Geotechnical Report
for the Exelon Generation Company, LLC
Early Site Permit

Site Safety Analysis Report
Appendix A

Contents

1. Introduction A-1-1
1.1 Purpose, Approach, and Scope A-1-1
1.1.1 Purpose A-1-1
1.1.2 Approach A-1-2
1.1.3 Scope A-1-2
1.2 Investigation Planning and Regulatory Guidance A-1-3

2. Existing Information A-2-1
2.1 Site Surficial Conditions A-2-1
2.2 Regional and Site Geology A-2-1
2.2.1 Regional Physiography A-2-1
2.2.2 Regional Stratigraphy A-2-1
2.2.3 Regional Structural Geology A-2-2
2.2.4 Site Physiography A-2-3
2.2.5 Site Geology A-2-3
2.2.6 Site Structural Geology A-2-4
2.3 Geotechnical Explorations A-2-4
2.3.1 Drilling and Sampling A-2-4
2.3.2 Seismic Surveys A-2-5
2.4 Laboratory Testing A-2-5
2.4.1 Strength Tests A-2-5
2.4.2 Dynamic Tests A-2-5
2.4.3 Other Physical Tests A-2-6
2.5 Clinton Power Station Facility Foundation Excavation and Backfill A-2-6
2.5.1 Excavation A-2-6
2.5.2 Dewatering A-2-6
2.5.3 Excavation Base Treatment A-2-7
2.5.4 Structural Fill and Backfill A-2-7
2.6 Response of Soil and Rock to Static and Dynamic Loading A-2-7
2.6.1 Liquefaction Potential A-2-8
2.6.2 Bearing Capacity A-2-8
2.6.3 Settlement A-2-8
2.6.4 Lateral Earth Pressures A-2-9

3. Field Explorations and Observations A-3-1
3.1 Soil and Rock Drilling and Sampling A-3-1
3.1.1 Locations of Boreholes A-3-1
3.1.2 Soil Drilling and Sampling A-3-2
3.1.2.1 Sampling Intervals, Methods, and Logging A-3-2
3.1.2.2 Standard Penetration Tests Hammer Calibration A-3-3
3.1.2.3 Sample Handling, Preservation, and Transport A-3-4
3.1.2.4 Borehole Completion A-3-4

3.1.3 Rock Coring and Sampling A-3-4
3.2 Piezometer Installation A-3-5
3.3 Cone Penetrometer Testing A-3-6
3.4 Suspension Logging Test A-3-6
3.5 Survey of Investigation Locations A-3-7

4. Laboratory Testing Methods and Results A-4-1
4.1 Classification and Static Engineering Properties Testing A-4-1
4.2 Dynamic Testing A-4-2

5. Geologic and Geotechnical Conditions at the EGC ESP Site A-5-1
5.1 Regional and Site Geology A-5-1
5.1.1 Regional Geology A-5-2
5.1.2 Site Geology A-5-2
5.1.3 Other Geologic Considerations A-5-3
5.1.3.1 Karst Terrain A-5-3
5.1.3.2 Mine Subsidence A-5-4
5.1.3.3 Natural Gas Production and Oil Fields A-5-4
5.1.3.4 Groundwater Springs A-5-4
5.1.3.5 Landslides A-5-5
5.1.3.6 Overall Geologic Suitability A-5-5
5.2 Geotechnical Conditions A-5-5
5.2.1 Soil Profile A-5-5
5.2.2 Soil Classifications and Rock Characteristics A-5-6
5.2.2.1 Richland Loess A-5-6
5.2.2.2 Wisconsinan Till (Wedron Formation) A-5-7
5.2.2.3 Interglacial Zone (Weathered Glasford Formation) A-5-7
5.2.2.4 Illinoian Till (Unweathered Glasford Formation) A-5-8
5.2.2.5 Lacustrine Deposits A-5-8
5.2.2.6 Pre-Illinoian Till and Alluvial/Lacustrine Deposits A-5-9
5.2.2.7 Rock Characteristics A-5-10
5.2.3 Compressibility and Strength Characteristics A-5-10
5.2.3.1 Consolidation Test Results A-5-10
5.2.3.2 Shear Strength Results A-5-12
5.2.4 Dynamic Properties of Soil A-5-13
5.2.4.1 Compressional and Shear Wave Velocities A-5-13
5.2.4.2 Modulus and Damping Properties A-5-15

6. Response of Soil and Rock to Dynamic and Static Loading A-6-1
6.1 Liquefaction Potential A-6-1
6.1.1 Method of Evaluation A-6-1
6.1.2 Results of Liquefaction Evaluations A-6-3
6.2 Bearing Capacity A-6-4
6.3 Settlement Potential A-6-5
6.4 Lateral Earth Pressures A-6-5
6.5 Other Considerations A-6-6

7. Conclusions Relative to Application for the EGC ESP A-7-1
7.1 Information for Early Site Permit Submittal A-7-1
7.2 Information Required for Final Design A-7-2

8. References A-8-1

Attachments

A-1 Borehole Logs and Rock Coring Logs
A-2 Piezometer Construction Logs
A-3 GRL SPT Hammer Calibration Test Report
A-4 Stratigraphic Cone Penetrometer Test Report
A-5 GeoVision Suspension Logging Report
A-6 TSC Laboratory Test Results
A-7 Results of Resonant Column/Cyclic Torsional Shear Testing

Tables

3-1 Piezometer Construction Information and Groundwater Piezometric Surface Elevations A-3.T-1
3-2 Surveyed Investigation Point Coordinates and Elevations A-3.T-2
4-1 Summary of Shelby Tube and Pitcher Samples and Corresponding Geotechnical Test Results A-4.T-1
5-1 Field Recorded Characteristics of Major Stratigraphic Units A-5.T-1
5-2 Summary of Shear and Compression Wave Velocity Test Data A-5.T-2
5-3 Comparison of Laboratory Shear Wave Velocity to In Situ Velocity A-5.T-3
6-1 Summary of Liquefaction Calculations – Expected Maximum Earthquakes - Borehole B-1 ..... A-6.T-1
6-2 Summary of Liquefaction Calculations – Expected Maximum Earthquakes – Borehole B-2 ..... A-6.T-2
6-3 Summary of Liquefaction Calculations - Expected Maximum Earthquakes – Borehole B-3 ..... A-6.T-3
6-4 Summary of Liquefaction Calculations - Expected Maximum Earthquakes – Borehole B-4 ..... A-6.T-4
6-5 Summary of Liquefaction Calculations – FOS Variation w/ M and PGA - Borehole B-1 ..... A-6.T-5
6-6 Summary of CPS Facility Structure Foundation Performance Parameters A-6.T-7

Figures

1-1 EGC ESP and CPS Site Locations Map
2-1 Regional Geologic Cross Sections
2-2 Regional Glacial Map and Physiographic Divisions
2-3 Comparison of Terminology Used During Previous Site Investigations
2-4 Regional Bedrock Geology Map
2-5 Original CPS Site Investigation Locations
2-6 Southwest-Northeast Cross Section (A-A′) Through CPS Site
3-1 EGC ESP Geotechnical Investigation Locations
5-1 Northwest-Southeast Cross Section (B-B′) Through EGC ESP Site
5-2 Southwest-Northeast Cross Section (C-C′) Through EGC ESP Site
5-3 Axes of Major Bedrock Valleys in Central Illinois
5-4 Thickness of the Mahomet Sand
5-5 Bedrock Surface Contours
5-6 Variation of SPT Blowcount $N'_{(60)}$ with Elevation – EGC ESP Site
5-7 Richland Loess – Atterberg Limits (PL and LL) and Moisture Content
5-8 Richland Loess – Dry Density and Moisture Content
5-9 Wisconsinan Till – Atterberg Limits (PL and LL) and Moisture Content
5-10 Wisconsinan Till – Dry Density and Moisture Content
5-11 Interglacial Zone – Atterberg Limits (PL and LL) and Moisture Content
5-12 Interglacial Zone – Dry Density and Moisture Content
5-13 Illinoian Till – Atterberg Limits (PL and LL) and Moisture Content
5-14 Illinoian Till – Dry Density and Moisture Content
5-15 Pre-Illinoian Till – Atterberg Limits (PL and LL) and Moisture Content
5-16 Pre-Illinoian Till – Dry Density and Moisture Content
5-17 All Soils – Atterberg Limits (PL and LL) and Moisture Content
5-18 All Soils – Dry Density and Moisture Content
5-19 Shear and Compressional Wave Velocities and Other Soil Properties
5-20 G/Gmax Plot - Resonant Column and Cyclic Torsion Test Results
5-21 Material Damping Plot - Resonant Column and Cyclic Torsion Tests Results
5-22 Gmax Variation with Confining Pressure – Resonant Column Test Results
5-23 G/Gmax Plot - Resonant Column and Cyclic Torsion Test Results Compared to EPRI Curves
5-24 Material Damping Plot - Resonant Column and Cyclic Torsion Test Results Compared to EPRI Curves
6-1 Factor of Safety Against Liquefaction with Depth Borehole B-1
6-2 Factor of Safety Against Liquefaction with Depth Borehole B-2
6-3 Factor of Safety Against Liquefaction with Depth Borehole B-3
6-4 Factor of Safety Against Liquefaction with Depth Borehole B-4
6-5 Factor of Safety Against Liquefaction with Depth: Variable PGA for M = 6.5 at B-1
6-6 Factor of Safety Against Liquefaction with Depth: Variable M for PGA = 0.25 at B-1

Acronyms and Abbreviations

Many of the acronyms and abbreviations listed below are specific to geotechnical terminology in this report and thus may differ from those presented in Appendix A of the Administrative Information for the Exelon Generation Company, LLC, Early Site Permit.

