Revision 1

HYDROGEOLOGIC INVESTIGATION REPORT

FLEETWIDE ASSESSMENT
CLINTON POWER STATION
DE WITT COUNTY, ILLINOIS

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EXECUTIVE SUMMARY

This Hydrogeologic Investigation Report (HIR) documents the results of Conestoga-Rovers & Associates' (CRA's) May 2006 Hydrogeologic Investigation Work Plan (Work Plan) pertaining to the Clinton Power Station (Station) in De Witt County, Illinois. CRA prepared this HIR for Exelon Generation Company, LLC (Exelon) as part of its Fleetwide Program to determine whether groundwater at and in the vicinity of its nuclear power generating facilities has been adversely impacted by any releases of radionuclides.

CRA collected and analyzed information on historical releases, the structures, components, and areas of the Station that have the potential to release tritium or other radioactive liquids to the environment and past hydrogeologic investigations at the Station. CRA used this information, combined with its understanding of groundwater flow at the Station to identify the Areas for Further Evaluation (AFEs) and sample locations for the Station.

CRA collected 17 groundwater samples and six surface water samples at the Station. CRA also collected a full round of water levels on two occasions from the newly installed and existing wells and measured surface water levels. In addition, five water samples were collected from the Unit 2 Pit drainage system on June 27, 2006. All groundwater and surface water samples were analyzed for tritium, strontium-89/90, and gamma-emitting radionuclides. The Unit 2 Pit water samples were analyzed for gamma emitting-radionuclides and tritium.

The results of the hydrogeologic investigation are:

- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective Lower Limits of Detection (LLDs) in any of the groundwater, surface water or Unit 2 Pit water samples obtained and analyzed during the course of this investigation;
- Strontium-89/90 was not detected at a concentration greater than the LLD of 2.0 picoCuries per liter (pCi/L) in any of the groundwater or surface water samples obtained and analyzed during the course of this investigation;
- Tritium was not detected at concentrations greater than the United States Environmental Protection Agency drinking water standard of 20,000 pCi/L in any of the groundwater, surface water or Unit 2 Pit water samples obtained during the course of this investigation;

- Low levels of tritium were detected at concentrations greater than the LLD of 200 pCi/L in only four of the 17 groundwater samples collected;
- Based on the results of this investigation, tritium is not migrating off the Station property at detectable concentrations;
- Based on the results of this investigation, there is no current risk of exposure to radionuclides associated with licensed plant operations through any of the identified potential exposure pathways; and
- Based on the results of this investigation, there are no known active releases into the groundwater at the Station.

Based upon the information collected to date, CRA recommends that Exelon conduct periodic monitoring of selected sample locations.

1.0 INTRODUCTION

Conestoga-Rovers & Associates (CRA) has prepared this Hydrogeologic Investigation Report (HIR) for Exelon Generation Company, LLC (Exelon) as part of its Fleetwide Program to determine whether groundwater at and near its nuclear power generating facilities has been adversely impacted by any releases of radionuclides. This report documents the results of CRA's May 2006 Hydrogeologic Investigation Work Plan (Work Plan), as well as several other investigative tasks recommended by CRA during the course of the investigation. These investigations pertain to Exelon's Clinton Nuclear Power Station in De Witt County, Illinois (Station) (see Figure 1.1).

The Site, including the Station, is defined as all property, structures, systems, and components owned and operated by AmerGen Energy Company LLC (AmerGen) located at RR 3 Box 228, Clinton, Illinois. The approximate Site and Station boundaries are depicted on Figures 1.1 and 1.2.

Pursuant to the Work Plan, CRA assessed groundwater quality at the Station in locations designated as Areas for Further Evaluation (AFEs). The process by which CRA identified AFEs is discussed in Section 3.0 of this report.

The objectives of the Work Plan were to:

- characterize the geologic and hydrogeologic conditions beneath the Station including subsurface soil types, the presence or absence of confining layers, and the direction and rate of groundwater flow;
- characterize the groundwater/surface water interaction at the Station, including a determination of the surface water flow regime;
- evaluate groundwater quality at the Station including the vertical and horizontal extent, quality, concentrations, and potential sources of tritium and other radionuclides in the groundwater, if any;
- define the probable sources of any radionuclides released at the Station;
- evaluate potential human, ecological or environmental receptors of any radionuclides that might have been released to the groundwater; and
- evaluate whether interim response activities are warranted.

2.0 STATION DESCRIPTION

The following section presents a general summary of the Station location and definition, overview of Station operations, surrounding land use, and an overview of both regional and Station-specific topography, surface water features, geology, hydrogeology, and groundwater flow conditions. This section also presents an overview of groundwater use in the area.

2.1 STATION LOCATION

The property owned by AmerGen consists of approximately 14,000 acres (the Site), of which approximately 461 acres (the Station) are used for generating electricity (Figure 1.1). The other 13,539 acres of property include an approximate 4,895-acre Clinton Lake, the land associated with the aqueduct, and surrounding agricultural and recreational land. The Station's address is RR 3 Box 228, Clinton, Illinois 61727. The Site is owned and operated by AmerGen.

The Station, for the purpose of this report, is defined as the PA and the adjacent support areas. This HIR excludes land associated with Clinton Lake, the land associated with the downstream portion of the aqueduct, and surrounding agricultural and recreational land.

2.2 OVERVIEW OF COOLING WATER OPERATIONS

The Station is a nuclear power plant, which produces electricity for subsequent distribution to the United States' Eastern Interconnect System. Construction of the Station began in the fall of 1975 and the operations started in February 1987. The Station operates one 1,140 gross megawatt electric, boiling water reactor to generate power under Nuclear Regulatory Commission (NRC) Operating License No. NPF-62.

Cooling water for the Station is withdrawn from the North Fork leg of Salt Creek by way of three large pumps. The North Fork of Salt Creek is part of Clinton Lake, which is a man-made lake. The Circulating Water System is routed through the circulating water lines to deliver water to the main condenser in sufficient quantities to condense the turbine exhaust steam. After the cooling water is used to condense steam, this cooling water is then piped to the Seal Well, and then to the discharge flume. The discharge flume is the starting point of the aqueduct, which is an unlined, earthen, man-made river, which routes the cooling water along a 3.1-mile route where it discharges into the Salt Creek leg of Clinton Lake. The Station discharges water to Clinton Lake via several outfalls under one National Pollutant Discharge Elimination System (NPDES) Permit IL0036919 (McLaren and Hart, 1999a). The portion of Clinton Lake between the point of discharge and the point of withdrawal (approximately 9.9 miles) is known as the cooling loop.

Tritium-containing materials are stored and treated within the Radioactive Waste (Radwaste) Building and excess liquids are stored within the Cycled Condensate Storage Tank, which is to the north of the Station. Along with cooling water, the Station is permitted to discharge Radwaste treatment system effluent to the discharge flume. The Station's last discharge of waste treatment system effluent was in September 1992. Since 1992, the Station has used evaporators, filters, demineralizers, and carbon beds, which are in the Radwaste Building, to treat the effluent.

2.3 SURROUNDING LAND USE

Based on information from the United States Geologic Survey (USGS) Geographic Information System (GIS) Layer of National Landcover Data Set for Central Illinois, 82 percent of the land surrounding the Station is used for farming (USGS, 1990). The Station leases a large portion of their property back to farmers for agricultural use. Land to the north of the Station is used for agricultural purposes. Most of the remaining land around the Station is used for recreational purposes. These recreational areas include the 9,300-acre Clinton Lake Recreational Area, which includes the 4,895-acre Clinton Lake and Mascoutin State Park (USGS, 1990), located west of the Station. The land to the east and south of the Station is undeveloped. The land surrounding the Station is depicted on Figure 1.1.

2.4 STATION SETTING

The following section presents a summary of the topography, surface water features, geology, hydrogeology, and groundwater flow conditions in the region surrounding the Station. The information was primarily gathered from these reports:

- Draft Site Redress Plan for Exelon Early Site Permit, prepared by CH2M Hill, dated January 2003;

- Draft Emergency Plan for Exelon Early Site Permit, prepared by CH2M Hill, dated January 2003;
- Draft Site Safety Analysis Report for Exelon Early Site Permit, prepared by CH2M Hill, dated January 2003; and
- Draft Environmental Report for Exelon Early Site Permit, prepared by CH2M Hill, dated January 2003.

2.4.1 TOPOGRAPHY AND SURFACE WATER FEATURES

Figure 1.2 presents portions of some of the relevant surface water features on the Station property such as the sewage treatment lagoons, sediment ponds, and the aqueduct. The topography at the Station is generally flat, but slopes steeply near Clinton Lake. Surface water drains through the storm water system and man-made ditches and flows generally to the south. Surface water flow directions near the Station are shown on Figure 2.1.

The largest nearby surface water body is Clinton Lake, which is a 4,895-acre man-made cooling reservoir. Clinton Lake was formed by constructing an earthen dam 1,200 feet downstream from the confluence of the North Fork of Salt Creek and Salt Creek.

The PA and surrounding land is generally flat and covered by paved areas, roadways, and parking lots. These areas are drained by a storm water system that drains to the northwest corner of the PA, as shown on Figure 2.1.

2.4.2 GEOLOGY

This section presents an overview of the geology near the Station based upon Illinois geologic publications. Figure 2.2 presents a geologic cross-section of the regional stratigraphy near the Station based on information from the Early Site Permit reports identified in Section 2.4, above.

2.4.2.1 OVERBURDEN DEPOSITS

The Station is located within the Illinois Basin west of the LaSalle Anticlinal Belt. The regional geology is comprised of an average of 250 feet of Quaternary overburden deposits. These glacial features are largely Wisconsinan, Illinoian, and pre-Illinoian aged deposits such as alluvial outwash, windblown loess, and lakebed clays or silts as well as icelaid till (Illinois Power, 2001).

The alluvial deposits, known as the Henry Formation, consist of fine-grained flood plain deposits overlying coarse-grained outwash deposits (Illinois Power, 2001). The floodplain deposits are commonly silt with some fine sand and clay. Outwash consists of sand and gravel with varying amounts of clay. The thickness of the Henry Formation varies, ranging up to 48 feet in some locations. The Henry Formation is only found near creeks and is not present beneath the Station (Illinois Power, 2001).

Overburden units at the Station were mapped in 1998 and were reported in the Stack Unit Mapping report (ISGS, 1988). The overburden units were variable across the Station, as described as follows:

- bJ(p) – most of the southeastern, eastern, and northeastern portions of the Station. Richland Loess less than 6 meters (19 feet) thick overlying the Wedron Clay Till Formation of loamy and sandy diamictons greater than 6 meters (19 feet) thick, overlying a discontinuous portion of the Glasford Formation of silty and clayey diamictons less than 6 meters (19 feet) thick. These units go to approximately 15 meters (48 feet) below ground surface (bgs) (ISGS, 1988).
- ah(p)- the northwestern portion of the Station. Cahokia Alluvium less than 6 meters (19 feet) thick overlying the Henry Formation less than 6 meters (19 feet) thick, overlying a discontinuous portion of the Glasford Formation of silty and clayey diamictons less than 6 meters (19 feet) thick. These units go to approximately 15 meters (48 feet) bgs (ISGS, 1988).

The sequence of overburden deposits encountered during excavation activities associated with construction of the Station were, in descending order, as follows (Illinois Power, 2001):

- Richland Loess - clayey silt (approximate thickness of 5 feet);
- Wedron Clay Till Formation (Wisconsinan) - clayey sandy silt till with interbedded discontinuous lenses of stratified silt, sand or gravel (approximate thickness of 35 to 45 feet);
- Robien Silt - silt with some organics and trace clay and fine-grained sand (reportedly only 2 feet thick);
- Glasford Formation (Illinoian) - sandy silt till with interbedded discontinuous lenses of stratified silt, sand or sandy silt (approximate thickness of 790 feet); and

- Banner Formation (Kansan) - stratified silt, sand clay till and sand and gravel outwash (reported thickness of up to 140 feet).

