GOLDER

REPORT

Location Restrictions Demonstration - Bottom Ash Landfill

Great River Energy - Stanton Station

Submitted to:

Great River Energy
Coal Creek Station
2875 Third Street SW
Underwood, North Dakota 58576

Submitted by:

Golder Associates Inc.
44 Union Boulevard, Suite 300 Lakewood, Colorado, USA 80228

+1 303 980-0540

1894194

October 16, 2018

Table of Contents

FIGURES

APPENDICES

1.0 INTRODUCTION

This report presents documentation and certification of the Location Restrictions Demonstration for the Bottom Ash CCR Landfill (Bottom Ash Landfill) at Great River Energy's (GRE) Stanton Station. The Bottom Ash Landfill is an existing coal combustion residuals (CCR) landfill. This report addresses the requirements of the United States Environmental Protection Agency's (EPA's) CCR rule (40 CFR 257.64, (EPA, 2015)). The location restrictions as defined in the CCR rule are summarized in the following sections.

1.1 Site Background

GRE's Stanton Station was a coal-fired power plant located in Mercer County, North Dakota, approximately three miles southeast of the city of Stanton along the Missouri River. Stanton Station began generating power in 1966 and ceased power production in February 2017. CCRs are managed in composite-lined surface water impoundment cells and dry waste facilities regulated and permitted by the North Dakota Department of Health (NDDH) in accordance with North Dakota Administrative Code (NDAC) Article 33-20, Solid Waste Management and Land Protection.

Stanton Station has two CCR facilities that are within the purview of the EPA CCR rule (Figure 1):

- Bottom Ash CCR Landfill (Bottom Ash Landfill) - The Bottom Ash Landfill is located south of the plant site and west of the Bottom Ash Impoundment.
- Bottom Ash CCR Surface Impoundment (Bottom Ash Impoundment) - The Bottom Ash Impoundment is located south of the plant site and east of the Bottom Ash Landfill and consists of three interconnected cells designated the north, center, and south cells.

2.0 LOCATION RESTRICTIONS

Per the CCR rule definitions, the Bottom Ash Landfill is considered an existing CCR landfill and is subject only to the Unstable Areas location restriction requirement (40 CFR 257.64).

3.0 UNSTABLE AREAS

Per 40 CFR 257.64, new and existing CCR landfills, new and existing CCR surface impoundments, and all lateral expansions must not be located in unstable areas, unless a demonstration can be made that shows the structural components of the unit will not be disrupted. The rule defines an unstable area as a location that is susceptible to natural or human-induced events or forces capable of impairing the integrity of some or all of the structural components responsible for preventing releases from a CCR unit. Unstable areas can include poor foundation conditions, areas susceptible to mass movements, and karst terrains. Per the rule, structural components are any component used in the construction and operation of the unit that is necessary to ensure the integrity of the unit and to prevent a release, and can include liners, leachate collection systems, embankments, spillways, outlets, final covers, and inflow design flood control systems.

Per the rule, the following factors were considered in determining whether the facilities have been located within unstable areas:

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

Potential indications of unstable areas are evaluated during the annual visual inspections required to satisfy 40 CFR Part 257.84. These inspections are specifically meant to assess hydraulic structures, upstream and downstream slopes, berm crests, and the toe of the facility to look for signs of structural weakness, differential settlement, or other conditions that could affect stability. No evidence of differential settlement or other indications of unstable areas has been observed at the facility during the annual inspections performed in 2015, 2016, 2017, and 2018 (Golder, 2016) (Golder, 2017) (Golder, 2018)(2018 inspection report not yet issued).

3.1 Soil Conditions

The Bottom Ash Landfill is constructed in Missouri River alluvial deposits. The alluvial deposits have two distinct subunits: upper and lower. The upper subunit consists of a silty sand and clay and the lower subunit is an outwash sand and gravel (Barr, 2011).

The foundation soils of the Bottom Ash Landfill consist of native soils (silty sand and clay) and some clay fill. Based on historic site information of CCRs and native soils as well as site observations and geotechnical testing, the site conditions do not indicate that the facility is located in an unstable area susceptible to significant differential settlement. Additionally, the site facilities are routinely inspected for both state and federal regulatory requirements. The facility will continue to be inspected per state and federal regulatory requirements, and signs of significant differential settlement will be documented and corrected as needed.

3.2 Geologic and Geomorphologic Features

Regional geology of the area surrounding Stanton Station is documented in the *Hydrogeologic Assessment Report, Stanton Station Ash Ponds* (Braun Intertec, 1993). Physiographically, Stanton Station is located in the Missouri Slope District of the Glaciated Missouri Plateau Section of the Great Plains Province (Braun Intertec, 1993) (NDDH, 2005). Subsurface and surficial stratigraphy of Mercer County and the adjacent Oliver County were reviewed in depth by C.G. Carlson for the North Dakota Geological Society (Carlson, 1973). Primary near-surface stratigraphic units in the area of Stanton Station include the Tongue River Formation and Cannonball Formation, with named lignite beds prominent in the vicinity of the site.

Near-surface geology at Stanton Station consists of two primary geologic units: the upper alluvial terrace deposits of the Missouri River, and underlying sediments and bedrock belonging to the Bullion Creek Formation, each of which have varying extents and thicknesses across the site (Braun Intertec, 1993). Karst is not known to exist at Stanton Station based on USGS information (USGS, 2004) or site historical information from site borings and test pits (see Figure 2).

3.3 Human-Made Features

No prior mining is known to have occurred within the footprint of the facility, or adjacent to the facility, that would undermine the stability of the facility.

No significant fills, excavations, or structures are present adjacent to the facilities.

The Bottom Ash Landfill is not located in an unstable area caused by human-made features.

3.4 Safety Factor Assessment

Slope stability was evaluated for the Bottom Ash Landfill by performing a safety factor assessment (Appendix A). Factors of safety were computed for circular failure surfaces using Spencer's method for force and moment equilibrium. Non-circular analyses were not performed since no critical interfaces were defined. Global stability was analyzed, which evaluates the overall stability of a cross section through the entire facility, including underlying foundation materials and perimeter berms (as applicable). Appendix A describes site geometry, material properties, water tables, and phreatic surfaces in more detail.

Results of the factor of safety assessment indicate that the Bottom Ash Landfill is stable for the scenarios modeled, which represent maximum anticipated loading conditions. The factor of safety for circular analysis was computed to be 5.4.

4.0 CERTIFICATION

The undersigned attest to the completeness and accuracy of the above written Location Restrictions Demonstration and certify that the location of the Bottom Ash Landfill at Stanton Station meets the requirements detailed in 40 CFR 257.64 and is not located in an unstable area.

Golder Associates Inc.

Craig Schuettpelz, PE
Senior Project Engineer

Todd Stong, PE
Associate and Senior Consultant

KAC/TJS/ds

https://golderassociates.sharepoint.com/sites/23291g/deliverables/reports/ss_bal_locationdemo_fnl_16oct18/1894194_bal_location_demo_fnl_15oct18.docx

5.0 REFERENCES

Barr. (2011). *2010 Annual Groundwater Monitoring Report, Stanton Station Ash Disposal Facility, NDDH Solid Waste Permit #SP043.*

Braun Intertec. (1993). *Hydrogeologic Assessment Report for Stanton Station.*

Carlson, C. (1973). *Geology of Mercer and Oliver Counties, North Dakota. Bulletin 56 - Part I, for the Norht Dakota Geological Society. County Ground Water Studies 15 - Part I, for the North Dakota State Water Commission.*

EPA. (2015). *Environmental Protection Agency, Code of Federal Regulations Title 40 Part 257: Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities.*

Golder. (2016). *Annual Inspection Report - Great River Energy - Stanton Station - Bottom Ash Landfill.*

Golder. (2017). *Annual Inspection Report - Great River Energy - Stanton Station - Bottom Ash Landfill.*

Golder. (2018). *Annual Inspection Report - Great River Energy - Stanton Station - Bottom Ash Landfill.*

NDDH. (2005). *Permit for a Solid Waste Managment Facility, North Dakota Department of Health - Division of Waste Management Permit No SP-043.*

USGS. (2004). *Digital Engineering Aspects of Karst Map, U.S. Geological Survey, National Atlas of the United States of America.*

