Rockwell is estimated to be 187. Failure of Bridge Creek Dam could cause failure of Lake Rockwell Dam. Kent, Munroe Falls, and Akron are located downstream of Lake Rockwell Dam and would likely be affected by failure of Lake Rockwell Dam. Table 2.6.3.2.a displays the total vulnerable population, structures and EPL for the estimated inundation area of Bridge Creek Dam.

Bridge Creek Dam does not have a detailed emergency action plan or inundation mapping. The owner does routinely inspect and maintain the dam.

### *Rocky Fork Lake Dam*

Rocky Fork Lake Dam is located on Rocky Fork near Bainbridge. Rocky Fork joins Paint Creek 6 miles downstream, which flows toward Chillicothe and then into the Scioto River. Discharge from failure of the dam is estimated to at least 5 times greater than the 1% flood discharge. Communities and their distances downstream include Bainbridge at 12 miles and Chillicothe at 35 miles. The extent of dam failure inundation is expected to extend beyond Chillicothe. Dam failure inundation would damage habitable structures, local roads, state routes, industrial properties, and railroads. Table 2.6.3.2.a displays the total vulnerable population, structures and EPL for the estimated inundation area of Rocky Fork Lake Dam.

Rocky Fork Lake Dam does not have a detailed emergency action plan or inundation mapping. The assessment provided above was partially based on inundation mapping for Paint Creek Dam, located on the near Rocky Fork Lake Dam and regulated by the US Army Corps of Engineers.

The assessment provided above was partially based on inundation mapping for Paint Creek Dam. Rocky Fork Lake Dam and Paint Creek Dam are of similar size and construction, which allows for some comparison of the expected extent of inundation. Paint Creek Dam is regulated by the US Army Corps of Engineers.

### *Wolf Run Lake Dam*

Wolf Run Lake Dam is located on West Fork Duck Creek near Belle Valley. West Fork Duck Creek flows south along Caldwell and into Duck Creek 26 miles downstream of the dam. Discharge from failure of the dam is estimated to be at least 11 times greater than the 1% flood discharge. Communities and their distances downstream include Belle Valley at 1 mile, Caldwell at 6 miles, and Macksburg at 25 miles. The extent of dam failure inundation is expected to extend beyond Macksburg

and to be approximately the 1% flood at that location. Dam failure inundation would damage habitable structures, local roads, state routes, and interstates. Table 2.6.3.2.a displays the total vulnerable population, structures and EPL for the estimated inundation area of Wolf Run Lake Dam.

A detailed EAP and inundation mapping are in the process of being developed for Wolf Run Lake Dam. The inundation mapping is nearly complete and was used for this assessment.

## **STATE OWNED / CRITICAL FACILITIES VULNERABILITY ANALYSIS & LOSS ESTIMATION**

### **Methodology**

Comparing the state-owned and critical facility structure inventory identified and discussed in Section 2.1 of this plan with the inundation information discussed in Section 2.6 of this plan, an assessment of vulnerable state-owned structures and critical facilities was completed for the top ten dams in Ohio. This assessment provided an approximation of the state-owned structures and critical facilities at risk for each dam inundation area.

For the dams located in the counties that were not inventoried and listed in Section 2.1, field visits to the downstream dam site determined if state-owned structures or critical facilities over \$1M were in the potential inundation area if the dam were to fail.

The estimate of potential loss for all state-owned structures and critical facilities, except for that of state-owned dams, was determined using the methodology identified in Section 2.1 of this plan. The estimate of potential loss of state-owned dams includes costs associated with dam construction after construction plans were finalized. That estimate is then increased using a 2 percent interest to bring the EPL to present day value. The estimate of potential loss of these structures are lower-end estimates of replacement costs with the assumption of complete dam failure through its maximum section and losing its principal spillway.

### **Results**

To date there are no state-owned structures or critical facilities located in the potential inundation areas of the top ten dams discussed in this section.

## 2.7 WILDFIRE

Each year in Ohio, an average of 800 wildfires burn 4,000 to 5,000 acres of forest and grassland within ODNR Division of Forestry's forest fire protection district. The protection district includes all 185,000 acres of Ohio's 20 State Forests, as well as all privately owned lands within the district boundaries. The forest fire protection district corresponds mostly to the state's unglaciated hill country (southern and eastern Ohio), and also encompasses a section of northwest Ohio (Maumee SF area). Ohio's wildfire seasons occur primarily in the spring (March, April and May) before vegetation has "greened-up", and the fall (October and November) when leaf drop occurs. During these times, and especially when weather conditions are warm, windy and with low humidity, cured vegetation is particularly susceptible to burning. Fuel (vegetation, woody debris), weather (wind, temperature, humidity) and topography (hills and valleys) when combined present an unpredictable danger to unwary citizens and firefighters in the path of a wildfire.

While Ohio government agencies and local fire departments are accustomed to handling seasonal wildfires, occasional extreme events can make conditions dangerous and disruptive. Heavy fuel accumulations oftentimes make wildfire suppression extremely difficult due to more intense blazes. Occasionally, heavy fuel loadings and topography create problems in limiting access to fires, and lead to the need for heavy equipment use in suppression. Prolonged drought may cause an exceptionally long or active wildfire season, as well as contribute to extreme wildfire behavior or burning conditions. Multiple concurrent fires can tax resources and quickly create a lack of manpower and other resources and retard the ability to suppress fires rapidly and safely.

Wildland Urban Interface (WUI) conditions may create a serious issue of concern in Ohio, as well. WUI is defined as the situation where homes, residences, and structures are in close proximity to forested lands and grasslands prone to wildfire. This creates a situation where, in the event of a wildfire, personal and property safety are put in jeopardy. Additionally, WUI situations force fire departments to shift focus from fire suppression to structure protection, consequently increasing exposure time and risk. WUI situations are most effectively addressed prior to wildfire occurrence by individual homeowners. Mitigation strategies include reducing flammable vegetation and debris within 30 feet of the structure, choosing less flammable landscape species, using fire resistant building materials, and practicing safe open burning techniques. Currently in Ohio, there are no building codes that require wildfire safety considerations in construction, nor do insurance companies offer premium breaks for homeowners who do include wildfire safety measures around their homes.

In Fall 2003, ODNR Division of Forestry implemented Firewise Ohio, a statewide WUI safety initiative, in response to the growing WUI situation in Ohio. Firewise Ohio is focused on cooperating with local fire departments to create effective WUI and wildfire prevention and safety programs at the community level. To this point, Firewise Ohio has been very successful, and many fire departments from high-hazard areas are taking advantage of proactive Firewise Ohio opportunities including grants, prevention materials, and pre-planning efforts. Additionally, two

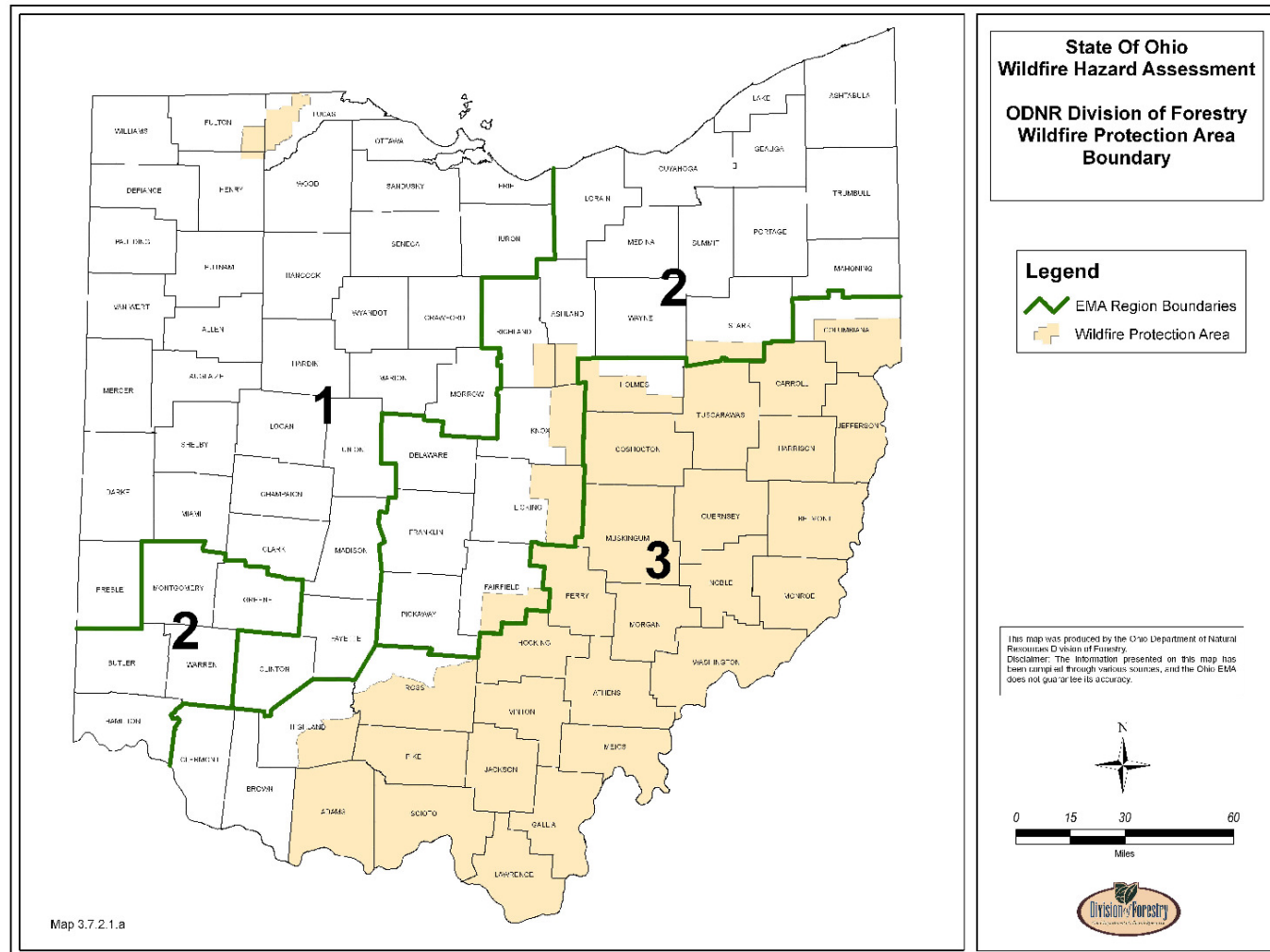
communities at risk to wildfire in Ohio (Maynard, Belmont County and Washington Township, Scioto County) have attained national Firewise Communities USA status in recognition of their outstanding work in community wildfire prevention and safety.

Open burning (burning of yard waste or debris) is regulated by state laws and local burning ordinances, which may vary from one jurisdiction to another. ORC 1503.18 addresses kindled fires regulations, and states that outside municipal limits, open burning is prohibited from 6 am to 6 pm during the months of March, April, May, October and November. It is during these times of the year and days that wildfires are most likely to occur and are the most difficult to control. Additionally, the Ohio EPA enforces OAC 3745-19, which regulates materials that may or may not be incinerated through open burning. Prohibited substances include petroleum based materials, food waste, and animal carcasses. For a complete list of materials and regulations, contact the Ohio EPA Division of Air Pollution Control. To ensure compliance with all regulations, residents should contact their local fire official with jurisdiction for the applicable laws.

## **RISK ASSESSMENT**

### **Location**

Wildfires in Ohio occur most frequently in the southern, southeastern, and eastern parts of the state. This area is predominantly unglaciated, hilly country, and varies in land cover type, including abundant forests and grasslands. The Ohio Department of Natural Resources (ODNR) Division of Forestry is responsible for wildland fire protection on all state and private lands within this area. Additionally, ODNR Division of Forestry has wildfire protection responsibility in a disjunct area in northwest Ohio surrounding Maumee State Forest (*See Map 2.7.2.1.a*). Local and volunteer fire departments across these parts of Ohio typically provide initial response wildfire suppression service within their respective jurisdictions. Following response to a wildfire event, local fire departments within the ODNR Division of Forestry wildfire protection area are encouraged to file a wildfire report to ODNR Division of Forestry. Wildfire reports contain information such as date, time, location, size, etc. Filing wildfire reports to ODNR Division of Forestry is not mandatory, only encouraged.

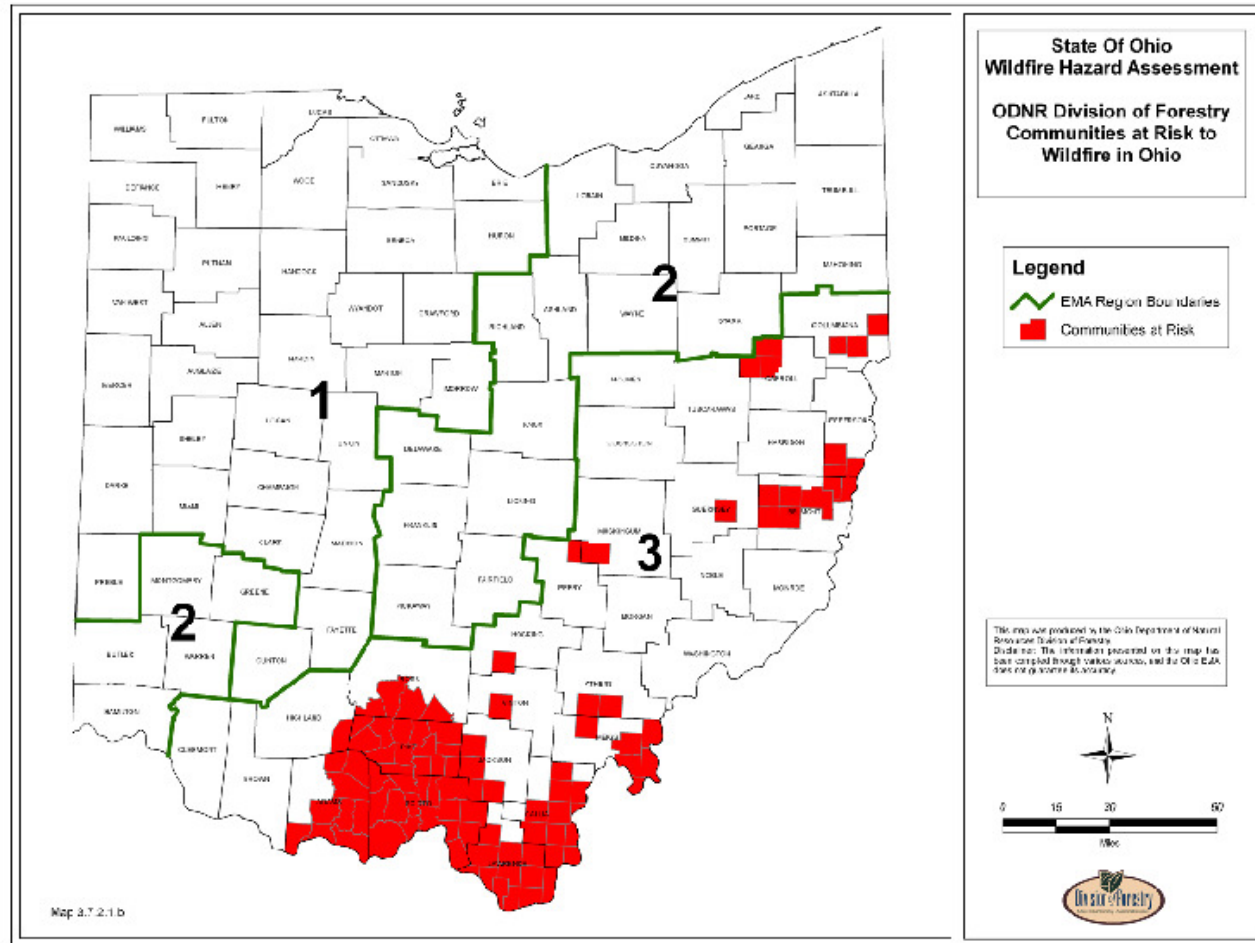


Counties that lie outside of the ODNR Division of Forestry wildfire protection area typically do not experience many wildfire events due to land use and land cover type (agricultural, developed urban/suburban). Fire departments from these counties do not file any wildfire reports; therefore ODNR Division of Forestry does not have a dataset for wildfire occurrence in these areas.

**Region 1** ODNR Division of Forestry collects wildfire data from fire departments in Lucas, Henry, and Fulton Counties in Region 1, as these counties contain parts of Maumee State Forest. ODNR Division of Forestry does not collect wildfire report data in the remainder of Region 1 counties. Land cover type in Region 1 is predominantly agricultural land, or generally not forested; therefore, wildfire occurrence and risk are not as great. From 1/1/1997 – 11/20/2007, 227 wildfires burning 679 acres were reported in the three mentioned counties of Region 1.

**Region 2** The majority of Region 2 lies outside of the ODNR Division of Forestry wildfire protection area – 6 counties straddle the wildfire protection area boundary. Ashland County contains Mohican State Forest, which is located completely within Region 2. Ashland and neighboring Richland counties reported 57 wildfires burning 172 acres from 1/1/1997 – 11/20/2007. Additional portions of Region 2 counties that report wildfires to ODNR Division of Forestry include SE Fairfield, W Licking, W Knox, and S Stark. Region 2 contains Ohio's most developed metropolitan hubs, as well as centers of highest population density. Wildland fuel types (woodland, grasslands) are not as abundant; accordingly, wildfire risk and occurrence is not as great. One notable location for potential large scale and damaging wildfire in Region 2 is the Mentor Marsh in Lake County, east of Cleveland. Mentor Marsh is a 691-acre nature preserve that has converted to nearly a monoculture of eight-12 foot high non-native *Phragmites* grass. This area is highly flammable, especially in spring with high winds coming off Lake Erie. Mentor Marsh has experienced 10 wildfire events since 1979, four of these being extremely noteworthy: May 1982 – 200 acres, May 1987 – 120 acres, May 1992 – 400 acres, April 2003 – 375 acres. All of these large-scale events were determined to be arson caused. Many homes, businesses, and high valued property are endangered by wildfire events in Mentor Marsh.

**Region 3** Counties within Region 3 represent areas of highest wildfire risk and hazard in the State of Ohio. The vast majority of wildfires in Ohio occur in Region 3 due in part to abundant forested lands and grasslands. Population distribution and regional socio-cultural aspects contribute to higher wildfire occurrence, as well. Topography in Region 3 has more variety with numerous ridges and hollows, as opposed to flatter areas in western and central Ohio, which contributes to more complex wildfire behavior. ODNR Division of Forestry has identified 101 communities at risk (CAR) to wildfire in Ohio through GIS analysis, and all 101 CAR lie within Region 3 (see *Map 2.7.2.1.b*). ODNR Division of Forestry collects wildfire data from fire departments in all counties of Region 3, with the exception of Brown and Clermont Counties.



## Past Occurrences

Ohio has experienced 8,235 wildfires that burned 42,622 acres between 1/1/1997 and 11/20/2007. These statistics were taken from wildfire reports filed by local and volunteer fire departments in southern, southeastern, eastern, as well as the disjunct northwest Ohio section within the ODNR Division of Forestry fire protection area. Wildfires that have occurred on federal lands in Ohio are not included in this data. It can be safely assumed that less than 100% of all wildfires on state and public land are reported; consequently, actual total occurrence and acres burned are suspected to be higher than data indicates.

Weather is the primary factor that determines the severity of fall and spring wildfire seasons in Ohio. Drought condition, combined with windy days create red flag, or extremely high fire danger. Consequently, the past fire occurrence record can be closely linked to historical weather data. Weather conditions leading up to and in 1930 resulted in the worst year to date for wildfires in Ohio in history, as 15,400 acres were recorded as burned over the course of the year. Extreme drought in 1950 and continuing for the next several years provided for very active wildfire seasons. March 27, 1950 considered the worst day in Ohio fire control history – 65 fires burned a total of 5,900 acres. In 1952, continued summer drought spurred a record fall fire season in Ohio and neighboring states. ODNR Division of Parks and Division of Wildlife employees assisted in suppression efforts, and the Ohio National Guard was also called out to help. A total of 680 wildfires burned 22,445 acres in the fall of 1952. Drought conditions in 1963 required placing on alert the ODNR Division of Forestry's pilots, 2000 fire wardens, 150 ODNR Division of Forestry employees, as well as several thousand volunteer firefighters and the Ohio National Guard. One or more fires were reported everyday from September 17 through November 29, and October showed a record number of fires for that month. 1988 was another severe wildfire year, as drought conditions required that CCC crews be mobilized, as well as all trained Division employees. More recently, 1999 proved to be a busy year for wildfire in Ohio, as an above average 7,836 acres were burned by nearly 1,500 wildfires.

**Table 2.7.a: Wildfire occurrence and acres burned for selected counties in Ohio – top ten counties in terms of acres burned (1/1/1997 – 11/20/2007)**

| County                                                             | # of fires | Total acres burned | County     | # of fires | Total acres |
|--------------------------------------------------------------------|------------|--------------------|------------|------------|-------------|
| Lawrence                                                           | 1,649      | 11,865             | Jackson    | 294        | 1,181       |
| Scioto                                                             | 564        | 6,945              | Ross       | 284        | 975         |
| Gallia                                                             | 565        | 5,609              | Belmont    | 232        | 970         |
| Pike                                                               | 427        | 2,316              | Athens     | 183        | 800         |
| Adams                                                              | 353        | 1,203              | Tuscarawas | 244        | 680         |
| *Note: All counties in this table are located in Ohio EMA Region 3 |            |                    |            |            |             |

Over the past ten years, average fire size in Ohio calculated from wildfire report data is 5.17 acres. The smallest reported wildfire was >.10 acre (multiple counties and dates), while the largest reported fire was 1,016 acres (Scioto County, 4/14/2003).

**Table 2.7.b: Wildfire occurrence by class size (1/1/1997 – 11/20/2007)**

| Class | Description               | # of fires | Total acres burned |
|-------|---------------------------|------------|--------------------|
| N/A   | Not calculated            | 119        | 126.02             |
| A     | > .25 acres               | 1703       | 271.62             |
| B     | .26 acres – 9.9 acres     | 5477       | 11,098.88          |
| C     | 10 acres – 99.9 acres     | 887        | 20,824.51          |
| D     | 100 acres – 299.9 acres   | 41         | 6,075              |
| E     | 300 acres – 999.9 acres   | 7          | 3,210              |
| F     | 1000 acres – 4999.9 acres | 1          | 1016               |

Over 99.9% of wildfires in Ohio are caused by human action or accident. Due to the nature of these ignitions, many wildfires in Ohio burn into close proximity of homes and structures. Since human behavior is to blame for the vast majority of wildfire starts in Ohio, an opportunity exists to influence behavior change and subsequently decrease wildfire occurrence. Many proactive steps have been taken by ODNR Division of Forestry and local fire departments to educate Ohio citizens about wildfire and home safety, and efforts will continue in the future.

**Table 2.7.c: Causes of wildfires in Ohio (1/1/1997 – 11/20/2007)**

| Cause                                | # of fires | Total acres burned |
|--------------------------------------|------------|--------------------|
| Debris burning                       | 3,395      | 13,754.3           |
| Incendiary (arson)                   | 1,174      | 9,217.02           |
| Equipment                            | 224        | 694.13             |
| Smoking                              | 177        | 691.83             |
| Campfires                            | 128        | 572.93             |
| Children (playing with matches etc.) | 87         | 188.96             |
| Lightning                            | 56         | 76.52              |
| Railroad                             | 22         | 35.16              |
| Other/Unknown                        | 2,972      | 17,391.22          |

*\*Note: Other/Unknown indicates wildfire was not investigated to the point of confidently determining cause of ignition*

### Probability of Future Events

According to research and historical record, wildfires have occurred every spring and fall in the hardwood forests and grasslands of southern, southeastern, and eastern Ohio for hundreds of years, and will continue to do so in the future. The number of occurrences, size of wildfires, and severity of burn fluctuate annually in response to a variety of factors including:

- Weather – daily, monthly, seasonal, annual, and long-term trends in:
  - Precipitation
  - Relative Humidity
  - Temperature
  - Wind

- Fuels – condition of 1, 10, 100, 1000 hour fuels in terms of:
  - Moisture content
  - Arrangement
  - Accumulation level
  - Availability
- Ignitions – presence or absence of wildfire starts:
  - Human caused
    - Debris burning – compliance with ORC 1503.18, and safe debris burning techniques
    - Incendiary – arsonists at large
    - Wildfire prevention and awareness efforts
- Suppression Response – Capability and timeliness of initial attack:
  - Quickness of response to the incident
  - Local / Volunteer FD capability
  - Availability of state and local resources
    - Number of concurrent wildfires

### **Environmental Impacts**

Wildfires can have a beneficial environmental impact. Heat is required by certain plants and trees to germinate seeds, and a fire clears out the dead underbrush. The smoke from the fire increases air pollution, not only in the vicinity of the fire, but also hundreds of miles away. Wildfires destroy fragile habitats and ecosystems. They threaten endangered and protected species. Wildfires also effect and can be the cause of changes in the water quality, damaging aquatic ecosystems.