In general, the pre-Illinoian strata occur above depths of 35 feet bgs [700 feet above mean sea level (AMSL)]. The Illinoian Glasford Formation is encountered at depths below 35 feet bgs and ranges from approximately 570 feet AMSL to 700 feet AMSL. Older Kansan-aged lacustrine deposits and till were encountered beneath the Glasford Formation from elevations that ranged from approximately 500 to about 570 feet AMSL (Illinois Power, 2001).

2.4.2.2 BEDROCK

The top of bedrock is found regionally at elevations ranging from 360 to 510 feet AMSL. Beneath the Station, boring data confirm that bedrock occurs at an elevation of approximately 550 feet AMSL (or 180 feet bgs).

The uppermost bedrock in the Station area is Pennsylvanian aged, interbedded limestone, siltstone, and shale of the McLeansboro Group and Modesto Formation. The Pennsylvanian bedrock is characterized by sharp changes vertically in rock type and by lateral continuity of units such as limestone and coal.

Mississippian-Silurian-Devonian age bedrock lies beneath the Pennsylvanian strata and consists primarily of thick-bedded Mississippian limestone and sandstone underlain by a Devonian-aged shale, which in turn overlies Devonian-Silurian dolomite and limestone.

2.4.3 HYDROGEOLOGY

This section describes the hydrogeology at the Station, as known prior to the completion of this hydrogeologic investigation. The Station-specific hydrogeology determined from the investigation completed pursuant to the Work Plan is discussed in Section 5.2.

Groundwater in the region originates from these aquifer systems near the Station (Illinois Power, 2001):

- recent alluvial deposits (flood plain silts and fluvial sands and gravels) along streams;

- layers and lenses of sand or sand and gravel within the sequence of Wisconsian and Illinoian lacustrine silts and glacial tills;
- Kansan-aged glacial outwash sands and gravels located in buried bedrock valleys;
- Pennsylvanian-aged limestone/sandstone aquifers; and
- Mississippian and Devonian-Silurian dolomite/limestone aquifers.

The recent alluvial deposits provide good water supplies where thick sequences of sand and gravel are present, typically near larger streams with well-developed flood plains. Water supply wells in the alluvial deposits adjacent to Kickapoo Creek are an example of a groundwater source from the alluvial deposits (Illinois Power, 2001).

Approximately 200 feet of glacial drift underlie the Station. These deposits are divided into two hydrogeologic units. The shallow (Wisconsinan and Illinoian) overburden sequence (up to 150 feet deep) consists of lacustrine silts and silty/clayey tills, which have limited groundwater availability. Older (Kansan) sand and sand and gravel deposits that underlie the fine-grained material in-fill buried bedrock valleys and produce prodigious quantities of good quality groundwater (Illinois Power, 2001).

The Wisconsinan deposits are typically fine grained with only occasional, shallow and very localized sand and gravel. Groundwater in the Wisconsinan deposits occurs under unconfined conditions, usually within 2 to 20 feet bgs. Regional groundwater movement in the Wisconsinan till plain is generally west and southwest towards the Illinois River. The water table mimics the land surface and topography influences local groundwater movement, particularly near tributary streams that receive recharge from the shallow groundwater regime (Illinois Power, 2001).

The distribution of sand lenses and layers also controls groundwater availability in the underlying Illinoian tills. Compared to the Wisconsin strata, the sands within the Illinoian tills are thicker and more laterally extensive, providing small to moderate amounts of groundwater. Groundwater in these deeper overburden deposits is confined (Illinois Power, 2001).

Kansan sand and gravel deposits of the Banner Formation in the buried Mahomet Bedrock Valley comprise the major aquifer in the area. Yields of up to 2,000 gallons per minute (gpm) may be obtained from a suitably constructed well located in the main channel of the valley. As discussed in Section 2.4.4, the deep Kansan outwash provides most of the major public groundwater supplies in the region (Illinois Power, 2001). The

Pennsylvanian bedrock also provides minor amounts of groundwater, which are typically of poor quality (Illinois Power, 2001).

The groundwater system of most interest at the Station is the upper glacial deposits. The groundwater table in the upper glacial deposits (Wisconsinan) beneath the Station generally occurs within 15 feet bgs. The highest groundwater level in the Station area measured during previous investigations was an elevation of 729.7 feet AMSL.

Several discontinuous sand lenses, ranging in thickness from several inches to 22 feet were encountered in these previous borings completed near the Station between an elevation of 650 feet AMSL and 730 feet AMSL. The excavation for construction of the nuclear plant extended to an approximate elevation of 680 feet AMSL, penetrating some of these lenses. Most of the sand deposits encountered at and near the Station are discontinuous pockets or lenses (Illinois Power, 2001).

Additional groundwater elevation data from piezometers installed in July 2002 indicate that the water table elevation in the shallow groundwater zone, which corresponds to the clayey sandy silt till of the Wisconsinan Wedron Clay Till Formation, is between 725 feet AMSL and 730 feet AMSL (Illinois Power, 2001).

2.5 AREA GROUNDWATER USE

The Station does not use groundwater as a potable resource. The Station obtains its potable water from the North Fork leg of Salt Creek. Groundwater is available from a number of sources near the Station. Groundwater is found chiefly in local sand and gravel deposits in the shallow overburden and extensive sand and gravel deposits near the base of the overburden sequence in buried bedrock valleys (Illinois Power, 2001).

Bedrock wells are not used in any of the public water supply systems within 15 miles of the Station; however, minor amounts of groundwater are obtained from the shallow bedrock. Use of bedrock groundwater supply is limited because of poor regional water quality and the availability of shallower sources of potable groundwater (Illinois Power, 2001).

The largest volumes of groundwater are extracted from the deep sand and gravel aquifers in the region. These deep aquifers are the principal source of drinking water for many municipalities in the region and individual wells may produce 500 gpm. The Updated Final Safety Analysis Report (Illinois Power, 2001) reported that within

15 miles of the Station, approximately 65 percent of the total public groundwater supplies are pumped from the Mahomet Bedrock Valley aquifer. Shallow alluvial deposits associated with present day streams are also locally important sources of drinking water. For example, water supply wells in the alluvial deposits adjacent to Kickapoo Creek supply water to the town of Heyworth, McLean County at rates up to 200 gpm (Illinois Power, 2001).

Groundwater in the shallow overburden occurs in silty clay or clayey silt tills at depths of 5 to 15 feet bgs. Occasionally, shallow large diameter wells are dug into the till and may yield relatively small water sources. Records show that most domestic wells near the Station are less than 150 feet deep and produce from local sand lenses in the upper glacial tills rather than from the deeper Mahomet Bedrock Valley aquifer (Illinois Power, 2001).

The town of De Witt is approximately 2.5 miles to the east of the Station. The town obtains its drinking water from a well that is approximately 1.6 miles to the east of the Station. The well is cross-gradient of the Station, is reportedly several hundred feet deep, and is completed in the Mahomet Aquifer (Illinois Power, 2001).

3.0 AREAS FOR FURTHER EVALUATION

CRA considered all Station operations in assessing groundwater quality at the Station. During this process, CRA identified areas at the Station that warranted further evaluation or "AFEs". This section discusses the process by which AFEs were selected.

CRA's identification of AFEs involved the following components:

- Station inspection on March 22 and 23, 2006;
- interviews with Station personnel;
- evaluation of Station systems;
- investigation of confirmed and unconfirmed releases of radionuclides; and
- review of previous Station investigations.

CRA analyzed the information collected from these components combined with information obtained from CRA's study of hydrogeologic conditions at the Station to identify those areas where groundwater potentially could be impacted from operations at the Station.

CRA then designed an investigation to determine whether any confirmed or potential releases or any other release of radionuclides adversely affected groundwater. This entailed evaluating whether existing Station groundwater monitoring systems were sufficient to assess the groundwater quality at the AFEs. If the systems were not sufficient to adequately investigate groundwater quality associated with any AFE, additional monitoring wells were installed by CRA.

The following sections describe the above considerations and the identification of AFEs. The results of CRA's investigation are discussed in Section 5.0.

3.1 SYSTEMS EVALUATIONS

Exelon launched an initiative to systematically assess the structures, systems and components that store, use, or convey potentially radioactively contaminated liquids. Maps depicting each of these systems were developed and provided to CRA for review. The locations of these systems are presented on Figure 3.1. The Station identified a total of 17 systems that contain or could contain potentially radioactively contaminated liquids. The following presents a list of these systems.

System Identification	*Description*
1	Condensate System
2	Cycled Condensate System
3	Fuel Pool Cooling and Clean-up
4	Low Pressure Core Spray
5	Suppression Pool System
6	Shut Down Service Water System
7	Plant Service Water System
8	Circulation Water System
9	Laundry Equipment Floor Drains
10	High Pressure Core Spray
11	Residual Heat Removal System
12	Sewage Treatment System
13	Reactor Core Isolation Cooling System
14	Containment, Auxiliary, and Fuel Building Equipment Drains
15	Containment, Auxiliary, and Fuel Building Floor Drains
16	Turbine, Radwaste, Control Building, and Diesel Generators Equipment Drains
17	Turbine, Radwaste, Control Building, and Diesel Generators Floor Drains

After these systems were identified, Exelon developed a list of the various structures, components and areas of the systems (e.g., piping, tanks, process equipment) that handle or could potentially handle any radioactively contaminated liquids. The structures, components, and areas may include:

- aboveground storage tanks;
- condensate vents;
- areas where confirmed or potential historical releases, spills or accidental discharges may have occurred;
- pipes;
- pools;
- sumps;

- surface water bodies (i.e., basins, pits, ponds, or lagoons);
- trenches;
- underground storage tanks; and
- vaults.

The Station then individually evaluated the various system components to determine the potential for any release of radioactively contaminated liquid to enter the environment. Each structure or identified component was evaluated against the following seven primary criteria:

- location of the component (i.e., basement or second floor of building);
- component construction material (i.e., stainless steel or steel tanks);
- construction methodologies (i.e., welded or mechanical pipe joints);
- concentration of radioactively contaminated liquid stored or conveyed;
- amount of radioactively contaminated liquid stored or conveyed;
- existing controls (i.e., containment and detection); and
- maintenance history.

System components, which were located inside a building or that otherwise had some form of secondary containment, such that a release of radioactively contaminated liquid would not be discharged directly to the environment, were eliminated from further evaluation. System components that are not located within buildings or did not have some other form of secondary containment were retained for further qualitative evaluation of the risk of a release or radioactively contaminated liquid to the environment and the potential magnitude of any release.

Exelon's risk evaluation took into consideration factors such as:

- the potential concentration of radionuclides;
- the volume of liquid stored or managed;
- the probabilities of the systems actually containing radioactively contaminated liquid; and
- the potential for a release of radioactively contaminated liquid from the system component.

These factors were then used to rank the systems and system components as to the risk for a potential release of radioactively contaminated liquid to the environment. The evaluation process resulted in the identification of structures, components, and areas to be considered for further evaluation.

3.2 HISTORICAL RELEASES

CRA also reviewed information concerning confirmed or potential historical releases of radionuclides at the Station, including reports and documents previously prepared by Exelon and compiled for CRA's review. CRA evaluated this information in identifying the AFEs. Any historical releases identified during the course of this assessment that may have a current impact on Station conditions are further discussed in Section 3.4.

3.3 STATION INVESTIGATIONS

CRA considered previous Station investigations in the process of selecting the AFEs for the Station. This section presents a summary of the pre-operational radiological environmental monitoring program, past station investigations, and the radiological environmental monitoring program.

