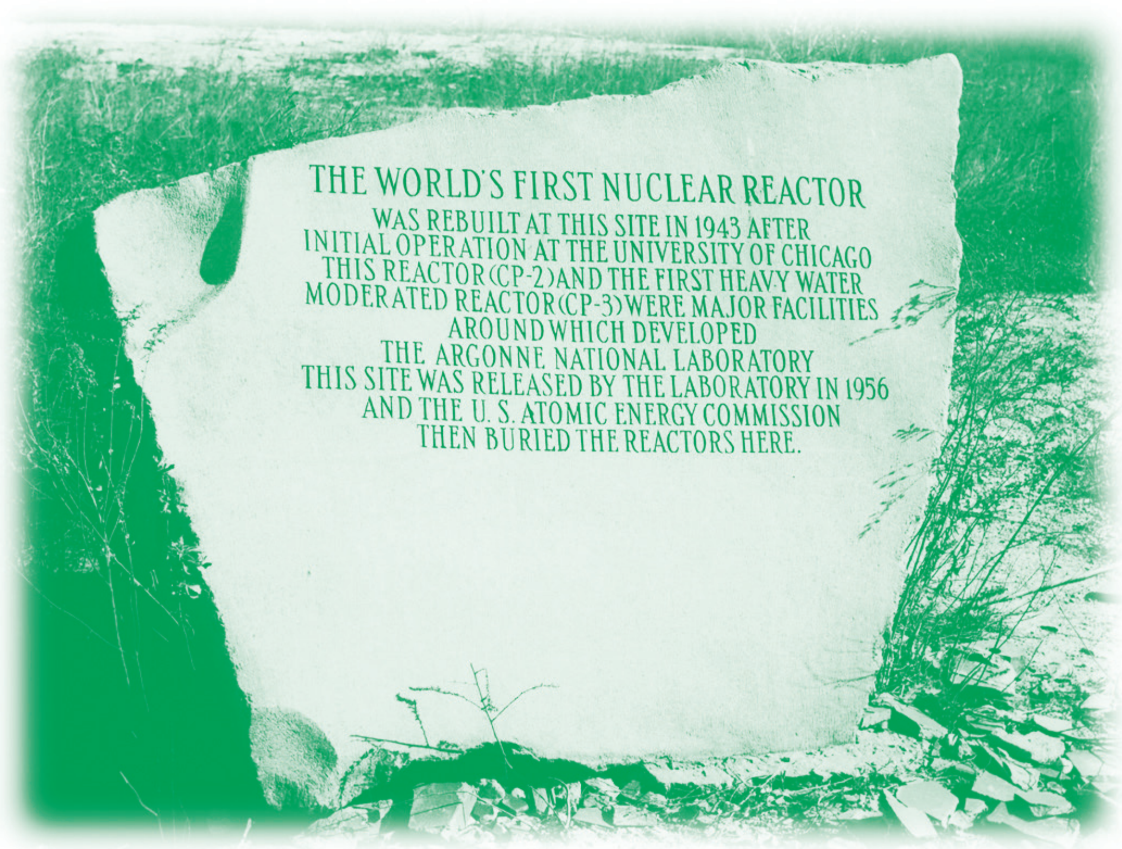
ANL-14/01

Surveillance of Site A and Plot M Report for 2013

Environment, Safety, and Quality Assurance



ANL-13/01

Surveillance of Site A and Plot M Report for 2012

by
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Environment, Safety, and Quality Assurance Division, Argonne National Laboratory

May 2014

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PREFACE

This report is prepared for the U. S. Department of Energy (DOE) by the Environment, Safety, and Quality Assurance Division (ESQ) at Argonne National Laboratory (Argonne). The results of the environmental monitoring program at Site A and Plot M and an assessment of the impact of the site on the environment and the public are presented in this publication. Funding to support this program was provided by the DOE Office of Legacy Management (LM) through the DOE Grand Junction Office.

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SURVEILLANCE OF SITE A AND PLOT M

REPORT FOR 2013

1.0 SUMMARY

The results of the environmental surveillance program conducted at Site A/Plot M in the Palos Forest Preserve for calendar year 2013 are presented within this document. The current surveillance program consists of the collection and analysis of surface and subsurface water samples to determine the amount of hydrogen-3 and strontium-90 present in the environment around the site of the former research facility (Site A) and waste burial site (Plot M).

The 2013 results indicate that, with a few exceptions, the amounts of hydrogen-3 and strontium-90 are slowly decreasing as a result of decay and dilution. The maximum potential radiation dose to a hypothetical resident near Plot M resulting from residual radioactivity in this area was estimated to be 4.2 mrem/year based on very conservative assumptions. A more realistic estimate of potential dose is 0.006 mrem per visit for an occasional visitor to the park. The potential dose is well below the allowable dose to the general public of 100 mrem/year.

Hydrogen-3 concentrations in surface water in two small streams that pass by Plot M were below the detection limit of 0.1 nCi/L upstream of Plot M, increased up to 80.4 nCi/L at a groundwater seep adjacent to Plot M, and then decreased to a maximum of 16 nCi/L downstream. None of the samples from five surface water bodies in the area contained hydrogen-3 above detection limits.

Hydrogen-3 continued to be detected in nine wells surrounding Plot M. Most results were found to be slowly decreasing and similar to previous results. Borehole BH02 had hydrogen-3 concentrations similar to 2012 but higher than recent years. BH06 exhibited higher than normal hydrogen-3 concentrations, possibly due to increasing groundwater elevations in 2013. BH35 continued a trend of increasing hydrogen-3 concentrations which started in 2003. Low levels of strontium-90 were found in groundwater from five of the nine wells but all

concentrations were below groundwater quality standard of 8 pCi/L. The strontium-90 results are consistent with those measured in the past.

Five wells in the vicinity of Site A were found to contain much lower amounts of hydrogen-3 than the Plot M wells. The amounts present were found to be slowly decreasing and were consistent with past observations. Low levels of strontium-90 were found in two of the five wells. All results were below groundwater quality standards.

Ten deep wells constructed in the dolomite bedrock underlying the site were found to contain low levels of hydrogen-3, all well below the groundwater quality standard of 20 nCi/L. The 2013 results were consistent with past findings.

Two unused former picnic wells were sampled. Both wells had low levels of hydrogen-3 similar to some of the 2012 results, but these levels were higher than the results found in the years from 2009 to 2012. All results were well below the EPA Primary Drinking Water standard of 20 nCi/L.

The results of the surveillance program continue to indicate that the radioactivity remaining at Site A/Plot M does not endanger the health or safety of the public visiting the site, using the picnic area, or living in the vicinity.

2.0 INTRODUCTION

2.1 Site History

The environmental surveillance program discussed in this report is an ongoing activity that resulted from the 1976-1978 radiological characterization of the former site of Argonne National Laboratory and its predecessor, the University of Chicago's Metallurgical Laboratory. This site was part of the World War II Manhattan Engineer District Project and was located in the Palos Forest Preserve southwest of Chicago, IL. Research was conducted at two locations in the Palos Forest Preserve: Site A, a 19-acre area that contained experimental laboratories and nuclear reactor facilities; and Plot M, a 150 ft x 140 ft area used for the burial of radioactive waste. The location of the Palos Forest Preserve is shown in Figure 2.1 and the locations of Site A and Plot M are shown in Figure 1.2. Previous comprehensive reports on this subject[1,2] provide additional detail and illustrations on sampling locations and provide descriptive material along with the results through 1981. There are annual reports available for 1982 through 2012.[3-33] While earlier data will not be repeated in this report, reference is made to some of the results.

Operations at Site A began in 1943 and ceased in 1954. Among the research programs carried out at Site A were reactor physics studies, fission product separations, hydrogen-3 recovery from irradiated lithium, and work related to the metabolism of radionuclides in laboratory animals. Radioactive waste and radioactively-contaminated laboratory articles from these studies were buried at Plot M. At the termination of the programs, the reactor fuel and heavy water, used for neutron moderation and reactor cooling, were removed and shipped to Oak Ridge National Laboratory. The biological shield for the CP-3 reactor located at Site A, together with various pipes, valves, and building debris, was buried in place in 1956.

