Location Restrictions Evaluation for Retrofitted Bottom Ash Pond (BAP) Cardinal Operating Company – Cardinal Power Plant 306 County Road 7E Brilliant, Ohio

January 3, 2022

Submitted to:

Cardinal Operating Company
306 County Road 7E
Brilliant, Ohio 43913

Submitted by:

Cox-Colvin & Associates, Inc.
7750 Corporate Blvd.
Plain City, Ohio 43064
(614) 526-2040

Cox-Colvin & ASSOCIATES, INC. ENVIRONMENTAL SERVICES

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1.0 Introduction

Cox-Colvin & Associates, Inc. (Cox-Colvin) is pleased to provide Cardinal Operating Company (Cardinal) with this Location Restrictions Evaluation report for the retrofitted Bottom Ash Pond (BAP) at their power plant located at 306 County Road 7E in Brilliant, Ohio (Site, Figure 1-1).

The purpose of this BAP Location Restrictions Evaluation report is to provide a description of Cardinal's Coal Combustion Residual (CCR) Unit compliance with respect to the United Stated Environmental Protection Agency (USEPA) CCR Rule Sections 40 CFR 257.60, 61, 62, 63, and 64. This report provides background information about the Site and the BAP as well as compliance information with respect to each section of the pertinent CCR rule.

The horizontal coordinate values provided in this report are based upon the North American Datum of 1927 (NAD27). The vertical datum used for reporting the elevations within this report is National Geodetic Vertical Datum of 1929 (NGVD 29).

Sections 2.0 and 3.0 of this report provide general background information on the BAP, while Sections 4.0 to 8.0 address specific requirements of the CCR Rule. Findings and conclusions are provided in Section 9.0, with certification by a qualified Professional Engineer (PE) in Section 10.0. References are included in Section 11.0.

2.0 Background Information

A general background of the facility and BAP is presented below.

2.1 Facility Location Description

The Cardinal Plant is a three-unit, 1,800 MW total capacity coal-fired generating station located in Jefferson County south of Brilliant, Ohio along the Ohio River. Each generating unit is equipped with an electrostatic precipitator (ESP) for removal of fly ash particulate matter, a selective catalytic reduction (SCR) system for removal of nitrogen oxide, and flue gas desulphurization (FGD) systems for removal of sulfur dioxide (AEP and Geosyntec Consultants 2005a, AEP 2014). The CCR unit considered in this location restrictions evaluation is the retrofitted BAP that is expected to go into operation in 2022. The BAP and the main plant area are shown on Figure 1-1.

2.2 Description of CCR Unit

The BAP, prior to the 2021 retrofit, was part of the Bottom Ash Complex (BAC) that was comprised of two surface impoundments consisting of a bottom ash pond (North Pond) and a recirculation pond (South Pond). The ponds remained connected by a pipe and were, therefore, treated as a single unit monitored as the "BAP" CCR unit.

The new, retrofitted BAP covers only a portion of the area of the historical BAP and is equivalent to the former South Pond. Cardinal is repurposing the North Pond of the former BAC for NPDES (non-CCR low volume waste) use. Following the repurposing of the North Pond, the South Pond is the only CCR unit in the BAC and will be referred to as the BAP moving forward. The BAP will receive bottom ash transport water and will be operated in a closed loop system.

An excavator placed on an "island" or "peninsula" of deposited bottom ash in the center of the BAP will be used to dredge settled bottom ash for dewatering. Once dewatered, the ash will be loaded onto trucks and either beneficially used as construction material or placed in the FAR I Residual Solid Waste Landfill, a dry landfill disposal unit located north of the plant. Water will be recirculated for bottom ash sluicing. There will be no discharge facilities from the BAP, except for a blowdown line to the Unit 3 FGD system to control the water level in the pond and to manage water quality (Sargent & Lundy 2020).

2.3 Construction and Operational History

The BAC was originally constructed in the 1960s as part of the construction of Generating Units 1 and 2. The original pond was constructed with embankments rising less than 10 ft above the pond bottom. In 1974, the pond underwent extensive modification, including the addition of the berm separating the BAP and RCP. During this time, the current dikes were founded above the original basin dikes, extending the dikes to their current crest elevation of 670 ft. In 2008, a vinyl sheet pile wall was installed in the RCP with a top elevation of 668.0 ft. This separated the RCP into two pond segments, a northern recirculation pond where water was recirculated back to the Units for ash sluicing and a southern final ash water settlement pond from which discharge to the Ohio River via NPDES Outfall 023 (AEP 2014, CHA Companies 2009) was performed as necessary. Discharge to the Ohio River through the principal spillway occurred only during high rainfall events where the spillway activated, releasing the water. In 2010, the BAP crest elevations were surveyed and found to vary from 668.3 ft to 669.4 ft. AEP subsequently restored the design crest elevation of 670.0 ft (S&ME 2016).

Beginning in January of 2022, the South Pond in the BAC will receive bottom ash as the "BAP" CCR unit, and the northern pond will be repurposed for non-CCR uses under a NPDES permit. The liner system will be composed of a geosynthetic clay over a graded and compacted native soil base in accordance with the CCR Rule permeability requirement and topped with a geomembrane. The liner system will be protected by additional geotextile and natural gravel (Sargent & Lundy 2020, Sargent & Lundy 2021b).

2.4 Area and Volume

The BAP will have a surface area of approximately 7 acres and a storage capacity of approximately 74 acre-feet.

3.0 Hydrogeologic Setting

Hydrogeologic conditions at the BAP are discussed in the following sections.

3.1 Climate

The 2020 average monthly temperature and precipitation values for the Brilliant, Ohio area are presented in the table below (NOAA 2021a). The climatological data was collected from the nearest weather station (USC00466442) located in New Cumberland, West Virginia, which is 28 miles north of Brilliant[1].

NOAA Climatological Summary (2020)		
Month	**Average Temperature (°F)**	**Precipitation (Inches)**
January	34.7	3.67
February	33.6	3.94
March	43.9	7.24
April	46.6	4.79
May	57.5	3.42
June	68.3	2.66
July	76.4	3.87
August	73.1	3.48
September	64.6	2.66
October	54.7	3.29
November	46.6	2.69
December	34.0	3.59

3.2 Geologic Setting

The BAP is located in an area of Ohio which was unglaciated during the last ice age. The surficial geology at the BAP consists of alluvial silt, clay, and sand deposited by the Ohio River floodwaters, underlain by glacial outwash deposits of sand and gravel. The glacial outwash deposits extend to thebedrock surface that occurs at approximately 50-75 ft below the natural ground surface at the BAP. Bedrock consists of interbedded shales, sandstones, coal, and limestones of the Pennsylvanian-aged Conemaugh Formation (BBC&M 2009).

