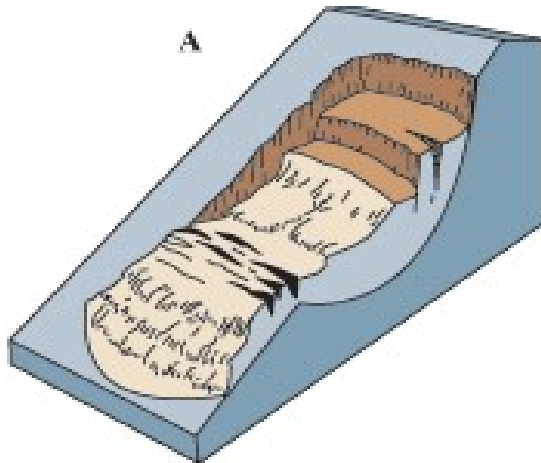


2.5 LANDSLIDE

Per the Ohio Department of Natural Resources – Division of Geological Survey GeoFacts publication, a landslide is the downward and outward movement of soil and rock material on slopes. There are three main types of landslides that occur in Ohio (<http://geosurvey.ohiodnr.gov/portals/geosurvey/PDFs/GeoFacts/geof08.pdf>):

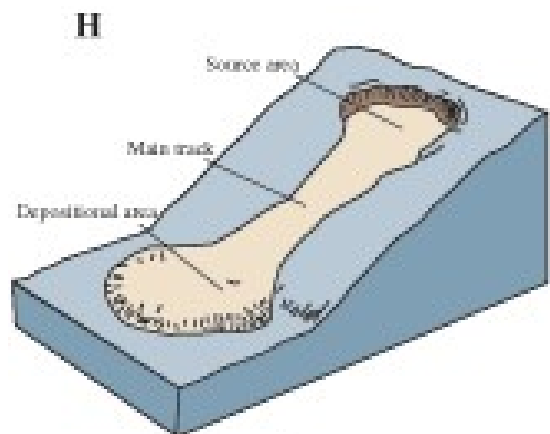


Rotational landslide

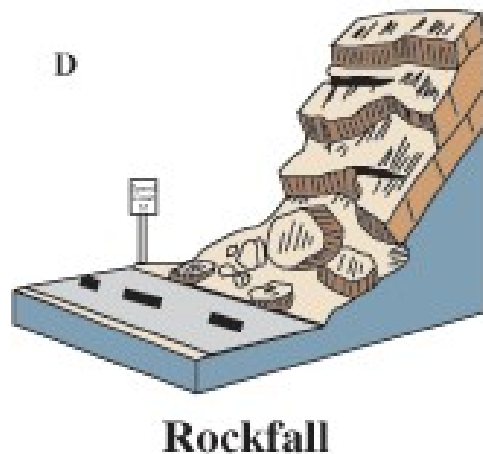
Rotational Slump: the movement of a mass of weak rock or sediment as a block unit along a curved slip plane. In Ohio, these types of slides commonly involve hundreds of thousands of cubic yards of material and extend for hundreds of feet. The crown or head, located in the upper section of the ground surface, consists of one or more rupture zones (scarps) that form a stair-step pattern of displaced blocks. The surfaces of these blocks are commonly rotated backward (reverse slope) and form depressions where water may accumulate, creating small ponds or swampy areas. Trees on these blocks may be inclined upslope, toward the top of the hill. The lower, downslope end (toe) of a rotational slump is a fan-shaped, bulging mass of material characterized by radial

ridges and cracks. Trees on this portion of the landslide may be inclined at strange angles, giving rise to the descriptive terms "drunken" or "staggering" forest. Rotational slumps may develop comparatively slowly and commonly require several months or even years to reach stability; however, on occasion, they may move rapidly, achieving stability in only a few hours.

Earthflow: involves rock, sediment, or weathered surface materials moving downslope in a mass. The most common form of earth movement in Ohio, earthflow involves a smaller area than a rotational slump and forms a hummocky topography of ridges and swales. Trees may be inclined at odd angles throughout the length of an earthflow. Earthflows are most common in weathered surface materials, do not necessarily indicate weak rock, and are also common in unconsolidated glacial sediments. The rate of movement of an earthflow is generally quite slow.