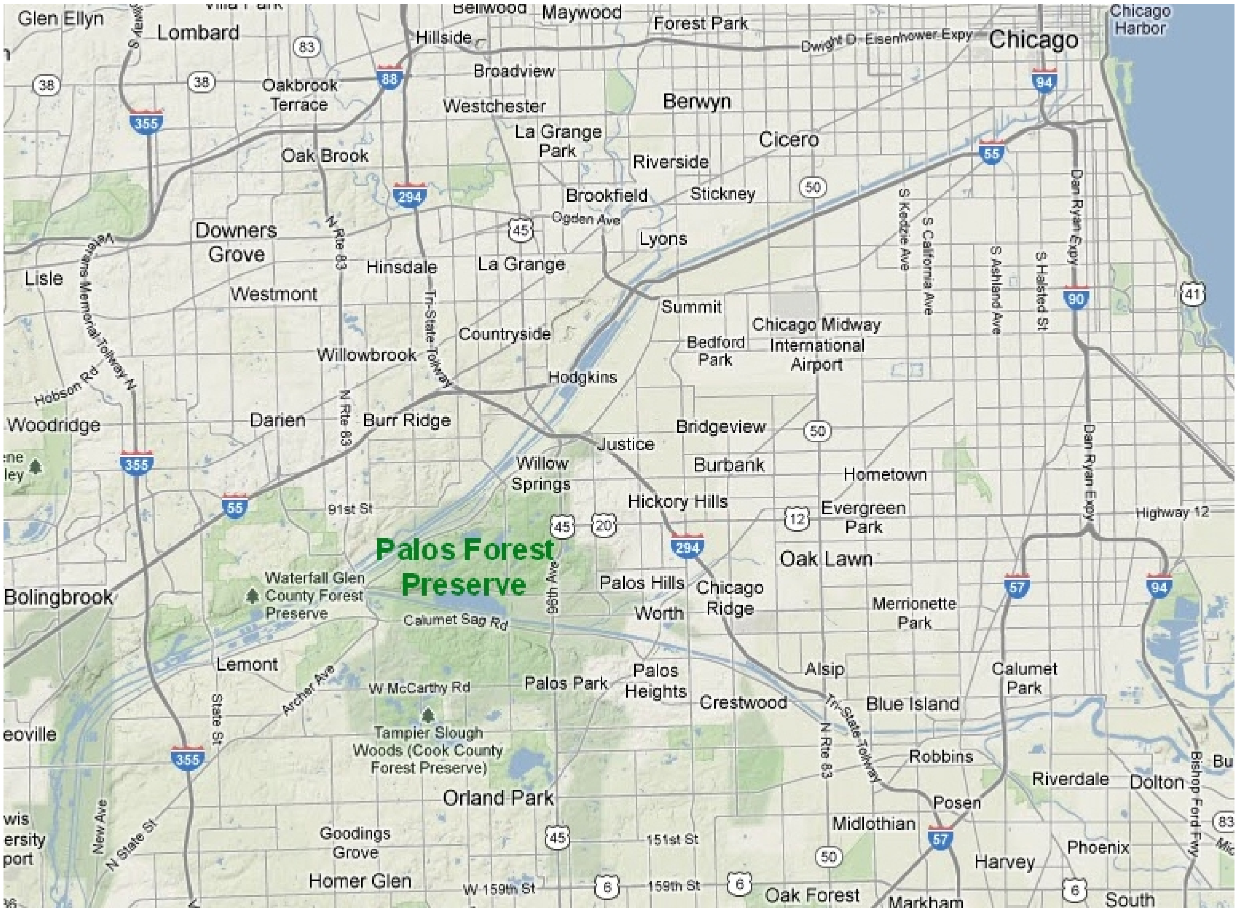

Figure 2.1 Location of Palos Forest Preserve on Chicago-Area Map

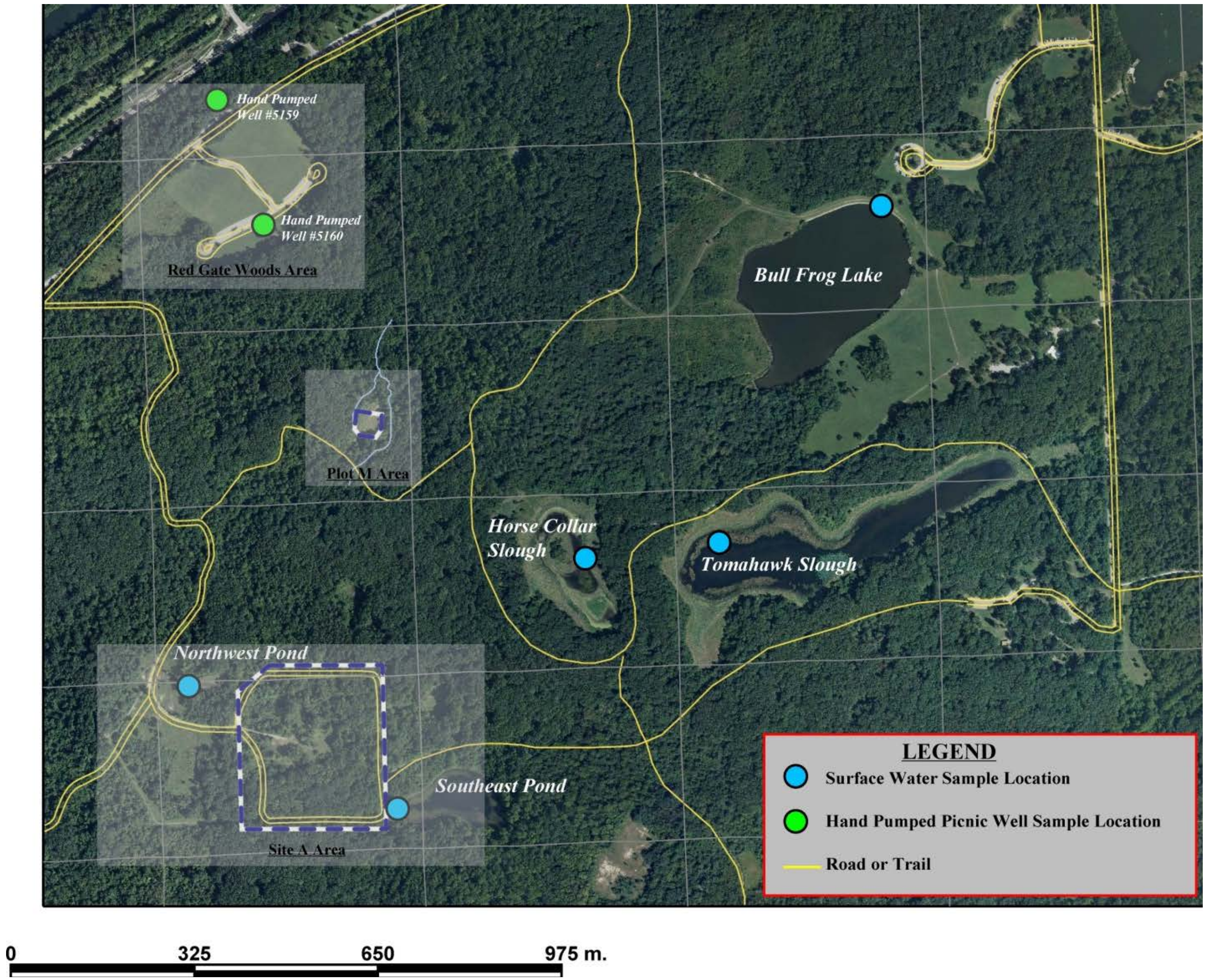

Figure 2.2 Palos Forest Preserve Showing Location of Site A/Plot M Surface Water Bodies and Former Picnic Wells

Burial of radioactive waste at Plot M began in 1944 and was discontinued in 1949. Waste was buried in six-foot deep trenches and covered with soil until 1948, after which burial took place in steel bins. The steel bins were removed in 1949 and sent to Oak Ridge National Laboratory for disposal, but the waste buried in trenches was allowed to remain in place. Concrete sidewalls, eight feet deep, were poured around the perimeter of the burial area and a one-foot thick reinforced concrete slab was poured over the top. The concrete slab was covered with soil and seeded with grass. Both the Site A and Plot M areas were decommissioned in 1956.

In 1973, elevated levels of hydrogen-3 (as tritiated water) were detected by Argonne in two nearby hand-pumped picnic wells (#5167 and #5159). Later investigations found the hydrogen-3 to be migrating from the Plot M burial plot into the surrounding soil and aquifers. As a result, a radiological survey of the entire Palos Forest Preserve site was conducted by Argonne in 1976 with special emphasis on the Site A and Plot M areas.[1]

In 1990, elevated levels of radioactivity were discovered outside the original developed area. By 1997, additional characterization and remediation had been completed by DOE to remove residual radioactivity and document the remediation of the area.

The terminology used in previous reports is continued in this report. A hole drilled and well installed into the glacial drift is called a borehole. Water from such wells is called groundwater. Monitoring wells drilled into the dolomite bedrock are called dolomite holes or deep holes. The former hand-pumped drinking water wells, which are completed into or close to the dolomite bedrock, are called picnic wells. They are identified by a location name and well number.

The results of radioactivity measurements are expressed in this report in terms of picocuries per liter (pCi/L) for strontium-90 and nanocuries per liter (nCi/L) for hydrogen-3 in water samples. Radiation effective dose equivalent calculations are reported in units of millirem (mrem) or millirem per year (mrem/y). The use of the term dose throughout this report means effective dose equivalent. Other abbreviations of units are defined in the text.

2.2 Site Characteristics

Geologically, Plot M is constructed on a moraine upland which is dissected by two valleys, the Des Plaines River valley to the north and the Calumet Sag valley to the south. The upland is characterized by rolling terrain with poorly developed drainage. Streams are intermittent and drain internally or flow to one of the valleys. The area is underlain by glacial drift, dolomite, and other sedimentary rocks. The uppermost bedrock is Silurian dolomite, into which both the picnic wells and some of the monitoring wells are placed. The dolomite bedrock is about 200 feet thick. The overlying glacial drift has a thickness that ranges from 165 feet at Site A to zero at the Des Plaines River and Calumet Sag Canal, and the boreholes terminate in this layer. The depth to bedrock at Plot M is about 130 feet.

Hydrologically, the surface water consists of ponds and intermittent streams. When there is sufficient precipitation, the intermittent stream that drains Plot M flows from the highest point near Site A, past Plot M, continues near the Red Gate Woods picnic well (#5160 in Figure 2.2), and discharges into the Illinois and Michigan (I&M) Canal. The groundwater in the glacial drift and dolomite forms two distinct flow systems. The flow of groundwater in the drift is controlled principally by topography. The groundwater in the dolomite, which is recharged by groundwater migrating downward through the glacial drift, flows toward two discharge areas, the Des Plaines River to the north and the Calumet Sag Canal to the south. There is no groundwater usage downgradient of Site A/Plot M. The former hand-pumped picnic wells have been disabled by removing the handles. These wells are currently used only for groundwater monitoring.

The climate is that of the upper Mississippi valley, as moderated by Lake Michigan, and is characterized by cold winters and hot summers. Precipitation averages about 37 inches annually. The largest rainfalls occur between April and September. The average monthly temperature ranges from 21°F in January to 73°F in July. Approximately 8.9 million people reside within 50 miles of the site; the population within a five-mile radius is about 150,000. The only portion of the Palos Forest Preserve in the immediate area of Plot M and Site A that is developed for public use is the Red Gate Woods picnic area (Figure 2.2), although small numbers of individuals use the trails that pass through more remote areas of the Preserve.

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3.0 MONITORING PROGRAM

3.1 Purpose of Monitoring Program

The monitoring conducted at Site A/Plot M was conducted in accordance with the Long-Term Surveillance and Maintenance Plan for Site A and Plot M, Palos Forest Preserve, Cook County, Illinois, issued in December 2004[34]. DOE−LM conducts stewardship activities at Site A and Plot M to protect human health and the environment and to comply with applicable regulations. The overall goal of stewardship is to protect human health and the environment near the site through a combination of government ownership, conducting regular inspections, maintaining institutional controls, facilitating public awareness, and monitoring environmental media. The Long Term Stewardship Plan defines the following two major monitoring objectives:

- Document that existing contaminant concentrations continue to decrease as expected due to radioactive decay and other natural processes, and

- Detect any potential future releases.

The monitoring program is assessed every three to five years to determine if the goals are being met. At each review, changes to the monitoring program may be recommended. The current monitoring program was developed in 2004 after reviewing over 20 years of monitoring data. DOE-LM staff worked closely with the property owner, representatives from the State of Illinois, Argonne National Laboratory, local stakeholders, and the DOE Chicago Operations Office to devise a streamlined monitoring program that focuses on known contaminants, likely migration pathways and sampling locations that provide the most useful information. The sampling locations were chosen to determine if the protective measures in place remain adequate to prevent exposure to the public. The constituents of concern (COC) in groundwater and surface water at Site A/Plot M were found to be limited to hydrogen-3 and strontium-90. The current monitoring program is focused on these parameters.

3.2 Structure of Monitoring Program

The Site A/Plot M monitoring program follows the guidance for monitoring at DOE facilities.[35] Although Site A/Plot M is not an active DOE facility, the same monitoring principles are applicable to this site. The monitoring program is designed to assess the concentration of hydrogen-3 and strontium-90 in groundwater near these sites, and to monitor hydrogen-3 in two of the former picnic wells in the Palos Forest Preserve and several surface water bodies in the vicinity. This is accomplished by analyzing water collected from wells and surface water. Sampling locations are described in the following sections. Samples from all locations are collected and analyzed for hydrogen-3 quarterly. Additional sample volume is collected semiannually from the Site A and Plot M boreholes and analyzed for strontium-90.

During 2013, 150 samples were collected and 179 analyses were performed. Individual results are presented in following sections. Plot M well BH09 was dry during the first, third and fourth quarter, and the surface water stream around Plot M was dry during the third quarter, thus no samples were collected at these locations during those quarters. During the first quarter, Site A well BH54 yielded only enough water for the hydrogen-3 sample: therefore, the strontium-90 sample could not be collected. All other planned samples were collected.

The samples were analyzed by the Argonne ESQ radiochemistry laboratories using DOE-approved methods. The detection limit for hydrogen-3 in water is 0.1 nCi/L and 0.25 pCi/L for strontium-90 in water. The uncertainties associated with individual concentrations for strontium-90 shown in some of the tables are the statistical counting errors at the 95% confidence level. Because of the amount of hydrogen-3 data presented in many of the tables, the uncertainty values are not included. In such cases, the following typical uncertainties apply:

Hydrogen-3 Concentration (nCi/L)	Uncertainty (% of Conc.)
0.1-1.0	40-5%
1-10	5-1%
> 10	1%

3.3 Surface Water

Surface water samples were collected from four sampling locations along the two streams that flow around Plot M, shown in Figure 3.1. Location 6 is near a spot where a groundwater seep releases shallow groundwater to the stream. The other locations are in the stream bed. There was no flow present during the third quarter of 2013, thus no samples were collected. The samples were analyzed for hydrogen-3 and the results are shown in Table 3.1. The same concentration pattern in the water flowing around Plot M was observed this year as in the past. Concentrations were below the detection limit upstream of Plot M (Location 1); hydrogen-3 was the highest near the seep at (Location 6); and lower concentrations were found downstream of Plot M (Locations 7 & 8). The amounts of hydrogen-3 found in 2013 were consistent with results from previous years. Hydrogen-3 concentrations have been found to vary from year to year, depending in part on the amount of precipitation prior to sample collection. Despite seasonal variations, in general the hydrogen-3 concentrations in surface water have exhibited a steady decline since the 1990s.

