



Revision 1

HYDROGEOLOGIC INVESTIGATION REPORT

FLEETWIDE ASSESSMENT QUAD CITIES GENERATING STATION CORDOVA, ILLINOIS

**Prepared For:
Exelon Generation Company, LLC**

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**Prepared by:
Conestoga-Rovers
& Associates**

651 Colby Drive
Waterloo, Ontario
Canada N2V 1C2

Office: (519) 884-0510
Fax: (519) 884-0525

web: <http://www.CRAworld.com>

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EXECUTIVE SUMMARY

This Hydrogeologic Investigation Report (HIR) documents the results of Conestoga-Rovers & Associates' (CRA's) May to July 2006 hydrogeologic investigation pertaining to the Quad Cities Generating Station in Cordova, Illinois (Station). 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 any historical releases, the structures, components, and areas of the Station that have the potential to release tritium or other radioactively contaminated 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 Areas for Further Evaluation (AFEs) and sample locations for the Station.

CRA installed 22 monitoring wells and collected 32 groundwater samples (22 from newly installed monitoring wells, two from existing monitoring wells near the AFEs, and eight from water supply wells) and two surface water samples at the Station. All groundwater and surface water samples were analyzed for tritium, strontium-89/90, and gamma-emitting radionuclides.

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 or surface 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 detected at concentrations greater than LLD of 200 pCi/L in groundwater samples from nine wells in the vicinity of and south/southwest of the Service and Reactor Buildings, from two wells north/northwest of the Turbine Building, and in surface water samples collected from the Spray Canal. The concentrations of tritium in groundwater greater than the LLD of 200 pCi/L ranged from 250 ± 126 to $9,640 \pm 660$ pCi/L with the exception of MW-QC-102I at $32,600 \pm 977$, which is greater than the United States Environmental Protection

Agency (USEPA) drinking water standard of 20,000 pCi/L. These tritium detections are likely related to the historical releases;

- Tritium was detected in the Station's Spray Canal at 497 ± 140 pCi/L and 550 ± 14 pCi/L, which is well below USEPA's drinking water standard of 20,000 pCi/L. The tritium in the Spray Canal is likely associated with the canal's water supply, the Big Fish Well (740 pCi/L ± 152);
- Based on the results of this investigation, tritium has not migrated off site 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 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) 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. The investigations pertain to Exelon's Quad Cities Generating Station in Cordova, Illinois (Station) (see Figure 1.1) between May and July 2006. The Station is defined as all property, structures, systems, and components owned and operated by Exelon located at 22710 206th Avenue North, Cordova, Illinois. The approximate property boundaries are depicted on Figure 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 at 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, quantity, 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

This section presents a summary of the Station location and definition, an 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 Station is located at 22710 206th Avenue North, Cordova, Illinois (see Figure 1.1). The Station property consists of approximately 784 acres. The Station is owned by Exelon Nuclear (75 percent) and MidAmerican Energy (25 percent). Figure 2.1 presents a Station base map with the Station infrastructure shown.

2.2 OVERVIEW OF COOLING WATER OPERATIONS

The Station consists of two nuclear reactors, associated structures and ancillary buildings, a 310-foot main stack, intake and discharge canals, and a former Spray Canal. The Spray Canal is approximately 3 miles long and was used for condenser cooling water until 1983, at which time it was changed to a facility to raise game fish for release into the Mississippi River.

The Station's generating system consists of a two-unit nuclear-powered steam electric plant. Each unit is a boiling water reactor (BWR) that produces a net electrical power output of 930 megawatts. Unit 1 began commercial operation on February 18, 1973, and Unit 2 began commercial operation on March 10, 1973. The Station currently operates under the Nuclear Regulatory Commission (NRC) Operating Licenses DPR-29 and DPR-30 and is permitted to discharge liquid waste to the Mississippi River under its National Pollutant Discharge Elimination System (NPDES) permit IL0005037.

A BWR plant consists of two separate fluid loops. A separate loop design avoids mixing the fluids of one loop with the fluids of the other. The loops are called the primary loop and the cooling loop.

The main purpose of the primary loop is to transfer the energy generated from fission in the fuel to the turbine generator. It is a closed loop system. Nuclear fission creates heat in the fuel. This heat produces steam, which is passed through a steam dryer and

moisture separator. The steam turns the turbine generator, which makes electricity. The unused steam is exhausted to the condenser where it is condensed into water. The resulting water is pumped out of the condenser with a series of pumps, reheated, and pumped back to the reactor vessel.

The main purpose of the cooling loop is to use cooler river water to condense the steam in the condenser and transfer the heat to the environment. This loop is a single pass process. The cooling water is pumped to the discharge bay and then discharged back to the Mississippi River.

The total flow of river water through Units 1 and 2 for condenser circulating water and service water is approximately 970,000 gallons per minute (gpm). Water is withdrawn from the river at the intake bay through a canal that is perpendicular to the river flow. The Station uses a two-pipe diffuser system to discharge cooling water to the Mississippi River from the discharge bay. The pipes are 16 feet in diameter and lie on the bottom of the river across the main river flow. Water is discharged into the deepest part of the river through regularly spaced jet nozzles in the pipes.

Radioactive liquid wastes (radwastes) are collected in sumps and drain tanks at various locations at the Station and then transferred to tanks in the Radwaste Building for processing, storage, and release. Liquid wastes that can be reused are returned to the Contaminated Condensate Storage Tanks (CCSTs). Liquid wastes that cannot be reused are returned to the Radwaste System for reprocessing or discharging to the river (NRC, 2004). Liquid wastes are discharged via the River Discharge Tank (RDT). Water from the RDT is pumped out to the diffuser house that empties into the south diffuser below the water surface. The liquid waste mixes with the effluent from the discharge bay prior to dispersion out the diffuser pipe.

2.3 SURROUNDING LAND USE

The area surrounding the Station to the north, east, and south is rural farmland and woods. There is an industrial park 1 mile further to the north, and the Cordova Energy Center, a gas-fired power plant, is located 1 mile to the southeast.

The Station is located on the east bank of the Mississippi River opposite the mouth of the Wapsipinicon River. The Upper Mississippi River National Wildlife and Fish Refuge is across the river from the Station and also on islands in the river about 2 miles downstream from the Station.

2.4 STATION SETTING

The following section presents a general summary of the topography, surface water features, geology, hydrogeology, and groundwater flow conditions near the Station. The information was primarily gathered from Chapter 2.5 of the Quad Cities Station Updated Final Safety Analysis Report (UFSAR, Revision 8, October 2005). The main references the UFSAR relies upon are listed in Section 10.0. CRA checked and verified all UFSAR references that apply to this HIR.

2.4.1 TOPOGRAPHY AND SURFACE WATER FEATURES

The Station is located in Rock Island County, which is within the Galesburg Plain physiographic subsection of the Till Plains Section of the Central Lowland Province. A flat to gently rolling topography in the Central Lowland Province characterizes almost all of Illinois. The Galesburg Plain is level to undulating and is largely an Illinoian stage glacial drift but only locally is there prominent glacial topography. Much of the surface topography mimics the underlying bedrock surface.

The Station's natural grade level is at an elevation of 594.5 feet above mean sea level (AMSL). The Station is on moderately high ground on the east bank of the Mississippi River. The ground surface rises from the river to form steep bluffs approximately 20 to 40 feet in height. The bluffs are breached in places by gullies extending short distances inland.

The Station is on the east side of the Mississippi River opposite the mouth of the Wapsipinicon River. The Upper Mississippi River near the Station is composed of a series of slack-water pools during low flow. The pools are formed by navigation dams located on the river both above and below the Station. The Station is located near Pool #14; the normal elevation of this pool is 572 feet AMSL (Blume, 1966).

Station surface water bodies include the former Spray Canal, discharge bay, intake bay, and dredge ponds. Silt pumped from the intake bay and from the Mississippi River in front of the intake bay is deposited in the dredge ponds. The dredge ponds contain river sediment so tritium impact from the Station is not anticipated.

2.4.2 GEOLOGY

The region is on the extreme northwest flank of the Illinois Basin. The upper bedrock consists of Paleozoic sedimentary strata that dip gently, at approximately 15 to 20 feet per mile, to the southeast toward the center of the Illinois Basin. The region is on the south limb of the Savanna-Sabula Anticline (also known as the Plum River Fault Zone), which trends east-west through Carroll County, several miles north of the Station. The Paleozoic sedimentary rocks are of Silurian and older age and are on the order of 3,000 feet thick. They are underlain by Precambrian crystalline rocks (granite and granodiorite) (Blume, 1966).

Beneath the Station are unconsolidated sediments comprised of clay, silt, sand, and gravel deposited as glacial till, outwash, and river alluvium deposits. The unconsolidated sediments are underlain by bedrock of Silurian (Niagaran/Alexandrian Dolomite), Ordovician (Maquoketa Shale, Galena - Platteville Dolomite, and Glenwood - St. Peter Sandstone), and Cambrian age (dolomites, sandstones, and shales) (Blume, 1966).