[1] Although the Steubenville, Ohio weather station (USC00338025) is closer, data at that station is not collected with the same consistency as the New Cumberland, WV weather station.

3.3 Surface Water and Surface Water-Groundwater Interactions

Surface water on the plant property exits through NPDES outfalls, surface water off plant property enters tributaries prior to reaching the Ohio River. The nearest tributary entering the Ohio River is Salt Run, located approximately 0.6 miles to the north. Riddles Run and Blockhouse Run are located approximately 1.4 and 1.6 miles to the north, respectively.

Surface water east of the BAP, including any seepage from exposed bedrock in the hillside west of Ohio State Route 7, is expected to infiltrate unconsolidated materials at least partially and migrate through the vadose zone to groundwater, resulting in localized groundwater flow direction toward the Ohio River to the east. However, groundwater beneath the BAP will also be affected by river stage in the adjacent Ohio River.

The BAP is designed to be self-contained with impermeable liners. As such, no interaction between CCR waters and either surface water or groundwater is anticipated. There will be no discharge facilities from the BAP, except for a blowdown line to the Unit 3 FGD system to control the water level in the pond and to manage water quality (Sargent & Lundy 2020).

3.3.1 Water Users

Four wells on site at Cardinal are used to supply drinking water to the plant. The well records indicate well depths ranging from approximately 80 to 90 ft below ground surface with all four wells being screened in the glacial outwash.

According to the Jefferson County Water and Sewer District, there are no surface water intakes supplying water to the town of Brilliant, Ohio. Brilliant's water source comes from two groundwater wells located at a water treatment plant approximately three miles northeast of the BAP (Geosyntec 2016).

4.0 Required Isolation from Uppermost Aquifer

According to 40 CFR 257.60 of the CCR Rule, "new CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must be constructed with a base that is located no less than 1.52 meters (five feet) above the upper limit of the uppermost aquifer, or must demonstrate that there will not be an intermittent, recurring, or sustained hydraulic connection between any portion of the base of the CCR unit and the uppermost aquifer due to normal fluctuations in groundwater elevations (including the seasonal high water table)".

4.1 Aquifer Description and Piezometric Analysis

The unconsolidated material beneath the BAP consists of three distinct lithologies (Cox-Colvin 2022):

1. Fill materials. These are approximately 10-20 feet in thickness.
2. An alluvium unit consisting of silt, clay, and sand deposited by the Ohio River floodwaters that is approximately 10-20 feet in thickness.
3. A unit of glacial outwash and alluvial deposits of sand and gravel that is approximately 5- 50 feet in thickness.

The unconsolidated materials extend to the bedrock surface approximately 50-75 feet below the BAP. Bedrock is shallower on the western side of the BAP (nearer the hillside) and deeper on the eastern side of the BAP (nearer the Ohio River). Bedrock consists of interbedded shale, sandstone, coal, and limestone of the Pennsylvanian Age Conemaugh Formation.

The glacial outwash materials form the uppermost aquifer beneath the BAP. The alluvium silt and clay material overlying the sand and gravel outwash materials is also saturated and in hydraulic connection with the outwash; however, usable quantities of groundwater would be obtained from the underlying sand and gravel materials that have much higher hydraulic conductivity and not the low-yielding silts and clays. The alluvial silt and clay material is, therefore, not part of the uppermost aquifer. The highest observed elevation of the uppermost aquifer materials (sand and gravel) in monitor wells surrounding the BAP was 637.1 ft.

Potentiometric elevations at monitor wells in the aquifer from June 2016 through August 2021 ranged from 643.11 to 645.86 ft. The seasonal high-water table is not expected to be higher than 645.86 ft.

4.2 Compliance

A topographical as-built survey of final grade (top of native soils plus additional sand material to strengthen the floor) prior to liner installation showed a minimum elevation of 652.90 ft (Hull 2021). This is 15.8 ft above the top of the uppermost aquifer (637.1 ft) and 7.0 ft above the seasonal high-water table (645.86 ft). As such, the BAP at the Cardinal Plant meets the location restriction requirement for placement and isolation above the uppermost aquifer and complies with 40 CFR 257.60.

Furthermore, installation of both a geosynthetic clay liner (GCL) and an HDPE geomembrane will prevent sustained hydraulic connection between any portion of the base the base of the CCR unit and the uppermost aquifer unit, as does the 10-20 feet of natural alluvial silt and clay materials beneath the CCR unit and overlying the sand and gravel aquifer.

5.0 Wetlands Impact

According to 40 CFR 257.61 of the CCR Rule, "New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located in wetlands, as defined in §232.2 of this chapter, unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section that the CCR unit meets the requirements of paragraphs (a)(1) through (5) of this section."

5.1 Review of Local Wetlands

Cox-Colvin reviewed the United States Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI) data to determine whether the BAP is located on a wetland.

The USFWS wetland mapping data (USFWS 2021) near the BAP is provided in Appendix A. Possible wetland areas shown on the map were established qualitatively by USFWS analysts using 1 meter (or less) digital color infrared aerial photography from 2007. Field characterization of hydrological and vegetative conditions of potential wetland areas at the Property has not been conducted by USFWS. As such, the map is better interpreted as an indicator of where wetland conditions may be present.

The NWI map depicts the BAP as a "Freshwater Pond". However, the BAP pond, along with a second pond immediately to the north (North Pond), are not Freshwater Ponds but impounded plant treatment ponds and are, therefore, not wetlands. There are no other wetlands shown on the NWI map that are encroaching on the footprint of the BAP.

5.2 Compliance

The BAP is not located in a wetland and is, therefore, compliant with 40 CFR 257.61 of the CCR Rule.

6.0 Fault Areas

According to 40 CFR 257.62 of the CCR Rule, "New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located within 60 meters (200 feet) of the outermost damage zone of a fault that has had displacement in Holocene time unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section that an alternative setback distance of less than 60 meters (200 feet) will prevent damage to the structural integrity of the CCR unit."

6.1 Regional Geologic Structural Features and Tectonic Setting

The following information was reviewed with respect to faults near the BAP:

- According to Ohio EPA policy DSIWM-27-20-128 (2004), "Earthquakes 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. These zones are characterized by deeply buried and poorly known faults. To date, no fault in Ohio has exhibited evidence of movement during Holocene time."
- According to the ODNR, "Ohio earthquakes are shallow-focus events, that is, they occur in the upper portion of the crust at depths of about 3 to 6 miles, in crystalline (igneous and metamorphic) rocks of Precambrian age. Precambrian rocks are nowhere exposed in the state and lie beneath Paleozoic sedimentary rocks at depths of about 2,500 feet in western Ohio to more than 12,000 feet in southeastern Ohio" (Hansen and Fox 2020). Based on this, any unidentified fault lines beneath the site are likely to be located at depths much greater than 60 m (200 feet).
- The United States Geological Survey (USGS) seismic hazard program includes maps depicting faults during the Holocene epoch (about the last 10,000 years). This data is shown on Appendix B[2] and indicates that no fault zones exist at the Cardinal Site (USGS 2021a).

