Location Restriction Criteria - Certification Report

Public Service Company of Colorado –
Cherokee Station

CCR Impoundments

Denver, Colorado
October 2018

Prepared For:
Public Service Company of Colorado

HDR
1670 Broadway, Suite 3400, Denver, CO 80202
303.764.8800

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LIST OF ABBREVIATIONS AND ACRONYMS

AMSL Above Mean Sea Level
CCR Coal Combustion Residuals
CDPHE Colorado Department of Public Health and Environment
CFR Code of Federal Regulations
CGS Colorado Geological Survey
EDOP Engineering Design and Operations Plan
EPA U.S. Environmental Protection Agency
HDPE High Density Polyethylene
NEHRP National Earthquake Hazards Reduction Program
PGA Peak Ground Acceleration
PSCo Public Service Company of Colorado
RCRA Resource Conservation and Recovery Act
USGS United States Geological Survey

Qualified Professional Engineer Certification

I hereby certify, as a Professional Engineer in the State of Colorado, that the information in this document was assembled under my direct supervisory control. This report is not intended or represented to be suitable for reuse by PSCo or others without specific verification or adaptation by the Engineer.

I hereby certify, as a Professional Engineer in the State of Colorado, that the information contained in this report has been prepared in accordance with the requirements of 40 CFR §257. I further certify that a satisfactory demonstration of the requirements of 40 CFR Sections §257.60, §257.61, §257.62, §257.63 and §257.64 have been made.

SIGNATURE:

MATTHEW MICHAEL ROHR
53467

16OCT2018

Matthew M Rohr, PE
Colorado Licensed Professional Engineer No. 0053467
My license renewal date is October 31, 2019

1 Introduction

This Location Restriction Certification report has been prepared for the existing CCR impoundments located at the Public Service Company of Colorado (PSCo) - Cherokee Station (Site). This report conforms to 40 CFR Part 257. This report was prepared to address the federal CCR regulations for disposal of ash under subtitle D of the Resource Conservation and Recovery Act (RCRA). The final rule was published in the Federal Register, Volume 80 Number 74 on April 17, 2015, and became effective on October 19, 2015.

1.1 General Information

Figure 1 shows the Cherokee Station in Section 11 of Township 3 South, Range 68 West of the 6th Principle Meridian in Adams County, Colorado. The land-surface elevations range from approximately 5,190 feet above mean sea level (AMSL) at the southwestern corner of the Site to approximately 5,130 feet AMSL at the northeastern corner. Figure 2, Cherokee Station Layout shows the various facilities and infrastructure located at the Cherokee Station.

1.2 Type of Facility

Cherokee Station currently has three incised impoundments that were used for storage of CCR: the West, Center, and East impoundments (Figure 2). All three CCR impoundments were constructed in 1957, have depths of approximately 20 feet, and do not have engineered low-permeability liners. The detailed geometry of each impoundment is provided in Attachment C. All three of the impoundments ceased receiving CCR and non-CCR wastes in 2018 and are being closed in fall 2018, with all CCR planned to be removed by the end of 2018. The closure of these CCR impoundments consists of removing all waste in accordance with “closure by removal of CCR” under 257.102(c). Closure will also meet the requirements of Section 9 of Colorado Department of Public Health and Environment’s (CDPHE) Solid Waste Regulations (6-CCR 1007-2, Part 1).

2 Location Restrictions

40 CFR §257.60-64 applies to new CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units.

2.1 Placement Above The Uppermost Aquifer 40 CFR §257.60

The 40 CFR §257.60 places restrictions on locating the base of a CCR landfill or surface impoundment within 5 feet of the uppermost aquifer. It states the following:

“New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be constructed with a base that is located no less than 1.52 meters (5 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)."

The uppermost aquifer under Cherokee Station is the alluvial aquifer associated with the nearby South Platte River and is present across the site. Groundwater under the facility flows east, perpendicular to the South Platte River, where it ultimately discharges to the river (GeoTrans, Inc., 2009). The static groundwater level is shallow, measured between 5 and 25 feet below the top of monitoring well casings in 2009 by GeoTrans, Inc. (2009). The alluvial aquifer is between 8 and 38 feet thick, mostly sandy, in the area of the impoundments and is underlain by the low permeability claystone deposits of the Denver Formation that inhibits vertical downward flow to the deeper, regional Arapahoe Aquifer (GeoTrans, Inc. 2009). The Denver Formation is over 70 feet thick in this area (CDH, 1993).

Based upon original impoundment drawings, the bottoms of the three impoundments are at an elevation of approximately 5,119 feet as shown on the plan view and cross sections in Attachment C. The water table elevation in wells immediately around the three impoundments determined from well surveys and depth to water measurements collected between 2015 and 2017 ranges from 5,110 to 5,127 feet elevation (HDR, 2018). **The base of the CCR impoundments does not meet the requirement in 257.60 to be greater than 5 feet above the upper limit of the uppermost aquifer beneath the impoundment.**

2.2 Wetlands 40 CFR §257.61

The 40 CFR §257.61 places restrictions on locating CCR landfills and surface impoundments in areas designated as wetlands. It states the following:

"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."

Definition of Wetlands

The CFR Regulations (40 CFR *§232.2*) defines wetlands and other waters of the U.S. as:

- *All waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide.*
- *All interstate waters including interstate wetlands.*
- *All other waters such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation or destruction of which could affect interstate or foreign commerce including any such waters:*
    - *Which are, or could be, used by interstate or foreign travelers for recreational or other purposes; or*

  - *From which fish or shellfish are, or could be, taken and sold in interstate or foreign commerce; or*
  - *Which are used, or could be used, for industrial purposes by industries in interstate commerce.*
- *All impoundments of waters otherwise defined as waters of the U.S. under the definition.*
- *Tributaries of waters of the U.S. identified above.*
- *The territorial seas.*
- *Wetlands adjacent to waters (other than waters that are themselves wetlands) identified in the paragraphs above. The term "adjacent" means bordering, contiguous, or neighboring. Wetlands separated from other waters of the U.S. by human-made dikes or barriers, natural river berms, beach dunes, and the like are "adjacent wetlands.*

Wetlands can be waters of the U.S. and are defined by 40 CFR *§232.2 (3)(iv)* as areas that are *inundated or saturated by surface or ground water at a frequency and duration sufficient to support—and that under normal circumstances do support—a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas*.

No wetlands or other waters of the U.S. were identified within the project study area. The National Wetlands Inventory map incorrectly identified the three CCR impoundments as freshwater emergent wetlands. Currently, the area consists of one open water (the West Impoundment) with little to no riparian or wetland vegetation. The Center and East impoundments are currently dewatered for the purpose of removing all CCR in accordance with 257.102(c). These impoundments were inspected prior to commencement of dewatering and found to contain little to no riparian or wetland vegetation. The three CCR impoundments located in the project study area are isolated from the nearby South Platte River, therefore are not considered waters of the United States. Topographic, National Hydrology Dataset, and National Wetlands Inventory maps within and near the project study area are provided in Figure 3.

Based on the site reconnaissance, the existing CCR impoundments are not located within any known wetlands.

2.3 Fault Areas 40 CFR §257.62

The 40 CFR §257.62 places restrictions on locating CCR landfills and surface impoundments in close proximity to active fault areas. It states the following:

"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 the damage to the structural integrity of the CCR unit."

The Holocene time period is defined in the CCR Rule (40 CFR § 257.53, 2015) as the most recent epoch of the Quaternary period, extending from the end of the Pleistocene Epoch, at 11,700 years before present, and continues to present.

The proximity of the Cherokee Station to faults that have been active in Holocene time was investigated through research conducted for identifying such fault zones. The results of this research document the absence of Holocene time fault zones within 200 feet from the Cherokee Station and the three CCR impoundments.

This conclusion is supported by a review of project reports and published literature that included:

Regional Topographic and Geologic Maps and Hydrogeologic Study
Topographically, the Cherokee Station is located on a broadly rolling terrain area northeast of the intersection of interstate highways I-70 and I-25 along the west bank of the South Platte River as shown by the *U.S. Geological Survey*, *2017* map (Figure 4). Elevations vary from a high of approximately 5,190 feet AMSL at the southwestern corner of the Station to a low of approximately 5,130 feet AMSL at the northeastern corner. Geologically, the Station resides in alluvium materials. As shown in the *Lindvall, 1980* map (Figure 5), these range from relatively recent (Post-Piney Creek Alluvium) materials near the active channel to older deposits (e.g., Piney Creek Alluvium and Broadway Alluvium) at depth and preserved on terraces overlooking the river. The alluvial deposits consist largely of coarse sands and gravels, with local cobbles as well as lenses of clays and silty sands. Underlying the alluvial deposits, is bedrock of the Paleocene and Upper Cretaceous Denver Formation. It consists largely of claystones, mudstones, and sandstones interbedded with scattered lenticular conglomerates. The Denver Formation also crops out along a thin band from the southwestern corner of the site to the northeastern corner of the site. West of the Denver Formation outcrop, the Slocum Alluvium is present at the surface. Except for the early Paleocene lava flows in the upper part of the Denver formation (Van Horn, 1957), evidence of later geologic activity in the region has not been identified.

Maps and Reports by the Colorado Geological Survey (CGS), and the United States Geological Survey (USGS) relative to faulting in the area.
Using information from a variety of sources, the Colorado Geological Survey compiled information on nearly 100 potentially hazardous faults in Colorado that ruptured the earth's surface during the past 2 million years (*Widmann et al., 1998*). These faults are shown as wide lines on the map in Figure 6. Faults with evidence of movement during the past 130,000 years are often considered active faults. These faults are shown in red on Figure 6. Similar information further dividing the Quaternary faults into late, latest, middle and latest Quaternary, is depicted by the interactive Quaternary Fault and Fold Database released by the *U.S. Geological Survey and Colorado Geological Survey, 2006*. In addition to identifying well-constrained or inferred locations of faults, this interactive database also provides information, such as geologic setting, fault orientation, fault type, sense of movement, slip rate, recurrence interval, and the time of the most recent surface-faulting event, on faults and associated folds that are believed to be sources of earthquakes greater than magnitude 6 (M>6). These faults are shown as color-coded lines on the map in Figure 7, with the latest

Quaternary (<15,000 years) being denoted by orange. The closest documented latest Quaternary active fault to the site is the Williams Fork Mountains fault, which is located approximately 68 miles to the northwest. Nevertheless, review of available geologic and fault maps does not indicate the presence of active or potentially active faults in the proximity of the Cherokee Station that have been active in Holocene or previous time (epoch).

2.4 Seismic Impact Zones 40 CFR §257.63

The 40 CFR §257.63 places restrictions on locating CCR landfills and surface impoundments in seismic impacted zones. It states the following:

"New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located in seismic impacted 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 site."

The Federal Register Volume 80 No. 74 defines a seismic impact zone as the following:

"A Seismic impact zone means an area having a 2% or greater probability that the maximum expected horizontal acceleration, expressed as a percentage of earth's gravitational pull (g), will exceed 0.10 g in 50 years."

The U.S. Geological Survey (USGS) Earthquake Hazards Program interactive website was used to determine the earthquake hazard for the Site. The 2009 *National Earthquake Hazards Reduction Program* (NEHRP) seismic design maps indicated a mapped peak ground acceleration of 0.091 g for the Station area on rock (seismic site classification B). Using the shear wave velocity test results from the June 2011 Kumar & Associates *Geotechnical Engineering Study, Cherokee Station Steam Generating Plant* report, a best estimate site shear wave velocity of 1,250 ft/s in the top 100 feet was used for this evaluation (Attachment A). The aforementioned shear wave velocity corresponds to a seismic site classification C (very dense soil and soft rock). Using the default seismic site classification adjustment factor of 1.2 for seismic site classification C results in a design peak ground acceleration of 0.109 g.

Based on the subsurface information and seismic hazard spectral response maps, the peak ground acceleration at the Site exceeds the threshold value of 0.10 g in 50 years; indicating the site is located in a seismic impact zone. This would require that "…*the owner or operator demonstrate 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 site."* However, these impoundments do not contain liners or leachate collection and removal systems. Also, these impoundments are fully incised, and therefore do not contain any type of earthen or manmade dam structure that could impound surface water, and potentially fail during a seismic event. Due to the lack of structural components defined by the CCR rule, and the incised geometry of the impoundments, these impoundments do not need

to "…*demonstrate that they are designed to resist the maximum horizontal acceleration in lithified earth material for site.*"

2.5 Unstable Areas 40 CFR §257.64

The 40 CFR §257.64 places restrictions on locating CCR landfills and surface impoundments in unstable areas. It states the following:

"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. 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 geological or geomorphologic features; and (3) On-site or local human-made features or events (both surface and subsurface)."

Based on the available geotechnical explorations performed at the site, the subsurface soils encountered in the vicinity of these impoundments generally consist of alluvium to the top of sandstone or claystone bedrock. The alluvium is generally described as medium to very dense sand with variable gravel and occasional silty sand zones. Monitoring well borings performed near the impoundments are included in Attachment B. Three out of the four monitoring well borings taken around the impoundments shows bedrock at or near the base of the impoundment at approximate elevation of 5,119 feet. One of the borings taken near the southeast corner of the East Ash Pond (MW-10) shows approximately 18 feet of alluvial sand on top of the bedrock at the base of the East Impoundment which is likely to be medium to very dense based on the descriptions provided in other nearby borings on-site at this same elevation. Soft or compressible soils were not noted in any of the monitoring well borings in the vicinity of the three impoundments.

Based on our evaluation of the geotechnical investigations and cross sections of the impoundments, these impoundments are not located in an unstable area.

3 Summary

The Cherokee Station CCR impoundments (East, Center and West Ash Impoundments) meet and/or exceed the following location restriction requirements required for existing impoundments detailed in 40 CFR Part 257:

40 CFR §257.61 – Wetlands

40 CFR §257.62 – Fault Areas

40 CFR §257.63 – Seismic Impact Zones

40 CFR §257.64 – Unstable Areas

However, it cannot be demonstrated that the Cherokee Station CCR impoundments meet the following location restriction requirements:

40 CFR §257.60 – Upper Most Aquifer

As a result of not meeting the requirements of §257.60, Cherokee Station is required to cease placing additional CCR and non-CCR waste streams in the CCR impoundments and close the impoundments in accordance with §257.102 within 6 months of making this determination. Prior to this determination, PSCo had ceased placing waste streams within the CCR impoundments and had commenced closure of those impoundments by removal of CCR in accordance with 257.102(c).

4 References

1) Cherokee Station Waste Impoundments Engineering Design and Operations Plan, Denver, Colorado, HDR January 2016, Revised January 2017
2) Geotechnical Engineering Study, Cherokee Station Steam Generating Plant, Kumar & Associates, Inc., June 2011.
3) HDR, Inc., 2018, Groundwater Monitoring 2017 Annual Report for Compliance with the Coal Combustion Residuals (CCR) Rule Cherokee Station, January 30, 2018.
4) HDR Inc., Monitoring Well Installation Report for Compliance with the Coal Combustion Residuals (CCR) Rule, July 20, 2016.
5) Lindvall, R.M., 1980, Geologic Map of the Commerce City Quadrangle, Adams and Denver Counties, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-1541, scale 1:24,000.
6) Unruh, J. R., Wong, I. G., Bott, J. D., Silva, W. J. , Lettis, W. R., 1993, Seismotectonic evaluation, Rifle Gap Dam, Silt Project, Ruedi Dam, Fryingpan-Arkansas Project, northwestern Colorado, U.S. Bureau of Reclamation final report, William Lettis & Associates and Woodward Clyde consultants, 154 p., 1993.
7) U.S. Geological Survey and Colorado Geological Survey, 2006, Quaternary fault and fold database for the United States, accessed September 21, 2018, from USGS web site: http://earthquake.usgs.gov/hazards/qfaults/.
8) U.S. Geological Survey, 2017, Commerce City, Colorado - 7.5 Minute Topographic Map Series, 1:24,000.
9) Van Horn, R., 1957, Bedrock geology of the Golden Quadrangle, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ-103, scale 1:24,000.
10) Widmann, B.L., Kirkham, R.M., and Rogers, W.P., 1998, Preliminary Quaternary fault and fold map and database of Colorado: Colorado Geological Survey Open-File Report 98-8, 331 p.