FIGURE 1

Stanton Station CCR Facilities

REFERENCES

1. AERIAL IMAGE FROM UNITED STATES DEPARTMENT OF AGRICULTURE NATIONAL AERIAL IMAGERY PROGRAM, PUBLISHED 2017.

CLIENT
GREAT RIVER ENERGY
STANTON STATION
STANTON, NORTH DAKOTA

PROJECT
LOCATION RESTRICTION DEMONSTRATION

CONSULTANT
GOLDER

YYYY-MM-DD	2018-09-13
DESIGNED	KAC
PREPARED	RFS
REVIEWED	CCS
APPROVED	TJS

TITLE
STANTON STATION CCR FACILITIES

PROJECT NO.	REV.	FIGURE
1894194	A	1

Path: \\Denver\acad\GREAT RIVER ENERGY\STANTON\99_PROJECTS\1894194\Groundwater Separation\02_PRODUCTION\DWG\ | File Name: Figure 1.dwg

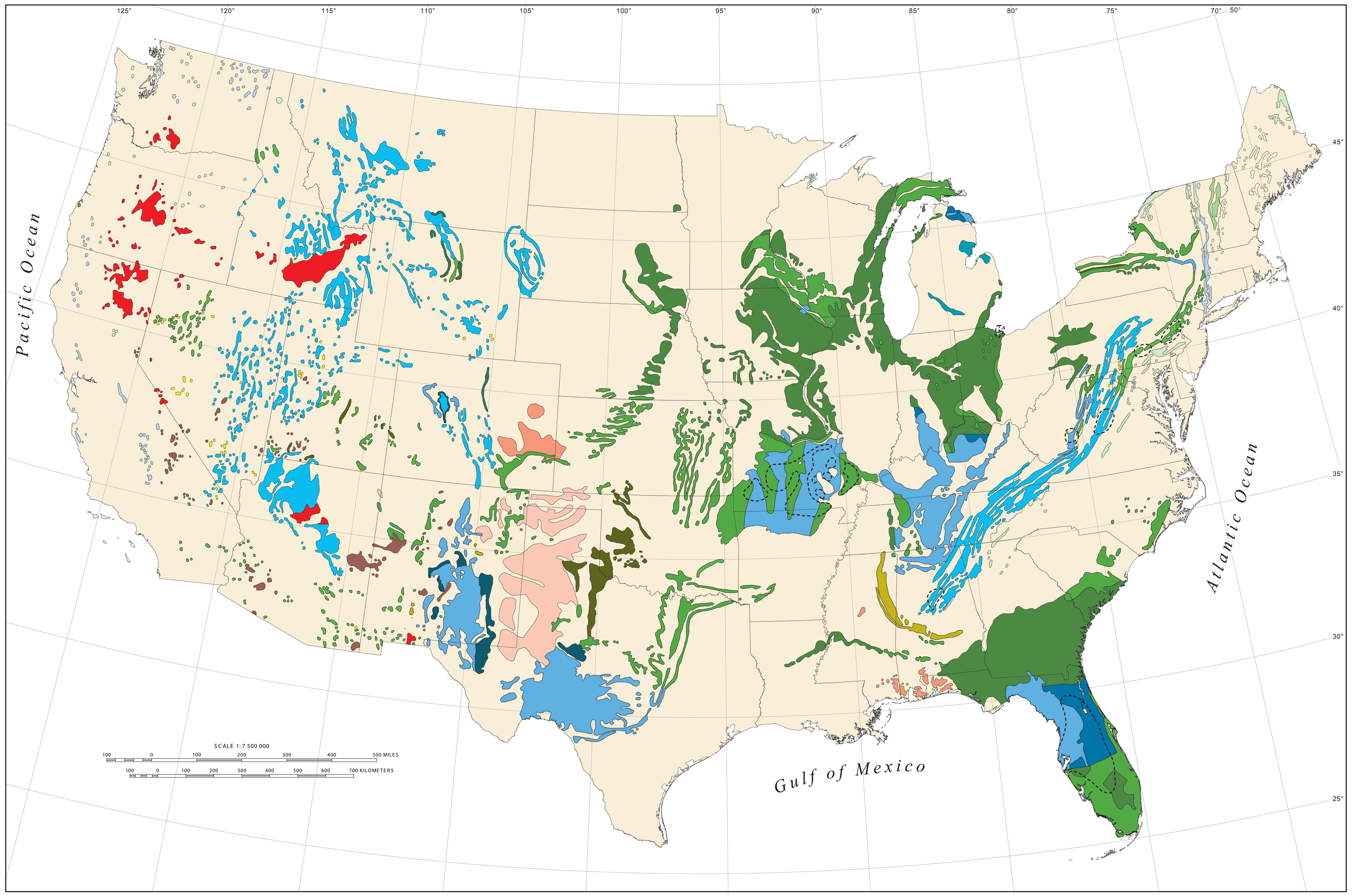
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

1 in

0

FIGURE 2

Digital Engineering Aspects of Karst Map



FISSURES, TUBES, AND CAVES OVER 1,000 FT (300 M) LONG; 50 FT (15 M) TO OVER 250 FT (75 M) VERTICAL EXTENT

- In metamorphosed limestone, dolostone, and marble
- In moderately to steeply dipping beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock beneath an overburden of noncarbonate material 10 ft (3 m) to 200 ft (60 m) thick
- In moderately to steeply dipping beds of gypsum
- In gently dipping to flat-lying beds of gypsum

FISSURES, TUBES, AND CAVES GENERALLY LESS THAN 1,000 FT (300 M) LONG; 50 FT (15 M) OR LESS VERTICAL EXTENT

- In metamorphosed limestone, dolostone, and marble
- In crystalline, highly siliceous intensely folded cabonate rock
- In moderately to steeply dipping carbonate rock
- In gently dipping to flat-lying carbonate rock
- In gently dipping to flat-lying beds of carbonate rock beneath an overburden of noncarbonate material 10 ft (3 m) to 200 ft (60 m) thick
- In moderately to steeply dipping beds of gypsum
- In gently dipping to flat-lying beds of gypsum
- In gently dipping to flat-lying beds of gypsum beneath and overburden of nongypsiferous material 10 ft (3 m) to 200 ft (60 m) thick
- In carbonate zones in highly calcic granite (Alaska only)
- In moderately to steeply dipping beds of carbonate rock with a thin cover of glacial till and frost-derived residual soil (Alaska only)

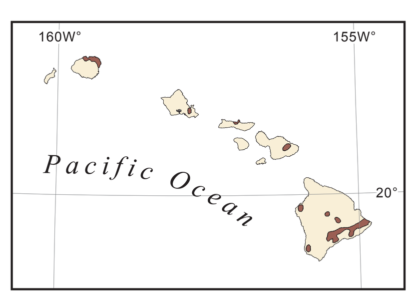
FISSURES, TUBES, AND CAVES GENERALLY ABSENT; WHERE PRESENT IN SMALL ISOLATED AREAS, LESS THAN 50 FT (15 M) LONG; LESS THAN 10 FT (3 M) VERTICAL EXTENT