In addition to the destruction of wildlife habitats, wildfires have a number of secondary impacts. With the loss of the vegetation, there is an increase risk of landslides or mudslides following a heavy rain. These then have an effect on the environment. Invasive weeds and grasses take root and prohibit the growth and spread of native species altering the ecosystem.

## **VULNERABILITY ANALYSIS & LOSS ESTIMATION**

### **Methodology**

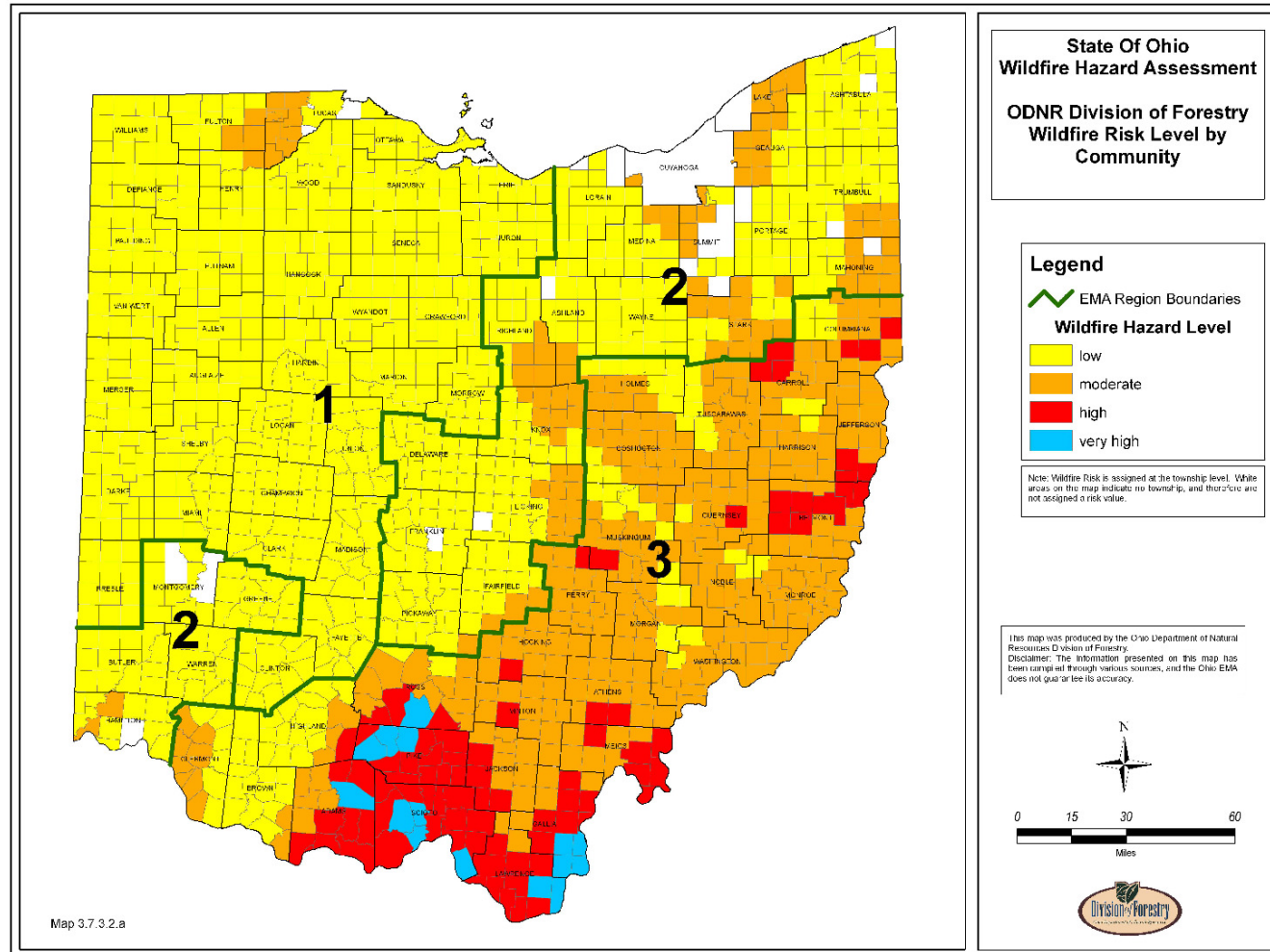
In order to accurately and quantitatively determine statewide wildfire risk, ODNR Division of Forestry combined several available datasets, using GIS tools and extensions, to complete a wildfire hazard assessment. Datasets integrated in the wildfire assessment include historic wildfire occurrence (all available wildfire reports submitted to ODNR Division of Forestry from Ohio fire departments), land use / land cover (LULC) data (1994 Landsat TM coverage data), and statewide population density. These three datasets were chosen to represent a risk (wildfire occurrence), hazard (land cover/fuel type), and value (population/homes). The township level was chosen to assign wildfire risk because rural fire departments in Ohio are typically organized at the township level. Evaluating wildfire hazard at the township level better illustrates the areas that need to increase wildfire prevention and

awareness programs. It also indicates the local fire departments that are responsible for particular high-risk jurisdictions.

Each of these respective datasets were converted to a raster format, and categorical values were reclassified accordingly: for example, hardwood LULC type was given a value of 8 while urban cover type was given a value of 0 (to indicate flammability), zero – 10 wildfires was valued at 1 while 500 – 650 wildfires was valued at 10 (to indicate occurrence risk), etc. A weighted calculation was then performed using the ArcGIS raster calculator function, whereby a total wildfire hazard value was computed from the reclassified values as such: historic reported wildfire occurrence 50%, LULC 37.50%, population density 12.50%. The calculation resulted in a new raster. The calculated wildfire hazard value was broken into four categories and labeled low, moderate, high, and very high. Factors pertinent to overall wildfire hazard level not incorporated into the calculation include fire department capability and water availability. The ODNR Division of Forestry wildfire hazard assessment was most recently update on 12/15/2006.

## **Results**

The product of this project, the Ohio wildfire hazard assessment map, accurately indicates wildfire hazard level for all townships in Ohio (see map 2.7.3.2.a). Communities at risk to wildfire in Ohio are those townships that were attributed with a calculated wildfire hazard value equal to high or very high.



Region 1 and Region 2 are assessed as having generally low wildfire hazard, with several pockets of moderate risk of wildfire. Region 3 is assessed as having generally moderate risk of wildfire, with a sizeable section of southern Ohio having high or very high wildfire risk (Gallia, Lawrence, Scioto, Adams, Pike, southern Ross Counties). Southeastern and eastern Ohio were assessed as having an additional 29 communities rated as having high wildfire hazard. Particular high-risk groups in southeastern and eastern Ohio occur in southern Athens and Meigs Counties, as well as in Belmont and southern Jefferson Counties.

High valued personal property, including homes, machinery, agricultural crops, and tree plantations in areas of high or very high wildfire hazard are more vulnerable to damage by wildfire. Fire engines belonging to local fire departments are occasionally damaged while suppressing wildfires. A great amount of personal property has been saved by fire departments through effective and safe wildfire suppression

Table 2.7.d

Estimate of Potential Losses to Wildfire by Region - 1/1/1997 - 11/20/2007

| Region 1     |            |               |                 |                  | Region 2     |            |                |                 |                    | Region 3     |              |                 |                  |                     |
|--------------|------------|---------------|-----------------|------------------|--------------|------------|----------------|-----------------|--------------------|--------------|--------------|-----------------|------------------|---------------------|
| County       | Events     | Acres         | Damage          | Loss Avoided     | County       | Events     | Acres          | Damage          | Loss Avoided       | County       | Events       | Acres           | Damage           | Loss Avoided        |
| Allen        | 0          | 0.00          | \$0             | \$0.00           | Ashland      | 19         | 12.28          | \$200           | \$325,000.00       | Adams        | 354          | 1202.90         | \$36,278         | \$1,456,757.00      |
| Auglaize     | 0          | 0.00          | \$0             | \$0.00           | Ashtabula    | 0          | 0.00           | \$0             | \$0.00             | Athens       | 183          | 800.31          | \$26,550         | \$150.00            |
| Champaign    | 0          | 0.00          | \$0             | \$0.00           | Butler       | 0          | 0.00           | \$0             | \$0.00             | Belmont      | 232          | 969.09          | \$3,340          | \$846,800.00        |
| Clark        | 0          | 0.00          | \$0             | \$0.00           | Cuyahoga     | 0          | 0.00           | \$0             | \$0.00             | Brown        | 0            | 0.00            | \$0              | \$0.00              |
| Clinton      | 0          | 0.00          | \$0             | \$0.00           | Delaware     | 0          | 0.00           | \$0             | \$0.00             | Carroll      | 209          | 472.12          | \$19,485         | \$1,623,200.00      |
| Crawford     | 0          | 0.00          | \$0             | \$0.00           | Fairfield    | 33         | 70.31          | \$250           | \$155,000.00       | Clermont     | 0            | 0.00            | \$0              | \$0.00              |
| Darke        | 0          | 0.00          | \$0             | \$0.00           | Franklin     | 0          | 0.00           | \$0             | \$0.00             | Columbiana   | 239          | 748.40          | \$3,440          | \$846,800.00        |
| Defiance     | 0          | 0.00          | \$0             | \$0.00           | Geauga       | 2          | 0.30           | \$0             | \$0.00             | Coshocton    | 226          | 553.45          | \$36,300         | \$873,060.00        |
| Erie         | 0          | 0.00          | \$0             | \$0.00           | Greene       | 0          | 0.00           | \$0             | \$0.00             | Gallia       | 565          | 5608.52         | \$3,084          | \$191,129.00        |
| Fayette      | 0          | 0.00          | \$0             | \$0.00           | Hamilton     | 0          | 0.00           | \$0             | \$0.00             | Guernsey     | 240          | 663.18          | \$7,480          | \$700.00            |
| Fulton       | 53         | 72.97         | \$29,702        | \$1,853.00       | Knox         | 122        | 230.11         | \$1,200         | \$1,530,000.00     | Harrison     | 163          | 611.78          | \$1,909          | \$965,000.00        |
| Hancock      | 0          | 0.00          | \$0             | \$0.00           | Lake         | 2          | 775.00         | \$11,000        | \$50,000.00        | Highland     | 46           | 230.35          | \$0              | \$230.00            |
| Hardin       | 0          | 0.00          | \$0             | \$0.00           | Licking      | 126        | 302.77         | \$26,400        | \$120,000.00       | Hocking      | 135          | 621.69          | \$3,000          | \$1,271,225.00      |
| Henry        | 9          | 32.61         | \$0             | \$0.00           | Lorain       | 0          | 0.00           | \$0             | \$0.00             | Holmes       | 126          | 321.96          | \$1,800          | \$1,320,300.00      |
| Huron        | 0          | 0.00          | \$0             | \$0.00           | Mahoning     | 0          | 0.00           | \$0             | \$0.00             | Jackson      | 295          | 1182.68         | \$8,210          | \$226,904.00        |
| Logan        | 0          | 0.00          | \$0             | \$0.00           | Medina       | 0          | 0.00           | \$0             | \$0.00             | Jefferson    | 174          | 635.61          | \$4,320          | \$565,500.00        |
| Lucas        | 165        | 727.71        | \$40,100        | \$222,000.00     | Montgomery   | 0          | 0.00           | \$0             | \$0.00             | Lawrence     | 1,652        | 11876.50        | \$34,559         | \$1,118,920.00      |
| Madison      | 0          | 0.00          | \$0             | \$0.00           | Pickaway     | 7          | 34.25          | \$0             | \$0.00             | Meigs        | 272          | 613.24          | \$32,560         | \$6,400.00          |
| Marion       | 0          | 0.00          | \$0             | \$0.00           | Portage      | 0          | 0.00           | \$0             | \$0.00             | Monroe       | 120          | 341.94          | \$23,960         | \$48,800.00         |
| Mercer       | 0          | 0.00          | \$0             | \$0.00           | Richland     | 39         | 159.45         | \$16,450        | \$575,000.00       | Morgan       | 104          | 272.27          | \$0              | \$17,550.00         |
| Miami        | 0          | 0.00          | \$0             | \$0.00           | Stark        | 52         | 222.87         | \$100           | \$0.00             | Muskingum    | 261          | 608.25          | \$35,540         | \$2,800.00          |
| Morrow       | 0          | 0.00          | \$0             | \$0.00           | Summitt      | 0          | 0.00           | \$0             | \$0.00             | Noble        | 77           | 312.85          | \$30,300         | \$0.00              |
| Ottawa       | 0          | 0.00          | \$0             | \$0.00           | Trumbull     | 0          | 0.00           | \$0             | \$0.00             | Perry        | 132          | 263.85          | \$435            | \$170.00            |
| Paulding     | 0          | 0.00          | \$0             | \$0.00           | Warren       | 0          | 0.00           | \$0             | \$0.00             | Flke         | 427          | 2316.09         | \$89,160         | \$675,000.00        |
| Preble       | 0          | 0.00          | \$0             | \$0.00           | Wayne        | 0          | 0.00           | \$0             | \$0.00             | Poss         | 284          | 974.81          | \$80,100         | \$697,551.00        |
| Putnam       | 0          | 0.00          | \$0             | \$0.00           | <b>TOTAL</b> | <b>402</b> | <b>1807.34</b> | <b>\$55,600</b> | <b>\$2,755,000</b> | Scioto       | 570          | 7072.85         | \$96,467         | \$5,671,868.00      |
| Sandusky     | 0          | 0.00          | \$0             | \$0.00           |              |            |                |                 |                    | Tuscarawas   | 245          | 679.50          | \$65,955         | \$2,734,000.00      |
| Seneca       | 0          | 0.00          | \$0             | \$0.00           |              |            |                |                 |                    | Vinton       | 126          | 638.62          | \$60,000         | \$0.00              |
| Shelby       | 0          | 0.00          | \$0             | \$0.00           |              |            |                |                 |                    | Washington   | 153          | 592.88          | \$78,250         | \$263,500.00        |
| Van Wert     | 0          | 0.00          | \$0             | \$0.00           |              |            |                |                 |                    | <b>TOTAL</b> | <b>7,610</b> | <b>41185.69</b> | <b>\$782,482</b> | <b>\$21,424,314</b> |
| Williams     | 0          | 0.00          | \$0             | \$0.00           |              |            |                |                 |                    |              |              |                 |                  |                     |
| Wood         | 0          | 0.00          | \$0             | \$0.00           |              |            |                |                 |                    |              |              |                 |                  |                     |
| Wyandot      | 0          | 0.00          | \$0             | \$0.00           |              |            |                |                 |                    |              |              |                 |                  |                     |
| <b>TOTAL</b> | <b>227</b> | <b>833.29</b> | <b>\$69,802</b> | <b>\$223,853</b> |              |            |                |                 |                    |              |              |                 |                  |                     |

## **VULNERABILITY ANALYSIS & LOSS ESTIMATION OF STATE-OWNED / CRITICAL FACILITIES**

State-owned structures and property within areas of high and very high wildfire hazard are obviously more at risk to damage by wildfire than those in urban or low risk areas. (See Map 2.7.4.2.a)

High valued state-owned property has been damaged in the past by wildfire. Thousands of acres of merchantable timber and tree plantations have been lost or damaged by wildfire. In February 2002, a wildfire in Crown City Wildlife Area, Gallia County, burned approximately 709 acres through a hardwood plantation reclamation project. Damages were estimated at nearly \$100,000. Machinery, such as bulldozers and trucks, belonging to state agencies are occasionally damaged while suppressing wildfires.

Exposure to wildfire, regardless of size, creates an inherently hazardous situation. In 1989, a state employee lost their life while battling a wildfire in southern Ohio, and a second was severely burned. Local firefighters have incurred numerous injuries, both severe and minor, while en route to and during suppression of wildfire in Ohio.

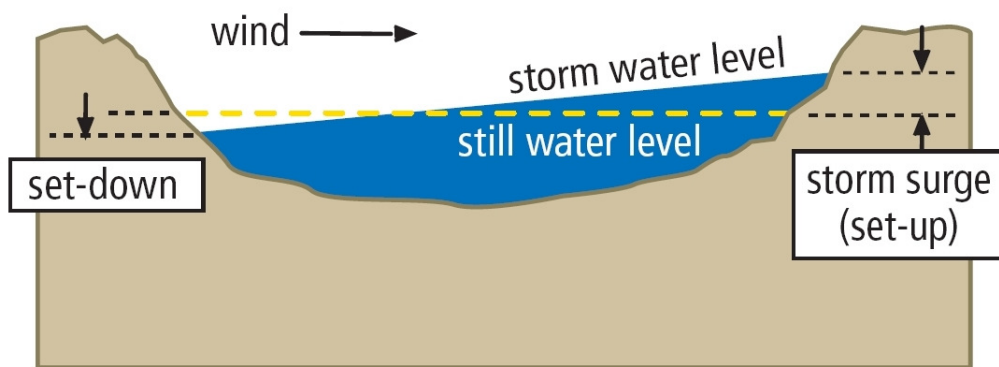
## 2.8 SEICHE / COASTAL FLOODING

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 through 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 are dependant on a number of factors. Wind speed 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 impact on artificial bodies of water such as reservoirs.

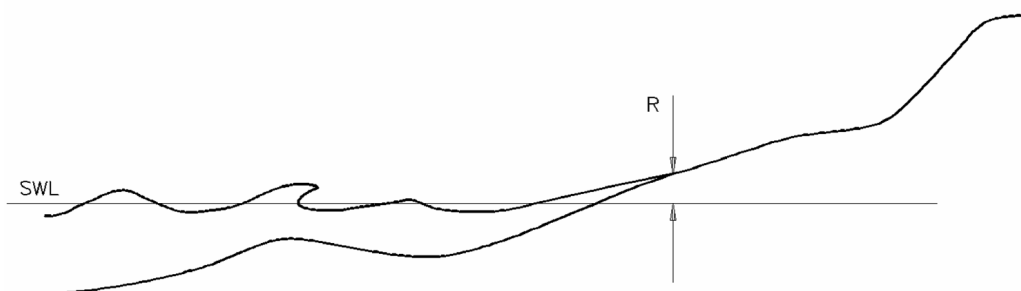
The United States Army Corps of Engineers office in Detroit Michigan developed a profile of seiche as part of a larger work analyzing water levels for the Great Lakes. Figure 2.8.a displays the static impact seiche has on a body of water with water levels rising on the downwind shore and falling along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

**Figure 2.8.a**



**Lake Profile Showing Wind Set-Up**

Figure 2.8.b provides a detailed description of the combined impact of wind and wave actions. The base water level for the lake is marked as the SWL or still water elevation. 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 surprisingly 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 generally from Ohio's eastern boarder to Lorain ranges from 15 to 24 feet deep with a shoreline of sandy beaches up 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. Prior to human intervention much of extreme northwest Ohio was swamp and wetlands with few permanent human inhabitants.

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.

### **Past Occurrences**

The National Climactic Data Center (NCDC) 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 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 losses.

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 water covered, including Monroe and Second Streets, and at Point Place on Maumee Bay. Water was also over a road in Jerusalem Township. In Ottawa County, roads were flooded in Port Clinton and sandbagging was done at some local businesses. Also, on Catawba Island, waves were coming over at least one road. At Bayview (Sandusky County), County Road 259 was flooded. Losses were estimated at \$50,000 from the 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, seventy five to one hundred families evacuated near the Vermilion and Huron Rivers, while those on Mudbrook Road moved to the second floor 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 impacted 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), 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, Erie) and Maumee Bay (Lucas) and flooding had progressed further inland in some areas. In Sandusky and Huron (Erie), 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.

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 boarder. This could be an additional factor in why Region 2 counties have no record of seiche or storm surge impacts.

### **Probability of Future Events**

Although the NCDC data covers only two years of events in the late 1990's, it is clear seiche / storm surge coastal flooding have a significant impact in Ohio. Based on the seven event profiles, it appears these events may occur between two and five times in a 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.

### **Environmental Impacts**

Seiche and coastal flooding have the same environmental impacts as that of riverine flooding. The harm to the environment comes in the form of hazardous materials. Hazardous materials are carried away from flooded out properties and distributed throughout the floodplain. Industrial and agricultural chemicals and wastes, solid wastes, raw sewage, and common household chemicals comprise the majority of hazardous materials spread by flood waters. The pollution from these chemicals and wastes not only cost a considerable amount to clean up, but contaminate everything that they come in contact with, ranging from buildings to wildlife to a community's water supply.

In addition to hazardous materials, seiche and coastal flooding contribute to coastal erosion and its effects.

## 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 pool lake water elevations for each county were taken 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 below, estimates for business interruption and building loss are

| 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           |
| <b>TOTAL</b> | <b>574,386</b> | <b>\$8,743,489,700</b>  | <b>455</b>         | <b>2,184</b>         | <b>1,476</b>        | <b>1,059</b>        | <b>309</b>          | <b>914</b>               | <b>4</b>                   | <b>\$8,560,000</b>         | <b>\$974,880,000</b>    |

\$8,560,000 and \$974,880,000, respectively.

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).

| <b>Table 2.8.b</b>                                                        |                   |                                |                           |                             |                            |                            |                            |                                 |                                   |                                   |                                |
|---------------------------------------------------------------------------|-------------------|--------------------------------|---------------------------|-----------------------------|----------------------------|----------------------------|----------------------------|---------------------------------|-----------------------------------|-----------------------------------|--------------------------------|
| <b>Estimate of Potential Losses to Seiche / Coastal Flooding Region 2</b> |                   |                                |                           |                             |                            |                            |                            |                                 |                                   |                                   |                                |
| <b>County</b>                                                             | <b>Population</b> | <b>Building Exposure Value</b> | <b>1-10% Damage Count</b> | <b>11-20 % Damage Count</b> | <b>21-30% Damage Count</b> | <b>31-40% Damage Count</b> | <b>41-50% Damage Count</b> | <b>Substantial Damage Count</b> | <b>Essential Facilities Count</b> | <b>Estimated Business Interup</b> | <b>Estimated Property Loss</b> |
| 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                   |
| <b>TOTAL</b>                                                              | <b>1,897,374</b>  | <b>\$2,396,004,000</b>         | <b>85</b>                 | <b>272</b>                  | <b>286</b>                 | <b>92</b>                  | <b>20</b>                  | <b>13</b>                       | <b>0</b>                          | <b>\$580,000</b>                  | <b>\$88,240,000</b>            |

## **VULNERABILITY ANALYSIS & LOSS ESTIMATION OF STATE OWNED / CRITICAL FACILITIES**

HAZUS-MH MR3 results do not indicate any anticipated loss to structures typically owned by the State. Seiche / coastal flooding events are limited to the shores of Lake Erie and the associated counties. Although there are no building damages noted, there will likely be impact to state parks and wetlands which may require intervention. Overall discussion of state-owned structures and critical facilities are identified in section 2.1, Table 2.1.a, and Appendix C.

## 2.9 EARTHQUAKE

Earthquakes occur as a result of the constant motion of the earth. Current science describes the earth in three major regions: the core, mantle and crust. Figure 2.9.a provides a three dimensional representation of the earth's regions.

The core is hot and consists of two subsections. The very center of the planet's core is hottest and solid. Surrounding the solid center is a liquid (i.e. molten material / magma) layer.

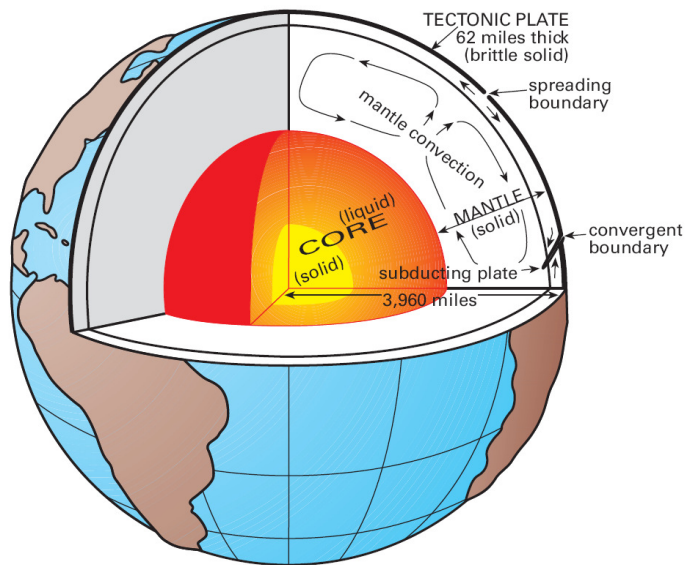
The mantle is cooler than the core and although solid circulates with the consistency of malleable plastic. Through convection, the portion of the mantle closest to the core heats and subsequently rises in the same manner as the air in the earth's atmosphere. Conversely, the upper portion of the mantle transfers its heat to the crust cools and descends back toward the core.

The crust is also solid; however, unlike the mantle it is rigid and brittle. The crust consists of a number of individual plates, each in constant motion, resting on the mantle. The boundaries where plates meet are the locations where new crust develops (spreading boundary) and alternately existing crust material returns to the mantle (convergent boundary.)