Figures

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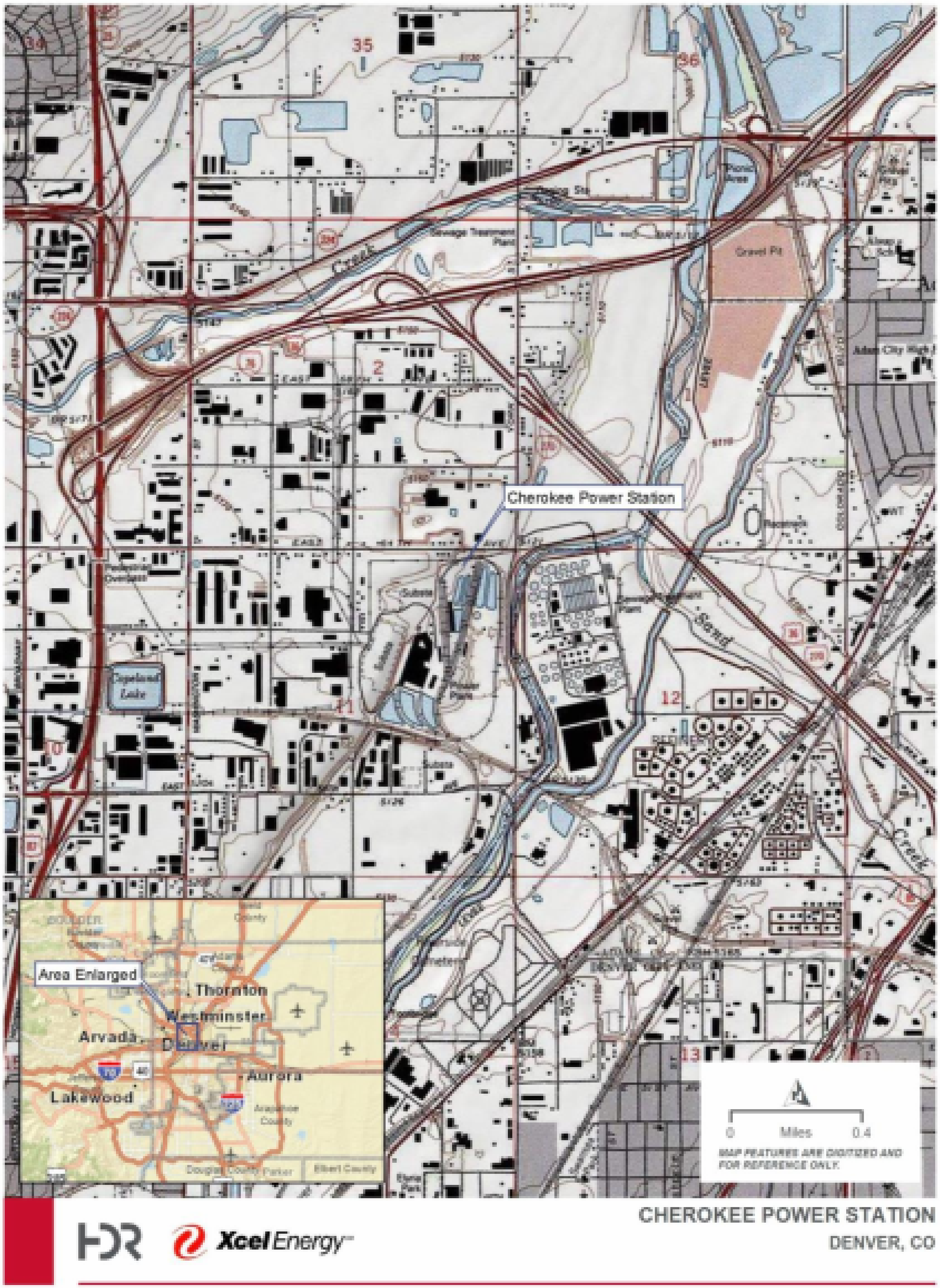
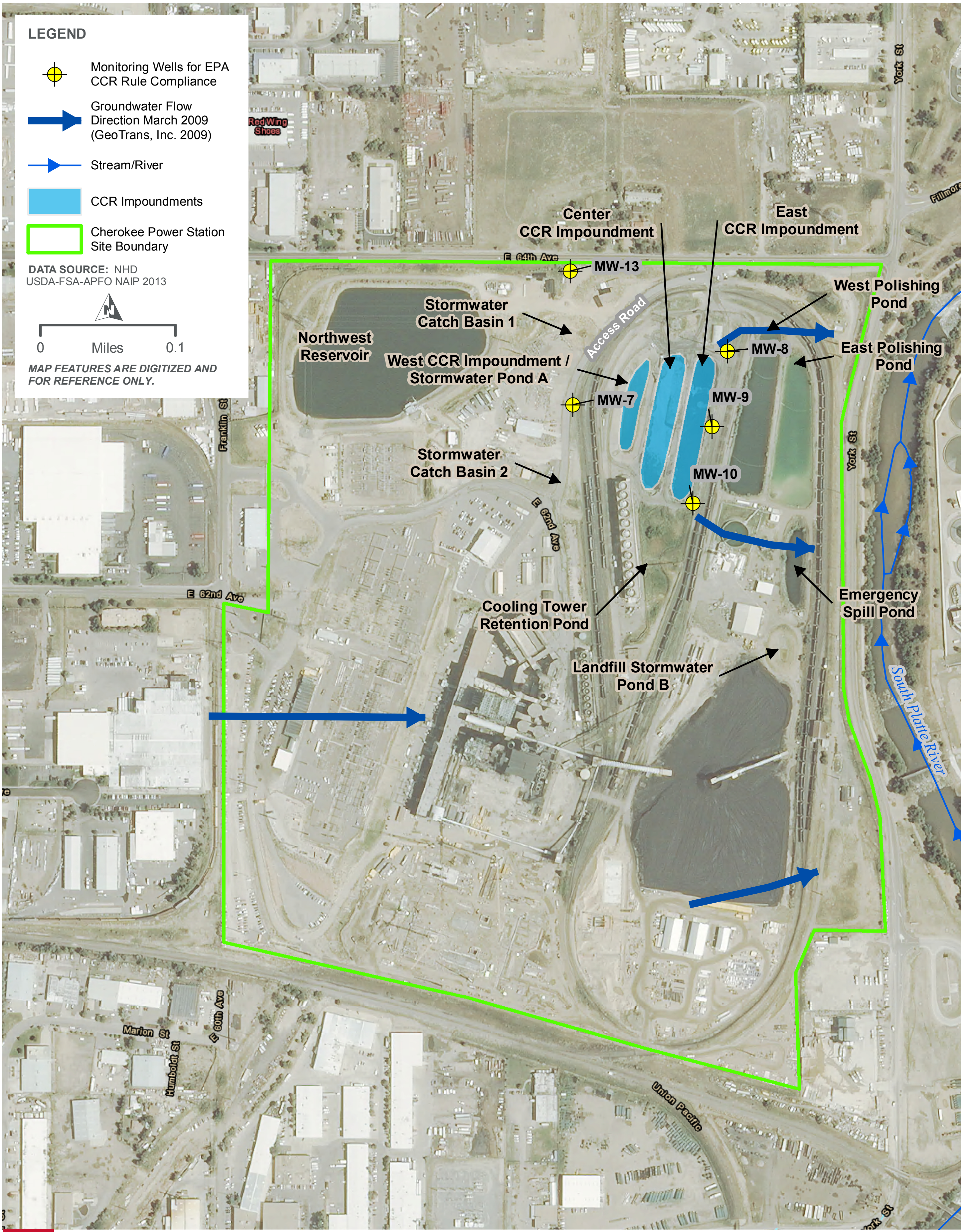


Figure 1. Cherokee Station Location Map

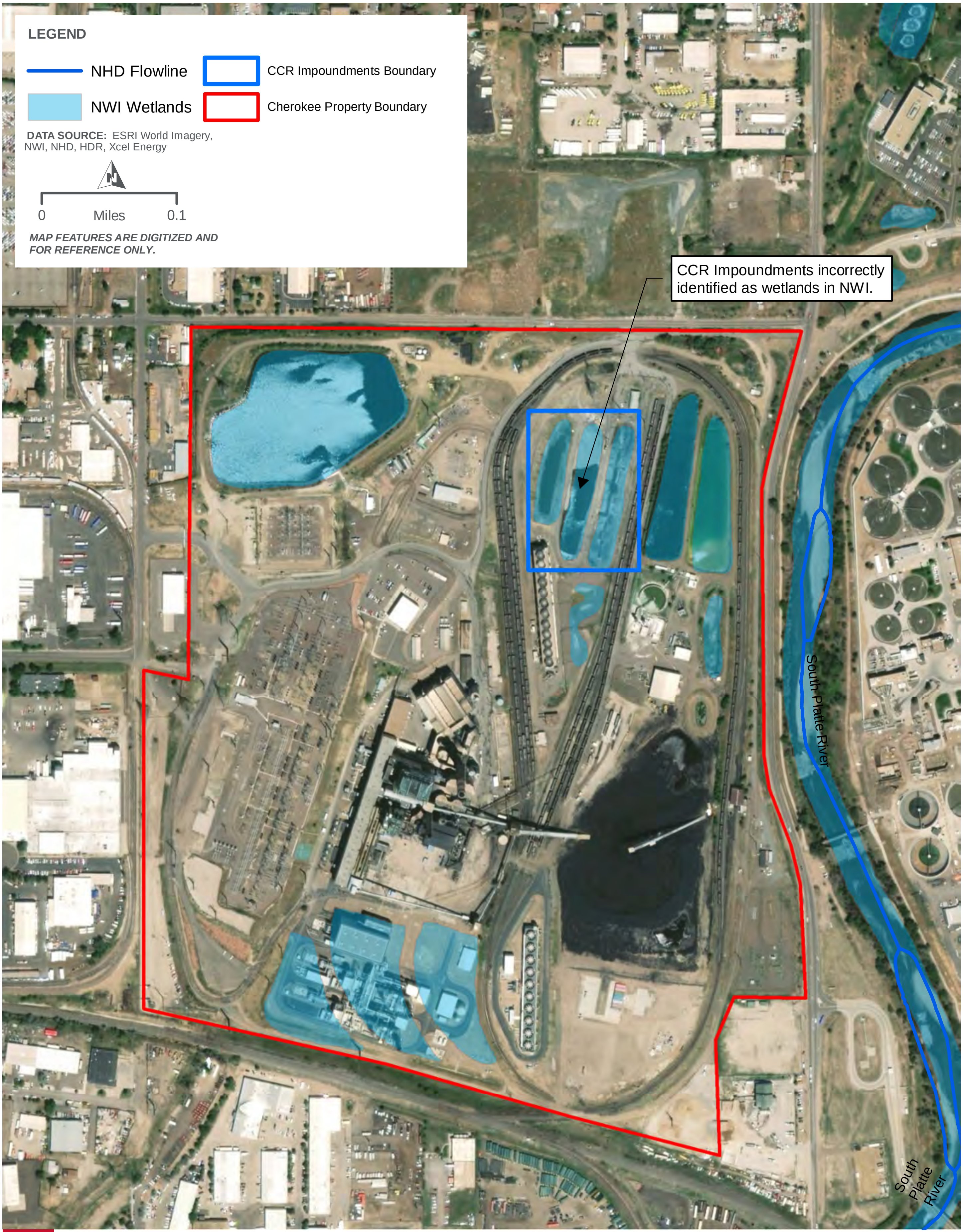


CHEROKEE POWER STATION

DENVER, CO

Figure 2. Cherokee Station Layout and Monitoring Wells Location Map

Source: Esri, HERE, Garmin, © OpenStreetMap contributors
Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community



CCR Impoundments incorrectly identified as wetlands in NWI.

CHEROKEE POWER STATION

ADAMS COUNTY, CO

Figure 3. Wetland Inventory Map

PATH: J:\2015\15-115_XCEL_CORE_SAMPLING_TESTING_(WALTHER)\MAP_DOCS\DELINEATIONREPORT_CHEROKEE\CHEROKEE_ASHDISPOSALSTUDYAREAWOUS.MXD - USER: AKAPLE - DATE: 10/16/2018

USGS
science for a changing world

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

The National Map
US Topo

COMMERCE CITY QUADRANGLE
COLORADO
7.5-MINUTE SERIES

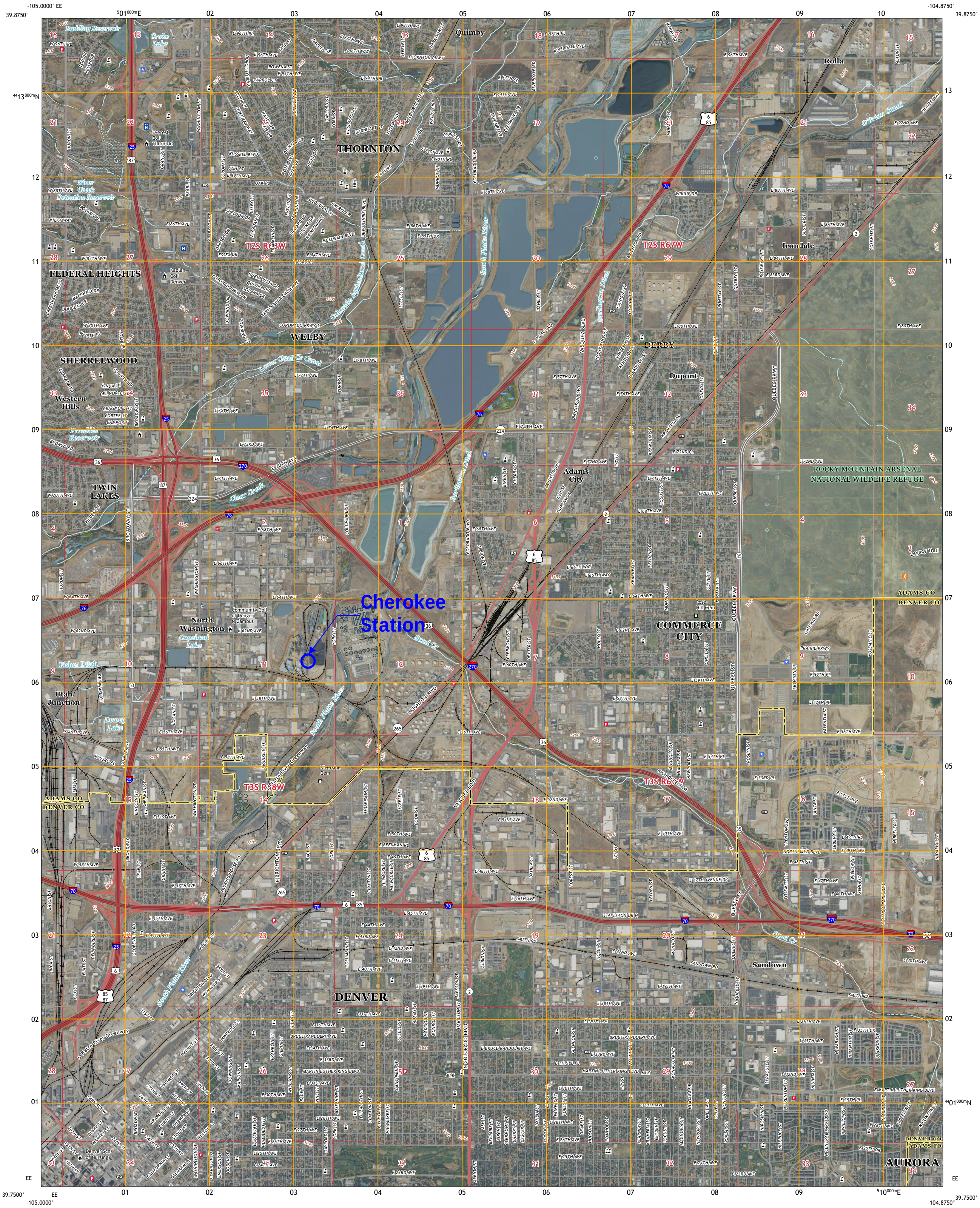


Figure 4. USGS Topographic Quadrangle Map

Produced by the United States Geological Survey
North American Datum of 1983 (NAD83)
World Geodetic System of 1984 (WGS84). Projection and
1 000-meter grid:Universal Transverse Mercator, Zone 13S

This map is not a legal document. Boundaries may be generalized for this map scale. Private lands within government reservations may not be shown. Obtain permission before entering private lands.