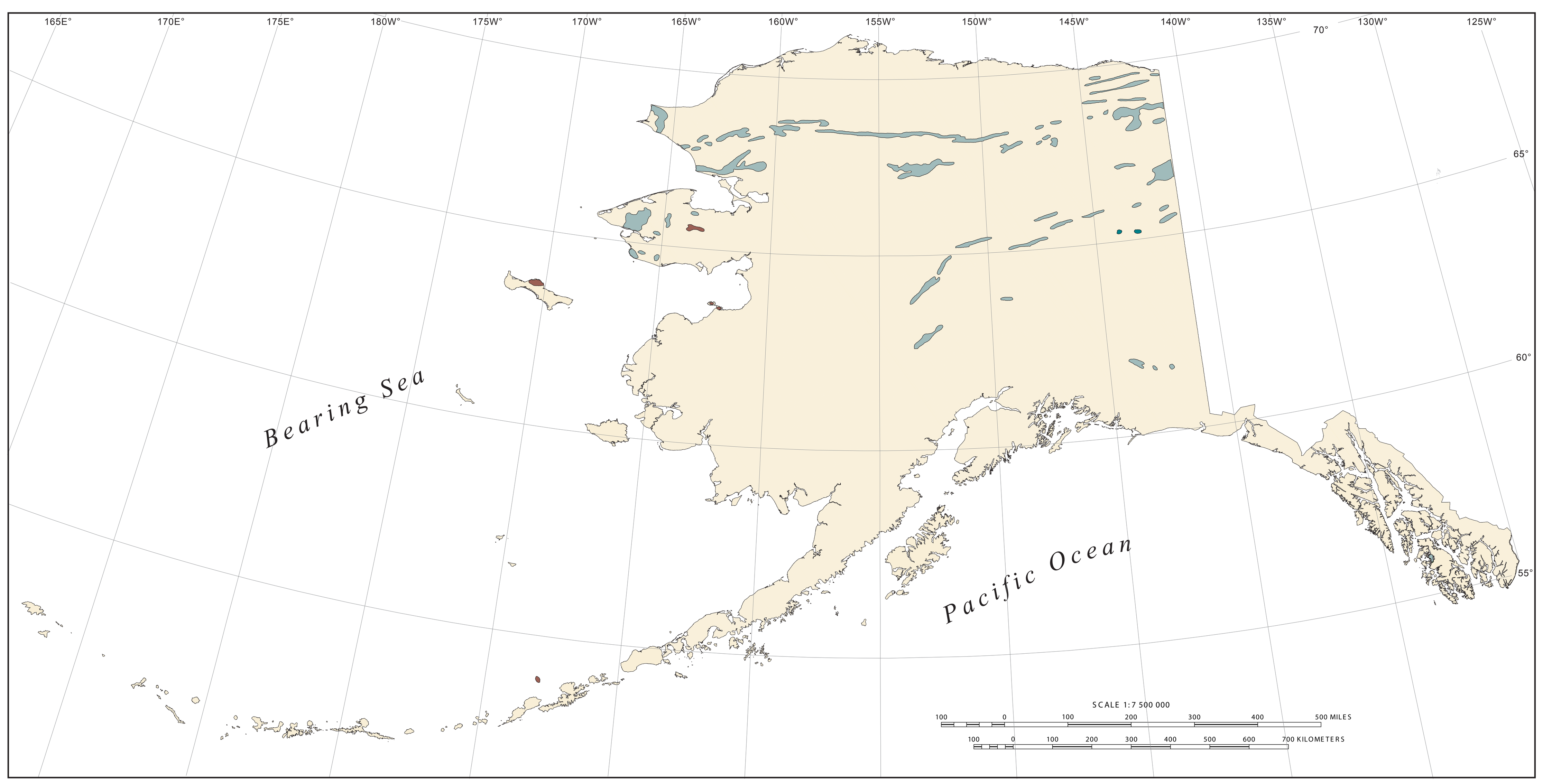
- In crystalline, highly siliceous intensely folded carbonate rock
- In moderately to steeply dipping beds of carbonate rock
- In gently dipping to flat-lying beds of carbonate rock

FEATURES ANALOGOUS TO KARST

- Fissures and voids present to a depth of 250 ft (75 m) or more in areas of subsidence from piping in thick unconsolidated material
- Fissures and voids present to a depth of 50 ft (15 m) in areas of subsidence from piping in thick, unconsolidated material
- Fissures, tubes, and tunnels present to a depth of 250 ft (75 m) or more in lava
- Fissures, tubes, and tunnels present to a depth of 50 ft (15 m) in lava

Areas in which extensive historical susidence has occurred





Albers equal area projection
North American Datum 1983
standard parallels 25°N and 50°N
longitude of central meridian 96°W
latitude of projection origin 37°N

Digital Engineering Aspects of Karst Map : A GIS version of Davies, W.E., Simpson, J.H., Ohlmacher, G.C., Kirk, W.S., and Newton, E.G., 1984, Engineering aspects of karst: U.S. Geological Survey, National Atlas of the United States of America, scale 1:7,500,000

by Bret D. Tobin and David J. Weary

U.S. Geological Survey Open-File Report 2004-1352

Introduction

This data set was converted from a printed map to a digital GIS coverage to provide users with a citable national-scale karst data set to use for graphic and demonstration purposes until new, improved data are developed. These data may be served on the internet or distributed freely with proper citation. Because it has been converted to GIS format, this data can be easily projected, displayed and queried for multiple uses in GIS. The karst polygons of the original map were scanned from the stable base negatives of the original, vectorized, edited, and then attributed with unit descriptions. All of these processes potentially introduce small errors and distortions to the geography. The original map was produced at a scale of 1:7,500,000; this coverage is not as accurate and should be used for broad scale purposes only. It is not intended for any site-specific studies.

The following text is taken verbatim from the original map, which was printed front and back on a single sheet.

ENGINEERING ASPECTS OF KARST

By
William E. Davies

Distinctive surficial and subterranean features developed by solution of carbonate and other rocks and characterized by closed depressions, sinking streams, and cavern openings are commonly referred to as karst. The term was used first to describe the region of Carso in northeastern Italy and northern Yugoslavia, where solution landscape was studied in the 19th century. Originally the term defined surface features derived by solution of carbonate rocks, but subsequent use has broadened the definition to include sulfates, halides, and other soluble rocks. The term has been expanded also to cover interrelated forms derived by solution on the surface in the subsurface. A further expansion of the concept of karst was the introduction of the term "pseudokarst" to designate karstlike terrain produced by processes other than the dissolution of rocks (Burger and Dubertret, 1975). When used in its broadest sense, the term encompasses many surface and subsurface conditions that give rise to problems in engineering geology. Most of these problems pertain to subterranean karst and pseudokarst features that affect foundations, tunnels, reservoir tightness, and diversion of surface drainage. Environmental aspects of karst lead to additional problems in engineering geology, especially in site selection. Subterranean openings may be the habitat of unique and, in some cases, endangered fauna. The openings are also conduits for water and refuse disposal from the surface or, in caves, for pollutants that can be carried for great distances. Many caves contain features of beauty and scientific interest that can be important esthetic factors in site selection for structures, transportation routes, and impoundments.

Although surface features of karst terrain (primarily sinkholes, solution valleys, and solution-sculptured rock ledges) are significant in engineering geology, they have not been included on this map because of the additional complexity that would occur in classification and portrayal.

The systematic study of karst in the United States started with W. M. Davis' (1930) theory on the origin of caves by deep-seated solution. Bretz (1942) obtained data, from studies in flat-lying carbonate rocks in the Midwestern States that supported Davis' theory. After World War II, studies of karst in the United States became widespread beginning with investigations in the Appalachian Mountains. Based on these studies, many of which were in areas of folded rock, older theories were modified with emphasis on maximum solution activity in a zone directly beneath a uniform water table (Davies, 1960). Since 1948, the exploration of caves and studies of landforms in carbonate terrains have produced a vast amount of data on karst. Reports of these explorations and studies have been primary sources in compiling this map on the subterranean aspects of engineering geology of karst and pseudokarst. In addition, published logs of borings were used. Much of the information on the Eastern United States, principally for the Appalachian Mountains and Plateau, is from field observations.

The small scale of the map and the limited data on openings, other than caves, in soluble rocks restrict the use of the map to the most general types of planning and as a guide to areas where subterranean karst and pseudokarst features occur. The map cannot be used either for specific site selection or as a substitute for field examination in planning and site development. Because cartographic license was taken to portray the features at the small scale of this map, enlargement can lead to gross errors in location of the data presented.

Subterranean openings in karst range in size from minute voids to large caverns. Most of the openings are formed by solution processes along fractures, joints, and bedding planes. Caves and related solution features are common in most carbonate and gypsum terrains in the United States, except in the area formerly covered by Pleistocene ice sheets (Davies and LeGrand, 1972). The southward advance of these ice sheets covered New England, New York, northeastern and northwestern Pennsylvania, most of the States bordering the Great Lakes, and much of the area north of the Missouri River. Karst features in the formerly glaciated area are covered by glacial drift, and most caves and fissure openings have been eroded away or filled. The caves and open fissures that remain generally have less than 1,000 ft (300 m) each of passages large enough to be traversed by humans.

South of the formerly glaciated area, caves, open joints, fissures, and other subterranean karst features are present in most soluble rocks. In general, both the number and size of solution features increase inversely with latitude. In addition, the number and size also vary according to the age and structure of the soluble rock in which solution features develop. Solution features in folded rocks are subordinate to those in nondeformed rocks; those in rocks older than Mississippian are subordinate to those in Mississippian and younger rocks. These are broad generalizations, and local exceptions exist. However, these generalizations can be used as a hasty estimate of karst conditions.