Understanding the composition of the earth is crucial because earthquakes are often associated with boundaries where the plates slide against, rise over or sink under each other. The movement at many of the plate boundaries is not smooth and consistent, but rather they grind and jerk. As the entire plates move the boundaries become locked together and enormous amounts of tension build until a sudden release occurs realigning the plate edges and creating the observed earthquake.

The locations where the crust is fractured and sliding are called faults. California has several famous faults, e.g. the San Andreas Fault, which can be clearly observed though aerial photography. In cases where the crust is pulling apart, the location is called a rift. The Reelfoot Rift and associated rift valley located in Missouri is one of the largest in North America. Although many faults are located at

**Figure 2.9.a**



*Interior zones of the Earth (figure modified from Washington Division of Geology and Earth Resources, Information Circular No. 85, 1988). The Earth's crust consists of great plates that slowly move across the surface of the Earth in response to convection cells in the mantle. Most earthquakes occur where plates meet, such as at spreading or convergent boundaries.*

*Source: Educational Leaflet No. 9 Revised Edition 2007 Division of Geological Survey*

plate boundaries there can be numerous observed faults and rifts within. Ohio geologically contains both fault and rift zones.

Another significant source of earthquakes is associated with large bodies of magma, which are located near the earth's crust. The Hawaiian archipelago and Yellowstone National Park are examples where magma deposits are altering the crust and generating both volcanic activity and earthquakes.

Earthquake locations are recorded based on the latitude and longitude of the occurrence, called the epicenter, and the associated depth underneath the earth's surface. The energy released in earthquakes travels from the epicenter in seismic

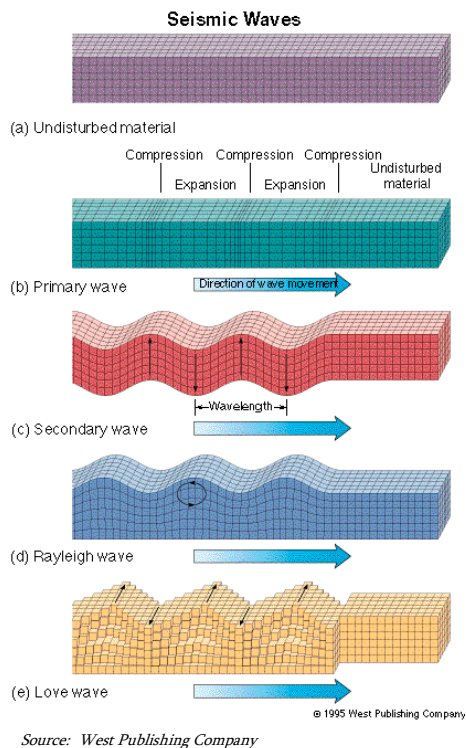


**Figure 2.9.b**

waves through the earth. The four major types of waves are often referred to as primary, secondary (body waves), Rayleigh and Love (surface waves), see Figure 2.9.b. Primary waves compress the earth's surface in front of it as they travel. Secondary waves cause the earth's surface to rise and fall perpendicular to its line of travel. Rayleigh waves travel in a circulating pattern similar to those in an ocean wave. Finally, Love waves cause the earth's surface to oscillate from side to side perpendicular to its line of travel. The primary and secondary waves travel faster than the Rayleigh and Love waves providing the initial evidence of an event.

Each wave impacts structures differently. For example, secondary waves have much greater impact in tall structures. Additionally, each wave has unique characteristics. The secondary wave, for example, cannot travel through fluids, including the molten outer core.

Location of earthquake events has the added dimension of land / crust composition. Within the United States, areas like southern California are primarily young, hot rock that is broken by mountain ranges. Under these conditions seismic waves are somewhat limited in their ability to travel (attenuation) reducing the overall area of impact. Conversely, seismic zones in the central and eastern United States have flat-lying, cold, brittle rocks with much thicker deposits of soil and sediments. Loosely consolidated materials such as sand and soil cause seismic waves to amplify ground motion.

When seismic waves travel through unconsolidated materials it can have the effect of turning solid land into quicksand. When this phenomenon, called liquefaction, occurs, any object located in the affected area may slide over or sink into the soil. Entire buildings, roadways and bridges may be significantly damaged.

One factor which greatly determines the extent of damage from an event is duration. Events can last anywhere from a few seconds to minutes. The longer the event is promulgating seismic waves the greater the opportunity for damage.

**Figure 2.9.c**

Earthquake forces are generally measured using an instrumental scale developed initially in 1935 by Charles Richter. The scale is open ended but generally ranges to 9+ (severe damage and ground deformation). The scale is logarithmic which can be confusing. For example, an earthquake rated as 2.0 magnitude is 30 times more powerful, in terms of energy released, than one rated 1.0. or a 7-magnitude earthquake is 900 times larger than a 5-magnitude earthquake.

Another method of measuring an earthquake event is by describing its intensity. Italian volcanologist Giuseppe Mercalli developed a widely used, simple scale in 1902 based on the previous Rossi-Forel scale. Over time experts have altered the original scale creating the currently used version named the Modified Mercalli Intensity Scale (MMI.)

Looking at Figure 2.9.c the exponential increases in damage for each single digit increase in the intensity scale is apparent. For example, MMI IX discusses shifted and damaged building while X describes mass destruction of masonry (brick) and frame (wood) buildings.

| Modified Mercalli Intensity Scale |                                                                                                                               | Magnitude Scale |
|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-----------------|
| I                                 | Detected only by sensitive instruments                                                                                        | 1.5             |
| II                                | Felt by few persons at rest, especially on upper floors; delicately suspended objects may swing                               | 2               |
| III                               | Felt noticeably indoors, but not always recognized as earthquake; standing autos rock slightly, vibrations like passing truck | 2.5             |
| IV                                | Felt indoors by many, outdoors by few, at night some awaken; dishes, windows, doors disturbed; standing autos rock noticeably | 3               |
| V                                 | Felt by most people; some breakage of dishes, windows, and plaster; disturbance of tall objects                               | 3.5             |
| VI                                | Felt by all, many frightened and run outdoors; falling plaster and chimneys, damage small                                     | 4               |
| VII                               | Everybody runs outdoors; damage to buildings varies depending on quality of construction; noticed by drivers of autos         | 4.5             |
| VIII                              | Panel walls thrown out of frames; walls, monuments, chimneys fall; sand and mud ejected; drivers of autos disturbed           | 5               |
| IX                                | Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken                     | 5.5             |
| X                                 | Most masonry and frame structures destroyed; ground cracked, rails bent, landslides                                           | 6               |
| XI                                | Few structures remain standing; bridges destroyed, fissures in ground, pipes broken, landslides, rails bent                   | 6.5             |
| XII                               | Damage total; waves seen on ground surface, lines of sight and level distorted, objects thrown up into air                    | 7               |

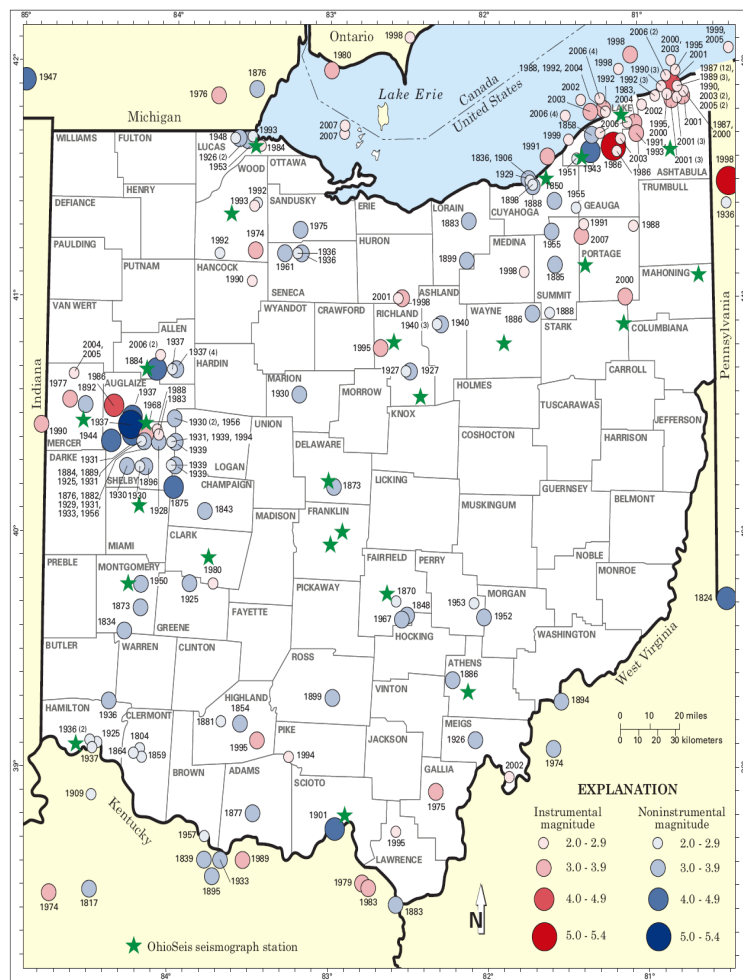
*General relationship between epicentral Modified Mercalli intensities and magnitude. Intensities can be highly variable, depending on local geologic conditions. (Modified from D. W. Steeples, 1978, Earthquakes: Kansas Geological Survey pamphlet.)*

*Source: Educational Leaflet No. 9 Revised Edition 2007 Division of Geological Survey*

## RISK ASSESSMENT

### Location

Earthquakes in Ohio are primarily located the northeast and far west-central portions of the state and historically have not exceed 5.4 magnitude (see Map 2.9.a). The map of historical epicenters lists all the events with magnitudes greater than 2.0. The size of the location marker increases with the magnitude of the event. Red circles represent instrumentally recorded events. Blue circles represent non-instrument recorded.



Locations of felt earthquakes or those with magnitudes of 2.0 or greater in Ohio and its border area. Locations and magnitudes of historic earthquakes are represented by symbols corresponding to felt area or maximum epicentral Modified Mercalli intensities. Noninstrumental locations may be in error by a considerable distance, especially for early events.

Source: Educational Leaflet No. 9 Revised Edition 2007. ODNR - Division of Geological Survey

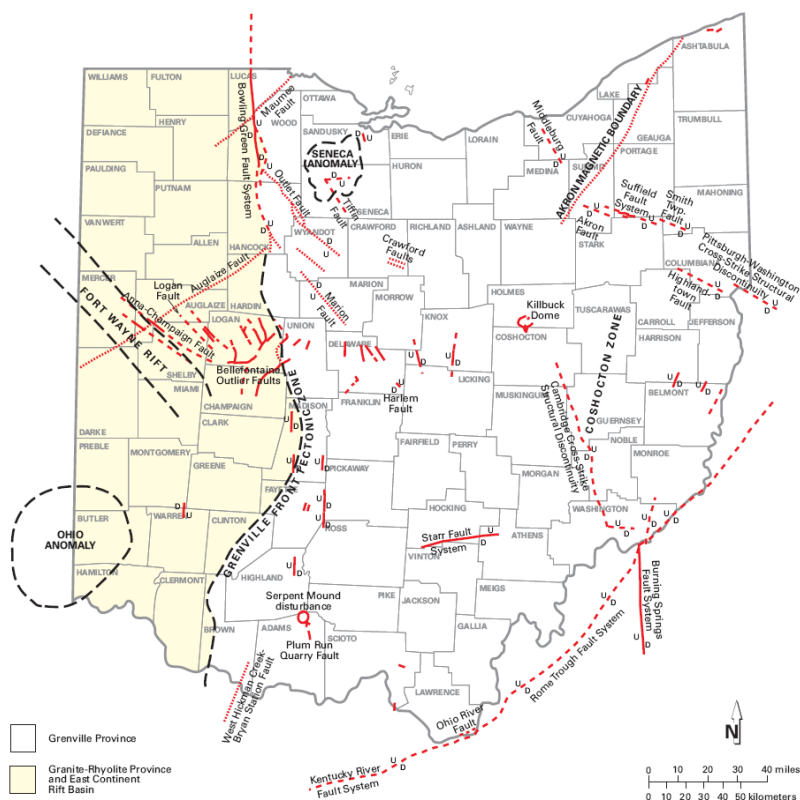
**Map 2.9.a**

These zones are characterized by deeply buried and poorly known faults, some of which serve as the sites for periodic release of strain that is constantly building up in the North American continental plate due to continuous movement of the tectonic plates that make up the Earth's crust.

The epicenter map clearly identifies the northeast Ohio counties of Ashtabula, Geauga and Lake in Region One as one of the most earthquake prone areas. Similarly in the west central counties of Auglaize, Champaign, Logan, Mercer, and Shelby represent a second nucleus of seismic activity in Region 3. Although there are clear clusters of activity, a limited number of events have occurred which are spread over a large portion of the state.

According to information published by the Ohio Division of Geological Survey, the origins of Ohio earthquakes, as with earthquakes throughout the eastern United States, are poorly understood at this time. Those in Ohio appear to be associated with ancient zones of weakness in the Earth's crust that formed during continental collision and mountain-building events about a billion years ago.

The Division of Geological Survey has developed a map of geologic features referred to as basement structures, which lie far below the earth's surface (see Map 2.9.b). The Region One active zone corresponds with the structure called the Akron Magnetic Boundary. Several geologists have speculated the boundary is a fracture zone in crystalline rocks lying more than 6,000 feet below the surface. The active area of Region Two matches to better understood features. The Fort Wayne Rift along with the Anna-Champaign, Logan and Auglaize faults, though still poorly understood, can be evaluated using the existing understanding of how these structures behave.



Basement structures in Ohio (modified from Division of Geological Survey Map PG-23, 2002). This map portrays a number of deep faults and other structures that have been identified by a variety of geologic studies. Some faults are well known, whereas others are speculative. Very few of them are visible at the surface. The Fort Wayne (Anna) rift in western Ohio is the site of numerous historic earthquakes.

**Map 2.9.b**

## LHMP Data

As indicated in the vulnerability analysis below, Hamilton County and Shelby County are the most likely counties in Ohio to be affected by a significant earthquake (Hamilton County's issues are compounded by the county's susceptibility to landslide and soil liquefaction). Both the Hamilton County and the Shelby County LHMP considers earthquakes, ranked fifth and sixth respectively, to be a high ranking concern for them. They acknowledge that an earthquake is a low probability, high consequence event. The lack of public awareness, building standards, and aging infrastructure were the reasons cited by Hamilton County for ranking earthquakes within their top five concerns. Shelby County, considered to be one of the most active seismic zones within the state, experiencing more than 40 since 1875, ranked earthquakes sixth based on past history of earthquakes including the most damaging earthquake to strike the state.

## Past Occurrences

Earthquakes are a continuously occurring hazard in Ohio. Eleven events were recorded by the Division of Geological Survey for the first 11 months of 2007. Data are available for events dating back over 200 years.

Most of Ohio's earthquake events are small, registering between 2 and 4 magnitudes. Significant events are discussed in Geological Survey document Educational Leaflet No. 9 which follows.

*Summer 1776:* The earliest Ohio earthquake to be noted occurred at 8 a.m. sometime in the summer of 1776 and was chronicled by John Heckewelder, a Moravian missionary, who reported that "the southwest side of the house was raised with such violence that the furniture of the room was nearly overturned." Heckewelder spent the summer of 1776 at the Moravian mission of Lichtenau, which was in present-day Coshocton County. Because his report is the only account of this event, it is impossible to determine an epicentral location with any certainty. In deed, the epicenter of this earthquake may not have been in Ohio.

*1811 and 1812:* On December 16, 1811, and January 23 and February 7, 1812, the largest earthquakes ever to strike the continental United States occurred at New Madrid, Missouri. These events were felt throughout an area of about 2 million square miles, including all of Ohio. In Ohio, some chimneys were toppled in the Cincinnati area, which experienced the strongest shaking from these events. Should earthquakes of this intensity be repeated at New Madrid, they would probably cause considerable damage in southwestern Ohio.

*June 18, 1875:* This earthquake was felt throughout an area of at least 40,000 square miles and was most in tense at Sidney (Shelby County) and Urbana (Champaign County), where masonry walls were cracked and chimneys toppled. It has been interpreted to have had an MMI of VII.

*September 19, 1884:* An earthquake in the vicinity of Lima (Allen County) had an epicentral MMI of VI. There were reports of fallen ceiling plaster as far away as Zanesville (Muskingum County) and Parkersburg, West Virginia. On the basis of a felt area of more than 140,000 square miles, this earthquake is estimated to have had a magnitude of 4.8. Workmen on top of the Washington Monument in Washington, D.C., reported feeling this earthquake.

*May 17, 1901:* During this earthquake, bricks were dislodged from chimneys and some windows were cracked in Portsmouth (Scioto County) and chimneys were damaged in Sciotoville. Modified Mercalli intensities of VI were generated in the epicentral area. Based on felt area, this earthquake is as signed a magnitude of 4.3.

*November 5, 1926:* This earthquake was centered near Pomeroy and Keno, in Meigs County, where chimneys were toppled. A stove was over turned at Chester. Modified Mercalli intensities of VII were generated in the epicentral area, but the earthquake apparently was felt only in portions of Meigs County and adjacent parts of West Virginia. On the basis of this small felt area, this event has been as signed a magnitude of 3.6. Explosive earth sounds were reported to have accompanied this earthquake.

*September 30, 1930:* This earthquake cracked plaster and toppled a chimney in Anna (Shelby County). An epicentral MMI of VII and a magnitude of 4.2 have been as signed to this event.

*September 20, 1931:* In this event, Anna and Sidney in Shelby County experienced toppled chimneys and cracked plaster. Store merchandise and crockery were knocked off shelves, and stones were jarred loose from the foundation of the Lutheran church in Anna. A ceiling collapsed in a school at Botkins, north of Anna. An MMI of VII and a magnitude of 4.7 have been assigned to this earthquake.

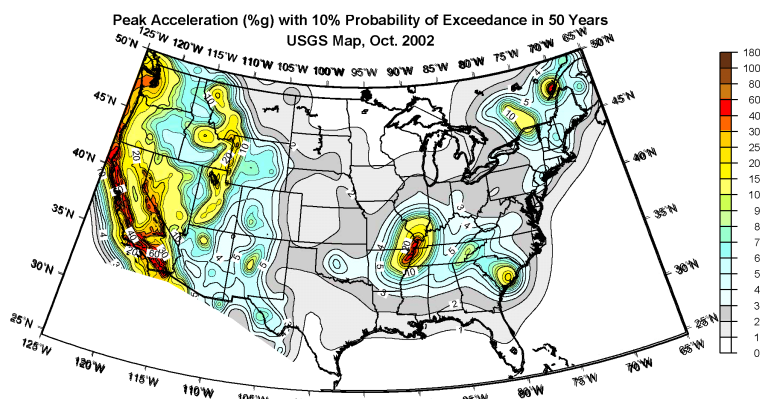
*March 2 and 9, 1937:* These two earthquakes are the most damaging to have struck Ohio. Maximum intensities were experienced at Anna (Shelby County), where an MMI of VII was associated with the March 2 event and an MMI of VIII with the March 9 event. In Anna, chimneys were toppled, organ pipes were twisted in the Lutheran church, the masonry school building was so badly cracked that it was razed, water wells were disturbed, and cemetery monuments were rotated. Both earthquakes were felt through out a multi-state area—plaster was cracked as far away as Fort Wayne, Indiana. The March 9 event was felt throughout an area of about 150,000 square miles. Analysis of seismograms from these earthquakes by the U.S. Geological Survey (Stover and Coffman, 1993) assigned magnitudes of 4.7 and 4.9, respectively, to these events. On the basis of felt area, these earthquakes have been assigned magnitudes of 4.9 and 5.4, respectively.

*January 31, 1986:* This earthquake, which had a magnitude of 5.0 and an MMI in the high VI range, occurred in Lake County, east of Cleveland, in the general vicinity of a magnitude 4.5 event in 1943. The 1986 earthquake cracked plaster and masonry, broke windows, and caused changes in water wells. The epicenter was only a few miles from the Perry nuclear power plant. It is the most intensively studied earthquake in Ohio and was the subject of several scientific reports (for example, Nicholson and others, 1988).

*July 12, 1986:* Minor damage, consisting primarily of cracked windows and plaster and fallen bricks from chimneys, was reported from this MMI VI earthquake centered northwest of Anna, near St. Mary's, in Auglaize County. It had a magnitude of 4.5.

*January 25, 2001:* The city of Ashtabula was struck by a 4.5-magnitude earthquake that caused minor damage to about 50 homes and businesses. This earthquake was the largest in a series of shallow earthquakes that began in 1987 and were attributed to fluids from a Class I deep-injection well. Nearly 40 earthquakes above 2.0 magnitude were recorded at Ashtabula through 2001. Prior to 1987, no

earthquakes had been noted in the area.



Source: USGS <http://pubs.usgs.gov/of/2002/ofr-02-420/USpga500v3-508.pdf>

## Probability of Future Events

Earthquakes have impacted Ohio as far back in history as written and oral records exist. There is clear precedence set to expect Ohio will continue to experience seismic

events for the foreseeable future. Probabilities of future events have been developed and mapped by the USGS (see Map 2.9.c). The measurement used in this estimation is based on the chance of ground shaking (e.g. peak ground acceleration) as a percentage of the natural force of gravity over time. In this analysis the extreme south western portion of Ohio has one in ten chance of experiencing an earthquake equal in force to three percent of the earth's gravity in the next 50 years due to its proximity to the New Madrid seismic zone.

Although future earthquakes events are guaranteed to occur in Ohio, the state has fortunately has not experienced any loss of life due to earthquakes. Damages are commonly limited to poorly built structures.

### **Environmental Impacts**

Earthquakes have the potential to have a large impact on the environment. Fault ruptures and landslides can dramatically alter the landscape. This alteration can cause habitat loss and alter groundwater and aquifers.

Secondary impacts would be similar to that of a tornado. Releasing hazardous materials, into the environment, from damaged facilities or pipelines that have hazardous materials, either chemical or petroleum based. The severity of the impact would be determined by the amount and type of material released. Air quality can be affected by lead and asbestos from damaged older structures. The smoke from fires caused by ruptured gas lines would also contribute to polluting the air. Water sources and supplies can become contaminated with not only hazardous materials, but also from debris and damage to treatment facilities that could permit raw sewage to enter the water supply.

## **VULNERABILITY ANALYSIS & LOSS ESTIMATION**

### **Methodology**

Loss estimates for Ohio's earthquake hazard were developed using FEMA's hazard analysis and loss estimation software HAZUS-MH and its extensive inventory of historical events. HAZUS has been used successfully for over a decade in California's earthquake preparation and response efforts. For the purpose of this initial effort, the analysis was completed using the program, data and estimated affects of ground shaking provided with the software which is also known as a level 1 analysis. It is important to interpret HAZUS-MH MR3 results with the clear understanding they are estimates and cannot be considered precise losses.

For the northeast Ohio analysis, the historical event of January 31, 1986, which strongly shook Ohio and was felt in 10 other states and southern Canada with a magnitude of 5.0, was used. Estimates for the west central area used the event of March 2, 1937 with an estimated magnitude of 5.4. Analysis for the 1811/1812 New Madrid event could not be performed due to constraints within the software.

Beginning with the county where the epicenter of where each event occurred, HAZUS-MH MR3 runs were performed on each contiguous county expanding outward, until loss estimates became negligible.

## Results

Region 1 counties with notable losses included: Allen, Auglaize, Darke, Hardin, Logan, Mercer and Shelby, (see table 2.9.a). Upon review of the HAZUS-MH MR3 analysis the results indicated very minimal impact of utility, transportation and critical



**Figure 2.9.d**

facilities. The categories which reflected the greatest impact are associated with the building inventory and are the focus of the loss estimation. The only other category with any loss is wastewater treatment and those were negligible by comparison.

The total population for the impacted area is 375,332 with a total building value of \$27,914,000,000. Impacts are reported in terms of damage degree, income losses and property damage. The HAZUS-MH MR3 User's Manual provides a basic diagram to depict the degrees of damage, (see Figure 2.9.d).

Using the building category Wood, Light Frame as an example the following descriptions are provided in the User's Manual to clarify the degrees of damage.

**Slight:** Small plaster or gypsum board cracks at corners of door and window openings and wall ceiling intersections; small cracks in masonry chimneys and masonry veneer.

**Moderate:** Large plaster or gypsum-board cracks at corners of door and window openings; small diagonal cracks across shear wall panels exhibited by small cracks in stucco and gypsum wall panels; large cracks in brick chimneys; toppling of tall masonry chimneys.

**Extensive:** Large diagonal cracks across shear wall panels or large cracks at plywood joints; permanent lateral movement of floors and roof; toppling of most brick chimneys; cracks in foundations; splitting of wood sill plates and/or slippage of structure over foundations; partial collapse of room-over-garage or other soft-story configurations; small foundation cracks.

**Complete:** Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to cripple wall failure or the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks.