Samples were collected quarterly from five surface water bodies in the vicinity of Site A. They are the pond northwest of Site A; the pond southeast of Site A; Horse Collar Slough; Tomahawk Slough; and Bull Frog Lake. These locations are identified in Figure 2.2. The samples were analyzed for hydrogen-3 and the results are presented in Table 3.2. All of the hydrogen-3 results were below the detection limit of 0.1 nCi/L.

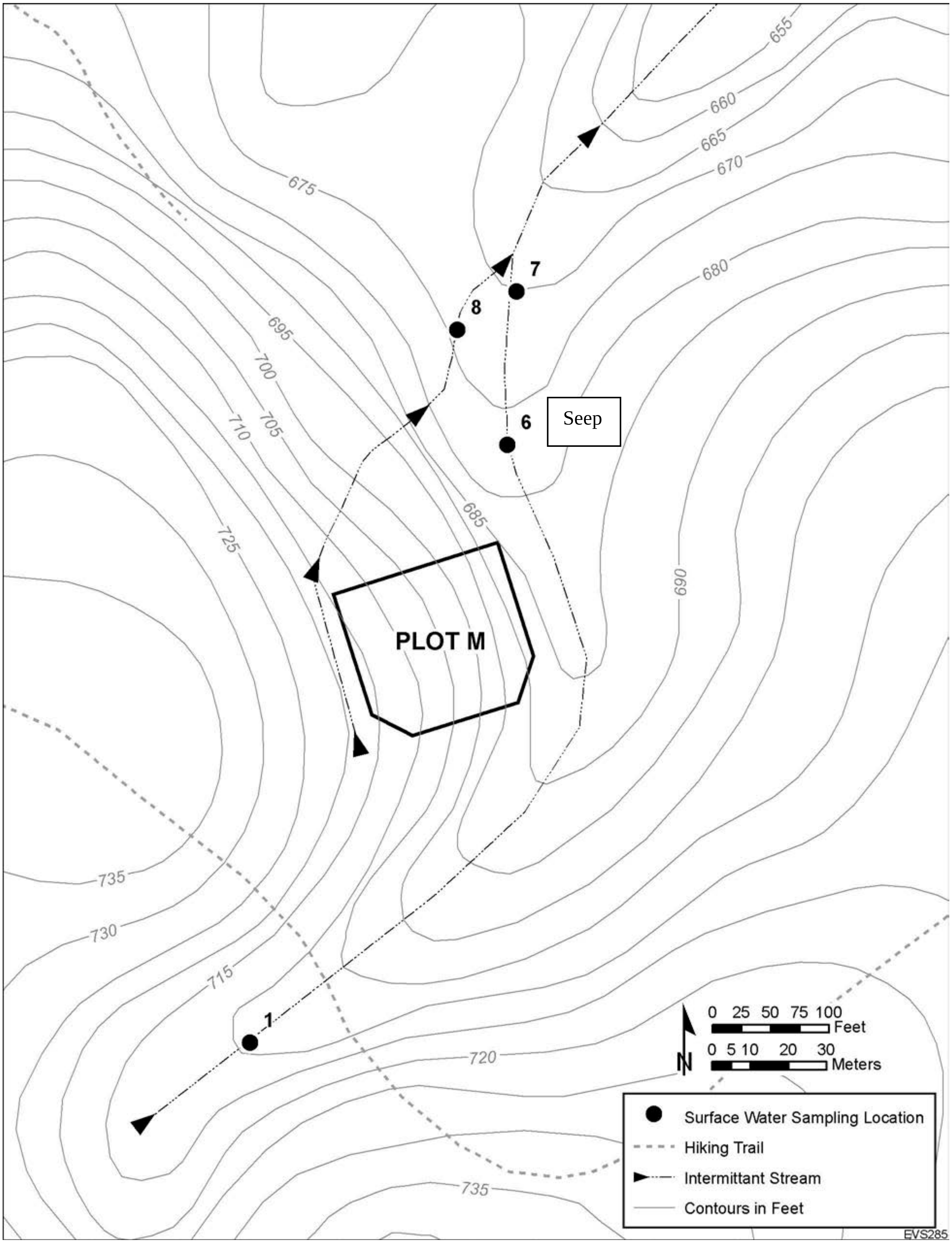

Figure 3.1 Stream Sampling Locations near Plot M

Table 3.1

Hydrogen-3 Content of Stream Next to Plot M, 2013
(Concentrations in nCi/L)

Location Number[1]	Date Collected			
	January 30	June 4	3rd Quarter	November 1
1	< 0.1	< 0.1	DRY	< 0.1
6 (Seep)	4.2	80.4	DRY	17.6
7	2.7	16.0	DRY	3.7
8	0.2	7.6	DRY	0.5

[1] See Figure 3.1

Table 3.2

Hydrogen-3 Content of Site A Area Ponds, 2013
(Concentrations in nCi/L)

Location[1]	Date Collected			
	January 30	June 4	September 4	October 22
NW Site A	< 0.1	< 0.1	< 0.1	< 0.1
SE Site A	< 0.1	< 0.1	< 0.1	< 0.1
Bull Frog Lake	< 0.1	< 0.1	< 0.1	< 0.1
Horsecollar Slough	< 0.1	< 0.1	< 0.1	< 0.1
Tomahawk Slough	< 0.1	< 0.1	< 0.1	< 0.1

[1] See Figure 2.2

3.4 Subsurface Water

3.4.1 Monitoring Wells - Plot M

Nine monitoring well screens within the glacial drift are present in and around Plot M (Figure 3.2). Two of these wells (BH09 and BH10) were drilled at a 45° angle to intercept groundwater under the waste. Water samples were collected and water level measurements were made in these nine wells quarterly. The slant well BH09 was dry the first, third, and fourth quarters.

All the water samples were analyzed for hydrogen-3 and the results are shown in Table 3.3; duplicate quality control sample results are shown in parentheses. The hydrogen-3 concentrations varied widely from well to well and in some cases from quarter to quarter. With the exception of several wells, the magnitudes of the hydrogen-3 concentrations are similar to those observed over the past several years. Most of the results indicate that hydrogen-3 concentrations are slowly decreasing in these wells.

During the fourth quarter, well BH02 had a hydrogen-3 concentration of 451 nCi/L. The first quarter the result was only 3.6 nCi/L. During the fourth quarter of 2012 hydrogen-3 was found to be 822 compared to a first quarter result of 9.1 nCi/L. These fourth quarter results were much higher than most of the results for samples collected since 1992. Figure 3.3 shows hydrogen-3 concentrations in this well since 1990. This figure also contains groundwater elevations in this well. Figure 3.3 shows that spikes in hydrogen-3 concentration have occurred in this well during 2003, 2005, 2012 and 2013. Most of the spikes in hydrogen-3 occurred at times when groundwater elevation was lower than normal. Lower groundwater elevations could change the direction that groundwater moves under Plot M, causing the tritium plume to pass near BH02 during dry periods.

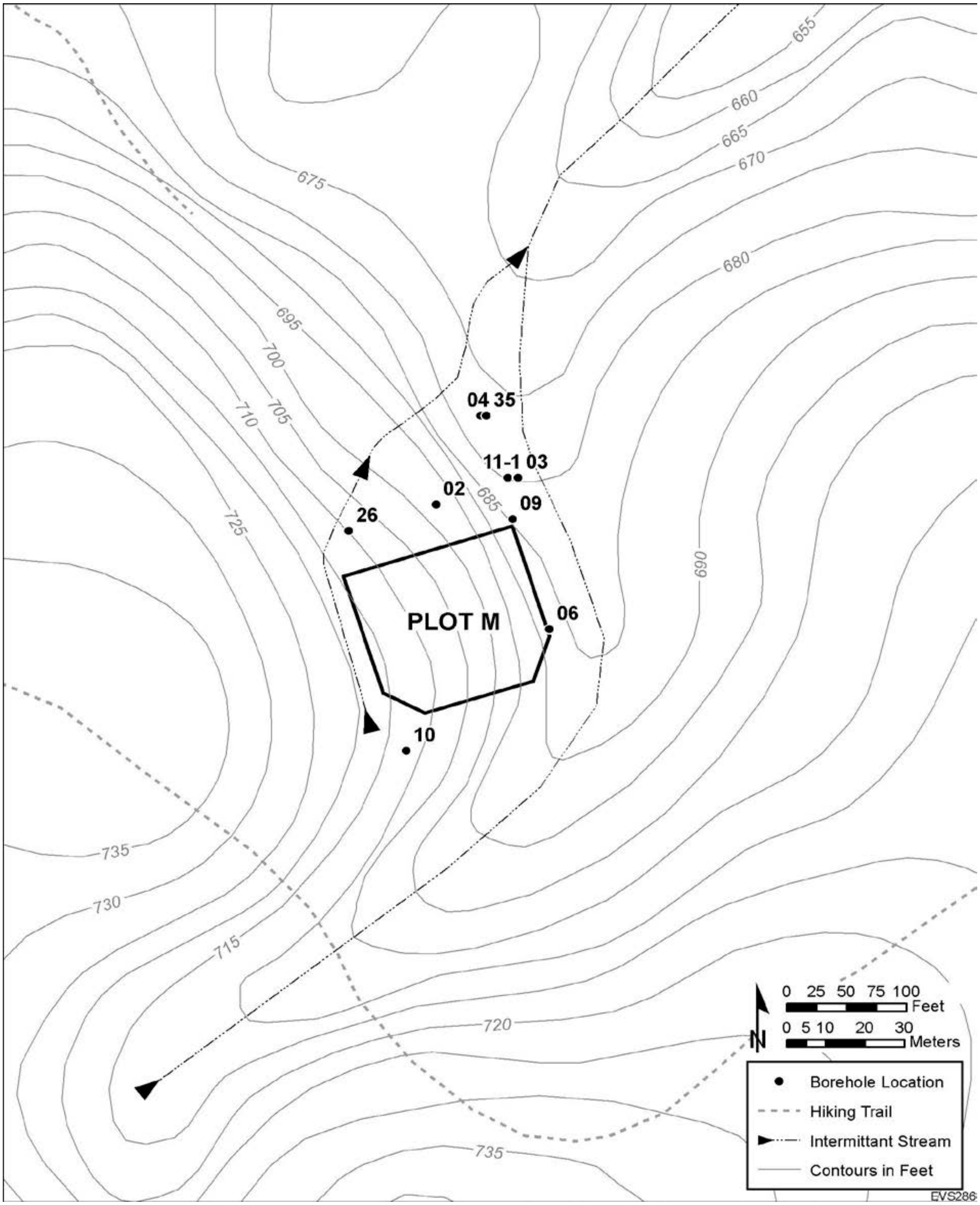

Figure 3.2 Map of Plot M Palos Site Showing Topography, Intermittent Stream, and Monitoring Well Locations

Table 3.3

Hydrogen-3 Content of Plot M Monitoring Well Water, 2013
(Concentrations in nCi/L)

Borehole Number	Depth (ft)	Date Collected			
		March 20	June 4	September 4	November 22
02	39.41	3.6	4.1	137	451
03	40.00	314 (327)[1]	278	279	306
04	36.05	360	377	361	368
06	40.30	116	133	748 (745)	638
09	40.00[2]	DRY	513	DRY	DRY
10	40.00[2]	173	36	199	329
11	39.30	98	110	95	101 (101)
26	60.65	41	59	170	189
35	105.50	577	581	585	604

[1] Duplicate QC sample results are denoted by parentheses.

[2] Slant hole drilled at 45º to a depth of 40 ft below the surface.

