

NEVADA NATIONAL SECURITY SITE

2010 DATA REPORT:

GROUNDWATER MONITORING PROGRAM

AREA 5 RADIOACTIVE WASTE MANAGEMENT SITE

January 2011

Prepared for:

U.S. Department of Energy
National Nuclear Security Administration
Nevada Site Office

Prepared by:

National Security Technologies, LLC
Las Vegas, Nevada

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AMSL	above mean sea level
BN	Bechtel Nevada
°C	degrees Celsius
Ca	calcium
CFR	Code of Federal Regulations
Cl	chloride
cm	centimeter
cm/yr	centimeter per year
DOE	U.S. Department of Energy
E	easting
°F	degrees Fahrenheit
F	fluoride
Fe	iron
ft	feet
GW	groundwater
HCO ₃	bicarbonate
IL	investigation level
in.	inch
in./year	inch per year
K	potassium
LCA	lower carbonate aquifer
m	meter
m/m	meter change in water level elevation per meter change in gradient direction
m ³ /m ³	void space volume (cubic meter) per total aquifer volume (cubic meter)
MDC	minimum detectable concentration
MDL	method detection limit
Mg	magnesium
mg/L	milligram per liter
mmhos/cm	millimhos per centimeter
Mn	manganese
N	northing
Na	sodium
NDEP	Nevada Division of Environmental Protection
NNSS	Nevada National Security Site
pCi/L	picocurie per liter
RCRA	Resource Conservation and Recovery Act
REEC _o	Reynolds Electrical and Engineering Company, Inc.
RWMS	Radioactive Waste Management Site
SC	specific conductance
SiO ₂	silicate
SO ₄	sulfate
TOC	total organic carbon
TOX	total organic halides
µg/L	microgram per liter

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EXECUTIVE SUMMARY

This report is a compilation of the groundwater sampling results from the Area 5 Radioactive Waste Management Site (RWMS). The data have been collected since 1993 and include calendar year 2010 results. During 2010, groundwater samples were collected and static water levels were measured at the three pilot wells surrounding the Area 5 RWMS. Samples were collected at UE5PW-1 on March 10 and August 10, 2010; at UE5PW-2 on March 10, August 10, and August 25, 2010; and at UE5PW-3 on March 31, August 10, and August 25, 2010. Static water levels were measured at each of the three pilot wells on March 1, April 26, August 9, and November 9, 2010. Groundwater samples were analyzed for the following indicators of contamination: pH, specific conductance, total organic carbon, total organic halides, and tritium. Indicators of general water chemistry (cations and anions) were also measured. Results from all samples collected in 2010 were within the limits established by agreement with the Nevada Division of Environmental Protection for each analyte. These data indicate that there has been no measurable impact to the uppermost aquifer from the Area 5 RWMS.

There were no significant changes in measured groundwater parameters compared to previous years.

The report contains an updated cumulative chronology for the Area 5 RWMS Groundwater Monitoring Program and a brief description of the site hydrogeology.

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1.0 INTRODUCTION

1.1 PURPOSE AND SCOPE

This report is a compilation of the groundwater sampling results from three monitoring wells located near the Area 5 Radioactive Waste Management Site (RWMS) at the Nevada National Security Site (NNSS), Nye County, Nevada, and includes the results for calendar year 2010. The NNSS is an approximately 3,561 square kilometer (1,375 square mile) restricted-access federal facility located approximately 105 kilometers (65 miles) northwest of Las Vegas, Nevada (Figure 1-1). Pilot Wells UE5PW-1, UE5PW-2, and UE5PW-3 are used to monitor the groundwater at the Area 5 RWMS (Figure 1-2). In addition to groundwater monitoring results, this report includes information regarding site hydrogeology, well construction, sample collection, and meteorological data measured at the Area 5 RWMS.

The disposal of low-level radioactive waste and mixed low-level radioactive waste at the Area 5 RWMS is regulated by U.S. Department of Energy (DOE) Order DOE O 435.1, "Radioactive Waste Management" (DOE, 2001). The disposal of mixed low-level radioactive waste is also regulated by the State of Nevada under the Resource Conservation and Recovery Act (RCRA) regulation Title 40 Code of Federal Regulations (CFR) Part 265, "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities" (CFR, 1999). The format of this report was requested by the Nevada Division of Environmental Protection (NDEP) in a letter dated August 12, 1997. The appearance and arrangement of this document have been modified slightly since that date to provide additional information and to facilitate the readability of the document. The objective of this report is to satisfy any Area 5 RWMS reporting agreements between DOE and NDEP.

1.2 SITE HYDROGEOLOGY

The Area 5 RWMS is located in northern Frenchman Flat in the southeast portion of the NNSS. Frenchman Flat is a topographically closed basin. Erosion of surrounding mountains has resulted in accumulation of thick, unsaturated, alluvial deposits above volcanic rocks within the basin (Bright et al., 2001). Alluvial and volcanic aquifers are present beneath the Area 5 RWMS and are believed to extend throughout much of the Frenchman Flat basin (Bechtel Nevada [BN], 2005). In this south-central portion of the NNSS, a moderately thick volcanic confining unit, consisting of altered volcanic rocks, separates the shallow alluvial and volcanic aquifers from the underlying regional lower carbonate aquifer (LCA) (BN, 2005; Lacznik et al., 1996).

The groundwater type from the three monitoring wells (UE5PW-1, UE5PW-2, and UE5PW-3) is sodium-bicarbonate. This type of water is common in the upper aquifers in Frenchman Flat. UE5PW-1 and UE5PW-2 are completed in the alluvial aquifer, and UE5PW-3 is completed in the volcanic aquifer. Similar groundwater chemistry and water table elevations in UE5PW-1, UE5PW-2, and UE5PW-3 indicate that the alluvial and volcanic aquifers are locally connected near the Area 5 RWMS.