6.2 Compliance

Based on a review of the available geologic literature within the vicinity of the Cardinal Site, the BAP is not located within 200 feet of the outermost damage zone of a fault that has had displacement in Holocene time. The BAP is, therefore, compliant with 40 CFR 257.62 of the CCR Rule.

[2] Appendix B contains USGS data regarding the Quaternary Period, which is inclusive of both the Pleistocene and Holocene epochs.

7.0 Seismic Impact Zones

According to 40 CFR 257.63 of the CCR Rule, "New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located in seismic impact zones unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section that all structural components including liners, leachate collection and removal systems, and surface water control systems, are designed to resist the maximum horizontal acceleration in lithified earth material for the site."

7.1 Definition and Regional Information

The maximum horizontal acceleration in lithified earth material means the maximum expected horizontal acceleration at the ground surface as depicted on a seismic hazard map, with a 2% probability of exceedance in 50 years.[3] If the peak ground acceleration (PGA) is less than 0.1 g, then the Site is not located in a seismic impact zone.

Seismic zones, which represent areas of the United States with the greatest seismic risk, are mapped by the USGS and readily available for all the United States (USGS 2021b). Based upon the BAP's location at Latitude: 40.235°; Longitude: -80.661°, USGS estimates a PGA of 0.0438 g at bedrock (Appendix C).

7.2 Compliance

The BAP is not in a seismic impact zone because the PGA of 0.0438 g is less than 0.1g. Therefore, the BAP complies with the requirements of 40 CFR 257.63 for seismic impact zones.

[3] The seismic impact zone is based on definitions in 40 CFR 257.53 of the CCR Rule. Per the USGS Unified Hazard Tool website (USGS 2021b), this is equivalent to a Time Horizon of 2,475 years. This is also equivalent to the 10% probability of exceedance in 250 years found in Ohio landfill regulations regarding location restrictions, although those regulations are not applicable to the BAP.

8.0 Unstable Areas

According to 40 CFR 257.64(a) of the CCR Rule, "An existing or new CCR landfill, existing or new CCR surface impoundment, or any lateral expansion of a CCR unit must not be located in an unstable area unless the owner or operator demonstrates by the dates specified in paragraph (d) of this section that recognized and generally accepted good engineering practices have been incorporated into the design of the CCR unit to ensure that the integrity of the structural components of the CCR unit will not be disrupted."

8.1 Definition and Review of Local Conditions

CCR Rule 40 CFR 257.64(b) further states that "The owner or operator must consider all of the following factors, at a minimum, when determining whether an area is unstable:

1. On-site or local soil conditions that may result in significant differential settling;
2. On-site or local geologic or geomorphologic features; and
3. On-site or local human-made features or events (both surface and subsurface)."

Each of these are discussed below.

8.1.1 Presence of Unstable Soil Conditions

Due to low seismicity in the region of Ohio where the plant is located, widespread liquefaction and other unstable soil conditions are not anticipated at the BAP. A Structural Stability Assessment conducted by AEP provided confirmation that the soils on site, consisting of alluvium silt, clay, and fine sand, are non-liquefiable (AEP 2016). In addition, the Stability Assessment investigated the composition of the BAP embankments and dike system and found that they are constructed of various fill materials including hard silty clay and fine gravel, and stiff to very stiff sandy lean clay, respectively (AEP 2014). These materials were determined to be stable as well and are unlikely to be susceptible to liquefaction due to low seismicity on the property. A Structural Stability Assessment, completed by Sargent and Lundy further indicated that the slopes of the dikes are properly protected against surface erosion (Sargent & Lundy 2021a).

A liquefaction potential assessment and liquefaction analysis were not conducted for the BAP as part of BBC&M's 2009 investigation (BBC&M 2009) but was part of their addendum evaluation in 2010 (BBC&M 2010). BBC&M performed a liquefaction screening analysis using the five techniques listed in the Federal Highway GECV No. 3. The screening criteria includes: (1) Geologic Age and Origin, (2) Fines Content and Plasticity Index, (3) Saturation, (4) Depth Below Ground Surface, and (5) Soil Penetration Resistance. BBC&M concluded in their 2010 report that, based on their review of the alluvium and fill soils for the borings drilled in 2009, liquefaction will not occur. Borings drilled in 2015 also indicate that the alluvium and fill are unlikely to be susceptible to liquefaction due to the low seismicity of the region even though there are some loose and medium dense low-fines content sandy soils present in the RCP fill at the south end.

The discussion of soil conditions in this section is intended to demonstrate that the proposed location of the retrofitted BAP is unlikely to contain unstable soils. This location restrictions evaluation does not consider the suitability of previously existing berms and structures in the retrofitted BAP. Those considerations are discussed in the permit to install application (Sargent & Lundy 2020), with additional relevant information available in the 2021 Structural Stability Assessment for Existing Bottom Ash Pond Complex (Sargent & Lundy 2021a).

8.1.2 Presence of Unstable Geomorphologic Features

There are several limestone strata underlying the Cardinal site; however, there are no observed or reported karst features evident. Further, Jefferson County is not located within the area mapped by the ODNR as a potential karst area in Ohio (ODNR 2016). A copy of ODNR's karst map is included in Appendix D.

The Site is located in a region where coal has been historically mined. Information obtained from ODNR (Appendix D) shows that underground abandoned mines are located in the vicinity of the BAP, although none are beneath the BAP (ODNR 2021b).

8.1.3 Presence of On-Site and Local Human Made Features and Events

Human made features near the BAP mostly consist of the BAP pond itself, the recirculation pump house and transport piping. The historical NPDES outfall has since been removed and re-located to the north pond. These features were engineered and permitted for the operation of the wastewater pond; therefore, they are not expected to have an adverse impact on the BAP.

The Cardinal plant units and town of Brilliant are located north of the BAC. Potential drawdown from nearby wells, including any plant wells, is not anticipated to have an adverse effect on the BAP due to the distance to these wells and the high hydraulic conductivity of sand and gravel aquifer materials along the Ohio River.

The BAP is located immediately west of the Ohio River. According to United States Army Corps of Engineers (USACE) records, the Ohio River elevation at this location is controlled by the Pike Island Dam, with a regular pool elevation of 644.0 ft (AEP 2014). Extreme flooding of the river may result in flood water along the outside of the perimeter berms. Notes on an AEP plan drawing provide 50-year and 100-year flood elevations for the Ohio River of 664.0 and 666.0 ft, which are both below the top of the embankment elevation of 670 ft (BBC&M 2010).

Slope erosion of the east berm of the BAP along the Ohio River during extreme flooding is possible in areas where rip rap is not present.