HAZUS results for building counts indicate 3,029 slight, 904 moderate, 120 extensive and 13 completely impacted structures. The total loss of income is estimated at \$9,550,000 and total property losses are estimated at \$174,710,000. This represents approximately a .6 percent overall loss ratio.

Table 2.9.a

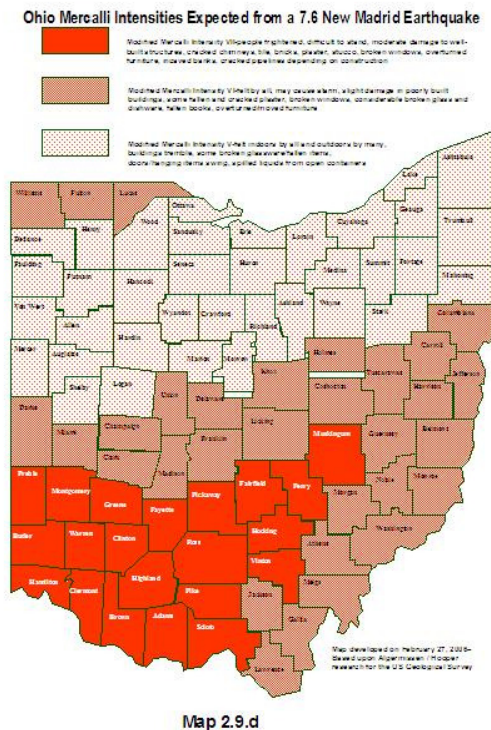
| Estimate of Potential Losses to Earthquake |                |                         |                     |                       |                        |                       |                    |                      |
|--------------------------------------------|----------------|-------------------------|---------------------|-----------------------|------------------------|-----------------------|--------------------|----------------------|
| Region 1                                   |                |                         |                     |                       |                        |                       |                    |                      |
| County                                     | 2001 Pop.      | Total Building Value    | Slight Damage Count | Moderate Damage Count | Extensive Damage Count | Complete Damage Count | Income Loss        | Property Loss        |
| Allen                                      | 108,522        | \$8,283,000,000         | 548                 | 148                   | 15                     | 1                     | \$1,600,000        | \$23,290,000         |
| Auglaize                                   | 46,453         | \$3,495,000,000         | 1,130               | 365                   | 57                     | 7                     | \$4,390,000        | \$88,120,000         |
| Darke                                      | 53,178         | \$3,774,000,000         | 110                 | 28                    | 3                      | 0                     | \$240,000          | \$2,450,000          |
| Hardin                                     | 31,945         | \$2,115,000,000         | 50                  | 12                    | 1                      | 0                     | \$100,000          | \$750,000            |
| Logan                                      | 46,115         | \$3,503,000,000         | 224                 | 60                    | 5                      | 0                     | \$350,000          | \$3,940,000          |
| Mercer                                     | 40,886         | \$2,938,000,000         | 305                 | 87                    | 9                      | 1                     | \$860,000          | \$12,870,000         |
| Shelby                                     | 48,233         | \$3,806,000,000         | 662                 | 204                   | 30                     | 4                     | \$2,010,000        | \$43,290,000         |
| <b>TOTAL</b>                               | <b>375,332</b> | <b>\$27,914,000,000</b> | <b>3,029</b>        | <b>904</b>            | <b>120</b>             | <b>13</b>             | <b>\$9,550,000</b> | <b>\$174,710,000</b> |

Region 2 counties with notable losses included: Ashtabula, Cuyahoga, Geauga, Lake and Trumbull (see Table 2.9.b). Again the notable losses are associated with building stock with relatively negligible losses to wastewater treatment facilities. The total population for the impacted area is 2,030,122 with a total building value of \$179,136,000,000. HAZUS results for building counts indicate 9,394 slight, 2,759 moderate, 380 extensive and 41 completely impacted structures. The total loss of income is estimated at \$35,580,000 and total property losses are estimated at \$590,750,000. This represents approximately a .4 percent overall loss ratio.

Table 2.9.b

| Estimate of Potential Losses to Earthquake |                  |                          |                     |                       |                        |                       |                     |                      |
|--------------------------------------------|------------------|--------------------------|---------------------|-----------------------|------------------------|-----------------------|---------------------|----------------------|
| Region 2                                   |                  |                          |                     |                       |                        |                       |                     |                      |
| County                                     | 2001 Pop.        | Total Building Value     | Slight Damage Count | Moderate Damage Count | Extensive Damage Count | Complete Damage Count | Income Loss         | Property Loss        |
| Ashtabula                                  | 102,729          | \$7,711,000,000          | 578                 | 160                   | 15                     | 1                     | \$1,320,000         | \$19,520,000         |
| Cuyahoga                                   | 1,384,252        | \$126,164,000,000        | 2,925               | 760                   | 83                     | 7                     | \$12,030,000        | \$121,920,000        |
| Gauga                                      | 92,294           | \$7,867,000,000          | 1,467               | 488                   | 73                     | 9                     | \$4,910,000         | \$103,840,000        |
| Lake                                       | 227,324          | \$19,804,000,000         | 4,118               | 1,276                 | 202                    | 24                    | \$16,710,000        | \$339,760,000        |
| Trumbull                                   | 223,513          | \$17,590,000,000         | 306                 | 75                    | 7                      | 0                     | \$610,000           | \$5,710,000          |
| <b>TOTAL</b>                               | <b>2,030,112</b> | <b>\$179,136,000,000</b> | <b>9,394</b>        | <b>2,759</b>          | <b>380</b>             | <b>41</b>             | <b>\$35,580,000</b> | <b>\$590,750,000</b> |

Although HAZUS evaluations of the 1811/1812 New Madrid Event cannot be conducted due to software constraints, the potential for damage from a similar earthquake exists. As part of preparations for a multi-state evaluation of the New Madrid hazard potential the USGS developed an updated damage evaluation for Ohio (see Map 2.9.d). The area marked in solid red would experience the greatest impact with moderate damage (broken windows, damaged chimneys, cracked walls) from a hypothetical 7.6 event.



One consideration which is beyond the scope of this analysis is the impact a New Madrid event would have on the highly landslide prone areas in Hamilton and Clermont counties. These counties are heavily urbanized containing the greater Cincinnati metropolitan area with millions of inhabitants and billions of dollars in development. In the case of Hamilton County, significant damage including the temporary closure of interstate route 75 resulting from roadway slippage has occurred due to landslide, without the impetus of ground shaking or liquefaction. When a major New Madrid event occurs affecting Hamilton County, the impact could include the closure of multiple interstate highways, rail lines, and significant building losses along with displaced inhabitants.

## STATE OWNED / CRITICAL FACILITIES VULNERABILITY ANALYSIS & LOSS ESTIMATION

### Methodology

HAZUS results for the earthquake prone areas include the category of government facilities. These would include all publicly owned structures. The methodology to earthquakes were identified in section 2.1.determine the vulnerability of state-owned structures and critical facilities to

### Results

Reviewing the results of the two epicentral counties yielded fewer than 10 impacted government structures with slight to moderate damage. The building codes in Ohio relative to earthquake design standards for publicly-owned structures have significantly mitigated potential for damage. The potential is further addressed by state-owned structures and critical facilities identified in Section 2.1, Table 2.1.a, and Appendix C.

## 2.10 COASTAL EROSION

Coastal erosion is defined as the gradual wearing away of the earth's surface by the natural forces of wind and water. The constant action of wind, waves, and ice flow has affected the coastline of Lake Erie<sup>1</sup>. Primarily, it is the waves and gravity that cause erosion. Waves undercut the land along the shore and gravity causes the land to slip into the water. As material from the bluff or bank slides into the lake, it too is eroded by waves. As this process continues, the shore moves farther landward<sup>2</sup>. Many natural factors affect erosion of the lakeshore, including shore and nearshore geology, shore relief, nearshore bathymetry, beaches, shoreline orientation, lake level fluctuations (long-term, annual, and storm surges), and climate changes (storm frequency, temperature, and precipitation)<sup>3</sup>.

The Lake Erie owes its fundamental existence to the presence of a basin or lowland that originated long before the Pleistocene Ice Age began 2 million years ago. This lowland was known as the valley of an east-flowing river, known as the Erigan River. This geology in the basin included Silurian and Devonian carbonates (limestone and dolomite) on the west and by Devonian shales on the east. Glacial ice was able to erode the less resistant shales (than the more resistant carbonate rocks) to a greater extent in the central basin and eastern basins. The first of the 4 major glacial advances during the Pleistocene obliterated this drainage system and deepened and enlarged the basin. Succeeding glaciations further deepened and enlarged it. Lake Erie, the southernmost of the Great Lakes, is also the shallowest because the ice was relatively thin (therefore lacking significant erosive power) when it reached so far south<sup>4</sup>. During the advancement of the glaciers, they eroded rock and soil and carried it with the flowing ice to the glacier edge where it was deposited as till released from melting ice. Laminated silt and clay were also deposited in proglacial lakes that formed along the margin of the glacier. These geologic materials are exposed in Lake Erie's bluffs and banks<sup>5</sup>. Upon final retreat of the glacier moving out of Ohio, the water started to discharge via the Niagara River. Glacial rebound raised the Niagara outlet and increased the water level in the Lake Erie basin. Due to a rapid glacial rebound in the upper Great Lakes, these lakes began to drain through the Lake Erie basin<sup>6</sup>. There has been a continued slow rise following the rapid rise that has brought Lake Erie to its current mean level of 571 feet above sea level.

The geologic settings vary throughout the length of Ohio's coast. From the Ohio-Pennsylvania border to Huron, Ohio, moderate to high relief shore consists of bluffs and slopes composed of glaciolacustrine sands, silts, clay, till, and/or shale. From Huron around Sandusky Bay to Marblehead peninsula, the shore is a low-relief plain composed of glaciolacustrine sediments and till, with shale exposed west of Huron and limestone exposed around Marblehead peninsula. At Sandusky Bay, two

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<sup>1</sup> Lake Erie Coastal Erosion Areas, included with 1998 CEA Designation packet

<sup>2</sup> Questions and Answers Regarding Ohio's Coastal Erosion Areas

<sup>3</sup> Updating Lake Erie Coastal Erosion Area Maps, Donald E. Guy, Jr., July 2005

<sup>4</sup> The History of Lake Erie by Michael C. Hansen

<sup>5</sup> Erosion of Coastal Bluffs in the Great Lakes, Mickelson, Edil, and Guy, USGS Professional Paper 1693

<sup>6</sup> The History of Lake Erie by Michael C. Hansen

barrier beach complexes extend across the baymouth. Around Marblehead Peninsula and Catawba Island, low to moderate banks/bluffs are composed of rock and till. West of Catawba Island, the landscape consists of low-relief lake plain and coastal wetlands (remnants of the Black Swamp). Nearshore slopes generally gentle and are composed of the same materials in bluff or bank. Beaches are typically narrow (<50 feet per 15 meters wide) to non-existent along much of the shore. Man-made features have affected the longshore transport of sand trapping sand on the updrift side at harbor jetties, power plant intakes, and long groins. Shore parallel structures have altered sand transport as well<sup>7</sup>.

Climate affects overall physical setting in the nearshore, beach, and shore zones. Long-term and annual fluctuations in lake level are due to changes in the volume of the lake resulting from changes in precipitation in the Great Lakes Basin. Short-term fluctuations are due to wind-driven storm surges, changes in barometric pressure, or inertial surges of water (seiches) that occur after lake level has been set up by either of the two previous agents. The greatest storm surges occur when the wind blows parallel to the long axis of the lake. Under extreme conditions, lake level at the confined ends of the lake may rise or fall more than six feet from pre-storm levels. Passage of storm systems through the Great Lakes can cause lake levels at the ends of the lake to fluctuate 10 to 11 feet over a period of several days. The most important storm surges along the western part of the Central Basin and all of the Western Basin are those generated by northeast winds because these storm surges are accompanied by large storm waves<sup>8</sup>.

The size of wind-generated waves depends upon wind speed and duration, open-water fetch distance, and water depth. The largest waves affecting the Ohio lakeshore are those generated by storm winds from the west through the northeast. Wave energy is highest from late fall through spring; however, lake level is at its lowest and shorefast ice typically forms a barrier between the waves and erodible shore material. Most wave erosion occurs during storms in early spring when the greatest amount of wave energy is expended on the shore. The largest waves to strike the shore are generated by onshore storms winds from the west to the northeast<sup>9</sup>. Wave erosion causes undercutting of the bluff or bank, mass wasting including block falls, rotational slumps, and debris flows, and lakebed downcutting of cohesive materials. Bedrock is not as easily eroded as the cohesive glacial sediments.

Although erosion of the bluff is necessary to sustain beaches, excessive erosion of the Lake Erie shoreline can be considered a hazard exposure.

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<sup>7</sup> Geologic Setting and Processes Along Lake Erie From Fairport Harbor to Marblehead, Ohio, D. Guy and L. Moore, 2006

<sup>8</sup> Geologic Setting and Processes Along Lake Erie From Fairport Harbor to Marblehead, Ohio, D. Guy and L. Moore, 2006

<sup>9</sup> Geologic Setting and Processes Along Lake Erie From Fairport Harbor to Marblehead, Ohio, D. Guy and L. Moore, 2006

## **RISK ASSESSMENT**

### **Location**

Lake Erie comprises 262 miles of the northern coast of Ohio bordering Lucas, Ottawa, Sandusky (Sandusky Bay), Lorain, Cuyahoga, Lake, and Ashtabula counties. Lake Erie, the 12<sup>th</sup> largest (area) lake in the world, it is about 210 miles long, 57 miles wide, and has a shoreline length of 871 miles (including the islands). With the exclusion of government-owned park and reserve areas, the coast is highly prized for commercial and residential development. In many cases, human activity has disrupted the natural function of beach formation and aquatic habitats. According to the Ohio Geological Survey, 95 percent of Ohio's Lake Erie shoreline is eroding.

### **LHMP Data**

All of the LHMPs for the counties that border Lake Erie (Ashtabula, Cuyahoga, Erie, Lake, Lorain, Lucas, Ottawa, and Sandusky), except Sandusky County and Lucas County, indicate that coastal erosion is a recognized hazard and ranked them either fourth or fifth for their county. Almost all of the plans reference the same data (Figure 2.10.a) provided by the Ohio Geological Survey. Erie County's LHMP indicated that they had completed a structural inventory in the late 1990's; but that data was not available to them at the time of writing their plan.

According to the Ottawa County LHMP there are 367 parcels, 130 of which have residential structures, located within the CEA. Using the residential average values previously determined for two townships, the estimated loss that would result would be approximately \$886,048 in Carroll Township and \$787,941 in Put-in-Bay Township if the structures were destroyed.

Only the Lake County and the Cuyahoga County LHMP address the issue of mitigation. Lake County conducted a HAZUS review of their coastal areas and provided the HAZUS data along with their plan to Ohio EMA. Cuyahoga County spent a considerable amount of time looking at mitigation efforts to coastal erosion. They mention in their LHMP the "*Ohio Coastal Management Program*" through Ohio Department of Natural Resources as a means of mitigation. The Ohio General Assembly passed the Ohio Coastal Management Law in 1988. This law authorized ODNR to act as lead agency in developing and implementing a comprehensive Coastal Management Program (OCMP) that is to integrate the management of Ohio's Lake Erie coastal region in order to preserve, protect, develop, restore and enhance its resources. OCMP attempts to establish a balance between resource protection and development, and to provide guidance to coastal property owners as well as government agencies and commercial interests.

## Past Occurrences

Unlike many of the other hazards affecting Ohio, Lake Erie is consistently undergoing coastal erosion. Although particular storms or development creates periods of increased occurrence, the shore is eroding slowly every day. To measure erosion, the net landward movement of the shore over a specific time is calculated. The position of characteristic shore features such as bluff lines can be determined from maps and aerial photographs. By analyzing the position of these features

**Table 2.10.a**

### Ohio Lake Erie Erosion Statistics by County

*Long-term: 1877 to 1973      and      Short-term: 1973 to 1990      Recession      Data      by      County*

| County        | Long-term Distance (ft.) | Long-term Rate (ft./yr) | Short-term Distance (ft.) | Short-term Rate (ft./yr.) |
|---------------|--------------------------|-------------------------|---------------------------|---------------------------|
| Ashtabula     | 82                       | 0.9                     | 28                        | 1.6                       |
| Lake          | 160                      | 1.7                     | 32                        | 1.9                       |
| Cuyahoga      | 60                       | 0.6                     | 8                         | 0.4                       |
| Lorain        | 80                       | 0.8                     | 12                        | 0.7                       |
| Erie (lake)   | 103                      | 1.6                     | 42                        | 2.5                       |
| Ottawa (lake) | 208                      | 2.0                     | 27                        | 1.6                       |
| Lucas         | 520                      | 5.4                     | 46                        | 2.7                       |
| Erie (bay)    | 241                      | 2.8                     | 32                        | 1.9                       |
| Ottawa (bay)  | 61                       | 2.0                     | 21                        | 1.2                       |

*Source: Ohio Division of Geological Survey <http://dnr.state.oh.us/geosurvey/>*

(recession lines) through time, the amount of recession can be determined and rates of recession can be calculated. Long-term and short-term recession data have been developed for each county (see table 2.10.a).

During 1929-30, the mid-1940s, 1952, the fall of 1972, the spring of 1973, and 1985, storms and high lake levels caused property damage along the low-lying areas, such as low glacial till bluffs, low glaciolacustrine banks, and barrier beaches and eroded high glacial till or glaciolacustrine bluffs inducing mass wasting in Erie, Lake, Cuyahoga, and Ashtabula counties. The short-term and long-term rates indicate that the low-lying areas have been extremely affected.

## Probability of Future Events

With shore structures increasing along the coastline, the shoreline becomes increasingly modified. Reports and studies suggest that wave erosion and mass wasting caused by Lake Erie will continue to erode the Ohio shore for the

foreseeable future. Damage to the built environment is inevitable without intervention and will warrant the full understanding of coastal processes within each stretch to rehabilitate the shoreline.

### **Environmental Impacts**

Coastal erosion has a limited direct impact to the environment because it is a localized event. The impact that it does have is to the potential loss of habitat to both plants and animals.

Coastal erosion's secondary effects would be the potential to increase coastal flooding and landslides, depending on the geography of the region. Each of these events would then have their own potential effects to the environment.

## **VULNERABILITY ANALYSIS & LOSS ESTIMATION**

### **Methodology**

The Ohio Geological Survey is in the process of reassessing Ohio's vulnerability to coastal erosion. According to the Ohio Revised Code, coastal erosion area designation must be conducted every 10 years and parcels at risk must be listed as Coastal Erosion Areas. The initial evaluation utilized 1973 and 1990 data and the results were published in 1998. Researchers utilize aerial photography to delineate exposure based on observed shoreline characteristics. The new evaluation will utilize aerial photographs from 1990 and 2004.

Once the preliminary designations of the coastal erosion areas are determined with extensive quality checking and ground proofing support, GIS layers are created and preliminary maps generated. Impacted property owners are contacted by mail of their inclusion and public meetings are held to provide an opportunity to see the risk assessment. Property owners may dispute the determination, if they believe that the shore features were not picked correctly and with proof that erosion did not occur. After all comments have been addressed, final maps are generated and final notifications are sent by mail to the coastal erosion area property owners.

Under normal circumstances the revised data from the coastal erosion areas would be aggregated by county and presented in tabular format. However, several factors must be considered before providing loss estimates. The factors of the decennial update that is in progress and preliminary results indicate significant changes in coastal erosion areas are expected from 1998 to 2008 must be weighed.

### **Results**

After extensive conversation with state partners and extensive consideration, the decision was made not to report losses on outdated data. Based on reports from the Ohio Geological Survey, data from the current update will be available in final format in late 2008 or early 2009. It is anticipated that the number of Coastal erosion area designations will decline from the 1998 designation. This is partially due to a marked increase in shoreline protection measures installed over the past ten years.

## **STATE-OWNED / CRITICAL FACILITIES VULNERABILITY ANALYSIS & LOSS ESTIMATION**

Coastal erosion has limited potential to affect all state-owned structures and critical facilities in the state and is confined mainly to Ohio Department of Natural Resources State Parks.

## 2.11 DROUGHT

Drought is a normal, recurrent feature of climate. Within the State of Ohio, drought is equally as possible to occur in one section of the state as it is in another. The effects of drought within the state vary though, based on land use (farming and cattle production as opposed to urban areas), economy (dependence on drought-impacted business (farming), geology (presence of an aquifer or ground structure that limits well production), and water source (public water supply, private well, cistern). Because of these in a general sense, drought originates from a deficiency of precipitation over an extended period of time, resulting in a water shortage for some activity, group, or environmental sector.

There are four primary types of drought: meteorological, hydrological, agricultural and socioeconomic. The State of Ohio is most often affected by agricultural and hydrological types of drought, and is often affected by both simultaneously. Below, these two types of drought are described in more detail.

*Agricultural Droughts.* Agricultural drought links characteristics of hydrological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, and reduced ground water or reservoir levels. The amount of water available for agricultural use demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. A good definition of agricultural drought accounts for the variable susceptibility of crops during different stages of crop development, from emergence to maturity. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield.

*Hydrological Drought.* Hydrological drought is associated with the effects of periods of precipitation (including snowfall) shortfalls on surface or subsurface water supply – stream flow, reservoir and lake levels and ground water. The frequency and severity of hydrological drought is often defined on a watershed or river basin scale. Although all droughts originate with a deficiency of precipitation, hydrologists are more concerned with how this deficiency plays out through the hydrologic system.

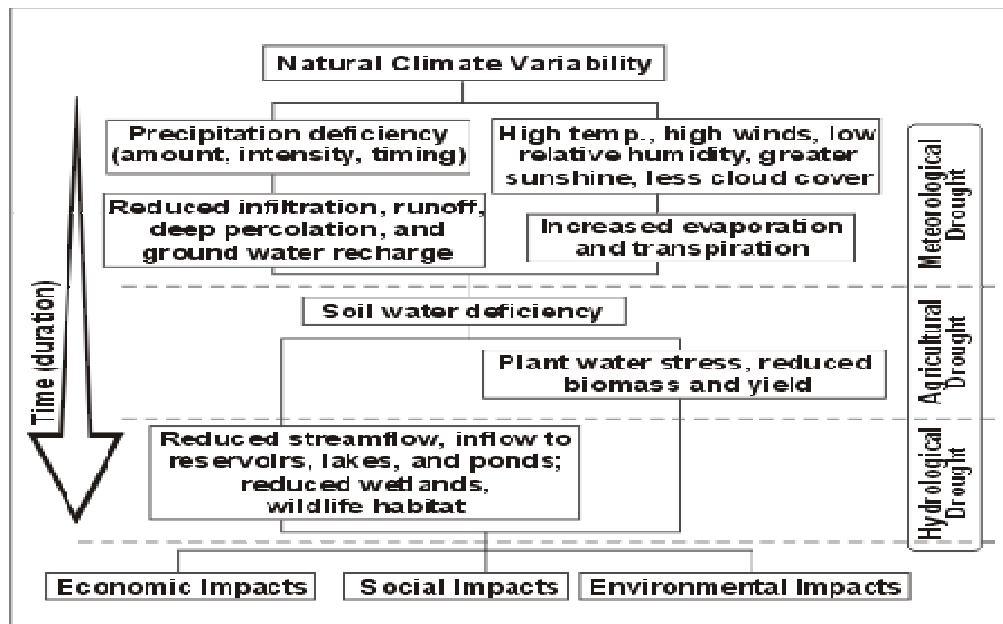
Hydrological droughts are usually out of phase with, or lag the occurrence of, meteorological and agricultural droughts. It takes longer for precipitation deficiencies to show up in components of the hydrological system such as soil moisture, stream flow, and ground water and reservoir levels. As a result, these impacts are out of phase with impacts in other economic sectors. For example, a deficiency in reservoir levels may not affect hydroelectric power production or recreational uses for many months.

Water in hydrologic storage systems (e.g., reservoirs, rivers) is often used for multiple and competing purposes (e.g., flood control, irrigation, recreation, navigation, hydropower, wildlife habitat), further complicating the sequence and quantification of impacts. Competition for water in these storage systems escalates during drought and conflicts between water users increase significantly.

Although climate is a primary contributor to hydrological drought, there are other factors such as changes in land use, deforestation, land degradation, and the construction of dams which can all affect the hydrological characteristics of a basin. Because regions are interconnected by hydrologic systems, the impact of meteorological drought may extend well beyond the borders of the precipitation-deficient area.

The flow chart, below, illustrates the progression of drought, and the relationship between meteorological, agricultural, and hydrological drought. Economic, social and environmental impacts are shown at the bottom of the chart, independent of the time scale, indicating that such impacts can occur at any stage during a drought.