3.3.1 PRE-OPERATIONAL RADIOLOGICAL ENVIRONMENTAL MONITORING PROGRAM

A pre-operational radiological environmental monitoring program (pre-operational REMP) was conducted to establish background radioactivity levels prior to operation of the Station. The environmental media sampled and analyzed during the pre-operational REMP were atmospheric radiation, fall-out, domestic water, surface water, marine life and foodstuffs. The pre-operational REMP was initiated in May 1980 and completed during the first quarter of 1987 with initial reactor criticality on February 27, 1987 (Clinton Power Station, 1987).

Atmospheric radiation monitoring consisted of gas and air particulate radioactivity measurements; direct radiation monitoring consisted of using thermoluminescence dosimeters to measure and record exposure to penetrating radiation; domestic water monitoring consisted of well water sample analysis; surface water monitoring consisted of sampling water and silt from Clinton Lake; marine life monitoring included sampling of fish and aquatic organisms (periphyton); and foodstuffs monitoring included sampling of green leafy vegetables, grass, milk (control only) and meat (indicator only), when available.

The locations from which these samples were collected are at the same stations for which samples are collected for the radiological environmental monitoring program (REMP), which is discussed in Section 3.3.2.

The analytical results from samples collected from water wells CCL-7 and CCL-12 included in the pre-operational REMP indicate that tritium was not detected in any groundwater samples at concentrations greater than the Lower Limit of Detection (LLD) of 200 to 300 picoCuries per liter (pCi/L). Gross beta analytical results ranged from 1.1 ± 0.9 pCi/L to a maximum detected activity of 5.1 ± 3.7 pCi/L.

The analytical results from samples collected from surface water locations (i.e., at Clinton Lake, at the intake screenhouse, at an upstream location and at a downstream location) indicated that out of 26 quarterly composite samples, tritium was detected once at 330 pCi/L in lake water at CL-13 (CL-13 is 3.6 miles southwest of the Station) and once at 220 pCi/L at the intake screenhouse; all other samples contained concentrations of tritium less than the LLD, which ranged from 174 to 300 pCi/L. Gross beta analytical results ranged from 1.1 pCi/L to a maximum detected activity of 7.6 ± 1.5 pCi/L. Pre-weapons testing tritium concentrations ranged from 6 to 24 pCi/L. The tritium concentrations detected in the lake water during the pre-operational REMP were attributed to fallout from weapons testing.

The pre-operational REMP concluded that an evaluation of the data from the pre-operational environmental survey indicates there is "nothing unusual in sources of radiation and radioactivity". The pre-operational REMP identifies that detections of radioactivity were influenced by the Chernobyl Nuclear Power Plant accidental release and fallout from nuclear weapons testing (Eisenbud, 1987).

3.3.2 RADIOLOGICAL ENVIRONMENTAL MONITORING PROGRAM

The REMP was initiated in 1987. The REMP includes the collection of multi-media samples including air, surface water, groundwater, fish, sediment, and vegetation. The samples are analyzed for beta and gamma-emitting radionuclides, tritium, iodine-131, and/or strontium as established in the procedures developed for the REMP. The samples are collected at established locations, identified as stations, so that trends in the data can be monitored.

An annual report is prepared providing a description of the activities performed and the results of the analysis of the samples collected from the various media. The latest report reviewed by CRA was prepared by Clinton Power Station and is entitled, Annual Radiological Environmental Operating Report, Clinton Power Station - Docket Number 50-461; January 1 through December 31, 2004. This report concluded, "…all comparisons among operational data and pre-operational data showed that during 2004, the operation of Clinton Power Station had no measurable effects upon the surrounding environment." The annual report is submitted to the NRC.

3.3.3 HISTORIC INVESTIGATIONS

This section summarizes historic investigations undertaken at the Station prior to this hydrogeologic investigation, related to actual or potential releases of radioactively contaminated liquids to the subsurface.

3.3.3.1 BASELINE SOIL AND GROUNDWATER INVESTIGATION

McLaren and Hart performed a Baseline Soil and Groundwater Investigation in association with the Station property transfer in 1999. During the investigation, two monitoring wells (MW-1 and MW-2) and 12 soil boring/groundwater screenings were sampled and analyzed for tritium. Tritium was not detected at concentrations greater than the LLD of 200 pCi/L (McLaren and Hart, 1999b).

No groundwater remediation has been required at the Station.

3.4 IDENTIFIED AREAS FOR FURTHER EVALUATION

CRA used the information presented in the above sections along with its understanding of the hydrogeology at the Station to identify AFEs, which were a primary consideration in the development of the scope of work in the Work Plan. The establishment of AFEs is a standard planning practice in hydrogeologic investigations to focus the investigation activities at areas where there is the greatest potential for impact to groundwater.

Specifically, AFEs were identified based on these six considerations:

- systems evaluations;
- risk evaluations;
- review of confirmed and/or potential releases;
- review of documents;
- review of the hydrogeologic conditions; and
- Station inspection completed on March 22 and 23, 2006.

Prior to CRA completing its analysis and determination of AFEs, Station personnel completed an exhaustive review of all historic and current management of systems that may contain potentially radioactively contaminated liquids.

CRA reviewed the systems identified by the Station, which have the potential for the release of radioactively contaminated liquids to the environment, and groundwater flow at the Station. This evaluation allowed CRA to become familiar with Station operations and potential systems that may impact groundwater. CRA then evaluated information concerning historic releases as provided by the Station. This information, along with a review of the results from historic investigations, was used to refine CRA's understanding of areas likely to have the highest possibility of impacting groundwater. Where at risk systems or identified historical releases were located in close proximity or were located in areas which could not be evaluated separately, the systems and historical releases were combined into a single AFE. At times, during the Station investigation, separate AFEs were combined into one or were otherwise altered based on additional information and consideration.

Finally, CRA used its understanding of known hydrogeologic conditions (prior to this investigation) to identify AFEs. Groundwater flow was an important factor in deciding whether to combine systems or historical releases into a single AFE or create separate AFEs. For example, groundwater beneath several systems that contain radioactively contaminated liquids that flows toward a common discharge point were likely combined into a single AFE. The AFEs were created based on known groundwater flow conditions prior to the work completed during this investigation.

Based upon its review of information concerning confirmed or potential historical releases, historic investigations, and the systems at the Station that have the potential for release of radioactively contaminated liquids to the environment combined with its understanding of groundwater flow at the Station, CRA has identified the following as the AFEs (see Figure 3.1).

AFE-Clinton-1 - Cycled Condensate System

The Cycled Condensate System was identified as an AFE because de-mineralized primary cooling water is transferred through underground pipes to the Cycled Condensate Aboveground Storage Tank (AST), which is roughly 200 feet north of the PA.

On May 3, 2006, after a recent rainfall, Station personnel collected a sample of water, which had collected in the contained valve sump located next to the Cycled Condensate Storage Tank. The results of the analysis from this sample indicated elevated concentrations of tritium in the water within the contained valve sump. Information provided by the Station suggests that the likely source of the detected tritium is the result of historical maintenance practices.

AFE-Clinton-2 – Reactor Core Isolation Cooling System

The Reactor Core Isolation Cooling System was identified as an AFE in order to investigate any residual impact related to a previous release of tritium in this area.

AFE-Clinton-3 – Circulating Water System

The Circulating Water System was identified as an AFE because, until September 1992, this system received permitted discharges of liquid radioactive effluent. This system includes the 3.1-mile unlined aqueduct.

AFE-Clinton-4 – North Power Block Discharge – Radwaste and Turbine Building Sumps

This system includes a series of floor drains in the Turbine and Radwaste buildings and underground pipes that have the potential to convey tritiated water from the northern end of the power block to the sediment pond. There have been no documented releases of tritiated water from the floor drains and underground pipes.

AFE-Clinton-5 – South Power Block Discharge –
Control Building/Diesel Generator Building Sumps

There are six sumps that could potentially contain tritiated water. There is no historical data that the liquids discharged from these sumps were sampled for tritium.

AFE-Clinton-6 – Shut Down Service Water System

The Shut Down Service Water System was identified as an AFE because effluent from the Containment Building has the potential to contain radioactively contaminated liquids.

4.0 FIELD METHODS

The field investigations completed for this HIR were completed in April, May, July, and August 2006. CRA supervised the installation of monitoring wells and staff gauges, and collected water samples from the newly-installed and existing monitoring wells as well as surface water locations. The field investigations were completed in accordance with the methodologies presented in the Work Plan (CRA, 2006).

4.1 STAFF GAUGE INSTALLATION

Figure 4.1 presents the location of the six surface water monitoring locations. CRA installed new staff gauges or used benchmarks of existing structures to measure surface water elevations as part of this investigation. CRA installed staff gauges at the south sediment pond (SW-2) and in the aqueduct (SW-7). Benchmarks were established at the remaining surface water monitoring locations. Station personnel provided elevation data to CRA for Clinton Lake that were used to determine the lake elevation at SW-1.

4.2 GROUNDWATER MONITORING WELL INSTALLATION

Prior to completing any ground penetration activities, CRA completed subsurface utility clearance procedures to minimize the potential of injury to workers and/or damage to subsurface utility structures. The subsurface clearance procedures consisted of completing an electronic survey within a minimum of 10-foot radius of the proposed location utilizing electromagnetic and ground penetrating radar technology. Additionally, an air knife was utilized to verify utilities were not present at the proposed location to a depth to 12 feet bgs.

Fourteen new monitoring wells were installed for the fleetwide hydrogeologic investigation (MW-CL-12I, MW-CL-13S/I, MW-CL-14S, MW-CL-15S/I, MW-CL-16S, MW-CL-17S, MW-CL-18S/I, MW-CL-19S, MW-CL-20S, MW-CL-21S, and MW-CL-22S). Figure 4.1 presents the locations of the 14 new monitoring wells. These locations were selected based on a review of all data provided, the hydrogeology at the Station, and current understanding of identified AFEs. Table 4.1 summarizes the well completion details. The monitoring well stratigraphic and instrumentation logs are presented in Appendix A.

The designation "S" in the well names denotes a shallow well. These "S" wells were installed and screened in the shallow groundwater zone. The designation "I" in the well names denotes an intermediate depth well. These "I" wells were installed in the intermediate groundwater zone, approximately 25 feet deeper than the shallow wells.

The monitoring well boreholes were completed in unconsolidated materials using 4.25-inch inside diameter hollow-stem auger (HSA) drilling techniques with split spoon sampling. Down hole drilling equipment was thoroughly steam cleaned between drilling locations and prior to leaving the Station. Decontamination fluids were containerized in 55-gallon drums, labeled and were staged at the Station pending characterization and management by the Station.

Specific installation protocols for the shallow monitoring wells were:

- each borehole was advanced to a depth of 12 feet below grade using vacuum excavation equipment (air knife) to ensure no underground utilities were damaged;
- the borehole was then advanced to the target depth using 4.25-inch inside diameter HSA;
- continuous split spoon samples were collected during HSA advancement. At depths greater than 30 feet below grade the sampling interval was increased to every 5 feet;
- a nominal 2-inch diameter No. 10 slot PVC screen, 10 feet in length, attached to a sufficient length of 2-inch diameter schedule 40 PVC riser pipe to extend to the surface, was placed into the borehole through the augers;
- a silica sand filter sand pack was installed in the annulus between the screen/riser pipe and the borehole to a minimum height of 2 feet above the top of the screen as the augers were removed;
- a minimum 2-foot thick seal consisting of 3/8-inch diameter bentonite pellets or chips was placed on top of the sand pack and hydrated using potable water;
- the remaining borehole annulus was sealed to within 3 feet of the surface using pure bentonite;
- the remaining portion of the annulus was filled with concrete and a 6-inch diameter protective above-grade casing or in higher traffic areas a flush road-way protective casing was installed; and
- cement-filled bollard posts were installed around selected monitoring well locations.

The overburden was classified using the Unified Soil Classification System (USCS). Soil cuttings and spoils from the vacuum excavation were containerized in 55-gallon drums, labeled and are staged at the Station pending characterization and management by the Station.