8.2 Compliance

Based on the completed analysis, the BAP is not located in an unstable area and is, therefore, compliant with 40 CFR 257.64.

9.0 Findings and Conclusions

Based on this location restrictions evaluation, the location of the BAP is suitable for construction of a CCR Unit in accordance with requirements of CCR Rule 40 CFR 257.60 through 257.64.

10.0 Professional Engineer Certification

The undersigned Professional Engineer registered in the State of Ohio is familiar with the requirements of 40 CFR part 257, subpart D and has visited and examined the facility. The undersigned Registered Engineer attests that the BAP is in compliance with the minimum location restrictions of 40 CFR 257.60 to 257.64, to the best of his knowledge and as documented in Sections 4.0 through 8.0 of this report.

This certification in no way relives the owner or operator of the facility of his duty to fully implement other relevant provisions of 40 CFR 257 subpart D.

Nick M. Petruzzi, PE, CPG
Principal Engineer
Registration No. E-73052 (Ohio)
Cox-Colvin & Associates, Inc.

1/3/22
Date

11.0 References

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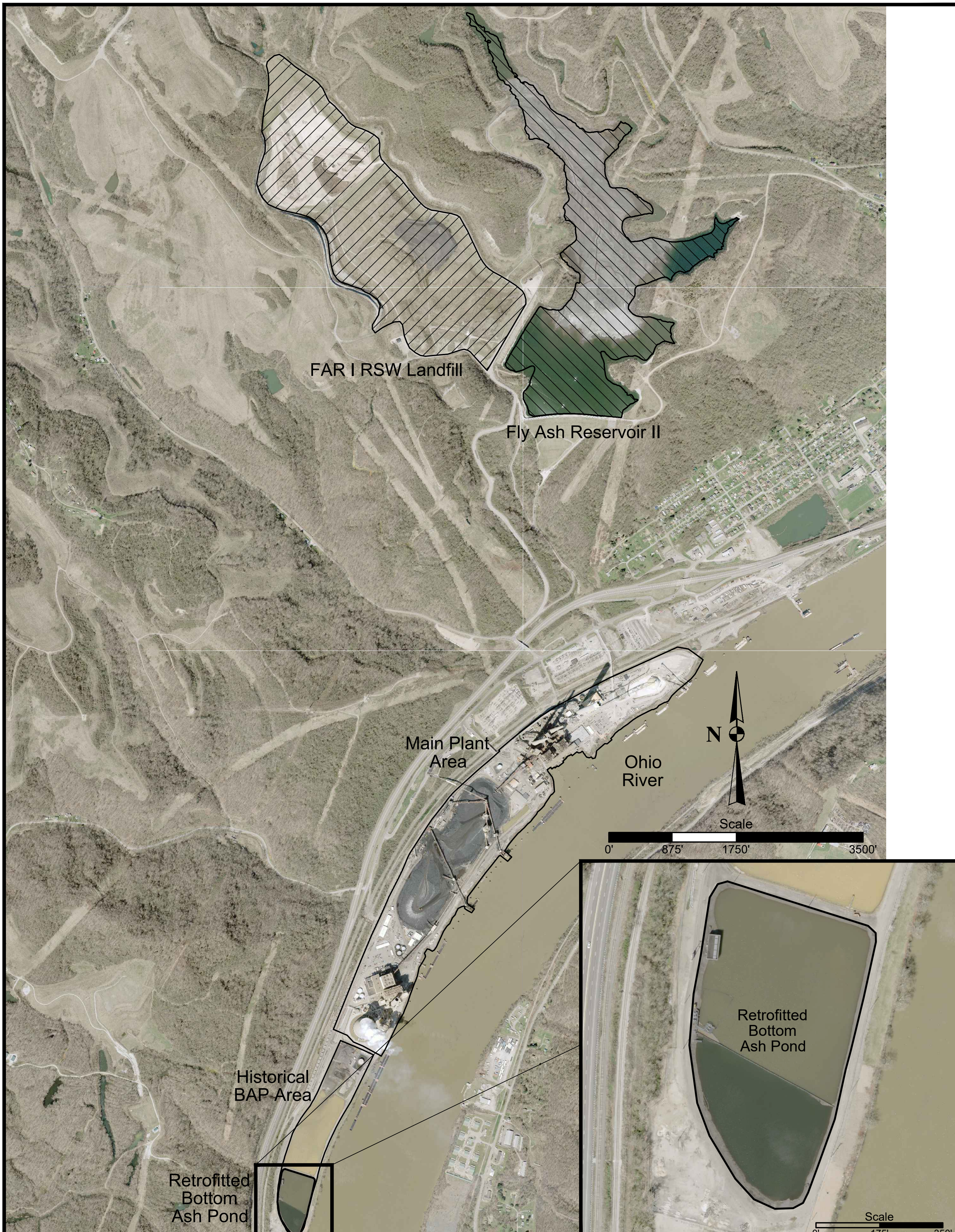
Figure