The Niagaran Dolomite is fossiliferous and sandy. In an abandoned Niagaran Dolomite quarry, which is located approximately 1 mile south of Cordova, there is a high degree of fracturing in the dolomite, and the dolomite was weather-stained along fractures but was a hard competent crystalline rock. Exploration test borings indicate that the upper bedrock surface is weathered to varying depths. Deep borings indicate that the Silurian Dolomite (Niagaran and Alexandrian Formations) is approximately 250 to 300 feet thick (Blume, 1966).

Figure 2.2 presents the stratigraphic column for the Rock Island area and the area to the south and southeast. Although the stratigraphic column shows the Pennsylvanian, Mississippian, and Devonian systems, these systems are not present in northern Rock Island County, where the first bedrock encountered beneath the overburden is Silurian Dolomite. Figure 2.3 presents a bedrock geologic map with a cross-section location. The Station is adjacent to the northern portion of the cross-section and is underlain by Silurian Dolomite. The cross-section in Figure 2.4 shows the sequence and structure of the bedrock in the Station area (J.E. Bruckmann and R.E. Bergstrom, 1968).

The dolomite bedrock surface in northern Rock Island County has been eroded by the ancient Mississippi drainage system. The Meredosia Channel, the upper portion of the Princeton Bedrock Valley system, is drift-filled lowland connecting the present Mississippi River Valley and the Green River Lowland to the east. The mean elevation of the bedrock surface in the channel is approximately 450 feet AMSL. However, a

glacially scoured groove more than 100 feet deep, nearly 4 miles long, and 3,000 feet wide is present along a portion of the south wall of the channel. It is thought that the Meredosia Channel was entered at least once by glaciers during each of the four major glaciations, with the glaciers entering first from the west and later from the east (L.D. McGinnis and P.C. Heigold). The channel has been filled with unconsolidated sediments.

The Station is on a rock hill that was left as an erosional remnant between channels (Blume, 1966), as is shown on Figure 2.5. The depth to bedrock beneath the Station is approximately 50 feet. South of the Station, the thickness of the sand and gravel increases greatly, to as much as 300 feet, due to the presence of the buried Meredosia Channel that cuts into the dolomite bedrock (Blume, 1966). Figure 2.6 shows the approximate northern extent of the Meredosia Channel.

2.4.3 HYDROGEOLOGY

Groundwater can be obtained from three aquifer systems:

- unconsolidated alluvial and outwash sand and gravel deposits, 40 to 60 feet thick in the vicinity of the Station;
- shallow Silurian dolomitic formations, approximately 200 to 250 feet thick; and
- artesian sandstone aquifers of Cambrian-Ordovician age.

The potential yield from the upper unconsolidated aquifer is unknown because of lack of local pumping data. But in other parts of the Mississippi Valley, this aquifer is generally capable of yielding large quantities of water on a long-term basis. The groundwater elevation in the unconsolidated aquifer ranged between 17 and 21 feet below ground surface (bgs) on the Station. The groundwater flow direction in this unit was anticipated in a westerly direction toward the Mississippi River. However, as noted in Section 2.4.2, the Station sits on bedrock high with buried bedrock valleys of the Meredosia Channel to the north and south (see Figure 2.5). These buried channels contain thick (greater than 200 feet) deposits of sand and gravel. The buried channels will likely affect the groundwater flow in the upper consolidated aquifer beneath the Station. It is also likely that the groundwater table will undergo seasonal fluctuations and that a temporary reversal of groundwater flow direction may occur from the Mississippi River (Blume, 1966). Based on published records, it is known that the Army Corps of Engineers maintains the water level in the Mississippi River adjacent to the Station at an elevation of 572 feet AMSL.

In addition to these natural effects, the groundwater flow direction may be affected locally by structure basements and foundations, and by sheet piles beneath the Station to a depth of 36 feet bgs at the river along the discharge bay and the inlet to the Spray Canal (sheet pile locations are illustrated on Figure 2.6)

The Silurian Dolomite formations yield moderate to high quantities of water, particularly in areas where unconsolidated sand and gravel sediments are present. Dolomite aquifers immediately below the alluvium and outwash deposits are slowly recharged from water in these deposits. Wells in the Cambrian-Ordovician sandstone artesian aquifers produce large quantities of water. Groundwater in the deep artesian aquifers is independent of the shallow near surface aquifers (Blume, 1966).

2.5 AREA GROUNDWATER USE

CRA performed a comprehensive private well survey in the vicinity of the Station. CRA obtained water well information from the Illinois State Geological Survey and the Illinois State Water Survey. Eighty-seven private wells were identified as potentially within 1 mile of the Station. CRA notes that the Illinois State Geological Survey and the Illinois State Water Survey data sources are not updated with abandoned or closed well information and distances from a referenced point may not be accurately reported. The private wells range in depth between 20 and 250 feet bgs with the oldest private well dating back to 1909 and the most recent private well being installed on November 3, 2005. Fifteen public, industrial, and commercial wells were identified as potentially within 1 mile of the Station. The public, industrial, and commercial wells range in depth from 58 to 1,800 feet bgs with the oldest well dating back to 1966 and the most recent well being installed in 2004. Thirteen of the public, industrial, and commercial wells are listed as being located at the Station. The remaining two public, industrial, and commercial wells list the owner as "Saddle Club Farms", a horse farm/dinner club no longer in operation that was located over 1 mile from the Station. Copies of the well logs obtained are provided in Appendix A.

The Station receives potable water from three wells:

- Well #1 (drilled 1966, 242 feet deep, cased to 52 feet bgs);
- Well #5 (drilled 1969, 264 feet deep, cased to 59 feet bgs); and
- Fish House Well #10 (drilled 2004, 135 feet deep).

None of these wells are of a suitable depth or construction to use for determining groundwater contours. The well locations are shown on Figure 2.6 (see Appendix A for well information).

The following water supply wells are also located at the Station:

- Fire Training Well (drilled 1987, 225 feet deep);
- Big Fish Well (drilled 1984, 175 feet deep);
- Little Fish Well (drilled 1986, 60 feet deep);
- Dry Cask Storage Well (also know as East Well, drilled approximately 1960, 84 feet deep); and
- Sewage Treatment Plant (STP) Sand Point Well (drilled 1985, 30 feet deep).

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 at the Station.

CRA's identification of AFEs involved the following components:

- Station inspection on March 22, 2006 accompanied by Station personnel;
- 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, CRA installed additional monitoring wells.

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 liquid. Maps depicting each of these systems were developed and provided to CRA for review. The locations of some of these systems are presented on Figure 3.1. The Station identified a total of 16 systems that contain or could contain potentially radioactively contaminated liquid. The following presents a list of these systems.

<i>System Identification</i>	<i>Description</i>
1000	Residual Heat Removal (RHR)/RHR Service Water
1300	Reactor Core Isolation Cooling
1400	Core Spray
2000	Radwaste includes Reactor Building Equipment and Floor Drains
2300	High Pressure Coolant Injection
2600	Sewage Treatment Plant
2600	Wastewater Treatment Plant
3000	Main Steam
3300	Condensate Transfer
4400	Circulating Water System
4900	Turbine Building Floor Drains
5400/9300	Off Gas
5650	Electro Hydraulic Control (EHC)
5700	Heating System/Heating Ventilation and Air Conditioning
5773	Heating Boilers
8900	High Rad Sample System (HRSS)

After these systems were identified, Exelon developed a list of the various structures, components, and areas of the systems (e.g., piping, tanks, and process equipment) that handle or could potentially handle radioactively contaminated liquid. 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 radiological contaminated liquid stored or conveyed;
- amount of radiological contaminated liquid stored or conveyed;
- existing controls (i.e., containment and detection); and
- maintenance history.

System components, which were located inside a building or 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 of 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 radioactive 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 a 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 reviewed information concerning confirmed or potential historical releases of radionuclides at the Station, including reports and documentation previously prepared by Exelon and compiled for CRA's review. CRA evaluated this information in identifying 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 also 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 (pre-operational REMP), past Station investigations, and the Radiological Environmental Monitoring Program (REMP).

3.3.1 PRE-OPERATIONAL RADIOLOGICAL ENVIRONMENTAL MONITORING PROGRAM

The pre-operational REMP report was conducted to establish background radioactivity levels prior to operation of the Station. The program was completed in December 1971 by Eberline Instrument Corporation for the Commonwealth Edison Company. The pre-operational REMP report included monitoring for atmospheric radiation, fall-out, domestic water, surface water, marine life, and foodstuffs.

Atmospheric radiation monitoring consisted of gas and air particulate radioactivity measurements; fall-out monitoring consisted of radioactivity measurements of soil, vegetation, and rain water; domestic water monitoring consisted of well water sample analysis; surface water samples were collected from the Mississippi River near the Station, the Davenport Water Works, and the East Moline Water Works; and foodstuffs monitoring included samples of milk.

The pre-operational REMP surface water tritium analytical results ranged from non detect at an unspecified Lower Limit of Detection (LLD) to $1,850 \pm 900$ picoCuries/liter (pCi/L).

Gross alpha groundwater analytical results ranged from non detect at unspecified LLDs to a maximum detected activity of 2.00 ± 0.9 pCi/L. Gross beta groundwater analytical

results (including tritium) ranged from non detect at unspecified LLDs to a maximum detected activity of 34.2 ± 2.3 pCi/L.