Most caves consist of a series of passages on one level. Some caves have multiple levels of passages that extend vertically as much as 300 ft (90 m). The levels are generally connected by shafts or large galleries. Most passages are less than 10 ft (3 m) high and less than 10 ft (3 m) wide. Maximum size of passages is about 100 ft (30 m) in height and width. In many caves, passages expand into galleries or rooms that are 30 to 200 ft (9 to 60 m) long and wide and up to 150 ft (45 m) high. The largest known solution opening in the United States is in Carlsbad Caverns, New Mexico, where a T-shaped room is 1,800 ft (550 m) long in one section, 1,100 ft (330 m) long in the other section, 255 ft (77 m) high, and up to 300 ft (90 m) wide.

Shafts are present in multiple-level caves and in some single-level caves. The deepest shafts are about 1,000 ft (300 m) deep, but in most caves they are less than 300 ft (90 m) deep. Most shafts are 30 ft (10 m) or less wide. In multiple-level caves, shafts connect levels; in other caves, the shafts are pits with no apparent connection at the base. Shafts are irregular in shape; some resemble funnels, and others are shaped like cylinders. Dome pits are cylindrical shafts that develop upward from a passage towards the surface of the Earth. Dome pits are up to 50 ft (15 m) wide and extend upward for as much as 150 ft (45 m). Their walls are uniform. Dome pits are capped by a cover of carbonate rocks 10 to 50 ft (3 to 15 m) thick. In many domes, the caps have collapsed and left vertical-sided open pits.

Virginia, West Virginia, Kentucky, Tennessee, Alabama, Missouri, Texas, and New Mexico contain hundreds of caves, each of which has over a mile of passages. At least one cavern system in each of these States has 10 to more than 100 mi (16 to 160 km) of passages. The largest known system is Flint Ridge-Mammoth Cave in Kentucky (Brucker, 1979), with over 200 mi (320 km) of passageways in an area of 362 mi (902 km).

Solution tubes with openings as much as 1 ft (0.3 m) wide and irregular alignment occupy portions of the carbonate bedrock. In some cases, the tubes connect with caves. However, the tubes generally lack the systematic patterns that are common in development of cavern passages. These tubes apparently predate cavern development. Although most tubes are seldom longer than a few hundred feet, they are interconnected and commonly act as conduits for subsurface drainage. During freezing weather, water from tubes can cause large buildups of ice where excavations intersect the tubes. At other times, the tubes lead to flooding of excavations and leaks in reservoirs and contribute to weakening of retaining walls.

Fissures (also referred to as open joints) up to 1 ft (0.3 m) wide result from limited solution along joints, fractures, and bedding planes. Fissures occur in various attitudes from vertical to gently inclined and generally are in repetitive geometrical patterns or sets. Fissures form systems that may extend for several thousand feet horizontally and over 300 ft (90 m) vertically. Some fissures or parts of fissures are filled with consolidated clay-silt and clay-gravel that seal them. The seals, however, are altered in contact with water and can be removed by running water. Fissures are commonly conduits for subterranean streams. In addition, they can cause serious engineering problems, such as reservoir leakage and instability of cuts, bridge abutments, piers, and dam foundations and abutments.

The depth to which solution openings occur depends on relief in an area, thickness of soluble rock, and geologic structure. The configuration and depth of the water table, in some cases, are controlling factors. Ground water in karst terrain generally is found in existing openings that extend tens to hundreds of feet below the water table. In the mountainous areas of the Western United States, the known vertical extent of solution openings is as much as 1,100 ft (330 m). In the Eastern United States, where relief is less, the vertical extent is generally less than 400 ft (120 m), with a maximum of 650 ft (200 m). Beneath many broad river valleys, solution features in carbonate rocks are present to a depth of about 100 ft (30 m) in both the Eastern and Western United States.

Surface subsidence (sinkhole development) occurs most commonly in areas where ground-water conditions are altered by excessive pumping or by diversion of surface drainage. Subsidence generally involves weathered bedrock and soil that bridge caverns, subterranean galleries, and dome pits. The collapse is caused by loss of support resulting from the reduction of hydrostatic pressure of ground water, by sapping, and by piping. Most subsidence forms shallow, steep-sided depressions up to 100 ft (30 m) wide and up to 20 ft (6 m) deep. However, in Florida and central Alabama, recent subsidence has resulted in nearly vertical sided sinkholes up to 425 ft (130 m) wide and 150 ft (45 m) deep.

Areas of local subsidence caused by mining operations and regional subsidence caused by withdrawal of ground water and petroleum in thick, unconsolidated sediments have not been included on the map of subterranean aspects of engineering geology of karst and pseudokarst because natural processes are involved only in a subordinate way in development of these phenomena. The problems of these types of subsidence are complex, and the areas involved are so extensive that they are best treated as subjects for another map.

In the New England States, solution terrain is confined to crystalline limestones and marbles mainly in northeastern Maine, western Vermont, and western Massachusetts. Solution features in these areas are primarily narrow fissures generally less than 200 ft (60 m) long and less than 30 ft (10 m) deep. A few small caves are known in western Vermont and in the Berkshire Mountains of western Massachusetts. In eastern Vermont and much of Maine, carbonate rocks high in silica and other impurities' are commonly, yet incorrectly, referred to as limestone. Solution features are generally absent in these rocks.

In the Appalachian Highlands, three major groups of carbonate rocks are in the karst regions. The Great Valley, in the eastern part of the Highlands, from southeastern New York to central Alabama, is a lowland up to 26 mi (42 km) wide eroded across dolomite, limestone, and shale of Cambrian and Ordovician age, Regionally, and to some extend reflecting differences in degree of karst development, the Great Valley is designated from north to south as the Kittatinny, Lehigh, Lebanon, Cumberland, Hagerstown, Shenandoah, and Tennessee Valleys. All types of solution features are present in the Great Valley, with small caves and fissures in southeastern New York and like features increasing in size and numbers southward. From central Virginia southward, large caves with over 1 mi (1.6 km) of passages in each are common, and fissures extend hundreds of feet in length and over 100 ft (30 m) in depth. The major geologic units involved in karst development in the Great Valley are the Elbrook (Cambrian), Conococheague (Cambrian-Ordovician), Beekmantown (Ordovician), and their equivalents. All are folded with steep dips, and overturning is common along the east half of the lowland. Faults are numerous and some major fault zones extend over 200 mi (320 km). Active subsidence is prevalent throughout the Great Valley and is a result primarily of alteration of the water table. Generally, the subsidence involves the opening of shallow fissures and shafts up to 10 ft (3 m) in diameter in farmland through removal of soil and thin rock cover over fissures, shallow cavern passages, and small dome pits. More extensive subsidence is in progress in the vicinity of Allentown and Harrisburg, Pennsylvania, where numerous subsidence depressions up to 100 ft (30 m) in diameter have developed. In Staunton, Virginia, active subsidence from collapse of rocks and soil covering shallow caves and fissures was recorded as early as 1911. Subsidence in the Staunton area resulted from large-scale piping of sinkhole soils by leakage from settling basins and from drawdown of the water table. In central Alabama, steep-sided, water-filled sinks, up to 425 ft (130 m) wide and 150 ft (45 m) deep, have formed recently by collapse of weathered limestone and thick soils covering limestone.

In the area west of the Great Valley, a sequence of limestones in the Upper Silurian (Tonoloway) and the Lower Devonian (Helderberg Group) forms subordinate ridges in southeastem New York, central Pennsylvania, eastern West Virginia, and western Virginia. The rock is folded, and dips are steep. Karst features include fissures extending several hundred feet vertically and caves with up to 1 mi (1.6 km) of large passageways. Subsidence is uncommon, but the fissures and caves have caused problems in foundations and abutments of dams, in cuts because of unstable wedges, and in tunnels that encounter earth fills in solution cavities.