Figure



Cox-Colvin & ASSOCIATES, INC. ENVIRONMENTAL SERVICES

Facility Layout,
Cardinal Power Plant,
Brilliant, Ohio

Figure 1-1

DATE: 10/28/2021

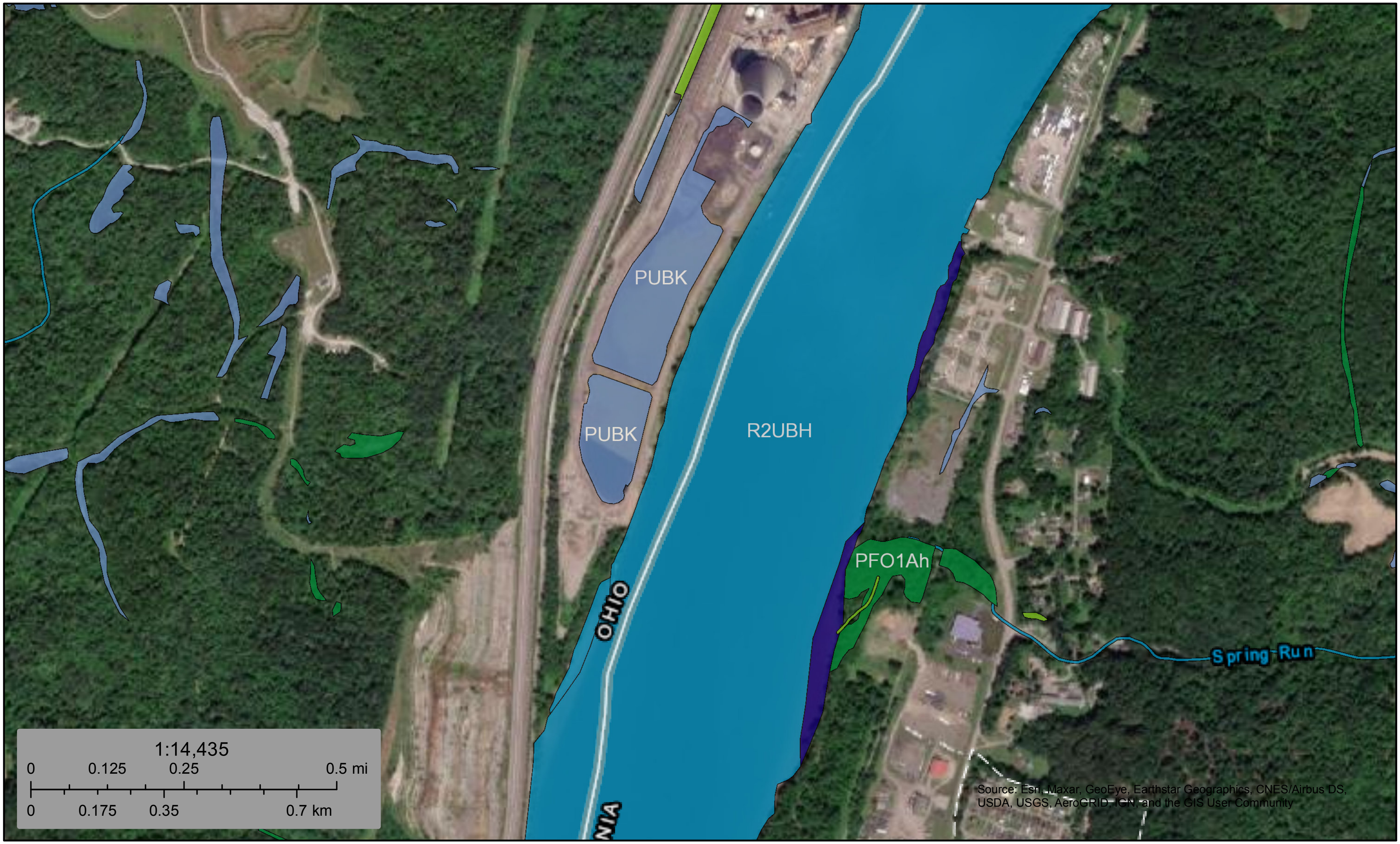
DWG NAME: Sitemap 3753

Appendix A

Wetlands

U.S. Fish and Wildlife Service
National Wetlands Inventory

BAP, Cardinal Plant, Brilliant, Ohio



October 29, 2021

Wetlands

- Estuarine and Marine Deepwater
- Estuarine and Marine Wetland
- Freshwater Emergent Wetland
- Freshwater Forested/Shrub Wetland
- Freshwater Pond
- Lake
- Other
- Riverine

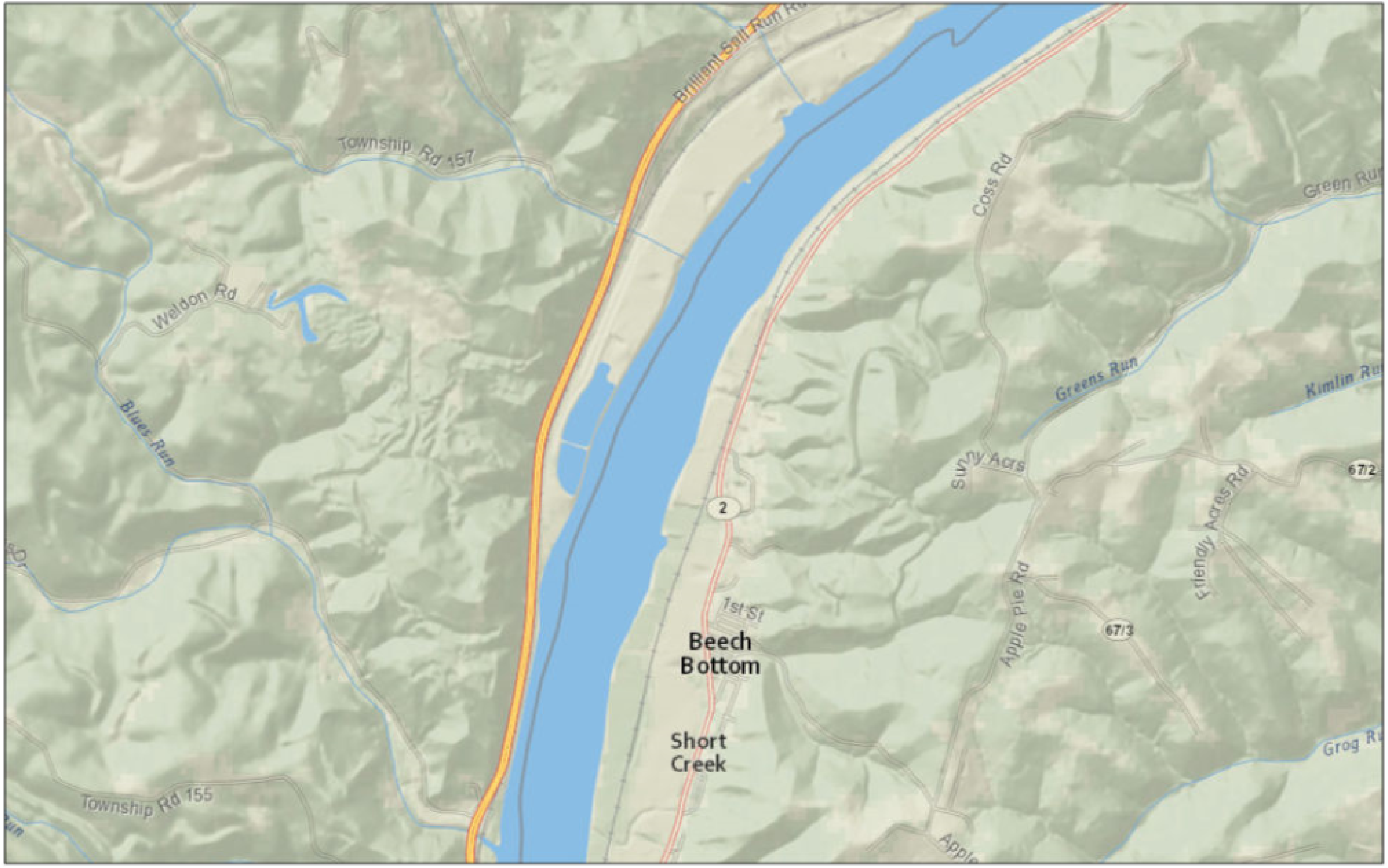
This map is for general reference only. The US Fish and Wildlife Service is not responsible for the accuracy or currentness of the base data shown on this map. All wetlands related data should be used in accordance with the layer metadata found on the Wetlands Mapper web site.