Earthflow



Rockfall: an extremely rapid, potentially dangerous downslope movement of earth materials. Large blocks of massive bedrock suddenly become detached from a cliff or steep hillside and free fall in a rolling, bounding, or sliding manner downslope. Most rockfalls in Ohio involve massive beds of sandstone or limestone. Surface water seeps into joints or cracks in the rock, increasing its weight and causing expansion of joints in freezing temperatures, thus prying blocks of rock away from the main cliff. Weak and easily eroded clay or shale beneath the massive bed is an important contributing factor to rockfall. All illustrations were provided by the USGS.

One or more of the following conditions contribute to the occurrence of landslide events:

- **Steep slope:** All landslides move downslope under the influence of gravity. Therefore, steep slopes, cliffs, or bluffs are a required element leading to a landslide, especially in conjunction with one or more of the conditions listed below.
- **Jointed rocks:** Fractures in rocks allow surface moisture to penetrate and weaken it. When the moisture freezes, it pries the rock masses apart at the joint.
- **Fine-grained, permeable rock or sediment:** Fine rock particles are particularly conducive to landslide development because large amounts of moisture can enter them easily, increasing the material's weight, reducing the bonding strength of individual grains, and dissolving grain-cementing materials.
- **Clay or shale units subject to lubrication:** Groundwater penetration of clay or shale can lead to a loss of binding strength between individual mineral grains and subsequent failure.
- **Large amounts of water:** Periods of heavy rainfall, excess snowmelt, or other events where water is accumulated saturate the zone above the normal water table and cause a landslide.

In addition to the conditions noted above, a landslide requires a triggering mechanism to initiate downslope movement. Several events or circumstances, many of them human-caused, can trigger landslides, including:

- **Vibrations** such as those from human-causes like blasting, the passing of a heavy truck, or from natural events like earthquakes, although no such occurrence has been documented in Ohio.
- **Over steepened slopes** caused by undercutting by stream or wave erosion, by human construction activities, or by the addition of fill material to the upper portion of a slope, disturb the equilibrium of a stable slope and cause the angle of stability to be exceeded.
- **Increased weight on a slope** caused by the addition of large amounts of fill, the construction of a building or other structure, or an unusual increase in precipitation, either from heavy rains or from artificial alteration of drainage patterns.
- **Removal of vegetation and trees** because of the loss of roots, which tend to hold the rock or sediment in place and soak up excess moisture.

RISK ASSESSMENT

LOCATION

Areas in southern and eastern Ohio have several conditions that can lead to the occurrence of landslide events. Thick deposits of broken and weathered bedrock fragments called colluvium, and lake silts, create slopes that are vulnerable to failure (among other geological factors). In addition, redbeds, soft shales that weather rapidly and slip, slide, and flow to form gentle contours that are quickly grassed over, have long presented landslide conditions in the Appalachian Plateau.