Monitoring well MW-12I, located on the northwest side of the PA between the Station and Clinton Lake, was initially proposed as a shallow monitoring well location. This monitoring well was intended to monitor shallow groundwater conditions downgradient of the Station. However, shallow groundwater was not encountered during the borehole advancement. Therefore, the monitoring well was completed as an intermediate depth well. This location is also along the top edge of a steep slope with approximately 30 feet of vertical relief, which is believed to account for the shallow water-bearing unit not being encountered.

4.3 GROUNDWATER MONITORING WELL DEVELOPMENT

To establish good hydraulic communication with the aquifer and to reduce the volume of sediment in the monitoring well, monitoring well development was conducted in accordance with these procedures:

- Monitoring wells were surged using a pre-cleaned surge block or bailer for at least 10 minutes.
- Water was purged from the monitoring well using an electric submersible or peristaltic pump.
- Groundwater was collected at regular intervals and the pH, temperature, and conductivity measured using field instruments. These instruments were calibrated daily according to the manufacturer's specifications. Additional observations such as color, odor, and turbidity of the purged water were recorded.
- Development continued until the turbidity and silt content of the monitoring wells was significantly reduced and three consistent readings of pH, temperature, and conductivity were recorded, or a maximum of eight-well volumes were purged.

A summary of the well development parameters is provided in Table 4.2.

In the event that a monitoring well was purged dry prior to stabilization, the well was allowed to recharge and purging was continued. This process continued until stabilization was achieved or a maximum of eight well volumes were removed. Development equipment was decontaminated between monitoring wells and new tubing was used at each monitoring wells. Water generated during development was containerized in 55-gallon drums, which were subsequently processed by the Station in accordance with their NPDES permit.

4.4 WELL INVENTORY

Figure 4.1 presents a map of the Station including the pre-existing monitoring well/piezometer network. CRA completed an inventory of the pre-existing well network to evaluate the integrity and status of the wells. This inventory included the opening of each well cap, measuring the depth-to-water, sounding the total well depth and recording the condition of the well.

The results of the inventory identified:

- pre-existing monitoring wells MW-8, MW-9, MW-10, and MW-11, are no longer present and were apparently abandoned. Seven of the 11 pre-existing monitoring wells are useable;
- the concrete pad at monitoring well MW-6 was heaved above the adjacent ground level but the well was still usable for hydraulic monitoring;
- the well casing at monitoring well MW-2 was bent at a depth of 4 feet below the top of the casing, which prevented lowering the groundwater sampling pump into the well. However, CRA sampled the well using a peristaltic pump; and
- piezometer E-4B was not inspected due to its distance from the Station. Three of the four existing piezometers are still usable.

The integrity and condition of the remaining monitoring wells and piezometers were found to be acceptable. Well construction logs were not available for the existing wells/piezometers.

CRA did not perform a public and private water supply well inventory as part of this hydrogeologic investigation due to the Station setting.

4.5 SURVEY

The 14 new monitoring wells and six new staff gauges were surveyed to establish reference elevations relative to mean sea level. The top of each well casing was surveyed to the nearest 0.01 foot relative to the National Geodetic Vertical Datum (NGVD), and the survey point was marked on the well casing. The survey included the ground elevation at each well to the nearest 0.10 foot relative to the NGVD, and the well location to the nearest 1.0 foot. A reference point was also marked on each staff gauge.

4.6 GROUNDWATER AND SURFACE WATER ELEVATION MEASUREMENTS

On May 22, 2006, CRA collected a round of water level measurements from the new monitoring wells and staff gauges installed in accordance with the Work Plan and from ten existing monitoring wells/piezometers. On August 8, 2006, CRA collected a second round of water level measurements from the monitoring wells/piezometers and staff gauges at the Station. Based on the measured depth to water from the reference point and the surveyed elevation of the reference point, the groundwater and surface water elevations were calculated. A summary of groundwater elevations for both events is presented in Table 4.3. Staff gauge measurements and corresponding surface water elevations are presented in Table 4.4.

Prior to the water level measurements, the wells were identified and located. Once the wells were identified, CRA completed a thorough inspection of each well and noted any deficiencies. Water level measurements were collected using an electronic depth-to-water probe accurate to ± 0.01 foot. The measurements were made from the designated location on the inner riser or steel casing of each monitoring well. The water level measurements were obtained using these procedures:

- The proper elevation of the meter was checked by inserting the tip into water and noting if the contact was registering correctly.
- The tip was dried, and then slowly lowered into the well until contact with the water was indicated.
- The tip was slowly raised until the buzzer began to activate. This indicated the static water level.
- The reading at the reference point was noted to the nearest hundredth of a foot.
- The reading was then re-checked.
- The water level was then recorded, and the water level meter decontaminated prior to use at the next well location.

4.7 GROUNDWATER, SURFACE WATER AND WATER SAMPLE COLLECTION

CRA conducted two groundwater sampling events during the completion of the Work Plan for this hydrogeologic investigation. A total of 14 monitoring wells and one piezometer were sampled between May 22 and May 25, 2006 and two additional monitoring wells were sampled on August 4, 2006. Of the 17 monitoring wells/piezometers sampled, 14 were newly installed. The two existing wells (MW-1 and MW-2) were selected for inclusion in this monitoring program based on their proximity to the AFEs. Piezometer B-3 was selected as a background monitoring location. The new monitoring wells were installed to complete the monitoring network near the AFEs. The sampling was scheduled to allow for 2 weeks to elapse between well development and groundwater sample collection.

CRA conducted the sampling using electric submersible pumps or peristaltic pumps and dedicated polyethylene tubing to employ low flow purging techniques as described in Puls and Barcelona (1996).

The groundwater in the monitoring wells was sampled by the following low-flow procedures:

- The wells were located and identified.
- A water level measurement was taken.
- The well was sounded by carefully lowering the water level tape to the bottom of the well (so as to minimize penetration and disturbance of the well bottom sediment), and comparing the sounded depth to the installed depth to assess the presence of any excess sediment or drill cuttings.
- The pump or tubing was lowered slowly into the well and fixed into place such that the intake was located at the mid-point of the well screen, or a minimum of 2 feet above the well bottom/sediment level.
- The purging was conducted using a pumping rate between 100 to 500 milliliters per minute (mL/min). Initial purging began using the lower end of this range. The groundwater level was monitored to ensure that a drawdown of less than 0.3 foot occurred. If this criterion was met, the pumping rate was increased dependent on the behavior of the well. During purging, the pumping rate and groundwater level were measured and recorded every 10 minutes.
- The field parameters [pH, temperature, conductivity, oxidation-reduction potential (ORP), dissolved oxygen (DO), and turbidity] were monitored during the purging to

evaluate the stabilization of the purged groundwater. Stabilization was considered to be achieved when three consecutive readings for each parameter, taken at 5-minute intervals, were within these limits:

pH	± 0.1 pH units of the average value of the three readings;
Temperature	± 3 percent of the average value of the three readings;
Conductivity	± 0.005 milliSiemen per centimeter (mS/cm) of the average value of the three readings for conductivity <1 mS/cm and ± 0.01 mS/cm of the average value of the three readings for conductivity >1 mS/cm;
ORP	± 10 millivolts (mV) of the average value of the three readings;
DO	± 10 percent of the average value of the three readings; and
Turbidity	± 10 percent of the average value of the three readings, or a final value of less than 5 nephelometric turbidity units (NTU).

- Once purging was complete, the groundwater samples were collected directly from the pump/tubing directly into the sample containers.
- In the event that the groundwater recharge to the monitoring well was insufficient to conduct the low-flow procedure, the well was pumped dry and allowed to sufficiently recharge prior to sampling.

The purging parameters are presented in Table 4.5.

All groundwater samples were labeled with a unique sample number, the date and time, the parameters to be analyzed, the job number, and the sampler's initials, as described in Section 4.9. The samples were then screened by the Station for shipment to Teledyne Brown Engineering, Inc. (Teledyne Brown). A sample key is presented in Table 4.6.

CRA containerized the water purged from the Station wells during the sampling, as well as the water purged from all of the wells during the hydrogeological investigation. The water was placed into 55-gallon drums, which will be processed by the Station in accordance with its NPDES permit.

Station personnel collected water samples from five locations within the Unit 2 Pit drainage system on June 27, 2006. The Unit 2 Pit sampling locations are shown on Figure 4.2. The water samples from the drainage system within the Unit 2 Pit were collected in response to an evaluation of the May 22, 2006 groundwater elevation data, which indicated that the shallow groundwater beneath the PA and most of the Station flows toward and discharges into the Unit 2 Pit.

On May 24, 2006, surface water samples were collected by CRA personnel at the four staff gauges and at the two locations on the north end of the Cooling Lake, just south of the Site. The surface water sampling locations are shown on Figure 4.1.

The samples were collected by submerging the sample container at the determined sample locations until completely filled. All samples were shipped to Teledyne Brown for analysis. Teledyne Brown's Quality Assurance Program is provided in Appendix B. A sample key is presented in Table 4.6.

4.8 DATA QUALITY OBJECTIVES

CRA has validated the analytical data to establish the accuracy and completeness of the data reported. Teledyne Brown provided the analytical services. The Quality Assurance Programs for the laboratory are described in Appendix B. Analytical data for groundwater and surface water samples collected in accordance with the Work Plan are presented in Appendix C. Data validation reports are presented in Appendix D. The data validation included the following information and evaluations:

- sample preservation;
- sample holding times;
- laboratory method blanks;
- laboratory control samples;
- laboratory duplicates;
- verification of laboratory qualifiers; and
- field quality control (field blanks and duplicates).

Following the completion of field activities, CRA compiled and reviewed the geologic, hydrogeologic, and analytical data.

The data were reviewed using these techniques:

- data tables and databox figures;
- hydrogeologic cross-sections; and
- hydraulic analyses.

4.9 SAMPLE IDENTIFICATION

Systematic sample identification codes were used to uniquely identify all samples. The identification code format used in the field was: WG–CL-MW-CL-20S–052306-JKAD-02. A sample key listing all the samples collected during the fleetwide investigation is presented in Table 4.6.

WG	-	Sample matrix -groundwater
WS	-	Sample matrix - surface water
RB	-	Sample matrix – rinse blank
CL	-	Station code
MW-CL-20S	-	Sample location
052306	-	Date
JKAD	-	Sampler initial
02	-	Sample number

4.10 CHAIN-OF-CUSTODY RECORD

The samples were delivered to Station personnel under chain-of-custody protocol. Subsequently, the Station shipped the samples under chain-of-custody protocol to Teledyne Brown for analyses.

4.11 QUALITY CONTROL SAMPLES

Quality control samples were collected to evaluate the sampling and analysis process.

Field Duplicates

Field duplicates were collected to verify the accuracy of the analytical laboratory by providing two samples collected at the same location and then comparing the analytical results for consistency. Field duplicate samples were collected at a frequency of one duplicate for every ten samples collected. A total of three duplicate samples were collected. The locations of duplicate samples were selected in the field during the performance of sample collection activities. The duplicate samples were collected simultaneously with the actual sample and were analyzed for the same parameters as the actual samples.

Rinsate Blank Samples

Rinsate blanks were collected to verify that decontamination procedures conducted in the field were adequate. Rinsate blanks were collected by routing Station-supplied demineralized water through decontaminated sampling equipment. Rinsate blanks were collected at a frequency of one rinsate blank for every day samples were collected using non-disposable or non-dedicated equipment. Two Rinsate blanks were collected.

Split Samples

Split samples were collected for the NRC for tritium simultaneously with the actual sample during the May 2006 sampling event. Samples were collected at each sample location. Split samples were delivered to the Station personnel and transferred to the NRC.

4.12 LABORATORY ANALYSES

Groundwater and surface water samples were analyzed for tritium and gamma-emitting radionuclides as listed in NUREG-1302 and strontium-89/90 as listed in 40 CFR 141.25. Water samples from the Unit 2 Pit drainage system were analyzed for gamma-emitting radionuclides and tritium.