σ_o'	mean confining pressure
γ	shearing strain amplitude
ASTM	American Society for Testing and Materials
bgs	below ground surface
C_c	compression index
C_r	recompression index
CCRR	corrected cyclic resistance ratio
CEUS	central and eastern United States
CFR	Code of Federal Regulations
CIU	isotropically consolidated-undrained
COL	combined operating license
CPS	Clinton Power Station
CPT	cone penetrometer testing
CRR	cyclic resistance ratio
CSR	cyclic stress ratio
D	damping ratio
EGC	Exelon Generation Company
ER	environmental report
ERTS	Earth Resources Technology Satellite
ESP	Early Site Permit
fps	feet per second
FOS	factor of safety
ft	foot/feet

g	acceleration of gravity
G	shear modulus
G/G_{max}	shear modulus ratio
GPS	global positioning system
GRL	GRL Engineers
in.	inch/inches
ISGS	Illinois State Geological Survey
ksf	kips per square foot
LL	liquid limit
LLC	Limited Liability Company
M	magnitude
MSF	magnitude scaling factor
mi	mile/miles
msl	mean sea level
NMFZ	New Madrid Fault Zone
OBE	Operating Basis Earthquake
P200	percentage of soil finer than the No. 200 sieve
P_c'	preconsolidation
pcf	pounds per cubic feet
pci	pounds per cubic inch
pga	peak ground acceleration
PI	plasticity index
PL	plastic limit
psf	pounds per square foot
psi	pounds per square inch
PVC	polyvinyl chloride
Q	unconfined compression
RQD	rock quality designation
SPT	standard penetration test
SSAR	site safety analysis report

SSE	safe shutdown earthquake
TSC	Testing Service Corporation
tsf	tons per square foot
UHS	ultimate heat sink
USAR	updated safety analysis report
USCS	United Soil Classification System
USGS	Unites States Geological Survey
USNRC	United States Nuclear Regulatory Commission
UU	unconsolidated-undrained
Vs	shear wave velocity
Vp	compression wave velocity
WGS	World Geodetic System
WUS	western United States

CHAPTER 1

Introduction

This Geotechnical Report was prepared as part of the Application for the Exelon Generation Company (EGC), Limited Liability Company (LLC), Early Site Permit (ESP). The EGC ESP Site is located adjacent to the operating Clinton Power Station (CPS) Site, in the center of the State of Illinois, approximately 10 miles (mi) east of the City of Clinton, Illinois. The work carried out for the EGC ESP application included geotechnical field explorations, laboratory testing, and engineering evaluations. This Geotechnical Report documents the methods, results, and interpretations of this work. Information contained in this Geotechnical Report is used as: (1) a basis for preparing sections in both the Site Safety Analysis Report (SSAR) and in the Environmental Report (ER) for the Application for the EGC ESP and (2) input to seismic hazards work completed for the EGC ESP Site. The seismic hazards work is summarized in Section 2.5 of the SSAR and discussed in detail within Appendix B of this SSAR.

1.1 Purpose, Approach, and Scope

The EGC ESP requires that geotechnical conditions at the EGC ESP Site be described and evaluated relative to requirements within the regulatory framework for an ESP. The purpose, approach, and scope of work that were performed to address these ESP requirements are summarized below.

1.1.1 Purpose

The primary purpose of the geotechnical work described in this Geotechnical Report is to demonstrate that geologic and geotechnical conditions at the EGC ESP Site are suitable for the future development of a reactor plant design. The following two conditions are required to demonstrate EGC ESP Site suitability:

- There are no geologic hazards that could affect the construction and operation of the facility. These geologic hazards could include potentially unstable slopes, active faults, or underground cavities.
- Relevant geotechnical site characteristics have been appropriately quantified. These site characteristics include static and dynamic soil properties, and specifically include liquefaction potential, bearing capacity, and shear wave velocity. Geotechnical site characteristics have been evaluated by the recent EGC ESP Site investigation, and by demonstration of consistency of the geotechnical soil properties at the EGC ESP Site with those at the CPS Site, as presented in Section 2.5 of the CPS USAR (CPS, 2002). Figure 1-1 shows the locations of the EGC ESP and CPS Sites.

The purpose of the geotechnical work described in this Geotechnical Report was not, however, to provide sufficient information to finalize the design and construction requirements for future development at the EGC ESP Site. Additional vendor-specific investigation activities may be required once a reactor plant design is selected.

1.1.2 Approach

The approach taken during the planning and performance of geotechnical work for the EGC ESP Site relies heavily on the extensive geotechnical database developed for the CPS Site. This existing database is found in the CPS USAR (CPS, 2002).

Significant numbers of field explorations, laboratory tests, and geotechnical studies were performed in the mid-1970s for design and construction of the CPS Facility, as reported in the CPS USAR. The EGC ESP Site is approximately 700 feet (ft) southwest of the CPS Site. Section 2.5 of the CPS USAR indicates that the geologic conditions are consistent within this distance. On this basis, the extensive geotechnical database for the CPS Site is considered applicable to the EGC ESP Site. A geotechnical program was developed to collect sufficient information at the EGC ESP Site to assess the similarity of conditions between the CPS and EGC ESP Sites. Field explorations and laboratory testing programs that would allow direct comparisons of data collected at the EGC ESP Site with the CPS Site database were developed and performed.

The approach to this geotechnical engineering work was also developed to address advances in soil testing that have occurred since the original geotechnical work was completed for the CPS Site. One of the primary areas of development over the past 30 years has been the characterization of the dynamic properties of soils. New methods of in situ dynamic property measurement and laboratory cyclic (dynamic) testing became available in the 1980s and 1990s. These new methods allow more accurate determination of shear wave velocity in situ and better determination of the variation of shear modulus and material damping properties of soil with shearing strain amplitude. Both developments enable higher quality site response modeling to be carried out during seismic ground response evaluations (i.e., determination of time histories and response spectra at the ground surface).

1.1.3 Scope

The scope of the geotechnical work completed for the EGC ESP includes the following activities:

- Review of geologic and geotechnical information summarized in Section 2.5 of the CPS USAR, as well as more current site-related literature available since the preparation of the CPS USAR;
- Field explorations consisting of soil drilling, rock coring, sampling of soil and rock, cone penetrometer testing (CPT) soundings, and shear wave velocity measurements using CPT and in-hole geophysical logging methods;
- Laboratory tests to evaluate physical soil properties, static properties, and dynamic properties of representative soils from the site; and
- Engineering studies to evaluate the liquefaction potential of cohesionless soil layers located below the groundwater table and to assess typical foundation design conditions such as bearing capacity, settlement characteristics, and lateral earth pressures.

When the scope of work was developed for the EGC ESP Site, the geotechnical requirements for an ESP versus the requirements for the combined operating license (COL) stage were

evaluated. A basic difference in concept between an ESP and the COL stage was identified, which affected the scope of geotechnical work developed for the EGC ESP Site. In contrast to the COL stage, an ESP involves an evaluation of the site characteristics relative to the requirements of a number of different potential reactor plant designs. These reactor plant designs differ in terms of size, loads, and geometry. As an example of these differences, the base of the power block could range from 30 ft bgs to over 100 ft bgs, depending on the particular vendor. Since the reactor plant design will not be selected until the future, specific geotechnical criteria required for the design of the specific reactor plant design structure are unknown at the time of this report (2003). Once the reactor plant design is selected, then additional geotechnical studies, including field explorations and laboratory testing, may be required to provide unit-specific design information.

This difference between an ESP and the COL stage led to the development of a scope of work which focused on confirming that geotechnical site characteristics at the EGC ESP Site are consistent with those previously determined for the CPS Site. The scope of the explorations, laboratory testing, and engineering evaluations was less for this confirmation work than would be expected for a green-field development. More attention was given to confirmation that the same soil layering with the same soil properties exists at the EGC ESP Site as exists at the CPS Site. Information normally needed for final design of foundations was deferred until the COL stage, when a specific reactor plant design with known dimensions and weights will be selected. Additional explorations and laboratory testing required for the COL stage to meet final design requirements depends on the foundation design requirements. The COL applicant will utilize the guidance provided in Regulatory Guide 1.132 when planning the locations, depths, and types of explorations for the final design. The scope of future final design explorations will also consider the importance of soil-property variation to system performance and the apparent margin in performance for the selected system in light of the potential soil-property variation.

1.2 Investigation Planning and Regulatory Guidance

The EGC ESP Site geotechnical investigation was planned and performed in accordance with guidance in the following two documents:

- Regulatory Guide 1.132: *Site Investigations for Foundations of Nuclear Power Plants* (USNRC, 1979).
- Regulatory Guide 1.138: *Laboratory Investigations of Soils for Engineering Analysis and Design of Nuclear Power Plants* (USNRC, 1978).