3.3.2 RADIOLOGICAL ENVIRONMENTAL MONITORING PROGRAM

The REMP was initiated at the Station in 1968. The REMP includes the collection of multi-media samples including air, surface water, groundwater, fish, clams, crabs, 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.

As part of REMP, surface water samples are collected at two locations and groundwater samples are collected at two locations. The Station collects quarterly groundwater samples from two off-site wells (sample locations Q-35 and Q-36) and analyzes the samples for tritium. Quarterly composites of weekly samples of Mississippi River water collected upstream (Q-34) and downstream (Q-33) from the Station are analyzed for tritium. The REMP reports for 2001 through 2004 state that tritium concentrations remained below the LLD of 200 pCi/L in all of the groundwater and river water samples. According to the Station, tritium concentrations in the well water and river water samples have remained less than the LLD of 200 pCi/L since this testing was first initiated.

The report reviewed by CRA was prepared by Station personnel and is entitled "Annual Radiological Environmental Operating Report for the Quad Cities Nuclear Power Station, dated May 2005". This report concluded that the operation of the Quad Cities Station had no adverse radiological impacts on the environment.

3.3.3 HISTORIC INVESTIGATIONS

No historic investigations related to radionuclides impact to groundwater were completed at the Station.

3.3.4 POWER PLANT DOCUMENTS - UFSAR REPORT

During the construction of the Station, a series of comprehensive investigations of regional and local geology, surface water, and groundwater conditions were conducted. These studies are documented in UFSAR Revision 8, October 2005.

3.4 IDENTIFIED AREAS OF 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, 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 that have the potential for the release of radioactively contaminated liquid 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 Station 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. This HIR details the AFEs investigated.

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 flow beneath several systems that contain radioactively contaminated liquid 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 identified five AFEs (see Figure 3.1).

AFE-Quad Cities-1 - Piping West of Radwaste Building/Floor Drain Surge Tank

This area was identified as an AFE due to its proximity to buried piping west of the Radwaste Building where historic releases have occurred and due to its proximity to the Floor Drain Surge Tank, which conveys waste and liquids potentially containing tritium.

AFE-Quad Cities-2 – Historic Releases Area South of Station Blackout Building (SBO)

This area was identified as an AFE due to its proximity to three reports of historic releases in this area. Historic releases related to this AFE occurred on August 17, 1975, December 10, 1979, and March 21, 1986. The locations of the releases are shown on Figure 3.2.

- On August 17, 1975, a Unit 2 feedwater valve leaked, releasing radioactively contaminated water to the soil east of the Trackway 2 (TW-2) rollup door. The impacted soil was excavated and shipped off site. Approximately 12,500 gallons of water were released: 8,500 gallons of feedwater and 4,000 gallons of fire suppression system water. Approximately 2,570 gallons of water entered the Unit 2 Oil/Water Separator, which was recovered and released through a permitted discharge point. Approximately 100 gallons of the water was released to Station surface soils in the vicinity of the TW-2 rollup door. Tritium was detected in Unit 2 Oil/Water Separator output at a concentration 97,000 pCi/L.

- On December 10, 1979, approximately 4,200 gallons of radioactively contaminated Residual Heat Removal (RHR) water was spilled into a storm drain system and on the surrounding blacktop east of the Unit 1 Reactor Building. Water which entered the Unit 1 Oil/Water Separator was recovered and released through a permitted discharge point. Based on subsequent sampling of the Unit 1 Oil/Water Separator, an estimated 25 millicuries were released through the discharge bay, which is a permitted pathway, and the remaining 12.8 millicuries went into the ground.
- On March 21, 1986, approximately 10 to 25 gallons of reactor water that contained tritium and radionuclides leaked onto the asphalt east of the Unit 1 Reactor Building from the Integrated Leak Rate Compressor. A small area of contaminated asphalt was removed. None of the water entered the storm drain.

All three of these historic releases occurred east of the Reactor Building, with the 1975 release occurring near the northeast corner of the Reactor Building and the 1979 and 1986 releases occurring at the current location of the Station Blackout Building (SBO).

AFE-Quad Cities-3 - CCSTs and Ancillary Piping

This area was identified as an AFE due to its proximity to the CCSTs and associated piping, which are not provided with secondary containment. Any historic releases from this storage system could potentially impact groundwater downgradient of the CCSTs.

AFE-Quad Cities-4 - Unit 1 Oil/Water Separator

This area was identified as an AFE as potential releases from the CCSTs and the south side of the plant would discharge to the Unit 1 Oil/Water Separator.

AFE-Quad Cities-5 - Unit 2 Oil/Water Separator

This area was identified as an AFE as potential releases from the north side of the plant would discharge to the Unit 2 Oil/Water Separator.

4.0 FIELD METHODS

The field investigations for this HIR were completed from May through July 2006. The initial field investigations completed for this HIR in May and June 2006 were focused near the five AFEs identified for the Station. Additional field investigations were completed in June and July 2006 to determine the vertical and lateral extent of tritium in groundwater. CRA supervised the installation of monitoring wells at the Station and collected samples from the newly installed monitoring wells, the existing monitoring wells, and the existing water supply wells, as well as from surface water locations. The field investigations were completed in accordance with the methodologies presented in the Work Plan (CRA 2006).

In 2002, CRA installed three monitoring wells (MW-1, MW-2, and MW-3), which were screened from 17 to 27 feet bgs and located in the northwest portion of the Protected Area (PA). CRA collected groundwater samples as part of a separate hydrogeologic assessment for non-radionuclide parameters. No impacts were detected.

4.1 SURFACE WATER GAUGING POINT INSTALLATION AND MONITORING

Figure 4.1 presents the location of the three new surface water gauging points installed as part of this investigation. SW-QC-1 and SW-QC-2 are located on bridges that cross the Station Spray Canal. A third surface water gauging point (SW-QC-3) was installed at the discharge bay near MW-QC-103I. These gauging points were used for surface water elevation monitoring.

4.2 GROUNDWATER MONITORING WELL INSTALLATION

Twenty-two new monitoring wells were installed at the Station as part of the fleetwide hydrogeologic investigation. Eleven monitoring wells were installed during the initial field investigations conducted in May 2006. These locations were selected based on a review of all data provided, the hydrogeology at the Station, and the current understanding of identified AFEs. An additional 11 monitoring wells were installed during the additional field investigations conducted in June and July 2006. These locations were selected based on a review of the hydrogeology at the Station, the current understanding of identified AFEs, and the analytical results from groundwater sampling conducted at the initial 11 monitoring wells and the eight water supply wells.

Monitoring well construction logs are provided in Appendix B. Figure 4.1 presents the location of the 22 new monitoring wells. Table 4.1 summarizes the monitoring well completion details.

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 used to verify utilities were not present at the proposed location to a depth of 10 feet bgs.

Specific installation protocols for the monitoring wells are described below:

- the borehole was advanced to the target depth using 4.25-inch inside diameter hollow-stem augers (HSA);
- a nominal 2-inch diameter (No. 10 slot) PVC screen, 5 or 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 filter sand pack consisting of silica sand was installed 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 bentonite 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 bentonite grout;
- the remaining portion of the annulus was filled with concrete and a 6-inch diameter protective above-grade or flush mount casing. The well head was fitted with a water-tight, lockable cap; and
- cement-filled bollard posts were installed around selected monitoring well locations.

The shallow soil borings completed in unconsolidated materials that were to be used for monitoring well installation were installed using 4.25-inch inside diameter HSA drilling techniques. The borehole depths ranged from 29 to 70 feet bgs. During the subsurface utility clearance activities described above, the borehole was periodically examined and the soil types documented. A description was added to each monitoring well construction log. The overburden soils were classified using the Unified Soil Classification System (USCS).

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 this procedure:

- Monitoring wells were surged using a pre-cleaned surge block for a period of at least 20 minutes.
- Water was purged from the monitoring well using an electronic submersible pump.
- Groundwater was collected at regular intervals with 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 minimum of ten well volumes was purged.

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

4.4 SURVEY

The new monitoring wells and surface water gauging points 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 at each gauging point.

4.5 GROUNDWATER AND SURFACE WATER ELEVATION MEASUREMENTS

On May 24, 2006 and July 26, 2006, CRA collected water level measurements from new monitoring wells and surface water gauging points installed in accordance with the Work Plan and from two existing monitoring wells. CRA collected additional water level measurements at the surface water gauging points on June 22, 2006. Based on the

measured depth to water from the reference point and the surveyed elevation of the reference point, the groundwater elevation was calculated. A summary of groundwater elevations is provided in Table 4.3. A summary of surface water elevations is provided 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 protective casing of each monitoring well. Surface water measurements were made from the designated location at each surface water gauging point.

The water level measurements were obtained using the following 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 light and/or buzzer just 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; and
- the water level was then recorded, and the water level meter decontaminated prior to use at the next well location.

4.6 GROUNDWATER AND SURFACE WATER SAMPLE COLLECTION

CRA conducted two rounds of groundwater and surface water sampling during the completion of the Work Plan for these hydrogeologic investigations. A total of 13 monitoring wells and eight water supply wells were sampled on May 31 and June 1, 2006. An additional 11 monitoring wells were sampled on July 27 and 28, 2006. Of the 24 monitoring wells sampled, 22 were newly installed. The sampling was scheduled to allow for 2 weeks to elapse between well development and groundwater sample collection. The two existing wells were selected for inclusion in this monitoring program based on their proximity to the AFEs. The new wells were installed to complete the monitoring network in the vicinity of the AFEs.