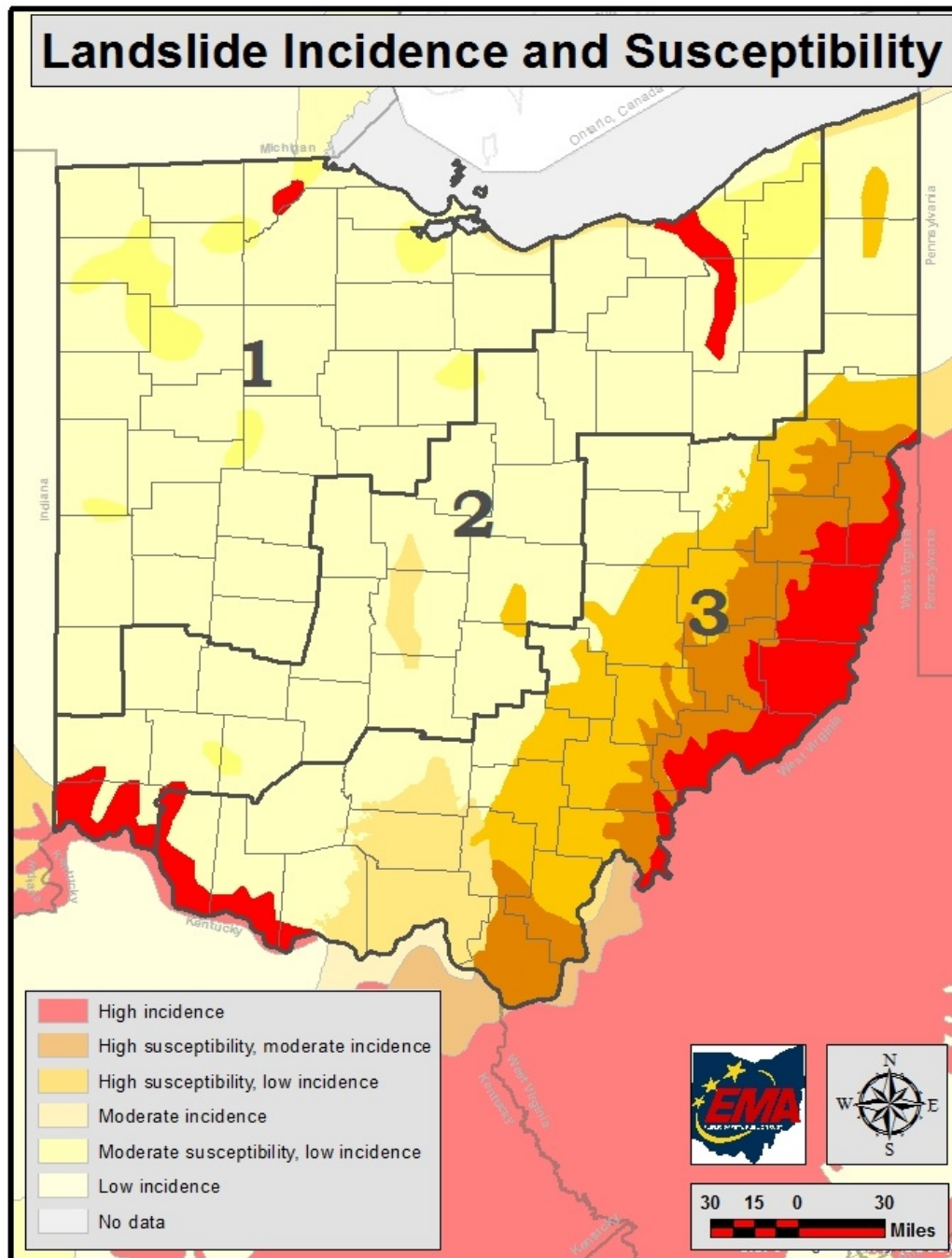
Per the USGS, (<https://geochange.er.usgs.gov/sw/impacts/geology/landslides/>) the Landslide incidence and susceptibility map (2.5.a) was digitized from the original stable-base manuscripts from USGS Professional Paper 1183. The map displays both the incidence of landslides and susceptibility of the land surface to landslides. Briefly, the map was constructed by evaluating geologic units shown on the geologic map of the United States (King and Beikman, 1974) and classifying them as having high, medium, or low landslide incidence based on number of known landslides, and as having the high, medium, or low susceptibility to landslide. High incidence was assigned to map units (indicated in red on the map) having more than 15 percent of their area involved in landslide; moderate incidence (in tan) to those having between 15 and 1.5 percent; and low incidence (in yellow) to those having less than 1.5 percent.

The largely subjective susceptibility indicators were defined as the probable degree of response of the rocks and soils at the surface to natural or artificial cutting or loading of slopes, or to anomalously high precipitation. The same percentages used to delimit landslide incidence were applied to the three categories of susceptibility. For example, a high susceptibility area would exhibit some movement over 15 percent or more of its surface area in response to widespread artificial cutting or high precipitation. The three susceptibility categories classified were: (1) high susceptibility with moderate incidence of landslide (dark brown); (2) high susceptibility combined with low landslide incidence (in gold); and (3) moderate susceptibility combined with low landslide incidence (in yellow/green).

Full weight could not be given to the important factors of slope angle and precipitation because no adequate slope or precipitation maps at the appropriate scale existed at the time the map was produced in 1982. A more detailed description about the construction of the map is given in the original U.S. Geological Survey Professional Paper 1183

Region 1 primarily has a low landslide incidence. The most notable exception to this is Lucas and Wood Counties, which are reported to have a high landslide incidence. (Map 2.5.a). Along with Region 1, Region 2 also has a primarily low landslide incidence. Within Region 2, Butler, Hamilton, Warren, Cuyahoga, and Summit are all identified as having a high landslide incidence, which does not reflect the regional trend. Region 3 is identified as having the most area susceptible to landslide (i.e., the Appalachian Plateau). The largest part of the region has a high susceptibility with a low or moderate incidence. However, most of Belmont and Monroe counties have a high landslide incidence with parts of Columbiana, Jefferson, Harrison, Washington, Athens, Meigs, Adams, Brown, and Clermont Counties having a high incidence as well.