Along the western edge of the Valley and Ridge province of the Appalachian Highlands, several large basinlike lowlands underlain by Cambrian and Ordovician carbonate rocks occur. The lowlands are eroded across large anticlines with steep dips on the flanks and moderate to steep plunges along the axes of the anticlines. In the Nittany and Kishacoquillas Valleys of Pennsylvania, and some smaller valleys designated as "coves," numerous caves occur, each with passageways 1,000 to 5,000 ft (300 to 1,5!)0 m) long The passages generally are 100 ft (30 m) or less below the surface. Many act as subterranean feeders that carry runoff from adjacent ridges to a few points of resurgence. The resurgent points are large springs with a daily flow of up to 1 million gallons or more (4 million or more). Fissures are present but seldom exceed 200 ft (60 m) in depth. Subsidence is not common, but deep cuts and excavations are subject to uncontrollable flooding if major subterranean conduits are encountered. In Germany Valley, West Virginia, solution features, primarily multiple-level caves and fissures, extend to depths of 350 ft (105 m) or more. Drainage of most of this valley is by way of one large spring. Subsidence from collapse of sinkholes is common, and potential for subsidence exists over numerous dome pits above caves.

The Appalachian Plateau's province and adjacent parts of the Interior Plains in West Virginia, Kentucky, Tennessee, northern Alabama, and southern Indiana contain the most intensely developed karst areas in the United States. The karstic carbonate rocks are Mississippian in age and include the Greenbrier limestone (West Virginia) and the Golconda, Ste. Genevieve. St. Louis, and Warsaw limestones and their equivalents elsewhere. Caves generally contain 3,000 ft (900 m) or more of passageways. Multiple-level caves are not common, but some large cave systems, such as Flint Ridge-Mammoth Cave in Kentucky and Organ Cave in West Virginia, have a multitude of complex passageways at various elevations that extend in aggregate from 30 to over 200 miles (48 to over 320 km). Dome pits, common in many caves, are areas of potential collapse. Many of the caves are large subterranean drainageways that receive streams flowing from adjacent highlands. Cuts and excavations intersecting these caves are subject to inundation from over 1 million cubic ft (40,000 m^3) of water stored in the subterranean reservoirs. Large sinkholes, up to 1 mi (1.6 km) wide and several hundred feet deep, are so numerous that the rims of many sinkholes intersect the rims of their neighbors. Suitable foundations for large structures are difficult to site. Deep cuts, mines, tunnels, and excavations commonly encounter deeply weathered rock and large volumes of weak soil filling cavern passages and fissures. Seasonal flooding is common from snow melt and from heavy rainfall that exceeds the infiltration capacity of sinkholes and the capacity of subterranean channels to carry the runoff. Subsidence in most of the area is not extensive except above the dome pits and along karst valleys in southern Indiana and in the Mammoth Cave plateau in Kentucky.

In the Southeastern United States, karst is extensive on the Coastal Plain in southern Alabama, Georgia, and Florida. The limestones in the karst area are primarily the Ocala Limestone and Jackson Formation of Eocene age and their equivalents. In the Dougherty Plain of southeastern Alabama and southern Georgia, the limestone has been weathered deeply, and in the southern part of the plain the limestone is covered by a residuum of sandy clay. In the northern part of the plain, only small areas of the limestone remain within the residuum. Subsidence occurs as broad, slowly developing, shallow sinkholes in the residuum. In Florida, subsidence is more extensive. In the northern half of the State, the limestone is covered by younger sand deposits that are locally over 100 ft (30 m) thick. In Polk County, subsidence has resulted in vertical-sided sinkholes up to 150 ft (45 m) deep and 425 ft (130 m) wide. The subsidence has engulfed several houses and resulted in large property losses to homeowners. The subsidence is related to alteration of ground-water levels in caverns and to collapse of the weathered carbonate rock that supports the surface deposits.

In the Southeastern United States, karst is extensive on the Coastal Plain in southern Alabama, Georgia, and Florida. The limestones in the karst area are primarily the Ocala Limestone and Jackson Formation of Eocene age and their equivalents. In the Dougherty Plain of southeastern Alabama and southern Georgia, the limestone has been weathered deeply, and in the southern part of the plain the limestone is covered by a residuum of sandy clay. In the northern part of the plain, only small areas of the limestone remain within the residuum. Subsidence occurs as broad, slowly developing, shallow sinkholes in the residuum. In Florida, subsidence is more extensive. In the northern half of the State, the limestone is covered by younger sand deposits that are locally over 100 ft (30 m) thick. In Polk County, subsidence has resulted in vertical-sided sinkholes up to 150 ft (45 m) deep and 425 ft (130 m) wide. The subsidence has engulfed several houses and resulted in large property losses to homeowners. The subsidence is related to alteration of ground-water levels in caverns and to collapse of the weathered carbonate rock that supports the surface deposits.

Cretaceous carbonate rocks of the Selma Group are extensive in central and western Alabama and northeastern Mississippi. These rocks show little alteration by solution, and open fissures, open joints, and caves are generally not present.

The Silurian limestones and dolomites (Niagaran) of northwestern Ohio and adjacent Indiana are buried beneath glacial drift. Only in northwestern Ohio, where the glacial deposits are less than 20 ft (6 m) thick, are there karst features large enough to cause problems in engineering geology. Caves, each generally with less than 1,000 ft (300 m) of passages, are present but not numerous. Fissures less than 100 ft (30 m) wide extend for hundreds of feet. Small areas of subsidence have been attributed to alteration of the water table by pumping processes in quarries several miles from the site of subsidence. Because of the flat terrain, excavations and cuts seldom are deep enough to encounter major karst features. In the vicinity of Sandusky, Ohio, and on some of the nearby islands in Lake Erie, beds of calcium sulfate expand and change because of weathering and may cause local problems in heaving.

Broad anticlines with gentle dips bring Ordovician limestones and dolomite to the surface in southwestern Ohio and north-central Kentucky. Small caves and numerous joint-controlled fissures occur. Subsidence is not common or extensive, but the fissures and caves that result contain a large volume of water that may flood excavations. Ordovician and Silurian carbonate rocks also are brought to the surface in a broad anticline in central Tennessee around Nashville. Karst conditions are similar to those in north-central Kentucky.

In the Lower Peninsula of Michigan, carbonate rocks are extensive but are buried deeply beneath glacial deposits. Silurian limestones along Lake Huron between Alpena and the Straits of Mackinac contain several large sinkholes up to 1 mi (1.6 km) long and 200 ft (60 m) deep. The sinkholes are interconnected by an extensive fissure system. Normally, the sinkholes are filled with water, but, over time, plugs in the fissure system fail and the lakes drain through the subterranean openings. Subsidence generally does not occur in the Lower Peninsula.

Ordovician limestones cover the south half of the Upper Peninsula of Michigan and extend through eastern and southern Wisconsin, eastern Iowa, and parts of southeastern Minnesota. Karstic features are poorly developed and consist of simple caves, each with less than 1,000 ft (300 m) of passageways and less than 50 ft (15 m) of vertical extent. Fissures developed along joint lines are in about the same size range as the caves. In the vicinity of Dubuque, Iowa, and extending into adjacent Wisconsin and Illinois, fissures several hundred feet long and more than 300 ft (90 m) deep have been encountered in lead-zinc mines. The fissures possibly are relict from older buried karst. Subsidence from karst features is rare, although subsidence over mines is extensive.

The Ozark Plateaus province and adjacent plains in Missouri and northern Arkansas have extensive karst areas. The Ozarks are a large regional structural dome with steep dips along the southern flank. The dome brings Cambrian and Ordovician limestones and dolomites to the surface. North and west of the dome are plains underlain by Mississippian carbonate rocks (Warsaw, St Louis, Ste. Genevieve, and equivalents). Within the Ozarks, caves, each with passages 1,000 ft (300 m) or more long, are common. The passages in most caves extend to a depth of less than 100 ft (30 m). Pits, formed by collapse into cavern shafts and dome pits, are common, and, in southern Missouri, active subsidence is extensive. Most of the pits are water filled. Fissures over 1,000 ft (300 m) long and more than 300 ft (90 m) deep are present in much of the area. Similar fissures are numerous in the lead-zinc mining region in southwestern Missouri and adjacent Oklahoma and Arkansas. Throughout the Ozarks, the caves and fissures give rise to serious problems in foundations and abutments of dams and with reservoir tightness, stability of bridge piers, and stability of cut slopes. The presence of large quantities of subterranean water is a problem in deep foundations.

The Niobrara Formation (Upper Cretaceous) and its equivalents are the most widespread carbonate rocks in western Kansas, eastern Nebraska, and southeastern South Dakota. The Niobrara is generally covered by more than 50 ft (15 m) of younger sediments. Small fissures, less than 1,000 ft (300 m) long and up to 100 ft (30 m) deep, are present, but they are not common and are generally irregularly spaced with 1,000 ft (300 m) or more of solid rock between fissures.