5.0 RESULTS SUMMARY

This section provides a summary of Station-specific geology and hydrogeology, along with a discussion of hydraulic gradients, groundwater elevations, and groundwater flow directions in the vicinity of the Station. This section also presents and evaluates the analytical results obtained from activities performed in accordance with the Work Plan.

5.1 STATION GEOLOGY

The geology beneath the Site consists of a relatively thick overburden deposit that overlies alternating layers of limestone, sandstone, shale, and coal. Figure 5.1 displays the locations of the hydrogeologic cross-sections across the Site. Hydrogeologic cross-sections in south-north, east-west, and north-south profiles are presented on Figures 5.2, 5.3, and 5.4, respectively. These locations were chosen because of their close proximity to the AFEs and structures potentially influencing groundwater flow patterns.

The stratigraphic units encountered during monitoring well installation activities consisted of the following:

- Richland Loess;
- Wedron Clay Till Formation; and
- Glasford Formation.

The Robien Silt, if contacted, could not be differentiated in the field from the Glasford Formation.

Monitoring wells MW-CL-14S, MW-CL-16S, and MW-CL-22S were installed in the PA adjacent to the Seal Well, Reactor Core Isolation Cooling Storage Tank, and Diesel Generating Building, respectively. At these locations compacted construction fill material, associated with the Station construction excavation, was encountered. This fill material consisted of compacted layers of silt and sand including concrete mud mats.

During construction, concrete mud mats were poured at specific locations, as the excavation was backfilled. These mud mats consisted of a lower strength concrete mixture that was poured to make a stable working platform to install pipes and conduits. Concrete mud mats were encountered between depths of 13.5 feet and 20 feet below grade (716 and 722 feet AMSL) at MW-CL-14S and at depths of 18 to 26 feet below grade (709 to 717 feet AMSL) at MW-CL-16S. The concrete mud mat was penetrated at both locations and the monitoring well screens were installed across the concrete and into the soil below.

Eight shallow monitoring wells (MW-CL-13S, MW-CL-15S, MW-CL-16S, MW-CL-17S, MW-CL-18S, MW-CL-19S, MW-CL-20S, and MW-CL-21S) were screened within the Wedron Clay Till Formation. The Wedron Clay Till Formation is the shallow overburden water bearing unit beneath the Site and is primarily a clayey, sandy, silt till with interbedded lenses of silt, sand, and gravel. The monitoring well logs for the new monitoring wells are presented in Appendix A.

Four intermediate depth monitoring wells were installed at an elevation that corresponds to the Glasford Formation. The Glasford Formation, reportedly is a sandy silt till with sand lenses and discontinuous sand layers (Illinois Power, 2001). Monitoring well MW-CL-12I was installed in a saturated section of sandy gray clay just above the sand layer that the other three intermediate wells are screened in and extends slightly into the sand layer.

Intermediate depth monitoring wells MW-CL-15I, MW-CL-13I, and MW-CL-18I, were installed in a sand layer. The top of the sand layer was encountered at depths that ranged from approximately 55 feet to 64 feet below grade with elevations ranging from 670 to 680 feet AMSL. The borings were terminated in the sand layer and did not penetrate to a deep unit. The maximum thickness penetrated was 7 feet at MW-CL-13I. As shown on the hydrogeologic cross-sections this sand layer appears to be continuous beneath the Station since the sand was encountered in each of the boreholes advanced.

Profile A-A' (Figure 5.2) is a north-south profile through the middle of the Site. The cross-section begins at Clinton Lake and terminates at MW-CL-20S near the Discharge Flume/aqueduct. This profile transects with AFEs Clinton 3 and 4 along the northern limit of the PA and AFEs Clinton 2 and 5 in the western portion of the PA. This profile also shows the relationship between the groundwater and the geology, Clinton Lake, the Unit 2 Pit, and building foundation excavations for Unit 1. The Unit 2 Pit is an approximately 35-foot deep excavation. This pit was excavated during Station construction for a second reactor. The second reactor was never constructed and the pit was never backfilled. The profile shows that the shallow groundwater unit intersects the Unit 2 Pit and illustrates the influence of the drainage system at the base of the pit on the groundwater table. This profile shows the groundwater divides near the aqueduct and near Clinton Lake. Profile A-A' also illustrates that the sand unit representing the intermediate groundwater unit is below the pit elevation (approximately 700 feet AMSL).

Profile B-B' (Figure 5.3) is an east-west profile that intersects AFE-Clinton-3. This cross-section begins in the west near the sediment ponds (AFE-Clinton-4) and runs northward to MW-CL-18S/I and north of AFE 4 to MW-CL-12I where it crosses AFE-Clinton-3 and then transects monitoring wells MW-CL-19S and MW-CL-13I/S, the latter of which is adjacent to AFE-Clinton-1. This profile shows the relationship between the groundwater and geology between the PA and the sediment ponds. This profile shows that the shallow groundwater unit near the Cycled Condensate Storage Tank is nearly at the same elevation as the pit located next to the storage tank. These data indicate that the base of the pit is in close contact with the shallow water table. This profile also indicates that the base of the sediment ponds is in contact with the shallow groundwater unit. This profile also shows that the shallow groundwater unit discharges to the ditch near monitoring well MW-CL-19S.

Profile C-C' (Figure 5.4) is a north-south profile through the eastern portion of the PA extending to the north into AFE-Clinton-1 (at MW-CL-13I/S). In addition to the features shown on Figure 5.4, this profile depicts the stratigraphic unit adjacent to the Radwaste Building and the Unit 2 Pit based on the geology encountered during the drilling of MW-CL-13S. This profile also shows the major influence that the Unit 2 Pit has on flow within the shallow groundwater system.

5.2 STATION HYDROGEOLOGY

This section describes the Station hydrogeology. There were two distinct groundwater flow regimes encountered during the investigation: the shallow regime, which is in the interbedded layers of the Wedron Clay Till Formation (above 690 feet AMSL) and the intermediate regime, which is in the sand layer beneath the Wedron Clay Till Formation (below 690 feet AMSL).

5.2.1 GROUNDWATER FLOW DIRECTIONS

Groundwater flow directions are provided on Figures 5.5 and 5.6 for the shallow groundwater system and Figures 5.7 and 5.8 for the intermediate system. Figures 5.5 and 5.7 represent water levels measured in May 2006. Figures 5.6 and 5.8 represent water levels measured in August 2006. The May and August groundwater flow directions are similar.

As shown on Figures 5.5 and 5.6, the shallow groundwater beneath the PA and most of the Station flows toward the Unit 2 Pit, which is approximately 35 feet deep. This flow pattern is not consistent with the hydrogeologic information used to develop the Work Plan. The radial shallow groundwater flow pattern is the result of the passive drainage system beneath the Unit 2 Pit. In response to this observation water samples from five locations within the Unit 2 Pit drainage system were collected on June 27, 2006.

North of the PA, the groundwater elevation at monitoring well MW-CL-18S is higher than the surface water elevation of Clinton Lake. This indicates there is a flow divide in the shallow groundwater flow regime between the Unit 2 Pit and Clinton Lake. North of the flow divide, shallow groundwater discharges into Clinton Lake. South of the PA, there is a flow divide near monitoring wells MW-7 and B-2. South of these wells groundwater flows west and eventually discharges into Clinton Lake.

The surface water elevation in the aqueduct on May 22, 2006 (723.75 feet AMSL) was lower than the groundwater elevation at nearby shallow monitoring well MW-CL-20S (724.69 feet AMSL). This indicates that shallow groundwater discharges into the aqueduct. The surface water elevations in the primary lagoon and secondary lagoon are approximately 9 feet higher than the groundwater elevations measured in the closest shallow monitoring well, MW-CL-20S. This indicates that groundwater does not discharge to these surface water features and they act as local sources of recharge for the shallow groundwater system.

West of the PA, the shallow groundwater flows west towards Clinton Lake. This area appears to be beyond the hydraulic influence of the Unit 2 Pit and probably represents the natural groundwater flow direction for the shallow groundwater. Groundwater elevations in this area are higher than the elevation of Clinton Lake indicating shallow groundwater west of the PA discharges into Clinton Lake.

The intermediate groundwater potentiometric elevation data are shown on Figures 5.7 and 5.8. As shown, this deeper groundwater flows westward towards Clinton Lake. The groundwater elevation at monitoring well MW-CL-18I is higher than the surface water elevation of Clinton Lake. This suggests that the intermediate groundwater system also discharges to Clinton Lake. As shown on Figures 5.2 and 5.4, the groundwater elevation within the intermediate zone is below the foundation of the Reactor Buildings. As shown on Figure 5.7, there is a radial flow pattern near the Unit 2 Pit. The base of the Unit 2 Pit is at 698 feet AMSL and is below the potentiometric surface of the intermediate groundwater indicating intermediate groundwater also locally discharges to the Unit 2 Pit.

5.2.2 MAN-MADE INFLUENCES ON GROUNDWATER FLOW

The PA is between Clinton Lake and the Unit 2 Pit (Figure 1.2). As shown on Profile A-A', Clinton Lake has an elevation of approximately 690 feet AMSL. There is a road adjacent to the Lake and then the ground surface rises sharply to the south to an elevation of approximately 735 feet AMSL. Shallow and intermediate groundwater discharges to Clinton Lake (See Section 5.2.1).

The foundation of the Reactor Building was installed to an elevation of 712 to 702 feet AMSL, which is below the water table as shown on Figure 5.2 (foundation elevation information provided by Station Engineering). The foundation of the building is beneath the water table so it is expected to act as a local diversion of groundwater flow.

As shown on Profiles A-A' and C-C', the Unit 2 Pit has a base elevation of 698 feet AMSL, which is also below the water table. Therefore, the groundwater table in the vicinity of the Unit 2 Pit flows toward and discharges into the pit. The Unit 2 Pit is in turn drained by a passive drainage system that discharges to Clinton Lake. Figures 1.2 and 4.2 illustrate this drainage system. The drainage system consists of several collection pipes connected by underground drainage pipes installed just below the base of the pit, which is mainly covered with concrete. There is also a concrete collection trough in the northern corner of the pit. The drainage system drains to a drainage pipe that runs under the Reactor Building. This drainage pipe was originally intended to be the cooling water Circulating Water System Pipe for the second reactor, which was never constructed. The elevation of the drainage system is approximately 695 feet AMSL and the elevation of the lake is 690 feet AMSL therefore, the pressure head is back towards the lake.

5.2.3 VERTICAL HYDRAULIC GRADIENTS

Three monitoring well nests (MW-CL-13S/I, MW-CL-15S/I, and MW-CL-18S/I) have been installed with wells in the shallow till and in the intermediate sand to determine the vertical distribution of impacted groundwater, and the vertical hydraulic gradient. The calculated vertical hydraulic gradients using the August 2006 water level data for the Site are provided in Table 5.1. Downward vertical hydraulic gradients that ranged from 0.11 feet/foot to 0.52 feet/foot were calculated at all three locations. The magnitude of the vertical hydraulic gradient is consistent and is greater than the horizontal hydraulic gradients.

5.2.4 LATERAL GROUNDWATER FLOW AND VELOCITY

The spacing of the shallow groundwater elevation contours provided on Figure 5.5 indicate that the horizontal hydraulic gradient in the shallow groundwater is variable. The horizontal hydraulic gradient along several groundwater flow paths was calculated by dividing the change in groundwater elevation along the groundwater flow path by the corresponding distance along the flow path.

As shown on Figure 5.5, immediately south of the Unit 2 Pit the horizontal hydraulic gradient in the shallow groundwater zone is steep, on the order of 0.1 feet/foot. This strong gradient is consistent with a relatively low hydraulic conductivity soil such as the clayey, sandy, silt till. On the other sides of the Unit 2 Pit the horizontal hydraulic gradient decreases as low as 0.03 feet/foot. The gradient increases as the shallow groundwater approaches the Unit 2 Pit, which is typical of a discharge boundary.