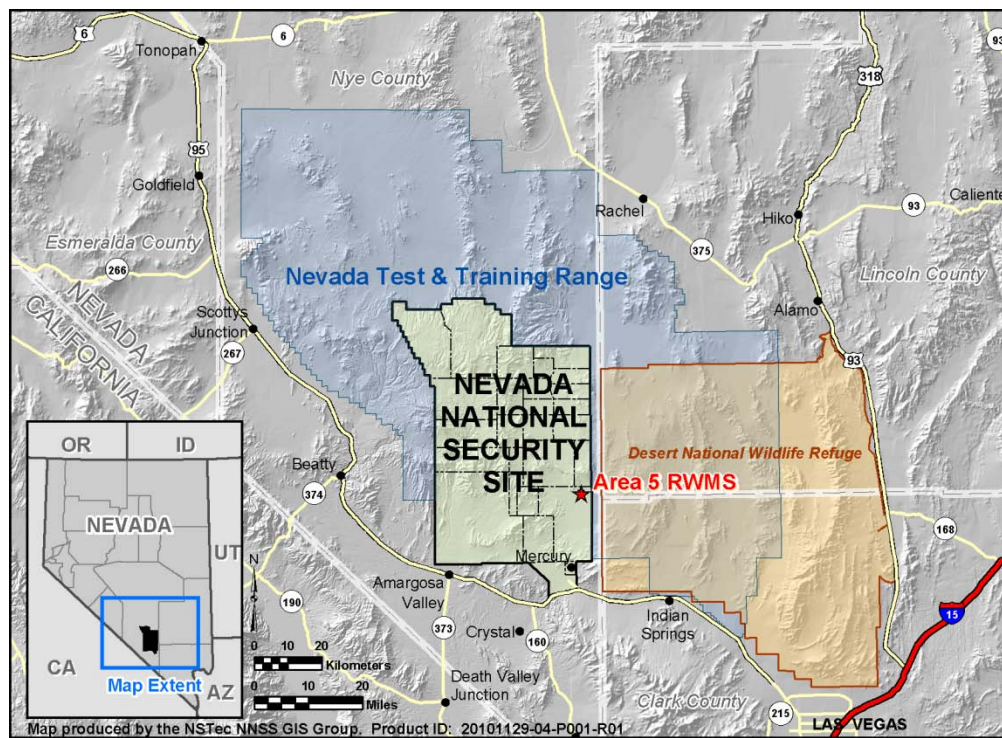


Figure 1-1. Location of the Area 5 RWMS and Nevada National Security Site within Nevada

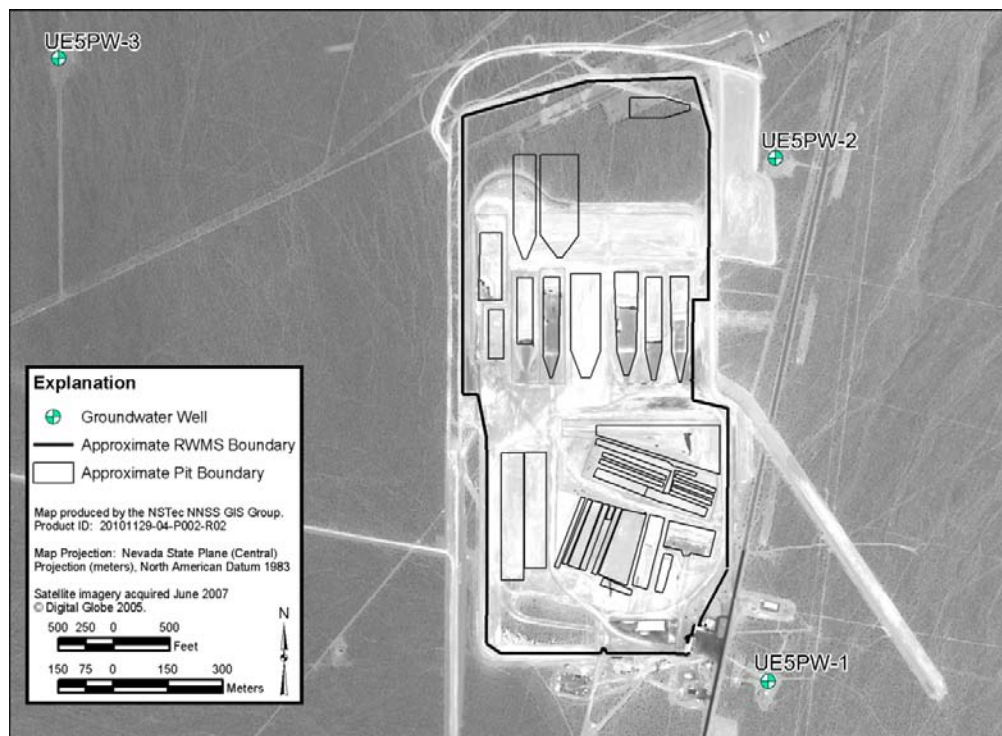


Figure 1-2. Location of Pilot Wells at the Area 5 RWMS

Some vertical groundwater flow occurs between the uppermost aquifers in Frenchman Flat and the underlying regional LCA (Navarro Nevada Environmental Services, 2010). Based on measured groundwater elevations above mean sea level (AMSL) (Figure 1-3), the lateral hydraulic gradient in the upper Frenchman Flat aquifer is very low. Lateral groundwater movement beneath Frenchman Flat primarily occurs within the deep carbonate aquifer and is generally from the northeast to southwest. It eventually discharges in Amargosa Valley and Ash Meadows in southwest Nevada and Death Valley in California (Figure 1-4) (Laczniak et al., 1996).

For more detailed descriptions of Area 5 RWMS site characteristics, refer to the report *Revised Area 5 Radioactive Waste Management Site, Outline of a Comprehensive Groundwater Monitoring Program* (BN, 1998).

1.3 MONITORING WELL DESCRIPTIONS

Pilot Wells UE5PW-1, UE5PW-2, and UE5PW-3 were drilled between March and November 1992, and the groundwater has been monitored since 1993. Each well is completed with a centralized 6.35-centimeter (cm) (2.50-inch [in.]) diameter stainless steel casing with an 18.3-meter (m) (60-feet [ft]) dual-screen filter pack attached to the bottom of the casing. The borehole annulus below and around the screen is filled with 6/12 coarse mesh sand (Reynolds Electrical and Engineering Company, Inc. [REECo], 1994).

UE5PW-1 is 255.7 m (839 ft) deep from top of casing and is screened from 232.3 m (762 ft) to 250.5 m (822 ft). UE5PW-1 is completed in alluvium. During 2010, the average water table depth below the top of the well casing was 235.82 m (773.69 ft), and the average water table elevation was 733.55 m (2,406.65 ft) AMSL.

UE5PW-2 is 280.3 m (919.5 ft) deep from top of casing and is screened from 253.0 m (830 ft) to 271.3 m (890 ft). UE5PW-2 is completed in alluvium. During 2010, the average water table depth below the top of the well casing was 256.43 m (841.30 ft), and the average water table elevation was 733.69 m (2,407.11 ft) AMSL.

UE5PW-3 is 291.1 m (955 ft) deep from top of casing and is screened from 267.6 m (878 ft) to 282.9 m (928 ft). UE5PW-3 is completed in volcanic rock. The alluvium/volcanic rock contact is 188 m (617 ft) deep at UE5PW-3 (REECo, 1994). During 2010, the average water table depth below the top of the well casing was 271.54 m (890.88 ft), and the average water table elevation was 733.69 m (2,407.11 ft) AMSL.