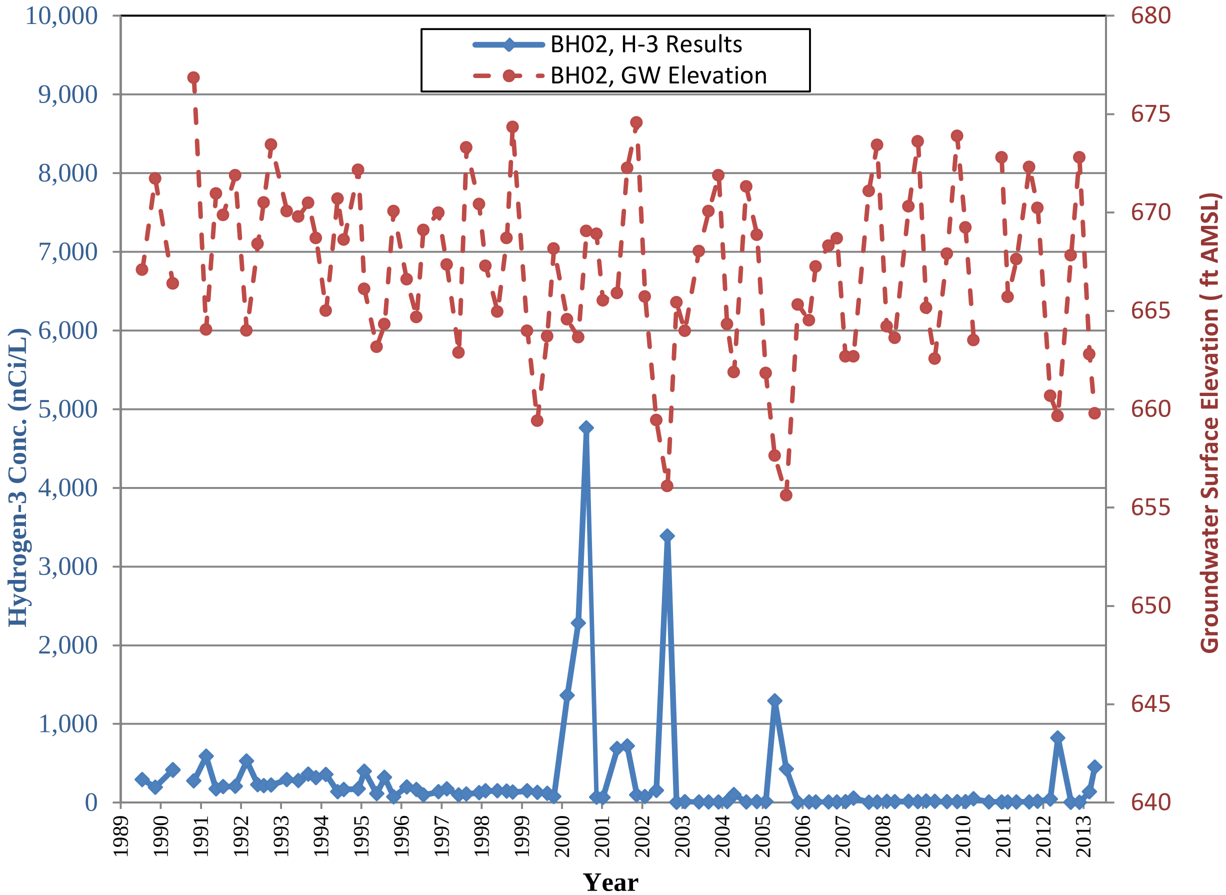

Figure 3.3 Hydrogen-3 and Groundwater Elevation in Well BH02

Well BH06 contained unusually high hydrogen-3 concentrations the third and fourth quarters. From 1998 through the first half of 2009 the hydrogen-3 concentrations ranged from 50 to 150 nCi/L. Starting in 2009, hydrogen 3 concentrations have increased, reaching 1534 nCi/L in 2011, 488 nCi/L in 2012, and 748 in 2013 nCi/L. The trend in hydrogen-3 concentrations in BH06 is shown in Figure 3.5, which also shows groundwater elevations in this well. Since 2010 groundwater elevations have fluctuated more than during the period between 1993 and 2010. The changing groundwater elevations could be responsible for the recent increase in hydrogen-3 concentrations.

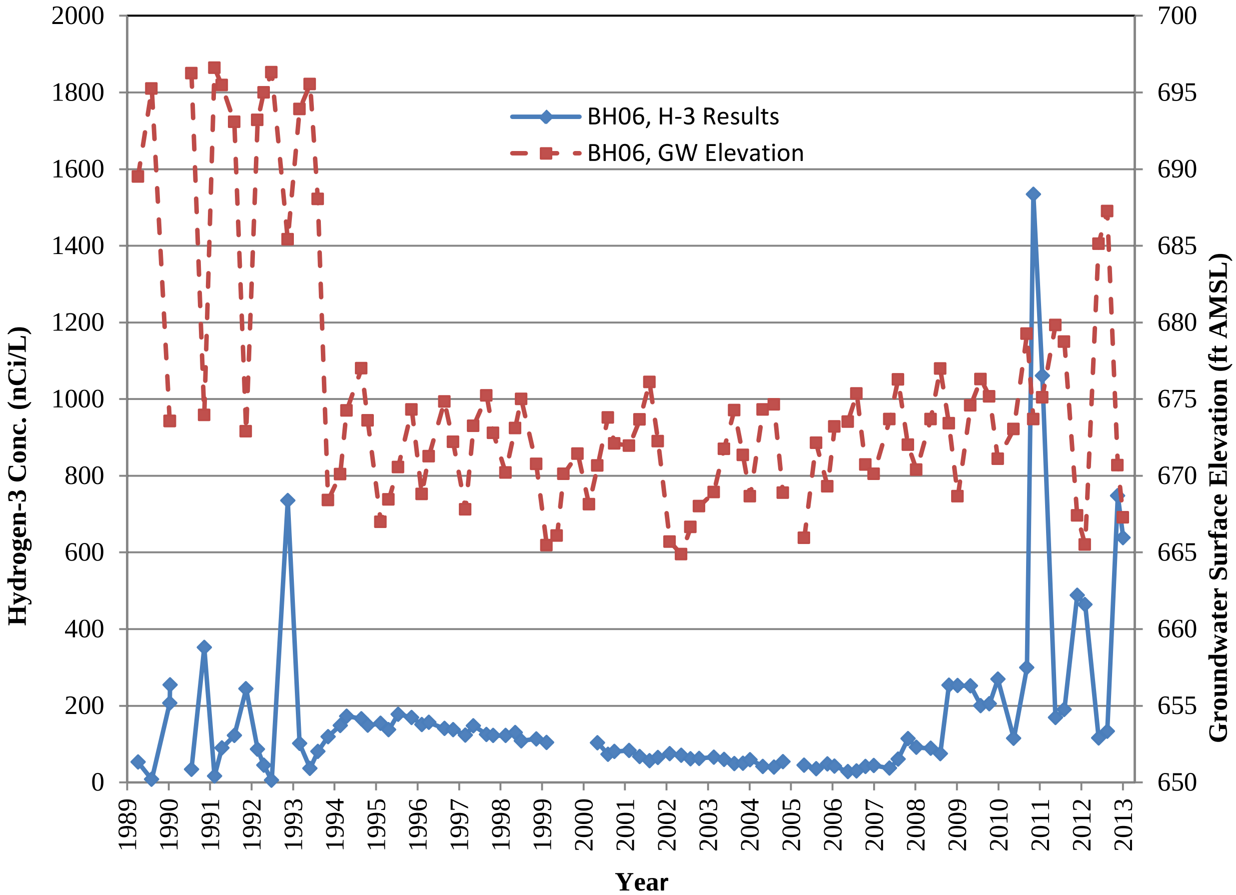

Figure 3.4 Hydrogen-3 and Groundwater Elevation in Well BH06

Well BH35 hydrogen-3 concentrations measured in the last few years, shown in Figure 3.4, appear to be increasing compared to the low hydrogen-3 concentrations found in 2003; however, the concentrations measured in 2013 were similar to concentrations recorded prior to 2000.

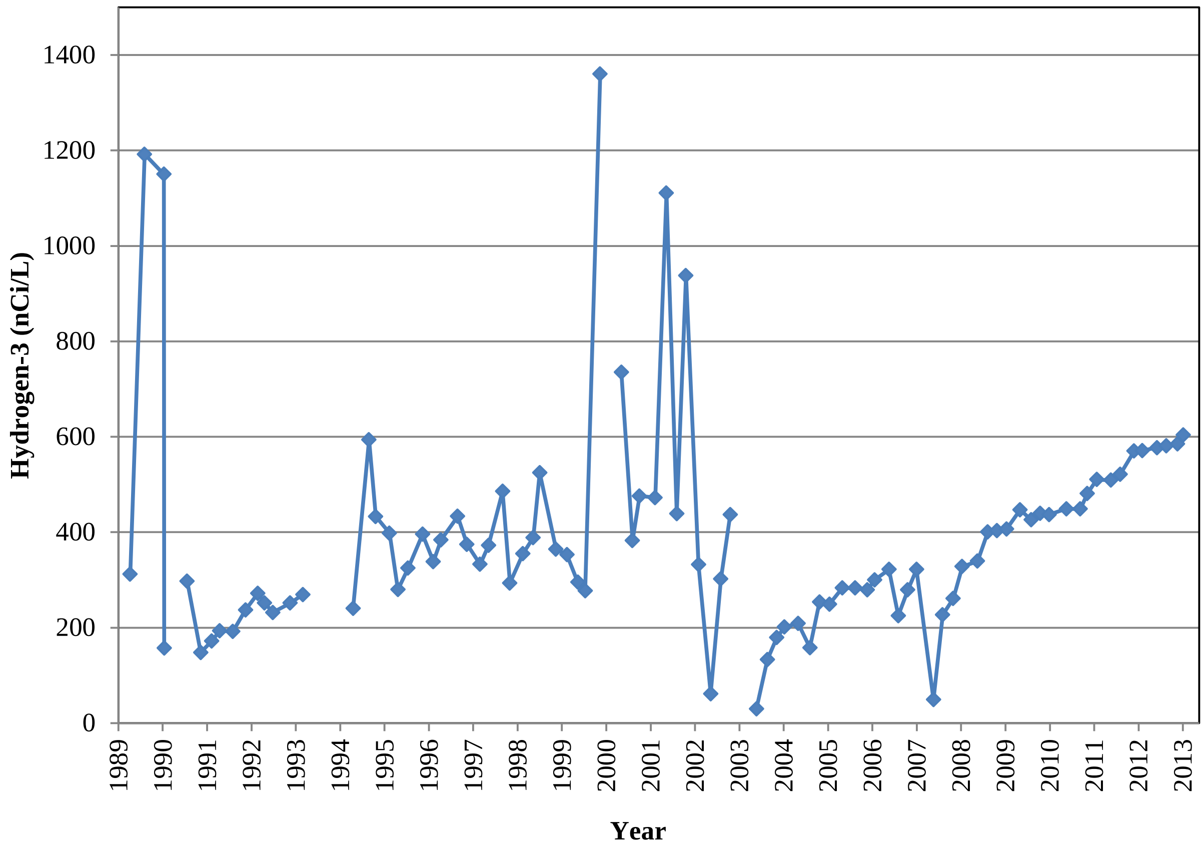

Figure 3.5 Hydrogen-3 in Well BH35

Boreholes BH03 and BH04, which historically contained some of the highest hydrogen-3 concentrations, continued to show a steady decline during 2013. BH09, which is a slant well screened directly beneath the waste trenches, has often contained high and highly variable hydrogen-3 concentrations. The concentration from the one sample collected in 2013 was consistent with prior years and shows a slowly decreasing concentration.