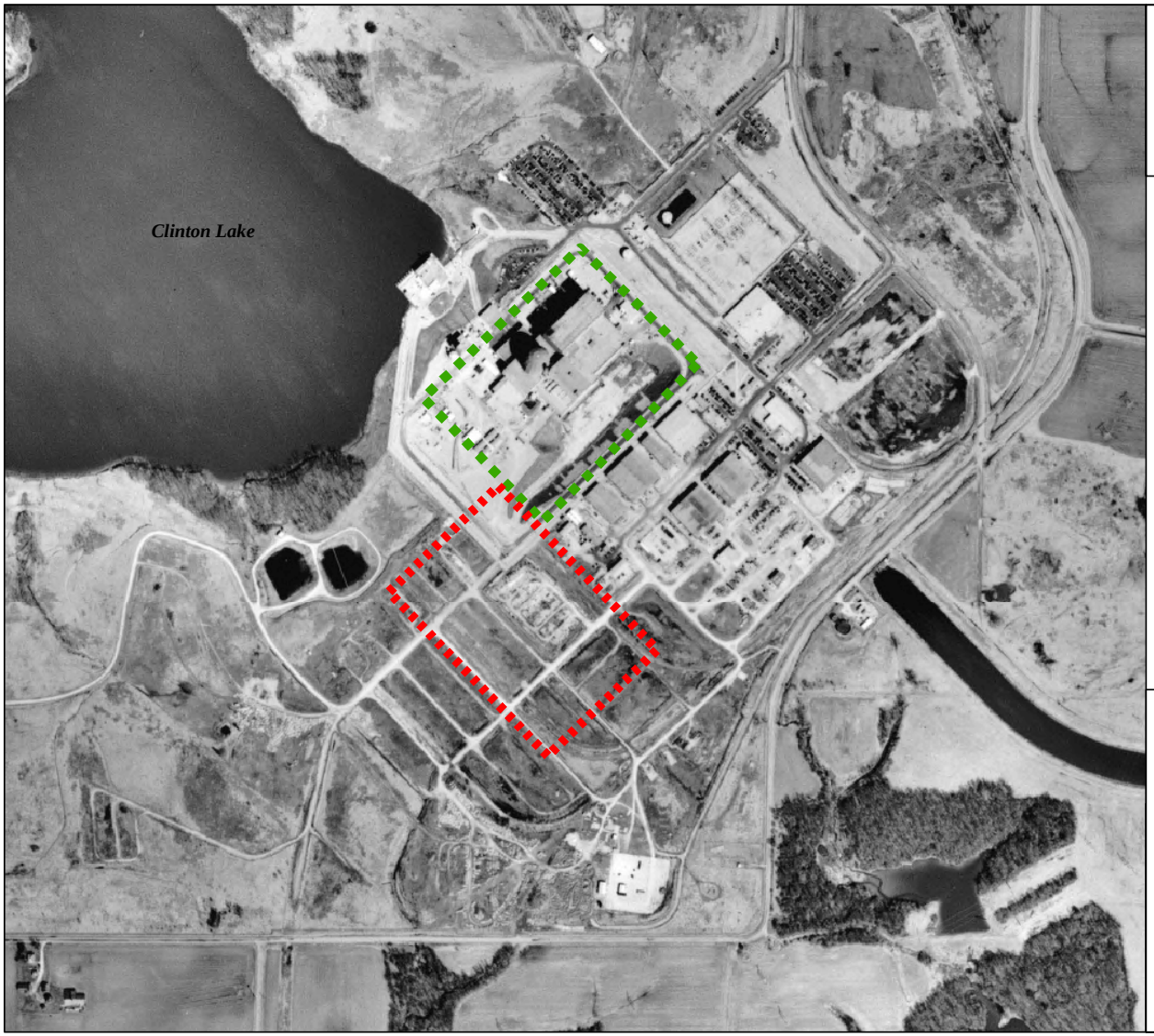
These regulatory guides were developed for use in the planning of subsurface investigations for design and licensing of nuclear power plants. The EGC ESP Site investigation is not intended to provide all information sufficient for facility design, but rather to confirm that the site is suitable for future development. Therefore, not all of the guidance provided in these regulatory guides is applicable to the EGC ESP Site. Relevant guidance from these documents, such as subsurface investigation methods, sample collection and preservation procedures, and laboratory procedures, has been followed. Since the reactor plant design has not been selected or configured, other guidance in these documents is not applicable for the EGC ESP, such as the spacing and depth of penetration of geotechnical boreholes

beneath Class I Structures. This information will be developed and provided as part of the COL stage.

The following draft regulatory guides were also reviewed during planning of the EGC ESP Site geotechnical investigation:

- Draft Regulatory Guide 1101 (DG-1101): *Site Investigations for Foundations of Nuclear Power Plants* (proposed Revision 2 of Regulatory Guide 1.132)(USNRC, 2001a).
- Draft Regulatory Guide 1105 (DG-1105): *Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites* (USNRC, 2001b).
- Draft Regulatory Guide 1108 (DG-1108): *Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants* (proposed Revision 1 of Regulatory Guide 1.138) (USNRC, 2001c).

As with the regulatory guides, not all of the guidance in the draft guides is applicable to the EGC ESP Site geotechnical investigation. Relevant guidance from the draft guides was considered while planning the EGC ESP Site geotechnical investigation, but guidance in the regulatory guides was given primary consideration where guidance differed between the regulatory guides and the draft guides.



Geotechnical Report for the EGC Early Site Permit

Figure 1-1
EGC ESP And CPS Site Locations Map

Legend

Approximate CPS Site Footprint

EGC ESP Site Footprint

N

Fee

0 300 600 1,200

CHAPTER 2

Existing Information

This chapter provides a summary of information that can be found in the CPS USAR for the CPS Site. The CPS USAR includes information on the regional and site geology, results of field explorations, results of laboratory tests on soil samples from the CPS Site, observations associated with the excavation and backfill work done during construction of the CPS facility, and information on the response of soil and rock to static and dynamic loading. The EGC ESP Site is approximately 700 ft from the CPS Site and the geologic conditions are similar at both sites; therefore, the geologic and geotechnical data for the CPS Site is relevant to conditions at the EGC ESP Site.

2.1 Site Surficial Conditions

Ground surface topography in the vicinity of the CPS Site is relatively flat, ranging from approximately 730 to 740 ft above mean sea level (msl). The CPS Site is occupied by the operating facility and support structures, as well as numerous gravel and paved roadways and parking structures. Clinton Lake is located adjacent to the CPS Site to the northwest.

2.2 Regional and Site Geology

The regional and site geology for the CPS Site is fully described in Sections 2.5.1, 2.5.2, and 2.5.3 of the CPS USAR. The summary of information presented in this section of the Geotechnical Report supports interpretations of the geologic conditions at the EGC ESP Site discussed in Chapter 5.

2.2.1 Regional Physiography

The region of the United States in which the CPS Site is located is part of the Till Plains Section of the Central Lowland Physiographic Province (see the CPS USAR, Section 2.5.1.1.1). Terrain in central Illinois and adjacent Indiana is typical of the province, and it consists of undulating, low-relief topography formed by a glacial drift cover that ranges in thickness from a few tens of feet to several hundreds of feet. Much of the Till Plains Section is characterized by landforms of low, commonly arcuate ridges, called moraines, interspersed with relatively flat intermorainal areas. Postglacial stream development has dissected the drift mantle and, in some areas along the main valleys, preglacial bedrock has been exposed by erosion. However, there are no bedrock exposures near the site area.

2.2.2 Regional Stratigraphy

As discussed in Section 2.5.1.1.2 of the CPS USAR, the regional surface geology is dominated by relatively thin deposits of Quaternary glacial drift. During the Quaternary, widespread glacial deposition occurred in the regional area as a result of continental glaciation. The resulting Quaternary deposits are classified as part of the Pleistocene Series.

The deposits consist predominantly of glacial or glacially-derived sediments of glacial till, outwash, loess (a wind-blown silt), and glaciolacustrine deposits, as well as alluvium.

There were four major periods of glaciation during the Pleistocene time in the regional area that resulted in the surface geology. From youngest to oldest, these periods are known as the Wisconsinan, Illinoian, Kansan, and Nebraskan Stages. Wisconsinan deposits are found near ground surface throughout the region. Illinoian age deposits are present beyond the limit of Wisconsinan glaciation in northern and central Illinois. Illinoian age deposits are also found beneath the Wisconsinan drift cover. Kansan and Nebraskan age glacial deposits are present at the surface and in the subsurface in areas of Iowa, Missouri, and parts of western and east-central Illinois.

Most of the regional Quaternary glacial materials are underlain by thick sequences of gently dipping (25 ft per mi) Paleozoic sedimentary rock, although Mesozoic and Cenozoic age deposits lie above Paleozoic rock in a few areas in the Mississippi Embayment, western Illinois, eastern Missouri, and southern Indiana. The bedrock surface throughout much of Illinois is of the Paleozoic age, Pennsylvanian system, and ranges from hundreds to thousands of feet in thickness. The Paleozoic sedimentary rock sequence is punctuated by several non-conformities of regional importance, reflecting widespread advances and withdrawals of the Paleozoic seas across the interior of North America.

Older Paleozoic bedrock of Mississippian, Devonian, Silurian, Ordovician, and Cambrian Systems underlay Pennsylvanian bedrock. These underlying Paleozoic systems range from hundreds to thousands of feet in thickness, and consist primarily of shales, limestones, and sandstones. The thickness of bedrock sequences is dependant on original deposition and subsequent erosion, and Paleozoic bedrock is significantly thicker at the center of structural basins such as the Illinois Basin. Beneath the Paleozoic is a basement complex of Precambrian igneous and metamorphic rock. Basement Precambrian igneous rock ranges from 2,000 to 13,000 ft bgs.

2.2.3 Regional Structural Geology

The North Central United States is one of the more stable areas of the United States (see the CPS USAR, Section 2.5.2.1.1). The dominant structures of the regional area and vicinity are the Illinois Basin and its bounding structures. The Illinois Basin is an oval-shaped basin in southeastern Illinois with the axis of the basin is approximately 350 mi long, and the minor axis is approximately 250 mi long. The deepest part of the basin in southeastern Illinois has sediments that are 12,000 to 14,000 ft thick. This basin is surrounded by and contains structural arches, embayments, fault zones, and anticlines. Locally, folds and faults are superimposed across the region. Predominant among these is the LaSalle Anticline, located approximately 40 mi of the CPS Site (see Figure 2-1).

The Illinois Basin and other regional structural features typically formed during intermittent slow subsidence and gentle uplift through the Paleozoic. The erosion of most of the upper portion of the Paleozoic and overlying geologic record does not allow precise dating of the end of formation of some of the regional structural features. However, there is no evidence that faulting, folding, or other structural sediments continued during the Pleistocene.