Salt beds in south-central and southwestern Kansas form karst areas. Fissures are extensive, with openings more than 1,000 ft (300 m) long and over 300 ft (90 m) deep. Throughout the saline rock, recent subsidence has resulted from natural causes, as well as from alteration of the water table by solution mining and open pit mining.

In western South Dakota and adjacent parts of Wyoming and Montana, Paleozoic and Cretaceous carbonate rocks, arched steeply upwards, encircle the structural dome that forms the Black Hills. Caves and open fissures are common in the Paleozoic carbonate rocks. A few caves contain many miles of passages but most of the cave passages and fissures in the Black Hills area only extend up to 3,000 ft (900 m) in length and are generally less than 150 ft (45 m) in depth. Closely spaced solution joints also are prevalent.

In western Oklahoma and in the eastern part of the Texas Panhandle, extensive areas of karstic gypsum occur. Small open fissures up to 50 ft (15 m) deep and 1,000 ft (300 m) long are present. Passages in caves in gypsum are generally of similar length and depth.

The Edwards Limestone (Cretaceous) in west-central Texas forms an extensive plateau. Large caves and fissures are present to a depth of 600 ft (180 m), and both fissure systems and passages of single caves commonly extend for more than 1 mi (1.6 km). Both the caves and fissures contain large quantities of water in their deeper parts.

Permian carbonate rocks in central and southern New Mexico contain numerous well-developed karst features. Caves are generally very large and contain miles of passages with a vertical extent of 1,000 ft (300 m) or more. Fissures are of similar size and are interconnected, forming networks that extend for several miles. Closely spaced open joints, enlarged by solution, and numerous small, near-surface solution tubes cause extensive trouble in reservoir tightness throughout this karst area.

In northern and central Arizona, the Kaibab Limestone (Lower Permian) and its equivalents are karstic. North of the Grand Canyon, subterranean openings are primarily widely spaced fissures up to 1,000 ft (300 m) long and 250 ft (75 m) or more deep. South of the Grand Canyon, the fissures are more closely spaced and a few shallow caves are present. East of Flagstaff, there is an area of open fissures. These fissures are over 300 ft (90 m) deep, up to 1,000 ft (300 m) long, and up to 3 ft (1 m) wide. They cut the Coconino Sandstone, as well as the Kaibab Limestone (Colton, 1938).

The Madison Limestone (Mississippian) lies under karst areas in western Montana and adjacent parts of Idaho and Wyoming. Passages in a single cave are commonly up to 2 mi (3.2 km) long. Open fissures up to 1,000 ft (300 m) long and shallow, open joint systems are also common. Fissures and cavern passages extend as much as 1,000 ft (300 m) deep. Large quantities of water are present in the lower parts of the fissures and in some of the deeper cavern passages. Relict karst features developed during times of disconformity at the end of the Mississippian are common in the Madison Limestone. Most of the relict features are solution tubes, caves, and small fissures that have been filled with younger deposits that are now lithified. Because of differences in materials, residual openings, and secondary solution, these features can give rise to foundation problems and leakage.

Karst features in Alaska are not well known. Most of these features are shallow, swalelike depressions developed in a thin cover of residual soil and glacial till that lies over intensely folded limestone. A few cave openings are in limestone bluffs, but most cave entrances are hidden by a cover of spalled rock fragments. Streams crossing limestone terrains commonly disappear into the soil mantle and resurge at contact with insoluble rocks bordering the limestone. No subsidence features have been reported in Alaska.

Pseudokarst conditions in the United States develop in areas of thick, unconsolidated sediments and are primary features in basalt lava. In addition, in Mississippi and Alabama. numerous subsidence features occur in unconsolidated silt, sand and gravel of the Coastal Plain; these subsidence features are analogous to karst features. The subsidence occurs as numerous shallow depressions that are generally less than 50 ft (15 m) deep and up to 1 mi (1.6 km) or more wide. The depressions occur in Miocene and Pliocene sediments 800 to 1,000 ft (240 to 300 m) or more thick. Oligocene carbonate rocks are present beneath these sediments. The origin of the depressions is not understood The depressions appear to be associated with poorly drained areas such as flat lowlands and elevated, dissected, higher erosion surfaces. The depressions apparently are confined to flat surfaces and are not present on slopes that bound the flat surfaces. Excavations in the depressions probably would encounter weak and unstable soil and would be subject to flooding.

The High Plains of western Texas and adjacent States contain numerous depressions, some of which are as much as 3 mi (4.8 km) long and up to 1 mi (1.6 km) wide. They vary from "buffalo wallows," 3 to 10 ft (1 to 3 m) deep, to steep-sided features as much as 250 ft (75 m) deep. The depressions are aligned along a series of major joints and apparently formed by piping and removal of fine-grained material along joint planes at depths greater than 250 ft (75 m). Deep excavations in the depressions encounter weak, unstable soils and are subject to flooding from ground water during occasional periods of high rainfall.

Pseudokarst features in late Cenozoic basalt lava fields are extensive in some regions of the west. The largest regions with this type of pseudokarst are in the Snake River area of Idaho, in part of the Columbia Basalt Plateau in Washington and Oregon, and in the lava fields of northeastern California. Smaller areas are in New Mexico, Arizona, Utah, Nevada, southern California and on the Seward Peninsula in Alaska. The pseudokarst features include lava tubes, fissures, open sinkholes, and caves formed by extrusion of the still-liquid portion of the lava. Subsurface solution of the bedrock and subsequent collapse are not involved in the formation of these features. Lava tubes, in the form of tunnels, are up to 20 ft (6 m) in diameter, and some extend for several miles. Fissures are common but seldom extend for more than 1,000 ft (300 m). The fissures and lava tubes, in contrast to solution features, are not in geometrical sets but are generally parallel and extend in the direction of the flow of the lava. Fissures and lava tubes are generally near-surface features, but some are as much as 250 ft (75 m) deep. "Sinkholes" in lava generally lack the symmetry of those developed in solution terrain. The lava sinks are commonly less than 100 ft (30 m) wide, but a few large sinks, notably in the Snake River area of Idaho, are as much as 1 mi (1.6 km) or more wide. Most of the lava sinks are irregular in shape and generally are shallow features (less than 30 ft (10 m) deep), although some are 150 ft (45 m) or more deep. Many of the sinks have near-vertical sides or overhangs. Lava pseudokarst features present problems in foundations, abutments, and reservoir tightness. In addition, the tubes and related permeable lava often contain large quantities of water that may lead to flooding and slope-stability problems in cuts and excavations.

Acknowledgments and gratitude are extended to Allen W. Hatheway, Cambridge, Massachusetts, for information and guidance on pseudokarst in lava, to the thousands of members of the National Speleological Society whose papers on caves and karst areas they explored are the basic sources used in compilation of this map, and to members of the U.S. Geological Survey and various State Geological Surveys for information they contributed and for technical review and advice on this map and text.

REFERENCES CITED

Bretz, J. H., 1942, Vadose and phreatic features of limestone caverns. Journal of Geology, v 50, no. 6, pt2 , p. 675-811.

Brucker, Roger, 1979, New Kentucky Junction. Proctor-Mammoth Link Puts System over 200 miles, National Speleological Society News, v 37, no. 10. October, p. 231-236.

Burger, A., and Dubertret, L., 1975, Hydrogeology of Karstic terrain: Paris, International Association of Hydrogeologists, p. 159.

Colton, S., 1938, Exploration of limestone solution cracks: Museum of Northern Arizona, Museum Notes, v. 10, no. 10, p. 29-30.

Davies, W. E.. 1960, Origin of caves in folded limestone (Appalachian Mountains) *in* Moore, G W., ed.. Origin of limestone caves; a symposium with discussion: National Speleological Society, Bulletin, v. 22, pt. 1, p. 5-18.

Davies, W E., and LeGrand, H. E., 1972, Karst of the United States; *in* Herak, M. and Stringfield, V. T.. eds., Karst; important karst regions of the northern hemisphere. New York Elsevier Publishing Co., p. 467-505.

Davis, W. M.. 1930, Origin of limestone caverns: Geological Society of America Bulletin, v. 41, no.3, p, 475-628.