**Figure 2.11.a**  
**The Drought Cycle**



Source: National Weather Service – Public Fact Sheet, August 2006  
<http://www.nws.noaa.gov/om/brochures/climate/Drought.pdf>

National Drought Mitigation Center, <http://www.drought.unl.edu/whatis/concept.htm>

## Measuring Drought

The Palmer Drought Severity Index (PDSI) is a soil moisture algorithm. The PDSI was developed by W.C. Palmer in 1965. Many U.S. government agencies and states rely on the PDSI to trigger drought relief programs and responses. Most of the agency-based actions within the Ohio Emergency Operation Plan's Drought Incident Annex are triggered by the PDSI.

**Figure 2.11.b**  
**Palmer Drought Severity Index Classifications**

|                |                     |
|----------------|---------------------|
| 4.0 or greater | Extremely Wet       |
| 3.0 to 3.99    | Very Wet            |
| 2.0 to 2.99    | Moderately Wet      |
| 1.0 to 1.99    | Slightly Wet        |
| 0.5 to 0.99    | Incipient Wet Spell |
| 0.49 to -0.49  | Near Normal         |
| -0.5 to -0.99  | Incipient Dry Spell |
| -1.0 to -1.99  | Mild Drought        |
| -2.0 to -2.99  | Moderate Drought    |
| -3.0 to -3.99  | Severe Drought      |
| -4.0 or less   | Extreme Drought     |

Source: Palmer Drought Severity Index

[http://www.math.montana.edu/~nmp/materials/ess/mountain\\_environments/intermediate/ystone/palmer\\_more.html](http://www.math.montana.edu/~nmp/materials/ess/mountain_environments/intermediate/ystone/palmer_more.html)

The PDSI is based on the supply-and-demand concept of the water balance equation, taking into account more than just the precipitation deficit at specific locations. The objective of the PDSI is to provide standardized measurements of moisture conditions, so that comparisons using the index can be made between locations and between time periods (usually months). The PDSI is calculated based on precipitation and temperature data, as well as the local Available Water Content of the soil. The Palmer Index is designed so that a -4.0 in South Carolina has the same meaning in terms of the moisture departure from a climatological normal as a -4.0 does in Ohio.

The Palmer Index is typically calculated on a monthly basis, and a long-term archive of the monthly PDSI values for every climate division in the United States exists with the National Climatic Data Center from 1895 through the present. Weekly Palmer Index values are calculated for climate divisions (the State of Ohio has ten climate divisions) during every growing season.

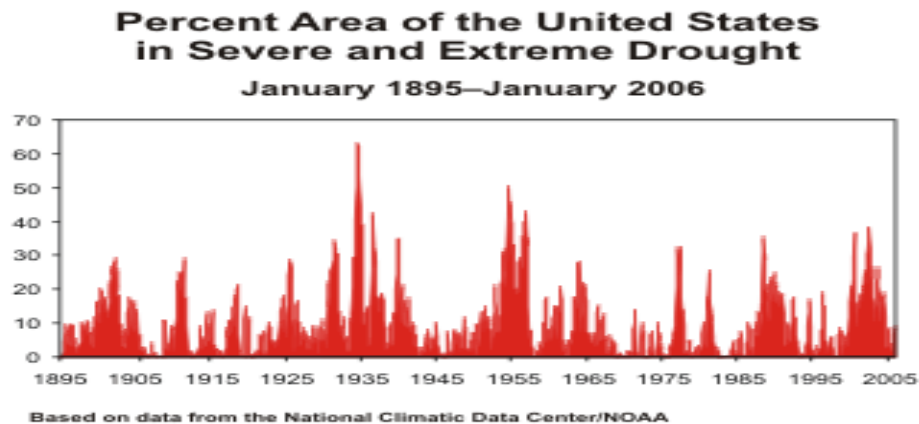
## **RISK ASSESSMENT**

### **Location**

The National Drought Mitigation Center (NDMC) has calculated values showing the spatial extent of drought based on historical Palmer Drought Severity Index (PDSI) data. The annual average of 18.1% was calculated by selecting the month of each year from 1895 to 1995 with the greatest spatial extent of severe or extreme drought and averaging the values.

Using PDSI data, the NDMC created data indicating the percent of time each climate division in the United States was in severe or extreme drought, from 1896–1994. The data show the spatial extent of drought for various time periods. The worst recent drought event occurred in July 1988, with 36% of the country in severe or

extreme drought. The worst drought event ever recorded occurred in July 1934, with 65% of the United States experiencing severe to extreme drought.



Source: National Climatic Data Center, *Understanding Your Risk and Impacts – A Comparison of Droughts, Floods, and Hurricanes in the United States*. <http://www.drought.unl.edu/risk/us/compare.html>.

**Figure 2.11.c**

### Past Occurrences

The table below lists the number of years that the United States has had severe or extreme drought in the 100 years from 1896 to 1995, based on the Palmer Drought Severity Index (PDSI). The data is divided and analyzed based on NOAA river basins. The chart shows that some part of the United States has experienced a severe or extreme drought in each year from 1896 to 1995, and that in 72 years, droughts covered more than 10% of the country.

**Table 2.11.a**  
**Number of Years with Severe or Extreme Drought between 1896 to 1995**

| % area of basin/region | >0% | >10% | >25% | >33% | >50% | >66% | >75% | >90% | 100% |
|------------------------|-----|------|------|------|------|------|------|------|------|
| United States          | 100 | 72   | 27   | 13   | 1    | 0    | 0    | 0    | 0    |
| Upper Mississippi      | 77  | 55   | 43   | 30   | 19   | 12   | 9    | 3    | 1    |
| Mid-Atlantic           | 69  | 49   | 32   | 24   | 12   | 5    | 4    | 0    | 0    |
| South Atlantic/Gulf    | 79  | 47   | 25   | 15   | 9    | 3    | 3    | 0    | 0    |
| Ohio                   | 67  | 51   | 34   | 28   | 16   | 12   | 9    | 4    | 3    |
| Missouri               | 90  | 70   | 43   | 33   | 17   | 10   | 4    | 3    | 0    |
| Pacific Northwest      | 86  | 61   | 42   | 33   | 23   | 14   | 9    | 1    | 0    |
| California             | 53  | 45   | 40   | 30   | 14   | 9    | 5    | 3    | 3    |
| Great Basin            | 71  | 65   | 43   | 37   | 19   | 6    | 3    | 1    | 1    |
| Lower Colorado         | 56  | 54   | 35   | 28   | 16   | 11   | 10   | 4    | 3    |
| Upper Colorado         | 50  | 50   | 42   | 34   | 27   | 25   | 16   | 9    | 8    |
| Rio Grande             | 58  | 47   | 32   | 24   | 15   | 8    | 5    | 2    | 2    |
| Texas Gulf Coast       | 49  | 48   | 38   | 26   | 22   | 13   | 10   | 9    | 7    |
| Arkansas–White–Red     | 65  | 48   | 27   | 23   | 14   | 7    | 4    | 0    | 0    |
| Lower Mississippi      | 56  | 38   | 19   | 15   | 4    | 1    | 0    | 0    | 0    |
| Souris–Red–Rainy       | 66  | 57   | 38   | 29   | 19   | 10   | 8    | 5    | 2    |
| Great Lakes            | 73  | 58   | 32   | 23   | 9    | 3    | 2    | 2    | 0    |
| Tennessee              | 31  | 31   | 27   | 24   | 21   | 16   | 13   | 5    | 5    |
| New England            | 56  | 44   | 27   | 13   | 8    | 5    | 4    | 0    | 0    |

Source: National Climatic Data Center, *Understanding Your Risk and Impacts – A Comparison of Droughts, Floods, and Hurricanes in the United States*. <http://www.drought.unl.edu/risk/us/compare.html>.

## **Probability of Future Events**

The probability of future occurrences of drought in Ohio is difficult to predict; however, there are two factors that may influence future drought conditions: ENSO, and climate change.

### *El Nino and La Nina Southern Oscillation*

A great deal of research has been conducted in recent years on the role of interacting systems, or teleconnections, in explaining regional and even global patterns of climatic variability. These patterns tend to recur periodically with enough frequency and with similar characteristics over a sufficient length of time that they offer opportunities to improve our ability for long-range climate prediction, particularly in the tropics.

Every two-to-seven years off the western coast of South America, ocean currents and winds shift, bringing warm water westward, displacing the nutrient-rich cold water that normally wells up from deep in the ocean. The invasion of warm water disrupts both the marine food chain and the economies of coastal communities that are based on fishing and related industries. Because the phenomenon peaks around the Christmas season, the fishermen who first observed it named it El Niño (“the Christ Child”). In recent decades, scientists have recognized that El Niño is linked with other shifts in global weather patterns. The intensity and duration of an ENSO event is varied and hard to predict. Typically, it lasts anywhere from 14-to-22 months, but it can be much longer or shorter. El Niño often begins early in the year and peaks between the following November.

During an El Niño–Southern Oscillation (ENSO) event, the Southern Oscillation is reversed. Generally, when pressure is high over the Pacific Ocean, it tends to be low in the eastern Indian Ocean, and vice versa. It is measured by gauging sea-level pressure in the east (at Tahiti) and west (at Darwin, Australia) and calculating the difference. El Niño and Southern Oscillation often occur together, but also happen separately. High positive values of the SOI indicate a La Niña, or “cold event”. La Niña is the counterpart of El Niño and represents the other extreme of the ENSO cycle. La Niña years often (but not always) follow El Niño years. A table listing the El Niño and La Niña events since 1900 can be found on the next page.

**Table 2.11.b**  
**ENSO Phases Since 1900**

|                   |                | Negative PDO: 1900-1924, 1947-1976, 1999-2002                                                                                                  | Warm phase PDO: 1925-1946, 1977-1998, 2003-2005                                                      |
|-------------------|----------------|------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| <b>ENSO Phase</b> | La Niña (cool) | 1904, 1907, 1909, 1910, 1911, 1917, 1918, 1921, 1923, 1950, 1951, 1955, 1956, 1963, 1965, 1968, 1971, 1972, 1974, 1975, 1976, 1999, 2000, 2001 | 1925, 1932, 1934, 1938, 1939, 1943, 1944, 1945, 1984, 1985, 1986, 1989, 1996                         |
|                   | ENSO Neutral   | 1901, 1902, 1908, 1913, 1916, 1922, 1947, 1948, 1949, 1953, 1954, 1957, 1960, 1961, 1962, 1967, 2002                                           | 1927, 1928, 1929, 1933, 1935, 1936, 1937, 1946, 1979, 1981, 1982, 1990, 1991, 1993, 1994, 1997, 2004 |
|                   | El Niño (warm) | 1900, 1903, 1905, 1906, 1912, 1914, 1915, 1919, 1920, 1924, 1952, 1958, 1959, 1964, 1966, 1969, 1970, 1973                                     | 1926, 1930, 1931, 1940, 1941, 1942, 1977, 1978, 1980, 1983, 1987, 1988, 1992, 1995, 1998, 2003, 2005 |

Source: Climate Impacts Group, Joint Institute for the Study of the Atmosphere and the Ocean, University of Washington, <http://www.cses.washington.edu/cig/pnwc/compensopdo.shtml>.

Understanding the connections between ENSO (and La Niña) events and weather anomalies around the globe can help in forecasting droughts, floods, tropical storms and hurricanes. NOAA estimates that the economic impacts of the 1982–83 El Niño, perhaps the strongest event in recorded history (see map, below), conservatively exceeded \$8 billion worldwide, from droughts, fires, flooding, and hurricanes. Between 1,000–2,000 deaths have been blamed on the event and the disasters that accompanied it. In addition, the extreme drought in the United States' Midwest during 1988 has been linked to the “cold event”, or La Niña, of 1988 that followed the ENSO event of 1986–87.

It is possible that the direct impacts of climate change on water resources might be hidden beneath natural climate variability. With a warmer climate, droughts and floods could become more frequent, severe, and longer-lasting. The potential increase in these hazards is a great concern given the stresses being placed on water resources and the high costs resulting from recent hazards. The drought of the late 1980s showed what the impacts might be, if climate change leads to a change in the frequency and intensity of droughts across the United States. From 1987 to 1989, losses from drought in the United States totaled \$39 billion. More frequent extreme events such as droughts and floods could end up being more cause for concern than the long-term change in temperature and precipitation averages.

### Climate Change

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### **Environmental Impacts**

As demonstrated by the “Dust Bowl” of the 1930’s, droughts can have a severe impact on the environment. The most obvious effect droughts have on the environment is reduced stream flows, loss of wetlands, and changes in water quality. With the lack of water, vegetation dries out and dies. This increases the threat of wildfires, land subsidence, and soil erosion from both water and wind. These in turn have their own effect on the environment on top of the drought. In addition to these effects, air quality is also diminished due to dust from wind erosion and pollutants.

### **VULNERABILITY ANALYSIS & LOSS ESTIMATION**

Drought risk is based on a combination of the frequency, severity, and spatial extent of drought and the degree to which a population or activity is vulnerable to the effects of drought. The degree of a region’s vulnerability depends on the environmental and social characteristics of the region and is measured by their ability to anticipate, cope with, resist, and recover from drought.

Society’s vulnerability to drought is determined by a wide range of factors, both physical and social, such as demographic trends and geographic characteristics. People and activities will be affected in different ways by different hazards.

There is a sequence of impacts associated with meteorological, agricultural, and hydrological droughts in Ohio. When drought begins, the agricultural sector is usually the first to be affected because of its heavy dependence on stored soil water, which can be rapidly depleted during extended dry periods. If precipitation deficiencies continue, then people dependent on other sources of water will begin to feel the effects of the shortage. Those who rely on surface water (reservoirs and lakes) and subsurface water (ground water) are usually the last to be affected. A short-term drought that persists for 3-to-6 months may have little impact on these sectors, depending on the characteristics of the hydrologic system and water use requirements.

When precipitation returns to normal and meteorological drought conditions have abated, the sequence is repeated for the recovery of surface and subsurface water supplies. Soil water reserves are replenished first, followed by stream flow, reservoirs and lakes, and ground water. Drought impacts may diminish rapidly in the agricultural sector because of its reliance on soil water, but linger for months or even years in other sectors dependent on stored surface or subsurface supplies. Ground water users, often the last to be affected by drought during its onset, may be last to experience a return to normal water levels. The length of the recovery period is a function of the intensity of the drought, its duration, and the quantity of precipitation received as the episode terminates.

Socioeconomic definitions of drought associate the supply and demand of some economic good with elements of meteorological, hydrological, and agricultural drought. It differs from the other types of drought because its occurrence depends on the time and space processes of supply and demand to identify or classify droughts. The supply of many economic goods, such as water, forage, food grains, fish, and hydroelectric power, depends on weather. Socioeconomic drought occurs when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply.

FEMA estimated in 1995 that drought costs the United States \$6–8 billion annually. Other studies have indicated that drought losses average \$200 million to \$1.24 billion annually in the Great Plains. This range is based on crop losses and other direct and indirect losses. According to NOAA's National Climatic Data Center, in 1999, a drought that affected twenty-eight Ohio counties caused \$200 million in crop damages.

The Dust Bowl years of the 1930s and the drought of 1988–89 are both contenders for the worst drought on record in the United States. Economic losses are often hard to calculate and compare for a variety of reasons: lack of historical records and economic models, and past and present costs that are often based on different criteria. Today, many different types of losses are often included in an economic analysis, such as energy losses, ecosystem losses, and consumer purchasing losses, but they were not typically included in previous analyses and are difficult to assess in retrospect.

A 1975 study noted that the 1930s droughts were considered to be the most economically damaging droughts to affect the United States. It is estimated that total costs due to the 1988 drought, including losses in agriculture, energy, water, ecosystems, and other sectors of the economy, were roughly \$39 billion, making it the most expensive natural disaster ever to affect the nation.

## **STATE-OWNED / CRITICAL FACILITIES VULNERABILITY ANALYSIS & LOSS ESTIMATION**

Drought does not pose a specific threat to state-owned structures. The larger threat from drought would be based on the agricultural and drinking water demands with a limited supply.

## 2.12 SEVERE SUMMER STORMS

Severe summer storms traditionally precede an approaching cold air mass. In the northern hemisphere, the spin of the earth naturally produces weather patterns affecting North America, which travel from west to east across the continent. Key components to the formation of storms are a low pressure zone, high pressure zone and the jet stream.

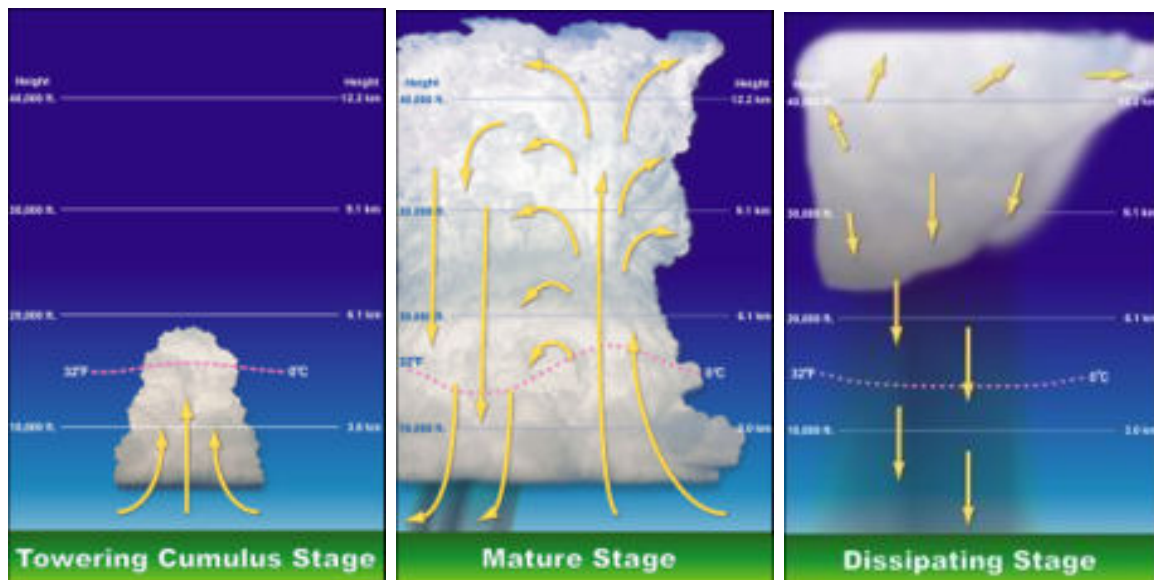
The troposphere is the lowest portion of Earth's atmosphere containing approximately 75% of the atmosphere's mass and almost all of its water vapor. Air at this level is acted upon by the earth surface (land and water) and the heating cycle associated with sunlight. Unlike other portions of the atmosphere which are largely homogenous, at the surface discrete areas or bubbles exist of differing temperature, water vapor content and pressure. Warm areas (low pressure) tend to rise pressing on the borders of surrounding cool areas (high pressure). It is where the pressure zones interface that temperature changes cause water vapor in the air to condense creating precipitation. The warmer the overall temperature of the atmosphere and the greater the volume of water vapor present, the larger the associated perception event.

Jet streams are fast flowing, relatively narrow air currents found in the atmosphere around 11 kilometers (36,000 ft) above the surface of the Earth. They form at the boundaries of adjacent air masses with significant differences in temperature, such as of the polar region and the warmer air toward the equator. These air currents migrate north and south in a snakelike pattern changing their relative location as the planet's axis tilts with each passing year. These winds act on the high and low pressure zone moving them across the continent and shifting them north and south.

Thunderstorms develop when large differences exist between adjacent zones combined with significant water vapor. As warm air begins to lift, it eventually starts to cool and condensation takes place. When the moisture condenses, heat is released which further aids in the lifting process. If enough instability is present in the atmosphere, this process will continue long enough for cumulonimbus clouds to form, which supports lightning and thunder (see Diagram 2.12.a). As water droplets rise into the colder air, they can freeze. When the velocity of wind becomes great enough, the ice pellets are repeatedly lifted and dropped in the storm adding layers of ice with each cycle. Once the wind cannot support the weight of the ice pellet it falls the ground in the form of hail.

One key component to a thunderstorm is lightning, an atmospheric discharge of electricity. High speed videos (examined frame-by frame) show that most lightning strikes are made up of multiple individual strokes. A typical strike is made of 3 to 4 strokes. The sudden increase in pressure and temperature from lightning produces rapid expansion of the air surrounding and within a bolt of lightning. In turn, this expansion of air produces a sonic shock wave which produces the sound of thunder. Lightning, other storm components, often seeks a path though the tallest object available. Trees, utility line/poles, tall buildings and even humans can be sought as a pathway for the discharging electricity.

Summer storms are considered high wind events by the National Climatic Data Center when surface winds meet or exceed 50 knots or 57.6 miles per hour. It is possible for winds in strong storms to exceed 100 miles per hour with, gusts even stronger.



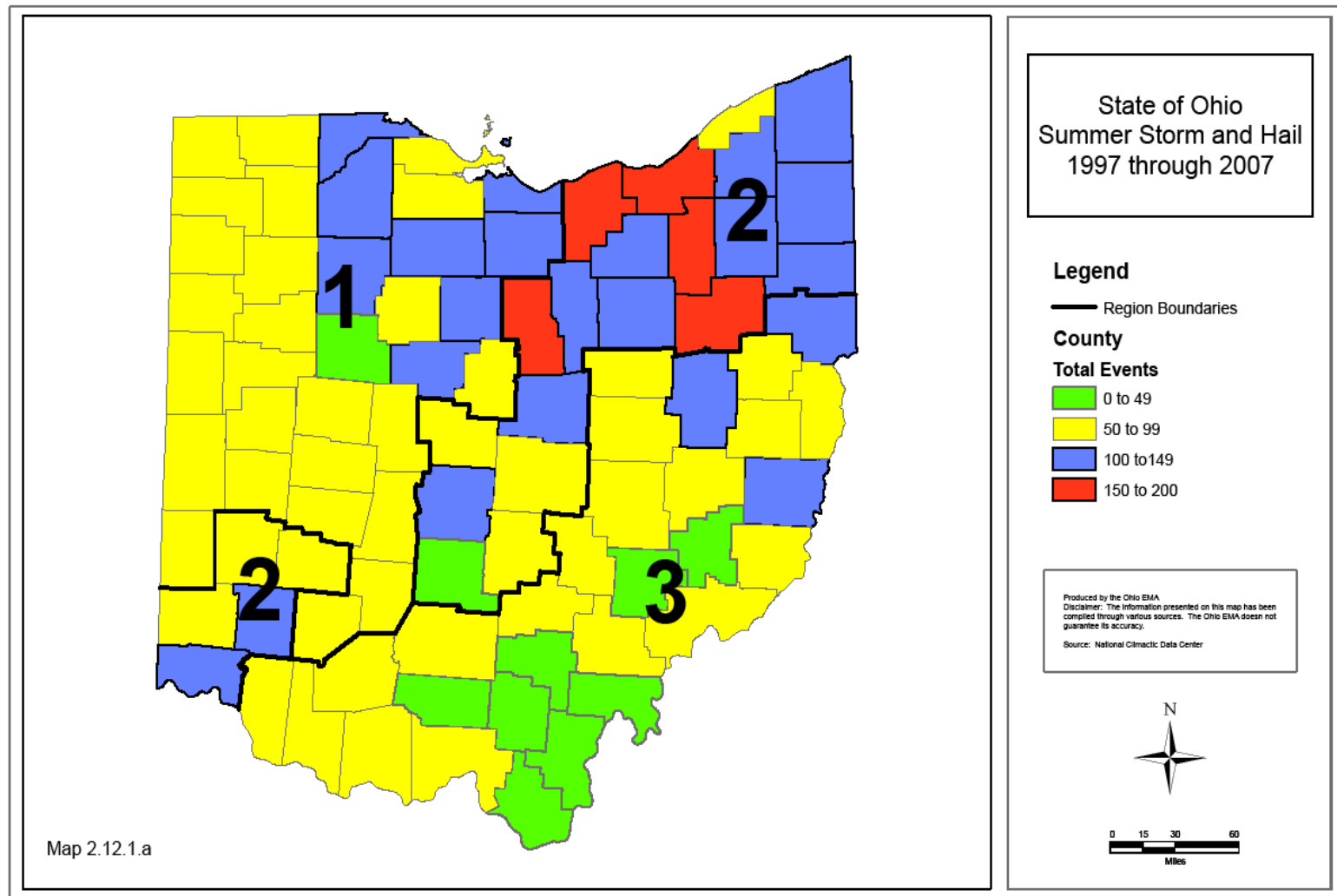
Source: Wikipedia <http://en.wikipedia.org/wiki/Thunderstorm>

**Figure 2.12.a**

## RISK ASSESSMENT

### Location

Severe summer storms and associated high wind / hail events are common throughout Ohio and reported hundreds of times each year. Analysis of number of reported occurrences from 1997 to 2007 by the National Climatic Data Center shows a clear concentration in North-Central and North-East Ohio (see map 2.12.2.1.a) The five counties with the highest number of reported occurrences, 150 to 200 over ten years, are Richland, Lorain, Cuyahoga Summit and Stark counties all in Region 2. Conversely, a concentrated area of low reported occurrences, 0 to 49 over ten years, exists in South-Central Ohio with most in Region 3.