At the monitoring well locations, CRA conducted the sampling using dedicated tubing and a peristaltic pump or a submersible electronic pump, and employed 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 5 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 the following 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); and

- once purging was complete, the groundwater samples were collected directly from the pump/tubing directly into the sample containers.

All groundwater samples were labeled with a unique sample number, the date and time, the parameters to be analyzed, the project number, and the sampler's initials. The samples were screened by the Station for shipment to Teledyne Brown Engineering, Inc. (Teledyne Brown).

A groundwater sample key is presented in Table 4.5. Purging parameters for the monitoring wells are presented in Table 4.6.

Water samples collected on May 31 and June 1, 2006 from the existing water supply wells were collected from existing taps or spigots on the well pump header or distribution. Prior to collecting a water sample, the water was allowed to flow from the tap or spigot for several minutes. Water purging parameters for these supply wells are presented in Table 4.7.

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

Surface water samples were collected on May 31, 2006 at the two gauging points along the Station Spray Canal. The surface water sampling locations (SW-QC-1 and SW-QC-2) are presented on Figure 4.1.

The surface water samples were collected by submerging a disposable bailer in the Spray Canal. The samples were poured directly from the disposable bailer into the sample containers. The samples were shipped to Teledyne Brown for analysis.

4.7 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 Program for the laboratory is described in Appendix C. Analytical data for groundwater and surface water samples collected in accordance with the Work Plan are presented in Appendix D. Data validation memoranda are presented in Appendix E. 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 the following techniques:

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

4.8 SAMPLE IDENTIFICATION

Systematic sample identification codes were used to uniquely identify all samples. The identification code format used in the field was: WG-QC-SW-QC-001-053106-JH-002. A summary of sample identification numbers is presented in Table 4.5.

WG	-	Sample matrix - groundwater
WS	-	Sample matrix - surface water
RB	-	Sample matrix - rinse blank
QC	-	Station code
SW-QC-001	-	Sample location
053106	-	Date
JH	-	Sampler initial
002	-	Sample number

4.9 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.

4.10 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 five 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. Three rinsate blanks were collected.

Split Samples

Split samples were collected by CRA for the NRC for tritium simultaneously with the actual sample at each sample location. Split samples were delivered to the Station personnel and made available to the NRC. In addition, split samples were collected May 31, 2006 at monitoring wells MW-QC-106I and MW-QC-107I for the NRC and were given to the NRC representative.

4.11 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.

5.0 RESULTS SUMMARY

This section provides a summary of Station geology and hydrogeology, along with a discussion of hydraulic gradients, groundwater elevations, and 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 encountered during monitoring well installation is consistent with the geology described in Section 2.4.2. The geology beneath the Station consists of unconsolidated sediments comprised of sand and gravel deposited as outwash and river alluvium deposits. The unconsolidated sediments are underlain by bedrock of Silurian (Niagaran/Alexandrian Dolomite), Ordovician (Maquoketa Shale, Galena - Platteville Dolomite, and Glenwood - St. Peter Sandstone), and Cambrian age (dolomites, sandstones, and shales).

Figure 5.1 displays the locations of the hydrogeologic cross-sections across the Station. These hydrogeologic cross-sections are presented on Figures 5.2 to 5.5. These cross-section locations were chosen because of their close proximity to the AFEs and structures potentially influencing groundwater flow patterns.

The new shallow, intermediate, and deep interval wells installed pursuant to the Work Plan were installed in the overburden. The Station is underlain by overburden deposits consisting primarily of unconsolidated sediments comprised of fine- to coarse-grained sands and trace gravel (see Section 2.4.2). The monitoring well logs are presented in Appendix B.

Figure 5.2 is a southwest-northeast cross-section (A-A') through the middle of the Station. It begins near monitoring well MW-QC-114I at the southwestern corner of the Station and terminates near the access road in the northeast portion of the Station. This cross-section also shows the relationship between the groundwater and geology, excavated areas, and Service Building foundations that were set just above the bedrock. The Service Building foundation in this area was constructed on concrete piers within the sand overburden fill to a depth of approximately 589.5 feet AMSL. The Service Building foundation is not seated in bedrock. Engineered compacted fill was placed around the foundation of the Service Building to the ground surface. The storm drain piping along this sectional line is located in the compacted engineered fill. The northern extent of the buried paleochannel or the Meredosia Channel is located to the south of the

Service Building. May 2006 groundwater elevations in the upper unconsolidated aquifer along this cross-section drop slightly from north (573.85 feet AMSL at MW-QC-101S) to south (572.51 feet AMSL at MW-QC-108S) due to the presence of the Meredosia Channel.

Figure 5.3 is a southeast-northwest profile (B-B') that intersects AFE-Quad Cities-2. This cross-section shows the relationship between the groundwater and geology, sheet piles, utilities, and building foundations. Sheet piles installed as part of the Station construction are located to the west of the Service Building. The sheet piles were set into the top of the dolomite bedrock. The discharge bay was also excavated into the top of dolomite bedrock in this portion of the Station. The northern extent of the buried paleochannel or the Meredosia Channel is located to the south of the Service Building. The surface of the dolomite bedrock in this portion of the Station drops approximately 100 feet based on the bedrock topography map (Figure 2.5). May 2006 groundwater elevations in the upper unconsolidated aquifer along this cross section drop slightly from northwest (573.09 feet AMSL at MW-QC-103I) to the southeast (572.77 feet AMSL at MW-QC-102I) due to the competing influence of the Meredosia Channel and the sheet piles.

Figure 5.4 is an east-west cross-section (C-C') through the Station to the Mississippi River. This profile shows the relationship between the groundwater and geology, excavated areas, building foundations, and the Mississippi River. The Reactor Building, Turbine Building, and Crib House foundations in this area were constructed to approximate depths of 548, 542.5, and 545 feet AMSL, respectively. The Reactor Building, Turbine Building, and Crib House foundations are seated in bedrock. Engineered compacted fill was placed around these buildings to the ground surface. The storm drain piping along this sectional line is located in the compacted engineered fill. May 2006 groundwater elevations in the fill overburden sand along this cross-section are relatively flat from east (573.85 feet AMSL at MW-QC-101S) to the west (573.82 feet AMSL at MW-QC-106S). Groundwater in the overburden flows around the building foundations to the southwest.

Figure 5.5 is a north-south cross-section (D-D') through the Station. This cross-section shows the relationship between the groundwater and geology, excavated areas, and building foundations. Engineered compacted fill was placed around the foundation of the Service Building to the ground surface. The storm drain piping along this sectional line is located in the compacted engineered fill. The northern extent of the buried Meredosia Channel is located to the south of the Service Building. Dolomite bedrock in this portion of the Station drops approximately 100 feet. May 2006 groundwater elevations in the upper unconsolidated aquifer along this cross-section drop from north

(574.30 feet AMSL at MW-1) to south (572.51 feet AMSL at MW-QC-108S) in response to the presence of the Meredosia Channel.

5.2 STATION HYDROGEOLOGY

Figure 5.1 presents the monitoring well network in relationship to the hydrogeologic cross-section locations. Hydrogeologic cross-sections are presented on Figures 5.2 to 5.5. The cross-sections show the overburden that overlies the dolomite bedrock. In general, the overburden consists of naturally occurring unconsolidated sand or sand fill (fill is present where the Station was excavated prior to construction of the buildings).

5.2.1 MAN-MADE INFLUENCES ON GROUNDWATER FLOW

The PA (Figure 1.2) is located at the west area of the Station and is surrounded by the lined Spray Canal. The Spray Canal was constructed with a polyvinyl chloride (PVC) liner underlain by 6 inches of sand covered by 1 foot of crushed rock. The polyethylene sheeting was placed on 1 foot of compacted sand and gravel.

The canal flows counter-clockwise around the Station during the time when the canal is being filled with water pumped from the Big Fish water supply well. The Station fills the canal in the spring for a 3-month period to a depth of approximately 3 feet. The depth of the water in the Spray Canal during the hydrogeologic investigation ranged from 4.21 feet at SW-QC-1 on May 31, 2006 to 1.61 feet at SW-QC-2 on July 26, 2006. The Spray Canal was initially operated as a component of the cooling water operations at the Station. Cooling water from the condenser was pumped to the Spray Canal to further reduce the water temperature prior to discharge from the discharge bay. The operation of the Spray Canal as part of cooling water operations was suspended in 1983. The Spray Canal was modified for use in fish hatchery operations. The Station fills the canal as part of a fish hatchery program for the Mississippi River.

When the canal is not being filled, there is no flow; however, there is a residual amount of water in some parts of the canal. Due to the higher head in the canal than the surrounding groundwater elevation (approximately 25 feet of head difference as of June 2006) there may be some groundwater recharge from the Spray Canal into the overburden. There is some evidence that seepage through the canal liner exists. Based on the HIR water level measurements and an understanding of the construction of the Spray Canal, the water leakage does not appear to have a significant effect on the groundwater flow direction within the PA.