Groundwater elevations in most of the shallow wells in 2013 recovered from the 2012 drought but decreased during the third and fourth quarter due to hot dry weather late in the year. The water levels in BH35, the 105 ft. deep drift well, remained relatively constant throughout the year. The depth to groundwater and groundwater elevations in the vertical wells are shown in Table 3.4. Groundwater elevations for the two slant wells are not included in this table since the angle of the well distorts the depth to water values. Due to the difference in depth of some of the wells, the elevation data could not be used to develop groundwater elevation contour maps of this area. The groundwater elevation difference between nearby wells indicates that a hydraulic connection between the wells cannot be assumed. In general, however, it appears that groundwater is moving to the northeast, toward the DesPlaines River.

Groundwater from the monitoring wells was analyzed twice for strontium-90. Samples were collected from all wells that yielded sufficient water for analysis. Well BH09 was dry during the fourth quarter, thus no sample was collected. The results are shown in Table 3.5. Strontium-90 concentrations greater than the detection limit of 0.25 pCi/L were found in six of the nine sampled wells. The highest strontium-90 concentration in 2013 was 6.44 pCi/L in water from BH09. As in the past, BH06, which is between the buried waste and the stream that flows around Plot M, showed measurable strontium-90 concentrations. The amount of strontium-90 found in these wells is greater than what would be expected from past radioactive fallout, the only known source of strontium-90 other than a release from Plot M. The data suggest that small but measurable amounts of strontium-90 have migrated from the waste into the surrounding glacial drift. However, all results were less than the State of Illinois Class 1 Ground Water Quality Standard value of 8 pCi/L.

Table 3.4

Water Level Measurements in Monitoring Wells Near Plot M, 2013

			Date Measured							
			March 20		June 4		September 4		October 22	
Well Number[1]	Depth (ft.)	Top of Casing Elevation (ft AMSL)[2]	Depth to water	Water Surface Elevation	Depth to water	Water Surface Elevation	Depth to water	Water Surface Elevation	Depth to water	Water Surface Elevation
2	39.41	692.70	24.89	667.81	19.90	672.80	29.92	662.78	32.93	659.77
3	40	693.30	38.71	654.59	37.44	655.86	35.31	657.99	38.53	654.77
4	36.05	682.20	21.49	660.71	14.49	667.71	22.11	660.09	25.26	656.94
6	40.3	704.90	19.78	685.12	17.65	687.25	34.23	670.67	37.63	667.27
11	39.3	693.00	21.47	671.53	15.52	677.48	29.63	663.37	32.58	660.42
26	60.65	692.30	53.02	639.28	49.51	642.79	49.78	642.52	51.10	641.20
35	105.5	682.40	94.50	587.90	94.03	588.37	94.22	588.18	94.18	588.22

[1] Water depth for wells 09 and 10 are not shown since these are slant wells

[2] From 1994 IT Study report

Table 3.5

Strontium-90 Content of Monitoring Well Water Samples Near Plot M, 2013
(Concentrations in pCi/L)

Well Number[1]	Depth (ft.)	June 4	November 22
02	39.41	<0.25	0.31 ± 0.04
03	40.00	< 0.25	< 0.25
04	36.05	< 0.25	< 0.25
06	40.30	1.67 ± 0.14	1.38 ± 0.12
09	40.00[2]	6.44 ± 0.51	DRY[4]
10	40.00[2]	0.25 ± 0.03 (<0.25)[3]	0.27 ± 0.03
11	39.30	1.87 ± 0.15 (1.67 ± 0.14)	1.75 ± 0.14
26	60.65	0.32 ± 0.04 (0.29 ± 0.03)	<0.25
35	105.50	<0.25 (<0.25)	<0.25

[1] See Figure 3.2

[2] Wells 09 and 10 are slant wells

[3] Duplicate QC sample results are denoted by parentheses

[4] During the fourth quarter well BH09 was dry so no samples were collected.

3.4.2 Monitoring Wells – Site A

Hydrogen-3 results for the six Site A monitoring wells sampled are shown in Table 3.6. The results of duplicate QC samples are shown in parentheses. The hydrogen-3 concentrations were low, most near or below the detection limits, and consistent with previous results. The hydrogen-3 concentrations at Site A are several orders of magnitude lower than Plot M and are decreasing. The highest results were in wells BH55 and BH56, most likely originating in the buried CP-3 biological shield. The results of the strontium-90 analyses are shown in Table 3.7. BH55 did not have sufficient water for the first strontium-90 sample. Only BH55 and BH56 had measurable hydrogen-3 and strontium-90 levels throughout the year.

Water levels were also measured in these monitoring wells and these measurements appear in Table 3.8. The same seasonal variation of groundwater elevation that was seen at Plot M can be seen in several of the wells in this area as well. The groundwater elevation in several other Site A wells has been very stable for the last several years.

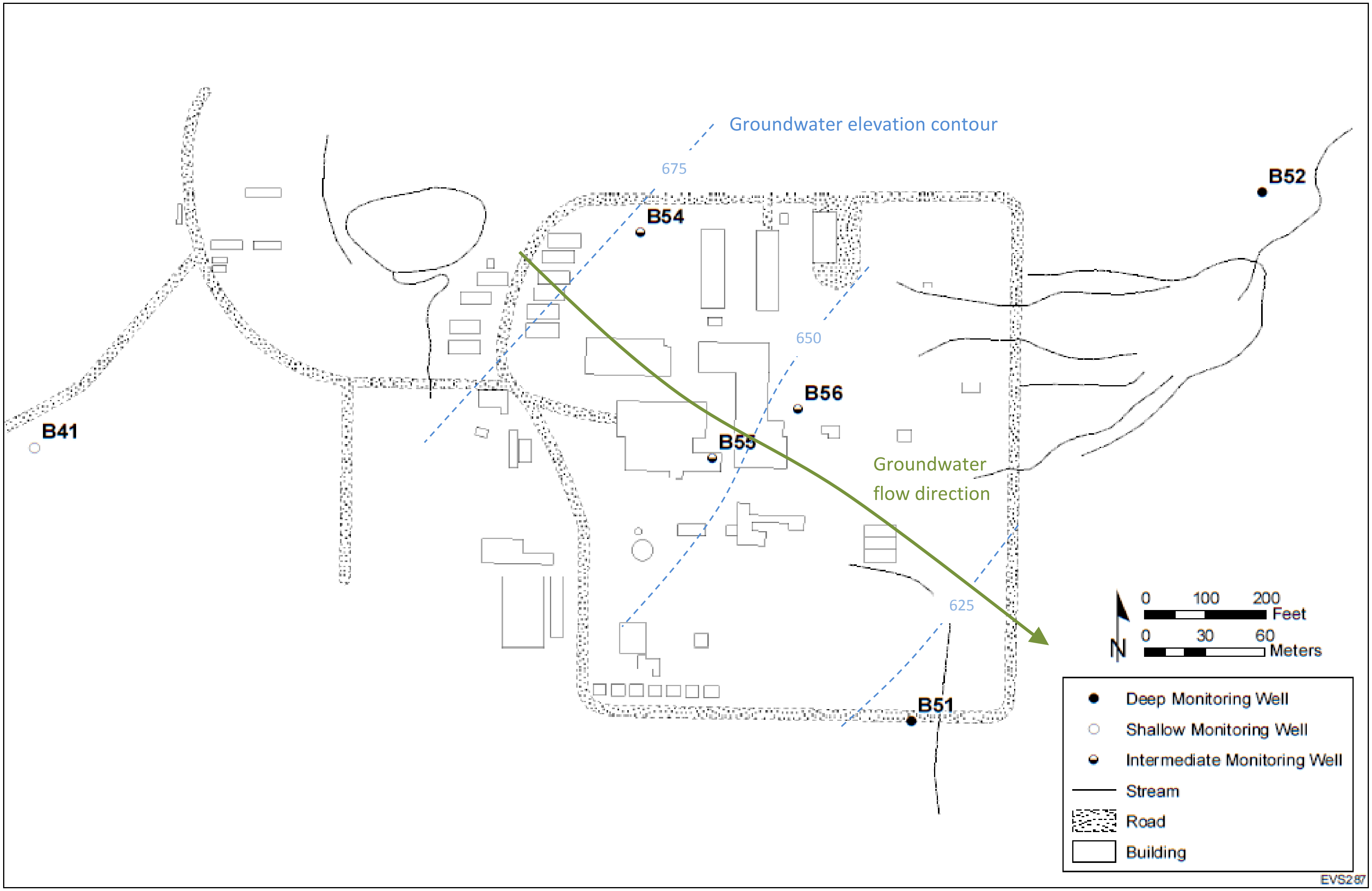

Figure 3.6 Monitoring Wells at Site A

Table 3.6

Hydrogen-3 Content of Monitoring Well Water Samples Near Site A, 2013
(Concentrations in nCi/L)

Well Number	Depth (ft.)	Date Collected			
		March 28	June 5	September 4	November 1
B41	25.83	0.11 (< 0.1)[1]	< 0.1	0.11	0.19
B51	116.40	< 0.1	< 0.1 (< 0.1)	< 0.1	< 0.1
B52	165.00	< 0.1	< 0.1	< 0.1	< 0.1
B54	63.40	0.13	< 0.1	< 0.1	< 0.1
B55	87.20	1.7	1.8	1.7	1.8
B56	102.40	2.1	1.9	1.8	1.6

Table 3.7

Strontium-90 Content of Monitoring Well Water Samples Near Site A, 2013
(Concentrations in pCi/L)

Borehole Number	Depth (ft.)	Date Collected	
		March 28	September 4
B41	25.83	< 0.25 (<0.25)	< 0.25
B51	116.40	< 0.25	< 0.25
B52	165.00	< 0.25	< 0.25
B54	63.40	< 0.25 (<0.25)	< 0.25
B55	87.20	Insufficient water	1.62 ± 0.13
B56	102.40	1.70 ± 0.14	1.76 ± 0.14

Table 3.8

Water Level Measurements in Monitoring Wells Near Site A, 2013

Well Number	Depth to Bottom (ft.)	Top of Casing Elevation (ft AMSL)[1]	Date Measured							
			March 28		June 5		September 4		November 1	
			Depth to water	Water Surface Elevation	Depth to water	Water Surface Elevation	Depth to water	Water Surface Elevation	Depth to water	Water Surface Elevation
B41	25.83	737.38	13.09	724.29	1.98	735.40	12.77	724.61	15.63	721.75
B51	116.4	715.93	101.50	614.43	100.95	614.98	101.26	614.67	100.73	615.20
B52	165	713.43	132.21	581.22	130.51	582.92	132.41	581.02	132.55	580.88
B54	63.4	732.03	57.70	674.33	56.69	675.34	56.76	675.27	57.17	674.86
B55	87.2	743.78	86.80	656.98	70.81	672.97	82.71	661.07	84.02	659.76
B56	102.4	742.23	88.50	653.73	88.91	653.32	87.80	654.43	87.65	654.58

[1] From 1996 Advanced Surveying and Mapping topo map

Figure 3.6 also contains the groundwater elevation contour lines and the groundwater flow direction as determined by the average of four groundwater elevation measurements from the four centrally-located wells. The contours indicate a steep hydraulic gradient to the southeast, toward Saganashkee Slough.

3.4.3 Dolomite Well Water

Ten wells cased into the dolomite bedrock are sampled to monitor the movement of hydrogen-3 in this aquifer. Most of the dolomite wells are located north of Plot M and east of the Red Gate Woods North Well (#5160), as shown in Figure 3.7.

Samples were collected from the dolomite wells quarterly. All samples were analyzed for hydrogen-3 and the results are shown in Table 3.9. All of the dolomite wells had low but measurable hydrogen-3 concentrations and all of the results are consistent with concentrations measured in the past. The well with the consistently highest hydrogen-3 results is DH15. Figure 3.8 shows the hydrogen-3 concentrations in DH15 since 1990. The hydrogen-3 results have been essentially stable in this well since 1997; however, some of the 2013 results were the highest recorded since 1996. All of the dolomite wells were well below the Class 1 Groundwater Quality Standard of 20 nCi/L.