Groundwater Monitoring Program
Area 5 Radioactive Waste Management Site

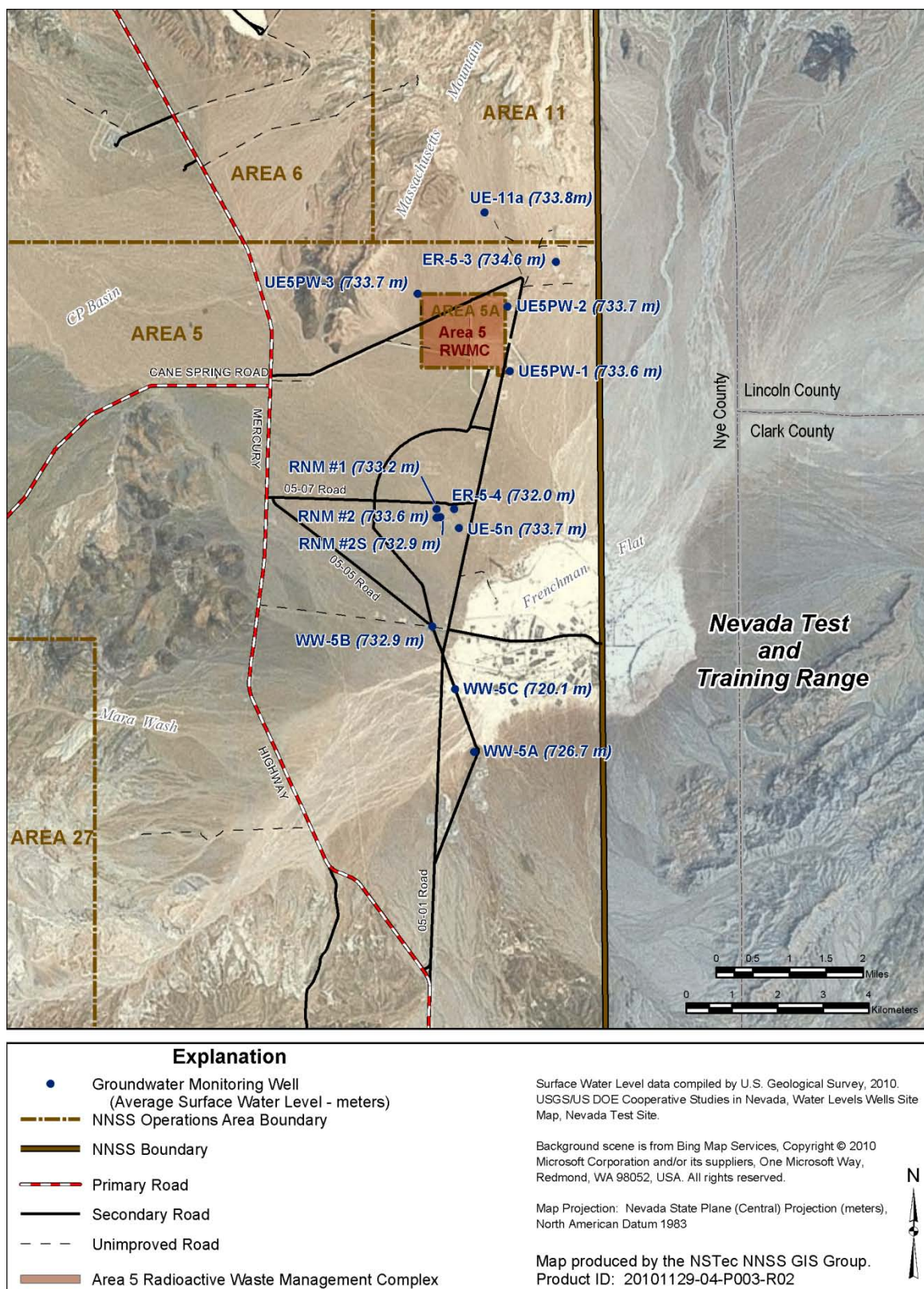


Figure 1-3. Average Water Level Elevation at Groundwater Monitoring Wells in the Vicinity of the Area 5 RWMS (U.S. Geological Survey, 2010)

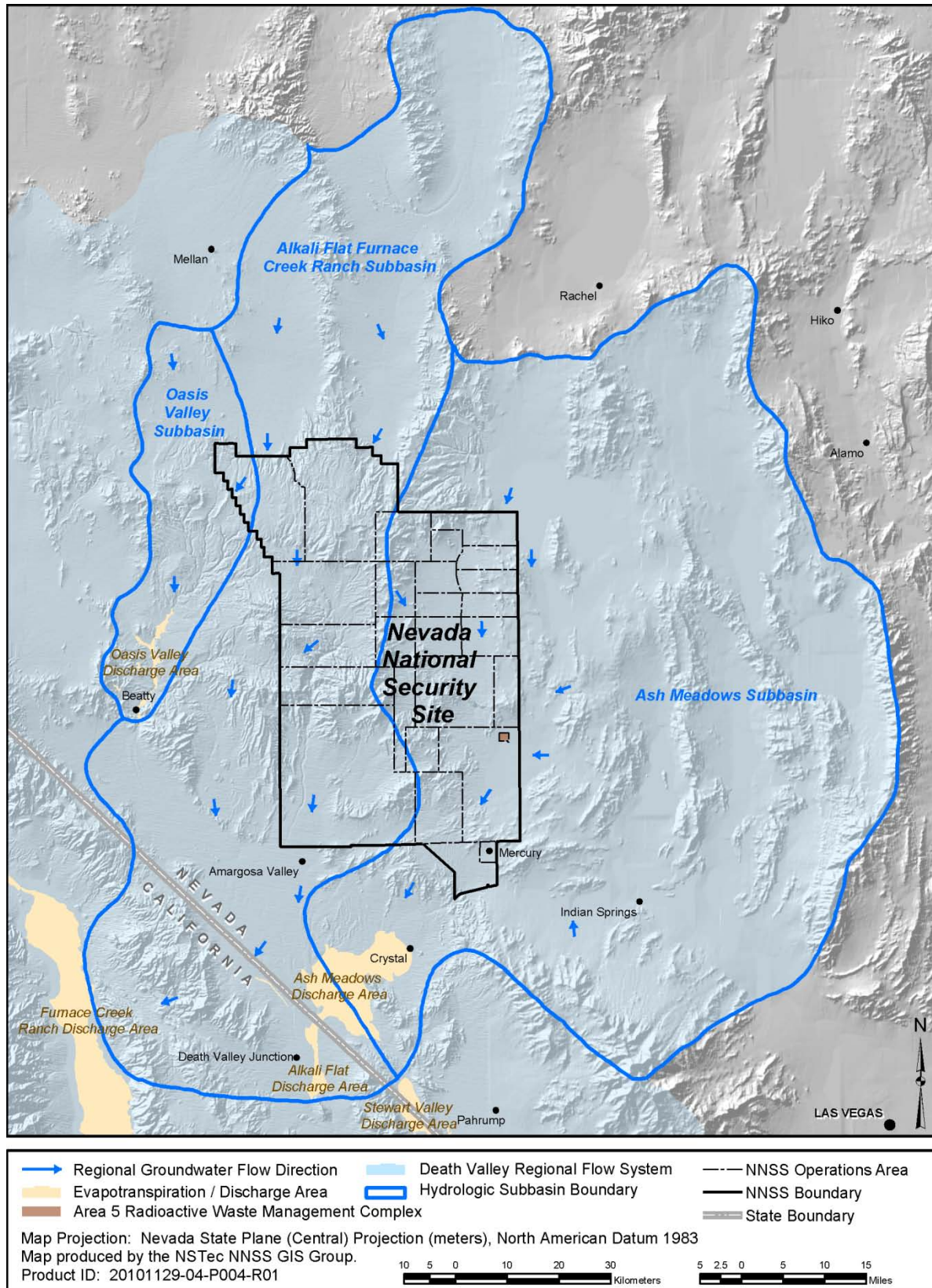


Figure 1-4. Groundwater Subbasins and Flow Directions in the Vicinity of the Area 5 RWMS