Map 2.5.a



LHMP DATA

Hamilton County – While Region 3 and parts of Region 2 have potentially high susceptibility and incidence to landslides. Hamilton County and the City of Cincinnati has some of the highest cost per capita in the United States for historical landslide damages. The 2013 Hamilton County Multi-Hazard Mitigation plan included a landslide assessment performed by the University of Cincinnati, which is summarized in Table 2.5.a.

Building Type	Number of Buildings	Estimated Losses/Exposure
Residential	1,346	\$279,851,500
Non-Residential	610	\$19,740,730
Critical Facilities	10	\$2,150,000
Totals	1,966	\$301,742,230

Table 2.5.a

According to the 2013 Hamilton County plan, landslides are considered to be their fourth area of concern for natural hazards, following flooding (number one), tornadoes, and severe storms. The county officials based their decision on the lack of building regulations in areas deemed high hazard for landslides. Also, the removal of vegetation in riparian corridors can increase the landslide potential, and this is not regulated systematically. Finally, the lack of public education and awareness limits communities' understanding of such geophysical and regulatory relationships. Hamilton County's goal to mitigate landslide events involves identification of methodologies used by other, similar communities, and they want to increase public awareness through outreach initiatives.

Stark County – The 2017 Stark County Multi-Jurisdictional All-Hazard Mitigation Plan states that landslides have occurred primarily in the western and southern portions of the county, near the villages of Brewster, East Canton, Navarre, Waynesburg, and Wilmot and the cities of Canal Fulton, Magnolia, Massillon, and North Canton. Safety problems for travelers caused by landslides are a growing concern. There are several highways that could become damaged as a result of landslides in Stark County. U.S. Routes 30 and 62, and State Routes 21, 43, 93, 172, 289, and 800 all are at risk.

PAST OCCURRENCES

Ohio has had a long history of damage from landslides; for example, geologists at the University of Cincinnati report that the Cincinnati metropolitan area has one of the highest per capita costs of landslide damage of any metropolitan area in the United States. Accounts of landslide concerns can date back to the 1970s. A 1980 U.S. Geological survey report estimated Hamilton County likely had the highest annual per capita landslide damage costs in the country. Within Hamilton County, Cincinnati alone was spending about \$500,000 annually on emergency landslide repairs. Despite the chronic problem, no long-term plan currently exists to permanently provide a solution. While landslides have been problematic in Cincinnati since the early to mid-1800s, documentation is limited. As the city began to expand and infrastructure was improved in the early 1900s, landslide hazards became better documented.

The University of Cincinnati report found that landslide damages in Hamilton County, primarily due to public road construction, averaged more than \$5 million each year between 1973 and 1978. Well-publicized landslides that occurred in the 1970s included those along Columbia Parkway, Hillside Avenue, Delhi Pike, and Huffman Court. Mt. Adams (Cincinnati, Ohio) is the most prominent topographic feature in Cincinnati. It is also home to one of the most expensive landslide remediation projects in the history of the U.S. The cost of remediation was \$44.5 million in 2005 dollars. A normal retaining wall for this slide could not be used because the failure surface was too deep.

Rockfalls have also caused dangerous conditions. Ohio DNR reports that on Christmas Eve in 1986, an individual traveling in an automobile was killed by falling rock along U.S. Route 52 in Lawrence County in southern Ohio. In 2017, ODOT reported several large boulders fell in Lawrence County blocking all four lanes of State Route 7 for several days. The westbound lanes of State Route 7 did not reopen for nearly a month. The photograph was provided by ODOT District 9.