Imagery..........Not Available
Roads.......... U.S. Census Bureau, Not Available
Names..........GNIS, Not Available
Hydrography..........National Hydrography Dataset, 2003
Contours..........National Elevation Dataset, 2015
Boundaries..........Multiple sources; see metadata file 2014 2016
Public Land Survey System..........BLM, 2011 2017
Wetlands..........FWS National Wetlands Inventory 1975 2010

MN
GN
0°2′
1 MILS
8°15′
147 MILS

UTM GRID AND 2017 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

U.S. National Grid
100,000 - m Square ID
EE
Grid Zone Designation
13S

SCALE 1:24 000

KILOMETERS 1 0.5 0 1 2
METERS 1000 500 0 1000 2000
MILES 1 0.5 0 1
FEET 1000 0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

CONTOUR INTERVAL 20 FEET
NORTH AMERICAN VERTICAL DATUM OF 1988

This map was produced to conform with the
National Geospatial Program US Topo Product Standard, 2011.
A metadata file associated with this product is draft version 0.6.18

COLORADO
QUADRANGLE LOCATION

1	2	3
4		5
6	7	8

1 Lafayette
2 Eastlake
3 Brighton
4 Arvada
5 Montbello
6 Fort Logan
7 Englewood
8 Fitzsimons

ADJOINING QUADRANGLES

ROAD CLASSIFICATION

Expressway	▬	Local Connector	▬
Secondary Hwy	▬	Local Road	▬
Ramp	▬	4WD	- - -

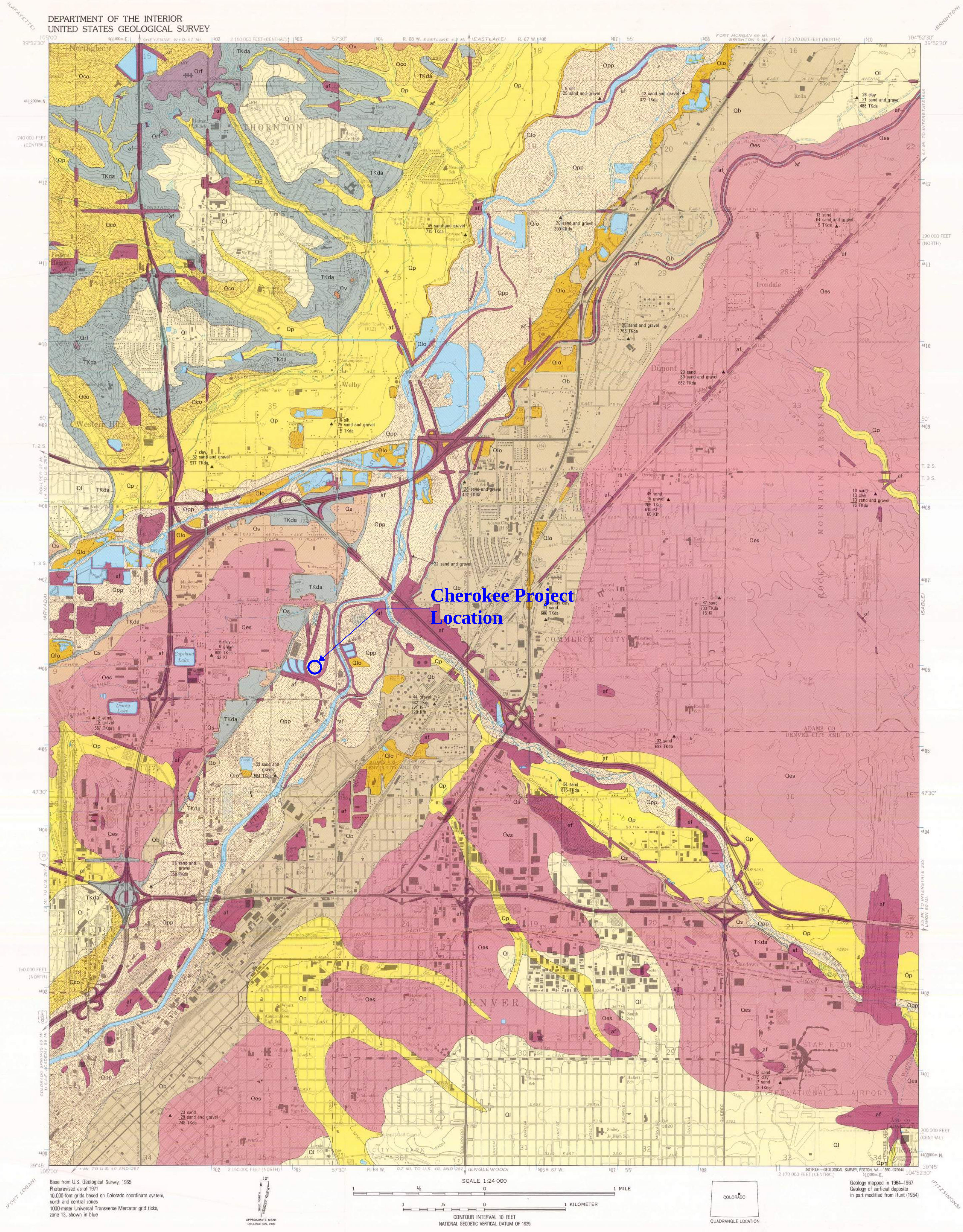
Interstate Route US Route State Route

COMMERCE CITY, CO
2017

7643016358643
NSN. 7643016358643
NGA REF NO. USGSX24K97643

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEOLOGIC QUADRANGLE MAP
COMMERCE CITY QUADRANGLE, COLORADO
GQ–1541



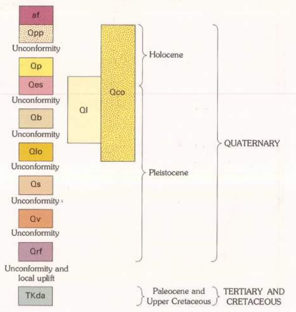
Base from U.S. Geological Survey, 1965
Photorevised as of 1971
10,000-foot grids based on Colorado coordinate system, north and central zones
1000-meter Universal Transverse Mercator grid ticks, zone 13, shown in blue

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Geology mapped in 1964–1967
Geology of surficial deposits in part modified from Hunt (1954)

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

af ARTIFICIAL FILL—Clay, silt, sand, gravel, and a variety of debris consisting of concrete, brick, wood, metal, plastic, glass, vegetation, and other trash. Includes engineered and compacted fill for highways, buildings, and bridge abutments; engineered and semiengineered fill for dams, canal and railway embankments, stream-channelization dikes, and some sanitary landfills; and uncompacted materials in local rubbish dumps. Two or more smelter slag waste deposits are mapped as artificial fill in the quadrangle. Thickness generally 5–20 ft (1.5–6 m), but some dams and embankments are as much as 30 ft (9 m) thick

Qpp POST-PINEY CREEK ALLUVIUM (HOLOCENE)—Light- to dark-grayish-brown clay, silt, sand, and small amounts of gravel. Dark-brown and dark-bluish-black humic bog clays, interbedded in places with sand and silt. Deposits forming the floodplains of the major streams have a high proportion of silt and sand. Mapped chiefly in Clear Creek, Sand Creek, and South Platte River valleys, but thin deposits are present in most minor tributary stream valleys. Thickness as much as 5 ft (1.5 m)

Qco COLLUVIUM (HOLOCENE AND PLEISTOCENE)—Gray, dark-gray, brown to light-brown sandy silt and clay. In places contains pebbles and cobbles. Developed on steep to gentle slopes; generally transitional downslope into Piney Creek Alluvium. Thickness commonly less than 5 ft (1.5 m)

Qp PINEY CREEK ALLUVIUM (HOLOCENE)—Brown, light-brown, light- to dark-gray interbedded sand, silt, and clay. Generally well stratified, humic material common in upper 1–2 ft (0.3–0.6 m); interbedded gravel in lower part. Upper part of alluvium generally finer grained than lower part. Occupies bottoms of almost every valley except those of Sand and Clear Creeks and South Platte River. Thickness commonly 5–10 ft (1.5–3 m)

Qes EOLIAN SAND (HOLOCENE AND PLEISTOCENE)—Light-brown fine sand, sandy silt, and clay. In some localities contains large amounts of clay and silty clay. Crossbedded in some places, but generally massive. Thickness generally less than 10 ft (3 m), but locally may be as much as 30 ft (9 m) thick

Ql LOESS (HOLOCENE AND PLEISTOCENE)—Yellowish-brown to light-grayish-brown sandy silt. Upper 2–4 ft (0.6–1.2 m) may contain appreciable amounts of clay and silty clay. Exhibits columnar structure, slightly calcareous, slightly sticky when wet. Thickness generally less than 10 ft (3 m), but may be as much as 20–25 ft (6–7.6 m) thick in southern part of the quadrangle

Qb BROADWAY ALLUVIUM (PLEISTOCENE)—Pink to light-brown, generally well stratified sand and gravel in well-defined terraces on the east side of the South Platte River valley. Upper 2–3 ft (0.6–0.9 m) commonly a clayey to pebbly silt. Thickness as much as 15 ft (4.5 m)

Qlo LOUVIERS ALLUVIUM (PLEISTOCENE)—Reddish- to yellowish-brown pebbly arkosic sand, coarse sand, cobble gravel, and a few boulders. Includes lenticular masses of silt and clay, commonly having contorted bedding. The coarse granular materials are stained and cemented locally by manganese and iron oxides, contain abundant mica, and generally are crossbedded. Many exposures are in pits excavated through younger alluvial deposits. Thickness commonly 15–20 ft (4.5–6 m) in terrace deposits along the South Platte River; thickness as much as 25–35 ft (7.6–10.6 m) in Clear Creek and South Platte River valleys

Qs SLOCUM ALLUVIUM (PLEISTOCENE)—Brown to reddish-brown, well-stratified pebbly clay, silt, sand, and gravel. A few scattered cobbles and boulders. Deposits generally grade transitionally downward from clay to silt and sand to gravel. A strongly developed calcium carbonate-enriched zone (relict soil) occurs in the upper part. Occurs chiefly on the terrace south of Clear Creek and west of the South Platte River in the southwestern part of the quadrangle. Thickness generally 10–15 ft (3–4.5 m)

Qv VERDOS ALLUVIUM (PLEISTOCENE)—Light-brown to reddish-brown, poorly sorted, stratified gravel, containing lenses of clay, silt, and sand. In places contains thin beds of white volcanic ash similar to the Pearlette family of ash beds. A strongly developed calcium carbonate-enriched zone occurs in the upper part. Occurs in small areas in the northwestern part of the quadrangle. Thickness as much as 20 ft (6 m)

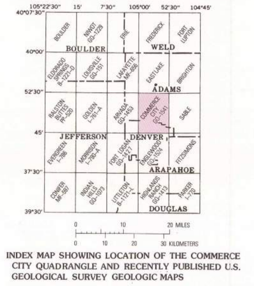
Qrf ROCKY FLATS ALLUVIUM (PLEISTOCENE)—Reddish-brown to light-brown poorly sorted coarse sand and gravel containing lenses of clay and silt, cobbles, and scattered boulders. A strongly developed calcium carbonate-enriched zone 2–4 ft (0.6–1.2 m) thick occurs near top of alluvium. Occurs only in northwestern part of the quadrangle. Thickness commonly 10–20 ft (3–6 m)

TKda DENVER (PALEOCENE AND UPPER CRETACEOUS) AND ARAPAHOE (UPPER CRETACEOUS) FORMATIONS—Brown, yellowish-brown, gray, and bluish-gray interbedded sandstone, claystone, siltstone, shale, and conglomerate. Crossbedded and lenticular units common throughout the formations. Olive-brown andesitic sandstone beds are diagnostic of the Denver Formation. The lower conglomerate member of the Arapahoe Formation is generally water bearing. Thickness of 785 ft (239 m) reported in well log from northeastern Commerce City in NE¼ sec. 5, T. 3 S., R. 67 W.

——— CONTACT—Approximately located

▲ 44 gravel
682 TKda
771 Kl
129 Kfh

ABBREVIATED COLUMNAR SECTION LOCALITY—Shows stratigraphic sequence and approximate thickness, in feet, of materials or map units at triangle, based on measurements from test hole, test pit, or excavation. Horizontal line separates surficial deposits, above line, from bedrock deposits, below line. Thickness of bedrock units are thicknesses which were preserved or penetrated and do not necessarily indicate complete thickness of unit. The following formations do not crop out in the Commerce City quadrangle, but are found in deeper wells: Kl, Cretaceous Laramie Formation and Kfh, Cretaceous Fox Hills Sandstone; Fox Hills Sandstone is generally water bearing. To convert to metric use the following formula: 1 ft equals 0.305 m



INDEX MAP SHOWING LOCATION OF THE COMMERCE CITY QUADRANGLE AND RECENTLY PUBLISHED U.S. GEOLOGICAL SURVEY GEOLOGIC MAPS

ENGINEERING PROPERTIES OF GEOLOGIC MAP UNITS

Most of the engineering-geologic problems in the Commerce City quadrangle involving construction and land-use activities are related to the unconsolidated surficial deposits, which mantle the bedrock to depths of as much as 100 ft (30.5 m); some are related to the underlying bedrock of the Denver and Arapahoe Formations. This discussion emphasizes the map distribution and physical properties of these geologic materials. Much of the information presented on the geologic map in the form of abbreviated columnar sections is from water-well logs and exploration drill holes; the remainder is from examination of foundation excavations, test pits, and natural rock outcrops. A brief statement of the principal geologic characteristics of each unit is given in the "Description of Map Units."

The following generalized statements regarding the engineering properties of the map units are based on field observations and on general performance information obtained from local engineers, contractors, builders, and property owners. This information, used in conjunction with the geologic map, should be helpful to land-use planners and developers, engineers, public officials, and others in making preliminary plans and designs. It must be stressed that such information should not take the place of detailed field and laboratory investigations required in the design of specific engineering structures.

Artificial fill

Permeability of artificial-fill deposits is variable; it is generally low in dams and highway fills, commonly high in trash dumps, and probably high laterally in sanitary landfills. The water table generally is low in highway and railway embankments, variable in dams, dikes, and canal embankments, and generally high in dumps and landfills in Clear Creek, Sand Creek, and South Platte River valleys. Most dams and highway embankments are well compacted; trash dumps and sanitary landfills commonly are very poorly compacted, however, some trash deposits may be interlayered with and covered by earth materials, which may be moderately compacted by the earthmoving equipment used in the covering operations. Excavation, using power equipment, varies from easy to difficult. Foundation stability conditions may be poor in landfill areas; concrete piers extending to suitable underlying material or bedrock are probably necessary for heavy structures. Stability conditions during earthquakes probably are very poor for structures founded on landfill deposits, and also for dams and embankments underlain by thick alluvial deposits. Slope-stability conditions usually are good to excellent in areas where fill is compacted, as in dams and highway embankments, and are very poor in compacted fill. Resistance to erosion by running water is moderate on slopes consisting of compacted fills protected by vegetation, but very poor where slopes are unprotected. Methane and other gases resulting from decaying organic matter in sanitary landfills and trash dumps may explode unless the deposits are properly vented. In addition, landfill and trash deposits which are below the water table, may pollute the ground water. Differential-settlement rates in improperly compacted artificial-fill deposits may cause rupturing of gas, water, or sewer pipes traversing such deposits. Smelter slag, which is included in artificial fill, consists of fused or partly fused glassy rock masses remaining after ore smelting. This material is melted and then poured in slag dumps. Slag deposits are generally very hard and dense, difficult to excavate, resistant to erosion, and have very low permeability.

Post-Piney Creek alluvium

Permeability of the alluvium is medium to low, particularly in clay and silt. The water table commonly is high in the valleys of Clear Creek, Sand Creek, and South Platte River, particularly in spring and early summer. Compaction of the material in thin layers using sheepsfoot or rubber-tired rollers usually is easy. Excavation is easy using power equipment. Foundation stability conditions are fair to good, except on bog clay or near stream channels where conditions are extremely poor. Stability conditions during earthquakes are probably poor to fair. Cut slopes may stand vertically for short periods of time after excavation or when dry, but will eventually slump to slopes of about 3:1 (3 horizontal distance to 1 vertical). The alluvium is moderately resistant to erosion, particularly if protected by vegetation. Areas of post-Piney Creek alluvium are subject to seasonal flooding; in addition, the high water-table conditions may cause dampness and flooding problems in basements.

Piney Creek Alluvium

Permeability is mainly low but may be somewhat higher in the sandy portion of the alluvium. The water table generally is 5 to 15 ft (1.5–4.5 m) below ground surface, but may be deeper, especially during fall and winter. Compaction in thin layers is usually easy using sheepsfoot or rubber-tired rollers. Excavation is easy using power equipment. Foundation stability conditions are fair to poor, and clayey parts of this unit may swell moderately when wetted. Stability conditions during earthquakes are probably poor to fair. Cut slopes may stand vertically for extended periods if dry, but eventually will slump to stable slopes of about 3:1 to 6:1. The deposits are subject to moderate erosion, particularly along streambanks, and to gully erosion on terrace surfaces.

Colluvium

Permeability of colluvial deposits is variable, but generally is low, particularly in the clayey parts. Compaction in thin layers is moderately easy with use of rubber-tired rollers. Excavation is easy using power equipment. Foundation stability conditions vary from poor to fair. Deposits having high clay content may be subject to moderate swelling when wetted. Stability conditions during earthquakes are probably fair to poor, depending on the moisture content of the material and angle of slope. Cut slopes in colluvium commonly stand vertically when dry, but may collapse or flow when wet. Deposits on steep slopes may be subject to landsliding if overloaded by construction, if support is removed from lower portions of the slope, or if the moisture content of the material is increased. Resistance to erosion by running water generally is poor on slopes not protected by vegetation, but is fair to good where vegetative cover is heavy.