During construction of the structures and buildings in the PA, a dam was constructed to minimize groundwater infiltration into the excavation and water was pumped from the excavation. This excavation was greater than 40 feet deep and on top of the underlying dolomite bedrock formations (UFSAR, 2005). The dam was constructed at the current location of the inlet bay and was subsequently removed after the completion of plant construction activities.

Sheet piles were installed around the discharge bay and the western portion of the Spray Canal as part of Station construction activities. The discharge bay sheet piles extend below the water table to an elevation of 535 feet AMSL, but not to the top of competent bedrock. They are set on crushed stone and rip rap. As such, groundwater flow is intercepted by the sheet pile walls, but will continue to flow beneath and through the sheet piles. The sheet piles are shown on Figures 5.3 and 2.6. The foundations or basements associated with the Reactor Building and the Turbine Building extend to depths below the water table and are set into the top of competent bedrock (see Figure 5.4). The total depth of the Reactor Building is 548 to 550 feet AMSL. The total depth of the majority of the Turbine Building is 542.5 feet AMSL. These basements are barriers to groundwater flow in the overburden.

The Station structures and utilities were reviewed to assess their impact on groundwater flow conditions. All non-process related utilities (e.g., storm drains) are above the groundwater table and do not appear to impact groundwater flow.

The Station and surrounding land is generally flat and is covered by paved areas, roadways, and parking lots. These areas are drained by a storm water system that drains to the north and south of the Station and passes by the location of MW-QC-102S (see Figure 3.1). The south storm water system drains to an Oil/Water Separator (Unit 1) at the south end of the PA whose outfall discharges to the discharge bay. The north storm water system drains to an Oil/Water Separator (Unit 2) at the north end of the PA whose outfall discharges to the intake bay.

The water level in the discharge bay fluctuates. The discharge bay water level was measured on May 31, 2006 at 576.91 feet AMSL, on June 22, 2006 at 576.53 feet AMSL, and on July 26, 2006 at 576.36 feet AMSL (see Table 4.4). The discharge bay water level was approximately 4 feet higher than the water level measured in nearby monitoring wells MS-QC-103I and MW-QC-105I (see Table 4.3) but does not appear to significantly affect groundwater flow direction in this area.

5.2.2 GROUNDWATER FLOW DIRECTIONS

Groundwater level measurements were collected in May and July 2006. Groundwater contours for the upper unconsolidated aquifer for these dates are presented on Figures 5.6 and 5.7, respectively. The May 2006 groundwater contour maps are based on data obtained from 13 wells while the groundwater contour maps from July 2006 are based on data from 24 monitoring wells.

Examination of Figure 5.6 shows that groundwater flow in May 2006 is primarily to the southwest towards the Mississippi River and the southern buried valley of the Meredosia Channel. Groundwater levels on the north side of the Station are approximately 2 feet above the controlled river level elevation. As discussed in the previous section, the foundations of the Reactor and Turbine Buildings restrict the groundwater flow, which causes the groundwater to flow around the buildings. The groundwater flow in the upper unconsolidated aquifer may have been affected by the pumping of the Big Fish Well to supplement the water level in the Spray Canal.

The Big Fish Well was completed in the upper unconsolidated aquifer at a depth of approximately 175 feet bgs. This well is capable of pumping on the order of 1,800 gallons per minute (gpm). In a typical year, the Big Fish Well is operated for up to 2 weeks in April to fill the Spray Canal. The well is then operated twice a week, running between 5 to 8 hours during each event through to early August to maintain a minimum water level in the canal.

Groundwater flow directions for the July 2006 water level monitoring event are shown on Figure 5.7. This figure provides a more complete representation of groundwater flow in the upper unconsolidated aquifer at the Station, given the larger data set and broader distribution of monitoring wells. In general, groundwater levels are approximately 2 feet lower than those measured in May 2006 (see Table 4.3). This indicates that seasonal fluctuations in the water table occur. In general, groundwater flows from the east to the west towards the Mississippi River. However, the groundwater flow diverges to a southerly and northerly component and flows towards both the buried valleys of the Meredosia Channel (see Figure 2.5 for Meredosia Channel detail). In July 2006, the river elevation was higher than all groundwater levels near the river, indicating that flow from the river to the aquifer is occurring. This will result in localized reversal in the flow direction. The river recharge also resulted in a much flatter hydraulic gradient at the Station than that measured in May 2006, when groundwater discharge to the river occurred. The data also show that basement walls restrict the groundwater flow, which causes the groundwater to flow around the buildings.

The water level in the discharge bay will fluctuate. The discharge bay water level was measured on May 31, 2006 at 576.91 feet AMSL, on June 22, 2006 at 576.53 feet AMSL, and on July 26, 2006 at 576.36 feet AMSL (see Table 4.4). The discharge bay water level was approximately 4 feet higher than the water level measured in nearby monitoring wells MS-QC-103I and MW-QC-105I (see Table 4.3) but does not appear to significantly affect groundwater flow direction in this area.

A comparison of the water levels in monitoring wells located on the east side of the sheet piles with river levels indicates that the sheet piles are not acting as an effective hydraulic barrier. This is illustrated on the groundwater contour map (Figure 5.6) by the minimal changes in contour spacing when the river level is compared to groundwater elevations in adjacent wells. There are no sheet piles along the river bank. The river bank protection consists of rip-rap (rocks) present to prevent erosion.

5.2.3 VERTICAL HYDRAULIC GRADIENTS

The HIR included the installation of monitoring well clusters in the upper unconsolidated aquifer to determine not only the vertical distribution of impacted groundwater (as necessary), but also the vertical hydraulic gradient within the aquifer. Vertical hydraulic gradients were calculated at the well pairs and are provided in Table 5.1. Downward vertical hydraulic gradients were calculated for four well pairs: MW-QC-101 and MW-QC-108, where the vertical hydraulic gradient was very slight, 0.001 feet/foot; MW-QC-106, where the vertical hydraulic gradient was 0.003 feet/foot; and MW-QC-109, where the vertical hydraulic gradient was 0.006 feet/foot. An upward vertical gradient was calculated for the remaining well pair, MW-QC-102, where the vertical hydraulic gradient was -0.003 feet/foot (May 30, 2006) and -0.0004 feet/foot (July 26, 2006).

The calculated vertical hydraulic gradients at the Station are slight and vary with proximity to the canal and Mississippi River. There were no significant vertical hydraulic gradients observed.

5.2.4 LATERAL GROUNDWATER FLOW AND VELOCITY

The calculated horizontal hydraulic gradient in the upper unconsolidated aquifer along the east side of the PA based on the May 2006 data is 0.002 feet/foot and based on the June 2006 data, after the installation of additional monitoring wells, is 0.0004 feet/foot. The horizontal hydraulic gradient was calculated by dividing the change in

groundwater elevation along the groundwater flow path by the corresponding distance along the flow path. The groundwater flow direction in this area is from the northeast to southwest during both monitoring events. Figure 5.6 displays the May 2006 groundwater elevation contours and Figure 5.7 displays the July 2006 groundwater elevation contours.

The calculated horizontal hydraulic gradient in the upper unconsolidated aquifer along the west side of the Turbine Building based on the May 2006 data is 0.004 feet/foot and based in the June 2006 data is 0.003 feet/foot. The general groundwater flow direction in this area is from east-northeast to west-southwest (Figure 5.6).

The hydraulic conductivity of the surficial sands is expected to be approximately 12 feet per day based on the median measurement from a study conducted at the Illinois-Indiana border of the shallow aquifer along Lake Michigan (USGS, 1996). The aquifer media tested in this study was consistent with unconsolidated aquifer material at the Station. The velocity of the shallow groundwater may be roughly approximated using the Station-specific hydraulic gradient with the literature value for hydraulic conductivity and a typical value for porosity. The hydraulic gradient range of 0.0004 to 0.004, based on the collected May 2006 and July 2006 data, with a hydraulic conductivity of 12 feet per day and an assumed porosity of 0.32, yields a velocity of 6 to 54 feet per year (USEPA, 1996). The hydraulic gradient and the calculated groundwater velocity are subject to seasonal fluctuation.

5.3 GROUNDWATER QUALITY

CRA personnel collected 32 groundwater samples from 22 newly installed monitoring wells, two previously installed groundwater monitoring wells, and eight existing water supply wells. The samples were analyzed for tritium and additional radionuclides. Teledyne Brown provided the analytical services. The Quality Assurance Program for the laboratory is described in Appendix C. The analytical data reports are in Appendix D.

The analytical data have 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 then 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 Figure 5.8.

The tritium groundwater data have been divided into upper and intermediate intervals of the upper unconsolidated aquifer. CRA evaluated the groundwater data using upper and intermediate overburden data sets to better understand the potential vertical distribution of tritium in Station groundwater.

Concentrations of tritium in groundwater samples collected south of the Turbine and Reactor Buildings and in the SBO Area ranged from 262 ± 130 pCi/L to $32,600 \pm 977$ pCi/L. The groundwater sample collected from MW-QC-102I, screened in the intermediate interval of the upper unconsolidated aquifer, had a tritium concentration of $32,600 \pm 977$ pCi/L. The following wells in the upper unconsolidated aquifer also revealed tritium concentrations greater than the LLD of 200 pCi/L, but less than 20,000 pCi/L: shallow wells MW-QC-102S, MW-QC-104S, and MW-QC-108S; intermediate wells MW-QC-108I, MW-QC-109I, and MW-QC-111I; deep well MW-QC-102D; and the Big Fish Well.