Landslides can be triggered by heavy rainfall and flooding, leading to multiple disasters in the same location. The most recent example is from April of 2018 when the State received a disaster declaration (DR- 4360) due to the severe storms, flooding, mudslides, and landslides that struck the southern and southeastern counties of Ohio. Federal funding also was available to State and eligible local governments on a cost-sharing basis for the repair or replacement of public facilities damaged by the severe storms, flooding, mudslides, and landslides in the counties of Adams, Athens, Belmont, Brown, Columbiana, Gallia, Hamilton, Harrison, Jackson, Jefferson, Lawrence, Meigs, Monroe, Morgan, Muskingum, Noble, Perry, Pike, Scioto, Vinton, and Washington Counties. The photograph was provided by ODOT.

The impact of most if not all landslide and rockfall events in Ohio are directly tied to rainfall events, therefore more damage data related to such events is captured under flood related damages for the purposes of FEMA's public assistance program.

OHIO DEPARTMENT OF TRANSPORTATION LANDSLIDE AND ROCKFALL INVENTORIES

The Landslide (10/2013) and Rockfall (12/2016) manuals prepared the ODOT Office of Geotechnical Engineering (OGE), provide rational approach to manage the unsafe or failed slopes/embankments and rockfalls. The manuals include a systematic process for collecting the information needed for decision-making.

LANDSLIDE MANUAL

(<http://www.dot.state.oh.us/Divisions/Engineering/Geotechnical/Geotechnical Documents/Manual%20of%20Landslide%20Inventory.pdf>)

This manual was developed by ODOT OGE to inventory soil slopes, to identify potential hazardous slopes, to assess relative risk for those slopes, to determine degree of monitoring required, and to allow for actions to be taken to reduce, minimize, or eliminate the risk to the public's safety and to protect the highway system. The intent of this manual is to facilitate the creation of a statewide landslide inventory process through the development of a statewide inventory procedure and the establishment of office and field methods. These methods should be used during the initial population of the inventory, inventory of new sites following the initial population, and for maintenance and monitoring of the sites. The data collected from the SdAD inventory process will be stored within the Geologic Hazard Management System (GHMS) and other related components of the ODOT GeoMS.

Essentially, this manual provides the information about the following:

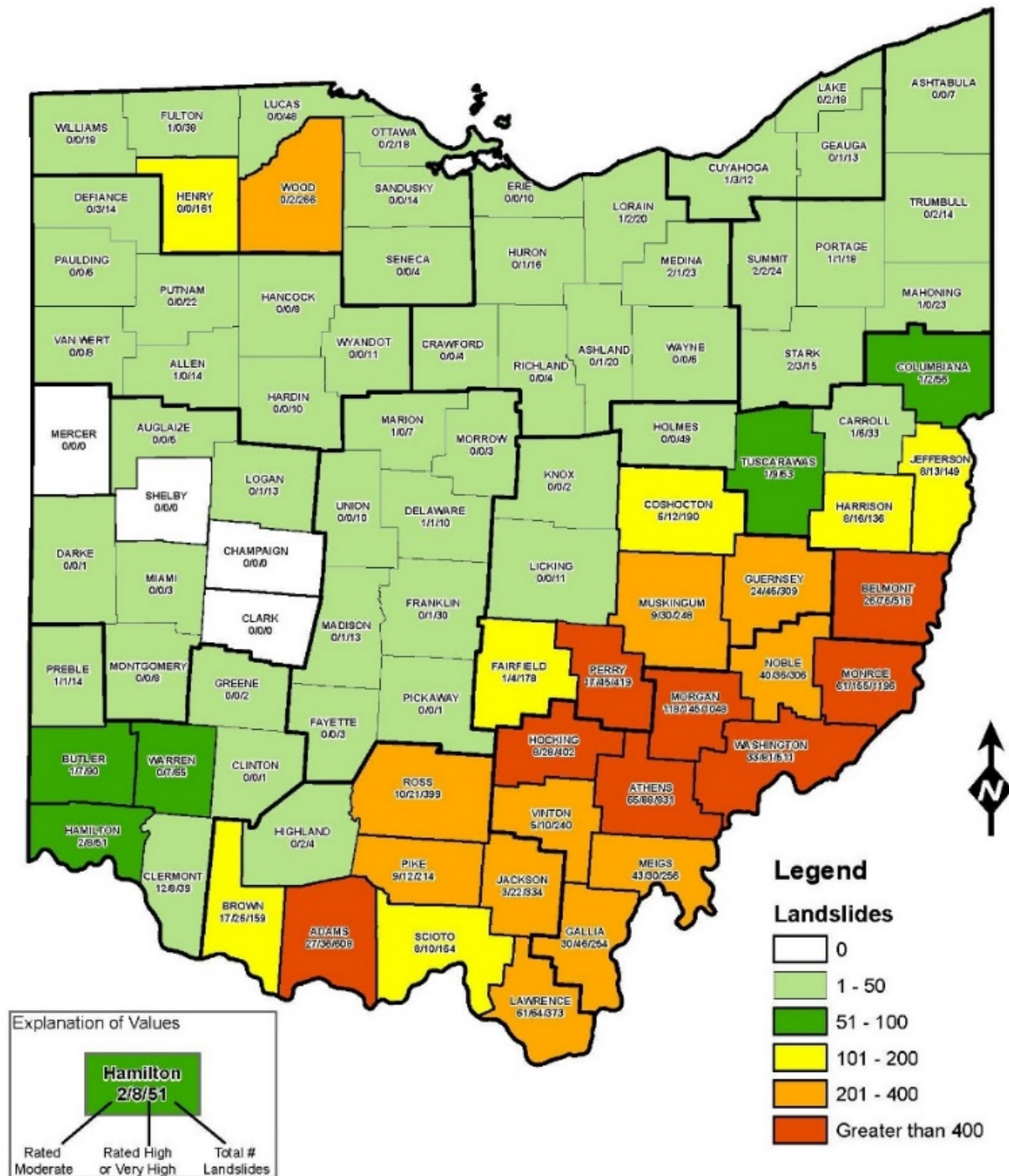
- procedure for landslide data collection;
- landslide hazard assessment using ODOT rating matrix; and
- guidance on the use of a global positioning system (GPS) and an internet website for the ODOT landslide database