National Wetlands Inventory (NWI)
This page was produced by the NWI mapper

Appendix B

Fault Areas

U.S. Geological Survey Quaternary Faults



10/29/2021, 1:24:16 PM

Fault Areas
- Class B
- historic
- late Quaternary
- latest Quaternary
- middle and late Quaternary

National Database
- Historic (< 150 years), well constrained location
- Historic (< 150 years), moderately constrained location

1:36,112

0 0.23 0.45 0.9 mi

0 0.38 0.75 1.5 km

National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, USGS

National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp. | USGS |

Appendix C

Seismic Impact Zones

Appendix C

U.S. Geological Survey - Earthquake Hazards Program

Unified Hazard Tool

Please do not use this tool to obtain ground motion parameter values for the design code reference documents covered by the U.S. Seismic Design Maps web tools (e.g., the International Building Code and the ASCE 7 or 41 Standard). The values returned by the two applications are not identical.

Input

Edition

Conterminous U.S. 2014 (v4.0.x)

Spectral Period

Peak Ground Acceleration

Latitude

Decimal degrees

40.235

Time Horizon

Return period in years

2475

Longitude

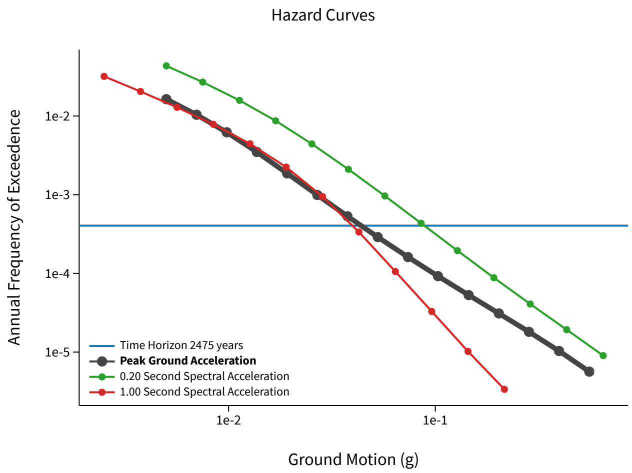
Decimal degrees, negative values for western longitudes

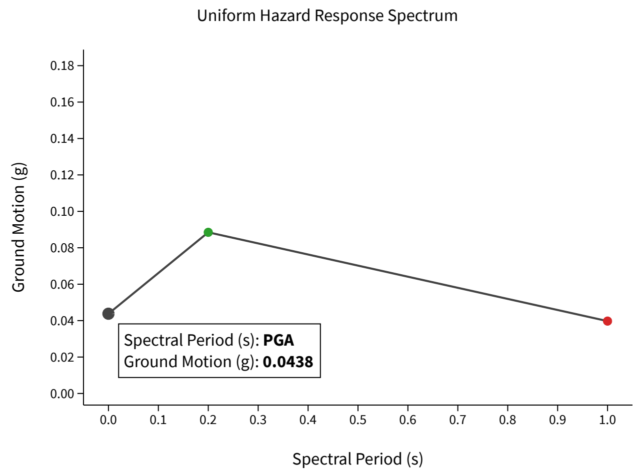
-80.661

Site Class

760 m/s (B/C boundary)

Hazard Curve



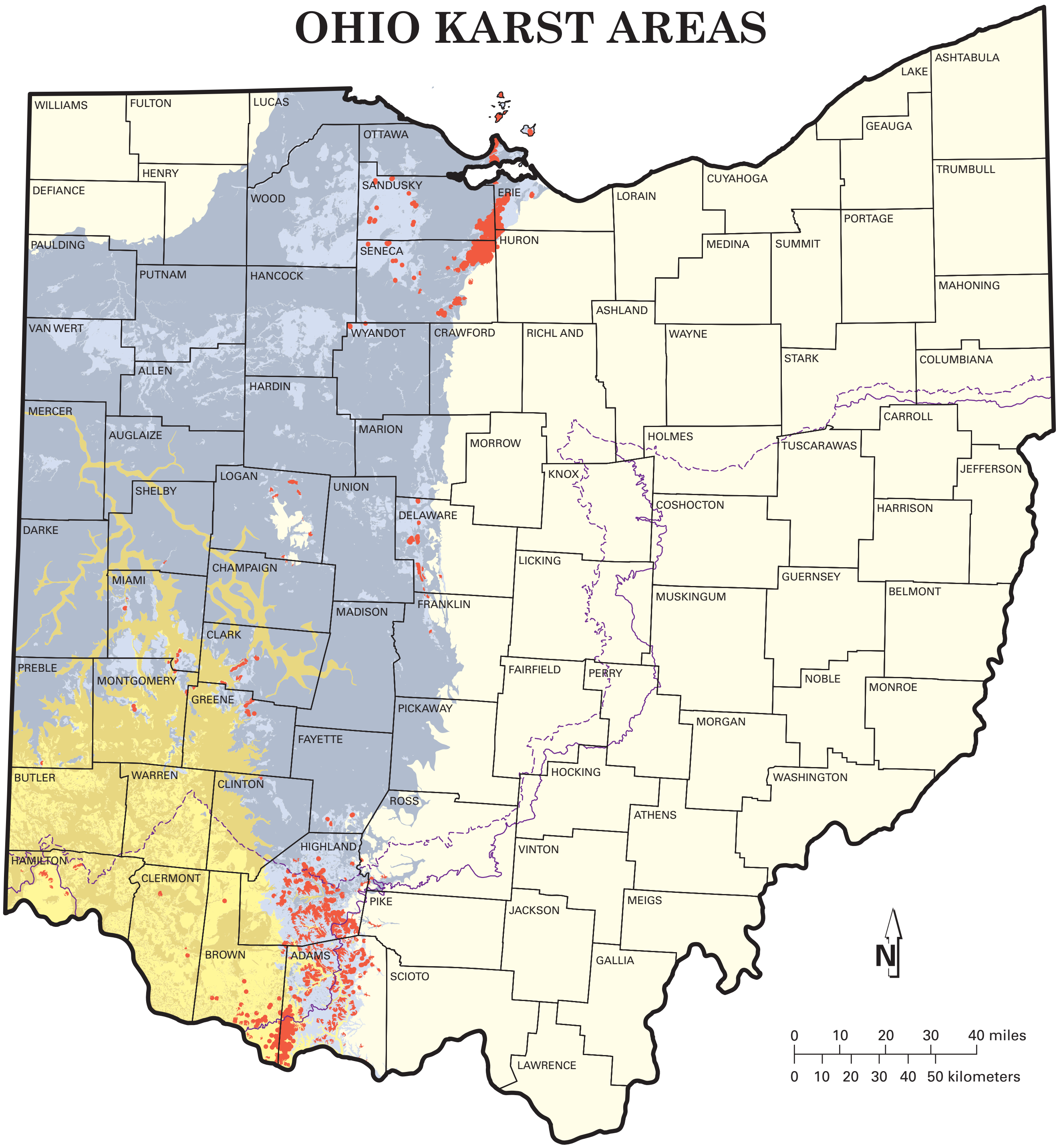


[View Raw Data]

