2.14 LAND SUBSIDENCE

Subsidence is the 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 1900s, underground salt, limestone, and gypsum mining began. All mining activities 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, and development on the ground surface. Abandoned underground coal mines in Ohio have the added environmental impact of discharging acidic water. If acidic mine water is discharged into creeks or streams, it can alter the chemical composition of the water habitat and cause considerable harm to sensitive aquatic life.

Per the ODNR, Division of Geological Survey, karst is a little-known, but unique and important landform that can be found throughout the state of Ohio. Regions that contain sinkholes and other solutional features, such as caves, springs, disappearing streams, and enlarged fractures, are known as karst terrains. Sinkholes form as bedrock dissolves and surface materials erode or collapse into the resulting voids. Sinkholes are the main hazard associated with karst landforms in Ohio, and there are thousands of them in the state.

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.

HAZARD PROFILE

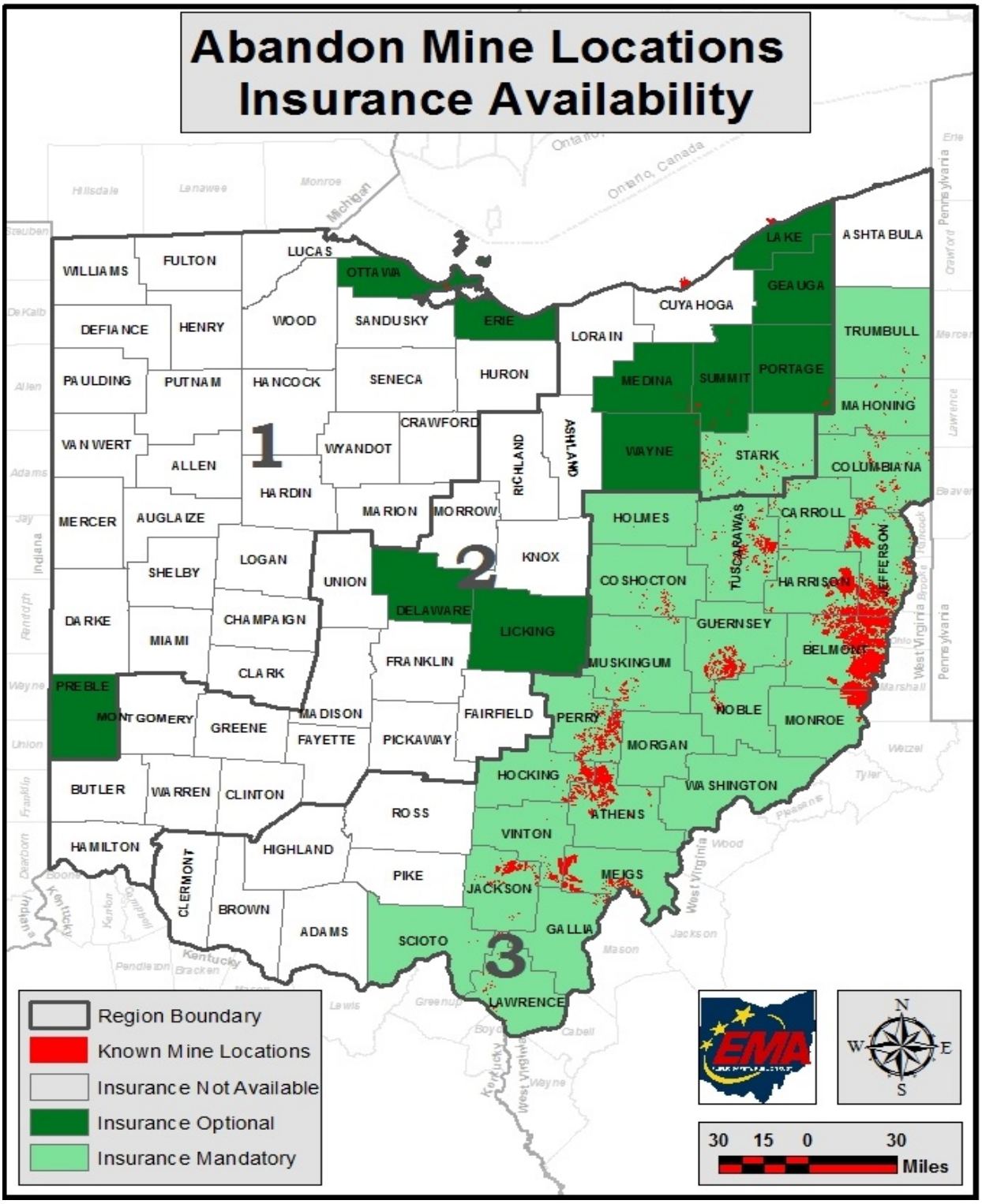
LOCATION

Beginning in the 1700s and continuing to today, there has been considerable coal mining in the Appalachian region of Ohio. In addition to coal, several salt, clay, and gypsum mines opened in counties close to Lake Erie. Finally, in central and southwestern Ohio, there are several isolated mines (Map 2.14a).

ODNR and the Ohio Department of Transportation (ODOT) actively inventories these geologic hazards and conducts risk assessments to determine the potential impact on the state's transportation infrastructure. Both mapped and unmapped underground mines pose a continued threat of subsidence to Ohio's transportation system. The statewide inventory and risk assessment of these mine sites is an ongoing process. Per the ODNR, Division of Mineral Resources Management, there are:

- 283 Surface Coal Mine Operation (203 active, 1118 released, 2502 abandoned, 2444 inactive & awaiting release)
- 26 Active Underground Coal Mines (permitted)
- 1,908 Surface IM Operations (828 active, 1080 released)
- 7 Active Underground IM Mines
- 3,606 Abandoned Underground Mines (Known)
- 6,450 Abandoned Surface Mines (based on topo maps and aerial reconnaissance)

Map 2.14a


Abandon Mine Locations
Insurance Availability
Region Boundary
Known Mine Locations
Insurance Not Available
Insurance Optional
Insurance Mandatory
1
2
3
EMA
N
W
E
S
30 15 0 30
Miles
LAKE
ASHTABULA
GEAUGA
CUYAHOGA
TRUMBULL
LORAIN
MEDINA
SUMMIT
PORTAGE
MAHONING
WAYNE
STARK
COLUMBIANA
HOLMES
CARROLL
TUSCARAWAS
HARRISON
JEFFERSON
COSHOCTON
GUERNSEY
BELMONT
MUSKINGUM
NOBLE
MONROE
PERRY
MORGAN
WASHINGTON
HOCKING
ATHENS
VINTON
MEIGS
JACKSON
GALLIA
LAWRENCE
SCIOTO
ADAMS
BROWN
CLERMONT
HIGHLAND
PIKE
ROSS
HAMILTON
BUTLER
WARREN
CLINTON
GREENE
MONTGOMERY
PREBLE
DARKE
MIAMI
CHAMPAIGN
CLARK
MADISON
FAYETTE
PICKAWAY
FAIRFIELD
FRANKLIN
DELAWARE
LICKING
KNOX
MARION
MORROW
RICHLAND
ASHLAND
CRAWFORD
WYANDOT
HARDIN
UNION
LOGAN
SHELBY
AUGLAIZE
MERCER
VAN WERT
ALLEN
PAULDING
PUTNAM
HANCOCK
SENECA
HURON
WOOD
SANDUSKY
ERIE
OTTAWA
DEFIANCE
HENRY
WILLIAMS
FULTON
LUCAS

The majority of abandoned mines are located in, or directly adjacent to, Region 3, and most of these were coal mines. Coal mine depths can range from less than 100 feet below the surface to 1,000 feet or more. Deeper mines, with solid layers of rock (i.e., strata) above the void and limited soil at the surface, are less likely to fail than those closer to the surface. The ODNR, Division of Geological Survey and ODOT have developed profiles of voids, support strata composition and surface soils for a limited number mines, in order to assist in understanding the potential for subsidence events. Analysis requires experts trained in geology and significant time, which limits 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.