Eolian sand

Deposits are very permeable, and surface drainage is generally good. The water table is usually low, but seepage of toxic materials from unlined wastewater storage reservoirs in eolian sand deposits at the Rocky Mountain Arsenal has contaminated the ground water in parts of the eolian sand in the northeastern part of the quadrangle. Use of vibratory equipment is generally necessary for satisfactory compaction of sand. The sand deposits are easily excavated using hand tools. For short periods of time after excavation, when the moisture content is moderately high, eolian sand may stand in vertical walls as much as 10 ft (3 m) high. Walls of trenches may collapse if not supported by shoring. Foundation stability conditions are good under moderate static loads, but heavy loads or vibrations may cause settlement. Eolian sand is not subject to swelling when wetted. Stability during earthquakes is probably low. Natural slopes of as much as 3:1 are usually stable. Resistance to erosion is low on steep slopes and cut banks, and is moderate to high in flat areas, owing to high permeability.

Broadway Alluvium

Permeability of the alluvium is moderate to high. The water table is usually 10 ft (3 m) or more below the ground surface. Compaction in thin layers is easy in clayey and sandy silt using sheepsfoot or rubber-tired rollers, but vibratory equipment may be required for the sandy and gravelly portions. Excavation is generally easy using light power equipment; in places hand tools are sufficient. Foundation stability conditions are good to excellent. Stability conditions during earthquakes probably are moderately good. Slope stability is reasonably good; cut slopes 5–10 ft (1.5–3 m) high may stand vertically for short periods after excavation, but shoring is mandatory in construction operations. Natural slopes of about 2:1 are generally stable and are moderately resistant to erosion, particularly when protected by vegetation. Deposits of Broadway Alluvium are a major source of sand and gravel in the valley of the South Platte River.

Loess

The vertical permeability of loess is moderate; lateral permeability is very low. The water table is generally very low. If moisture content is carefully controlled loess compacts easily into a hard dense state, using sheepsfoot or rubber-tired rollers. It is easily excavated using hand or power tools. Foundation stability is moderate when the loess is dry, but decreases rapidly as the moisture content increases. Loess has low density in the original depositional state but may compact markedly when excessive amounts of water or heavy loads are applied. Differential settlement may occur and cause problems to foundations when uncontrolled irrigation or puddling of backfill is allowed. Stability conditions during earthquakes are probably poor to fair. Cuts in loess will stand in nearly vertical walls as high as 10 ft (3 m) for periods of several years when dry, but will eventually slump to stable slopes of about 2:1 to 4:1. Shoring of trench excavations is recommended. Deposits are moderately resistant to erosion by running water on slopes protected by vegetation.

Louviers Alluvium

Permeability of the alluvium is generally very high, and the water table generally is within 10–15 ft (3–4.5 m) of the surface in the valleys of Clear Creek and the South Platte River. Compaction in thin layers is moderately easy using vibratory compactors or rubber-tired rollers. The alluvium is easily excavated using power equipment. Foundation stability conditions are good, and stability conditions during earthquakes are probably poor to fair. Cut slopes may stand vertically for short periods of time following excavation, but will eventually slump to stable slopes of about 3:1 to 4:1. Shoring is usually necessary in trenches and excavations. The alluvium is moderately resistant to erosion on gentle slopes, but is subject to undercutting of banks by running water. Deposits of Louviers Alluvium are a major source of sand and gravel in Clear Creek and South Platte River valleys.

Slocum Alluvium

Permeability is high in sand and gravel, but generally low in silty and clayey sand. The water table is usually from 10 to 20 ft (3–6 m) below the ground surface in the gravelly part of the alluvium. Compaction in thin layers is easy in the clayey part using sheepsfoot or rubber-tired rollers, but is moderately difficult in gravels, commonly requiring use of a vibratory compactor. Excavation is usually easy using power equipment. Foundation stability conditions are good to excellent; however, moderate swelling is possible in the clayey upper part, and such swelling pressures may be sufficient to crack concrete slabs, sidewalks, and driveways. Stability conditions during earthquakes are probably fair. Vertical cuts 8–10 ft (2.5–3 m) high are generally stable for several months after excavation, but subsequently may slump to slopes of from 2:1 to 4:1. Slocum Alluvium is moderately resistant to erosion, particularly when the slopes are protected by vegetation. Slocum deposits have been a source of sand and gravel in the area south of Clear Creek and west of the South Platte River in the west-central part of the quadrangle.

Verdos Alluvium

Verdos Alluvium crops out in small areas in the northwestern part of the quadrangle and also occurs beneath loess deposits in the same area. In the east-central part of the quadrangle, Verdos Alluvium deposits occur beneath eolian sand on higher parts of the Rocky Mountain Arsenal. Permeability is usually high in the sand and gravel parts of the alluvium, but low in the clay and silt parts. The water table is 5–10 ft (1.5–3 m) below ground surface in most areas, but may be deeper locally. Compaction in thin layers is generally easy using vibratory equipment in sand and gravel parts, and sheepsfoot and rubber-tired rollers in clayey materials. Excavation is easy using power equipment. Foundation stability conditions are fair to good in sand and gravel, but are only poor to fair in clay. Moderate swelling is likely in weathered clays in the upper part of the alluvium. Stability conditions during earthquakes are probably fairly good. Vertical cuts as high as 10 ft (3 m) are generally stable for several months after excavation, but most eventually slump to slopes of from 2:1 to 3:1. The alluvium is moderately resistant to erosion by running water. It is a source of sand and gravel.

Rocky Flats Alluvium

Outcrops of Rocky Flats Alluvium are limited to the northwestern part of the quadrangle. Permeability is moderately high in sand and gravel, but low in clayey and sandy silt and in the calcium carbonate-cemented zone. The water table is generally 10–15 ft (3–4.5 m) below ground level, but may be deeper locally. The alluvium is moderately easy to compact in thin layers using vibratory equipment or rubber-tired rollers. Excavation is easy to moderately easy using light power equipment, but boulders and the calcium carbonate-cemented zone may require the use of heavy equipment. Foundation stability conditions are generally good in the gravel parts of the unit, but clayey silts may swell moderately. Stability conditions during earthquakes are probably fair to good. Slope stability is moderate to good; excavations as deep as 10 ft (3 m) generally stand in nearly vertical walls for several months, but eventually will slump to 2:1 to 4:1 slopes. The alluvium is moderately resistant to erosion. In areas west of the quadrangle it is a source of sand and gravel for subgrades, roads and streets, and highway fills.

Denver and Arapahoe Formations

Permeability is moderately high in sandstone and conglomerate beds and very low in shale, siltstone, and claystone beds. Depth to the water table is variable; the conglomerate at the base of the Arapahoe Formation is usually water bearing and a fair source of water for small wells. Compaction of thin layers is moderately difficult in shale and poorly cemented siltstone and claystone, and impractical in sandstone and conglomerate. Power equipment is necessary for excavating in sandstone and conglomerate, and locally may require the use of explosives. Foundation stability conditions are generally good in sandstone and conglomerate, but ground-water seepage may be a problem locally; some of the shale, claystone, and siltstone units have very high swelling properties. Where the units contain high-swelling clays, concrete foundation piers supporting houses and other buildings should extend down through the near-surface zone of fluctuating ground-water saturation and penetrate several feet into the zone of permanent ground-water saturation. There the wet clays are permanently swollen to their maximum expansion. The placement of the concrete piers on the permanently swollen layers circumvents the heaving of structures that is caused by the alternate swelling (due to wetting) and shrinking (due to drying) of the clays in the near-surface layers. These layers alternate between wet and dry conditions as the water table rises and falls during the year. The water table generally reaches its highest level in early summer and is at its lowest level in October. A competent soils engineer can design concrete piers of proper diameter and depth for any given house or building. Stability conditions during earthquakes are probably good to very good. Slope stability is good to excellent; excavations in sandstone and conglomerate beds generally stand in vertical walls, but excavations in shale, siltstone, and claystone beds typically weather after a few months and slump to 1:1 or 2:1 slopes. Resistance to erosion by running water is moderate to excellent.

REFERENCES

Hunt, C. B., 1954, Pleistocene and recent deposits in the Denver area, Colorado: U.S. Geological Survey Bulletin 996–C, p. 91–140.

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Shroba, R. R., 1979, Geologic map and physical properties of the surficial and bedrock units of the Englewood quadrangle, Adams, Arapahoe, and Denver Counties, Colorado: U.S. Geological Survey Geologic Quadrangle Map GQ–1524, scale 1:24,000 (in press).

GEOLOGIC MAP OF THE COMMERCE CITY QUADRANGLE, ADAMS AND DENVER COUNTIES, COLORADO

By

Robert M. Lindvall

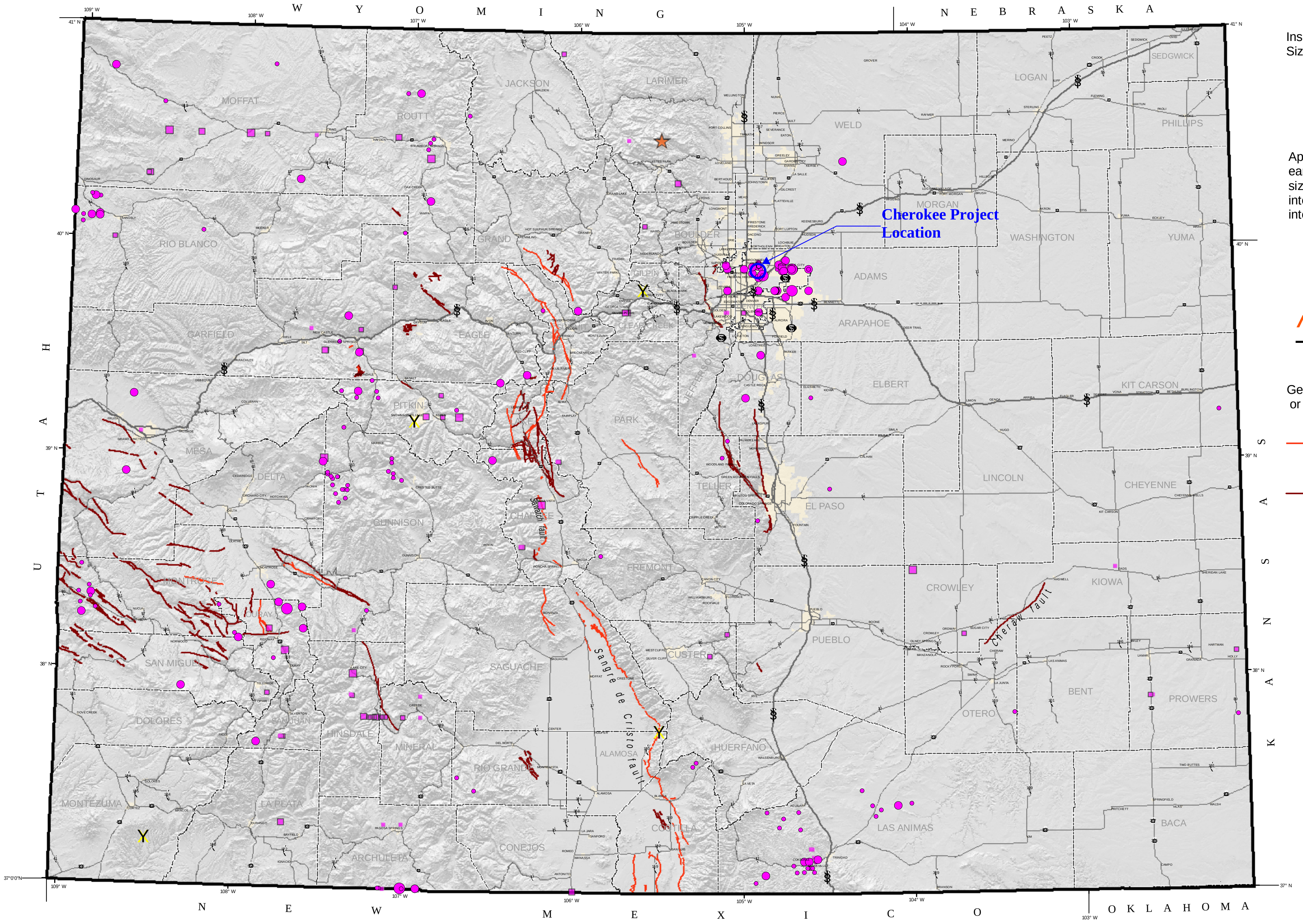
1980

Figure 5. Geology Map

For sale by Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225

COLORADO'S EARTHQUAKE and FAULT MAP

Showing Locations of Historical Earthquakes and Known or Suspected Geologically Young Faults



EARTHQUAKE EPICENTERS

Instrumentally located epicenters (~1962 to 2006)
Size of dot indicates magnitude.

- ● 5-5.5
- ● 4-4.9
- ● 3-3.9

Approximate location of pre-instrumental earthquake epicenters (~1867 to 1961). Square size indicates the maximum Modified Mercalli intensity for the earthquake (see back of map for intensity scale).

- ■ VII
- ■ VI
- ■ V
- ■ IV
- ■ I-III

1882 Earthquake; magnitude estimated at 6.6 +/- 0.6 (Spence and others, 1996)

QUATERNARY FAULTS

Geologically young faults that displace sediments or rocks deposited during the Quaternary Period (approximately past 2 million years).

- Known or suspected fault displacement of late Quaternary deposits (approximately past 130,000 years)
- Known or suspected fault displacement of middle to early Quaternary deposits (approximately past 130,000 to 2 million years old)

Y Permanent Seismic Stations - Includes four seismographs currently operated by the U.S. Geological Survey as part of the Advanced National Seismic System.

Cities and Towns

DATA SOURCES
Earthquake epicenters:
U.S. Geological Survey; Colorado Geological Survey; Kirkham and others, 2004; Kirkham and Rogers, 2000
Faults: *Colorado Geological Survey; Widmann and others, 1998*
Seismic Stations:
U.S. Geological Survey

This map does not meet U.S. National Map Accuracy Standards and is intended for general reference only.

Scale 1:1,150,000

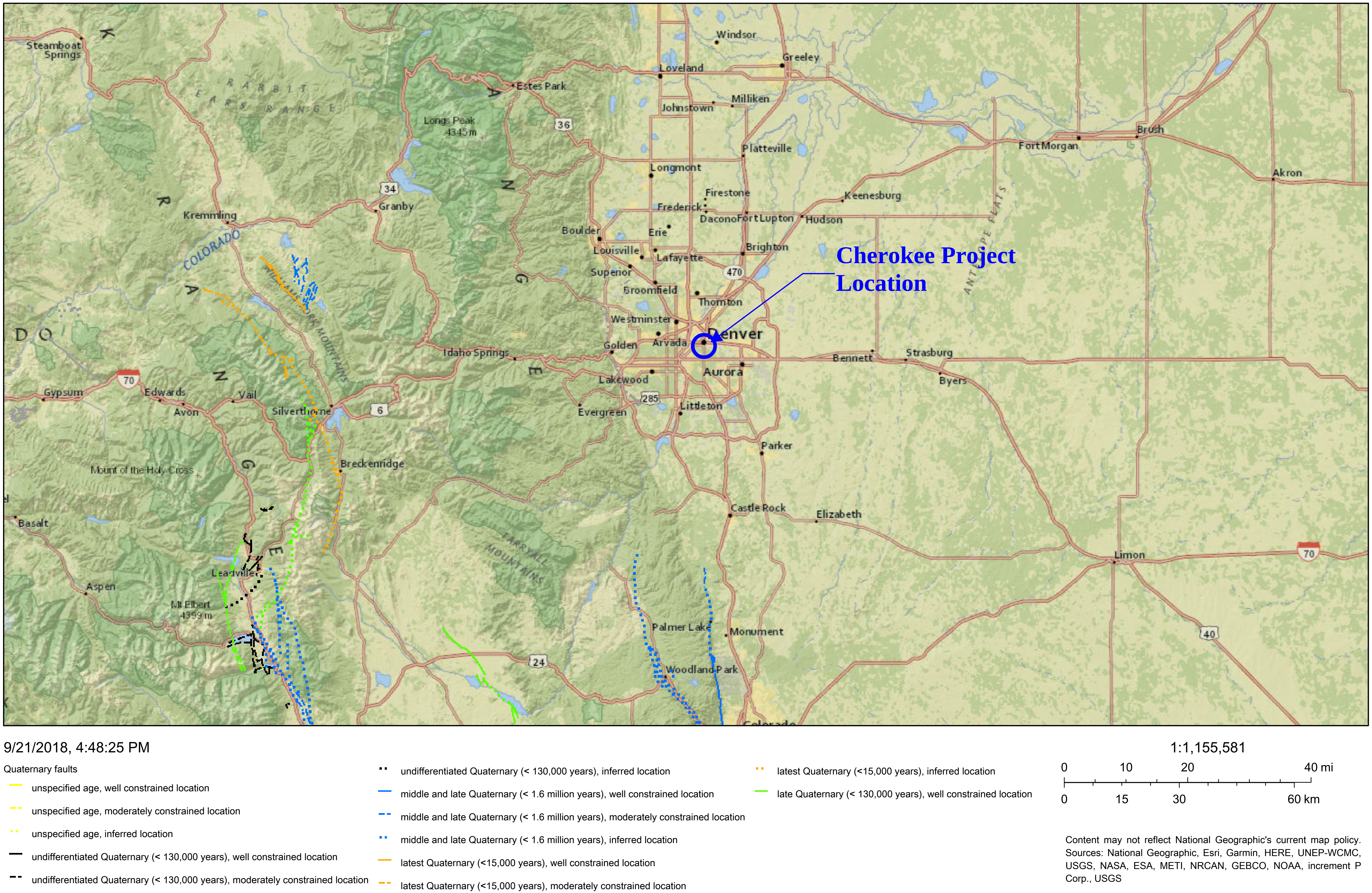
0 5 10 20 30 40 50
Miles

0 10 20 40 60 80
Kilometers

Map Compilation by
Matthew L. Morgan,
Colorado Geological Survey,
2006-2007

Figure 6. Earthquake and Fault Map

USGS Quaternary Faults and Folds Database



Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp., USGS

Figure 7. USGS Quaternary Faults Map

Web AppBuilder for ArcGIS

Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp. | USGS |

Attachment A

PGA Calculation

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USGS Design Maps Summary Report