Appendix D

Unstable Areas

OHIO KARST AREAS



EXPLANATION

- Silurian- and Devonian-age carbonate bedrock overlain by less than 20 feet of glacial drift and/or alluvium
- Silurian- and Devonian-age carbonate bedrock overlain by more than 20 feet of glacial drift and/or alluvium
- Interbedded Ordovician-age limestone and shale overlain by less than 20 feet of glacial drift and/or alluvium
- Interbedded Ordovician-age limestone and shale overlain by more than 20 feet of glacial drift and/or alluvium
- Probable karst areas
- Area not known to contain karst features
- Wisconsinan Glacial Margin
- Illinoian Glacial Margin

Recommended citation: Ohio Division of Geological Survey, 1999 (rev. 2002, 2006), Known and probable karst in Ohio: Ohio Department of Natural Resources, Division of Geological Survey Map EG-1, generalized page-size version with text, 2 p., scale 1:2,000,000.

OHIO KARST AREAS

Karst is a landform that develops on or in limestone, dolomite, or gypsum by dissolution and that is characterized by the presence of characteristic features such as sinkholes, underground (or internal) drainage through solution-enlarged fractures (joints), and caves. While karst landforms and features are commonly striking in appearance and host to some of Ohio's rarest fauna, they also can be a significant geologic hazard. Sudden collapse of an underground cavern or opening of a sinkhole can cause surface subsidence that can severely damage or destroy any overlying structure such as a building, bridge, or highway. Improperly backfilled sinkholes are prone to both gradual and sudden subsidence, and similarly threaten overlying structures. Sewage, animal wastes, and agricultural, industrial, and ice-control chemicals entering sinkholes as surface drainage are conducted directly and quickly into the ground-water system, thereby posing a severe threat to potable water supplies. Because of such risks, many of the nation's state geological surveys, and the U.S. Geological Survey, are actively mapping and characterizing the nation's karst regions.

The five most significant Ohio karst regions are described below.

BELLEVUE-CASTALIA KARST PLAIN

The Bellevue-Castalia Karst Plain occupies portions of northeastern Seneca County, northwestern Huron County, southeastern Sandusky County, and western Erie County. Adjacent karst terrain in portions of Ottawa County, including the Marblehead Peninsula, Catawba Island, and the Bass Islands, is related in geologic origin to the Bellevue-Castalia Karst Plain. The area is underlain by up to 175 feet of Devonian carbonates (Delaware Limestone, Columbus Limestone, Lucas Dolomite, and Amherstburg Dolomite) overlying Silurian dolomite, anhydrite, and gypsum of the Bass Islands Dolomite and Salina Group.

The Bellevue-Castalia Karst Plain is believed to contain more sinkholes than any of Ohio's other karst regions. Huge, irregularly shaped, closed depressions up to 270 acres in size and commonly enclosing smaller, circular-closed depressions 5 to 80 feet in diameter pockmark the land between the village of Flat Rock in northeastern Seneca County and Castalia in western Erie County. Surface drainage on the plain is very limited, and many of the streams which are present disappear into sinkholes called swallow holes.

Karst in the Bellevue-Castalia and Lake Erie islands region is due to collapse of overlying carbonate rocks into voids created by the dissolution and removal of underlying gypsum beds. According to Verber and Stansbery (1953, Ohio Journal of Science), ground water is introduced into Salina Group anhydrite ($CaSO_4$) through pores and fractures in the overlying carbonates. The anhydrite chemically reacts with the water to form gypsum ($CaSO_4 \cdot 2H_2O$), undergoing a 33 to 62 percent increase in volume in the process. This swelling lifts overlying strata, thereby opening fractures and creating massive passageways for conduction of greater volumes of ground water through the Silurian Bass Islands Dolomite and into underlying Salina Group strata. Gypsum, being readily soluble in water, is dissolved, creating huge voids. Overlying carbonates then collapse or break down, leaving surface depressions similar to those resulting from roof failure of an underground mine.

DISSECTED NIAGARA ESCARPMENT

The dissected Niagara Escarpment of southwestern Ohio includes the largest single area of karst terrain in the state and the greatest number of surveyed caves. It also is estimated to include the second-largest number of sinkholes in the state. The area is underlain by Silurian rocks of the Peebles Dolomite, Lilley Formation, Bisher Formation, Estill Shale, and Noland Formation in Adams, Highland, and Clinton Counties and the Cedarville Dolomite, Springfield Dolomite, Euphemia Dolomite, Massie Shale, Laurel Dolomite, Osgood Shale, and Dayton Formation in Greene, Clark, Miami, Montgomery, and Preble Counties. The Peebles-Lilley-Bisher sequence and the Cedarville-Springfield-Euphemia sequence constitute the Lockport Group.

Most karst features along the Niagara Escarpment in southwestern Ohio are developed in Lockport Group strata. More than 100 sinkholes and caves developed in the Lockport have been documented in the field, and more than 1,000 probable sinkholes in the Lockport have been identified on aerial photographs, soils maps, and topographic maps. As with most karst terrain, sinkholes developed on the Niagara Escarpment commonly show linear orientations aligned with prevailing joint trends in the area. The greatest concentration of sinkholes on the escarpment is south of the Wisconsinan glacial border in southern Highland and Adams Counties, where highly dissected ridges capped by Silurian carbonate rocks rise 150 to 200 feet above surrounding drainage. Illinoian till in these areas is thin to absent, and soils are completely leached with respect to calcium and calcium-magnesium carbonate. Such geologic settings are ideal for active karst processes, as downward-percolating, naturally acidic rain water is not buffered until it has dissolved some of the underlying carbonate bedrock. Other significant karst features of the Niagara Escarpment include small caves in escarpment re-entrants created by the valleys of the Great Miami and Stillwater Rivers in Miami County.

BELLEFONTAINE OUTLIER

The Bellefontaine Outlier in Logan and northern Champaign Counties is an erosionally resistant "island" of Devonian carbonates capped by Ohio Shale and surrounded by a "sea" of Silurian strata. Though completely glaciated, the outlier was such an impediment to Ice Age glaciers that it repeatedly separated advancing ice sheets into two glacial lobes—the Miami Lobe on the west and the Scioto Lobe on the east. Most Ohioans recognize the outlier as the location of Campbell Hill—the highest point in the state at an elevation of 1,549 feet above mean sea level.