1.4 SITE METEOROLOGY

Meteorological data are measured at the Area 5 RWMS. These data include temperature, relative humidity, barometric pressure, wind speed and direction, solar radiation, and precipitation. During 2010 the average daily temperature at 3 m height was 15.8 degrees Celsius (°C) (60.4 degrees Fahrenheit [°F]). The maximum observed temperature at 3 m height was 41.9°C (107.4°F) on July 15, 2010, and the minimum observed temperature at 3 m was -12.1°C (10.2°F) on November 27, 2010. The maximum observed wind gust at 3 m was 23.7 meters/second (53.0 miles per hour) on December 29, 2010. The average annual precipitation measured at the Area 5 RWMS from 1994 through 2010 is 12.1 cm per year (cm/yr) (4.76 in./yr). There were 19.0 cm (7.48 in.) of precipitation at the Area 5 RWMS during 2010. During the 16-year measurement period, 2010 is the fourth wettest year. There were 48 days of measurable precipitation in 2010 at the Area 5 RWMS. The wettest month in 2010 was December, which had approximately 44 percent of the 2010 precipitation. Monthly precipitation at the Area 5 RWMS from January 1994 through December 2010 is provided in Figure 1-5.

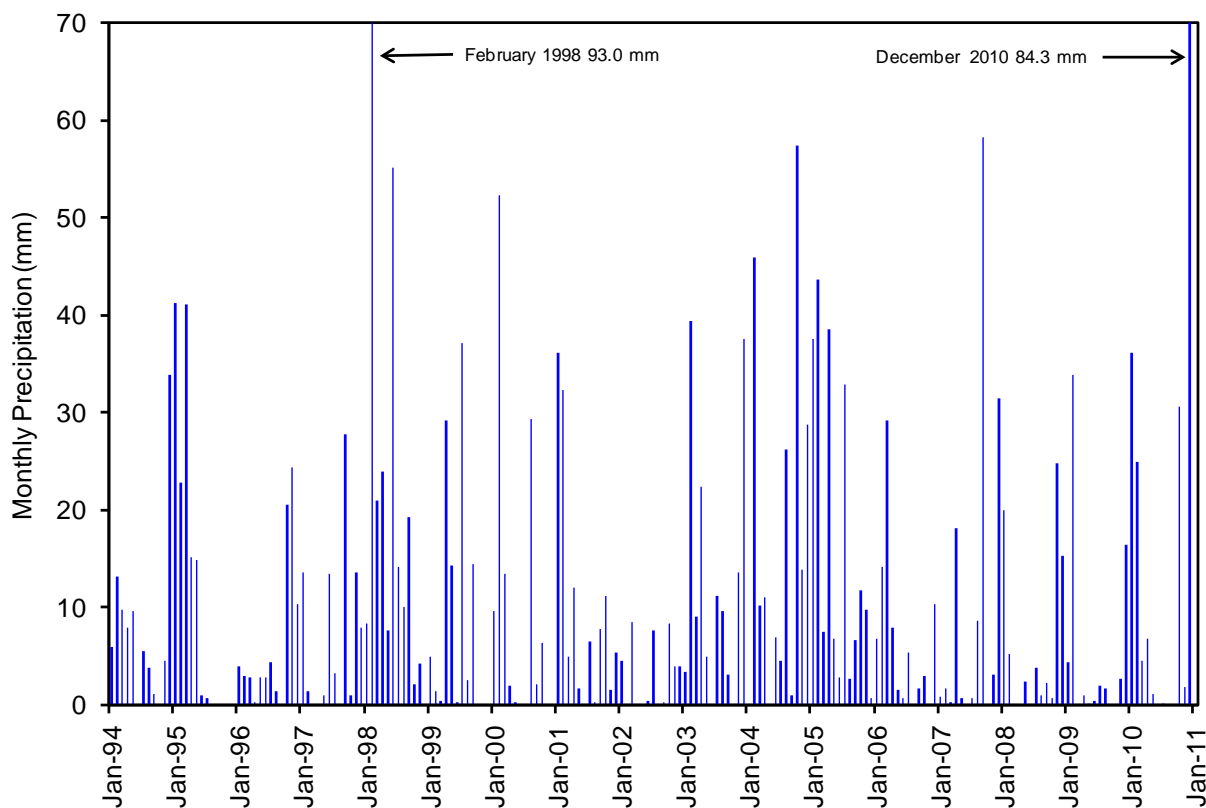


Figure 1-5. Monthly Precipitation at the Area 5 RWMS

2.0 MONITORING METHODS AND RESULTS

The groundwater at the Area 5 RWMS pilot wells has been monitored since 1993 (see Appendix A). The Groundwater Monitoring Program has transitioned from monitoring all parameters required by 40 CFR 265 to a program that monitors parameters applicable to the Area 5 RWMS. The current monitoring program is modeled after the 40 CFR 265 Detection Monitoring Program.

2.1 METHODS

Samples are tested semiannually for the analytes listed below, which are divided into groups representing indicators of contamination and general water chemistry parameters:

Indicators of contamination:

- pH
- Specific conductance (SC)
- Total organic carbon (TOC)
- Total organic halides (TOX)
- Tritium

General water chemistry parameters:

- Cations: calcium (Ca), iron (Fe), magnesium (Mg), manganese (Mn), potassium (K), sodium (Na)
- Anions: bicarbonate (HCO_3), sulfate (SO_4), chloride (Cl), fluoride (F)
- Silicate (SiO_2)

Investigation levels (ILs) for each analyte identified as an indicator of contamination were established by DOE and NDEP in 1998 (Table 2-1). Further groundwater analyses are required if an analyte's IL is exceeded. The intent of ILs is to replace the need for rigorous statistical analyses to identify contamination. Statistical analyses are not presented in this report, as agreed upon by NDEP in a letter dated April 17, 2000 (Liebendorfer, 2000). The ILs for pH and SC are based on the distributions of data collected from 1993 through 1996. Historic analyses for TOC, TOX, and tritium typically have concentration levels less than the method detection limit (MDL) or the minimum detectable concentration (MDC), so the ILs for TOC and TOX are set slightly above their MDLs or MDCs. The tritium IL is set at 2,000 picocuries per liter (pCi/L), which is 10 percent of the National Primary Drinking Water Standard of 20,000 pCi/L.