The presence of hydrogen-3 in these wells is explained by the 1988 USGS investigation[36] that indicated a hydrogen-3 plume underlies the stream which flows from Plot M and passes to the northeast of these wells (see Section 3.2). The plume has spread downward as well as downgradient, resulting in small amounts of hydrogen-3 in the dolomite.

Other dolomite wells with elevated hydrogen-3 are DH03 and DH04, which are closer to and downgradient of Plot M. The third and fourth quarter hydrogen-3 results for DH04 were 6.4 and 4.1 nCi/L respectively, higher than previous results. Previous analyses of soil core samples[36] indicated the presence of hydrogen-3 down to the drift-dolomite interface in the vicinity of these wells.

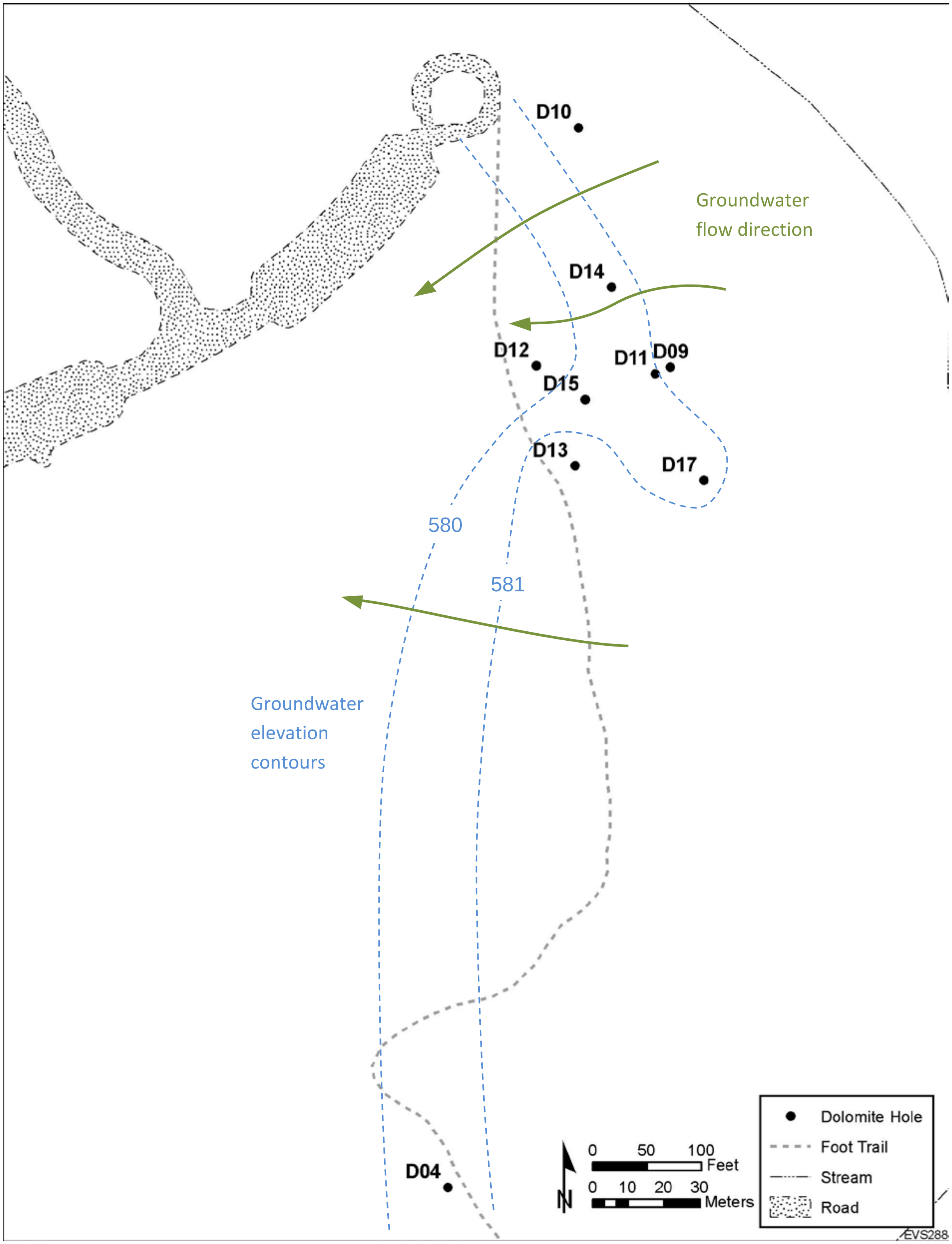

Figure 3.7 Locations of Dolomite Wells North of Plot M

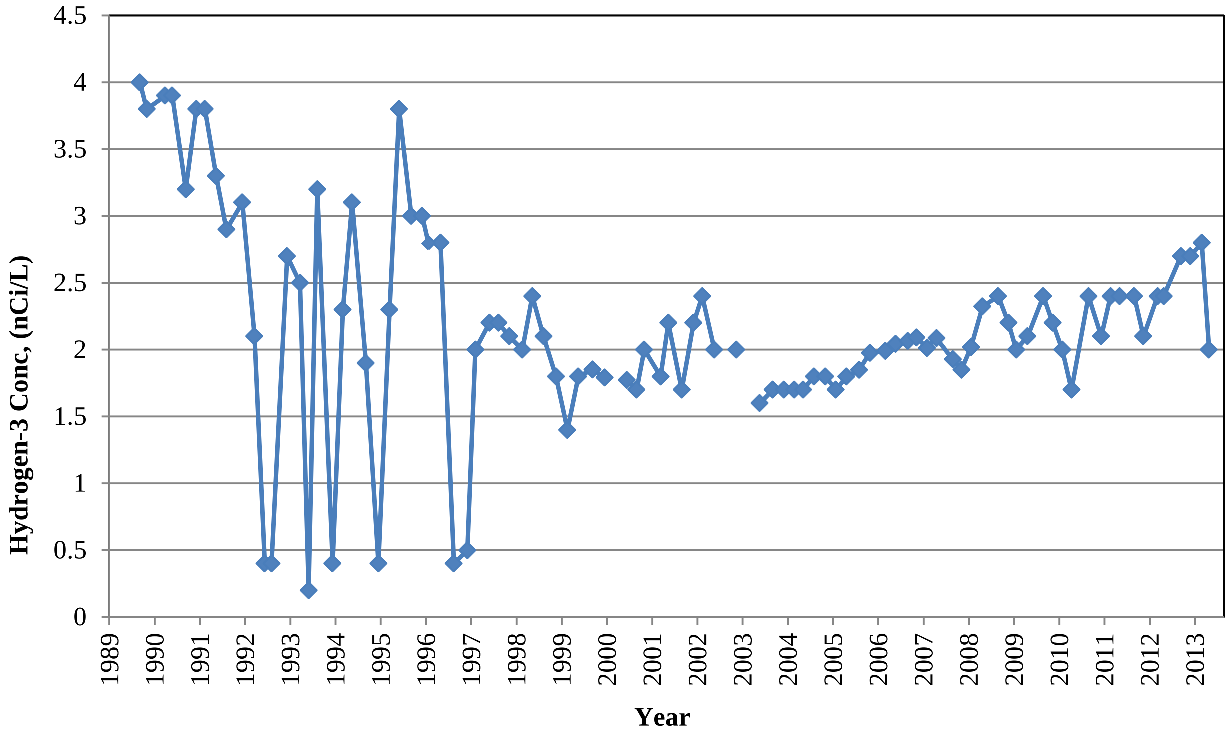

Figure 3.8 Hydrogen-3 Concentrations in Dolomite Well DH15

Table 3.9

Hydrogen-3 Content of Dolomite Well Water, 2013
(Concentrations in nCi/L)

Dolomite Well Number	Date Collected			
	March 20	June 4	September 4	November 1
D03	0.92	0.90	0.69	1.7
D04	0.95	0.85	6.4	4.1
D09	0.41	0.47	0.45	0.51
D10	0.68	0.71	0.61	0.57
D11	0.80	0.87	0.87	0.57
D12	1.0	0.97	0.98	0.44
D13	1.0	1.0	0.98	0.27
D14	0.73	0.76	0.76	0.75
D15	2.7	2.7	2.8	2.0
D17	0.25	0.29	0.13	0.14

Water levels were also measured in the dolomite wells and these measurements are in Table 3.10. Since these wells are completed in the dolomite aquifer, which is much deeper and not affected as much by weather, the groundwater elevations showed a seasonal variation of lower magnitude than what was observed in the shallow glacial till wells. The groundwater elevations in these wells were consistent with historical measurements in the wells and support the conclusion in the 1994 IT report[37] that groundwater in this area is moving towards the Des Plaines River Valley. Groundwater elevation contour lines and the groundwater flow direction are shown in Figure 3.7.

3.2.4 Former Picnic Wells

Sampling was conducted quarterly at two disabled forest preserve picnic wells (#5160 and #5159) located north of Plot M as shown in Figure 2.2. The Red Gate Woods North Well (#5160) was disabled in 1999 by removing the pump handle because of high fecal coliform levels. The well opposite Red Gate Woods (#5159) is in an undeveloped part of the park and is unusable as a water source since the pump handle has also been removed. All the samples were analyzed for hydrogen-3 and the results are listed in Table 3.11. The maximum and average hydrogen-3 concentrations since 1996 for wells #5160 and #5159 are presented in Table 3.12. The change in hydrogen-3 concentrations in these wells since 1992 is shown in Figure 3.9.

The hydrogen-3 concentrations in well #5160 found during 2013 were similar to the concentrations observed during the third and fourth quarter of 2012. These six results represent the highest hydrogen-3 concentrations in this well since 1996. For unknown reasons, the hydrogen-3 levels in this well have been increasing since 2010 after experiencing a significant decrease in 2008. The 2013 samples collected during the first two quarters from well #5159 contained concentrations of hydrogen-3 somewhat higher than observed in recent years, though occasional spikes of much higher concentration have been seen. The samples collected from this well during the third and fourth quarters were both less than the detection limit. In any case, the concentrations of hydrogen-3 in these picnic wells are all well below the Primary Drinking Water Standard of 20 nCi/L[38].