User–Specified Input

Report Title 6198 FRANKLIN ST DENVER CO
Wed September 26, 2018 18:45:57 UTC

Building Code Reference Document 2009 NEHRP Recommended Seismic Provisions
(which utilizes USGS hazard data available in 2008)

Site Coordinates 39.80993°N, 104.96862°W

Site Soil Classification Site Class C – "Very Dense Soil and Soft Rock"

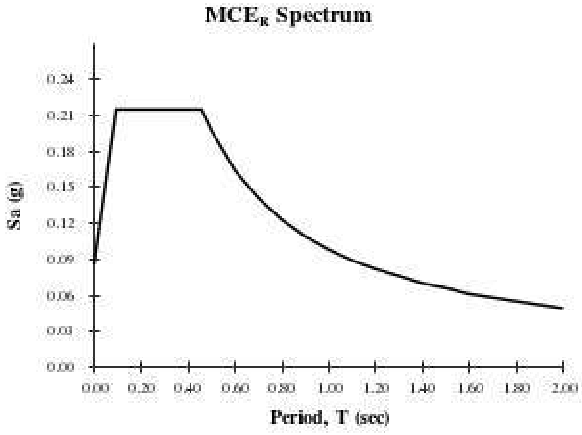
Risk Category I/II/III

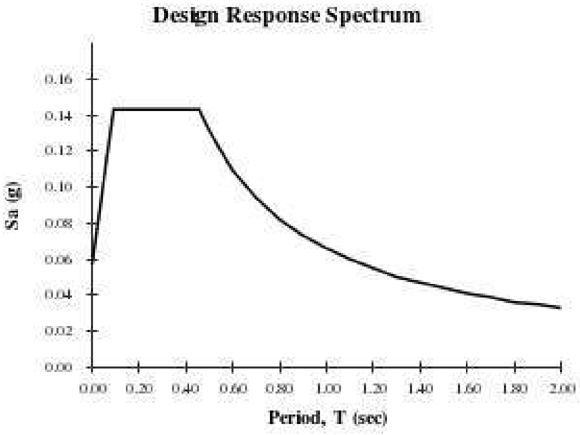
USGS–Provided Output

S_S = 0.179 g S_{MS} = 0.215 g S_{DS} = 0.143 g

S_1 = 0.058 g S_{M1} = 0.098 g S_{D1} = 0.066 g

For information on how the S_S and S_1 values above have been calculated from probabilistic (risk-targeted) and deterministic ground motions in the direction of maximum horizontal response, please view the detailed report.





For PGA_M, T_L, C_{RS}, and C_{R1} values, please view the detailed report.

Section 11.4.2 — Site Class

The authority having jurisdiction (not the USGS), site-specific geotechnical data, and/or the default has classified the site as Site Class C, based on the site soil properties in accordance with Chapter 20.

Table 20.3–1 Site Classification

Site Class	$\bar{v}_s$	$\bar{N}$ or $\bar{N}_{ch}$	$\bar{s}_u$
A. Hard Rock	>5,000 ft/s	N/A	N/A
B. Rock	2,500 to 5,000 ft/s	N/A	N/A
C. Very dense soil and soft rock	1,200 to 2,500 ft/s	>50	>2,000 psf
D. Stiff Soil	600 to 1,200 ft/s	15 to 50	1,000 to 2,000 psf
E. Soft clay soil	<600 ft/s	<15	<1,000 psf
	Any profile with more than 10 ft of soil having the characteristics: • Plasticity index *PI* > 20, • Moisture content *w* ≥ 40%, and • Undrained shear strength $\bar{s}_u$ < 500 psf		
F. Soils requiring site response analysis in accordance with Section 21.1	See Section 20.3.1		

For SI: 1ft/s = 0.3048 m/s 1lb/ft² = 0.0479 kN/m²

Section 11.4.3 — Site Coefficients, Risk Coefficients, and Risk–Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameters

Equation (11.4–1): $C_{RS}S_{SUH}$ = 0.907 x 0.198 = 0.179 g

Equation (11.4–2): S_{SD} = 1.500 g

S_S ≡ “Lesser of values from Equations (11.4–1) and (11.4–2)” = 0.179 g

Equation (11.4–3): $C_{R1}S_{1UH}$ = 0.897 x 0.064 = 0.058 g

Equation (11.4–4): S_{1D} = 0.600 g

S_1 ≡ “Lesser of values from Equations (11.4–3) and (11.4–4)” = 0.058 g

Section 11.8.3 — Additional Geotechnical Investigation Report Requirements for Seismic Design Categories D through F

Table 11.8–1: Site Coefficient F_{PGA}

Site Class	Mapped MCE Geometric Mean Peak Ground Acceleration, PGA				
	PGA ≤ 0.10	PGA = 0.20	PGA = 0.30	PGA = 0.40	PGA ≥ 0.50
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7 of ASCE 7				

Note: Use straight–line interpolation for intermediate values of PGA

For Site Class = C and PGA = 0.091 g, F_{PGA} = 1.200

Mapped PGA PGA = 0.091 g

Equation (11.8–1): $PGA_M = F_{PGA}PGA = 1.200 \times 0.091 = 0.109$ g

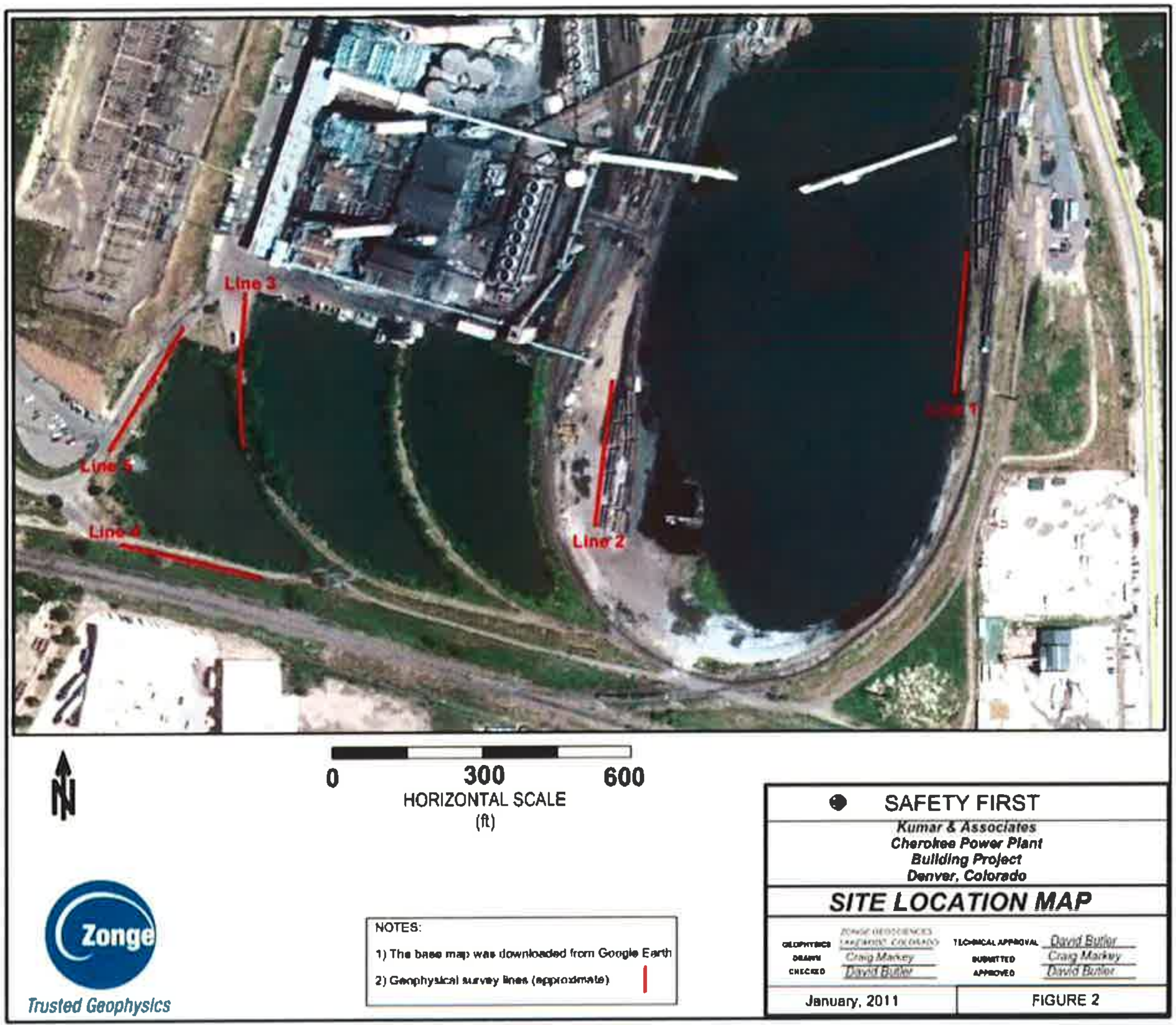


Figure 2 – *Generalized site map showing approximate locations and orientation of ReMi survey lines (shown in red). Lines are not drawn to scale.*

Step 3: Shear wave velocity modeling - The ReMi method interactively forward-models the normal-mode dispersion data picked from the p-f images with a code adapted from Saito (1979, 1988) in 1992 by Yuehua Zeng. This code produces results identical to those of the forward-modeling codes used by Iwata et al. (1998), and by Xia et al. (1999) within their inversion procedure. The modeling iterates on phase velocity at each period (or frequency) and reports when a solution has been found within the iteration parameters. This analysis approach and the propagation properties of surface waves allows velocity reversals (low shear-wave velocity layers at depth) to be modeled successfully.

Results / Interpretations

ReMi Vs100' shear-wave velocity results are presented on Figures 3 through 6. The Vs100' profiles represent a one-dimensional (1D) *seismic sounding* centered at the middle of each ReMi array. Thus, about halfway along each line would be the representative location of the 1D Vs data, if we were comparing results from a downhole or crosshole seismic test, for example. Locations for the ReMi lines were chosen based on the safety of the area and orientation with respect to possible noise sources. Lines 1 and 2 were placed on the West and East side of the coal pile, respectively. Noise from trains and nearby drilling allowed for acceptable data acquisition. The orientation of Line 3, perpendicular to the power plant, received high levels of energy traveling down the line. This environment also allowed for acceptable data acquisition.

Contrarily, the location of Line 4 did not receive adequate source energy, resulting in unacceptable data. Consequently, a location for a substitute line (Line 5) was approved by the site safety manager and data was acquired. The surface wave energy for Line 5 was much more favorable, resulting in acceptable data. As described in the previous section, ReMi data are derived by averaging the ambient noise across the geophone array and as such represent the bulk properties of the soil and/or rock beneath the array. Vs100' results from ReMi surveys have been shown in to be within 10-15% of Vs data obtained via crosshole or downhole testing, and can typically determine the depth to competent layers or bedrock also to within 10 to 15 percent.

ReMi data obtained at this site indicate: Line 1 Vs100' = 1210 ft/s (feet/second), Line 2 Vs100' = 1199 ft/s, Line 3 Vs100' = 1285 ft/s, and Line 5 Vs100' = 1307 ft/s. The average Vs100' value for all ReMi lines is **Vs100' = 1250 ft/s** at the Cherokee Power Plant project site in Denver. *As previously discussed, the data acquired from Line 4 were unacceptable and will not be included in the results.* Vs100' values for Lines 1, 2, 3 and 5 correlate to within 5% of the average. The Vs100' values listed here, presented on Figures 3, 4, 5, and 6, and in Tables 1-4 were computed in order to be used with Table 1613.5.2 of IBC 2006, or equivalent. Velocity values and layer thicknesses derived by the ReMi forward modeling process are also presented on Figures 3, 4, 5, and 6, and in Tables 1-4. Aside from Line 4, the quality of data at the Cherokee Power Plant project site in Denver site was good, and the models correlate well with each other and borehole data.

Based on the ReMi seismic results, unaltered bedrock is interpreted to be approximately 55-80 feet beneath the lines. The interpreted depth to bedrock is based on Vs values greater than or equal to 1,800 ft/s. All models show a sudden increase in Vs around this depth, and the general trend in the models correlate with each other.

Table 1 - Line 1 ReMi Data

Depth, ft	Vs, ft/s
0.0	641.0
5.0	641.0
5.0	806.0
17.0	806.0
17.0	891.0
31.5	891.0
31.5	1108.0
54.0	1108.0
54.0	1968.0
100.0	1968.0

Line 1 Vs100' = 1210 ft/s

Table 2 - Line 2 ReMi Data

Depth, ft	Vs, ft/s
0.0	641.0
7.5	641.0
7.5	875.0
19.0	875.0
19.0	960.0
35.5	960.0
35.5	1172.0
60.5	1172.0
60.5	1973.0
100.0	1973.0

Line 2 Vs100' = 1199 ft/s

Table 3 - Line 3 ReMi Data

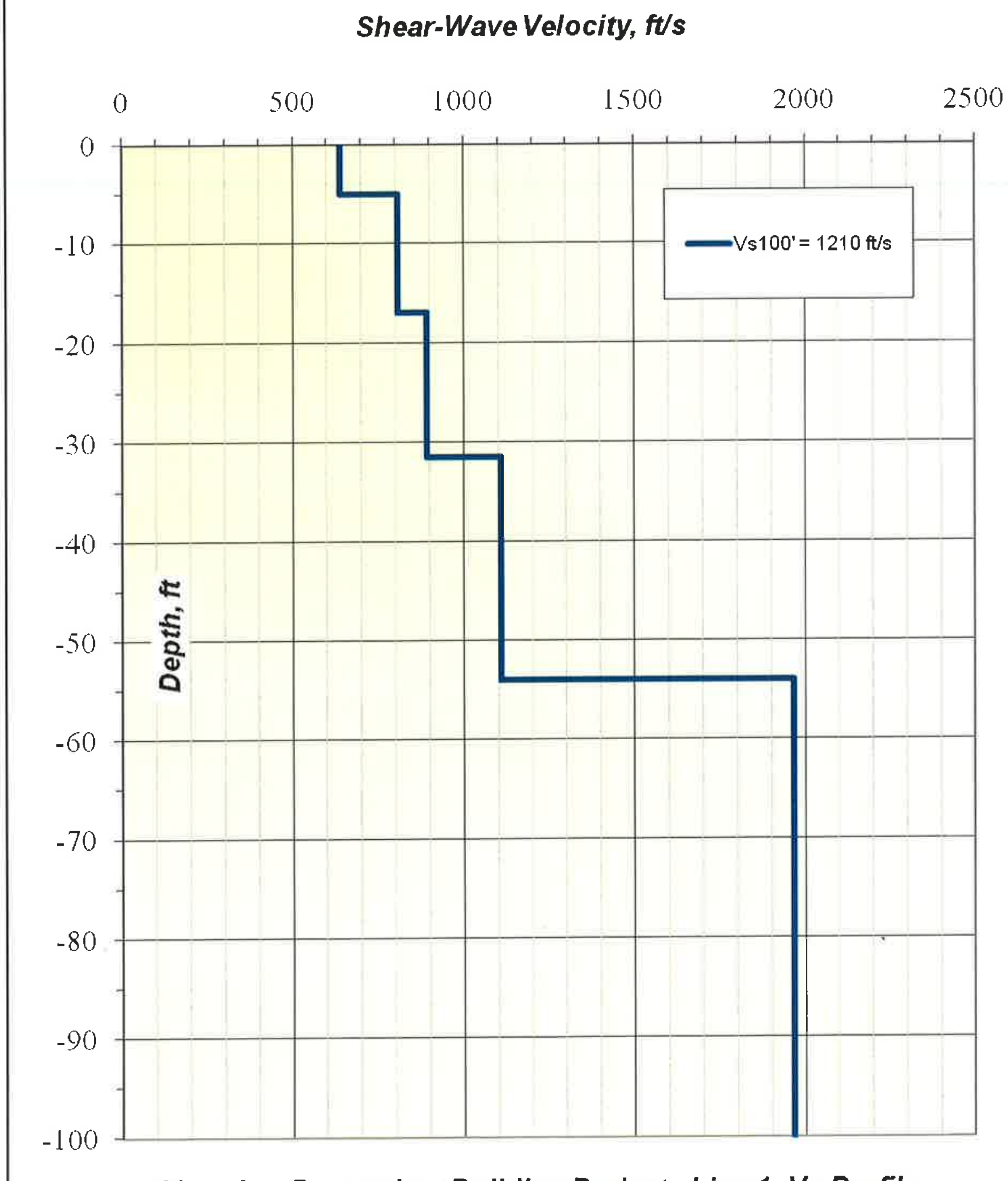
Depth, ft	Vs, ft/s
0.0	732.0
7.5	732.0
7.5	1172.0
23.0	1172.0
23.0	1230.0
35.0	1230.0
35.0	1294.0
63.0	1294.0
63.0	1331.0
82.0	1331.0
82.0	2079.0
100.0	2079.0