With a gradient of 0.02 to 0.1 feet/foot, the average horizontal groundwater velocity in the shallow groundwater zone can be calculated to be 0.3 feet/year to 1.5 feet/year. This is based on a porosity of 0.25 (Illinois Power, 2001) and a hydraulic conductivity of 0.01 feet/day from field hydraulic testing (Illinois Power, 2001).

West of the PA, beyond the influence of the groundwater that flows towards the Unit 2 Pit, the shallow groundwater flows west. Here the horizontal hydraulic gradient is lower still at 0.02 feet/foot and may be more representative of the natural groundwater gradient.

The calculated horizontal hydraulic gradient in the intermediate groundwater beneath the PA is 0.008 feet/foot. The spacing of the intermediate groundwater elevation contours provided on Figure 5.7 is fairly uniform, indicating that there is a limited variation in the horizontal hydraulic gradient in the intermediate sand. The lower hydraulic gradient is also consistent with the more permeable sands that the intermediate wells are screened in. The horizontal hydraulic gradient increases with increasing proximity to the Unit 2 Pit, similar to the shallow groundwater. Using the hydraulic gradient of 0.008 feet/foot with a hydraulic conductivity of 28 feet/day (Illinois Power, 2001) and a typical porosity of 0.32 (USEPA, 1996) yields an estimated horizontal groundwater velocity in the intermediate groundwater of 256 feet/year.

5.3 GROUNDWATER QUALITY

CRA collected 17 groundwater samples from all 14 newly installed monitoring wells and existing monitoring wells/piezometers MW-1, MW-2, and B-3 in accordance with the Work Plan. Teledyne Brown provided the analytical services. The Quality Assurance Program for the laboratory is described in Appendix B. The analytical data reports are provided in Appendix C.

The analytical data presented herein has been subjected to CRA's data validation process. CRA has used the data with appropriate qualifiers where necessary.

The data reported in the figures and tables does not include the results of recounts that the laboratory completed, except if those results ultimately replaced an initial report. The tables and figures, therefore, include only the first analysis reported by the laboratory. Where multiple samples were collected over time, the most recent result has been used in the discussion, below.

5.3.1 SUMMARY OF BETA-EMITTING RADIONUCLIDES ANALYTICAL RESULTS

A summary of the tritium results for the groundwater samples collected during this investigation is provided in Table 5.2 and shown on Figures 5.9 and 5.10.

All tritium concentrations were below the United States Environmental Protection Agency (USEPA) drinking water standard of 20,000 pCi/L. Tritium was not detected above the LLD of 200 pCi/L in 13 of the 17 groundwater samples collected.

The four samples that contained tritium at a concentration greater than the LLD of 200 pCi/L were collected from the shallow groundwater zone. These include samples from the following monitoring wells: MW-CL-13S (230 ± 114 pCi/L), MW-CL-14S (201 ± 107 pCi/L), MW-CL-21S (545 ± 138 pCi/L), and MW-CL-22S (278 ± 122 pCi/L) in the duplicate. The initial groundwater sample collected from monitoring well MW-CL-22S did not reveal a tritium concentration greater than the LLD.

Strontium-89/90 was not detected at concentrations greater than the LLD of 2.0 pCi/L. A summary of the strontium-89/90 results for the groundwater samples collected as part of the investigation that is the subject of this HIR is provided in Table 5.3 and shown on Figure 5.11.

5.3.2 SUMMARY OF GAMMA-EMITTING RADIONUCLIDES ANALYTICAL RESULTS

Gamma-emitting target radionuclides were not detected at concentrations greater than their respective LLD. A summary of the gamma-emitting radionuclides results for the groundwater samples collected as part of the investigation that is the subject of this HIR is provided in Table 5.3 and shown on Figure 5.11.

Other non-targeted radionuclides were also included in the tables but excluded from discussion in this report. These radionuclides were either a) naturally occurring and thus not produced by the Station, or b) could be definitively evaluated as being naturally occurring due to the lack of presence of other radionuclides which would otherwise indicate the potential of production from the Station.

5.3.3 SUMMARY OF FIELD MEASUREMENTS

Table 4.5 presents a summary of field measurements collected during the purging of the monitoring wells prior to sampling. These field measurements included pH, dissolved oxygen, conductivity, turbidity and temperature. The field parameters were typical of shallow glacial deposits. As such the pH values were found to be neutral with pH values around 7.0 and the conductivity was indicative of a shallow water table system subject to surface water recharge. Of note were the slightly elevated temperature readings (above 25 degrees Celsius) in the purge water from MW-CL-14S, which is located adjacent to the Seal Well, which receives circulating water from the Turbine Building.

5.4 SURFACE WATER QUALITY

Six surface water samples were collected from the locations shown on Figure 4.1. The samples were analyzed for tritium, gamma-emitting radionuclides, and strontium-89/90. Teledyne Brown provided the analytical services. The Quality Assurance Program for the laboratory is described in Appendix B. The analytical data reports are provided in Appendix C.

5.4.1 SUMMARY OF BETA-EMITTING RADIONUCLIDES ANALYTICAL RESULTS

A summary of the tritium results for the surface water samples collected in this investigation is provided in Table 5.4 and shown on Figure 5.9.

Tritium was not detected at concentrations greater than the LLD of 200 pCi/L.

Strontium-89/90 was not detected at concentrations greater than the LLD of 2.0 pCi/L. A summary of the strontium-89/90 results for the surface water samples collected in this investigation is provided in Table 5.5 and shown on Figure 5.11.

5.4.2 SUMMARY OF GAMMA-EMITTING RADIONUCLIDES ANALYTICAL RESULTS

Gamma-emitting target radionuclides were not detected at concentrations greater than their respective LLD. A summary of the gamma-emitting radionuclides results for the surface water samples collected in this investigation is provided in Table 5.5 and shown on Figure 5.11.

Other non-targeted radionuclides were also included in the tables but excluded from discussion in this report. These radionuclides were either a) naturally occurring and thus not produced by the Station, or b) could be definitively evaluated as being naturally occurring due to the lack of presence of other radionuclides which would otherwise indicate the potential of production from the Station.

5.5 WATER QUALITY-UNIT 2 PIT

Five water samples were collected from the Unit 2 Pit drainage system at the locations shown on Figure 4.2. The samples were analyzed for tritium and gamma-emitting radionuclides. Teledyne Brown provided the analytical services. The Quality Assurance Program for the laboratory is described in Appendix B. The analytical data reports are provided in Appendix C.

5.5.1 SUMMARY OF BETA-EMITTING RADIONUCLIDES ANALYTICAL RESULTS

A summary of the tritium results for the Unit 2 Pit water samples collected in this investigation is provided in Table 5.6 and shown on Figure 5.9.

Tritium was not detected above the LLD of 200 pCi/L in four of the five water samples collected. Tritium was detected at a concentration of 227 ± 126 pCi/L in the water sample collected from Drainage Pipe - 1D (see Figure 4.2).

5.5.2 SUMMARY OF GAMMA-EMITTING RADIONUCLIDES ANALYTICAL RESULTS

Gamma-emitting target radionuclides were not detected at concentrations greater than their respective LLD. A summary of the gamma-emitting radionuclides results for the water samples collected in this investigation is provided in Table 5.7 and shown on Figure 5.11.

Other non-targeted radionuclides were also included in the tables but excluded from discussion in this report. These radionuclides were either a) naturally occurring and thus not produced by the Station, or b) could be definitively evaluated as being naturally occurring due to the lack of presence of other radionuclides which would otherwise indicate the potential of production from the Station.

6.0 RADIONUCLIDES OF CONCERN AND SOURCE AREAS

This section discusses radionuclides evaluated in this investigation, potential sources of the radionuclides detected, and their distribution.

6.1 GAMMA-EMITTING RADIONUCLIDES

Gamma-emitting target radionuclides were not detected at concentrations greater than their respective LLD. Other non-targeted radionuclides were also included in the tables but excluded from discussion in this report. These radionuclides were either a) naturally occurring and thus not produced by the Station, or b) could be definitively evaluated as being naturally occurring due to the lack of presence of other radionuclides which would otherwise indicate the potential of production from the Station.

6.2 BETA-EMITTING RADIONUCLIDES

Strontium-89/90 was not detected in any of the groundwater or surface water samples collected at concentrations greater than the LLD of 2.0 pCi/L. Tritium was detected in five of the 28 total sample locations. Detected concentrations of tritium ranged from 201 ± 107 pCi/L to 545 ± 138 pCi/L.

Since only tritium was detected at concentrations greater than the LLDs, the following sections focus on tritium; specifically, providing general characteristics of tritium, potential sources, distribution in groundwater, and a conceptual model for migration.

6.3 TRITIUM

This section discusses the general characteristics of tritium, the distribution of tritium in groundwater and surface water, and the conceptual model of tritium release and migration.

6.3.1 GENERAL CHARACTERISTICS

Tritium (chemical symbol H-3) is a radioactive isotope of hydrogen. The most common forms of tritium are tritium gas and tritium oxide, which is also called "tritiated water." The chemical properties of tritium are essentially those of ordinary hydrogen. Tritiated water behaves the same as ordinary water in both the environment and the body. Tritium can be taken into the body by drinking water, breathing air, eating food, or absorption through skin. Once tritium enters the body, it disperses quickly and is uniformly distributed throughout the body. Tritium is excreted primarily through urine within a month or so after ingestion. Organically bound tritium (tritium that is incorporated in organic compounds) can remain in the body for a longer period.

Tritium is produced naturally in the upper atmosphere when cosmic rays strike air molecules. Tritium is also produced during nuclear weapons explosions, as a by-product in reactors producing electricity, and in special production reactors, where the isotopes lithium-7 and/or boron-10 are bombarded to produce tritium.

Although tritium can be a gas, its most common form is in water because, like non-radioactive hydrogen, radioactive tritium reacts with oxygen to form water. Tritium replaces one of the stable hydrogen atoms in the water molecule and is called tritiated water. Like normal water, tritiated water is colorless and odorless. Tritiated water behaves chemically and physically like non-tritiated water in the subsurface, and therefore tritiated water will travel at the same velocity as the average groundwater velocity.

Tritium has a half-life of approximately 12.3 years. It decays spontaneously to helium-3 (^{3}He). This radioactive decay releases a beta particle (low-energy electron). The radioactivity of tritium is the source of the risk of exposure.

Tritium is one of the least dangerous radionuclides because it emits very weak radiation and leaves the body relatively quickly. Since tritium is almost always found as water, it goes directly into soft tissues and organs. The associated dose to these tissues is generally uniform and is dependent on the water content of the specific tissue.

6.3.2 DISTRIBUTION IN STATION GROUNDWATER

This section provides an overview of the lateral and vertical distribution of tritium in groundwater beneath the Station.

Shallow Groundwater

Tritium was detected in only four of the 17 monitoring wells/piezometers sampled during this investigation at concentrations greater than the LLD of 200 pCi/L:

MW-CL-13S at 230 ± 114 pCi/L, which is located east of the PA and adjacent to the Cycled Condensate System; MW-CL-14S at 201 ± 107 pCi/L, which is located along the east side of the PA, west of the Seal Well; MW-CL-21S at 545 ± 138 pCi/L, which is located downgradient (upper water bearing unit) of the Cycled Condensate System; and the duplicate sample collected from MW-CL-22S at 278 ± 122 pCi/L, which is located downgradient of the Reactor Core Isolation Cooling System, South Power Block Discharge Control Buildings and Diesel Generator Sumps, and the Shut Down Service Water System. As shown in Table 5.2, tritium concentrations were less than the LLD of 200 pCi/L for all other groundwater samples.