Table 3.10

Water Level Measurements in Dolomite Wells, 2013

Well Number	Ground Surface Elevation	Top of Casing Elevation (ft AMSL)[1]	Date Measured: March 20		June 4		September 4		November 1	
			Depth to water	Water Surface Elevation	Depth to water	Water Surface Elevation	Depth to water	Water Surface Elevation	Depth to water	Water Surface Elevation
D03	678.10	679.50	95.50	584.00	97.30	582.20	99.09	580.41	99.30	580.20
D04	673.80	674.60	93.80	580.80	92.60	582.00	94.39	580.21	94.69	579.91
D09	655.61	656.30	73.00	583.30	72.65	583.65	72.72	583.58	72.81	583.49
D10	644.66	646.10	65.23	580.87	63.02	583.08	64.93	581.17	65.09	581.01
D11	655.36	656.90	76.44	580.46	75.18	581.72	86.33	570.57	77.17	579.73
D12	650.34	651.60	77.51	574.09	76.16	575.44	78.13	573.47	78.28	573.32
D13	658.10	659.20	77.48	581.72	76.92	582.28	78.73	580.47	78.91	580.29
D14	651.43	653.20	72.51	580.69	71.30	581.90	73.10	580.10	73.28	579.92
D15	659.14	660.80	80.08	580.72	78.90	581.90	80.74	580.06	80.87	579.93
D17	654.35	656.00	75.38	580.62	74.07	581.93	76.09	579.91	76.15	579.85

[1] From 1994 IT Study report

Table 3.11

Hydrogen-3 Content of Former Picnic Wells Near Site A/Plot M, 2013
(Concentrations in nCi/L)

Date Collected	Red Gate North 5160	Opposite Red Gate 5159
March 28	1.99	0.52
June 4	2.24	0.75
September 4	2.11	< 0.1
October 22	2.24	< 0.1
Average	2.14	0.35[1]

[1] The average hydrogen-3 result was calculated using the reported result of 0.06 nCi/L for the September and October samples

Table 3.12

Annual Maximum and Average Hydrogen-3 Concentrations in the Red Gate Woods Wells
(Concentrations in nCi/L)

Year	Red Gate Woods North (#5160)		Opposite Red Gate Woods (#5159)	
	Maximum	Annual Average	Maximum	Annual Average
1996	2.19	1.56	0.55	0.33
1997	1.26	1.00	1.13	0.35
1998	1.23	1.03	0.72	0.47
1999	1.22	1.07	2.14	0.45
2000	1.54	1.33	2.20	0.70
2001	1.59	1.49	0.27	0.16
2002	1.47	1.04	3.17	0.45
2003	1.78	1.06	1.49	0.43
2004	1.08	1.00	0.34	0.17
2005	1.01	0.95	0.34	0.19
2006	1.14	1.06	2.63	1.11
2007	1.45	1.28	0.66	0.33
2008	1.24	0.33	0.32	0.26
2009	0.13	0.10	0.50	0.33
2010	0.28	0.19	0.51	0.34
2011	0.91	0.67	3.60	1.10
2012	2.10	1.60	0.74	0.34
2013	2.24	2.14	0.75	0.35

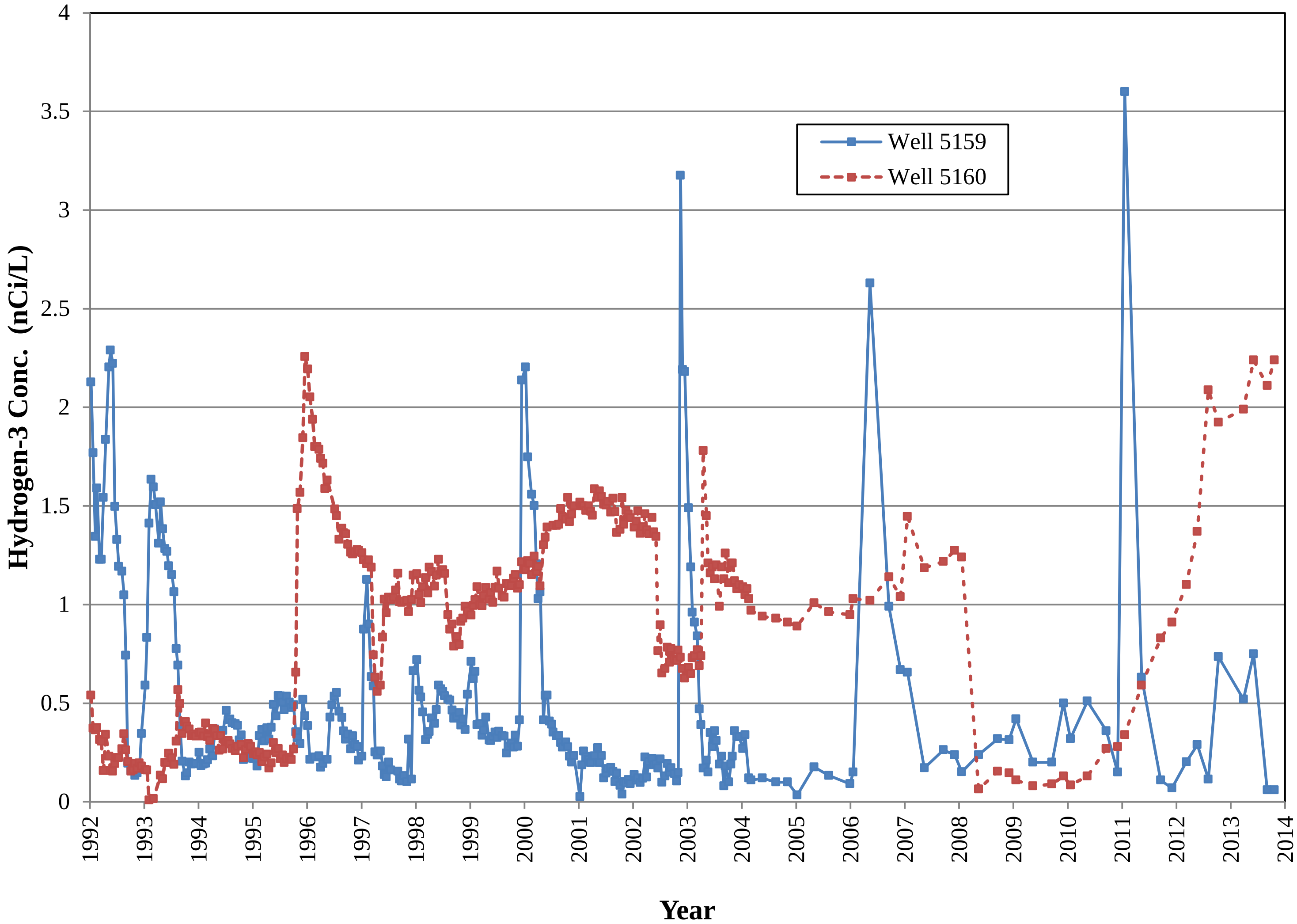

Figure 3.9 Hydrogen-3 Concentrations in Opposite Red Gate Woods (#5159) and Red Gate Woods North (#5160) Wells from 1992 Through 2013

4.0 SUMMARY OF POTENTIAL RADIATION DOSE AND RISK ESTIMATES

4.1 Dose Estimates

Since there is no consumption of water from surface water or wells, the radioactive material present does not represent an actual health risk to the public. However, to evaluate the risk from residual contamination if this water were to be consumed, the potential radiation dose to a hypothetical individual was estimated employing methodology prescribed in DOE guidance.[39] The committed effective dose equivalent from consumption of water was estimating by first calculating the total quantity of hydrogen-3 potentially ingested. Taking a very conservative approach, it was assumed the hypothetical individual drank only water containing hydrogen-3 at the levels found at the Plot M seep. The concentration of hydrogen-3 was multiplied by the general public water ingestion rate of 730 L/y.[40] This annual intake was then multiplied by the 50-year Committed Effective Dose Equivalent (CEDE) factor.[41] The CEDE for hydrogen-3 in water is 7.2 x 10^{-5} rem/µCi (based on the derived concentration standard of 1.9 x 10^{-3} µCi/mL). The highly conservative worst case scenario assumes that the hypothetical individual used water with the maximum hydrogen-3 concentration found near the seep (Location #6). The annual dose based on the maximum 2013 concentration of 80.4 nCi/L would be 4.2 mrem/y. A slightly less conservative estimate of dose based on the annual average seep concentration of 34 nCi/L (based on the three samples collected in 2013) would be 1.8 mrem/y. Similar dose calculations were made assuming the water in former Red Gate Woods North Well (#5160) was the sole source of water consumed. In this case the maximum dose would be 2.2 mrem/y and the average dose would be 0.11 mrem/y. For the Opposite Red Gate Woods Well (#5159) the maximum dose would be 0.039 mrem and the average dose would be 0.018 mrem/y. These estimated doses are shown in Table 4.1. The DOE dose limit for the public is 100 mrem/y, so even under highly conservative scenarios, the potential dose is well below DOE limits.

A more realistic estimation was made based on the scenario of an occasional visitor to the Plot M area. Assuming a visitor drinks one liter of water from the surface stream and one of the picnic wells, the doses from this potential exposure were estimated and presented in Table 4.2. As defined here, the maximum potential total dose received by an occasional visitor is the sum of doses from drinking seep water plus dose from drinking water from the former Red Gate Woods North Well (#5160). This maximum dose would be 0.00595 mrem per visit and 0.00261 mrem/y for the average dose. In order to put the doses into perspective with other types of radiation exposure, comparisons can be made to annual average doses received by the public from natural or other generally accepted sources of radiation.[42] These are listed in Table 4.3. It is obvious that the magnitude of the doses potentially received near Plot M from residual radioactive substances are insignificant compared to these common sources.

4.2 Risk Estimates

The potential for possible negative health effects from radiation doses from Plot M were also estimated to provide another perspective on interpreting the effects of radiation. Estimates for carcinogenic risk, the risk of contracting cancer from these exposures, are included in Table 4.1 and Table 4.2. Based on the BIER V report,[43] a dose of one mrem/y equates to an increased cancer risk of 7×10^{-7}. This conversion ratio is used to estimate incremental risk of contracting cancer from radiation exposure. For example, a carcinogenic risk of 10^{-7} would mean on average one additional cancer to 10,000,000 people exposed under the assumed exposure conditions. The EPA environmental protection standards are generally based on an acceptable risk between 10^{-4} and 10^{-6}. Examination of Table 4.1 indicates that even under the very conservative assumptions of sole source use of the water containing hydrogen-3 at Plot M at the annual average concentrations, the risk is less than the EPA standards. Table 4.2 shows that the hypothetical average dose to an occasional visitor of 0.00261 mrem/y would result in an increased cancer risk of about 1.8×10^{-9}. The incremental risk from exposure to radionuclides at Plot M can be compared to the risk associated with various life events. A few examples are shown in Table 4.4. The risk from the naturally-occurring sources of radioactivity listed in Table 4.3 is estimated to be about one additional cancer in a population of 8,000. Since the incremental risk from residual contamination at Site A/Plot M under even the most conservative assumptions is so low, the monitoring program results have established that the impact of radioactivity at Site A/Plot M is very low and it does not endanger the health of those living in the area or visiting the site.

TABLE 4.1

Dose from Continuous Exposure to Hydrogen-3 at Selected Locations, 2013

Assumed Source	Maximum Conc. (nCi/L)	Maximum Dose[1] (mrem/y)	Annual Average Conc. (nCi/L)	Annual Average Dose[1] (mrem/y)	Maximum Carcinogenic Risk
Surface Water					
Plot M Seep	80	4.2	34	1.8	3.0×10^{-6}
Well Water					
Red Gate Woods North (#5160)	2.2	0.12	2.1	0.112	8.2×10^{-8}
Opposite Red Gate Woods (#5159)	0.75	0.039	0.35	0.018	2.8×10^{-8}

[1] DOE Dose limit is 100 mrem/year

TABLE 4.2

Estimates of Hydrogen-3 Exposures to a Casual Visitor to Plot M, 2013

Pathway	Maximum Dose [1] (mrem/visit)	Annual Average Dose [1] (mrem/visit)	Average Carcinogenic Risk
Surface Water			
Plot M Seep	0.0058	0.0025	1.7×10^{-9}
Well Water			
Red Gate Woods North (#5160)	0.00016	0.00015	1.1×10^{-10}
Total	0.00595	0.00261	1.8×10^{-9}

[1] DOE Dose limit is 100 mrem/year

TABLE 4.3

Annual Average Dose Equivalent in the U. S. Population[1]

Source	Dose (mrem)
Natural Sources	
Radon	228
Internal (^{40}K and ^{226}Ra)	29
Cosmic	33
Terrestrial	21
Medical	
Computed Topography	147
Nuclear Medicine	77
Interventional Fluoroscopy	43
Conventional Radiography & Fluoroscopy	33
Consumer	13
Building Materials	
Commercial Air Travel	
Cigarette Smoking	
Mining and Agricultural	
Combustion of Fossil Fuels	
Highway and Road Construction Materials	
Glass and Ceramics	
Industrial	0.3
Nuclear-power Generation	
DOE Installations	
Decommissioning and Radioactive Waste	
Industrial, Medical, Educational, and Research Activities	
Contact with Nuclear-medicine Patients	
Security Inspection Systems	
Occupational	0.5
Medical	
Aviation	
Commercial Nuclear Power	
Industrial and Commercial	
Education and Research	
Government, DOE, and Military	
Total	**624**

[1]NCRP report No. 160.[42]

TABLE 4.4

Annual Risk of Death from Various Events

Cause	Risk
Lightning Strike	9.5×10^{-8}
Storm	4.4×10^{-7}
Flood	1×10^{-7}
Hurricane	2.5×10^{-7}
Drowning	8×10^{-6}
Air Travel	3×10^{-6}
Firearms	2×10^{-6}

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5.0 QUALITY ASSURANCE PROGRAM

All nuclear instrumentation used in this program is calibrated with standardized sources obtained from or traceable to the U. S. National Institute of Standards and Technology (NIST). The equipment is checked prior to the sample measurements with secondary counting standards to document proper operation. Samples were periodically analyzed in duplicate or with the addition of known amounts of a radionuclide to check precision and accuracy. Argonne participates in the DOE Mixed-Analyte Performance Evaluation Program (MAPEP), a twice per year analysis of two different sample matrices containing known amounts of various radionuclides. The results of our participation in this program for 2012 are published in ANL-13/02.[44]

Many factors enter into an overall quality assurance program other than the analytical quality control discussed above. Representative sampling is of prime importance. Appropriate sampling protocols are followed for each type of sampling being conducted. Water samples are pre-treated in a manner designed to maintain the integrity of the analytical constituent. For example, samples for strontium-90 analysis are acidified immediately after collection to prevent hydrolytic loss of metal ions and filtered to reduce leaching from suspended solids. Samples for hydrogen-3 analysis do not require filtration or acidification.