2.2.4 Site Physiography

The site lies within the Bloomington Ridged Plain physiographic subsection of the Till Plains Section, as summarized in the CPS USAR, Section 2.5.1.2.1 (and shown in Figure 2-2). The CPS Site is located in an area of uplands, consisting of Wisconsinan-age ground moraine that have been dissected by the Salt Creek and the North Fork of the Salt Creek. The uplands consist of gently rolling ground moraine, located just east of the Shelbyville end moraine, with local relief of about 10 ft, except near the drainage ways. Average elevation of the uplands is approximately 740 ft above msl.

Two perennial streams, Salt Creek and North Fork of the Salt Creek, are present near the CPS Site. The two streams join in the southern portion of the Site area. The two streams flow generally to the southwest with gradients of 2 to 3 ft per mi in the site area. They have eroded through the upland deposits of the Wisconsinan-age Wedron Formation and Robein Silt, the Illinoian-age weathered Glasford Formation, and into the upper part of the Illinoian-age unaltered Glasford Formation. The elevation of the floodplains of the two streams in the area is at approximately 660 ft above msl. Maximum relief in the area is on the order of 80 ft.

2.2.5 Site Geology

Near the CPS Site, approximately 170 to 360 ft of Quaternary deposits overlie an irregular Pennsylvanian bedrock surface that is largely erosional in origin and characterized by valleys (such as the Mahomet Bedrock Valley) and uplands that developed before glacial time (see the CPS USAR, Section 2.5.1.2.2). The CPS Site is located a few miles inside the extent of Wisconsinan glaciation (see Figure 2-2). Surficial deposits in the upland areas consist of a veneer of Richland Loess over glacial till of the Wedron Formation, both of the Woodfordian substage of the late Wisconsinan Stage. Other stratigraphic units in the upland area, with increasing depth, consist of the organic Robien silt (of the Farmdalian substage of the Wisconsinan Stage), an Interglacial zone consisting of weathered Glasford Formation glacial till deposited during the Illinoian Stage (also referred to as the Sangamonian Interglacial Zone on CPS Site borehole logs), and unweathered Glasford Formation till. Beneath the Glasford Formation lie Yarmouthian Stage lacustrine deposits and pre-Illinoian Stage glacial tills (see Figure 2-3).

In areas of low bedrock elevation in the vicinity, sandy glacial outwash of the Kansan Stage (likely the Mahomet Sand Member of the Banner Formation) are present above bedrock. However, because of a local bedrock high, the Mahomet sands are not present at the CPS Site. Rather, fine-grained alluvial soils associated with pre-Illinoian glaciations are typically present in immediate contact with bedrock in the area.

Bedrock in the vicinity of the CPS Site is of the Pennsylvanian system, and belongs to the Bond and Modesto Formations of the McCleansboro Group (see Figure 2-4). These formations generally consist of alternating bands of limestone, shale, siltstone, sandstone, and some coal seams. The base of the Bond Formation is marked by the Shoal Creek Limestone Member, which corresponds to the top of the Modesto Formation at an approximate elevation of 495 ft above msl at the CPS Site. The No. 8 Coal Member within the Modesto Formation was encountered as a 1-ft thick layer at borehole P-38 during the original CPS Site investigation (at an elevation of 431 ft above msl).

2.2.6 Site Structural Geology

The CPS Site is located in a tectonically stable area of North America. Although the CPS Site is within several miles of structural features, there is no evidence for surface faulting at the CPS Site or the area surrounding the CPS Site within a 25-mi radius. No faulting has been recognized in association with the foregoing structural features either from aerial photographs, Earth Resources Technology Satellite (ERTS) imagery, geophysical studies, borehole control, or excavation mapping. The glacial materials are devoid of lineaments or off-sets suggestive of faulting.

Borehole data show no tectonic folding or faulting in the Pleistocene deposits exposed in the excavations at the CPS Site, including the Robein Silt. Even if the bedrock unit elevation differences could be attributed to structural deformation, the relatively flat-lying and un-deformed Pleistocene drift overlying bedrock demonstrates that the stresses which would have been responsible for the deformation have been inactive since at least pre-Pleistocene time. The bedrock surface is an erosional surface, and in the CPS Site area there is no general relationship between Paleozoic structures and bedrock topography. Structure cannot, therefore, be inferred from bedrock topography. Further, faults which have been mapped in Illinois have shown no sign of movement during Quaternary time (see the CPS USAR, Section 2.5.1.2.3).

2.3 Geotechnical Explorations

Geotechnical investigations were performed to support design and construction of the CPS Facility. These investigations included traditional geotechnical drilling and sampling investigations, as well as seismic surveys (both downhole and surface methods). The scope of these investigations is presented in Section 2.5 of the CPS USAR.

2.3.1 Drilling and Sampling

A total of 76 geotechnical soil boreholes were advanced to various depths within the vicinity of the plant site bounded by Clinton Lake. These include 55 power block (P-series) boreholes, ten of which extended to bedrock. These explorations were advanced in an approximately 0.5 mi square area encompassing the existing CPS Facility and the peninsula of land currently surrounded by Clinton Lake. A few of these P-series boreholes were advanced at locations that are now flooded after the construction of the dam across Salt Creek. An additional 21 boreholes (AH-series) were advanced in the area southwest of the P-series boreholes. In addition to these samples, in the vicinity of the plant site, other boreholes were advanced within the ultimate heat sink (UHS), dam site, dam borrow area, and at several observation well locations. Generally, rotary wash or continuous-flight auger drilling methods were used for these boreholes. Figure 2-5 shows the locations of boreholes advanced near the CPS Site, as reported in the CPS USAR. Figure 2-6 shows the general southwest to northeast stratigraphic cross-section through the CPS Site as reported in the CPS USAR.

Geotechnical samples were collected from each of the CPS Site boreholes at various depths. Disturbed samples were collected during the investigation via standard penetration tests (SPTs), and undisturbed samples were collected with a Pitcher-tube sampler, a double-tube core sampler, a Shelby tube sampler, an Osterberg sampler, and a proprietary Dames and

Moore sampler. Rock coring was conducted in the upper Pennsylvanian bedrock at 12 P-series borehole locations. NX double-tube core barrel samplers were used to collect 2-inch (in.) diameter rock cores at these locations.

2.3.2 Seismic Surveys

Seismic surveys were conducted at the plant site and are described in Section 2.5.4.4 of the CPS USAR. Five different types of surveys were conducted. A seismic wave refraction survey evaluated overburden and bedrock compressional wave velocity. An uphole survey further evaluated overburden compressional wave velocities. A downhole survey evaluated shear wave velocities of overburden and bedrock. A surface wave survey and an ambient noise survey were also conducted.

Interpreted subsurface compressional wave velocity profiles from the seismic wave refraction survey are included in Figures 2.5-359 through 2.5-365 of the CPS USAR. Uphole survey results from the three test locations are included in Figures 2.5-366 through 2.5-368. One of these surveys was performed at plant site borehole P-14. Downhole surveys were performed at the same three locations for the uphole surveys (including at P-14). Results of the downhole surveys are included in Figures 2.5-369 through 2.5-371.

2.4 Laboratory Testing

A comprehensive set of geotechnical tests was performed on samples from numerous site boreholes during the work prior to construction, as well as on samples collected as part of the construction quality control program during the CPS Facility construction. These include strength tests, dynamic tests, and other physical tests as described in Section 2.5.4.2 of the CPS USAR. Specific tests performed on these samples are summarized below.

2.4.1 Strength Tests

Static strength tests were performed on numerous representative soil samples and are reported in Section 2.5.4.2.1 of the CPS USAR. Tests included unconfined compression, unconsolidated-undrained (UU) triaxial shear, consolidated-undrained triaxial shear (some with pore pressure measurement), and direct shear. Results of these tests are reported in Tables 2.5-6 through 2.5-17 of the CPS USAR, and are also summarized on the CPS USAR borehole logs. Strength tests were performed on samples from each stratigraphic unit encountered in the P-series boreholes. Unconfined compression tests were also performed on representative rock core samples.

2.4.2 Dynamic Tests

Dynamic tests were performed on various soil and rock samples from the plant site, dam site, and the UHS area and are described in Section 2.5.4.2.2 of the CPS USAR. Tests included dynamic triaxial shear tests, resonant column tests, and shockscope tests. The cyclic triaxial shear tests provided data on the strain-dependent shear modulus and soil damping values of the samples. Resonant column tests provided data on the shear modulus of the samples. Shockscope tests provided data on the compressional wave velocity of the samples.

Cyclic triaxial tests were performed on P-series borehole sample from each of the major soil stratigraphic units encountered at the site. Resonant column and shockscope tests were generally performed only on stratigraphic units left in place after construction (Illinoian and pre-Illinoian Stage deposits, plus Pennsylvanian bedrock), as well as on remolded samples used for structural fill. Results of the cyclic and dynamic tests are included in Tables 2.5-18 through 2.5-30 of the CPS USAR.

2.4.3 Other Physical Tests

Various other tests were performed on site samples, as reported in Section 2.5.4.2.3 of the CPS USAR. Tests included Atterberg limits, one-dimensional consolidation, in situ moisture, in situ dry density, and permeability, each of which was performed on samples from each major stratigraphic unit encountered in the P-series boreholes. Relative density tests were performed on Mahomet Bedrock Valley granular deposits (not encountered in the P-series boreholes), and chemical tests were performed on groundwater samples and on No. 8 and No. 7 coal samples.

Numerous other physical tests were performed on fill and foundation soils as part of the quality control program during CPS Facility construction, as reported in Section 2.5.4.2.6 of the CPS USAR. These tests included liquefaction (on granular fill), Atterberg limits, compaction and relative density, in situ moisture and dry density, and particle size analyses.

2.5 Clinton Power Station Facility Foundation Excavation and Backfill

A summary of the excavation, subgrade treatment, and backfill activities performed during construction of the CPS Facility main power station is included in Section 2.5.4.5.1 of the CPS USAR. These activities are briefly summarized below to provide context for the foundation performance analyses conducted for the CPS Facility which are described in Section 2.6 of this report.