Over one half of the counties in Ohio have between 50 and 99 reported summer storm events over the course of 10 years. These counties are predominantly in the western and central sections of the state. Based on the dispersion pattern generated, it can be reasonably concluded the number of summer storm events in Ohio is influenced by the proximity to Lake Erie.

### **Past Occurrences**

In 2003 the largest recorded event caused \$145,000,000 in hail damage to the central Ohio counties of Franklin and Delaware. The area impacted is urbanized with a large number of high valued residences. The largest single county event recorded occurred in 2006 with \$100,000,000 in estimated property damage in Licking County. Hail stones 1.75 inches in diameter damaged many homes and vehicles during a 15 minute period. In a similar event the Montgomery County, City of Huber Heights experienced \$70,000,000 of damages in 2001. Of the varied forces involved in summer storms, hail is the most destructive.

High wind events are more destructive from the perspective of transportation and utilities. Although the dollar value of the most destructive wind event is reported at \$750,000 in Erie county, the downed electric and phone cable along with the inaccessibility of emergency services from uprooted trees and utility poles creates a potentially life threatening situation.

### **Probability of Future Events**

The historical period used for severe summer storm analysis began with April 30, 1997 and closed April 30, 2007 based on statistics tabulated by the National Climatic Data Center. During this period over 5,000 events are documented with over 15,000 documented since 1950. Based on available documented occurrences, severe summer storms are the most prevalent natural hazard events in Ohio.

From January 1997 to August 2007 Ohio has received 19 presidential declarations. Of the declared events, 16 specifically cite severe storms as part of the description. Additionally, the only year Ohio did not receive a federal declaration for severe storm was 1999. Based on past experience, Ohio can reasonably expect at least one storm every two years large enough to trigger a federal declaration, as well as numerous smaller events.

### **Environmental Impacts**

Severe summer storms have little direct impact on the environment. High winds, heavy rains, and hail can damage vegetation and stir up sediment in waterways disrupting the ecosystems.

The impact that severe summer storms have on the environment is through the spawning tornados, flooding, and increased chance of wildfires from lightning strikes. Each of these events then impacts the environment.

## **VULNERABILITY ANALYSIS AND LOSS ESTIMATION**

### **Methodology**

During data development for the thunderstorm/high wind and hail hazard, it quickly became apparent the two must be addressed separately. Hail events, as stated earlier, are far more costly, but also have a much greater financial impact in urbanized areas. Events of the same magnitude can create \$10,000,000 worth of damage in an urban setting, or as little \$50,000 in forested or agricultural area. Of the 88 counties in Ohio, 22 percent reported no hail loss while 2 counties reported \$100,000,000 or more.

The extreme range of the data for hail would skew any useful thunderstorm/high wind analysis. As a result, the vulnerability and loss estimate by county for summer storms considers only thunderstorms/high wind events with hail is addressed by the state as a whole.

The 10-year summer storm losses (1997 to 2007) for each county provided the basis for estimating potential vulnerability and losses. To yield the per capita 10-year damage total for each county, the total damage for the decade was divided by the 2001 population. That figure divided by ten, resulted in the annual per capita damage figure for severe summer storms in each county (in raw dollar unadjusted for inflation). This is the figure that appears in the column on the right.

### **2.12.3.2 Results**

With an annual summer storm loss figure of \$1.67 per capita, based on the 2001 population of 11,381,725, Ohio can expect an annual statewide summer storm loss of approximately \$19,007,481 in the future. The 10-Year loss includes all residential, commercial, governmental structures, as well as infrastructure and public facilities for each county. Table 2.12.a shows severe summer weather per capita loss.

Table 2.12.a

| Estimate of Potential Losses to Summer Storms by Region |                  |                                        |                                       |              |                  |                                        |                                       |              |                  |                                        |                                       |
|---------------------------------------------------------|------------------|----------------------------------------|---------------------------------------|--------------|------------------|----------------------------------------|---------------------------------------|--------------|------------------|----------------------------------------|---------------------------------------|
| Region 1                                                |                  |                                        |                                       | Region 2     |                  |                                        |                                       | Region 3     |                  |                                        |                                       |
| County                                                  | 2001 Pop.        | 10-Year Cumulative Summer Storm Losses | Per-Capita Annual Summer Storm Losses | County       | 2001 Pop.        | 10-Year Cumulative Summer Storm Losses | Per-Capita Annual Summer Storm Losses | County       | 2001 Pop.        | 10-Year Cumulative Summer Storm Losses | Per-Capita Annual Summer Storm Losses |
| Allen                                                   | 108,522          | \$2,307,000                            | \$2.13                                | Ashland      | 52,786           | \$2,476,000                            | \$4.69                                | Adams        | 27,225           | \$768,000                              | \$2.82                                |
| Auglaize                                                | 46,453           | \$231,000                              | \$0.50                                | Ashtabula    | 102,729          | \$2,331,000                            | \$2.27                                | Athens       | 62,792           | \$324,000                              | \$0.52                                |
| Champaign                                               | 39,210           | \$333,000                              | \$0.85                                | Butler       | 335,992          | \$418,000                              | \$0.12                                | Belmont      | 69,605           | \$539,000                              | \$0.77                                |
| Clark                                                   | 143,969          | \$380,000                              | \$0.26                                | Cuyahoga     | 1,384,252        | \$5,735,000                            | \$0.41                                | Brown        | 43,425           | \$453,000                              | \$1.04                                |
| Clinton                                                 | 41,277           | \$1,614,000                            | \$3.91                                | Delaware     | 118,215          | \$367,000                              | \$0.31                                | Carroll      | 29,011           | \$406,000                              | \$1.40                                |
| Crawford                                                | 46,695           | \$2,386,000                            | \$5.11                                | Fairfield    | 125,109          | \$479,000                              | \$0.38                                | Clermont     | 180,970          | \$1,181,000                            | \$0.65                                |
| Darke                                                   | 53,178           | \$482,000                              | \$0.91                                | Franklin     | 1,081,784        | \$915,000                              | \$0.08                                | Columbiana   | 111,684          | \$790,000                              | \$0.71                                |
| Defiance                                                | 39,195           | \$218,000                              | \$0.56                                | Geauga       | 92,294           | \$1,735,000                            | \$1.88                                | Coshocton    | 36,803           | \$289,000                              | \$0.79                                |
| Erie                                                    | 79,321           | \$3,637,000                            | \$4.59                                | Greene       | 148,530          | \$377,000                              | \$0.25                                | Gallia       | 30,929           | \$149,000                              | \$0.48                                |
| Fayette                                                 | 28,387           | \$291,000                              | \$1.03                                | Hamilton     | 838,134          | \$1,240,000                            | \$0.15                                | Guernsey     | 40,899           | \$849,000                              | \$2.08                                |
| Fulton                                                  | 42,334           | \$355,000                              | \$0.84                                | Knox         | 55,250           | \$2,663,000                            | \$4.82                                | Harrison     | 15,813           | \$370,000                              | \$2.34                                |
| Hancock                                                 | 71,745           | \$1,250,000                            | \$1.74                                | Lake         | 227,324          | \$1,827,000                            | \$0.80                                | Highland     | 40,875           | \$300,000                              | \$0.73                                |
| Hardin                                                  | 31,945           | \$287,000                              | \$0.90                                | Licking      | 149,080          | \$476,000                              | \$0.32                                | Hocking      | 28,241           | \$265,000                              | \$0.94                                |
| Henry                                                   | 29,090           | \$99,000                               | \$0.34                                | Lorain       | 285,798          | \$4,698,000                            | \$1.64                                | Holmes       | 39,539           | \$2,174,000                            | \$5.50                                |
| Huron                                                   | 59,775           | \$3,235,000                            | \$5.41                                | Mahoning     | 254,810          | \$1,467,000                            | \$0.58                                | Jackson      | 32,743           | \$567,000                              | \$1.73                                |
| Logan                                                   | 46,115           | \$241,000                              | \$0.52                                | Medina       | 154,718          | \$2,864,000                            | \$1.85                                | Jefferson    | 72,705           | \$645,000                              | \$0.89                                |
| Lucas                                                   | 454,029          | \$1,969,000                            | \$0.43                                | Montgomery   | 553,579          | \$671,000                              | \$0.12                                | Lawrence     | 62,017           | \$202,000                              | \$0.33                                |
| Madison                                                 | 40,158           | \$224,000                              | \$0.56                                | Pickaway     | 52,840           | \$396,000                              | \$0.75                                | Meigs        | 22,920           | \$85,000                               | \$0.37                                |
| Marion                                                  | 65,639           | \$1,474,000                            | \$2.25                                | Portage      | 153,056          | \$4,405,000                            | \$2.88                                | Monroe       | 15,141           | \$212,000                              | \$1.40                                |
| Mercer                                                  | 40,886           | \$287,000                              | \$0.70                                | Richland     | 128,549          | \$2,741,000                            | \$2.13                                | Morgan       | 14,961           | \$48,000                               | \$0.32                                |
| Miami                                                   | 99,329           | \$308,000                              | \$0.31                                | Stark        | 378,098          | \$6,215,000                            | \$1.64                                | Muskingum    | 84,783           | \$461,000                              | \$0.54                                |
| Morrow                                                  | 32,319           | \$920,000                              | \$2.85                                | Summitt      | 542,899          | \$3,734,000                            | \$0.69                                | Noble        | 14,052           | \$214,000                              | \$1.52                                |
| Ottawa                                                  | 41,036           | \$5,708,000                            | \$13.91                               | Trumbull     | 223,513          | \$2,432,000                            | \$1.09                                | Perry        | 34,212           | \$254,000                              | \$0.74                                |
| Paulding                                                | 20,163           | \$397,000                              | \$1.97                                | Warren       | 168,229          | \$5,035,000                            | \$2.99                                | Pike         | 27,982           | \$137,000                              | \$0.49                                |
| Preble                                                  | 42,344           | \$310,000                              | \$0.73                                | Wayne        | 112,274          | \$2,759,000                            | \$2.46                                | Ross         | 73,437           | \$424,000                              | \$0.58                                |
| Putnam                                                  | 34,741           | \$1,138,000                            | \$3.28                                | <b>TOTAL</b> | <b>7,564,327</b> | <b>\$53,649,000</b>                    | <b>\$28.36</b>                        | Scioto       | 78,428           | \$271,000                              | \$0.35                                |
| Sandusky                                                | 61,653           | \$5,538,000                            | \$8.98                                |              |                  |                                        |                                       | Tuscarawas   | 91,521           | \$838,000                              | \$0.92                                |
| Seneca                                                  | 58,314           | \$2,079,000                            | \$3.57                                |              |                  |                                        |                                       | Vinton       | 12,953           | \$68,000                               | \$0.52                                |
| Shelby                                                  | 48,233           | \$523,000                              | \$1.08                                |              |                  |                                        |                                       | Washington   | 62,798           | \$1,321,000                            | \$2.10                                |
| Union                                                   | 40,909           | \$328,000                              | \$0.80                                |              |                  |                                        |                                       | <b>TOTAL</b> | <b>1,458,464</b> | <b>\$14,604,000</b>                    | <b>\$33.57</b>                        |
| Van Wert                                                | 29,432           | \$503,000                              | \$1.71                                |              |                  |                                        |                                       |              |                  |                                        |                                       |
| Williams                                                | 39,200           | \$167,000                              | \$0.43                                |              |                  |                                        |                                       |              |                  |                                        |                                       |
| Wood                                                    | 121,680          | \$9,263,000                            | \$7.61                                |              |                  |                                        |                                       |              |                  |                                        |                                       |
| Wyandot                                                 | 22,956           | \$966,000                              | \$4.21                                |              |                  |                                        |                                       |              |                  |                                        |                                       |
| <b>TOTAL</b>                                            | <b>2,200,232</b> | <b>\$49,448,000</b>                    | <b>\$84.95</b>                        |              |                  |                                        |                                       |              |                  |                                        |                                       |

The total 10-year cumulative summer storm loss for Region 1 is \$49,448,000, which is the highest in the state (annual per-capita of \$2.49). Within the region, Ottawa and Sandusky Counties have historically had the highest 10-year loss each exceeding \$5,000,000 affecting approximately 102,689 people. Henry County historically had the lowest 10-year loss at \$99,000 affecting 29,090 people.

Region 2 has the lowest 10-year cumulative summer storm loss in the state at a total of \$53,649,000 (annual per-capita of \$1.13). Within the region, Cuyahoga County has historically had the highest 10-year loss at a total of \$5,735,000 affecting approximately 1,384,252 people (see Table 2.12.3.2.a). Pickaway County has historically had the lowest 10-year loss at \$396,000 affecting 52,840 people.

Region 3 has a 10-year cumulative summer storm loss of \$14,604,000, which has affected a population of approximately 1,458,464 persons (annual per-capita of \$1.16). Holmes County has had experienced the highest 10-year loss at a total of \$2,174,000 affecting approximately 39,539 persons (see Table 2.12.3.2.a). Morgan County has had the least 10-year loss to summer storms at \$48,000, which affected approximately 14,963 persons (see Table 2.12.3.2.a).

Hail events cannot be logically assessed by county; however, based on the data, Ohio will experience hail storms generating \$25,000,000 or more of damages in developed areas once in a two year period. Predominantly rural areas range from a low of no reported losses in 19 counties to a high of \$975,000 in Gallia. Here again the highly sporadic nature of hail events makes county-to-county comparisons misleading. With 2,491 hail events and \$463,571,600 in damages over the analysis period, the mean event would cost \$186,062. However, the usefulness of such a statistic is highly debatable and is provided for illustration only.

Property damage is not the only loss associated with summer storms and hail. Over the analysis period 13 deaths and 98 injuries were attributed to these events. Of the injuries reported, 20 are attributed to a single event in Franklin County which involved a camp ground.

## **STATE-OWNED / CRITICAL FACILITIES VULNERABILITY ANALYSIS & LOSS ESTIMATION**

Since summer storms are non-spatial hazards and have the potential to affect all state-owned structures and critical facilities in the state, this section defaults to the overall discussion of state-owned structures and critical facilities identified in section 2.1, Table 2.1.a, and Appendix C.

## 2.13 INVASIVE SPECIES

According to the Ohio Department of Natural Resources, Division of Natural Areas and Preserves, of the approximately 3,000 species of plants known to occur in the wild in Ohio, about 75 percent are native or have occurred in Ohio before the time of substantial European settlement, about 1750. The other 25 percent, around 700 to 800 species, are not native to Ohio, having been introduced from other states or countries.

Most of these species never stray far from where they are introduced (gardens, urban areas, agricultural fields), yet some become very invasive and displace native plants in woodlands, wetlands, prairies, and other natural areas. Non-native plants have been introduced for erosion control, horticulture, forage crops, medicinal use, and wildlife foods as well as simply by accident. The top 10 species invading Ohio are:

- |                     |                         |
|---------------------|-------------------------|
| 1. Bush Honeysuckle | 6. Japanese Honeysuckle |
| 2. Autumn Olive     | 7. Japanese Knotweed    |
| 3. Buckthorn        | 8. Multiflora Rose      |
| 4. Common Reed      | 9. Purple Loosestrife   |
| 5. Garlic Mustard   | 10. Reed Canary Grass   |

Without natural predators or controls, invasive non-native plants are able to spread quickly and force out native plants. In Ohio, several non-native plants are invading woodlands and displacing native spring wildflowers. Other non-native plants are impacting our wetlands by creating monocultures. Native plant diversity is important for wildlife habitat, as many animals depend on a variety of native plants for food and cover.

According to the Aquatic Nuisance Species Task Force, which is a nationwide cooperative effort between many federal departments, the species listed below are a few of the many aquatic nuisance species that are potentially harmful to North American environments in which they are not native. (\* not currently in Ohio)

- |                           |                    |
|---------------------------|--------------------|
| 1. Zebra Mussel           | 10. Round Goby     |
| 2. Ruffe                  | 11. Sea Lamprey    |
| 3. Chinese Mitten Crab    | 12. Snakehead      |
| 4. European Green Crab    | 13. Nutria*        |
| 5. Brown Tree Snake*      | 14. Hydrilla       |
| 6. Eurasian Water Milfoil | 15. Applesnail     |
| 7. New Zealand Mudsnail   | 16. Water Hyacinth |
| 8. Asian Swamp Eel*       | 17. Rusty Crayfish |
| 9. Lionfish*              | 18. Giant Salvinia |

Lastly, according to the Ohio Department of Natural Resources, Division of Forestry one of the most invasive insect species in Ohio is the Emerald Ash Borer. This Asian pest is part of a group of insects known as metallic wood-boring beetles. Emerald Ash Borer affects all species of native ash found in Ohio. Because North American ash trees did not coexist in association with this pest, they have little or no resistance to its attack. This ash tree-killing insect from Asia that was unintentionally introduced to southeastern Michigan several years ago. In February of 2003, it was first found feeding on ash trees in northwest Ohio.

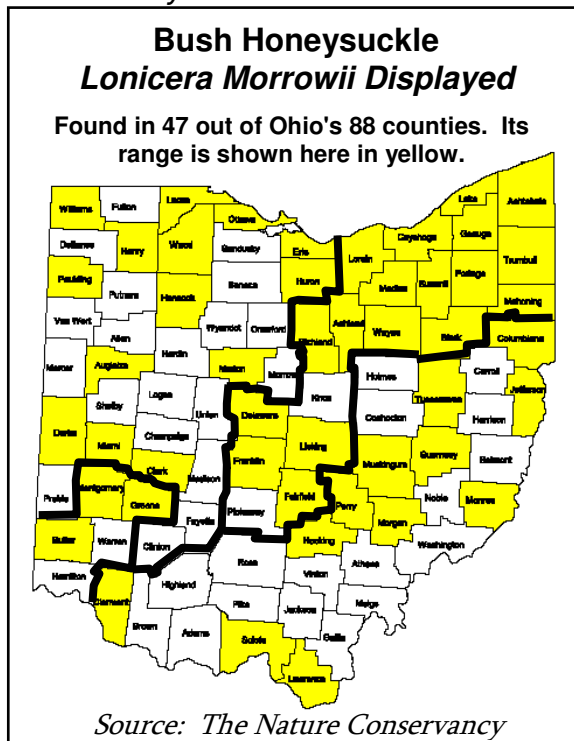
Emerald Ash Borer larvae feed on the living portion of the tree, directly beneath the bark. This eating habit restricts the tree's ability to move essential water and nutrients throughout the plant. In three to five years, even the healthiest tree is unable to survive an attack.

## RISK ASSESSMENT

### Location

The area invaded by each plant species varies based on its preferred environment. Those with the fewest limitations have spread to nearly every county in Ohio. Following is a description of each plant from the Ohio Department of Natural Resources, Division of Natural Areas and Preserves along with a map of know impacted counties from The Nature Conservancy.

*Bush Honeysuckles* consist of a number of upright shrubs which can grow 6-15 feet



in height. Each have dark green, egg-shaped leaves. The tubular flowers are white on the Amur and the Morrow (changing to yellow with age), and pink on the Tatarian. Berries range from red to orange, occasionally yellow, and are eaten and dispersed by birds.

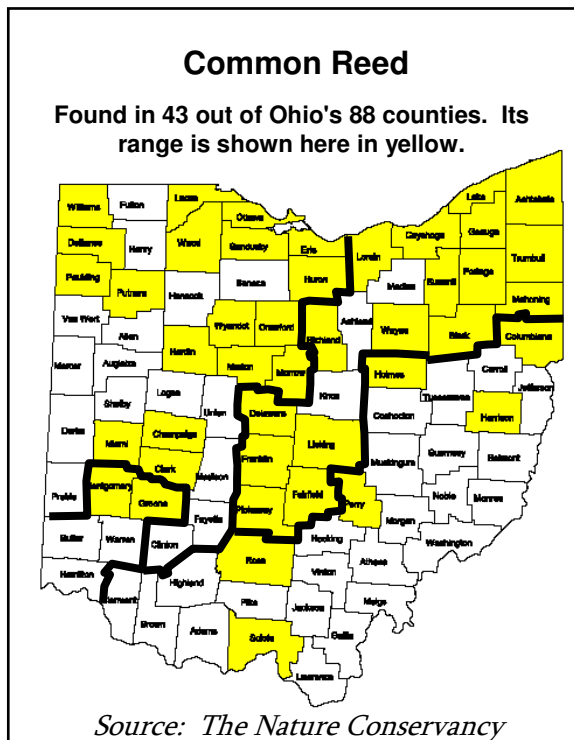
**Habitat:** The bush honeysuckles inhabit abandoned fields, roadsides, woodlands, and edges of marshes. Morrow is currently a problem in northern Ohio; Amur is found mostly in southwestern Ohio; and Tatarian is widespread in Ohio.

**Management:** The best control method is to cut and treat stumps with systemic herbicide. Sprouts from cut stems may be treated with a foliar application of systemic herbicide. Young shrubs are easy to pull or dig up. Be aware there is a native bush honeysuckle in Ohio (*Diervilla*

*lonicera*).



*The Common Reed*, or *Phragmites*, is a grass that reaches up to 15 feet in height.



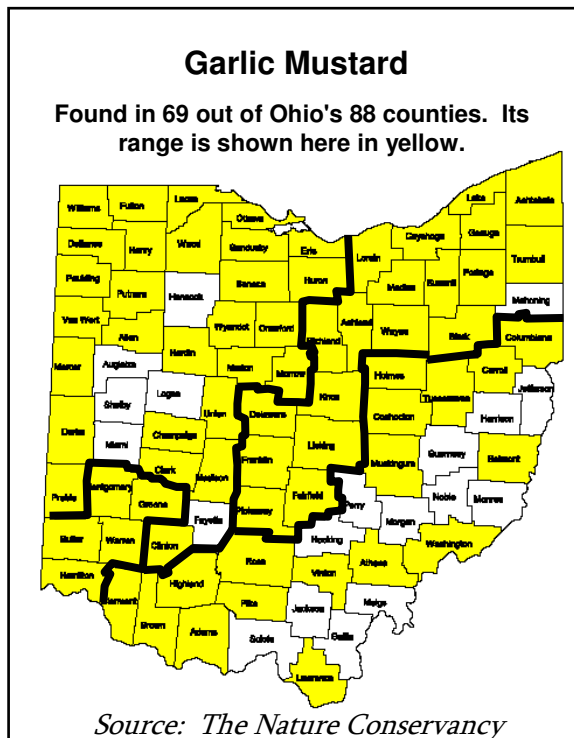
The leaves are smooth, stiff and wide with coarse hollow stems. The big, plume-like flower head is grayish-purple when in fruit. Common reed spreads mostly vegetatively forming huge colonies by sprouting new shoots through underground stems (rhizomes).

**Habitat:** Common reed grows in open wetland habitats and ditches primarily in northern Ohio. It occurs in still water areas of marshes, lake shores, riverbanks, and disturbed or polluted soils, often creating pure stands. Some populations are not invasive and may be native, however there is no reliable method to tell the two apart.

**Management:** Long-term management is necessary for control of this persistent plant. Cutting and/or treating stems with systemic herbicides is generally the most

effective, grass-specific herbicides are recommended in areas where native plants occur.

*Garlic Mustard* is a biennial herb. It begins as a rosette of leaves in the first year,



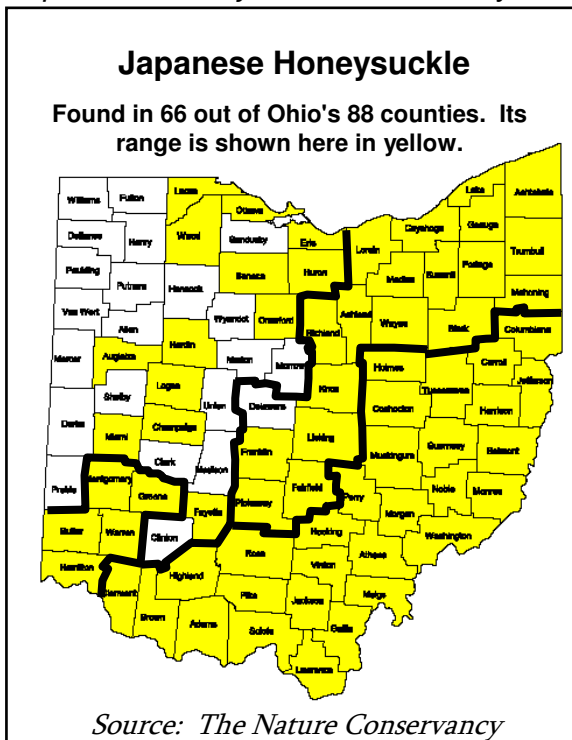
overwinters as a green rosette of leaves, flowers and fruits in the second year, and then dies. First-year rosettes consist of kidney-shaped, garlic-smelling leaves, the second-year plant grows a stem up to 4 feet tall with triangular, sharply-toothed leaves. The small, four-petaled flowers are white and grow in clusters at the top of the stem. Garlic mustard produces large quantities of seeds which can remain viable for seven years or more.