The volume of water in the casing is determined by measuring the water depth from the surface. In accordance with EPA guidance[45], stagnant water is removed from the wells prior to sampling. From one to three times the well volume is removed. After the well refills with groundwater, it is sampled by bailing with a Teflon bailer. The Red Gate Woods dolomite wells are not purged since they are open boreholes drilled into the bedrock where stagnant water does not accumulate. All samples are placed in precleaned bottles, labeled, filtered, and preserved (strontium-90 samples). All sampling equipment is cleaned by field rinsing with Type II deionized water. The samples are transferred to the analytical laboratory along with a chain-of-custody transfer document.

5.1 Applicable Standards

The standard that is relevant to this study is the DOE Order 458.1 which established a total effective dose limit of 100 mrem/y.[39] The dose limit and dose calculation methodology are applicable to all media: surface water, deep holes, boreholes, and picnic well water. The EPA drinking water standard[37] is not applicable to the picnic wells since they do not meet the definition of a public water system. However, the EPA standard of 20 nCi/L for hydrogen-3 or the IEPA Class I groundwater standard of 8 pCi/L for strontium-90 may be useful for some comparison purposes.

5.2 Analytical Methods

The analytical methods used to obtain the data in this report are the same as those used to generate the results presented in ANL-13/02.[44]

5.3 Intercomparison Program

Starting in 2012, Argonne began a program of splitting a subset of the samples it collects with the Illinois Emergency Management Agency (IEMA). The IEMA operates a laboratory that conducts radiological analyses using methods similar to Argonne's methods. The duplicate set of six samples is analyzed by both Argonne and the IEMA for cesium-137, strontium-90 and hydrogen-3 and the results are compared to ensure that comparable results are obtained. The results from the 2013 split samples are shown in Tables 5.1 through 5.3. The relative percent difference (RPD) for hydrogen-3 results from pairs of samples with both results greater than three times the minimum detectable activity (MDS) are shown in Tables 5.1. None of the pairs of strontium-90 or cesium-137 results both exceeded three times the MDA levels, thus the RPD was not calculated.

Table 5.1 Intercomparison Sample Hydrogen-3 Results for 2013

Sampling Location	Argonne H-3 Results (nCi/L)	Argonne Uncertainty	Argonne MDA	IEMA H-3 Results (nCi/L)	IEMA Uncertainly	IEMA MDA	RPD[c]
First Quarter							
Plot M Borehole #4	**359.6**[a]	0.827	0.1	**355.0**	1.220	0.114	0.32%
Plot M Borehole #10	**173.1**	0.575	0.1	**209.0**	0.938	0.114	4.70%
Site A Borehole #54	0.133[b]	0.049	0.1	0.0413	0.0691	0.114	-
Well 5160	**1.994**	0.077	0.1	**1.940**	0.113	0.114	0.69%
RGW Dolomite Well #10	**0.676**	0.058	0.1	**0.677**	0.0863	0.114	0.06%
RGW Dolomite Well #13	**0.995**	0.063	0.1	**0.916**	0.0919	0.113	2.08%
Second Quarter							
Plot M Borehole #4	**377.4**	0.829	0.1	**374.0**	1.250	0.113	0.23%
Plot M Borehole #10	**36.04**	0.267	0.1	**37.10**	0.400	0.113	0.72%
Site A Borehole #54	.097	0.049	0.1	0.124	0.0711	0.113	-
Well 5160	**2.236**	0.081	0.1	**2.050**	0.114	0.113	2.17%
RGW Dolomite Well #10	**0.711**	0.056	0.1	**0.638**	0.0849	0.113	2.69%
RGW Dolomite Well #13	**1.014**	0.061	0.1	**0.875**	0.0905	0.186	3.68%
Third Quarter							
Plot M Borehole #4	**360.6**	0.813	0.1	**370.0**	3.630	0.525	0.64%
Plot M Borehole #10	**198.8**	0.617	0.1	**208.0**	2.060	0.395	1.13%
Site A Borehole #54	.096	0.048	0.1	0.0185	0.111	0.186	-
Well 5160	**2.106**	0.079	0.1	**2.230**	0.149	0.186	1.43%
RGW Dolomite Well #10	**0.614**	0.056	0.1	0.460	0.119	0.186	-
RGW Dolomite Well #13	**0.984**	0.062	0.1	**0.950**	0.128	0.131	0.88%
Fourth Quarter			0.1				
Plot M Borehole #4	**367.6**	0.822	0.1	**364.0**	1.240	0.131	0.25%
Plot M Borehole #6	**637.7**	1.082	0.1	**634.0**	1.630	0.131	0.15%
Site A Borehole #54	0.060	0.047	0.1	0.0876	0.0805	0.131	-
Well 5160	**2.238**	0.082	0.1	**2.130**	0.123	0.131	1.24%
RGW Dolomite Well #10	**0.566**	0.062	0.1	**0.523**	0.0911	0.131	1.98%
RGW Dolomite Well #13	0.274	0.051	0.1	0.184	0.0829	0.114	-

a Bold font indicates the result is greater than three times the MDA

b Underline indicates result is greater than the MDA but less than three times the MDA.

c Relative Percent Difference (RPD) was calculated only for those results where both Argonne and IEMA results were greater than three times the MDA

Table 5.2 Intercomparison Sample Stontium-90 Results for 2013

Sampling Location	Argonne Sr-90 Results (pCi/L)	Argonne Uncertainty	Argonne MDA	IEMA Sr-90 Results (pCi/L)	IEMA Uncertainly	IEMA MDA
First Quarter						
Plot M Borehole #4	0.052	0.023	0.25	0.025	0.917	1.539
Plot M Borehole #10	0.274[a]	0.034	0.25	0.537	0.930	1.503
Site A Borehole #54	0.029	0.022	0.25	-0.213	0.900	1.539
Well 5160	0.039	0.023	0.25	-0.306	0.879	1.511
RGW Dolomite Well #10	0.006	0.022	0.25	-0.167	0.897	1.527
RGW Dolomite Well #13	0.030	0.023	0.25	-0.610	0.872	1.535
Second Quarter						
Plot M Borehole #4	0.060	0.024	0.25	0.909	0.788	1.142
Plot M Borehole #10	0.165	0.021	0.25	0.404	0.878	1.389
Site A Borehole #54	-0.010	0.014	0.25	-0.365	0.629	1.138
Well 5160	-0.010	0.021	0.25	-0.271	0.658	1.169
RGW Dolomite Well #10	0.043	0.023	0.25	-0.459	0.814	1.466
RGW Dolomite Well #13	-0.007	0.024	0.25	-0.123	0.748	1.284
Third Quarter						
Plot M Borehole #4	0.053	0.023	0.25	-0.4[c]	1.6	0.9
Plot M Borehole #10	0.211	0.030	0.25	-0.4	1.6	0.9
Site A Borehole #54	0.045	0.023	0.25	0.2	1.9	1
Well 5160	0.028	0.022	0.25	-0.7	1.8	1
RGW Dolomite Well #10	0.036	0.024	0.25	0.6	1.8	0.9
RGW Dolomite Well #13	0.015	0.022	0.25	-0.1	1.7	0.9
Fourth Quarter						
Plot M Borehole #4	0.034	0.022	0.25	-0.7	1.7	0.9
Plot M Borehole #6	**1.382**[b]	0.116	0.25	0.4	1.8	1
Site A Borehole #54	0.013	0.023	0.25	0.7	1.6	0.9
Well 5160	-0.026	0.020	0.25	-0.4	1.8	1
RGW Dolomite Well #10	0.008	0.020	0.25	-0.2	1.7	0.9
RGW Dolomite Well #13	-0.006	0.020	0.25	-0.3	1.6	0.9

a Underline indicates result is greater than the MDA but less than three times the MDA. The RPD was not calculated for these results.

b Bold indicated the result is greater than three times the MDA.

c The analytical method the IEMA used for Sr-90 samples during the third and fourth quarters generated results with one or two significant figures, compared to three of four significant figures for the previous two quarters using a different analytical method.

Table 5.3 Intercomparison Sample Cesium-137 Results for 2013

Sampling Location	Argonne Cs-137 Results (pCi/L)	Argonne Uncertainty	Argonne MDA	IEMA Cs-137 Results (pCi/L)	IEMA Uncertainly	IEMA MDA
First Quarter						
Plot M Borehole #4	-1.48	1.35	2	-1.25	1.07	3.15
Plot M Borehole #10	0.29	2.45	2	0.32	1.53	2.45
Site A Borehole #54	1.83	2.50	2	-0.50	1.03	3.10
Well 5160	-0.62	1.51	2	-1.33	0.94	2.74
RGW Dolomite Well #10	3.07[a]	2.48	2	1.87	1.05	3.26
RGW Dolomite Well #13	0.71	2.43	2	1.72	1.05	3.47
Second Quarter						
Plot M Borehole #4	-0.55	1.50	2	1.43	1.29	3.92
Plot M Borehole #10	-0.65	1.50	2	-0.78	1.05	3.13
Site A Borehole #54	2.24	1.49	2	-0.39	1.13	3.40
Well 5160	0.62	1.56	2	0.83	1.02	3.24
RGW Dolomite Well #10	1.89	2.51	2	-0.59	1.03	3.10
RGW Dolomite Well #13	0.23	0.16	2	-0.41	1.28	3.64
Third Quarter						
Plot M Borehole #4	-1.03	1.45	2	0.85	1.28	3.80
Plot M Borehole #10	-0.31	1.53	2	0.49	0.91	2.84
Site A Borehole #54	0.93	1.52	2	-1.14	1.05	2.97
Well 5160	-1.03	1.41	2	-0.42	1.08	3.26
RGW Dolomite Well #10	0.96	1.46	2	-0.61	1.35	3.80
RGW Dolomite Well #13	0.78	1.37	2	-1.17	0.90	2.62
Fourth Quarter						
Plot M Borehole #4	-1.13	1.44	2	2.36	0.94	3.11
Plot M Borehole #6	NA	NA	2	0.01	0.98	3.02
Site A Borehole #54	-0.89	1.52	2	-1.63	1.74	2.49
Well 5160	0.55	1.49	2	-1.49	1.27	3.47
RGW Dolomite Well #10	-0.45	1.47	2	0.64	0.86	2.74
RGW Dolomite Well #13	-0.03	1.50	2	0.70	1.01	3.20

a Underline indicates result is greater than the MDA but less than three times the MDA; therefore RPD was not calculated.

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