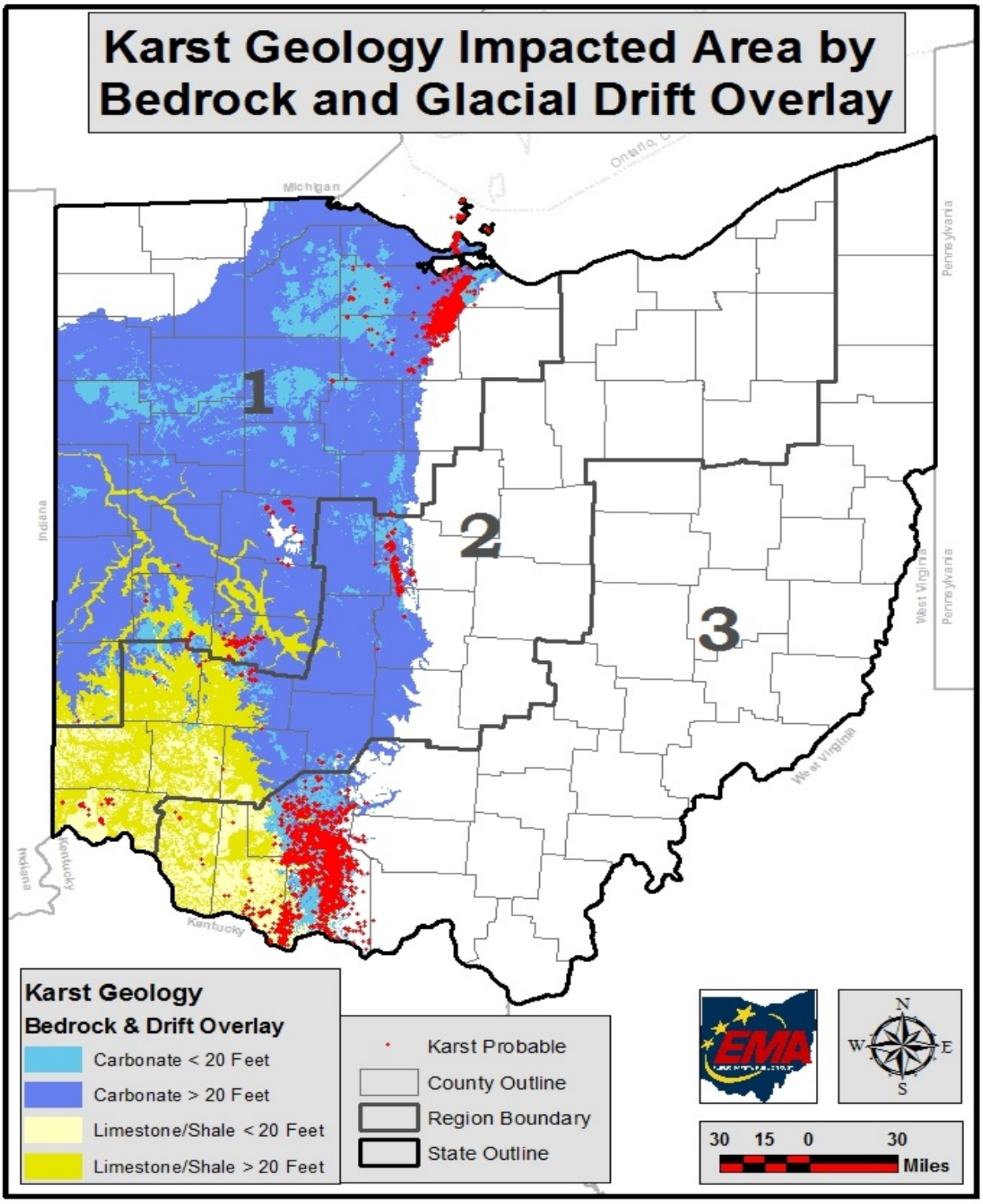
The Ohio Mine Subsidence Insurance Underwriting Association provides eligible Ohio counties with mine subsidence insurance (Map 2.14a). Under the program, 26 primarily Appalachian counties (Region 3) are required to carry mine subsidence insurance at a cost of one dollar annually. Additionally, eight 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.