**Habitat:** This woodland plant prefers some shade but is occasionally found in full sun. It invades upland and floodplain forests, savannas, yards, streams, trails, and roadsides throughout Ohio.

**Management:** Repeated prescribed burns in oak forests may be effective. Light infestations of garlic mustard can be hand pulled before or at flowering time. Plants

should be removed from the site after pulling, as the seeds may continue to mature. Systemic herbicides can be applied to the rosettes in early spring or late fall.

*Japanese Honeysuckle* is a woody semi-evergreen vine with opposite, oval leaves.



The flowers grow in pairs, are white to yellow, and very fragrant. Fruits, also in pairs, are purple to black berries. This vine climbs and drapes over native vegetation, forming dense patches.

**Habitat:** Japanese Honeysuckle thrives in disturbed habitats, such as roadsides, trails, fencerows, abandoned fields, and forest edges primarily in southern Ohio. Disturbances such as logging, road building, floods, and windstorms create an opportunity for this vine to invade native plant communities.

**Management:** Burning in combination with systemic herbicide application may be an effective control method. Herbicides can be applied to the leaves when native plants are dormant. Be aware there are native climbing honeysuckles in Ohio, such as *Lonicera Dioica*.

*Japanese Knotweed* shrub-like herb grows up to 10 feet tall. Stems are smooth and the pointed leaves vary from broadly oval to almost triangular. Flowers are greenish-white and very small. The seeds are dispersed by wind. Once established, the plants spread by a system of underground stems reaching 60 feet.

**Habitat:** Japanese Knotweed can grow in a wide variety of habitats. It is found in open areas, such as roadsides, streambanks, and woodland edges, primarily in eastern Ohio. It spreads quickly and forms dense thickets.

**Management:** Knotweed is very difficult to control. Leaves may be sprayed or stems cut and treated with systemic herbicide.

*Reed Canary Grass* reaches 2-5 feet tall. The hairless stems gradually taper to flat and rough leaf blades 3-10 inches long. The flowers occur in dense clusters and are green to purple, changing to beige and becoming more open over time. The plant spreads aggressively both by seed and by forming a thick system of underground stems (rhizomes).

**Habitat:** This grass occurs in wetlands, such as marshes, wet prairies, meadows, fens, stream banks, and seasonally wet areas throughout Ohio. Reed Canary Grass has been planted widely for forage and erosion control. Native strains possibly occur, however introduced strains are thought to be more invasive. There is no reliable method to tell the two strains apart.

**Management:** A combination of burning or mowing with systemic herbicides is the best method of control; grass-specific herbicides applied with wick applicators are recommended in areas where native plants occur.

*Multiflora Rose* is a dense spreading shrub with widely arching canes and stiff,

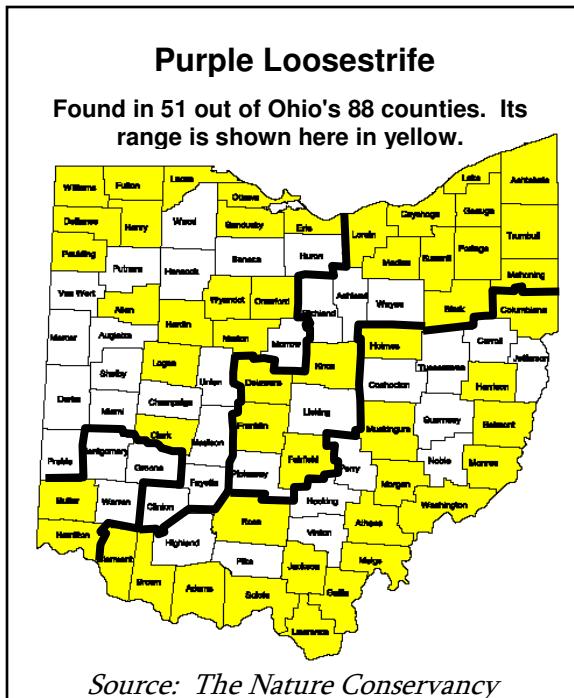
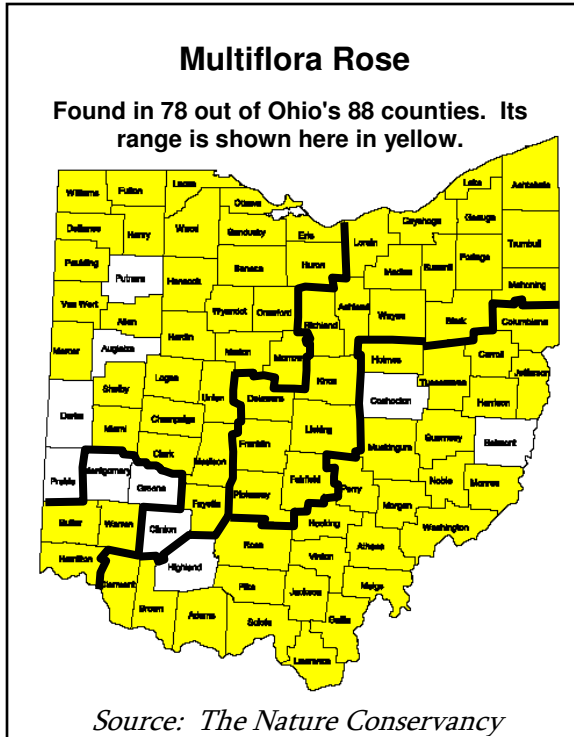
curved thorns. This shrub grows up to 15 feet tall with alternate, compound leaves of seven to nine oval leaflets. *Multiflora Rose* has numerous white flowers that produce clusters of small, red fruits. The fruits (called hips) are eaten by birds and mammals which help disperse the seeds. An individual plant can produce up to 500,000 seeds per year!

**Habitat:** *Multiflora rose* was formerly planted as a "living fence" to control livestock, stabilize soil and create barriers for roadways. It has also been planted as a wildlife cover and food source. This rose occurs in a wide range of habitats throughout Ohio but prefers sunny areas with well-drained soils.

**Management:** A long-term management program of mowing or cutting and treating stems with systemic herbicide several times during the growing season is recommended. Digging or hand-pulling small shrubs may also be effective.

*Purple Loosestrife* grows 3-7 feet tall and has a dense bushy growth of 1-50 stems. Long spikes of flowers are purple to magenta; linear-shaped leaves grow opposite along the square stems. *Purple Loosestrife* spreads aggressively by underground stems (rhizomes) and can produce as many as a million seeds per plant. Supposedly sterile strains of *L. virgatum* will outcross with this plant and produce seeds.

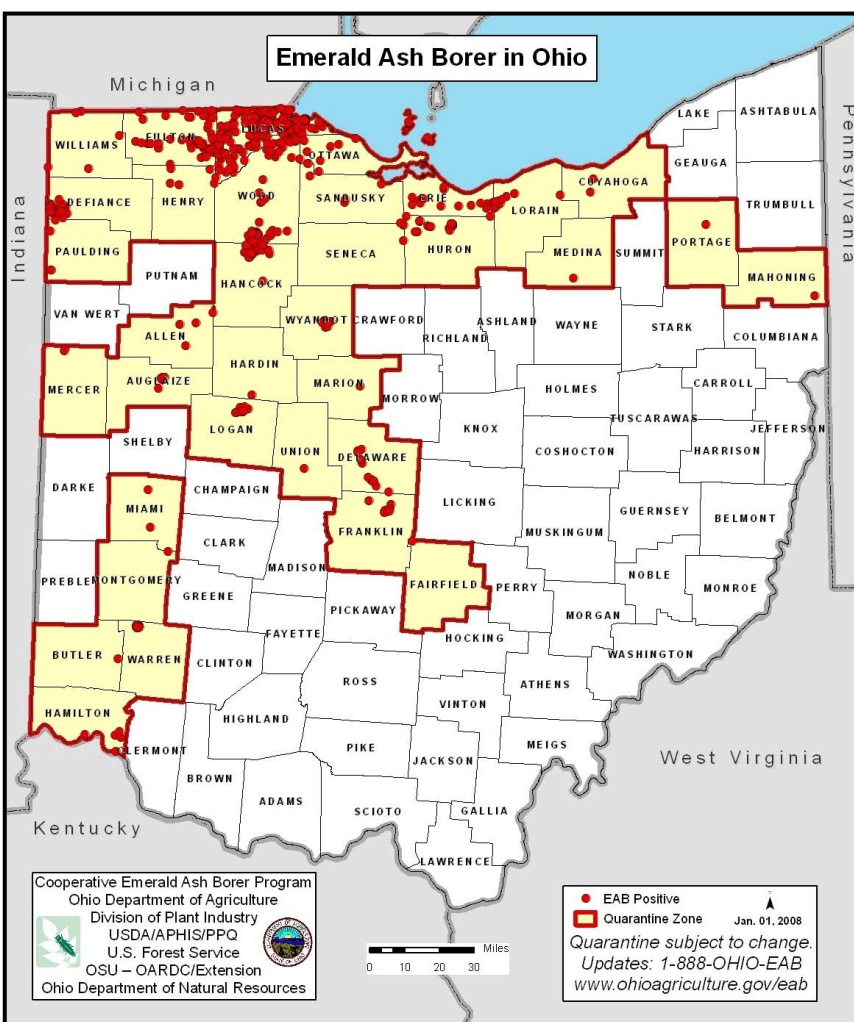
**Habitat:** *Purple Loosestrife* grows in a variety of wetland habitats including marshes, river banks, ditches, wet meadows, and edges of water bodies, primarily in northern Ohio. *Loosestrife* can invade both natural and disturbed



wetlands, replacing native vegetation with nearly pure stands of Loosestrife.

**Management:** Small stands of Purple Loosestrife can be controlled by hand-pulling, digging, or applying systemic herbicides to the foliage. Herbicides may be used to control large populations. Biological controls using insects are being researched in Ohio and other states and may be helpful in reducing infestations.

Of the 18 aquatic invasive species noted at the national level there are three the Ohio Department of Natural Resources specifically notes: the Round Goby, Eurasian Ruffe and Zebra Mussel. The Round Goby and Eurasian Ruffe are species of fish which have proven in all Great Lakes region to rapidly increase in numbers and some have seen a decrease in native fish populations. Exact counts and range of impacted waters are difficult to determine. Often sport fishermen are the first to confirm their presence. The Zebra Mussel is a mollusk found throughout Lake Erie and in a few inland lakes that will attach to any unprotected surface which may include native clams. All three species pose the greatest threat to Lake Erie with the potential of moving inland. The counties immediately impacted are Lucas, Ottawa, Sandusky, Erie, Lorain, Cuyahoga, Lake and Ashtabula.



The Emerald Ash Borer is currently in found in 35 of Ohio's 88 counties, six neighboring states and the province of Ontario. From its initial detecting in Northwest Ohio the insect has spread south to the Ohio river in the south and Pennsylvania in the East. One of the greatest problems increasing the spread of the insects is the transport of infected firewood. Quarantine areas have been established making the transport of firewood across county lines illegal.

## Past Occurrences

Invasive species of plants, fish and

insects have been arriving in Ohio since the establishment of European settlers in

the 1750s. With each improvement in the scale and speed of human transportation, the potential for unintended introduction of invasive species has increased. Organisms which could not survive the months long journey from Europe or Africa to America can make the journey in a matter of hours today. Several examples of species introduction pathways follow:

The Round Goby species was introduced from Eurasia into the St. Clair River and vicinity on the Michigan-Ontario border where several collections were made in 1990 on both the U.S. and the Canadian side. Speculation exists the Goby was transported from its native Caspian Sea by way of ballast tanks on ocean going vessels. Today the Goby is found in all the Great Lakes and is making inroads in all contiguous state watersheds.

The Multiflora Rose was introduced to the U.S. from Japan in 1886 as an understock for ornamental roses. Birds are responsible for spreading the seeds, which remain viable for a number of years. In the 1930s, the Soil Conservation Services advocated the use of Multiflora Rose for erosion projects and as a way to confine livestock. Hedges of Multiflora Rose have also been used as a crash barrier and to reduce headlight glare in highway medians.

The Emerald Ash Borer was introduced into North America sometime in the 1990's. The insect is believed to have been introduced into the U.S. in wood packing material from China. It was first reported killing ash trees in the Detroit and Windsor areas in 2002. Only species of ash are hosts for the beetle, which usually kill infested trees within a couple of years. Since then, infestations have been found throughout lower Michigan, Ohio, northern Indiana, the Chicago area, Maryland and recently in Pennsylvania.

Considering the thousands of plant, dozens of aquatic and unknown number of insect species introduced into Ohio over the past 250 years samples of the most often cited transfer media are provided here. Exotic species can arrive by a nearly endless number of vectors making a complete listing impossible.

### **Probability of Future Events**

Since the beginning of European colonization non-native species have been arriving in Ohio. With the increase in global trade and travel the probability of new and unexpected species arriving in Ohio will continue to grow. Legislation is in place around the world in an attempt to control the migration of unwanted species between ecosystems. The Ohio Department of Natural resources is currently battling the entrance of wild boars from Kentucky and West Virginia. In addition, there are several species of carp currently migrating up the Mississippi watershed from the Gulf Coast. Although not currently reported in any Ohio waterways, the probability of future infestations is near certain.

It is certain that new wanted and unwanted species will arrive in Ohio. The importance of controlling the integrity of existing ecosystems will require an ongoing state, national and international efforts to avoid unwanted infestations.

## **Environmental Impacts**

Invasive species, whether plant or animal, can have a significant impact on the environment and people. They change ecosystems, displace native species, decrease biodiversity, threaten endangered species, and are a potential health hazard. Invasive plants increase the environment's susceptibility to erosion, wildfires, and flood events with each having their own effect on the environment. Invasive animals can alter ecosystems by displacing native animals, including threatened and endangered species. They can also have important secondary impacts. For example, if the emerald ash borer were to kill a large number of ash trees, the resultant dead trees increases the fuel load and susceptibility to wildfire during drought conditions.

In addition, invasive plants can also alter the soil chemistry and reduce water table levels. This in turn negatively impacts local ecosystems. Finally, there is the potential for future introductions to cause negative impacts to human health.

## **VULNERABILITY ANALYSIS & LOSS ESTIMATION**

### **Methodology**

Impacts of invasive species tend to have commercial operational impacts, as opposed to many built environment impacts of the other hazards covered. Due to this unique situation, rather than a matrix of counties and losses the loss estimates will be presented using historical response costs to predict future losses in unadjusted dollars.

### **Results**

From the perspective of invasive plant species the Multiflora Rose is one of most expensive to combat in Ohio. Each individual plants ability to produce 500,000 seeds a year allows this invasive species to spread over large area with incredible speed. Agricultural groups are facing the highest exposure and expense in the form of infiltration of crop lands and eradication programs. According to agricultural experts associated with The Ohio State University, Ohioans are estimated to spend millions of dollars combating the Multiflora Rose. Precise dollar figures are not available due to the majority of response activities being performed by non-governmental entities.

Four know methods of responding to the species exist. First, is the removal of the plant as whole including the roots which is only cost effective is small applications. Second, is to repeatedly defoliate or mow down the plants which will eventually kill almost any plant. Third, is the use of herbicides applied as specific growing intervals. All of the above responses can be expensive and labor intensive. The last method is the use of Rose Rosette Disease, a mite-vectored virus, which is giving rise to a hope for a lower cost control agent.

Turning to invasive aquatic species, the Zebra Mussel is one of the most expensive to control. The mussels naturally collect on any solid surface and create significant problems for drinking water processing facilities and utilities. All in-water structures

are impacted including, but not limited to, piers, breakwalls, vessel hulls and vessel engines cooled with external water. Estimates for controlling infestations run between \$2 and \$10 million dollars a year depending on how many sources are aggregated. Should the Zebra Mussel effectively invade the river systems of Ohio, it is suggested the annual control costs could rise 10 fold.

Invasive insect species are both the direct source of damage to trees and a vector for other parasites. In the last century the north American population of Elm trees was decimated by a fungus which arrived on infected trees shipped to an Ohio furniture company. One of the primary transport methods is through beetles which the fungus uses as a host to move from tree to tree. The beetle's ability to fly exponentially increased the number of trees impacted. Trees located in non-urban areas posed financial impact only to loggers; however, the Elm was a popular urban tree and the cost to remove them ran into the millions over the years.

The Emerald Ash Borer which is currently impacting the north American Ash tree has already cost millions of dollars in attempts to identify and isolate infected trees. In Ohio alone there are an estimated 5 billion Ash trees at risk. Although many research centers are searching for an effective means of combating the insect, the only method currently available is the use of insecticides which have to be applied annually. The un-captured cost to treat Ash trees in Ohio will likely reach into the millions, as urban areas combat the insect.

## **STATE-OWNED / CRITICAL FACILITIES VULNERABILITY ANALYSIS & LOSS ESTIMATION**

Unlike many of Ohio's other hazards, invasive species have very limited impact on state-owned facilities. The most prominent impact to state facilities relates to the maintenance of marinas in Zebra Mussel impacted areas.

Since invasive species are not fixed hazards and have the potential to affect all state-owned structures and critical facilities in the state this section defaults to the overall discussion of state-owned structures and critical facilities identified in section 2.1., Table 2.1.a, and Appendix C.

## 2.14 LAND SUBSIDENCE

Subsidence is motion of the Earth's surface as it shifts downward relative to a benchmark (often sea-level) of the surrounding terrain. There are a number of causes for this effect. In Ohio the two primary causes are abandoned underground mines (AUMs) and karst. Underground mining of coal began in the early 1800's and continues to current day. In the 1900's underground salt, limestone and gypsum mining began. Most mining is accomplished by direct human action utilizing heavy machinery to remove the material; however, with salt there are cases where pressurized water is used to wash-out the deposit (solution mining). All of these mines create voids under the Earth's surface. Several key factors determining the potential for these voids to collapse include depth, mining technique used, types of rock and or soils above and development on the ground surface.

Abandoned underground coal mines in Ohio have the added environmental impact of discharging acidic water. It is common for coal mines to become charged with water. The collected water interacts with the remaining coal deposit and other materials becoming acidic. If acidic mine water is discharged into creeks or streams it can alter the chemical composition of the water habitat. Cases exist where changes in water acidity have caused sensitive aquatic life considerable harm.

Karst topography in Ohio is a landscape shaped by the dissolution of a soluble limestone or dolomite layers of bedrock. As surface water percolates down to the water table, it slowly dissolves away the limestone or dolomite creating voids under the Earth's surface. In cases where a visible depression is present, surface water may flow directly to the water table. Depending on the depth of the void, there may be no observable ground surface deformation. Deep voids may exist at or below the water table and, as a result the rock, is replaced by water. Long-term changes in the water table could destabilize deep voids resulting in surface deformation as observed in southern Missouri and northern Arkansas. Shallow voids are often underground caves or caverns, which lack any replacement support. With time, the roof of these voids may collapse and result in ground failure.

Once a hole or fissure appears in a karst area, surface water can travel directly to the aquifer bypassing the natural filtration and cleaning processes. The result has been contamination of aquifers from farm chemicals, animal waste, along with oil and gasoline from roadway runoff. Cases exist where aquifer contamination resulted in making the water unfit for human consumption. Also, karst topography can result in unusual flooding when water tables are high. Such flooding issues are difficult to address.

The last form of land subsidence in Ohio is associated with soils, which dramatically expand when wet and contract when dry. Structures built on these soils can experience significant shifting as the ground saturates and dries.

Currently there are no commercial insurance carriers which offer mine subsidence coverage in Ohio. In response, gaps in commercial insurance availability the Ohio FAIR Plan underwriting association was established in 1968 to provide a variety of essential insurance products for eligible properties unable to obtain insurance through the voluntary market. The Ohio Mine Subsidence Insurance Underwriting

Association provides eligible Ohio counties with mine subsidence insurance (see map 2.14.2.1.b.) Under the program 26 primarily Appalachian counties (Region 3) are required to carry mine subsidence insurance at a cost of one dollar annually. Additionally, eight counties in Region 2 and three counties in Region 1 are eligible to obtain insurance at the owner's discretion at a cost of five dollars annually. The remaining 51 counties are not eligible for mine subsidence insurance.

## **2.14.2 HAZARD PROFILE**

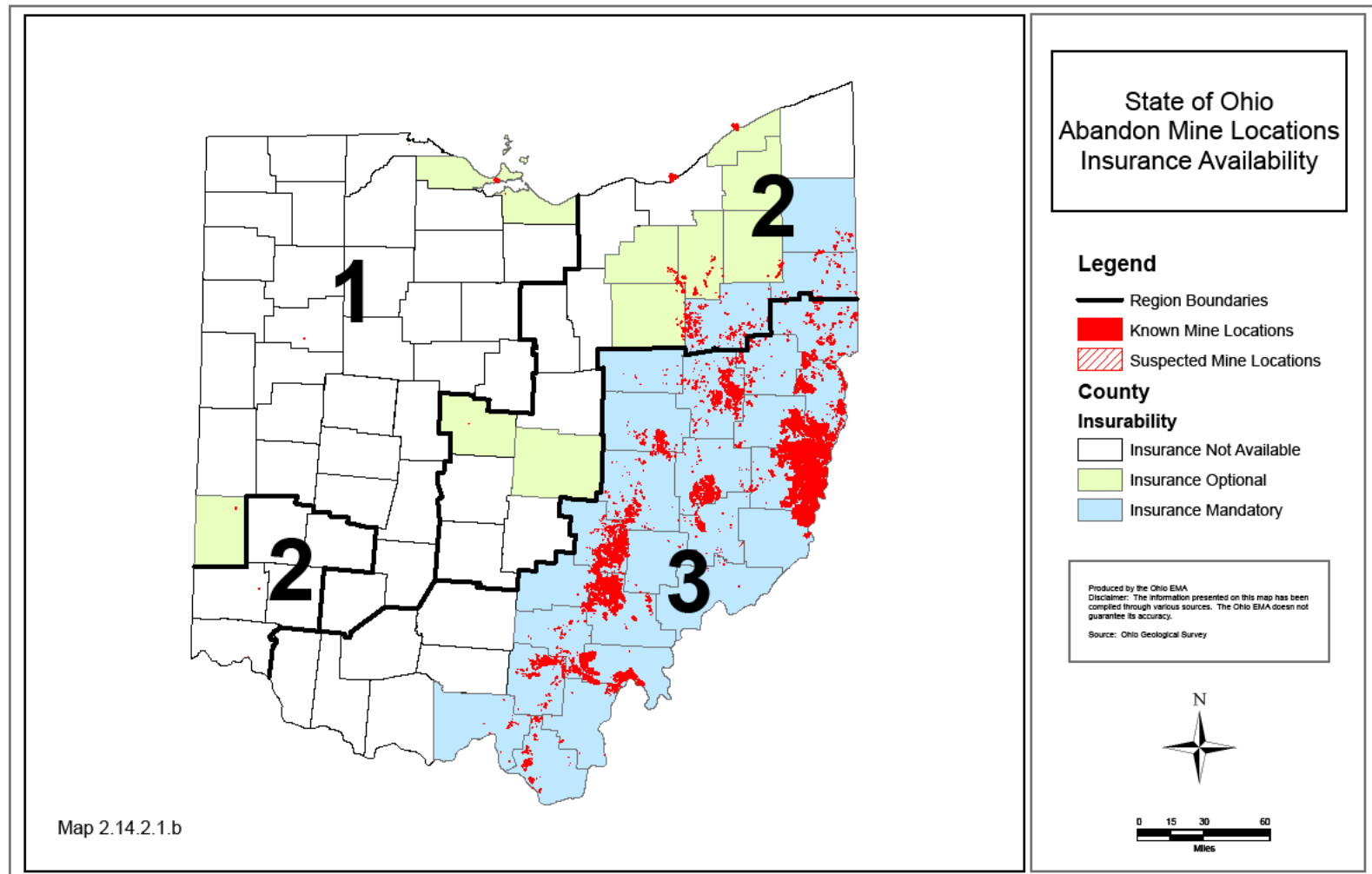
### **Location**

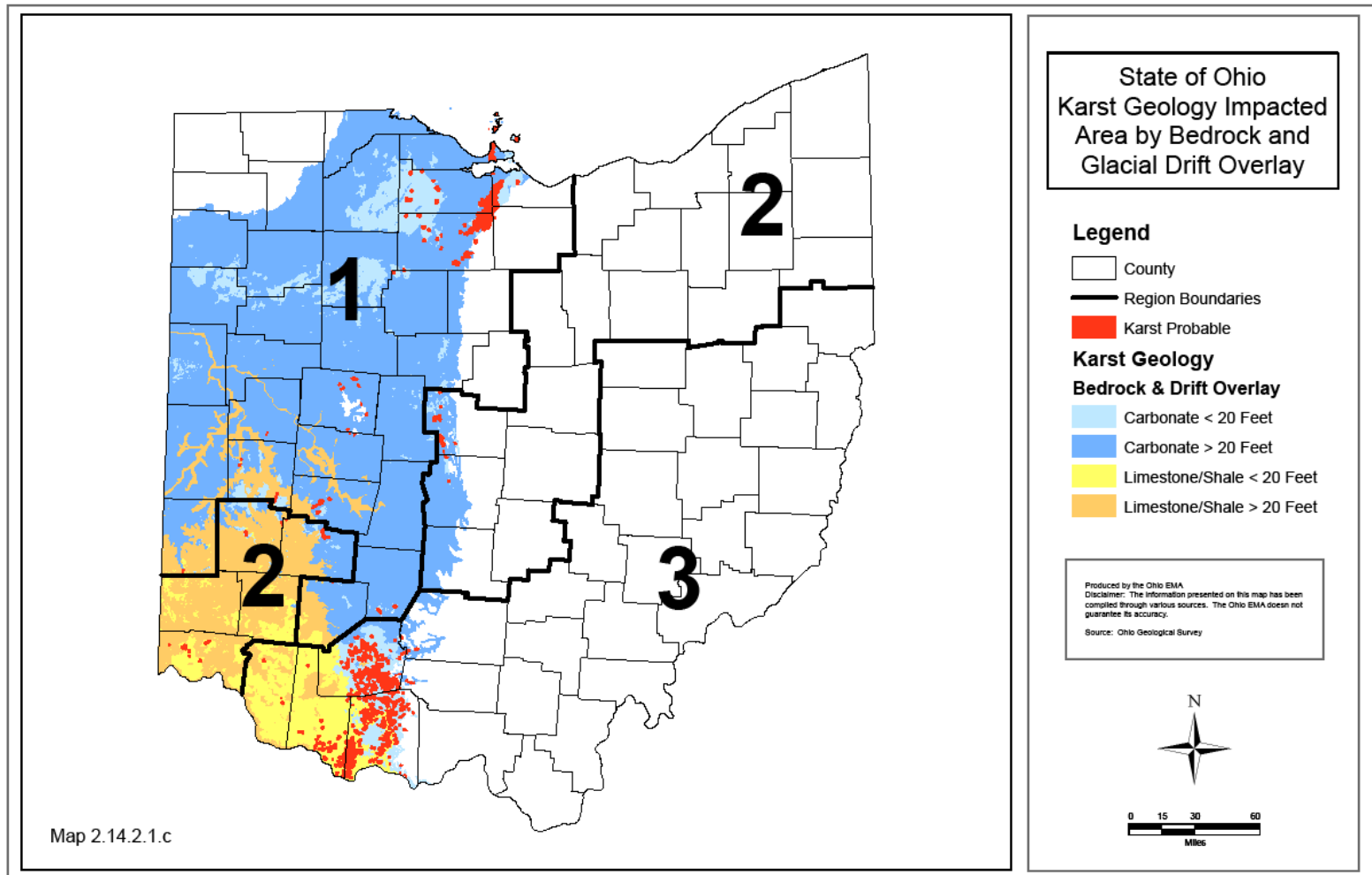
Beginning in the 1700's and continuing to today there has been considerable coal mining in the generalized Appalachian region of Ohio. In addition to coal, several salt, clay and gypsum mines have opened in counties close to Lake Erie. Finally in central and southwestern Ohio there are several isolated mines (*see map 2.14.2.1.a.*)