Line 3 Vs100' = 1285 ft/s

Table 4 - Line 5 ReMi Data

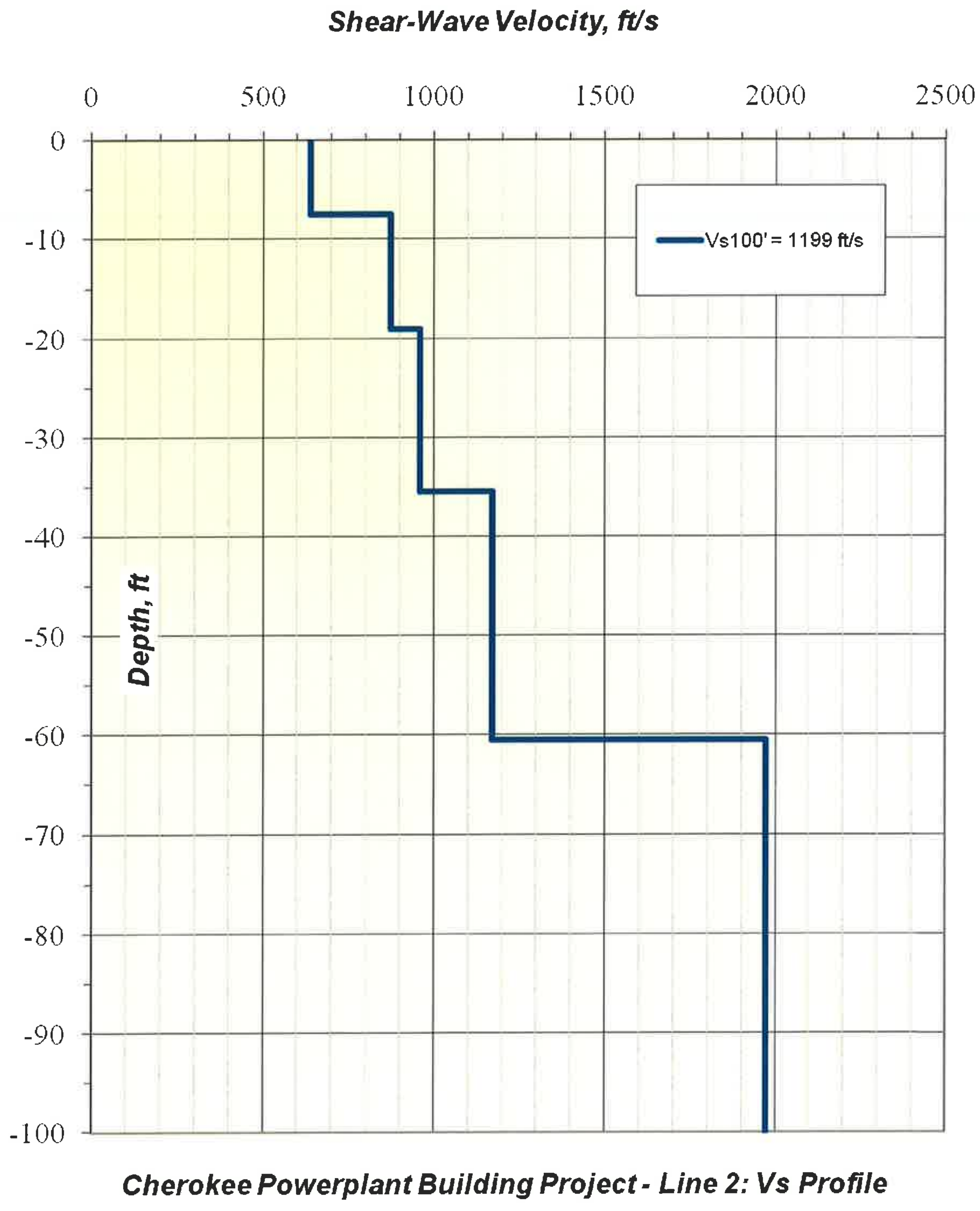
Depth, ft	Vs, ft/s
0.0	748.0
7.5	748.0
7.5	1203.0
23.0	1203.0
23.0	1294.0
63.0	1294.0
63.0	1331.0
81.0	1331.0
81.0	2069.0
100.0	2069.0

Line 5 Vs100' = 1307 ft/s



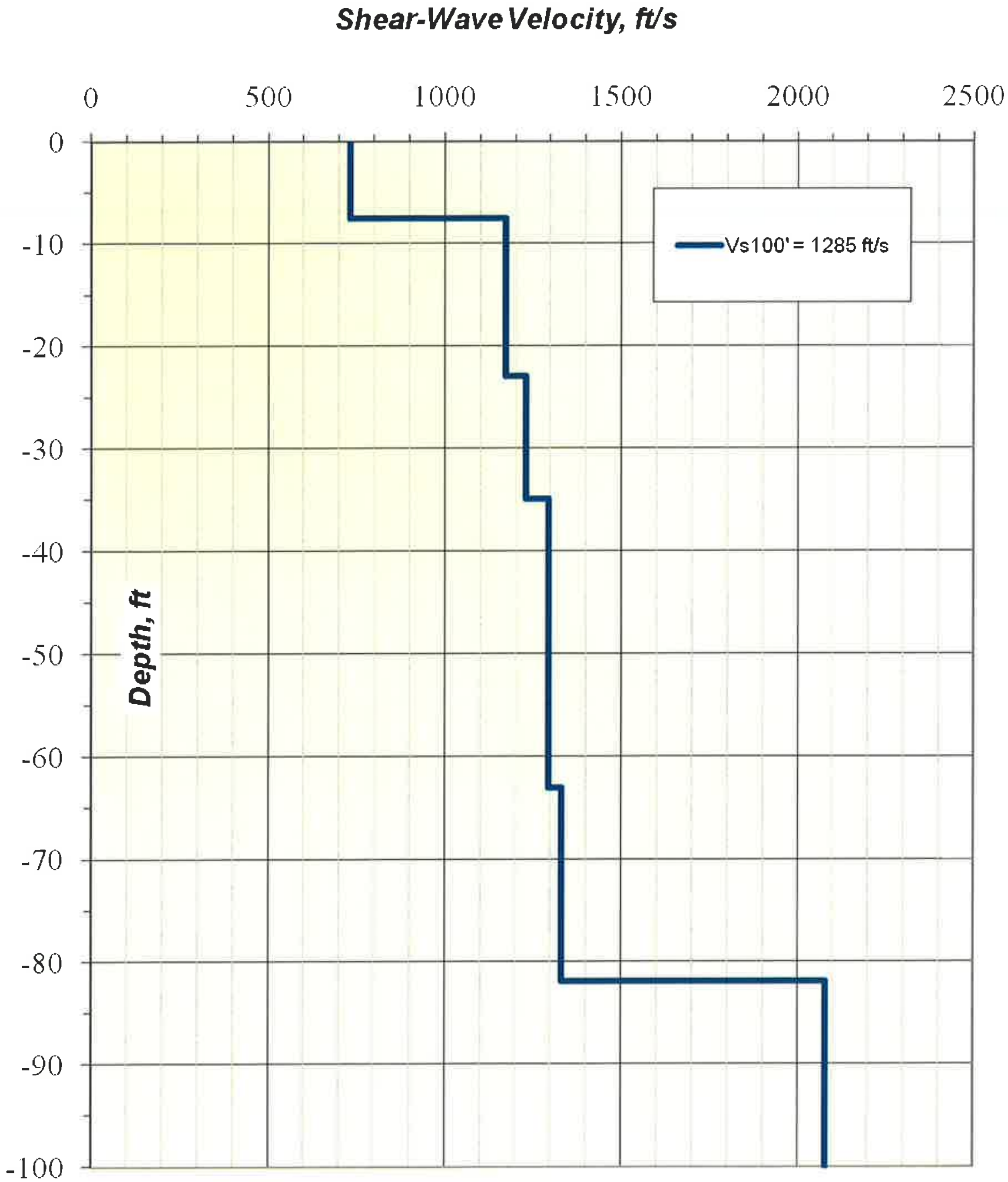
Cherokee Powerplant Building Project - Line 1: Vs Profile

Figure 3.



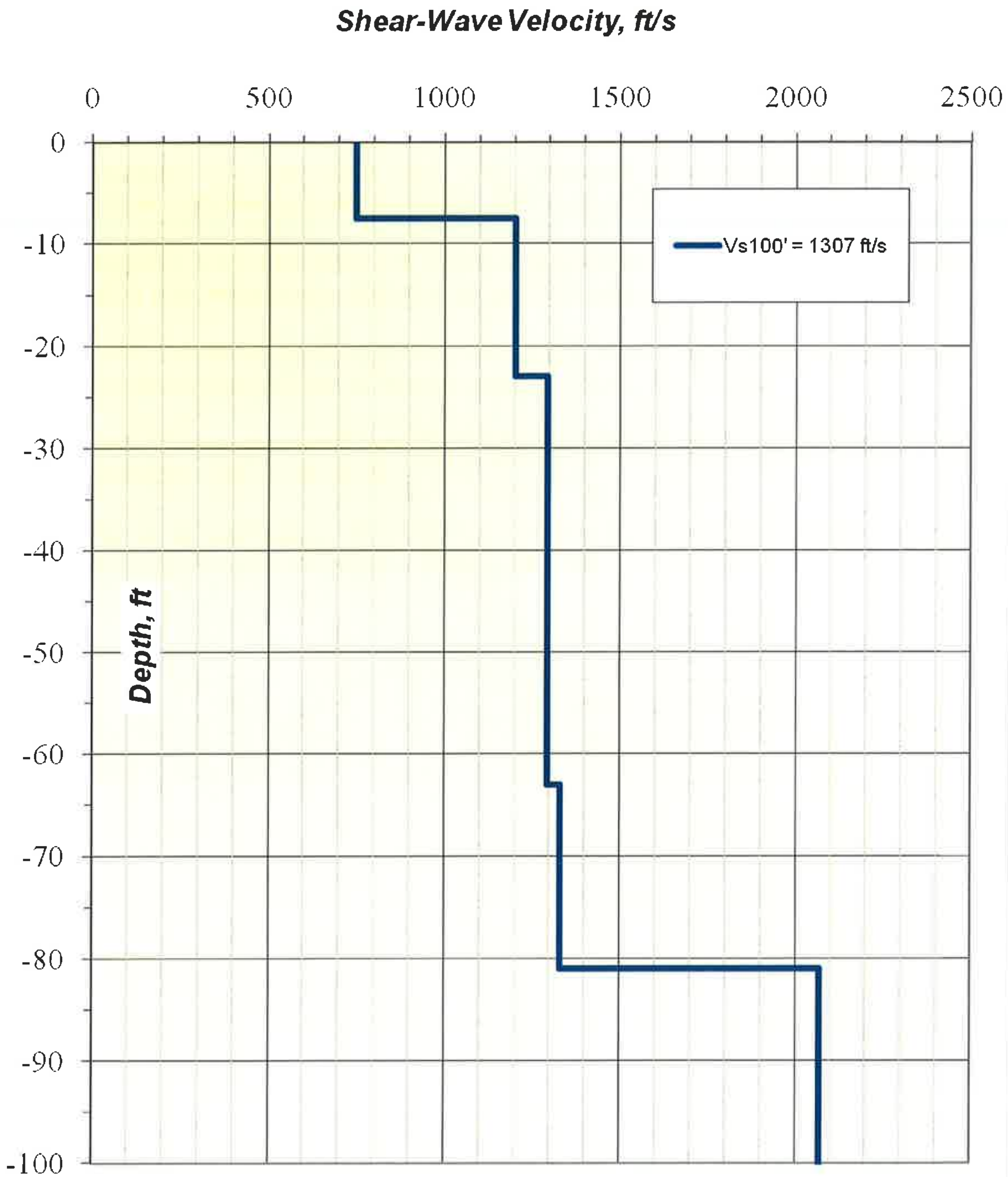
Cherokee Powerplant Building Project - Line 2: Vs Profile

Figure 4.



Cherokee Powerplant Building Project - Line 3: Vs Profile

Figure 5.



Cherokee Powerplant Building Project - Line 5: Vs Profile

Figure 6.

Attachment B

Monitoring Well Logs

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Table 2. Well Construction Details for New Groundwater Monitoring Wells Cherokee Station, 2015

Well	**Northing** (State Plane, NAD 1983 UTM Zone 13 N meters)	**Easting** (State Plane, NAD 1983 UTM Zone 13 N meters)	**Elevation TOC** (feet)	**Well Total Depth** (feet bgs)	**Depth of Screen Interval** (feet bgs)	**Well Stickup** (feet)	**Casing Type**	**Depth to Water** (feet BTOC)	**Static Water Level** (feet)
MW-7	503100.25399	4406795.9759	5153.86	11.59	6.6-11.6	1.16	2-inch Sch. 40 PVC	5.5	5148.36
MW-8	503284.39859	4406859.9822	5140.64	12.67	7.7-12.7	1.25	2-inch Sch. 40 PVC	8.3	5132.34
MW-9	503266.2015	4406770.1456	5141.26	23.18	13.2-23.2	1.57	2-inch Sch. 40 PVC	19.06	5122.20
MW-10	503243.54239	4406678.6084	5140.88	38.61	28.6-38.6	1.59	2-inch Sch. 40 PVC	25.41	5115.47
MW-13	503100.2539	4406795.9759	5174.497	32.75	22.8-32.8	2.05	2-inch Sch. 40 PVC	31.24	5143.257

Notes: TOC = top of casing; bgs = below ground surface; BTOC = below top of casing; Depth to water measured December 2015

Boring Log

Page 1 of 1

Project Name Xcel CCR	**Project No.** 266180-006	**Drilling Company** Site Services Drilling, LLC
Boring No. MW-7	**Location** Cherokee Station	**Drilling Rig Type and Drilling Method** CME-75 Hollow Stem Auger

Sample No.	Blow Count	Depth (feet)	Description (USCS)	Remarks
MW-7 0-6' bgs				Collected Sample MW-7 0-6' bgs submitted for geotechnical analysis
		5		
8-8.5' bgs	Not recorded		Gray 10YR 6/1; Clayey Silt (ML), dense weathered bedrock; friable; wet	depth to water ~6' bgs
		10		
12.5-13' bgs	Not recorded		Gray 10YR 6/1; Clayey Silt (ML), dense weathered bedrock; friable; wet; Iron mineralization	iron staining
		15		
		20		
		25		
		30		
		35		
		40		
		45		
		50		

			Logged By: Justin Bills	**Drilled/Sampled By:** Josh Eckhoff
Total Depth (feet)	**Water Level (feet)**			
13	**After Drilling:** 5.13	**Hours After:** Not recorded	**Date Started:** 11/9/2015	**Date Completed:** 11/9/2015

Boring Log

Page 1 of 1

Project Name	Project No.	Drilling Company
Xcel CCR	266180-006	Site Services Drilling, LLC

Boring No.	Location	Drilling Rig Type and Drilling Method
MW-8	Cherokee Station	CME-75 Hollow Stem Auger

Sample No.	Blow Count	Depth (feet)	Description (USCS)	Remarks
		5		
8.5-9' bgs	Not recorded		Brown 7.5YR 5/4; Coarse Silty Sand (SM), well sorted with Gravel >1"; wet	
		10		
MW-8 12'4"-12'8" bgs	Not recorded		Gray 10YR 6/1; Clayey Silt (ML), bedrock; friable	Sample MW-8 12'4"-12'8" submitted for geotechnical analysis
		15		
		20		
		25		
		30		
		35		
		40		
		45		
		50		

Total Depth (feet)	Water Level (feet)		Logged By:	Drilled/Sampled By:
			Justin Bills	Josh Eckhoff
	After Drilling:	Hours After:	Date Started:	Date Completed:
13.92	9.5	Not recorded	11/9/2015	11/9/2015

Boring Log

Page 1 of 1

Project Name Xcel CCR		**Project No.** 266180-006	**Drilling Company** Site Services Drilling, LLC
Boring No. MW-9	**Location** Cherokee Station		**Drilling Rig Type and Drilling Method** CME-75 Hollow Stem Auger