Groundwater was sampled at UE5PW-1 and UE5PW-2 on March 10, 2010, and August 10, 2010, and at UE5PW-3 on March 31, 2010, and August 10, 2010. UE5PW-2 and UE5PW-3 were resampled for TOC and TOX on August 25, 2010, because the results for the August 10, 2010, samples were slightly higher than expected. The current groundwater sampling procedure (National Security Technologies, LLC, 2006) was followed. Tritium samples were enriched prior to shipment to a contract laboratory for analysis. Tritium analyses were conducted by ALS Laboratory Group. All other analyses were conducted by Lionville Laboratory Incorporated.

Table 2-1. Investigation Levels of Indicator Parameters

Parameter	Investigation Level (IL)
pH	<7.6 or >9.2
SC	0.440 mmhos/cm ^a
TOC	1 mg/L ^b
TOX	50 µg/L ^c
Tritium	2,000 pCi/L

^a mmhos/cm = millimhos per centimeter

^b mg/L = milligrams per liter

^c µg/L = micrograms per liter

For TOC and TOX analysis, three replicate water samples were collected consecutively from each well for each analyte. This provides sufficient sample backups in case any sample result is above the analyte's IL. Well resampling is required if all three replicate water samples are above the analyte's IL. False detections of these analytes above their ILs and subsequent resampling of the wells have occurred in the past. Resampling was done at UE5PW-3 for the TOC results for samples collected on August 10, 2010. A second set of samples was collected on August 25, 2010. The average TOC result for the original samples was 1.13 mg/L and the average TOC result for the second set of samples was 0.56 mg/L.

2.2 RESULTS

This section lists the results for each of the five indicators of contamination, the general water chemistry parameters, and the groundwater elevation.

2.2.1 pH

The measured pH at each well remained within the ILs of 7.6 and 9.2 during 2010 (Table 2-2). The 2010 pH values ranged from 8.13 to 8.39 and represent the stable pH reading obtained from each well just prior to sampling for other analytes. Measured pH has remained relatively stable throughout the entire monitoring period (Figure 2-1). No groundwater contamination is indicated by the pH monitoring results.

Table 2-2. Area 5 RWMS pH Values

UE5PW-1		UE5PW-2		UE5PW-3	
Date	pH	Date	pH	Date	pH
03/31/1993	8.17	03/24/1993	7.99	04/14/1993	8.24
07/06/1993	8.30	06/22/1993	8.24	06/02/1993	8.68
09/01/1993	8.25	11/15/1993	8.40	10/12/1993	8.69
12/07/1993	7.91	01/19/1994	8.79	12/20/1993	8.60
06/15/1994	8.45	No sample		05/24/1994	8.87
08/01/1994	8.28	06/07/1994	8.81	08/08/1994	8.77
No sample		11/29/1994	8.79	01/18/1995	8.58
04/04/1995	8.25	04/04/1995	8.58	04/05/1995	8.28
11/09/1995	8.35	11/09/1995	8.08	11/09/1995	8.43
01/18/1996	8.41	01/25/1996	8.63	01/18/1996	8.55
04/16/1996	8.22	04/23/1996	8.21	04/23/1996	8.23
No sample		04/30/1996	8.15	04/30/1996	8.15
10/02/1996	8.18	10/02/1996	8.28	10/02/1996	8.18

Table 2-2. Area 5 RWMS pH Values (continued)

UE5PW-1		UE5PW-2		UE5PW-3	
Date	pH	Date	pH	Date	pH
11/20/1996	8.25	11/20/1996	8.16	11/20/1996	8.13
04/16/1997	8.33	04/16/1997	8.40	04/16/1997	8.25
11/05/1997	8.30	11/05/1997	8.17	11/05/1997	8.22
05/13/1998	8.31	05/13/1998	8.37	05/13/1998	8.34
07/29/1998	8.63	No sample		No sample	
10/28/1998	8.34	10/28/1998	8.32	10/28/1998	8.14
05/19/1999	8.50	05/19/1999	8.49	05/19/1999	8.47
10/27/1999	8.49	10/27/1999	8.52	10/27/1999	8.34
04/26/2000	8.50	04/26/2000	8.39	04/26/2000	8.24
08/09/2000	8.26	08/09/2000	8.14	08/09/2000	8.23
05/29/2001	8.46	05/29/2001	8.25	05/29/2001	8.27
10/03/2001	8.39	10/03/2001	8.22	10/03/2001	8.13
05/15/2002	8.46	05/15/2002	8.30	05/15/2002	8.32
10/22/2002	8.43	10/22/2002	8.23	10/22/2002	8.24
04/15/2003	8.54	04/15/2003	8.38	04/15/2003	8.42
10/22/2003	8.37	10/22/2003	8.24	10/21/2003	8.16
05/04/2004	8.50	05/04/2004	8.25	05/04/2004	8.26
10/19/2004	8.30	10/19/2004	8.32	10/20/2004	8.24
04/19/2005	8.48	04/19/2005	8.30	04/19/2005	8.33
10/11/2005	8.47	10/11/2005	8.27	10/11/2005	8.31
04/26/2006	8.34	04/26/2006	8.12	04/26/2006	8.17
10/10/2006	8.11	10/10/2006	8.03	10/10/2006	8.07
03/19/2007	8.37	03/19/2007	8.13	03/19/2007	8.44
08/29/2007	8.29	08/29/2007	8.09	09/05/2007	8.10
03/11/2008	8.08	03/11/2008	8.00	03/11/2008	8.03
09/10/2008	8.17	09/10/2008	8.08	09/10/2008	8.14
03/10/2009	8.40	03/10/2009	8.17	03/10/2009	8.22
08/18/2009	8.45	08/18/2009	8.25	08/18/2009	8.22
03/10/2010	8.37	03/10/2010	8.17	03/31/2010	8.13
08/10/2010	8.39	08/10/2010	8.27	08/10/2010	8.22

NOTE: Values before 05/19/1999 are means of multiple measurements and values from 05/19/1999 to present are the stable pH value measured just prior to sampling.