The majority of abandoned mines are located in, or directly adjacent to, Region 3. The overwhelming majority of these were coal mines. Coal mine depths can range from less than 100 feet below the surface to 1000 feet or more. There are a number of methods which can be employed to remove a coal deposit. Whether accomplished by hand/pick or machines, as the coal vein is removed often pillars of coal are left at intervals to support the mine roof. In some cases as the mine vein is depleted and miners withdraw, the pillars were removed. In these situations the depth of the mine becomes important. Deeper mines, with solid layers of rock (e.g. strata) above the void and limited soil at the surface, are less likely to fail than those closer to the surface. The Ohio Geological Survey and Department of Transportation have developed profiles of voids, support strata composition and surface soils for a limited number mines to assist in understanding the potential for subsidence events. Analysis requires experts trained in geology and significant time which constrains the number of sites assessed.

Other minerals mined include gypsum, clay and limestone primarily in Ottawa, Preble and Butler counties. Finally, very limited exposure to abandoned mines exists in Hamilton, Lucas, Erie, Delaware and Licking counties where the mineral being extracted was not available.

Karst features are associated with the western third of Ohio excluding the far northwestern counties of Williams, Fulton and Defiance (*see map 2.14.2.1.c.*) Nearly all of Region 1 and the far western sections of Regions 2 & 3 are impacted by karst geology. The limestone, shale and dolomite layers were deposited between 408 and 505 million years ago as the floor of an ancient sea. Later the continental plate would rise above the existing sea level creating dry land and vast salt deposits. These Sedimentary rock layers are naturally porous and dissolve into the water which passes through them.





The current landscape in the karst region of Ohio was created by glaciers as they advanced from the north reaching to the Ohio River roughly 14,000 years ago. When the last glacier receded it left behind a layer of unconsolidated material in a wide range of depths. The shallower the loose material layer, the greater the chance of water penetrating to the underlying bedrock, resulting in a void or ground deformation occurring. This is represented by the probable karst areas on the map which group into two significant clusters. In the south, the greatest impacted counties include Brown, Adams and Highland. In the north, the greatest impacted counties include Seneca, Huron, Erie, Sandusky and Ottawa.

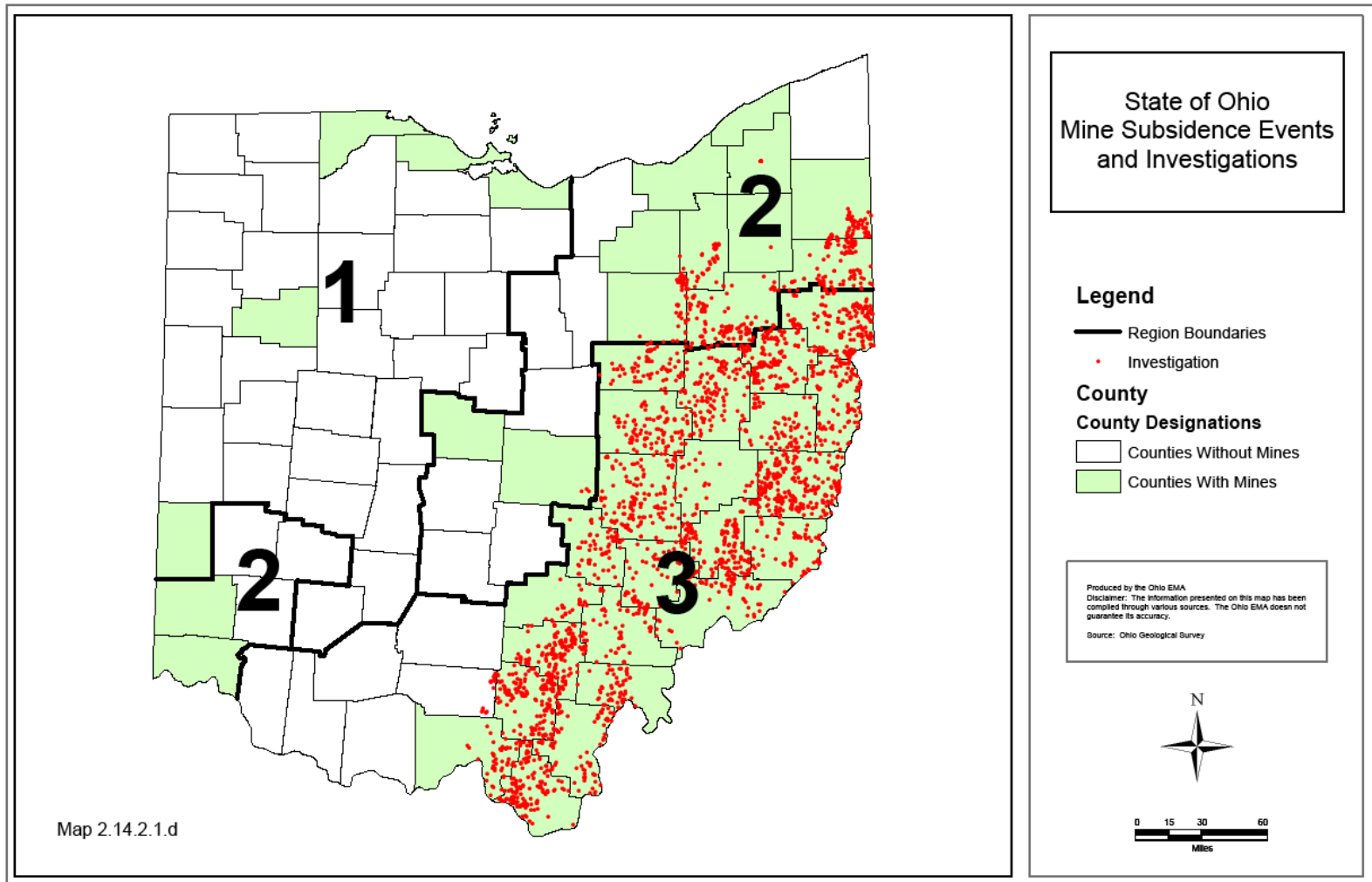
Areas which are reclaimed strip mines and other type of soils poorly suited for development are often mapped by local communities and the Ohio Department of Natural Resources. Ohio's built environment exposure to this type of hazard is very limited.

### **LHMP Data**

The City of Bellevue is located within the Bellevue-Castalia Karst Plain and resides within four counties; Erie, Huron, Sandusky, and Seneca. Of these counties, only Sandusky County's LHMP indicated that land subsidence was a hazard risk. They recognized that land subsidence, in the form of sinkholes, has a potential to occur; but also notes that there have been no incidents of land subsidence that has resulted in the damage of structures, personal injury, or loss of life. An area of concern for Sandusky County, in regards to land subsidence, is a Class I dam that is located in the southeastern portion of the county. However, Sandusky County, at this time, considers land subsidence and dam failure as having a low mitigation potential and have no current mitigation activities or plans for them.

### **Past Occurrences**

Abandoned underground mines in Ohio are monitored by the Ohio Department of Natural Resources, Division of Mineral Resources Management which is primarily federally funded. Within the division, two programs exist to address mine subsidence one for emergencies and a second for non-emergencies. Inspectors institute an investigation for every reported occurrence. The inspector uses several criteria to classify the emergency status of the event by determining first if it is mine related, second if there is an imminent and substantial threat to the public or the environment and finally if the onset was sudden and not part of a prolonged event. The emergency program gives priority to events which are directly affecting a structure (within 300 feet) or transportation route. Each year between 50 and 60 investigations are completed generating 25 to 30 projects of which 5 to 6 represent damage to a structure (*see map 2.14.2.2.d.*) When an event is classified an emergency, federal concurrence is requested followed by a streamlined engineering evaluation and hiring of a contractor. The time between the event and response is often within one week. Projects are undertaken to protect lives and property and can range from simple precautions to filling the void with cement to stabilize the area affected.



Subsidence events which do not qualify as an emergency, where people and infrastructure are not directly involved, must follow the standard state project development and bid process. Repeated emergency incidents can lead to larger non-emergency response. The City of North Canton (Region 2), Village of Cadiz (Region 3) and Village of New Lexington (Region 3) each experienced repeated emergency events culminating in area-wide engineering studies to address the problem. In each case comprehensive mitigation activities, including the installation of in mine support columns and the filling of voids, stabilized large areas which were subsidence prone.

The Ohio Department of Transportation has inventoried over 1,200 sites where abandoned underground mines underlie state highways, U.S. routes, and interstate highways. Since 1998, ODOT has been actively inventorying these geologic hazards and conducting risk assessments to determine the potential impact on our transportation infrastructure. The statewide inventory and risk assessment of these mine sites continues. However, there are an estimated 7,000+ underground mines across Ohio. As of 2005, only 50% of these mines have been recorded in the state's (ODNR) database. Approximately 2,700 of the 7,000 underground mines are unmapped. Both mapped and unmapped underground mines pose a continuing threat of subsidence to our transportation system.

Whenever an event affecting transportation infrastructure occurs, an initial site investigation is launched. The first step in the process involves the collection of basic information on the location, type of event, geologic setting, mining information for the area, impact on the roadway, and how it was discovered. The next step involves a site reconnaissance and the completion of a series of data collection forms starting with the Initial Site Evaluation. Compiled information is then used by the geologist or engineer to complete the risk assessment rating form. Each inventoried site receives a matrix score based on standardized criteria and scoring methods. Some examples of key scoring criteria are: number of surface deformation features, number of mine openings, thickness of unconsolidated material over the mine, thickness of rock overburden, height of the mine void(s), average daily traffic volume, hydrology, and secondary mining evidence. The overall rating provides ODOT a planning tool to prioritize sites across the state for remediation. With limited resources and the large number of mine subsidence problems, the abandoned underground mine inventory and risk assessment allows ODOT the means to direct expenditure of funds in a cost effective and logical manner.

The most notable event occurred in 1986 when an abandoned mine located in Guernsey County collapsed underneath Interstate 70 resulting in the closure of the entire interstate. Remediation included stabilizing the void and repairing the damaged roadway costing over \$10 million dollars.

Underground salt mining under Lake Erie to date has not generated any known subsidence; however, solution mining in Lake, Summit and Media counties have. The most dramatic case in Ohio is in the Lake County community of Painesville where an abandoned mine is responsible for a six foot surface depression. Due to its proximity of the impacted area to Lake Erie it is now filled with water. Other

solution mines in Summit and Media counties have experienced minor surface impacts. The potential impact of salt mining is epitomized in the failure of the Retsof mine in New York. The event was first misinterpreted as an earthquake. The collapse of the mine roof resulted in several 50 foot deep sink wholes which closed roadways, changes in the aquifer and the release of methane and hydrogen sulfide gases.

Karst events, to date, in Ohio have had very little direct impact from a subsidence perspective on the built environment; however, they have been very costly in terms of pollution and flooding. Two well documented karst related events deal with contamination of aquifers. The oldest researched event in Ohio is associated with the Village of Bellevue straddling the Huron / Sandusky county border. The 1961 study documents how from 1919 to 1946 the community permitted untreated wastewater injection wells and unimpeded groundwater runoff into sink holes as an acceptable water management program. In 1946 after the groundwater was determined unfit for human consumption, the Village abandoned its last well and has since spent millions of dollars to develop a potable system based on piping in water from safe sources from miles away.

The Village of Put-In-Bay located on South Bass Island in Lake Erie was the sight of an extensive gastrointestinal illness outbreak in 2004. The island is a popular warm weather tourist destination and, at the height of the season, over 1,000 cases of digestive related maladies were documented in people who had recently vacationed there. The investigation which began with the municipal systems quickly shifted to a number of transient non-community public water systems used for geothermal cooling, flushing toilets and outdoor cleaning which were found interconnected to the main water system. The karst topography allowed ground water to travel quickly between locations and is easily impacted by seasonal precipitation.

The only known subsidence impact to the built environment from karst formations is roadway damage. In 2007 State Route 19 was closed in Crawford County when an adjacent karst feature expanded destabilizing the road bed. Engineering studies including sonar and lidar analysis of the associated void are underway to determine the extent of the developing cavity and to determine a long-term solution. Although this is the first documented event where damage to the built environment can be directly attributed to karst formations, there is an effort underway through the Ohio Department of Transportation to collect detailed historical data of karst related roadway impacts in an effort to better understand and address future events.

During the construction of U.S. Route 33 near East Liberty, karst was encountered. Construction crews had to do considerable back-filling and reinforcing, creating a land-bridge to make sure the highway was secure.

Another example of the impact of karst was the construction of tunnels for sewage pipelines by the City of Dublin, Ohio. Sinkholes, filled with clayey overburden caused the expensive rock-boring machinery to clog and break, causing tremendous cost overruns.

Finally, one housing development in the City of Westerville (Franklin County) contains homes which have been dislodged and damaged by the effects of soils

which dramatically expand when wet and contract when dry. Since 2000 the Ohio EMA has purchased 6 damaged homes; however, this is the only known impact from this form of land subsidence.

### **Probability of Future Events**

Mine related land subsidence is an annual event impacting on average 5 homes or roadways. An additional 20 events occur each year on average which do not impact the built environment, yet may require remediation.

Unlike mine related events, karst events historically have manifested their impact in the form of ground water contamination. Based on past exposure, a significant event occurs approximately each decade. As the Ohio Department of Transportation begins to collect detailed data regarding the impact of karst events on federal aid highways, both the profile of the hazard and frequency of occurrence may experience significant change.

### **Environmental Impacts**

Land subsidence's impact on the environment can be quite noticeable with uneven surface topography and depressions in the earth's surface. The environmental impact is not limited to this. Land subsidence affects the wildlife's habitat that, depending upon the severity of the impact, may or may not return to normal over time. In addition to the loss of habitat, land subsidence has the potential to reroute, displace, and contaminate ground water, altering the immediate land and aquatic ecosystems. Land subsidence not only affect the immediate environment, but can pollute and impact ecosystems far from the event with contaminants (hazardous materials, sewage, etc.) being transported throughout the aquifer.

Land subsidence has a similar impact on the environment as an earthquake or landslide. They can impact all the utilities (gas, electric, petroleum pipe lines, storm sewers, sewage and septic systems, and water supplies) which in turn impact the environment. Air quality can be affected by lead and asbestos from damaged older structures. The smoke from fires caused by ruptured gas lines would also contribute to polluting the air. Water sources and surrounding landscape can become contaminated with not only hazardous materials, but also from debris and damage from waste water treatment facilities that could permit raw sewage to enter the environment.

## **VULNERABILITY ANALYSIS & LOSS ESTIMATION**

### **Methodology**

The only predictable impact which can be quantified for analysis is damage to Ohio's roadways. The Ohio Department of Transportation, Office of Geotechnical Engineering has a comprehensive inventory of the federal and state routes which intersect with known and estimated abandoned mines. The location, length of each segment, potential for failure, along with a host of other data is maintained in a database. The failure potential is broken into three categories: high, with failure

expected within 50 year; medium, with failure expected within 100 years; and low, with failure expected beyond 100 years. The segments are reported by length of the segment, with a 500 foot buffer, and number of lanes. The final and key piece of information supplied is the proven cost of \$1,000,000 per lane mile to replace roadways impacted by mine subsidence. For loss estimates the full cost per-mile is used with 50% and 25% used for medium and low respectively.

### **STATE-OWNED / CRITICAL FACILITIES VULNERABILITY ANALYSIS & LOSS ESTIMATION**

Land subsidence is a spatial hazard and has the potential to affect few, if any, state-owned structures and critical facilities but as seen could impact numerous lifelines. Beyond this the default section to the overall discussion of state-owned structures and critical facilities identified in section 2.1. Table 2.1.a, and Appendix C.

## 2.15 FUTURE GROWTH AND POTENTIAL RISK AREAS

The second edition of this plan has the added requirement to address future growth throughout Ohio and what impact natural hazards will have upon it. To determine growth patterns, the Ohio Office of Strategic Research published cumulative county statistics were reviewed. The profiles cover a broad range of characteristics ranging from demographics to taxable land value. The percentage of population growth or decline was calculated for the current planning period in counties where change was indicated. Since the approval of the original mitigation plan, the State of Ohio has had very little change in population between increases from births and decreases from out-migration.

Two counties were found to have double-digit population growth in Ohio; Delaware (Columbus Metropolitan Area) and Warren (Cincinnati Metropolitan Area). The Delaware county multi-jurisdictional mitigation plan clearly describes the problems associated with double digit increases in population and the associated growth of the built environment. Large sections of farmland are being developed into residential housing, retail commercial facilities and office parks with the associated roads and parking areas. As a direct result, older neighborhoods adjacent to local waterways have experienced a marked increase in water levels and flows during rain events. The county has a clear understanding of the problems, their implications and is working to address them through mitigation planning and educational outreach. Part of the difficulty in addressing the situation is that the growth areas are creating high value real estate for Ohio, while the impacted areas range from mobile home parks to older structures built in or close to the floodplain. Over time the size of the 100 year regulatory floodplain can be expected to increase due to development. Two other greater Columbus counties, Union and Fairfield, showed moderate growth, however no adverse impacts were observed.

The Warren County Regional Planning Commission has planned for structured growth which has resulted in minimal adverse impact. The Warren County multi-jurisdictional mitigation plan outlines the program objectives to:

- Discourage small, isolated subdivisions where soil conditions and lot size are not conducive to on-site wastewater disposal systems, where applicable.
- Encourage a logical pattern of residential development where future growth would occur in proximity to existing residential areas, within the designated Urban Service Areas of the township.
- Build multi-family housing at a scale that can accommodate the need, combined with prudent use of the Planned Unit Development process, to accomplish quality development, mitigating the impact of county utilities and other public services.
- Develop adequate, well designed and affordable housing for the elderly population, the handicapped and families with children.
- Give a stronger emphasis to establishing open space/green belt areas, separating developing residential areas from incompatible uses.

- Establish a system to encourage housing maintenance through a coordinated, ongoing inspection program by county and local officials.
- Encourage the repair or removal of dilapidated/substandard structures.
- Identify, document and protect older homes or residential areas of historical and/or architectural significance from unwanted, incompatible land uses.
- Explore the establishment of an historical zoning district to protect individual structures or neighborhoods of historical and/or architectural significance.

## **2.16 CONSEQUENCE ANALYSIS**

The EMAP standard for a HIRA requires the state program to include a consequence analysis for hazards identified in state HIRAs. The consequence analysis should consider the impact on the public; responders; continuity of operations including delivery of services; property, facilities and infrastructure; the environment; the economic condition of the state, and public confidence in the state's governance.

### **Impact on the public**

Based on the HIRA in the SOHMP, there is neither record of a historical event or impacts as identified in the vulnerability analysis that would be considered catastrophic from a statewide perspective. Historically, other than emerging disease/pandemic outbreaks, hazard events in Ohio tend to be moderate in size – possibly approaching widespread, but not necessarily rising to the level of catastrophic. Three natural hazard events that may have a broader impact on the public would be a large earthquake on the New Madrid fault, a statewide blizzard (such as the blizzard of 1978) or a widespread flood (Great Flood of 1913). Still, the impacts on the public from these three events would be moderate. Perhaps the hazard with the greatest impact on the public (in terms of numbers of individuals adversely affected) would be an emerging disease/pandemic outbreak or a terrorism event that included a nuclear dispersion device.

### **Impact on responders**

Because it is unlikely that hazard event would be widespread enough in Ohio to be “catastrophic,” existing mutual aid mechanisms and the ability to exercise Emergency Management Assistance Compact (EMAC), should be sufficient to handle any hazard event. The exception to this may be an emerging disease/pandemic outbreak.

### **Continuity of Operations (COOP)**

Communities and the State of Ohio continually develop and update COOP plans in the event facilities and/or agencies are impacted. State agencies also maintain disaster recovery plans which are largely IT focused. It is expected that affected agencies would exercise their COOP plans as appropriate. Private sector businesses are encouraged to develop business continuity plans, but they are not mandated by the state.

### **Property, facilities, and infrastructure**

The SOHMP has attempted to collect and create risk assessments and vulnerability analyses for the different hazards it profiled. One note of caution in utilizing these data is that aggregate dollar damage amounts and facilities affected by a multi-county region are for purposes of comparison in the SOHMP only. The SOHMP does not imply that a whole region would actually have an event occur where the maximum damages are sustained in all of the counties identified in the region.

## **Environment**

Certainly any hazard event has the potential for environmental impact. Flood events for example may result in pollution of streams and rivers due to combined sewage overflows and a tornado/wind event will disperse materials, trash and debris over a widespread area. A drought may affect the environment in a different way by drying up wetlands, and weakening/killing trees and forestlands. The three hazards that have a significant potential for environmental impact are: nuclear detonation/dispersion, emerging disease/pandemic outbreak, and flooding.

## **Economic condition of the state**

Because most hazards in Ohio would not result in a statewide catastrophe, the economic impacts, while potentially severe, would be recoverable. Also, Ohio has a diverse economy even though there are areas where certain segments of the economy are concentrated (manufacturing in Cleveland/Akron/Youngstown for example). From a geographic perspective, an event that would affect the greater Cleveland, Columbus, or Cincinnati area would have a greater impact than would a hazard affecting other areas of the state. Similarly, an invasive species or pest that would affect the corn or soybean crop statewide, or a drought might result in a more widespread deterioration of the economic condition of the state. Finally, an event affecting Columbus as it is the seat of state government could have a significant impact as centralized processing of payments to citizens for a variety of programs could be interrupted.

## **Public confidence in state governance**

As has been demonstrated in catastrophic events in other states and countries, public confidence in state governance is tightly linked to the government's response to a hazard event. Even in more regionalized or local disasters this is the case although the effect of the disaster on public confidence is similarly regionalized or localized. The hazards most likely to have a widespread effect on public confidence in state governance are those that either have the probability of statewide effect (drought, blizzards), those that have a high impact or consequence (terrorism, nuclear detonation/dispersion, emerging disease/pandemic outbreak) and those that have a short speed of onset (terrorism).