Intermediate Groundwater

Groundwater samples collected from the intermediate depth monitoring wells MW-1 (existing from prior investigations), MW-CL-12I, MW-CL-15I, MW-CL-13I, and MW-CL-18I did not contain tritium at concentrations greater than the LLD of 200 pCi/L.

Based upon the results of this investigation, there is no evidence of any tritium impact to the intermediate groundwater zone.

6.3.3 DISTRIBUTION IN STATION SURFACE WATER

Tritium was not detected at concentrations greater than the LLD of 200 pCi/L in any of the six surface water samples collected.

6.3.4 DISTRIBUTION IN STATION WATER- UNIT 2 PIT

Tritium was detected in only one of the five water samples collected from the Unit 2 Pit drainage system at a concentration greater than the LLD of 200 pCi/L: Drainage Pipe – 1D at 227 ± 126 pCi/L, located on the west side of the Unit 2 Pit, along the side of the power block (see Figure 4.2).

6.3.5 CONCEPTUAL MODEL OF TRITIUM RELEASE AND MIGRATION

This Section presents CRA's conceptual model of groundwater and tritium migration at the Station.

The intermediate groundwater system discharges into Clinton Lake. Groundwater moving within the intermediate groundwater zone is separated from the regional bedrock aquifer zones by the Wedron Clay Till and several other fine-grained glacial deposits collectively exceeding 200 feet in thickness. As of the date of this report, no tritium has been detected above the LLD of 200 pCi/L in any of the intermediate monitoring wells. This groundwater quality data further support the role of the Wedron Clay Till as an aquitard. As such, the focus of CRA's conceptual hydrogeologic model is the migration of groundwater and tritium within the shallow groundwater.

The shallow groundwater near the PA flows toward and discharges into the Unit 2 Pit. The Unit 2 Pit is approximately 35 feet deep and extends below the water table. There is a storm water collection system in the base of the Unit 2 Pit. This drainage system is the discharge point for all of the shallow groundwater beneath the PA and adjacent support areas. The collected groundwater discharges along with any storm water that enters the Unit 2 Pit, into Clinton Lake under the Station's NPDES Outfall No. 010.

North of the PA, there is a hydrologic divide in the shallow groundwater flow regime between the Unit 2 Pit and Clinton Lake. To the north of the divide, shallow groundwater discharges into Clinton Lake.

There are six surface water bodies at the Station. Two of the surface water bodies act as local sources of recharge for the shallow groundwater system. Groundwater discharges into four of the surface water bodies, as is described below.

The surface water elevations in the primary lagoon and secondary lagoon are approximately 9 feet higher than the groundwater elevations measured in the closest shallow monitoring well, MW-CL-20S. This indicates that groundwater does not discharge to the lagoons and they likely act as local sources of recharge for the shallow groundwater zone.

North of the PA shallow groundwater discharges into Clinton Lake. There is no evidence of detectable concentrations of tritium within this groundwater flow path.

East of the PA shallow groundwater discharges into the aqueduct. There is no evidence of detectable concentrations of tritium within this groundwater flow path.

During the May 2006 monitoring event, the surface water elevations in the sediment ponds were approximately 0.3 feet lower than the groundwater elevations measured in the closest shallow monitoring well. This indicates that groundwater discharges to these surface water features. However, if the groundwater level drops more than 0.3 feet, the sediment ponds could act as local sources of recharge for the shallow groundwater system.

To the west of the PA, the shallow groundwater flows west and discharges into Clinton Lake. There is no evidence of detectable concentrations of tritium within this groundwater flow path.

Tritium concentrations slightly greater than the LLD of 200 pCi/L were detected in groundwater that flows towards and discharges into the Unit 2 Pit. If higher concentrations of tritium were noted in the groundwater, it is likely that the concentration of any tritium will decrease as it migrates slowly toward the Unit 2 Pit due to natural decay as well as dilution from unimpacted groundwater also discharging to the Unit 2 Pit. Specifically, tritium was detected at concentrations greater than the LLD in samples collected from MW-CL-13S, MW-CL-14S, MW-CL-21S, and MW-CL-22S. A drainage system installed in the base of the Unit 2 Pit collects this groundwater and discharges it to Clinton Lake. Water samples collected from the drainage system located within the Unit 2 Pit contained only one detection of tritium (of five samples collected) slightly greater than the LLD of 200 pCi/L.

7.0 EXPOSURE PATHWAY ASSESSMENT

This section addresses the groundwater impacts from tritium and other radionuclides at the Station and potential risks to human health and the environment.

Based upon historical knowledge and data related to the Station operations, and based upon radionuclide analyses of groundwater samples, the primary constituent of concern (COC) is tritium. The discussions that follow are restricted to the exposure pathways related to tritium.

Teledyne Brown reports all samples to their statistically derived Minimum Detectable Concentration (MDC) of approximately 150 to 170 pCi/L, which is associated with 95 percent confidence interval on their hardcopy reports. However, the laboratory uses a 99 percent confidence range (± 3 sigma) for determining whether to report the sample activity concentration as detected or not. This 3-sigma confidence range typically equates to 150 (± 135.75) pCi/L.

Exelon has specified a LLD of 200 pCi/L for the Fleetwide Assessment. Exelon has also required the laboratory to report related peaks identified at the 95 percent confidence level (2-sigma).

This HIR, therefore, screens and assesses data using Exelon's LLD of 200 pCi/L. As is outlined below, this concentration is also a reasonable approximation of the background concentration of tritium in groundwater at the Station.

7.1 HEALTH EFFECTS OF TRITIUM

Tritium is a radionuclide that decays by emitting a low-energy beta particle that cannot penetrate deeply into tissue or travel far in air. A person's exposure to tritium is primarily through the ingestion of water (drinking water) or through ingestion of water bearing food products. Inhalation of tritium requires the water to be in a vapor form (i.e., through evaporation or vaporization due to heating). Inhalation is a minor exposure route when compared to direct ingestion or drinking of tritiated water. Absorption of tritium through skin is possible, but tritium exposure is more limited here versus direct ingestion or drinking of tritiated water.

7.2 BACKGROUND CONCENTRATIONS OF TRITIUM

The purpose of the following paragraphs is to establish a background concentration through review of various media.

7.2.1 GROUNDWATER

Tritium is created in the environment from naturally occurring processes both cosmic and subterranean, as well as from anthropogenic (i.e., man-made) sources. In the upper atmosphere, "cosmogenic" tritium is produced from the bombardment of stable nuclides and combines with oxygen to form tritiated water, which will then enter the hydrologic cycle. Below ground, "lithogenic" tritium is produced by the bombardment of natural lithium isotopes ^{6}Li (92.5 percent abundance) and ^{7}Li (7.5 percent abundance) present in crystalline rocks by neutrons produced by the radioactive decay of uranium and thorium. Lithogenic production of tritium is usually negligible compared to other sources due to the limited abundance of lithium in rock. The lithogenic tritium is introduced directly to groundwater.

A major anthropogenic source of tritium comes from the former atmospheric testing of thermonuclear weapons. Levels of tritium in precipitation increased during the 1950 and early 1960s, coinciding with the release of significant amounts of tritium to the atmosphere during nuclear weapons testing prior to the signing of the Limited Test Ban Treaty in 1963, which prohibited atmospheric nuclear tests.

7.2.2 PRECIPITATION DATA

Precipitation samples are routinely collected at stations around the world for the analysis of tritium and other radionuclides. Two publicly available databases that provided tritium concentrations in precipitation are Global Network of Isotopes in Precipitation (GNIP) and USEPA's RadNet database. GNIP provides tritium precipitation concentration data for samples collected world wide from 1960 to 2006. RadNet provides tritium precipitation concentration data for samples collected at Stations through the U.S. from 1960 up to and including 2006.

Based on GNIP data for sample stations located in the U.S. Midwest including Chicago, St. Louis and Madison, Wisconsin, as well as Ottawa, Ontario, and data from the University of Chicago, tritium concentrations peaked around 1963. This peak, which approached 10,000 pCi/L for some stations, coincided with the atmospheric testing of thermonuclear weapons. Tritium concentrations showed a sharp decline up until 1975 followed by a gradual decline since that time. Tritium concentrations in Midwest precipitation have typically been below 100 pCi/L since around 1980.

The RadNet database for several stations in the U.S. Midwest (Chicago, Columbus, Indianapolis, Lansing, Madison, Minneapolis, Painesville, Toledo, and Welsch, MN) did not show the same trend, which can attributed to pre-1995 data handling procedures. The pre-1995 data were rounded to the nearest 100 pCi/L, which damped out variances in the data. The post-1995 RadNet data, where rounding was not applied, exhibit much more scatter, and similar to the GNIP data, the vast majority of the data were less than 100 pCi/L.

CRA constructed a non-parametric upper tolerance limit with a confidence of 95 percent and a coverage of 95 percent based on RadNet data for USEPA Region 5 from 2004 to 2005. The resulting upper tolerance limit is 133 pCi/L, which indicates that CRA is 95 percent confident that 95 percent of the ambient precipitation concentration results are below 133 pCi/L. The statistical confidence, however, must be compared with the limitations of the underlying RadNet data, which does not include the minimum detectable concentration for a majority of the measurements. Some of the RadNet values below 200 pCi/L may be approximated. Nevertheless, these results show a background contribution for precipitation of up to 133 pCi/L.

7.2.3 SURFACE WATER DATA

Tritium concentrations are routinely measured in large surface water bodies, including Lake Michigan and the Mississippi River. Surface water data from the RadNet database for Illinois sampling stations include East Moline (Mississippi River), Moline (Mississippi River), Marseilles (Illinois River), Morris (Illinois River), Oregon (Rock River), and Zion (Lake Michigan). As is the case for the RadNet precipitation data, the pre-September 1995 Illinois surface water data was rounded to the nearest 100 pCi/L, creating a dampening of variances in the data. The post-1995 Illinois surface water data, similar to the post-1995 Midwest precipitation data, were less than 100 pCi/L with the exception of the Moline (Mississippi River) station. Tritium surface water concentrations at this location varied between 100 and 800 pCi/L, which may reflect local natural or anthropogenic inputs.

The pre-operational REMP data indicate that out of 26 quarterly composite samples, tritium was detected only twice at concentrations of 330 pCi/L and 220 pCi/L. All other samples contained concentrations of tritium less than the LLD, which ranged from 174 to 300 pCi/L.

The USEPA RadNet surface water data typically has a reported 'Combined Standard Uncertainty' of 35 to 50 pCi/L. According to USEPA, this corresponds to a ± 70 to 100 pCi/L 95 percent confidence bound on each given measurement. Therefore, the typical background data provided may be subject to measurement uncertainty of approximately ± 70 to 100 pCi/L.

7.2.4 DRINKING WATER DATA

Tritium concentrations in drinking water from the RadNet database for three Illinois sampling stations (Chicago, Morris, and East Chicago) exhibit similar trends as the precipitation and surface water data. As with the precipitation and surface water data, the pre-1995 data has dampened out variances due to rounding the data to the nearest 100 pCi/L. The post-1995 results show tritium concentrations in samples of drinking water were less than 100 pCi/L and less than the tritium concentrations found in precipitation and surface water.

The pre-operational REMP data indicate that tritium was not detected in any groundwater samples at the laboratory limit of detection ranging from 200 to 300 pCi/L.

7.2.5 EXPECTED TRITIUM BACKGROUND FOR THE STATION

As reported in the GNIP and RadNet databases, since 1980, tritium concentrations in U.S. Midwest precipitation has typically been less than 100 pCi/L. Additionally, since 1995, tritium concentrations reported in the RadNet database for Illinois surface water and groundwater, have typically been less than 100 pCi/L. Based on the USEPA Region 5's 2004 to 2005 RadNet precipitation data, 95 percent of the ambient concentrations of tritiated water in Illinois are expected to be less than 133 pCi/L, based on a 95 percent confidence interval. Tritium concentrations in surface water and drinking water are expected to be comparable or less based on historical data and trends.