The Preliminary Rating will segregate the lower priority sites from the groups that will receive detailed data collection efforts. This Manual will outline a tiered data collection methodology which will allow landslides within Ohio to be rated for relative risk of slope instability to the public and Ohio's highway system. The map (2.5.b) was created by the Office of Geotechnical Engineering (OGE) and represents the number of landslide by county that are currently impacting the State's highway system. The map indicates the number of moderately and highly rated landslides, along with the total number of landslides for each county. The counties with the most impacted roadways are Monroe (1196), Morgan (1048) and Athens (831).



OHIO DEPARTMENT OF TRANSPORTATION

Total Geohazards: Landslide Inventory



Created: 2/15/2017

Table 2.5.b

ROCKFALL MANUAL

http://www.dot.state.oh.us/Divisions/Engineering/Geotechnical/Geotechnical_Documents/Manual%20for%20Rockfall%20Inventory.pdf

Rockfalls can constitute a major hazard along Ohio roadways, posing a risk to life, property, and traffic safety. As a result of rockfalls, maintenance problems are constantly occurring, resulting in a strain on the Ohio Department of Transportation (ODOT) funds and manpower. A rockfall inventory will be performed for the state highway system as noted in ODOT's policy on geohazards. This inventory will include all natural and manmade slopes with exposed bedrock.

The data collection procedures are grouped into four (4) primary sections with subsections:

- Site Inventory and Preliminary Rating
- Tier 1 Site Rating
- Tier 2 Site Rating
- Tier 3 and Tier 4 Site Rating