Sample No.	Blow Count	Depth (feet)	Description (USCS)	Remarks
		5		
8' bgs	Not recorded		Ash, loose, dry	
8.5-9' bgs	Not recorded		Dark brown 10YR 4/3; Fine Silty Sand (SM), poorly sorted, medium dense; moist	Depth to water ~10' bgs
		10		
13-13.5' bgs	Not recorded		Dark brown 10YR 4/3; Fine Silty Sand (SM), poorly sorted, medium dense; wet at 10' bgs	
		15		
18-18.5' bgs			Dark brown 10YR 4/3; Silty Sand (SM), well sorted with Gravel <1"; wet	
MW-9 19'10"-20'2" bgs		20		Sample MW-9 19'10"-20'2" bgs submitted for geotechnical analysis
21-21.5' bgs			Yellowish brown 10YR 5/4; Clayey Silt (ML); wet	
22' bgs			Silt; Grayish blue weathered bedrock; wet	
		25		
		30		
		35		
		40		
		45		
		50		

			Logged By: Justin Bills	**Drilled/Sampled By:** Josh Eckhoff
Total Depth (feet)	**Water Level (feet)**			
23.18	**After Drilling:** 20.6	**Hours After:** Not recorded	**Date Started:** 11/9/2015	**Date Completed:** 11/9/2015

Boring Log

Page 1 of 1

Project Name Xcel CCR	**Project No.** 266180-006	**Drilling Company** Site Services Drilling, LLC
Boring No. MW-10	**Location** Cherokee Station	**Drilling Rig Type and Drilling Method** CME-75 Hollow Stem Auger

Sample No.	Blow Count	Depth (feet)	Description (USCS)	Remarks
		5		
8-8.5' bgs	Not recorded		Yellowish brown 10YR 5/4; Fine Sand (SM) with trace Gravel <1"; moist	
		10		
14.5-15' bgs	Not recorded		Brown 10YR 5/3; Very Fine Sand (SP), poorly sorted; moist	
		15		
16' bgs			Brown 10YR 5/3; Medium Silty Sand (SP): moist	
			Brown 10YR 5/3; Clayey Sand, well sorted with Gravel >1"	
		20		
MW-10 20'4"-20'8" bgs				Sample MW-10 20'4"-20'8" bgs submitted for geotechnical analysis
		25		
25.5-26' bgs			Light brown 7.5YR 6/4; Coarse Sand (SW); well sorted; wet	Depth to water ~26' bgs
		30	As above	
			Light yellowish brown 10YR6/4; Silt (ML); stiff; moist	
		35		
			Silt (ML); blue gray bedrock; moist	
		40		
		45		
		50		

			Logged By: Justin Bills	**Drilled/Sampled By:** Josh Eckhoff
Total Depth (feet)	**Water Level (feet)**			
	After Drilling:	**Hours After:**	**Date Started:**	**Date Completed:**
38.61	27.6	Not recorded	11/10/2015	11/10/2015

Attachment C

CCR Impoundments Plan and Sections

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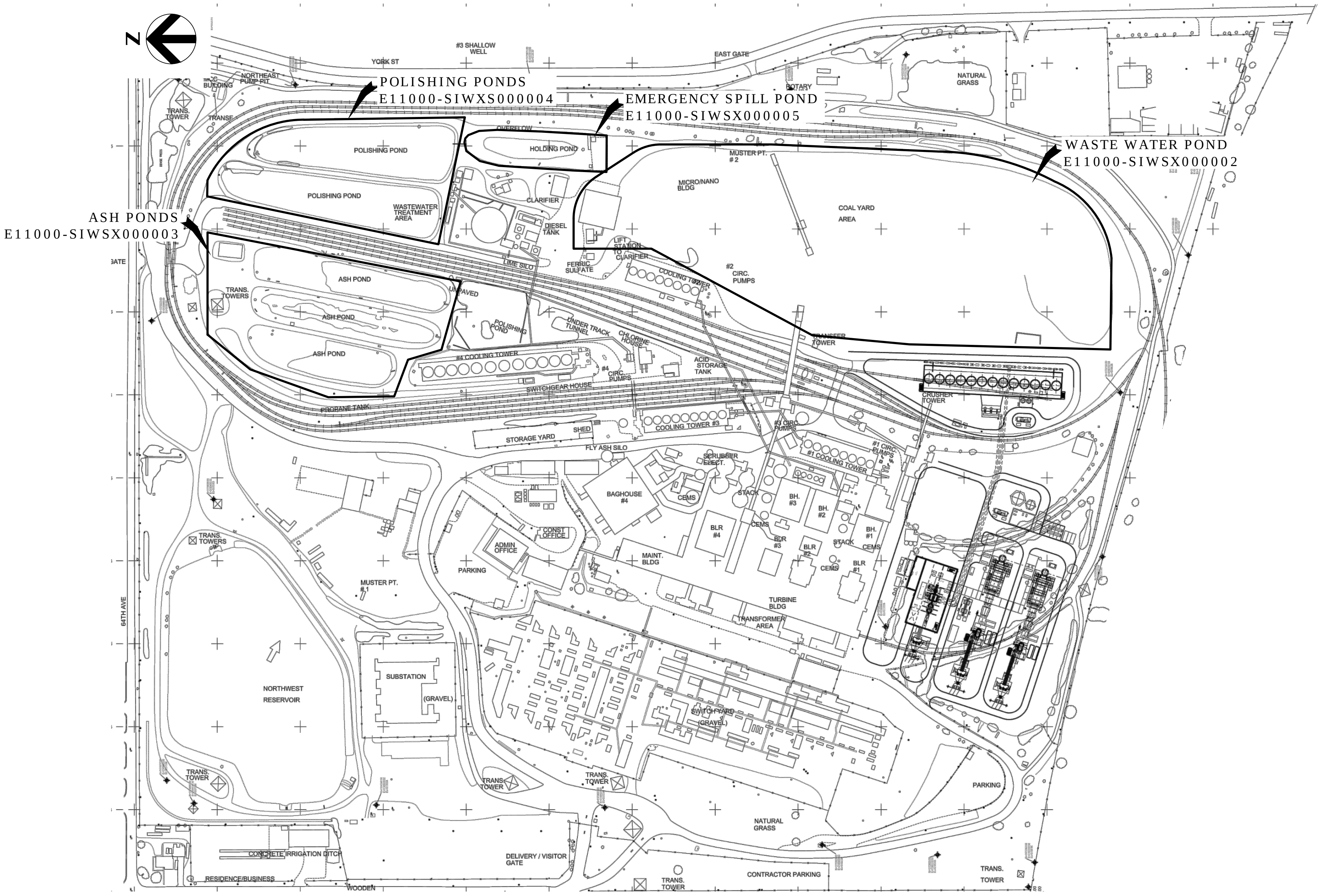
A B C D E F G H I J K

FOR REFERENCE ONLY



LOCATION MAP

150 0 150 300

1 INCH = 150 FT.

CHEROKEE SEGS - COMMON
POND IMPOUNDMENT - PROJECT

50% ALL PONDS REVIEW: 06/30/17

NO	REVISION	ZONE	DATE	BY	CHK	ENG
A	50% ALL PONDS REVIEW		06/30/17	BMB	RDM	BJB

NO	REVISION	ZONE	DATE	BY	CHK	ENG

REFERENCE DRAWINGS

DWG NO.	MANUFACTURER	DESCRIPTION

REFERENCE DRAWINGS

DWG NO.	MANUFACTURER	DESCRIPTION

Xcel Energy®
PUBLIC SERVICE COMPANY
OF COLORADO

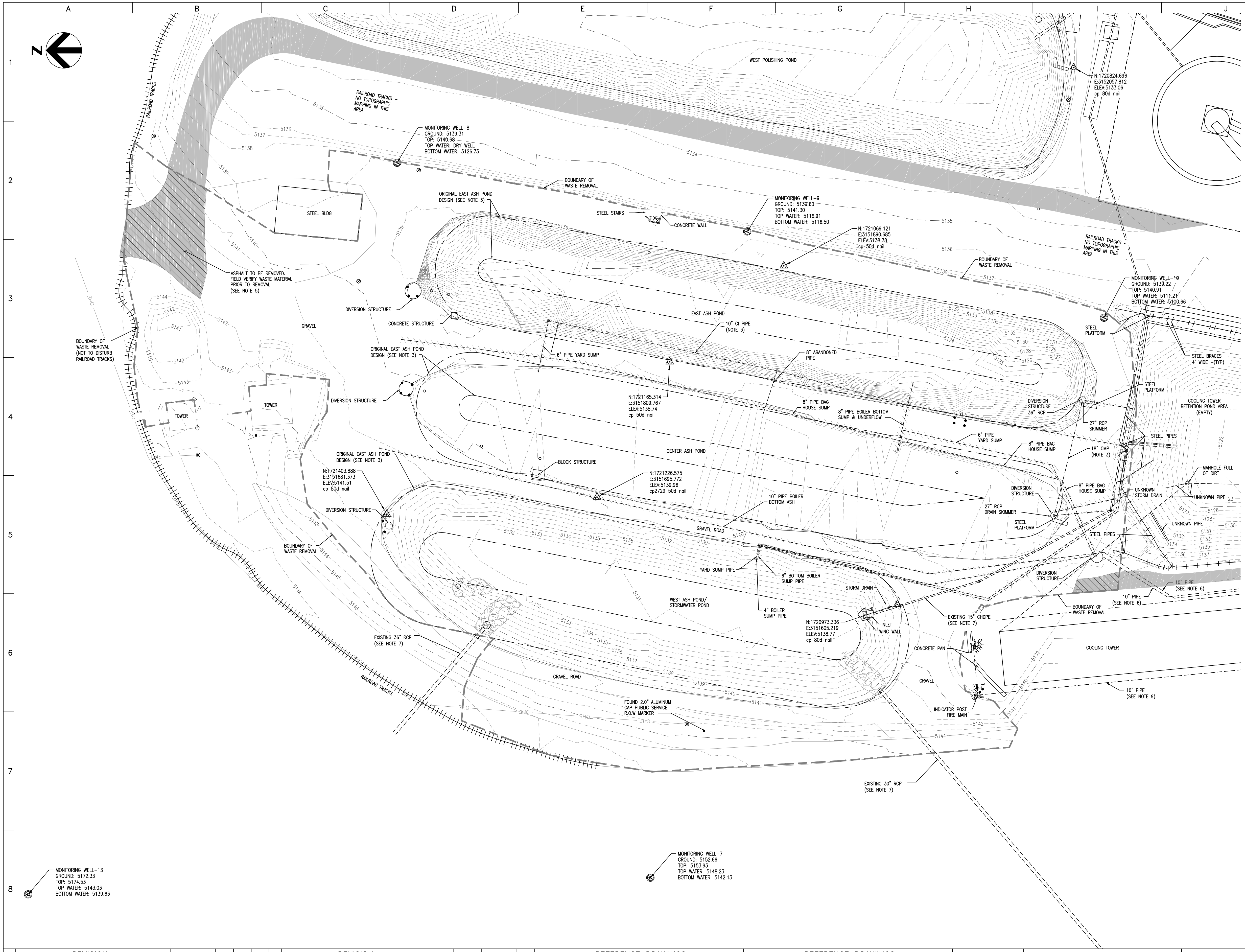
DWN: HDR–BB	DATE: 06/30/17	CHK:XXX	DATE: XXX
ENG: HDR–DM	DATE: XXX	CHK:XXX	DATE: XXX
PM: HDR–MR	DATE: XXX	PROJ. NO:800002047413	
APVD: HDR–BB	DATE: XXX	SCALE:AS SHOWN	

CHEROKEE SEGS – COMMON
POND IMPOUNDMENT PROJECT
AREA MAP

HDR ENGINEERING INC.
1670 BROADWAY, SUITE 3400
DENVER, CO 80202

DWG NO
E11000–SIWXS000001
SHEET NO
2
REV 0

FOR REFERENCE ONLY



NOTES:

1. UTILITY LOCATIONS ARE APPROXIMATE AND ARE TO BE FIELD VERIFIED BY CONTRACTOR.
2. ALL UNDERGROUND UTILITIES MAY NOT BE SHOWN.
3. SEE ORIGINAL POND DESIGN DRAWING NUMBER 110–2.14 FOR POND LIMITS & UTILITY PIPING.
4. SEE ORIGINAL POND DESIGN DRAWING NUMBER 110–2.126 FOR POND LIMITS & UTILITY PIPING.
5. LIMITS OF EXCAVATION FOR WASTE REMOVAL MAY VARY IN FIELD AND SHALL BE EXCAVATED AS NEEDED.
6. SEE DWG NO. 22194 SHEET P6–1C FOR ASH POND PIPES.
7. SEE DWG NO. SIGRS000001–10 FOR STORM WATER/WEST ASH.
8. SEE DWG NO. 110–22.3 FOR UTILITY PIPING
9. MONITORING WELL MEASUREMENTS SHOWN ARE FROM SURVEY. ADDITIONAL READINGS WERE TAKEN AND USED IN POND DESIGN.

50% ALL PONDS REVIEW: 06/30/17

NO	REVISION	ZONE	DATE	BY	CHK	ENG
A	50% ALL PONDS REVIEW		06/30/17	RMP	RDM	BJB

NO	REVISION	ZONE	DATE	BY	CHK	ENG

REFERENCE DRAWINGS

DWG NO.	MANUFACTURER	DESCRIPTION
SIGRS000001–10	SARGENT&LUNDY	CLEANAIR CLEAN JOBS – PLOT PLAN
22194–P6–1C	UTILITY ENG.	MICRO/NANO FILTRATION SYSTEMS – PLOT PLAN
110–2.14	PSCO	EAST ASH POND OVER FLOW
110–7.126	PSCO	ASH SETTLING POND – PLAN AND DETAILS
10–22.3	PSCO	CHEROKEE STEAM PLANT – FIRE PROTECTION

REFERENCE DRAWINGS

DWG NO.	MANUFACTURER	DESCRIPTION

Xcel Energy®
PUBLIC SERVICE COMPANY
OF COLORADO

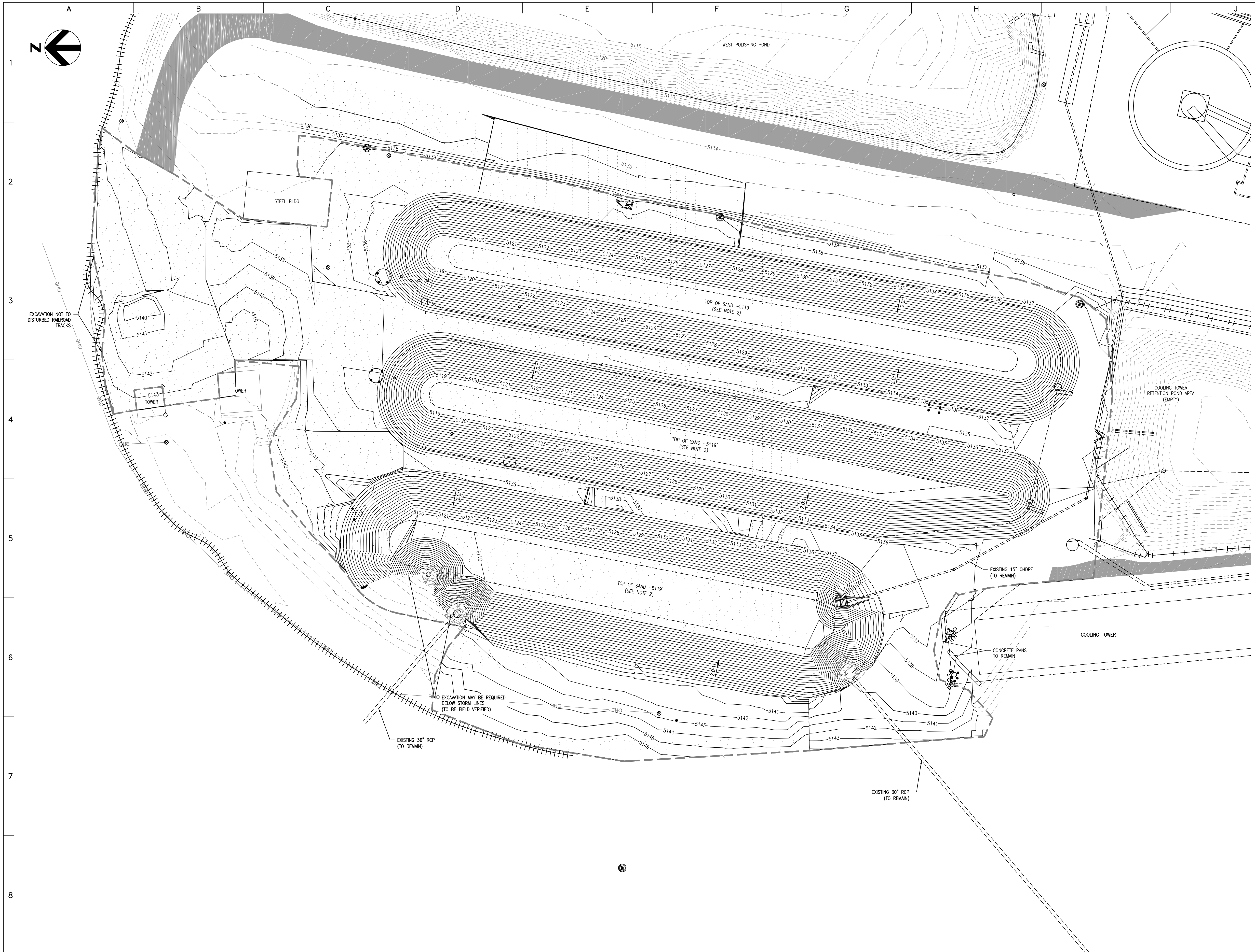
DWN: HDR–RP	DATE: 06/30/17	CHK:XXX	DATE: XXX
ENG: HDR–DM	DATE: XXX	CHK:XXX	DATE: XXX
PM: HDR–MR	DATE: XXX	PROJ. NO:10025968	
APVD: HDR–BB	DATE: XXX	SCALE: 1" = 30'–0"	

CHEROKEE SEGS – COMMON
ASH PONDS
EXISTING CONDITIONS & DEMOLITION

HDR ENGINEERING INC.
1670 BROADWAY, SUITE 3400
DENVER, CO 80202

DWG NO
E11000–SIWXS000003
SHEET NO
1
REV 0

FOR REFERENCE ONLY



ESTIMATE OF QUANTITIES

CCR REMOVAL 55,500 CY

NOTES

1. VOLUME REPRESENTS EXCAVATION FROM EXISTING TOPOGRAPHY TO TOP OF CLEAN NATIVE SAND.
2. TOP OF SAND ELEVATION WAS ESTIMATED BASED OFF ORIGINAL DESIGN DRAWINGS FOR POND GRADING. ORIGINAL POND BOTTOM OF 5119' WAS USED AND 3FT OF SOIL CONTAMINATION BELOW POND BOTTOM WAS ASSUMED RESULTING IN TOP OF SAND = 5116'. A 3' INCREASE IN ELEVATION ADJUSTMENT WAS APPLIED TO ACCOMMODATE OLD VS CURRENT SURVEY DATUM'S (NGVD29 VS NAVD88) RESULTING IN THE TOP OF SAND LAYER BEING 5119' FOR NAVD88 SURVEY. NGVD29 DATUM WAS ASSUMED, BUT NOT CALLED OUT ON ORIGINAL DRAWINGS.