2.5.1 Excavation

The excavation for the main power station was performed with heavy earth moving scrapers. The excavation extended to an elevation of between 680 to 683 ft above msl, to locate the subgrade for foundations in the Illinoian till of the unweathered Glasford Formation. The depth of excavation was up to 56 ft, and the horizontal extent of the base of the excavation extended a minimum of 20 ft outside the structure extents. Cut slopes were no steeper than 1:1 (horizontal to vertical).

2.5.2 Dewatering

Dewatering was accomplished by a network of perforated pipes and ditches set along the perimeter of the base of the excavation. Groundwater seepage into the excavation during construction was minimal due to the tight nature of the clayey till soils. Some water was contributed by isolated sand lenses within the till.

2.5.3 Excavation Base Treatment

A comprehensive construction quality control program was implemented to verify a suitable subgrade for foundation construction. The subgrade consisted predominantly of unweathered till, with some local pockets of sand. Native soils in the subgrade that did not meet the construction specifications of 130 pounds per cubic foot (pcf) (for cohesive soils) or relative density of 85 percent (for granular soils) were improved by compaction. Soils that could not be improved were locally excavated and replaced with a cement/fly ash mixture, which was field tested to meet a deflection specification. Figure 2.5-375 of the CPS USAR shows the locations where the subgrade was excavated and replaced.

2.5.4 Structural Fill and Backfill

Compacted granular fill was used to fill the excavation from the subgrade to the foundation elevation. The granular fill was taken from a borrow location approximately 2.25 mi south of the main power station. The borrow was a clean sandy Salt Creek alluvial material. The borrow material was placed in horizontal lifts, and compacted with a smooth-wheel vibratory roller. Relative density and dry density were measured frequently for each 1-ft vertical fill interval as part of the construction quality control program. Of the 4,798 density tests performed, only 175 resulted in relative densities below the specification of 85 percent. Analysis of the distribution of these results indicated that they were well dispersed, and would not adversely affect the foundation performance.

Upon completion of structural fill placement, the monolithic basemat foundation for the main power block was constructed, and building construction commenced. The Salt Creek borrow material was also used as backfill around the structures, and was placed and compacted under the same performance specifications as the subgrade materials. A compacted cohesive material was used as backfill at elevations greater than 720 ft above msl.

2.6 Response of Soil and Rock to Static and Dynamic Loading

The responses of soil and rock to static and dynamic loading for the CPS Facility are presented in Section 2.6.5 of the CPS USAR, and are summarized below. These evaluations considered the liquefaction potential of granular fill and the static stability conditions for each structure. The liquefaction potential of native materials left in place after excavation, and of the backfill material itself, was evaluated and is described in Section 2.5.4.8 of the CPS USAR. Evaluation of static stability included calculation of bearing capacity, settlement, and lateral earth pressures for each structure, as presented in Section 2.5.4.10 of the CPS USAR. Table 2.5-63 of the CPS USAR summarizes critical foundation loading information for the main power plant including the foundation elevation, gross static foundation pressure, and net static foundation pressure for each of the structures. This information was used for the evaluation of static stability. A summary of parameters utilized for soil-rock-structure interaction analyses is presented in Table 2.5-48 of the CPS USAR. Results of the soil-structure interaction analyses are summarized in Section 3.7 of the CPS USAR. Section 6 of this Geotechnical Report compares the soil responses to static and dynamic loading for the CPS Site, as summarized below, with expected responses at the EGC ESP Site.

2.6.1 Liquefaction Potential

The potential for liquefaction of subsurface sand deposits near the main power station (both granular structural fill and subsurface sand lenses left below the excavation) was evaluated and is summarized in Section 2.5.4.8 of the CPS USAR. Liquefaction potential in the structural fill was evaluated based on the cyclic triaxial compression test results for compacted fill samples, specifically on the resulting cyclic vertical stress to confining stress ratio that results in liquefaction after 10 cycles. The factor of safety (FOS) was calculated as the ratio of the cyclic shearing stress at liquefaction (producing liquefaction at 10 cycles) to the average cyclic shearing stress induced by the earthquake. The minimum calculated FOS against liquefaction was reported to be approximately 2 for the structural fill. Analysis of liquefaction in granular pipe bedding and in sand fill under other structures also determined that liquefaction was not a concern.

Liquefaction analysis for natural sand deposits left below the excavation is summarized in Attachment B2.5 of the CPS USAR. For this analysis, the primary considerations were the relative density of the deposits (as correlated from corrected SPT blowcounts), soil gradation, and overburden pressure. Based on the conditions of the various sand lenses encountered during the subsurface investigation below the main power plant, liquefaction was not considered to be of concern in any of these sand deposits.

2.6.2 Bearing Capacity

Bearing capacity evaluations are discussed in Section 2.5.4.10.2 of the CPS USAR. Conventional analyses assuming local shear failure were used to calculate ultimate bearing capacities for the foundation soils. The results of the analyses are summarized in Table 2.5-63 of the CPS USAR.

The lowest calculated ultimate bearing capacity for the structures was approximately 25.5 tons per square foot (tsf) (for the Service Building, a non-Category I structure founded within the Wisconsinan till). Ultimate bearing capacity for foundations of safety-related structures constructed on the unweathered Illinoian till and engineered granular fill ranged from approximately 40 to 61 tsf. The minimum FOS against bearing capacity failure was 18.8.

2.6.3 Settlement

Settlement of the plant power block structures was evaluated for the foundation loads and elevations summarized in Table 2.5-63 and Section 2.5.4.10.3 of the CPS USAR. The first step involved assessing the rate of rebound and settlement during excavation, fill placement, and construction of the foundation mat. This allowed estimation of the zero-settlement origin for evaluating plant settlement, defined at the completion of the mat foundation and beginning of structure construction.

Settlement of the power block structures with time was modeled with the computer code SETTLE. Consolidation properties for the subgrade soils were taken from representative P-series consolidation test results and are reported in Table 2.5-62 of the CPS USAR. Independent settlement analyses were conducted for the mat, one assuming a completely rigid mat, and another assuming a flexible mat. The actual settlement of the mat was

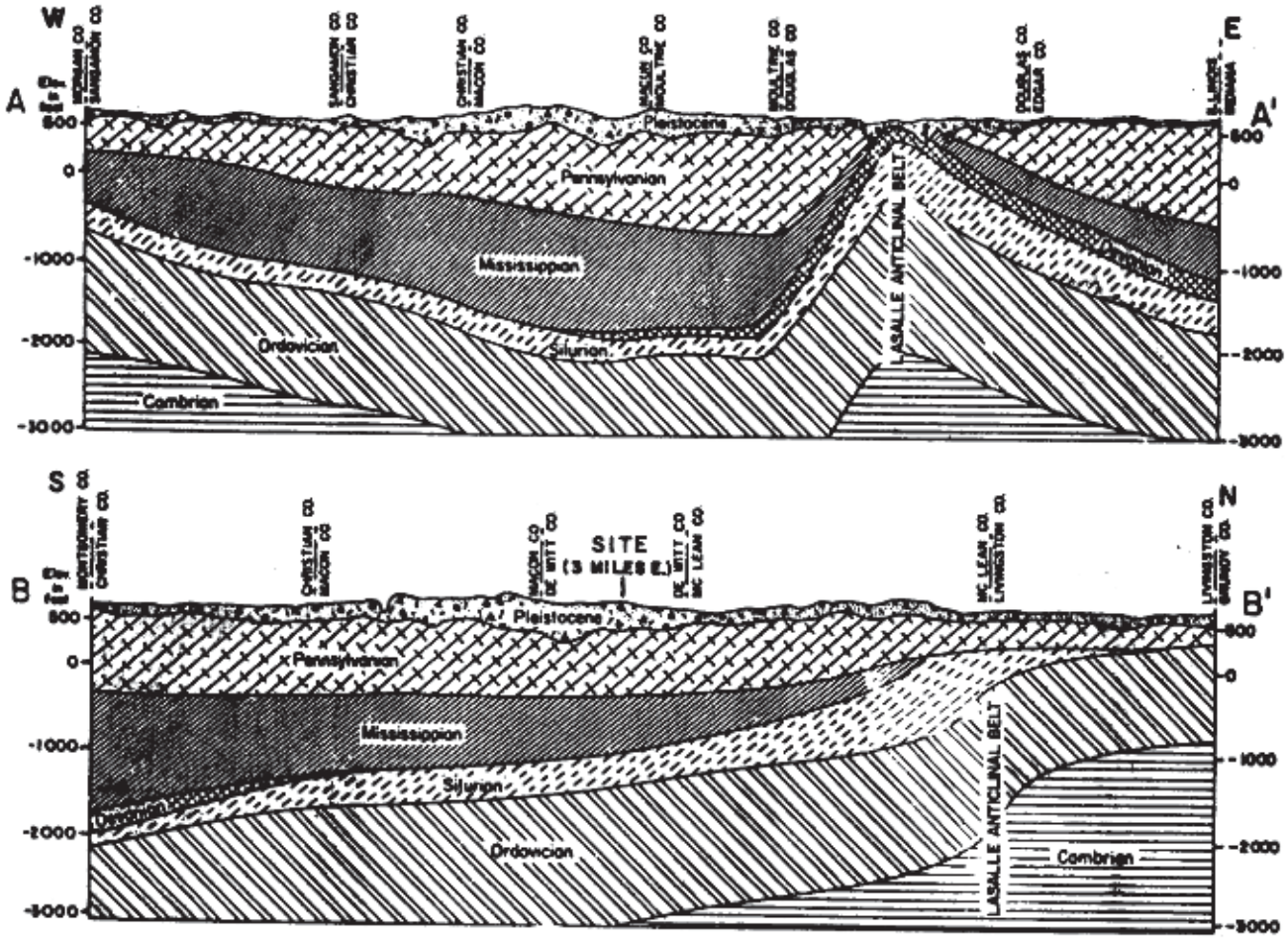
considered to be a combination of these two modeled conditions. The calculated final settlement of the mat is shown in Figure 2.5-433 of the CPS USAR.