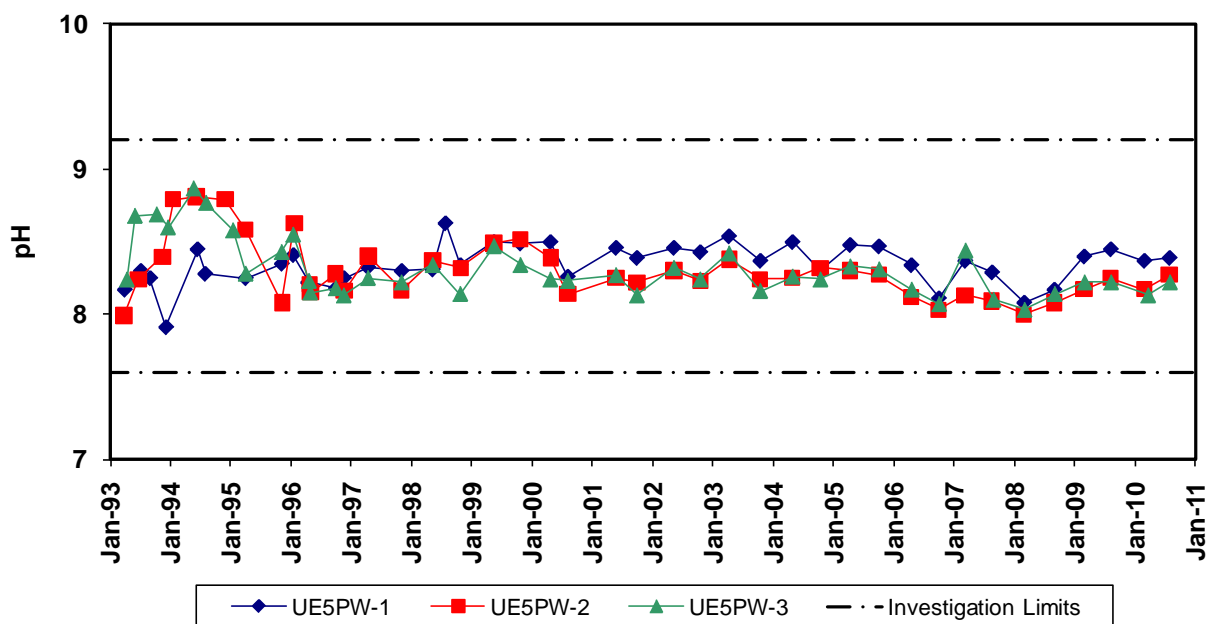


Figure 2-1. Area 5 RWMS Time Series Plot of pH

2.2.2 Specific Conductance

The 2010 measured SC of water samples from each well remained below the IL of 0.440 mmhos/cm and ranged from 0.345 to 0.375 mmhos/cm (Table 2-3). On March 31, 2010, a SC result of 0.424 mmhos/cm was measured at UE3PW-3. This value is not reported in Table 2-3 because it is not consistent with the measurements of 8/18/2009 and 8/10/2010. SC values from each well have remained relatively stable throughout the entire monitoring period (Figure 2-2). No groundwater contamination is indicated by the SC monitoring results.

Table 2-3. Area 5 RWMS SC Values in mmhos/cm

UE5PW-1		UE5PW-2		UE5PW-3	
Date	SC	Date	SC	Date	SC
03/31/1993	0.401	03/24/1993	0.371	04/14/1993	0.383
06/06/1993	0.391	06/22/1993	0.411	06/02/1993	0.382
09/01/1993	0.391	11/15/1993	0.384	10/12/1993	0.376
12/07/1993	0.383	01/19/1994	0.371	12/20/1993	0.359
06/15/1994	0.383	06/07/1994	0.363	05/24/1994	0.363
08/01/1994	0.380	No Sample		08/08/1994	0.367
No Sample		11/29/1994	0.325	01/18/1995	0.338
04/04/1995	0.320	04/04/1995	0.336	04/05/1995	0.347
11/09/1995	0.366	11/09/1995	0.348	11/09/1995	0.352
01/18/1996	0.360	01/25/1996	0.343	01/18/1996	0.355
04/16/1996	0.363	04/23/1996	0.355	04/23/1996	0.363
No Sample		04/30/1996	0.356	04/30/1996	0.379
10/02/1996	0.383	10/02/1996	0.363	10/02/1996	0.376
11/20/1996	0.374	11/20/1996	0.365	11/20/1996	0.378
04/16/1997	0.385	04/16/1997	0.364	04/16/1997	0.376

Table 2-3. Area 5 RWMS SC Values in mmhos/cm (continued)

UE5PW-1		UE5PW-2		UE5PW-3	
Date	SC	Date	SC	Date	SC
11/05/1997	0.377	11/05/1997	0.358	11/05/1997	0.361
05/13/1998	0.377	05/13/1998	0.356	05/13/1998	0.370
07/29/1998	0.373	No Sample		No Sample	
10/28/1998	0.380	10/28/1998	0.358	10/28/1998	0.370
05/19/1999	0.379	05/19/1999	0.351	05/19/1999	0.369
10/27/1999	0.370	10/27/1999	0.355	10/27/1999	0.370
04/26/2000	0.378	04/26/2000	0.355	04/26/2000	0.369
08/09/2000	0.378	08/09/2000	0.357	08/09/2000	0.370
05/29/2001	0.377	05/29/2001	0.358	05/29/2001	0.371
10/03/2001	0.376	10/03/2001	0.358	10/03/2001	0.371
05/15/2002	0.386	05/15/2002	0.374	05/15/2002	0.384
10/22/2002	0.374	10/22/2002	0.368	10/22/2002	0.368
04/15/2003	0.372	04/15/2003	0.355	04/15/2003	0.369
10/22/2003	0.376	10/22/2003	0.357	10/21/2003	0.373
05/04/2004	0.378	05/04/2004	0.361	05/04/2004	0.353
10/19/2004	0.372	10/19/2004	0.352	10/20/2004	0.365
04/19/2005	0.377	04/19/2005	0.359	04/19/2005	0.369
10/11/2005	0.368	10/11/2005	0.352	10/11/2005	0.364
04/26/2006	0.361	04/26/2006	0.341	04/26/2006	0.357
10/10/2006	0.384	10/10/2006	0.363	10/10/2006	0.376
03/19/2007	0.390	03/19/2007	0.330	03/19/2007	0.332
08/29/2007	0.385	08/29/2007	0.359	09/05/2007	0.378
03/11/2008	0.386	03/11/2008	0.371	03/11/2008	0.386
09/10/2008	0.378	09/10/2008	0.360	09/10/2008	0.375
03/10/2009	0.376	03/10/2009	0.363	03/10/2009	0.386
08/18/2009	0.377	08/18/2009	0.363	08/18/2009	0.376
03/10/2010	0.379	03/10/2009	0.358	No Sample	
08/10/2010	0.363	08/10/2010	0.345	08/10/2010	0.359

NOTE: Values before 05/19/1999 are means of multiple measurements and values from 05/19/1999 to present are the stable SC value measured just prior to sampling.