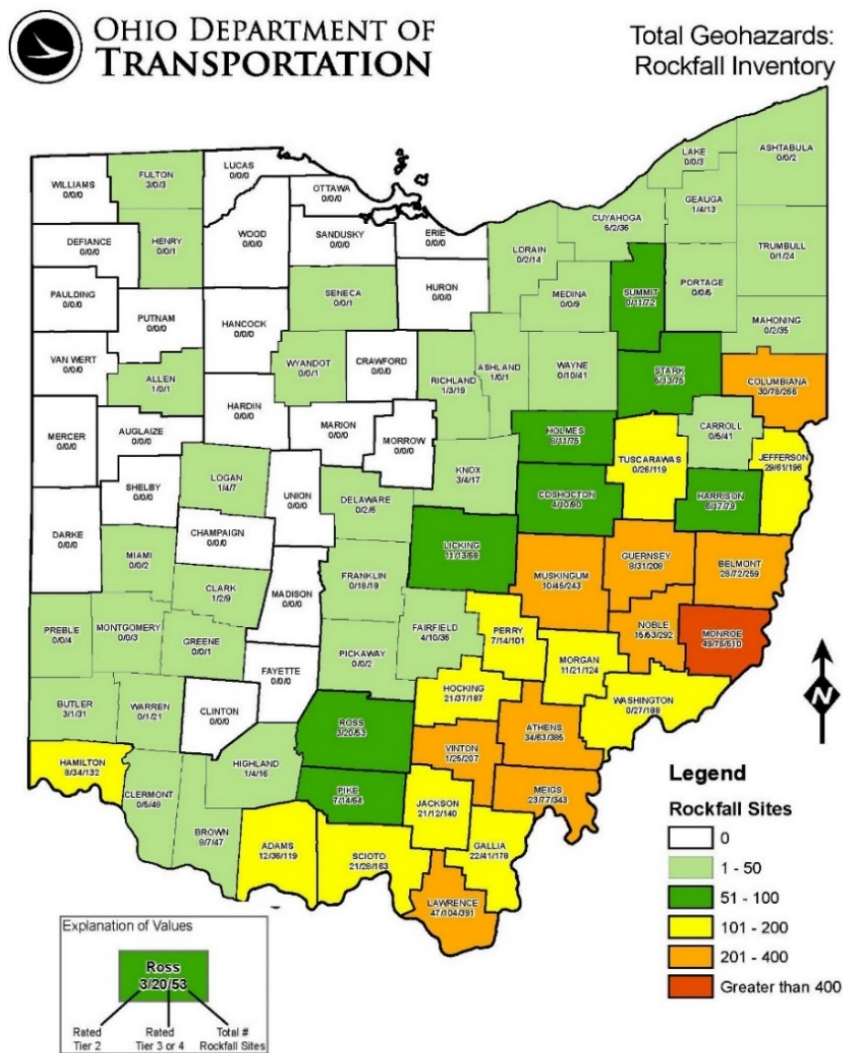


Table 2.5.c

This Manual outlines a tiered data collection methodology which allows rock slopes within Ohio to be rated for relative rockfall risk to the public and Ohio's highway system. The data collected from each site is incorporated into an Enterprise Database and integrated into a GIS system. The inventory consists of identifying and locating Inventory Sites within the rock slopes situated along Ohio's highway system. Generally, this inventory will be concerned with rock slopes located above the roadway, unless a rockfall event below the road could result in adverse impacts to the highway system.

PROBABILITY OF FUTURE EVENTS

Landslide probability is highly site-specific, and cannot be accurately characterized on a statewide basis, except in the most general sense. Statewide analyses for potential landslides have been performed by the US Geological Survey (USGS). The possible landslide incidence and susceptibility was discussed earlier in this chapter and illustrated on Map 2.5.a. When factoring for the previous USGS analyses (map 2.5.a) and the impacts documented in ODOT landslide (2.5.b) and Rockfall (2.5.c) manuals, Region 3 is identified as having the most area susceptible to landslide.

VULNERABILITY ANALYSIS & LOSS ESTIMATION

METHODOLOGY

The only predictable impact that 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 existing landslide and rock fall events. The location, length of each segment, potential for failure, along with a host of other data is maintained in a database (<https://gis.dot.state.oh.us/tims/Map/Geotech>). The counties with the greatest number of impacts are located within Region 3, particularly Athens, Lawrence, Morgan and Monroe Counties.

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

METHODOLOGY

Using the geocoded state owned and state leased critical facilities listing provided by the Ohio Department of Administrative Services (DAS), and the Landslide Incidence and Susceptibility map created and maintained by USGS, Ohio EMA GIS staff performed a buffer, which joined the two data sets and produced a new data set. This new data set allowed us to quantify the risk to the state owned and state leased critical facilities based upon their physical location within each county. For the purpose of this analysis, those critical facilities located within areas with a low incidence (less than 1.5 % chance) of landslide were not included.

RESULTS

The results were weighted based upon the number of critical facilities in each county that were located within areas of high incidence (having more than 15 % chance of landslide). There are counties who had a larger overall number of critical facilities located within areas that fell within the a category noted on the landslide incidence and susceptibility map, but were not considered to be at the same risk level as those counties with critical facilities located within high incidence areas.

Region 1 has a very low potential of loss, with only one county (Lucas) having any critical facilities within an area of high incidence and only eight counties total with possible losses. The vast majority of the region's possible losses and impacted critical facilities are located within Lucas County.