Actual settlement profiles with time were compared to the predicted settlement at four monitoring locations at the main power station. Results are shown in Figures 2.5-434 to 2.5-437 of the CPS USAR. These results show that the actual power block settlement was approximately half of the predicted settlement at most locations, indicating that conventional consolidation analyses using the consolidation test results provided a conservative estimate of settlement.

2.6.4 Lateral Earth Pressures

Subsurface walls of structures were designed to withstand lateral soil and groundwater pressures under both static and dynamic loading conditions. The method used to evaluate lateral pressures is described in Section 2.5.4.10.4 of the CPS USAR. At-rest horizontal earth pressure coefficients were approximated based on backfill placement condition and approximate friction angles of the backfill. Dynamic horizontal earth pressures were calculated by applying a horizontal earthquake acceleration to the soil pressure behind the wall. Lateral earth pressure calculations are shown in Figure 2.5-492 of the CPS USAR.

Figure 2-1
Regional Geologic Cross Sections



Notes:

1. Reprinted from: CPS, 2002

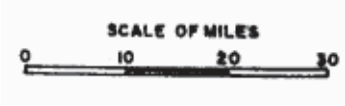
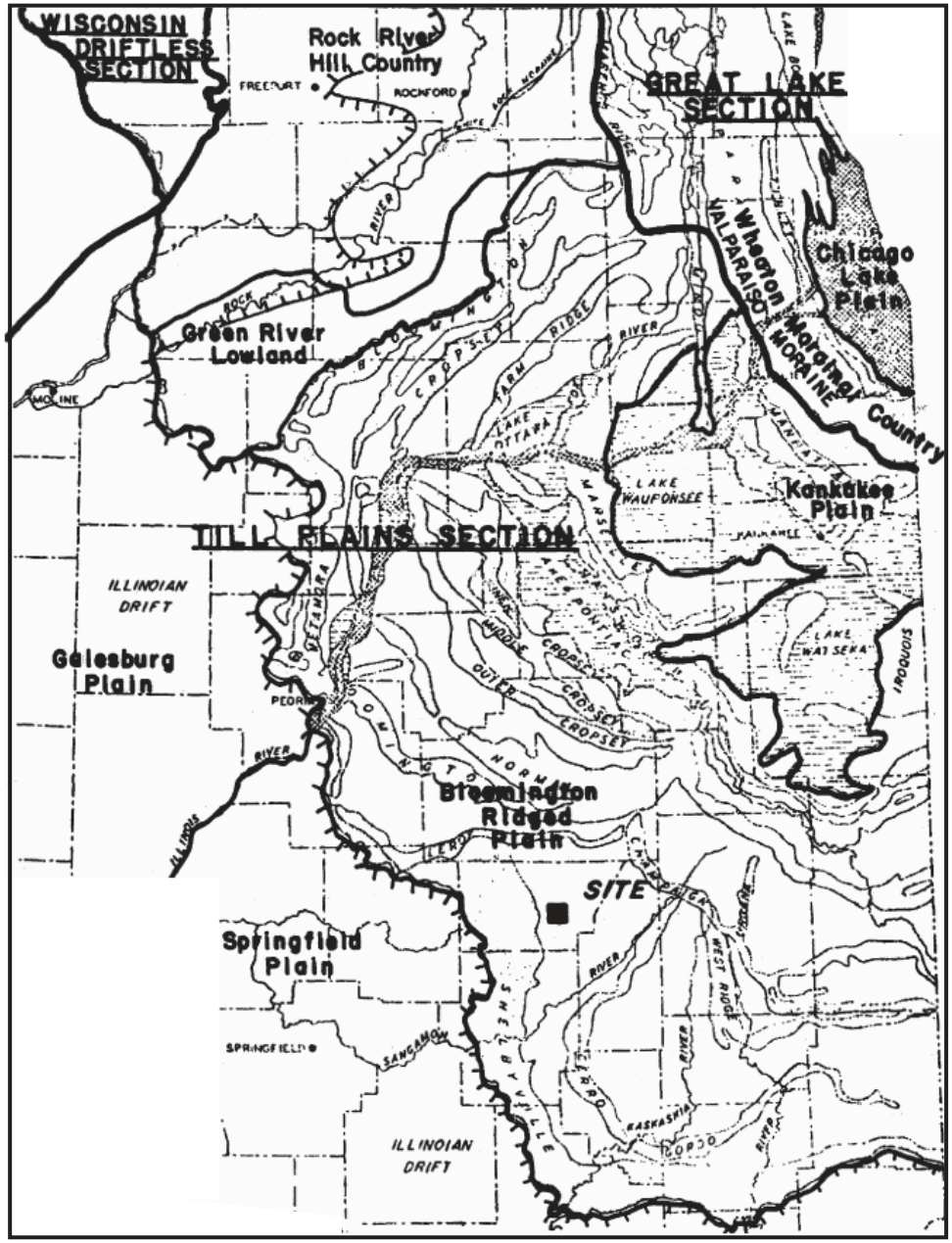


Figure 2-2
Regional Glacial Map and Physiographic Divisions



Legend

- Moraines
- Kankakee Torrent Area
- Lake Chicago and Outlet
- Limit of Wisconsinan Glaciation in Illinois

Notes:

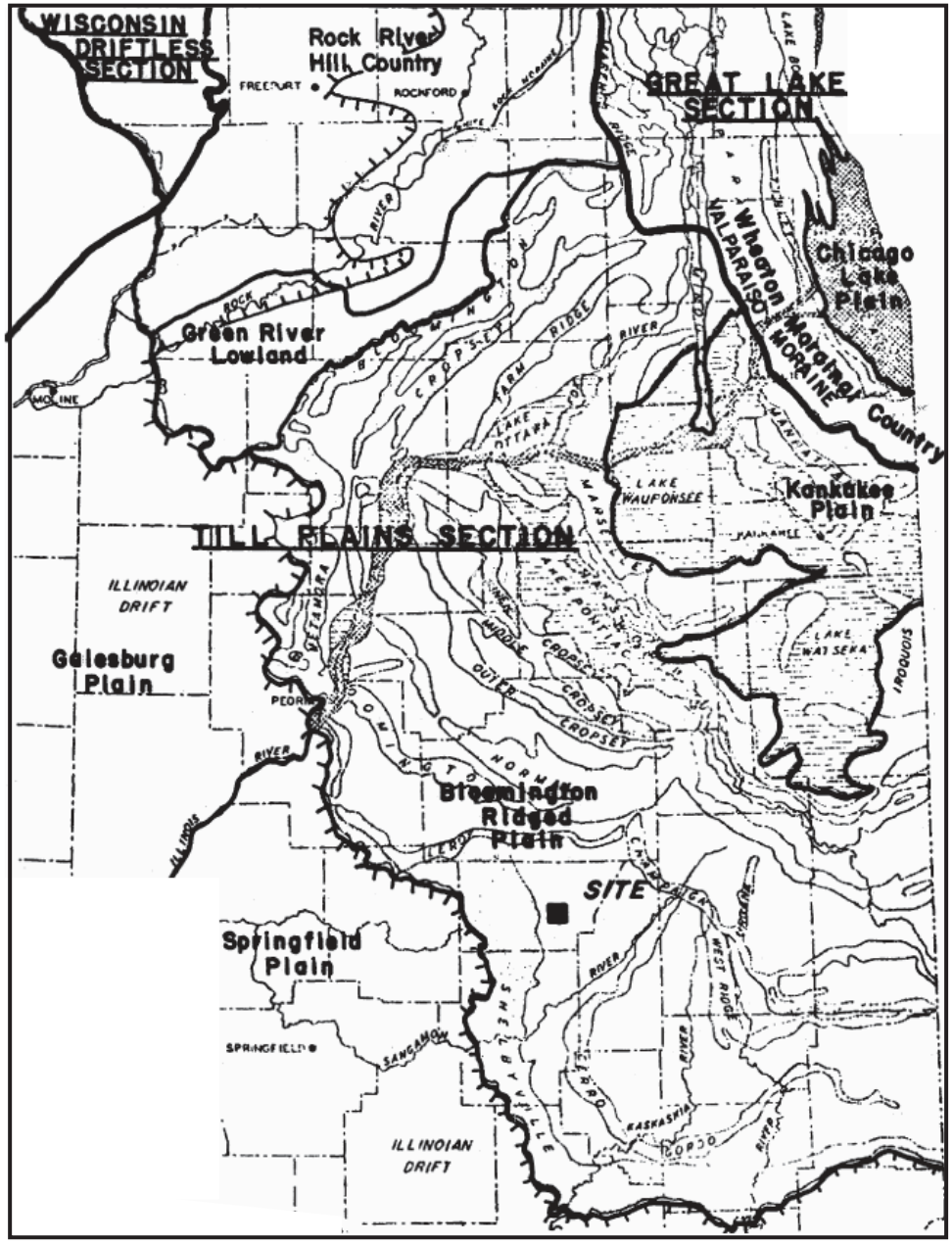
1. These physiographic sections and subsections are part of the central lowland physiographic province.
2. The areas shown in white are primarily glacial drift and ground moraine except for the Wisconsin driftless section and parts of the Green River lowland.
3. Reprinted from: CPS, 2002

N

0 10 20 mi

Scale in miles

Figure 2-2
Regional Glacial Map and Physiographic Divisions



Legend

- Moraines
- Kankakee Torrent Area
- Lake Chicago and Outlet
- Limit of Wisconsinan Glaciation in Illinois