The following publications have not been cited in the text but are works that cover the subject of karst in great detail.

Ford, T. D., and Cullingford, C. H, D., eds., 1976, The science of speleology: London, Academic Press, 593 p.

Jakucs, Laszlo, 1977, Morphogenetics of karst regions: New York, Halstead Press, 284 p.

Jennings, J. N.. 1971, Karst: Cambridge, M.I.T. Press, 252 p.

Sweeting, M M.. 1972, Karst landforms: London, MacMillan, 362 p.

Sweeting, M. M.. ed.. 1981, Karst geomorphology: Benchmark Papers in Geology, v. 59, Stroudsburg, Hutchinson Ross Publishing, 427 p.

APPENDIX A

Bottom Ash Landfill Safety Factor Assessment

GOLDER

CALCULATIONS

DATE	September 26, 2018	**PREPARED BY**	KAC
DOCUMENT NO.	1894194 - Slope Stability	**CHECKED BY**	CCS
SITE NAME	Stanton Station - Bottom Ash Landfill	**REVIEWED BY**	TJS

Bottom Ash Landfill Stability Analysis

1.0 METHOD

Slope stability analyses were performed for the Bottom Ash CCR Landfill (Bottom Ash Landfill) using a limit-equilibrium-based commercial computer program, Rocscience SLIDE 8.0. Factors of safety were computed for circular slip surfaces using Spencer's method for force and moment equilibrium to evaluate limiting conditions. Circular analysis focuses on movement through coal combustion residuals (CCR), including global movement of material inside and outside the facility boundaries.

2.0 ASSUMPTIONS

2.1 Geometry

The cross section used for stability analysis is shown on Figure 1 and is representative of a long CCR slope and a portion of the soil containment berm. This section is assumed to represent maximum loading conditions and the most critical section for slope stability analysis. Slope stability analyses focused on movement through both soil (embankment and underlying soils) as well as CCR contained in the facility (Figure 2).

The external berms of the facility have approximate 3H:1V slopes from the drainage ditch (approximate elevation 1700 feet) to an approximate crest elevation of 1708 feet. The design top of final cover grades on the south side of the Bottom Ash Landfill have 4% grades from the berm crest to a final peak elevation of approximately 1723 feet. These conditions are assumed to represent the maximum facility loading conditions for the Bottom Ash Landfill.

Material in the Bottom Ash Landfill consists primarily of bottom ash, but may contain minor amounts of construction and demolition (C&D) material after plant deconstruction is complete. For the purposes of stability analysis, material in the landfill was modeled as bottom ash.

2.2 Material Properties

Input parameters for the material properties have been defined and described in the attached engineering worksheet and are summarized in the table below.

Material	Moisture/Density			Static Shear Strength	
	γ_{dry}	w	γ_{wet}	ϕ'/δ	c'/a
	pcf	%	pcf	degrees	psf
Historic Embankment Fill	112	11	124	30	100
Natural Soil and Final Cover	104	19	124	30	100
Bottom Ash	70	19	83	40	50

Golder and the G logo are trademarks of Golder Associates Corporation
golder.com

2.3 Subsurface Water Conditions

Groundwater monitoring wells surrounding the Bottom Ash Landfill indicate groundwater levels of approximately 1700 feet on the south side of the facility to approximately 1692 feet on the north side. Site observations and groundwater level measurements indicate that water levels are below the base of the Bottom Ash Landfill.

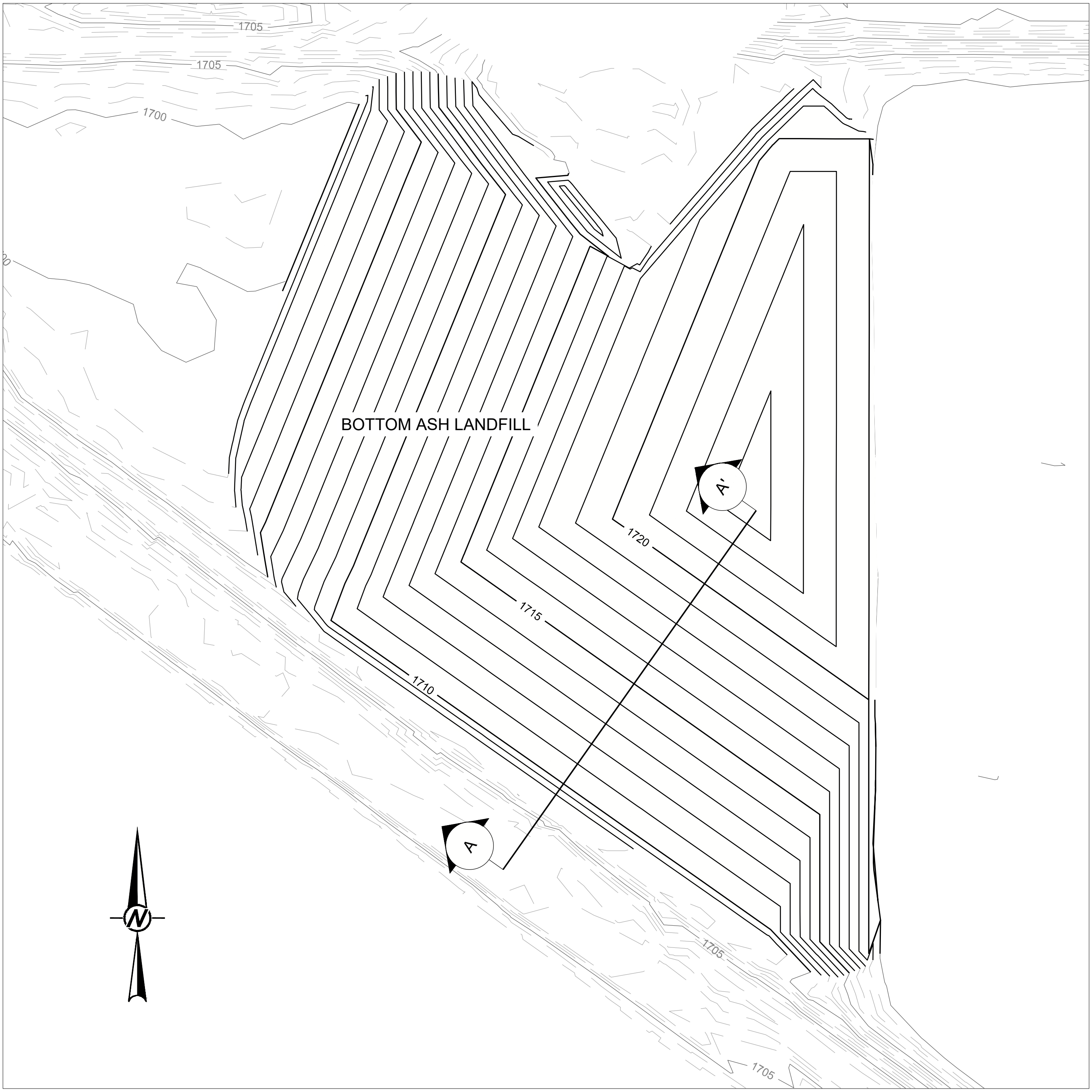
2.4 Seismic Loading Conditions

Stanton Station, located in central North Dakota, is in an area with low historic seismic activity. Since the site is not located within a seismic impact zone, seismic loading conditions were not evaluated as part of these stability analyses.

3.0 RESULTS/CONCLUSIONS

A factor of safety of 5.4 (Figure 3) for the critical circular surface was calculated based on these analyses for surfaces through both soil and CCR materials. Typically, a factor of safety greater than 1.5 is desired under long-term, maximum loading conditions. If ongoing monitoring indicates the Bottom Ash Landfill is not performing in accordance with the design, additional analyses may be required to evaluate whether design or operational changes are necessary.