Although it is not known for having an especially well-developed karst terrain, the outlier is the location of Ohio's largest known cave, Ohio Caverns. The greatest sinkhole concentrations are present in McArthur and Rushcreek Townships of Logan County, where the density of sinkholes in some areas approaches 30 per square mile. Sinkholes here typically occur in upland areas of Devonian Lucas Dolomite or Columbus Limestone that are 30 to 50 feet or more above surrounding drainage and are covered by less than 20 feet of glacial drift and/or Ohio Shale.

SCIOTO AND OLENTANGY RIVER GORGES

The uplands adjacent to the gorges of the Scioto and Olentangy Rivers in northern Franklin and southern Delaware Counties include areas of well-developed, active karst terrain. These uplands also are among the most rapidly developing areas of the state, which means karst should be a consideration in site assessments for commercial and residential construction projects.

The Scioto River in this area has been incised to a depth of 50 to 100 feet into underlying bedrock, creating a shallow gorge. The floor, walls, and adjacent uplands of the gorge consist of Devonian Delaware and Columbus Limestones mantled by up to 20 feet of Wisconsinan till. Sinkhole concentrations up to 1 sinkhole per acre are not uncommon in Concord, Scioto, and Radnor Townships of Delaware County. The sinkholes range in diameter from about 10 to 100 feet and commonly are aligned linearly along major joint systems.

The Olentangy River is approximately 5 miles east of the Scioto River in southern Delaware County and occupies a gorge that is narrower and up to 50 feet deeper than the Scioto River gorge. The floor and the lower half of the walls along the Olentangy gorge are composed of Delaware and Columbus Limestones, the upper half of the walls is composed of Devonian Ohio and Olentangy Shales mantled by a thin veneer of glacial drift. Karst terrain has developed along portions of the gorge in a manner similar to karst terrain along the Scioto River.

ORDOVICIAN UPLANDS

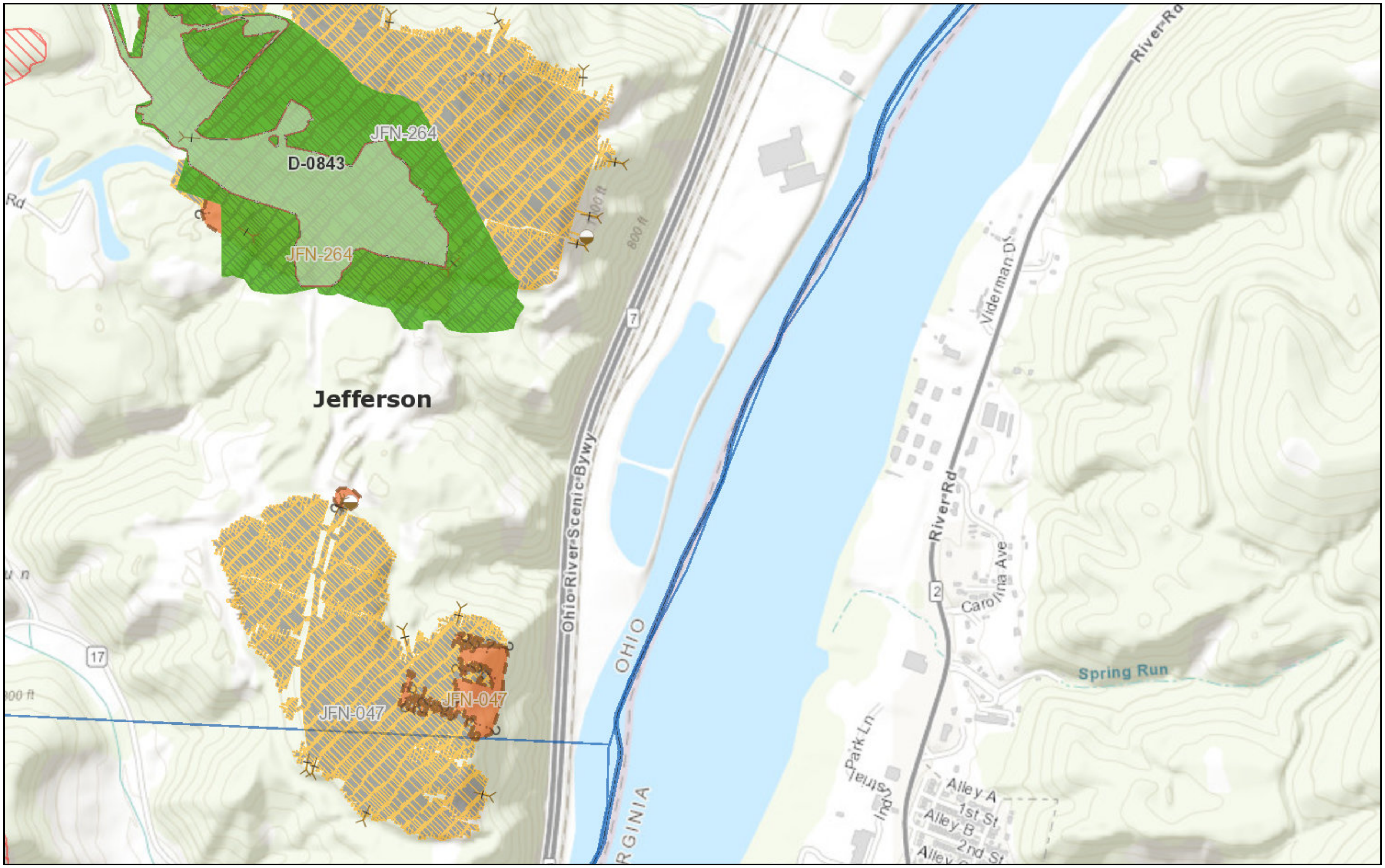
The Ordovician uplands of southwestern Ohio are the location of surprisingly well-developed karst terrain despite the large component of shale in local bedrock. Numerous sinkholes are present in Ordovician rocks of Adams, Brown, Clermont, and Hamilton Counties.

The carbonate-rich members of the Grant Lake Formation (Bellevue and Mount Auburn), Grant Lake Limestone (Bellevue and Straight Creek), and the upper portion of the Arnheim formation are the Ordovician units most prone to karstification; however, the shale-rich (70 percent shale, 30 percent limestone) Waynesville Formation also has been subjected to a surprising amount of karst development in southeastern Brown and southwestern Adams Counties, just north of the Ohio River.

ACKNOWLEDGMENT

The Division of Geological Survey gratefully acknowledges the Ohio Low-Level Radioactive-Waste Facility Development Authority for its financial support for mapping Ohio karst terrain.

BAP, Cardinal Plant, Brilliant ,Ohio



October 29, 2021

Current
- Air Shaft
- Drift Entry
- Vertical Mine Shaft
- Slope Entry

Past
- Air Shaft
- Drift Entry
- Vertical Mine Shaft
- Slope Entry
- Locations

1:18,056

0 0.15 0.3 0.6 mi

0 0.25 0.5 1 km

Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri

Ohio Dept. of Natural Resources