In addition, the following two groundwater samples collected north and northwest of the Turbine and Reactor Buildings revealed tritium concentrations greater than the LLD that ranged from 250 ± 126 pCi/L (shallow overburden monitoring well MW-2) to 371 ± 134 pCi/L (water supply well Little Fish Well).

Strontium-89/90 was not detected at a concentration 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 this HIR is presented in Table 5.3 and shown on Figure 5.9.

5.3.2 SUMMARY OF GAMMA-EMITTING RADIONUCLIDES ANALYTICAL RESULTS

Gamma-emitting target radionuclides were not detected at concentrations greater than their respective LLDs. A summary of the gamma-emitting radionuclide results for the

groundwater samples collected as part of this investigation that is the subject of this HIR is provided in Table 5.3 and shown on Figure 5.9.

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 4.6 presents monitoring well purging parameters collected during the well purging and sampling activities. These field measurements included pH, dissolved oxygen, ORP, conductivity, turbidity, and temperature. The field parameters were typical of a shallow sand aquifer with carbonate source rock (i.e., the underlying limestones and shales). As such, the pH values were found to be approximately 7.0 and the conductivity was indicative of a shallow water table system subject to surface water recharge. The conductivity of the water purged from MW-QC-104S was elevated when compared to the readings from other sampling locations.

5.4 SURFACE WATER QUALITY

Two surface water samples were collected from the two gauging points located at the Spray Canal 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 C. The analytical reports are presented in Appendix D.

5.4.1 SUMMARY OF BETA-EMITTING RADIONUCLIDE ANALYTICAL RESULTS

A summary of the tritium results for the surface water samples collected in this investigation is provided in Table 5.2 and shown on Figure 5.8. Surface water samples collected from locations SW-QC-1 and SW-QC-2 contained tritium at concentrations of 550 ± 143 pCi/L and 497 ± 140 pCi/L, respectively.

Strontium-89/90 was not detected at concentrations that were greater than the LLD of 2.0 pCi/L. A summary of the strontium-89/90 analytical results for surface water samples collected in this investigation is presented in Table 5.3 and shown on Figure 5.9.

5.4.2 SUMMARY OF GAMMA-EMITTING RADIONUCLIDES ANALYTICAL RESULTS

Gamma-emitting target radionuclides were not detected at concentrations greater than their respective LLDs. A summary of the gamma-emitting radionuclides results for the surface water samples collected in this investigation is provided in Table 5.3 and shown on Figure 5.9.

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 LLDs. 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 samples collected at concentrations greater than the LLD of 2.0 pCi/L. Tritium was detected in 13 of the 34 total sample locations. Concentrations of tritium ranged between 250 ± 126 pCi/L to $32,600 \pm 977$ pCi/L.

Since only tritium was detected at concentrations greater than the LLD during the fleetwide investigation, 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 from the body 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 (^3He). 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 GROUNDWATER / SURFACE WATER

This section provides an overview of the lateral and vertical distribution of tritium detected in groundwater and the distribution of tritium in surface water at the Station. Tritium has been the only parameter detected in the upper unconsolidated aquifer at a concentration greater than the LLD of 200 pCi/L. This observation is based upon the studies recently completed at the Station. Consequently, this section of the report will focus on the distribution of tritium in the upper and intermediate intervals of the upper unconsolidated aquifer.

Tritium concentrations that are greater than the LLD of 200 pCi/L are limited to three areas at the Station. The first area is located to the north and northwest of the Turbine Building. The second larger area is located to the south and southwest of the Reactor, Service, and SBO Buildings. Tritium was also detected in the Spray Canal, the third area. The tritium detections are summarized in Table 5.2 and shown on Figure 5.8.

North and Northwest of Turbine Building

Tritium was detected at concentrations slightly above the LLD of 200 pCi/L in MW-2, completed to 27 feet bgs in the upper zone of the upper unconsolidated aquifer, and the Little Fish Well, completed to 60 feet bgs. Both of these wells are located north and northwest of the Turbine Building. Groundwater in this area of the Station has been determined to flow from northeast to southwest towards the Mississippi River based on the May 2006 groundwater elevations, with a more westerly flow component present during July 2006.

Historical tritium analytical data for groundwater samples collected from the Little Fish Well are available back to 2003. These samples were analyzed in accordance with NUREG 1302 to an LLD of 3,000 pCi/L (LLD of 200 pCi/L for the five March 10, 2006 samples). Tritium was not detected in any of the samples collected at concentrations greater than the LLD.

As part of the May 31, 2006 sampling event, tritium was detected in the Little Fish Well at concentrations of 371 ± 134 pCi/L. Tritium was not detected at concentrations greater than the LLD (200 pCi/L) in the sample from the Fish House Well. The Fish House Well is screened within the Niagaran Dolomite of the Hunton Megagroup. The driller's well log shows that competent dolomite begins at 69 feet bgs and that the well was cemented with bentonite grout to a depth of 71 feet bgs. Therefore, the Fish House Well draws water from the dolomite aquifer from 71 feet bgs and deeper. Based on the Fish House Well information, the adjacent 60 foot deep Little Fish Well, screened from 50 to 60 feet bgs, is screened within the upper unconsolidated aquifer (the sand aquifer above the dolomite). The Spray Canal is located north and hydraulically upgradient of well MW-2 and the Little Fish Well. Tritium was detected in surface water samples collected from the Spray Canal. The upper unconsolidated aquifer in this portion of the Station may be partially recharged from surface water in the Spray Canal at the dam/end of the canal when it is in use during the spring and summer, as discussed previously in Section 5.2.1.

South/Southwest of Reactor, Service, and SBO Buildings

Tritium has been detected at concentrations greater than the LLD of 200 pCi/L in the area south and southwest of the Reactor, Service, and SBO Buildings. Specifically, monitoring wells MW-QC-102S, MW-QC-102I, MW-QC-102D, MW-QC-104S, MW-QC-108S, MW-QC-108I, MW-QC-109I, and MW-QC-111I, and the Big Fish Well contained concentrations of tritium greater than the LLD. Groundwater flow direction in this area of the Station varies seasonally, and groundwater flows either from northeast to southwest towards the Mississippi River or from east to west towards the Mississippi River.

The concentration of tritium in the Big Fish Well, screened at three intervals from 77 feet to 175 feet in the unconsolidated deposits of the Meredosia Channel, has been reported as less than the Station LLD of 3,000 pCi/L (2003 through 2006 samples). The new monitoring wells in this area are screened from 18 to 70 feet bgs within the unconsolidated aquifer. The highest concentration of tritium, $32,600 \pm 977$ pCi/L, was detected in the groundwater sample collected at MW-QC-102I. Tritium was also detected in the groundwater sample collected from MW-QC-109I at $1,140 \pm 182$ pCi/L in the vicinity of historical release referenced in AFE-Quad Cities-2 in Section 3.4. Tritium was detected as far south as MW-QC-111I at a concentration of $420J \pm 133$ pCi/L, but was not detected in either MW-QC-114I or MW-QC-115S, which are located further south of MW-QC-111I. Tritium detections above the LLD are limited to a localized area between the Reactor and Service Buildings to the north and the Spray Canal to the south. Tritium has not been detected above the LLD of 200 pCi/L in wells adjacent to the Mississippi River (MW-QC-112I, MW-QC-113I, MW-QC-114I, and the STP Sand Point Well) or beyond the area delineated by the Spray Canal.

Wells with tritium detections greater than the LLD of 200 pCi/L, MW-QC-102S, MW-QC-102I, MW-QC-102D, MW-QC-104S, MW-QC-108S, MW-QC-108I, MW-QC-109I, MW-QC-111I, and the Big Fish Well, are downgradient of the AFE-Quad Cities-2 SBO Area, which is the likely source of tritium in these wells. Figure 6.1 presents a profile depicting detected tritium concentrations along cross-section A-A'. Figure 6.2 presents a plan view depicting detected tritium concentrations.

Surface Water

Tritium was detected in the surface water samples collected from the Spray Canal at sampling points SW-QC-1 and SW-QC-2 at concentrations of 550 ± 143 pCi/L and 497 ± 140 pCi/L, respectively. The Spray Canal is filled with water pumped from the Big Fish Well, which is impacted by tritium.

6.3.3 CONCEPTUAL MODEL OF TRITIUM RELEASE AND MIGRATION

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

Tritium has not been detected at concentrations greater than the LLD of 200 pCi/L in samples collected from bedrock potable supply wells located at the Station (Well #1, Well #5, and Fish House Well #10). As such, CRA's conceptual hydrogeologic model focuses on the migration of groundwater and tritium in the upper unconsolidated aquifer.

Within the upper unconsolidated aquifer, tritium was not detected in monitoring wells installed adjacent to the Mississippi River (STP Sand Point Well, MW-QC-103I, MW-QC-105I, MW-QC-106S, MW-QC-106I, MW-QC-112I, MW-QC-113I, and MW-QC-114I). Tritium was also not detected in the monitoring wells installed adjacent to residential properties (MW-QC-115S and MW-QC-116S). Therefore, the vertical and horizontal extent of tritium impact to Station groundwater is limited to the Station property.