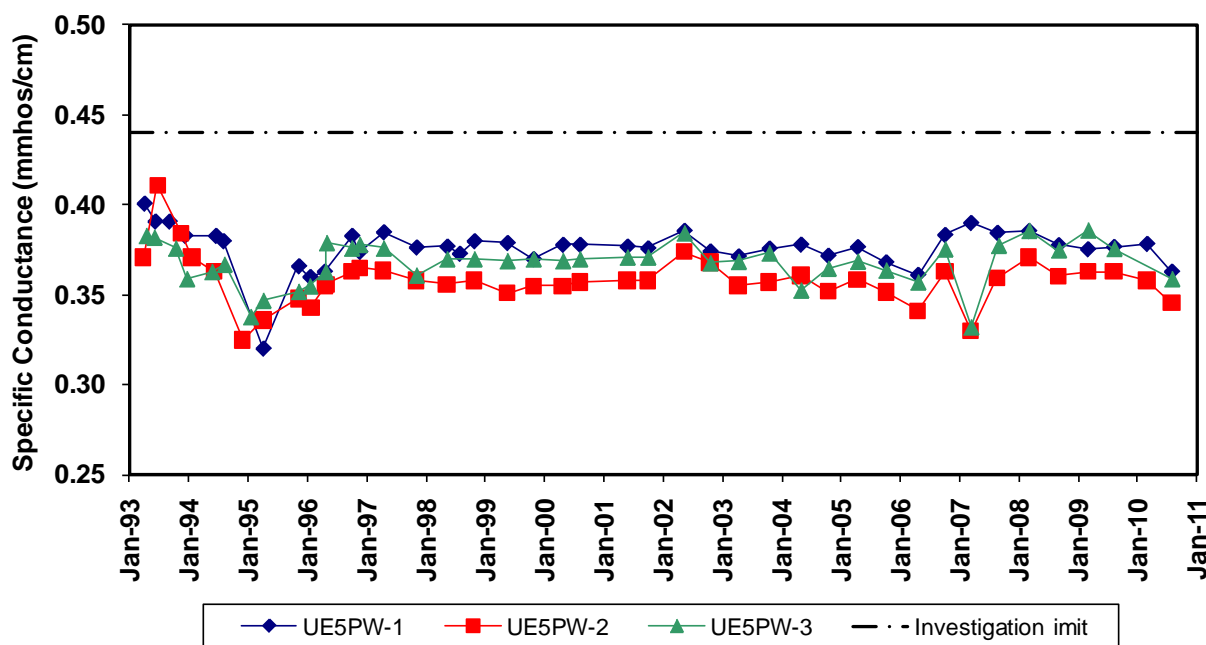


Figure 2-2. Area 5 RWMS Time Series Plot of SC

2.2.3 Total Organic Carbon

Three samples were collected consecutively from each well on each sample date for TOC analysis. The averages of the three sample measurements are reported in Table 2-4. When sample TOC values fell below the sample's MDL of 0.5 mg/L, then the value 0.5 mg/L was used to calculate the reported average. Values shown as <0.5 mg/L indicate that all three sample results were less than the MDL.

The average TOC results from UE5PW-1 are 0.537 mg/L on March 10, 2010 (0.61, <0.5, and <0.5 mg/L), and 0.557 mg/L on August 10, 2010 (0.67, <0.5, and <0.5 mg/L). The average TOC results from UE5PW-2 are 0.76 mg/L on March 10, 2010 (<0.5, 0.63, and 1.15 mg/L), and 0.98 mg/L on August 10, 2010 (0.92, 1.53, and <0.5 mg/L). The average TOC results from UE5PW-3 are 0.60 mg/L on March 31, 2010 (0.57, 0.64, and 0.58 mg/L), and 1.13 mg/L on August 10, 2010 (1.90, 0.67, and 0.82 mg/L). The average TOC result for UE5PW-3 on August 10, 2010, exceeds the TOC IL of 1.0 mg/L, and the average TOC result for UE5PW-2 on August 10, 2010, is very close to the TOC IL. Both wells were resampled on August 25, 2010. The average TOC result for UE5PW-2 on August 25, 2010, is <0.5 mg/L and the average TOC result for UE5PW-3 on August 25, 2010, is 0.56 mg/L (0.68, <0.5, and <0.5 mg/L). The TOC results for resampling on August 25, 2010, are provided in Table 2-4 and Figure 2-3.

TOC values have remained relatively low and stable throughout the monitoring period (Figure 2-3). Most variation in TOC values is the result of variation in the MDL. No groundwater contamination is indicated by the TOC monitoring results.

Table 2-4. Area 5 RWMS TOC Values in mg/L

UE5PW-1		UE5PW-2		UE5PW-3	
Date	TOC	Date	TOC	Date	TOC
03/31/1993	<1.0	03/24/1993	<1.0	04/14/1993	<1.0
07/06/1993	<1.0	06/22/1993	<1.0	06/02/1993	<1.0
09/01/1993	<1.0	11/15/1993	<1.0	10/12/1993	<1.0
12/07/1993	<1.0	01/19/1994	<1.0	12/20/1993	<1.0
No Sample		06/07/1994	<1.0	No Sample	
08/01/1994	1.7 ^a	11/29/1994	<1.0	08/08/1994	<1.0
01/18/1995	0.20	01/18/1995	0.50	01/18/1995	0.23
04/04/1995	<1.0	04/04/1995	<1.0	04/05/1995	<1.0
11/09/1995	<1.0	11/20/1995	<1.0	11/09/1995	<1.0
04/16/1996	<0.3	04/30/1996	<0.3	04/30/1996	<0.3
10/02/1996	<0.3	10/02/1996	<0.3	10/02/1996	<0.3
11/20/1996	<0.3	11/20/1996	<0.3	11/20/1996	<0.3
04/16/1997	<0.3	04/16/1997	<0.3	04/16/1997	<0.3
11/05/1997	<0.3	11/05/1997	<0.3	11/05/1997	<0.3
05/13/1998	<1.0	05/13/1998	<1.0	05/13/1998	<1.0
10/28/1998	<1.0	10/28/1998	<1.0	10/28/1998	<1.0
05/19/1999	<1.0	05/19/1999	<1.0	05/19/1999	<1.0
10/27/1999	<1.0	10/27/1999	1.3	10/27/1999	<1.0
No Sample		12/13/1999	<0.5	No Sample	
04/26/2000	0.98 ^a	04/26/2000	0.60 ^a	04/26/2000	1.3 ^a
08/09/2000	<0.5 ^b	08/09/2000	<0.5 ^b	04/26/2000	<0.5 ^b
05/29/2001	0.51 ^b	05/29/2001	<0.5 ^b	05/29/2001	0.53 ^b
10/03/2001	<0.5	10/03/2001	<0.5	10/03/2001	<0.5
05/15/2002	<0.5	05/15/2002	<0.5	05/15/2002	<0.5
10/22/2002	<0.5	10/22/2002	0.55	10/22/2002	0.58
04/15/2003	0.51	04/15/2003	0.58	04/15/2003	0.52
10/22/2003	0.64	10/22/2003	0.68	10/21/2003	0.62
05/04/2004	0.55	05/04/2004	<0.5	05/04/2004	0.58
10/19/2004	0.58	10/19/2004	0.90	10/20/2004	0.83
04/19/2005	0.65	04/19/2005	0.62	04/19/2005	0.50
10/11/2005	0.60	10/11/2005	0.53	10/11/2005	<0.5
04/26/2006	<0.5	04/26/2006	0.97	04/26/2006	0.51
10/10/2006	0.80	10/10/2006	1.12	10/10/2006	0.52
03/19/2007	0.62	03/19/2007	0.54	03/19/2007	<0.5
08/29/2007	<0.5	08/29/2007	<0.5	09/05/2007	<0.5
03/11/2008	<0.5	03/11/2008	<0.5	03/11/2008	<0.5
09/10/2008	0.54	09/10/2008	0.56	09/10/2008	<0.5
03/10/2009	0.52	03/10/2009	0.55	03/10/2009	<0.5
08/18/2009	0.55	08/18/2009	0.56	08/18/2009	0.52
03/10/2010	0.54	03/10/2010	0.76	03/31/2010	0.60
08/10/2010	0.56	08/25/2010	<0.5	08/25/2010	0.56