Karst features are associated with the western third of Ohio, excluding the far northwestern counties of Williams, Fulton, and Defiance (Map 2.14b). Nearly all of Region 1 and the far western sections of Regions 2 and 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.

Map 2.14b


Karst Geology Impacted Area by Bedrock and Glacial Drift Overlay
Michigan
Ontario
Pennsylvania
Indiana
West Virginia
Kentucky
1
2
3
Karst Geology
Bedrock & Drift Overlay
Carbonate < 20 Feet
Carbonate > 20 Feet
Limestone/Shale < 20 Feet
Limestone/Shale > 20 Feet
Karst Probable
County Outline
Region Boundary
State Outline
EMA
N
W
E
S
30 15 0 30
Miles

LHMP DATA

The City of Bellevue is located within the Bellevue-Castalia Karst Plain and resides within four counties; Erie, Huron, Sandusky, and Seneca. Three of the four counties (Huron did not) 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 have 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.

Sandusky, Erie, and Seneca Counties all have specific mitigation action items related to karst and land subsidence, such as to identify high-risk areas and evaluate land-use planning techniques to mitigate future events.

PAST OCCURRENCES

Abandoned underground mines in Ohio are monitored by the ODNR, 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. 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. The time between the event and response is often within a 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.

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 problems. 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 most notable transportation-related 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 has not generated any known subsidence to date; however, solution mining in Lake, Summit and Medina Counties has. 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 the proximity of the impacted area to Lake Erie, it is now filled with water.

Until recently, Karst events in Ohio 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 sinkholes 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 water from safe sources. In February 2008, more than 200 homes experienced flooding in Bellevue when runoff from

heavy snows and spring rains flooded underground karst chambers. Experts believed building pressure caused the pent-up water to surge up existing sinkholes and cracks, flooding homes and yards. A section of State Route 269 was swamped from February through June 2008.

The Village of Put-In-Bay, located on South Bass Island in Lake Erie, was the site 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 began with the municipal systems and quickly shifted to a number of transient, non-community, public water systems used for geothermal cooling, flushing toilets, and outdoor cleaning. These systems were found interconnected to the main water system. The karst topography allowed groundwater to travel quickly between locations and is easily affected by seasonal precipitation.

The only known karst-related subsidence impact to the built environment is roadway damage. In 2007 State Route 19 was closed in Crawford County when an adjacent karst feature expanded destabilizing the robed.

Some examples of the impact of karst during construction include U.S. Route 33 near East Liberty, where construction crews had to perform considerable back-filling and reinforcing, creating a land-bridge to make sure the highway was secure. Another example would be the construction of tunnels for sewage pipelines by the City of Dublin (Franklin County). Sinkholes, filled with clayey overburden caused the expensive rock-boring machinery to clog and break, resulting in 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 an average of five homes or roadways. Approximately 20 additional events occur each year that 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 groundwater contamination. Based on past exposure, a significant event occurs approximately each decade.

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 (https://gis.dot.state.oh.us/tims/Map/Geotech).

ODOT updated their AUM Inventory and Risk Assessment Manual in January of 2018. This new manual has an updated methodology for assessing the risk and impact of AUMs on federal and state routes. The new methodology makes use of an initial and detailed site evaluation process. This process then ranks the

AUM on a 4 tier scale. More detailed information about the manual is available at http://www.dot.state.oh.us/Divisions/Engineering/Geotechnical/Pages/GeoHazards.aspx

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

Land subsidence is a spatial hazard, but is spatial-specific in that it would only affect very small areas given an occurrence. Therefore, this hazard has a very limited potential of affecting any state-owned or state-leased facilities. However, it should be noted that such events could impact lifelines, which could have significant effects on the functionality of various state facilities.