The groundwater flow in May within the upper unconsolidated aquifer beneath the Station is from northeast to southwest, toward the southern buried valley of the Meredosia Channel. As shown on Figure 5.6, groundwater flow appears to divide around the Reactor and Turbine Buildings, as a result of the foundations sitting on bedrock. Groundwater may also undergo seasonal fluctuations as a result of the filling of the Spray Canal and water level change within the Mississippi River. CRA observed seasonal changes in the two rounds of groundwater levels collected. The groundwater flow in July is, in general, from east to west, but the groundwater flow diverges to a southerly and northerly component toward the buried valleys of the Meredosia Channel (see Figure 5.7). There is no indication from this HIR investigation that tritium-impacted groundwater is migrating off Station.

Hydrogeologic Framework

Groundwater flow within the upper unconsolidated aquifer at the Station is to the southwest toward the Mississippi River in May 2006 and generally to the west toward the Mississippi River in July 2006, with southerly and northerly components present.

Groundwater moving within the overburden is separated from the deeper regional bedrock aquifer zones by the upper dolomite. In the vicinity of the Turbine and Reactor Buildings, groundwater flow in the upper unconsolidated aquifer is affected by the building foundations, as they extend to the bedrock. This results in a deviation of the flow around the buildings.

In May 2006, groundwater from the west side of the Turbine Building discharges into the intake bay and the Mississippi River to the southwest. The southern component of flow is also influenced, to some degree, by the pumping of the Big Fish Well and by the Meredosia Channel. The Big Fish Well was constructed in the Meredosia Channel, an ancient channel of the Mississippi River that eroded the bedrock. This channel has been filled over time with unconsolidated sediments ranging from approximately 50 to 300 feet deep (Blume, 1966). The well construction logs indicate that the Big Fish Well was screened over three intervals (77 to 97, 118 to 148, and 157 to 175 feet bgs) and has an overall depth of 175 feet. Pumping tests performed on this well indicate that it can pump at a sustained rate of 1,800 gpm.

In a typical year, the Big Fish Well is operated for up to 2 weeks in April to fill the Spray Canal. The Big Fish Well is then operated twice a week, running between 5 to 8 hours during each event through to early August to maintain a minimum water level in the canal. The canal is used for a fish hatchery. During the time of sustained pump operation, the water table should draw down around the well. Given the constraints imposed by the presence of the Turbine/Reactor Building foundation, groundwater will flow in a north to south direction towards the Big Fish Well, within the capture zone of the well when the pump is operated. However, given the high rate of hydraulic conductivity present in the shallow aquifer, the shallow unconsolidated aquifer will recharge quickly after the pumping has stopped. Pumping of the Big Fish Well draws water from the upper unconsolidated aquifer. Pumping at this location may draw surface water from the Mississippi River east towards the southern portion of the Station.

The northern edge of the Meredosia Channel runs along the southern portion of the Station as shown on Figure 2.6. This channel eroded the top of the dolomite bedrock in this portion of the Station and further influences overburden groundwater flow at the Station to a further southern flow. CRA believes that the location of the channel directs overburden groundwater flow in a southwest direction.

In July 2006, general groundwater flow in the upper unconsolidated aquifer is to the west toward the Mississippi River. However, the groundwater flow diverges to a southerly and northerly component and flows towards both buried valleys of the

Meredosia Channel. The southern component of flow is also influenced, to some degree, by the pumping of the Big Fish Well.

Sources and Migration of Tritium

Tritium was detected above the LLD of 200 pCi/L in three areas at the Station:

- north and northwest of the Turbine Building;
- south/southwest of the Reactor, Service, and SBO Buildings; and
- surface water.

This distribution of tritium (both within the shallow water table zone and within the deeper portions of the upper unconsolidated aquifer) is likely related to the following water release history:

- historical releases of tritium to the subsurface that have been documented by the Station that are associated with AFE-Quad Cities-2; and
- potential recharge of the upper unconsolidated aquifer from the Spray Canal.

All tritium detections appear to be related to historical releases at AFE-Quad Cities-2. The groundwater data suggest that a release of tritium has occurred in AFE-Quad Cities-2 to the north and upgradient of MW-QC-102S and MW-QC-102I, possibly in the vicinity of MW-QC-109S and MW-QC-109I. The effect of the periodic operation of the Big Fish Well pump is to pull the release in the direction of the Big Fish Well. This is explained by tritium detections in groundwater samples from MW-QC-102S, MW-QC-102I, MW-QC-102D, MW-QC-108S, MW-QC-108I, MW-QC-111I, and the Big Fish Well. CRA notes that the historical releases associated with AFE-Quad Cities-2 occurred as long ago as 21 years. The effects of groundwater flow (advection), diffusion, and dilution have resulted in the current distribution of tritium to the south and west of AFE-Quad Cities-2. There is no indication from the HIR investigation that tritium-impacted groundwater is migrating off the Station property.

In addition, the tritium detected in the Spray Canal is also likely attributable to historic releases in the AFE-Quad Cities-2. The Spray Canal is filled from water pumped from the Big Fish Well. Tritium was detected at a concentration of 740 ± 152 pCi/L in the groundwater sample collected from the Big Fish Well. The source of tritium detected in the Spray Canal, therefore, is likely the same as the source of tritium in the Big Fish Well, which is historic releases from AFE-Quad Cities-2.

The Spray Canal potentially recharges overburden groundwater downgradient of the Spray Canal. Water from the Spray Canal enters the upper unconsolidated aquifer in the northern portion of the Site and water drawn from the Little Fish Well is partially recharged from the Spray Canal in this area of the Site. Therefore, the source of tritium detected in the Little Fish Well and MW-2 is also the historic releases associated with AFE-Quad Cities-2.

Based on the results of the hydrogeologic investigation that is the subject of this HIR, tritium-impacted groundwater is not migrating off the Station property.

Naturally occurring isotopes not produced by the Station were identified and excluded from this report.

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 99 percent confidence range (± 3 sigma) for determining whether to report the sample activity concentration as detected or not. This 3-sigma confidence interval typically equates to 150 (± 135.75) pCi/L.

Exelon has specified an 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 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 ${}^6\text{Li}$ (92.5 percent abundance) and ${}^7\text{Li}$ (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. Concentrations 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 radionuclide analyses. 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 worldwide 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 until 1975 followed by a gradual decline since that time. Tritium concentrations in Midwest precipitation have typically been less than 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 be 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, most of the data were less than 100 pCi/L.

CRA constructed a non-parametric upper tolerance limit with a confidence of 95 percent and 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 less than 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 less than 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 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.

Routine surface water measurements for tritium sampling locations upstream of the Quad Cities Generating Station show that concentrations in the Mississippi River are consistently less than 200 pCi/L (Exelon, 2005).

Pre-operational REMP quarterly and semi-annual surface water composite samples collected from downstream and on-Station locations were analyzed for tritium. Tritium was not detected in surface water samples collected from the Davenport Water Works, the Moline Water Works, and the Inlet Canal for 1969, 1970, and 1971 (1st quarter). Pre-operational REMP tritium detections in surface water are provided below.

1968 semi-annual (3rd and 4th quarter) results were as follows:

- East Moline Water Treatment Plant - $1,850 \pm 900$ pCi/L;
- Davenport Water Treatment Plant - $1,590 \pm 850$ pCi/L; and
- Intake Canal - 900 ± 60 pCi/L.

1971 2nd quarter tritium results were as follows:

- East Moline Water Treatment Plant - 540 ± 370 pCi/L;
- Davenport Water Treatment Plant - 540 ± 370 pCi/L; and
- Intake and Discharge Canal - 180 ± 370 pCi/L.

1971 3rd quarter tritium results were as follows:

- East Moline Water Treatment Plant - 700 ± 230 pCi/L;
- Davenport Water Treatment Plant - 730 ± 230 pCi/L; and
- Intake and Discharge Canal - 590 ± 210 pCi/L.

1971 4th quarter tritium results were as follows:

- East Moline Water Treatment Plant - 770 ± 200 pCi/L;
- Davenport Water Treatment Plant - 850 ± 200 pCi/L;
- Intake Canal - 610 ± 200 pCi/L; and
- Discharge Canal - 420 ± 200 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.

7.2.5 EXPECTED TRITIUM BACKGROUND FOR THE STATION

As reported in the GNIP and RadNet databases, tritium concentrations in U.S. Midwest precipitation have typically been less than 100 pCi/L since 1980. Tritium concentrations reported in the RadNet database for Illinois surface water and groundwater, at least since 1995, 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 limit. 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 near crystalline basement rock, however, can potentially show elevated concentrations of tritium due to lithogenic sources.

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

Two potential exposure pathways were considered during the evaluation of tritium in groundwater:

- potential groundwater migration on and off the Station property to private and public groundwater users; and

- potential groundwater migration off the Station property to a surface water body.

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

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

Tritiated groundwater would migrate to the south-southwest and the north-northwest with groundwater flow away from the Station towards the Mississippi River.