Concentrations in groundwater similar to surface water and drinking water are expected to be less than precipitation values. The lower groundwater concentrations are related to the age of the groundwater as compared to the half-life of tritium. Deep aquifers in proximity to crystalline basement rock, however, can potentially show elevated concentrations of tritium due to lithogenic sources.

As was noted in Section 7.0, the analytical laboratory is reporting tritium results to a LLD of 200 pCi/L. This concentration also represents a reasonable representation of background groundwater quality, given the data for precipitation, surface water, and drinking water.

Based on the evaluation presented above, the background concentration for tritium at the Station is reasonably represented by the LLD of 200 pCi/L.

7.3 IDENTIFICATION OF POTENTIAL EXPOSURE PATHWAYS AND POTENTIAL RECEPTORS

Three potential exposure pathways were considered during the evaluation of tritium in groundwater.

- groundwater migration off the Station Property to private and public groundwater users (drinking water exposure);
- groundwater migration off the Station Property to a surface water body (recreational exposure); and
- surface water migration (or groundwater migration) from the PA to the storm drain system in the Unit 2 Pit (Exelon Clinton worker exposure).

The following section provides an overview of each of these three potential exposure pathways for tritium in groundwater.

7.3.1 POTENTIAL GROUNDWATER MIGRATION TO DRINKING WATER USERS OFF THE STATION PROPERTY

The groundwater beneath the Station is not used as a potable resource for its operations. The Station obtains its water from North Fork leg of Salt Creek. Shallow tritiated groundwater would migrate either to Clinton Lake or to the Unit 2 Pit. Also, the shallow groundwater occurs in the Wedron Clay Till, which is relatively impermeable and not used as a source of potable water. Therefore, there is no complete exposure pathway for shallow groundwater ingestion.

While the intermediate groundwater may be viable as a potable groundwater source, the groundwater flow path is not consistent with groundwater migration from the Station. The intermediate groundwater flows north beneath the PA and discharges into Clinton Lake. Intermediate groundwater has not been impacted by tritium. The lower potion of the Wedron Clay Till may isolate the intermediate groundwater from shallow tritiated groundwater. Therefore, there is no complete exposure pathway for intermediate groundwater ingestion.

Given the flow path towards Clinton Lake, the absence of tritium in the intermediate groundwater zone, and the decreasing concentration of tritium with depth, there is no complete exposure pathway for ingestion of groundwater from deeper zones. Accordingly, there is no complete exposure pathway from groundwater in the shallow, intermediate or deep groundwater to drinking water users off the Station property, and there is no current risk of exposure associated with groundwater ingestion.

7.3.2 POTENTIAL GROUNDWATER MIGRATION TO SURFACE WATER USERS OFF THE STATION PROPERTY

Under this potential exposure pathway, groundwater migrates off the Station Property to Clinton Lake.

Tritium has not been detected at concentrations greater than the LLD of 200 pCi/L in the intermediate groundwater zone. The concentrations of tritium in shallow groundwater are only slightly greater than the LLD of 200 pCi/L and are orders of magnitude less than the USEPA drinking water standard of 20,000 pCi/L. Furthermore, one out of five water samples collected from the Unit 2 Pit drainage system contained tritium at a concentration that was only slightly greater than the LLD. Therefore, although this migration pathway is potentially complete, there is no current risk of exposure associated with groundwater migration to surface water off the Station property.

7.3.3 POTENTIAL GROUNDWATER MIGRATION TO SURFACE WATER ON THE STATION PROPERTY

Under this potential exposure pathway, groundwater containing tritium would have discharged to surface water located on Site such as the sediment ponds, the primary lagoon, the secondary lagoon or the aqueduct.

The surface water elevations in the primary lagoon and secondary lagoon are approximately 9 feet higher than the groundwater elevations measured in the closest shallow monitoring well, MW-CL-20S. This indicates that there is no potential for groundwater to discharge into the primary lagoon, the secondary lagoon or the aqueduct.

The surface water elevation in the sediment ponds is 0.3 feet lower than the water table. Therefore, there is a potential groundwater to surface migration in this area of the Site. However, the concentrations of tritium in shallow groundwater are orders of magnitude below the USEPA drinking water standard of 20,000 pCi/L.

The shallow groundwater unit beneath most of the Station discharges into the Unit 2 Pit. The Unit 2 Pit is drained by a passive drainage system that in turn discharges to Clinton Lake via a drainage pipe that runs under the Reactor Building and to the Lake. Therefore, there is a potential groundwater to surface water pathway in this area of the Station. However, the concentrations of tritium in shallow groundwater are orders of magnitude lower than the USEPA drinking water standard of 20,000 pCi/L.

Therefore, although this potential exposure pathway is partially complete, there is no current risk of exposure associated with groundwater migration to surface water on the Station property.

7.4 SUMMARY OF POTENTIAL TRITIUM EXPOSURE PATHWAYS

In summary, there are three potential exposure pathways for tritium originating in or adjacent to the PA:

- potential groundwater migration off the Station Property to private and public groundwater users;
- potential groundwater migration off the Station Property to a surface water body; and

- potential groundwater migration from the PA to surface water bodies on Station Property.

Based upon the groundwater, surface water, and Unit 2 Pit water data provided and referenced in this investigation, none of the potential receptors are at risk of exposure to concentrations of tritium in excess of USEPA drinking water standards (20,000 pCi/L).

7.5 OTHER RADIONUCLIDES

Target radionuclides were not detected at concentrations greater than their respective LLD in any of the groundwater, surface water, or Unit 2 Pit water samples collected. Other non-targeted radionuclides were also included in the tables but excluded from discussion in this report. These radionuclides were either a) naturally occurring and thus not produced by the Station, or b) could be definitively evaluated as being naturally occurring due to the lack of presence of other radionuclides which would otherwise indicate the potential of production from the Station.

8.0 CONCLUSIONS

Based on this hydrogeologic investigation, CRA concludes:

Groundwater Flow

- The shallow groundwater beneath the Station primarily flows radially toward the Unit 2 Pit. The excavation is approximately 35 feet deep and contains a storm water collection system that drains to Clinton Lake.
- The intermediate groundwater flows west and discharges into Clinton Lake. The groundwater elevation within the intermediate zone is below the Unit 2 Pit and the foundation of the Containment Building.

Groundwater Quality

- Tritium was not detected in groundwater at concentrations greater than the USEPA drinking water standard of 20,000 pCi/L.
- Tritium was not detected at concentrations greater than the LLD of 200 pCi/L in 13 of the 17 groundwater samples collected as part of this investigation.
- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in any of the 17 groundwater samples collected as part of this investigation.
- Strontium-89/90 was not detected at a concentration greater than the LLD of 2.0 pCi/L in any of the 17 groundwater samples collected as part of this investigation.

Surface Water Quality

- Tritium was not detected in surface water at concentrations greater than the USEPA drinking water standard of 20,000 pCi/L.
- Tritium was not detected at concentrations greater than the LLD of 200 pCi/L in any of the six surface water samples collected as part of this investigation.
- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in any of the six surface water samples collected as part of this investigation.

- Strontium-89/90 was not detected at a concentration greater than the LLD of 2.0 pCi/L in any of the six surface water samples collected as part of this investigation.

Unit 2 Pit Water Quality

- Tritium was not detected in Unit 2 Pit water samples at concentrations greater than the USEPA drinking water standard of 20,000 pCi/L.
- Tritium was not detected at concentrations greater than the LLD of 200 pCi/L in four of the five Unit 2 Pit water samples collected as part of this investigation.
- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in any of the five Unit 2 Pit water samples collected as part of this investigation.

AFE-Clinton-1 – Cycled Condensate System

- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-1.
- Strontium-89/90 was not detected at a concentration greater than the LLD of 2.0 pCi/L in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-1.
- Tritium was detected at a concentration above the LLD (200 pCi/L) in the groundwater samples collected from MW-CL-14S (201 ± 107 pCi/L) and MW-CL-21S (545 ± 138 pCi/L), which are downgradient of the Cycle Condensate System. Tritium was also detected in the groundwater sample collected from MW-CL-13S, which is upgradient of the Cycled Condensate System, at a concentration of 230 ± 114 pCi/L.

AFE-Clinton-2 – Reactor Core Isolation System

- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-2.

- Strontium-89/90 was not detected at a concentration greater than the LLD of 2.0 pCi/L in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-2.
- Tritium was not detected at concentrations greater than the LLD of 200 pCi/L in any of the groundwater samples collected from the monitoring wells near the Reactor Core Isolation System, except the trace concentration in the duplicate groundwater sample collected from MW-CL-22S (278 ± 122 pCi/L).

AFE-Clinton-3 – Circulating Water System

- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-3.
- Strontium-89/90 was not detected at a concentration greater than the LLD of 2.0 pCi/L in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-3.
- Tritium was not detected at concentrations greater than the LLD of 200 pCi/L in any of the groundwater samples collected from the monitoring wells near the Circulating Water System, except the trace concentration in the groundwater sample collected from MW-CL-14S (201 ± 107 pCi/L).
- Gamma-emitting radionuclides, tritium, and strontium-89/90 were not detected in the surface water sample collected and analyzed from the aqueduct.

AFE-Clinton-4 – North Power Block Discharge – Radwaste and Turbine Building Sumps

- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-4.
- Strontium-89/90 was not detected at a concentration greater than the LLD of 2.0 pCi/L in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-4.
- Tritium was not detected at concentrations greater than the LLD of 200 pCi/L in six of the seven groundwater samples collected from monitoring wells near AFE-Clinton-4. A trace concentration of tritium (201 ± 107 pCi/L) was detected in groundwater samples from the seventh monitoring well.

AFE-Clinton-5 – South Power Block Discharge –
Control Building/Diesel Generator Building Sumps

- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-5.
- Strontium-89/90 was not detected at a concentration greater than the LLD of 2.0 pCi/L in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-5.
- Tritium was not detected at concentrations greater than the LLD of 200 pCi/L in any of the groundwater samples collected from the monitoring wells near the South Power Block Discharge, except the trace concentration in the duplicate groundwater sample collected from MW-CL-22S (278 ± 122 pCi/L).
- Gamma-emitting radionuclides, tritium, and strontium-89/90 were not detected in the surface water sample collected and analyzed from Clinton Lake.

AFE-Clinton-6 – Shutdown Service Water System

- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in any of the groundwater samples collected from the four monitoring wells in the vicinity of AFE-Clinton-6.
- Strontium-89/90 was not detected at a concentration greater than the LLD of 2.0 pCi/L in any of the groundwater samples collected from the monitoring wells in the vicinity of AFE-Clinton-6.
- Tritium was not detected at concentrations greater than the LLD of 200 pCi/L in any of the groundwater samples collected from the monitoring wells near the Shutdown Service Water System, except the trace concentration in the duplicate groundwater sample collected from MW-CL-22S (278 ± 122 pCi/L).
- Gamma-emitting radionuclides, tritium, and strontium-89/90 were not detected in the surface water sample collected and analyzed from Clinton Lake.

Potential Receptors

- Based on the results of this investigation[1], there is no current risk from exposure to radionuclides associated with licensed plant operations through any of the identified potential exposure pathways.

General Conclusions

- Based on the results of this investigation, tritium is not migrating off the Station property at detectable concentrations.
- Based on the results of this investigation, there are no known active releases into the groundwater at the Station.

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[1] Using the LLD specified in this HIR.

9.0 RECOMMENDATIONS

The following presents CRA's recommendations for proposed activities to be completed at the Station.

9.1 DATA GAPS

Based on the results of this hydrogeologic investigation, there are no data gaps remaining to support CRA's conclusions regarding the characterization of the groundwater regime and potential impacts from radionuclides at the Station.

9.2 GROUNDWATER MONITORING

Based upon the information collected to date, CRA recommends that Exelon conduct periodic monitoring of selected sample locations.

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