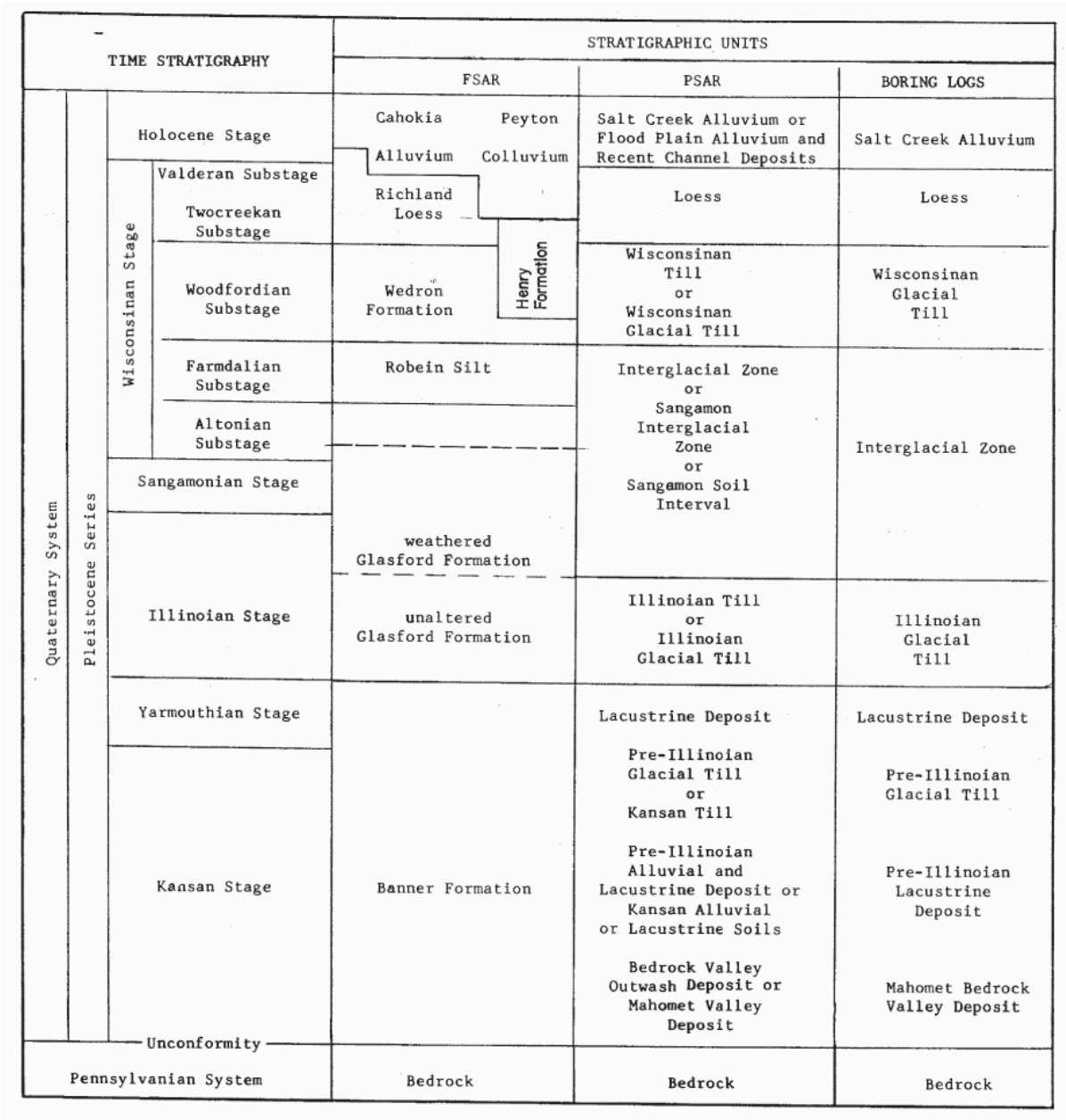
Notes:

1. These physiographic sections and subsections are part of the central lowland physiographic province.
2. The areas shown in white are primarily glacial drift and ground moraine except for the Wisconsin driftless section and parts of the Green River lowland.
3. Reprinted from: CPS, 2002

N

0 10 20 mi

Scale in miles



Geotechnical Report for the EGC Early Site Permit

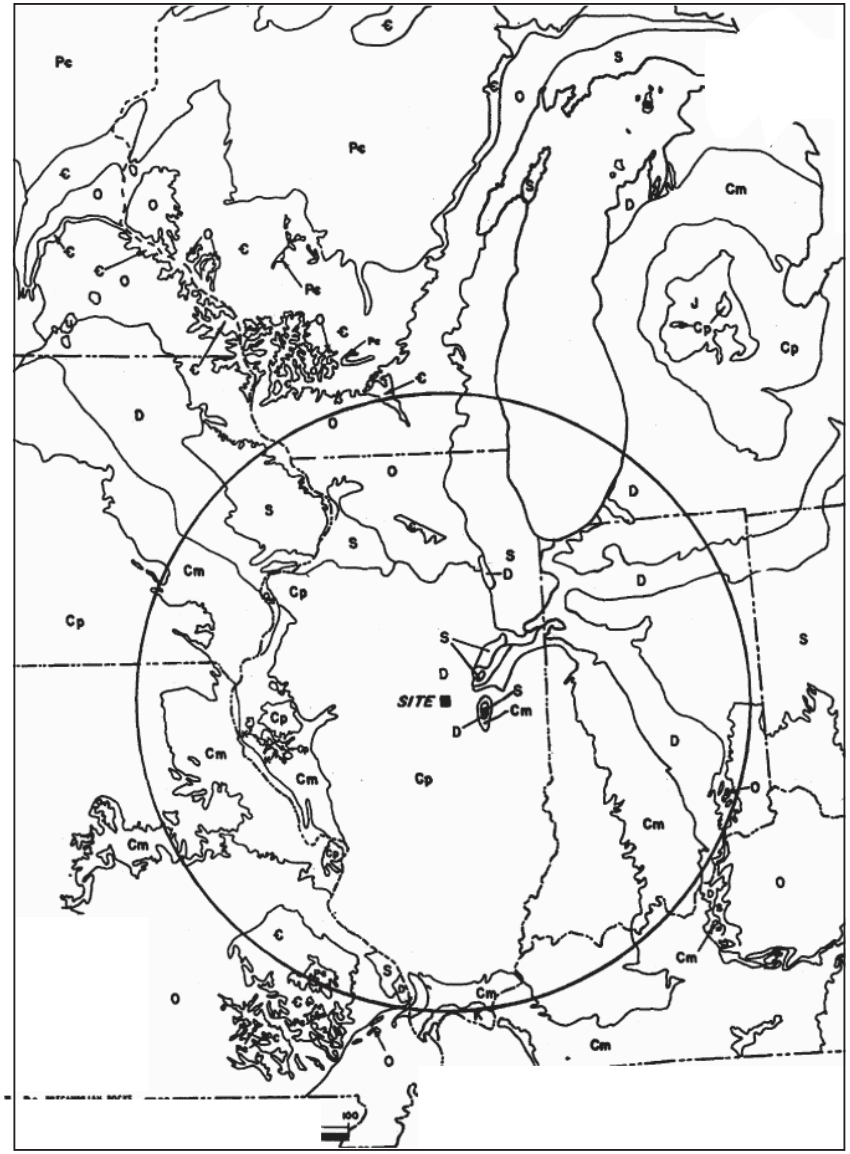
Figure 2-3

Comparison of Terminology Used During Previous Site Investigations

Legend

Notes:

1. Excavations for the Clinton Power Station did not extend below the unaltered Glasford formation.
2. Borings for the Clinton Power Station did not extend into rocks older than those of the Pennsylvanian system.
3. Illinoian-age till of the Glasford formation was subjected to a significant period of weathering during the Sangamonian stage and Altonian substage.
4. Deposits of Cahokia alluvium and Henry Formation were not differentiated.
5. The Holocene stage is represented by a significant period of weathering and development of agricultural soil profiles (modern soil).
6. Vertical scale does not represent either relative thickness of stratigraphic units or relative duration of time interval.
7. PSAR = Preliminary Safety Analysis Report
8. FSAR = Final Safety Analysis Report
9. USAR uses terminology listed in both the FSAR and PSAR columns.
10. Reprinted from: CPS, 2002