50% ALL PONDS REVIEW: 06/30/17

NO	REVISION	ZONE	DATE	BY	CHK	ENG
A	50% ALL PONDS REVIEW		06/30/17	RMP	RDM	BJB

NO	REVISION	ZONE	DATE	BY	CHK	ENG

REFERENCE DRAWINGS

DWG NO.	MANUFACTURER	DESCRIPTION
SIWXS000003-1	HDR	ASH POND-EXISTING CONDITIONS & DEMOLITION

REFERENCE DRAWINGS

DWG NO.	MANUFACTURER	DESCRIPTION

Xcel Energy®
PUBLIC SERVICE COMPANY
OF COLORADO

DWN: HDR-RP	DATE: 06/30/17	CHK:XXX	DATE: XXX
ENG: HDR-DM	DATE: XXX	CHK:XXX	DATE: XXX
PM: HDR-MR	DATE: XXX	PROJ. NO:10025968	
APVD: HDR-BB	DATE: XXX	SCALE:1" = 30'-0"	

CHEROKEE SEGS – COMMON
ASH PONDS
TOP OF SAND

HDR ENGINEERING INC.
1670 BROADWAY, SUITE 3400
DENVER, CO 80202

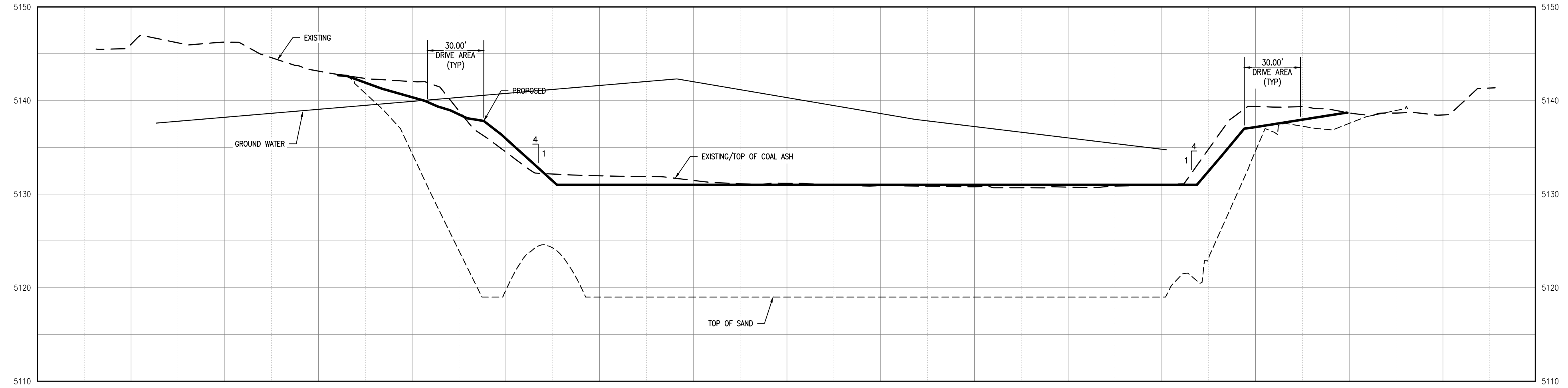
DWG NO
E11000-SIWXS000003
SHEET NO
2
REV 0

FOR REFERENCE ONLY

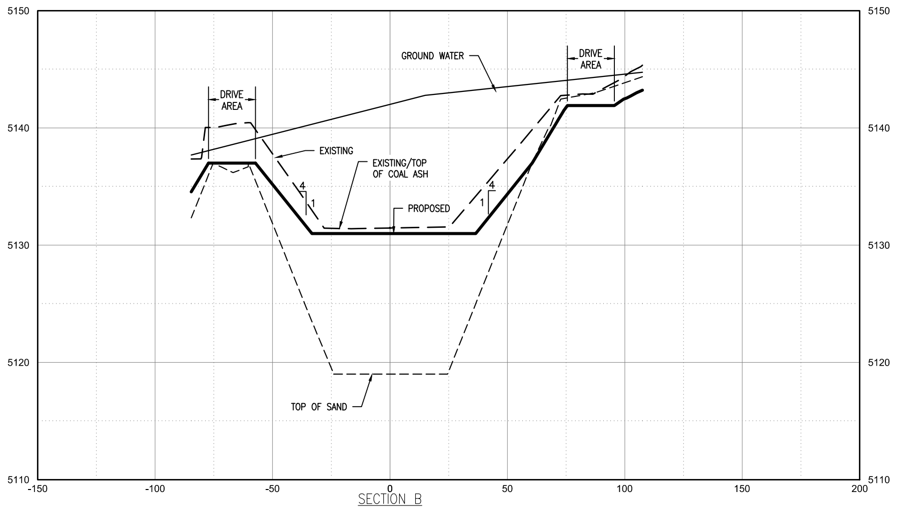
50% ALL PONDS REVIEW: 06/30/17

NOTES:

1. GROUND WATER ELEVATION ESTIMATED FROM SEASONAL HIGH MEASUREMENTS IN MONITORING WELLS.



WEST ASH POND - A
H Scale: 1" = 30.00'
V Scale: 1" = 6.00'



SECTION B
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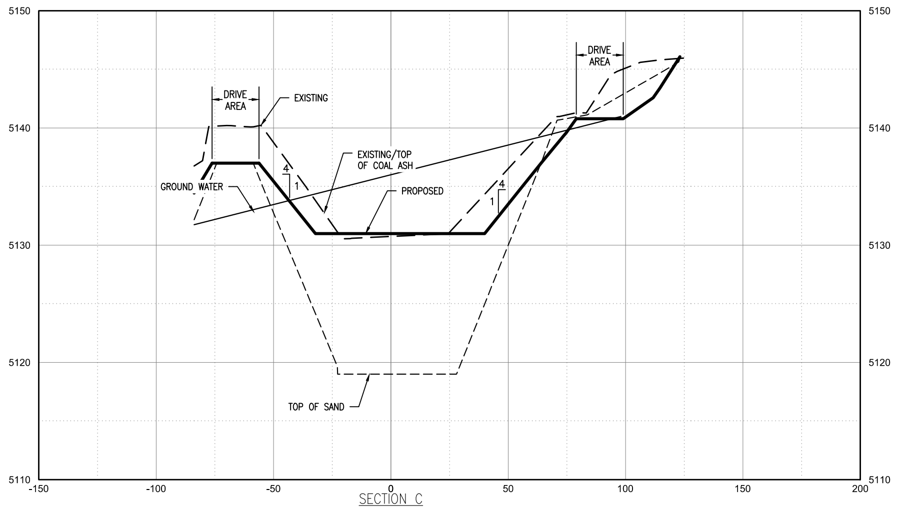
V SCALE: 1"=6.00'



SECTION C
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V SCALE: 1"=6.00'

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A	50% ALL PONDS REVIEW		06/30/17	RMP	RDM	BJB

NO	REVISION	ZONE	DATE	BY	CHK	ENG

REFERENCE DRAWINGS

DWG NO.	MANUFACTURER	DESCRIPTION
SIWXS000003-3	HDR	ASH POND - GRADING PLAN VIEW

REFERENCE DRAWINGS

DWG NO.	MANUFACTURER	DESCRIPTION

Xcel Energy®
PUBLIC SERVICE COMPANY
OF COLORADO

DWN: HDR-RP	DATE: 06/30/17	CHK:XXX	DATE: XXX
ENG: HDR-DM	DATE: XXX	CHK:XXX	DATE: XXX
PM: HDR-MR	DATE: XXX	PROJ. NO:10025968	
APVD: HDR-BB	DATE: XXX	SCALE: 1" = 30'-0"	

CHEROKEE SEGS - COMMON
ASH PONDS
SECTIONS A - C

HDR ENGINEERING INC.
1670 BROADWAY, SUITE 3400
DENVER, CO 80202

DWG NO
E11000-SIWXS000003
SHEET NO
4
REV 0

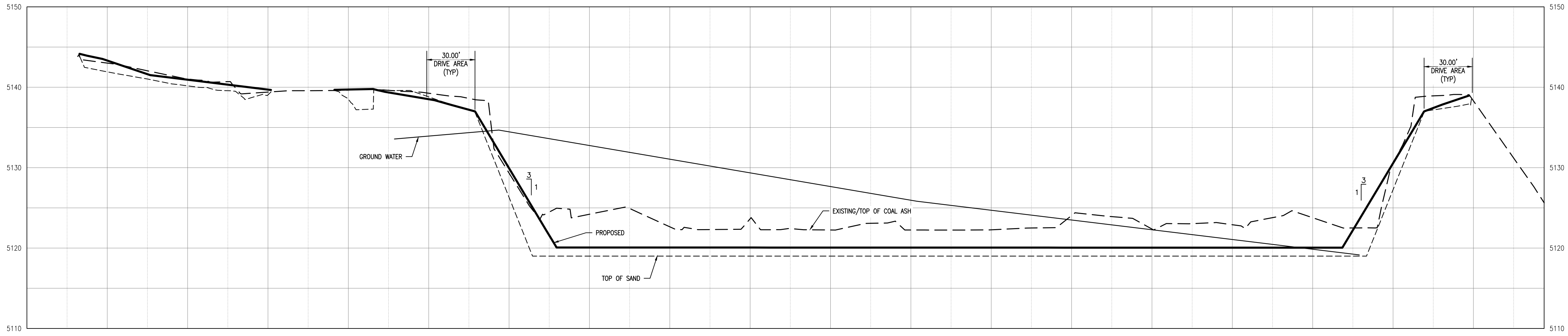
FOR REFERENCE ONLY

A B C D E F G H I J K

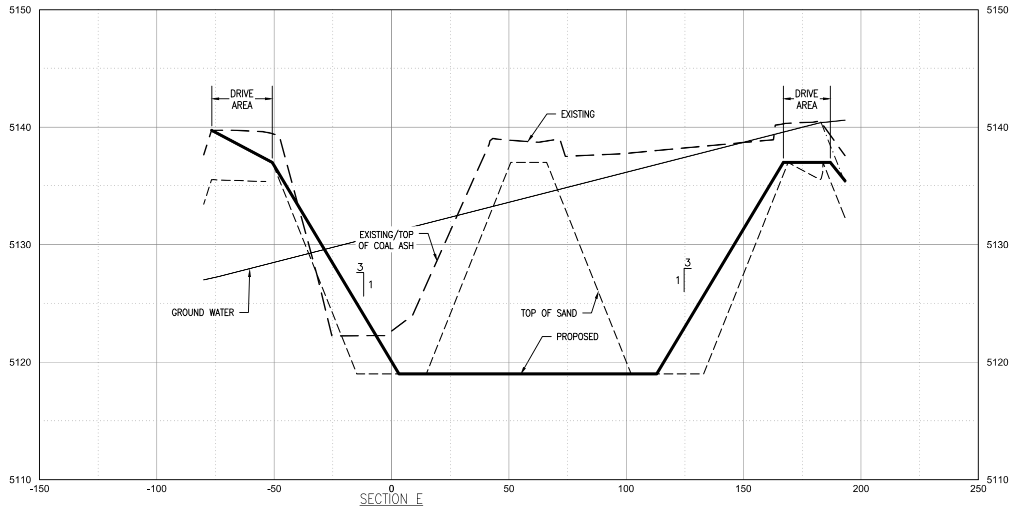
1 2 3 4 5 6 7 8

NOTES:

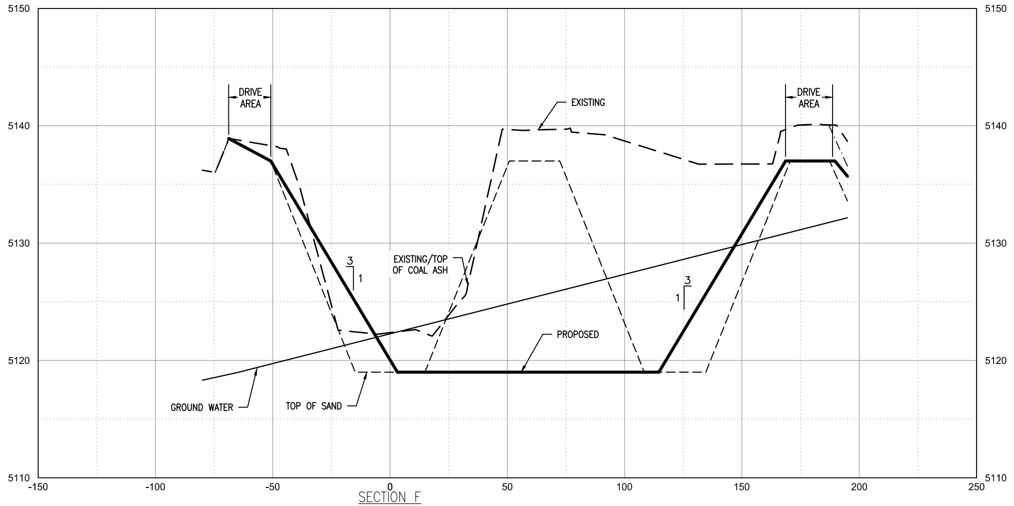
1. GROUND WATER ELEVATION ESTIMATED FROM SEASONAL HIGH MEASUREMENTS IN MONITORING WELLS.



EAST ASH POND – D
H Scale: 1" = 30.00'
V Scale: 1" = 6.00'



SECTION E
H SCALE: 1"=30.00'
V SCALE: 1"=6.00'



SECTION F
H SCALE: 1"=30.00'
V SCALE: 1"=6.00'

50% ALL PONDS REVIEW: 06/30/17

NO	REVISION	ZONE	DATE	BY	CHK	ENG
A	50% ALL PONDS REVIEW		06/30/17	RMP	RDM	BJB

NO	REVISION	ZONE	DATE	BY	CHK	ENG

REFERENCE DRAWINGS

DWG NO.	MANUFACTURER	DESCRIPTION
SIWXS000003-3	HDR	ASH POND – GRADING PLAN VIEW

REFERENCE DRAWINGS

DWG NO.	MANUFACTURER	DESCRIPTION

Xcel Energy®
PUBLIC SERVICE COMPANY
OF COLORADO

DWN: HDR–RP	DATE: 06/30/17	CHK:XXX	DATE: XXX
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PM: HDR–MR	DATE: XXX	PROJ. NO:10025968	
APVD: HDR–BB	DATE: XXX	SCALE: 1" = 30'–0"	

CHEROKEE SEGS – COMMON
ASH PONDS
SECTIONS D – F

HDR ENGINEERING INC.
1670 BROADWAY, SUITE 3400
DENVER, CO 80202

DWG NO
E11000–SIWXS000003
SHEET NO
5
REV 0