Region 1

County	Total Exposed Critical Facilities	Total Replacement Value	# of Critical Facilities in HIA	% of Critical Facilities in HIA
Lucas	46	\$ 273,893,286.00	22	47.8%
Defiance	8	\$ 7,200,331.00	0	0.0%
Putnam	1	\$ 1,227,541.00	0	0.0%
Mercer	6	\$ 885,687.00	0	0.0%
Erie	7	\$ 685,079.00	0	0.0%
Darke	1	\$ 626,117.00	0	0.0%
Hardin	3	\$ 302,153.00	0	0.0%
Henry	5	\$ 113,250.00	0	0.0%
TOTAL	77	\$ 284,933,444.00	22	

Table 2.5.b

Compared to Region 1, Region 2 has a significantly greater potential for loss. Region 2 has a total of eight counties with possible losses. Of those eight counties, four of them Summit, Hamilton, Butler and Cuyahoga have critical facilities within an area of high incidence. Cuyahoga County the greatest number of critical facilities (38) within an area of high incidence in the state. Franklin County has the highest total critical facilities (111), which are in an area that is susceptible to landslide, but none of those areas exceed moderate incidence. Region 2 also has the greatest potential losses in dollars, although much of this is driven by Franklin County.

Region 2

County	Total Exposed Critical	Total Replacement Value	# of Critical Facilities in HIA	% of Critical Facilities in HIA
Cuyahoga	71	\$ 223,491,915.00	38	53.5%
Summit	37	\$ 178,272,585.00	37	100.0%
Hamilton	29	\$ 172,251,987.00	29	100.0%
Butler	2	\$ 367,875.00	2	100.0%
Franklin	111	\$ 796,354,215.00	0	0.0%
Geauga	23	\$ 8,576,693.00	0	0.0%
Portage	1	\$ 684,224.00	0	0.0%
Fayette	1	\$ 5,000.00	0	0.0%
TOTAL	352	\$ 1,664,937,938.00	128	

Table 2.5.c

Region 3 has by far the highest number of counties with critical facilities, which could sustain potential losses from landslides (715). Region 3 had twenty-eight counties with the potential of loss and nine counties with critical facilities within an area of high incidence.

Region 3

County	Total Exposed Critical	Total Replacement Value	# of Critical Facilities in HIA	% of Critical Facilities in HIA
Washington	56	\$ 29,149,164.00	37	66.1%
Belmont	62	\$ 54,856,808.00	34	54.8%
Jefferson	37	\$ 7,592,901.00	23	62.2%
Clermont	23	\$ 3,710,528.00	23	100.0%
Monroe	19	\$ 6,522,681.00	19	100.0%
Harrison	30	\$ 9,054,441.00	16	53.3%
Brown	7	\$ 29,882,234.00	7	100.0%
Meigs	19	\$ 8,547,106.00	2	10.5%
Columbiana	37	\$ 13,835,662.00	1	2.7%
Scioto	55	\$ 171,351,723.00	0	0.0%
Noble	31	\$ 50,299,353.00	0	0.0%
Athens	31	\$ 45,496,640.00	0	0.0%
Guernsey	54	\$ 39,704,477.00	0	0.0%
Gallia	71	\$ 35,860,837.00	0	0.0%
Ross	19	\$ 19,248,265.00	0	0.0%
Jackson	18	\$ 15,130,501.00	0	0.0%
Lawrence	27	\$ 11,760,373.00	0	0.0%
Muskingum	17	\$ 9,232,685.00	0	0.0%
Vinton	20	\$ 5,854,782.00	0	0.0%
Morgan	10	\$ 3,950,084.00	0	0.0%
Pike	10	\$ 3,878,547.00	0	0.0%
Carroll	17	\$ 3,661,999.00	0	0.0%
Tuscarawas	17	\$ 2,921,475.00	0	0.0%
Ashtabula	12	\$ 1,889,649.00	0	0.0%
Hocking	2	\$ 1,373,320.00	0	0.0%
Trumbull	8	\$ 1,052,544.00	0	0.0%
Perry	5	\$ 979,866.00	0	0.0%
Adams	1	\$ 545,334.00	0	0.0%
TOTAL	715	\$ 587,343,979.00	162	

Table 2.5.d