The Station receives its potable water from the three potable wells on the property (Well #1, Well #5, and Fish House Well #10). The three potable wells are cased off through the upper unconsolidated (sand) aquifer and are screened in the Dolomite bedrock aquifer beneath the upper unconsolidated aquifer. Well #1 and Well #5 are upgradient of the source area. Although tritium was detected in the Little Fish Well, which is near the Fish House Well but screened in the upper unconsolidated aquifer, tritium was not detected in the deeper Fish House Well; this proves that the Fish House Well is isolated from the upper unconsolidated aquifer. The potable wells were sampled as part of the investigation and did not contain tritium or other radionuclides above background levels.

Although there is a potentially complete exposure pathway to these supply wells, there is no current risk of exposure associated with groundwater ingestion at the Station.

Residences are present both north and south of the Station. Tritium was not detected in monitoring wells installed adjacent to residential properties (MW-QC-115S and MW-QC-116S).

Although there is a potentially complete exposure pathway to the residential wells, there is no current risk of exposure associated with groundwater ingestion off the Station property.

7.3.2 GROUNDWATER MIGRATION TO SURFACE WATER USERS OFF THE STATION PROPERTY

Under this potential exposure route groundwater would migrate from the Station property to the Mississippi River. Potential exposures could occur if the groundwater discharge to the surface water body was sufficient to increase tritium levels in the

Mississippi River to detectable levels above background. Based on the results of the HIR, tritium has not migrated off the Station property at detectable concentrations. Tritium was not detected in the groundwater samples collected adjacent to the Mississippi River (STP Sand Point Well, MW-QC-112I, MW-QC-113I, and MW-QC-114I), which is somewhat indicative of river water quality.

This exposure pathway is incomplete as tritium was not detected above the LLD of 200 pCi/L in groundwater samples collected from monitoring wells installed adjacent to the Mississippi River. Therefore, there is no current risk of exposure to surface water users off the Station property.

7.4 SUMMARY OF POTENTIAL TRITIUM EXPOSURE PATHWAYS

There are two potential exposure pathways for tritium originating in or adjacent to the Station:

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

In summary, based upon the groundwater and surface 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 in the groundwater and surface water samples at concentrations greater than their respective LLDs. 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 all of the studies completed to date at this Station, CRA concludes:

Groundwater Flow

- Groundwater flow beneath the Station fluctuates seasonally. Groundwater was observed to flow to the south-southwest in May 2006 and toward the west in July 2006. Station groundwater discharges to the Mississippi River. Groundwater flows beneath the Station at a rate of approximately 6 to 54 feet per year.
- Groundwater flow at the Station is affected by the presence of a natural paleochannel, the Meredosia Channel. The northern extent of this paleochannel runs along the southern portion of the Station. The bedrock surface in this portion of the Station drops more than 100 feet.
- Groundwater flow within the PA is affected by the construction (basements/foundations) of the Reactor/Turbine Building structure, which was constructed into the Niagaran Dolomite. This building is a barrier to local lateral flow in the upper unconsolidated aquifer.
- The deeper bedrock water supply aquifers are not separated from the upper unconsolidated aquifer.
- Water from the Spray Canal enters the upper unconsolidated aquifer in the northern portion of the Station, and water drawn from the Little Fish Well is partially recharged from the Spray Canal in this area of the Station.

Groundwater Quality

- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in the samples collected as part of this investigation.
- Strontium-89/90 was not detected at concentrations greater than the LLD of 2.0 pCi/L in any of the groundwater samples collected as part of this investigation.
- Tritium was detected at concentrations greater than the LLD of 200 pCi/L in 11 of the 32 groundwater samples collected as part of this investigation.
- Tritium concentrations were identified in groundwater in two areas at the Station: wells downgradient of AFE-Quad Cities-2 (including the Big Fish Well) and wells downgradient of the Spray Canal (MW-2 and Little Fish Well).

- All tritium concentrations appear to be related to historical releases at AFE-Quad Cities-2. Tritium is present in wells south and southwest of AFE-Quad Cities-2, including the Big Fish Well.
- Tritium was not detected in monitoring wells installed adjacent to the Mississippi River at concentrations greater than the LLD of 200 pCi/L (STP Sand Point Well, MW-QC-103I, MW-QC-105I, MW-QC-106S, MW-QC-106I, MW-QC-112I, MW-QC-113I, and MW-QC-114I).
- Tritium was not detected in the monitoring wells installed adjacent to residential properties at concentrations greater than the LLD of 200 pCi/L (MW-QC-115S and MW-QC-116S).

Surface Water Quality

- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in the two 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 the two surface water samples collected as part of this investigation.
- Tritium was detected at concentrations greater than the LLD of 200 pCi/L in two surface water locations, SW-QC-1 and SW-QC-2, at concentrations of 550 ± 143 pCi/L and 497 ± 140 pCi/L, respectively.
- The likely source of tritium in the Spray Canal is historic releases associated with AFE-Quad Cities-2.

AFE-Quad Cities-1 - Piping West of Radwaste Building/Floor Drain Surge Tank

- Strontium-89/90 was not detected in the groundwater monitoring well at a concentration greater than the LLD of 2.0 pCi/L in the vicinity of AFE-Quad Cities-1.
- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in the groundwater monitoring well in the vicinity of AFE-Quad Cities-1.
- Tritium was not detected at a concentration greater than the LLD (200 pCi/L) in the groundwater sample collected from new monitoring well MW-QC-103I located to the southwest of this AFE area.
- There is no impact to groundwater from AFE-Quad Cities-1.

AFE-Quad Cities-2 - Historic Releases Area Near Station Blackout Building (SBO)

- Strontium-89/90 was not detected at a concentration greater than the LLD of 2.0 pCi/L in the groundwater monitoring wells in the vicinity of AFE-Quad Cities-2.
- Gamma-emitting radionuclides associated with licensed plant operations were not detected in the groundwater monitoring wells at concentrations greater than their respective LLDs in the vicinity of AFE-Quad Cities-2.
- Tritium was detected in groundwater samples from monitoring wells MW-QC-102S (9,410 ± 655 pCi/L sample and 9,640 ± 660 pCi/L sample duplicate), MW-QC-102I (32,600 ± 977 pCi/L sample and 31,800 ± 972 pCi/L sample duplicate), MW-QC-102D (3,930J ± 450 pCi/L), MW-QC-108S (1,460 ± 217 pCi/L), MW-QC-108I (1,890J ± 252 pCi/L), MW-QC-109I (768J ± 156 pCi/L), and MW-QC-111I (420J ± 133 pCi/L); and from water supply well Big Fish Well (740 ± 152 pCi/L).
- Water from the Big Fish Well fills the Spray Canal. Tritium was detected in Spray Canal surface water samples from sampling points SW-QC-1 (550 ± 143 pCi/L) and SW-QC-2 (497 ± 140 pCi/L).
- The Spray Canal potentially recharges overburden groundwater downgradient of the Spray Canal. Tritium was detected in water supply well Little Fish Well (371 ± 134 pCi/L) and monitoring well MW-2 (250 ± 126 pCi/L).
- Additional delineation of tritium in groundwater is not necessary.
- There have been three historical releases that have influenced the AFE.

AFE-Quad Cities-3 - CCSTs and Ancillary Piping

- Strontium-89/90 was not detected in the groundwater monitoring well at a concentration greater than the LLD of 2.0 pCi/L in the vicinity of AFE-Quad Cities-3.
- Gamma-emitting radionuclides associated with licensed plant operation were not detected at concentrations greater than their respective LLDs in the groundwater monitoring well in the vicinity of AFE-Quad Cities-3.
- Tritium was detected in the groundwater sample collected from new monitoring well MW-QC-104S (262 ± 130 pCi/L). This value is slightly greater than the LLD of 200 pCi/L.

AFE-Quad Cities-4 - No. 1 Oil/Water Separator

- Strontium-89/90 was not detected in the groundwater monitoring well at a concentration greater than the LLD of 2.0 pCi/L in the vicinity of AFE-Quad Cities-4.

- Gamma-emitting radionuclides associated with licensed plant operations were not detected at concentrations greater than their respective LLDs in the groundwater monitoring well in the vicinity of AFE-Quad Cities-4.
- Tritium was not detected at a concentration greater than the LLD (200 pCi/L) in the groundwater sample collected from new monitoring well MW-QC-105I located immediately to the northeast of this AFE area.
- There have been no impacts to groundwater from AFE-Quad Cities-4.

AFE-Quad Cities-5 - No. 2 Oil/Water Separator

- Strontium-89/90 was not detected in the groundwater monitoring wells at a concentration greater than the LLD of 2.0 pCi/L in the vicinity of AFE-Quad Cities-5.
- Gamma-emitting radionuclides associated with licensed plant operation were not detected in the groundwater monitoring wells at concentrations greater than their respective LLDs in the vicinity of AFE-Quad Cities-5.
- Tritium was not detected at a concentration greater than the LLD (200 pCi/L) in the groundwater sample collected from monitoring wells MW-QC-106S and MW-QC-106I located immediately southwest of this AFE area.
- There is no impact to groundwater from AFE-Quad Cities-5.

Potential Receptors

- 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 potential exposure pathways.

General Conclusions

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

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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