Geotechnical Report for the EGC Early Site Permit

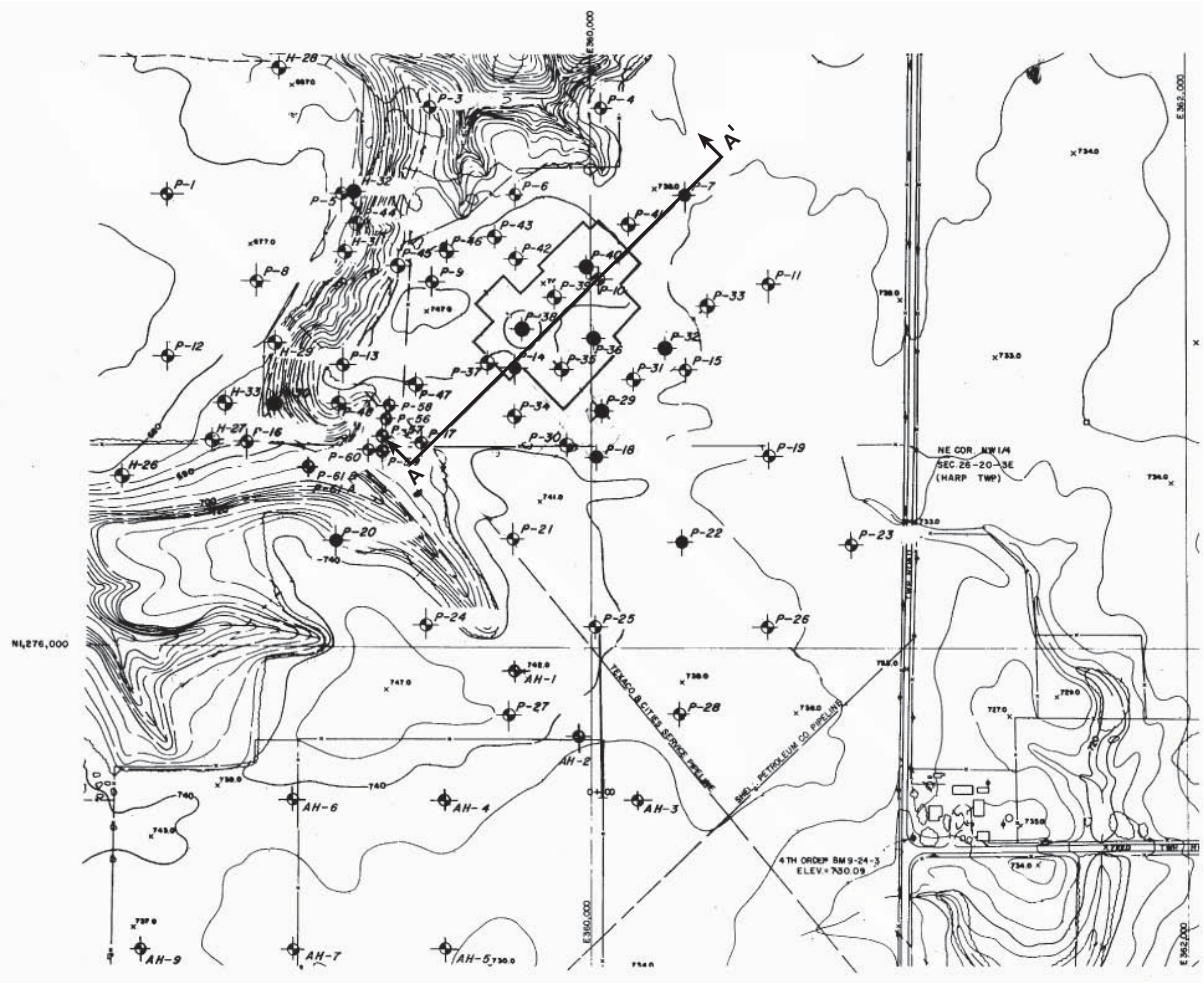
Figure 2-4
Regional Bedrock Geology Map

Legend

T	Tertiary Rocks
K	Cretaceous Rocks
J	Jurassic Rocks
Cp	Pennsylvanian Rocks
Cm	Mississippian Rocks
D	Devonian Rocks
S	Silurian Rocks
O	Ordovician Rocks
C	Cambrian Rocks
Pc	Precambrian Rocks

Notes:

1. Reprinted from: CPS, 2002



Geotechnical Report for the EGC Early Site Permit

Figure 2-5
Original CPS Site Investigation Locations

Legend

- 740 — Topographic Contours
- P-1 — Borehole Location
- Location of Borehole that Extended to Bedrock
- A — A' Section A-A' (See Figure 2-6)

Notes:
1. Modified from: CPS, 2002

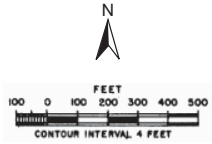
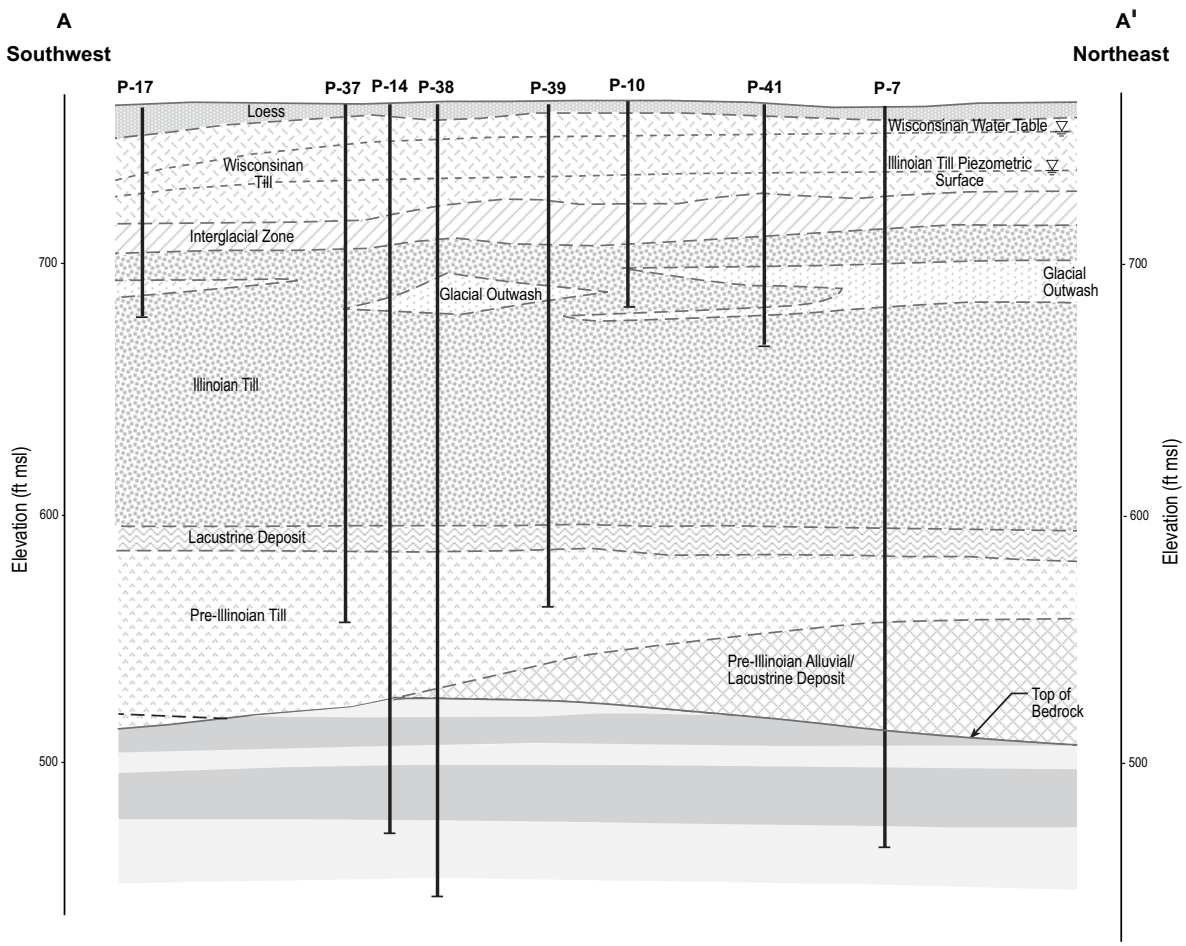


Figure 2-6
Southwest-Northeast Cross Section (A-A') Through CPS Site



Legend

Quaternary

- **Wisconsinan**
  - LOESS - Brown to mottled brown and gray clayey silt or silty clay with trace fine sand; Weathered
  - WISCONSINAN GLACIAL TILL - Brownish-gray to gray clayey silt or silty clay with sand and gravel; Contains irregular and discontinuous lenses of sand and silt throughout (glacial outwash and possibly local lacustrine deposits)
- **Sangamonian**
  - INTERGLACIAL ZONE - Includes dark gray to gray organic clayey silt or silty clay (colluvial soils), greenish to bluish-gray clayey silt with sand and gravel (reworked Illinoian Glacial Till)
- **Illinoian**
  - ILLINOIAN GLACIAL TILL - Brownish-gray to gray clayey silt with sand and gravel to very sandy silt or silty sand with some clay and gravel; Interbedded outwash deposits in upper horizons
  - GLACIAL OUTWASH - Gray silty sand and sandy silt, interlayered
- **Yar-Mouthian**
  - LACUSTRINE DEPOSIT - Brownish-gray to black and gray clayey silt to silt, organic in zones; Includes greenish to bluish-gray clayey silt with sand and gravel (reworked and weathered pre-Illinoian Glacial Till); Assignment to Yarmouthian Glacial Stage is tentative
- **Kansan**
  - PRE-ILLINOIAN GLACIAL TILL - Grayish-brown to brown silty clay and clayey silt with some sand and gravel; Brown color and relatively high clay content is characteristic; Tentatively assigned to Kansan Glacial Stage on the basis of clay analysis by Illinois State Geological Survey
  - PRE-ILLINOIAN ALLUVIAL & LACUSTRINE DEPOSIT - Consists of grayish-brown, brown, and green clayey silt and silty clay with sand and some gravel (reworked glacial till) and gray to brown clayey silt with organic debris (lacustrine or low energy alluvial deposit); Included as part of the Mahomet bedrock deposit in areas where it is underlain by sandy outwash deposits

Pennsylvanian

- BEDROCK - Interbedded layers of limestone, shale, and siltstone assigned to the McLeansboro Group, Modesto Formation on the basis of spore analysis of the coal encounter in boring B-31
- LIMESTONE - Greenish-gray, gray and brown, fine to coarsely crystalline, silty, thin bedded to massive, numerous shale partings in zones, fossiliferous.
- SHALE - Gray to dark gray shale, carcoraceous to calcareous; clayey in zones, expansive, slickensides; occasional concretion
- SILTSTONE - Light gray siltstone, micaceous, fine sandy, cross-bedded in zones; occasional interbedded layer of silty sandstone
- Coal Seam

P-17 Borehole Number

Notes:
1. Elevations refer to the USGS Datum
2. Recreated from: CPS, 2002
3. See Figure 2-5 for cross section location

0 — 200 ft
Approximate Horizontal Scale