Figures



LEGEND

1705 EXISTING TOPOGRAPHY

1715 PROPOSED TOP OF COVER TOPOGRAPHY

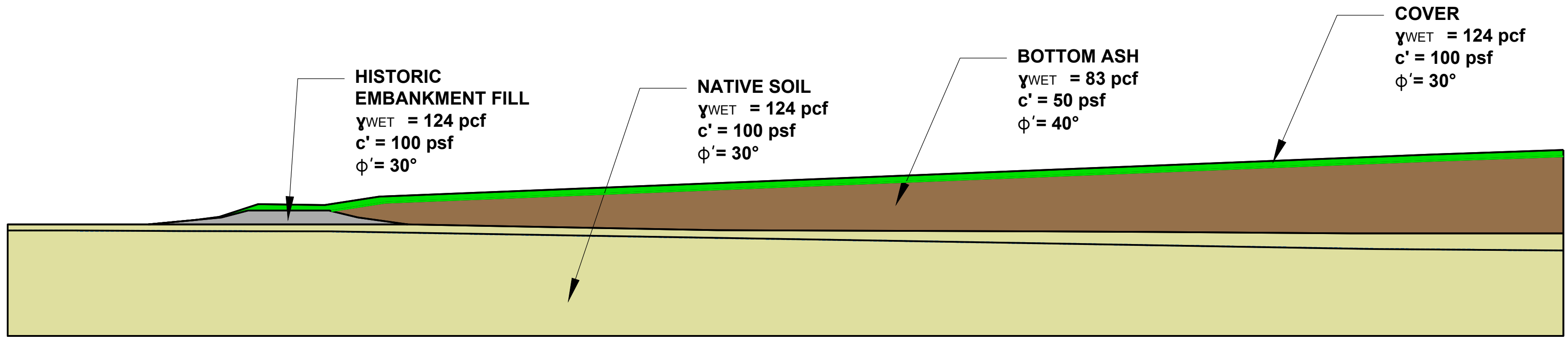
0 100 200
1" = 200' FEET

Path: \\Denver\acad\GREAT RIVER ENERGY\STANTON\99_PROJECTS\1894194\Stability\ | File Name: 1894194_BAL_SLIDE_PlanView.dwg

GOLDER

STANTON STATION - BOTTOM ASH LANDFILL
STABILITY ANALYSIS - PLAN VIEW SECTION

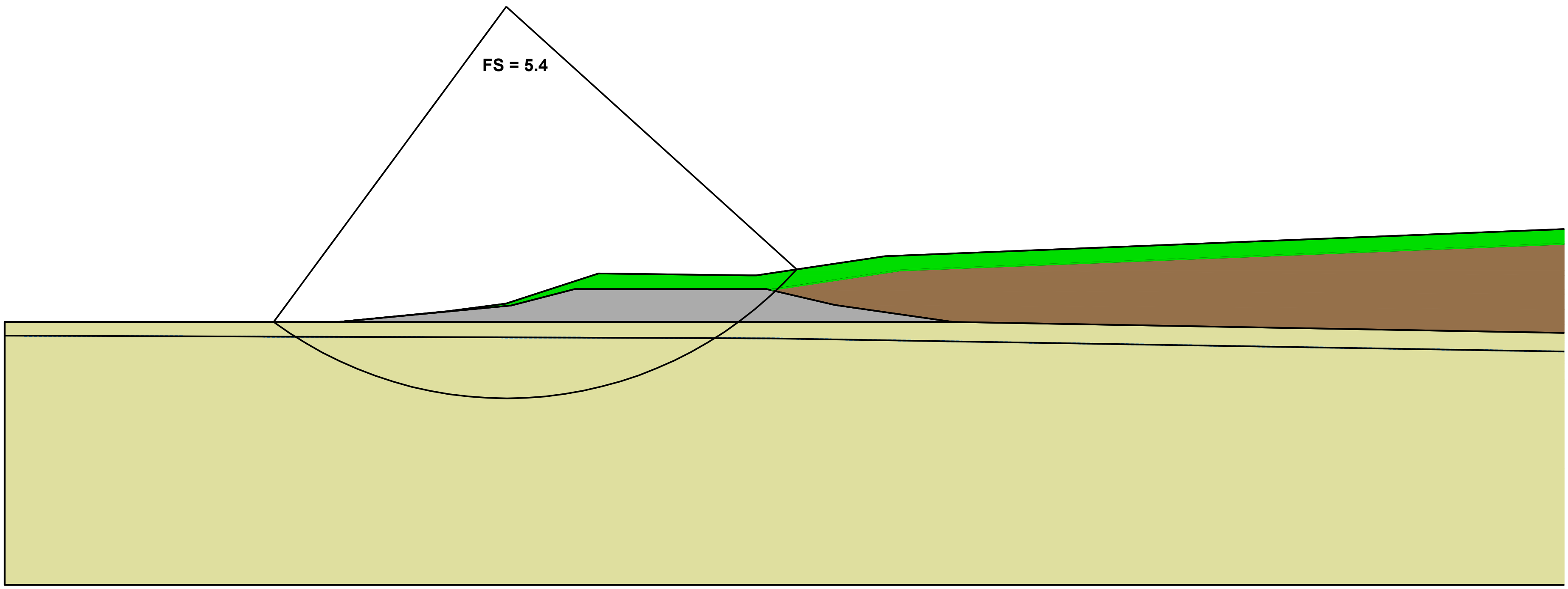
FIGURE 1



GOLDER

STANTON STATION - BOTTOM ASH LANDFILL
STABILITY ANALYSIS - GEOMETRY

FIGURE 2



GOLDER

STANTON STATION - BOTTOM ASH LANDFILL
STABILITY RESULTS - CIRCULAR ANALYSIS

FIGURE 3

Attachment A – Material Properties

DATE	September 26, 2018	**PREPARED BY**	KAC
DOCUMENT NO.	1894194	**CHECKED BY**	CCS
SITE NAME	Stanton Station – Bottom Ash Landfill	**REVIEWED BY**	TJS

Materials Properties

1.0 OBJECTIVE

Compile a list of material properties used in the engineering evaluation and indicate sources for all inputs.

2.0 MATERIALS

2.1 Historic Embankment Fill

Historic embankment fill properties were developed from soil samples collected from borings done for installation of the piezometers P-1 and P-2 drilled in October 2011. The historic embankment fill was classified as a silty sand (SM). Piezometer borings were advanced through the historic embankment and laboratory analyses were performed on three soil samples to determine dry density, five soil samples to determine moisture content, and two soil samples to determine plasticity and gradation.

Calculated dry unit weight values were 108.8, 111.0 and 114.9 pounds per cubic foot (pcf) with moisture varying between 9.0% and 13.6%. The average dry unit weight of 112 pcf and the average moisture content of 11% are used in the stability analysis to account for the material variability in the historic embankment fill. This results in a moist unit weight of 124 pcf.

The predominant soil in the embankment fill is silty sand (SM). A three-point triaxial shear test was performed to determine the effective stress shear strength parameters. An effective stress friction angle of 30 degrees and an effective cohesion intercept of 100 psf were selected for this analysis.

2.2 Natural Soil and Final Cover

The natural soils are predominantly silty sands (SM) with layers of fat clay (CH). The dry unity weight of the natural soils is 104 pcf based on the dry unit weight of a silty sand layer collected 22 feet below ground surface (bgs) from the boring for Piezometer P-1. The moist unit weight of 124 pcf was determined by averaging the moisture content of five silty sand samples collected from the borings for piezometers P-1 and P-2. The average moisture content was calculated as 19%.

The friction angle and cohesion were based on the silty sand from the historic embankment fill described above.

2.3 Bottom Ash

Bottom Ash input parameters are based on lab and field work performed by Golder on bottom ash samples collected from Great River Energy's Coal Creek Station. Based on visual observations, the bottom ash at Stanton Station is anticipated to behave similarly to that at Coal Creek Station.

The dry unit weight for compacted bottom ash is based on 95% standard Proctor densities from lab testing which gives a value of approximately 81 pcf. The dry unit weight of sluiced bottom ash is 60 pcf. An average value of 70

Golder and the G logo are trademarks of Golder Associates Corporation
golder.com

pcf was chosen for analysis based on a combination of compacted material and loosely placed material. The moisture content from field sampling of drained and saturated bottom ash ranged between 12% and 61%. For unsaturated conditions, a moisture content of 19% was assumed. Using the lab measured specific gravity of bottom ash (2.60); the moisture content of bottom ash for saturated conditions was determined to be between 40% and 65% (average 53%). Bottom ash was assigned an average moist unit weight of 83 pcf.

Lab direct shear strength testing of bottom ash indicated a residual effective cohesion of 463 psf and a residual friction angle of 40.3 degrees. Visual observations of the bottom ash material indicate little cohesion, therefore the effective cohesion was chosen as 50 psf and an effective friction angle of 40 degrees was chosen for analysis.

golder.com