^a Determined to be a false positive through resampling^b Multiple laboratories used; this value is average of Lionville Laboratory only

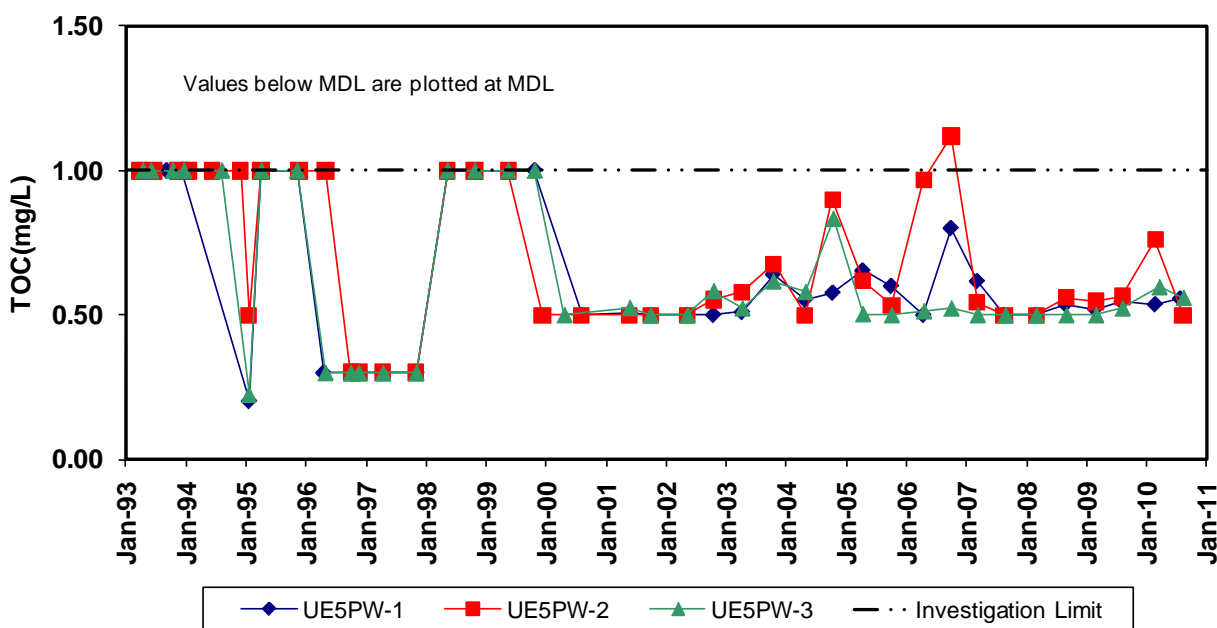


Figure 2-3. Area 5 RWMS Time Series Plot of TOC

2.2.4 Total Organic Halides

All 2010 TOX results are below the IL of 50 µg/L (Table 2-5). In 2010, three samples were collected from each well on each sample date, and the averages of the three sample results are reported in Table 2-5. When sample TOX values fell below the sample's MDL, the MDL was used to calculate the reported average. Values in Table 2-5 preceded by a less than symbol (<) indicate that all three samples were less than the MDL. TOC results for all three samples collected at UE5PW-1 and UE5PW-2 on March 10, 2010, UE5PW-3 on March 31, 2010, and UE5PW-3 on August 25, 2010, were less than the MDL. TOC results for the three samples collected from UE5PW-1 on August 10, 2010, were <5.0, 5.83, and 5.66 µg/L, and TOC results for the three samples collected from UE5PW-2 on August 25, 2010, were 7.75, < 5.0, and <5.0 µg/L. TOX values have remained relatively stable and below the IL throughout the monitoring period (Figure 2-4). No groundwater contamination is indicated by the TOX results.

Table 2-5. Area 5 RWMS TOX Values in µg/L

UE5PW-1		UE5PW-2		UE5PW-3	
Date	TOX	Date	TOX	Date	TOX
03/31/1993	17	03/24/1993	23	04/14/1993	<10
07/06/1993	<10	06/22/1993	<10	06/02/1993	13
09/01/1993	13	11/15/1993	<10	10/12/1993	<10
12/07/1993	<10	01/19/1994	<10	12/20/1993	<10
06/15/1994	<10	06/07/1994	<10	No Sample	
08/01/1994	11	11/29/1994	13	08/08/1994	<10
01/18/1995	<10	01/18/1995	<10	01/18/1995	<10
04/04/1995	<10	04/04/1995	<10	04/05/1995	<10
11/09/1995	<40	11/09/1995	<40	11/09/1995	<40
04/16/1996	<40	04/30/1996	<40	04/30/1996	<40
No Sample		10/02/1996	<20	10/02/1996	<20
11/20/1996	<20	11/20/1996	<20	11/20/1996	<20
04/16/1997	<20	04/16/1997	<20	04/16/1997	<20
11/05/1997	<20	11/05/1997	<20	11/05/1997	<20
05/13/1998	391 ^a	05/13/1998	843 ^a	05/13/1998	1000 ^a
07/29/1998	<5	No Sample		No Sample	
10/28/1998	<5	10/29/1998	<5	10/29/1998	<5
05/19/1999	<5	05/19/1999	<5	05/19/1999	<5
10/27/1999	<5	10/27/1999	<5	10/27/1999	7
04/26/2000	72 ^a	04/26/2000	59 ^a	04/26/2000	57 ^a
08/09/2000	92 ^{a,b}	08/09/2000	73 ^{a,b}	08/09/2000	83 ^{a,b}
05/29/2001	<12.7 ^b	05/29/2001	<12 ^b	05/29/2001	<12 ^b
10/03/2001	<6.1	10/03/2001	<5.8	10/03/2001	<5.2
05/15/2002	<5.2	05/15/2002	5.4	05/15/2002	<5.2
10/22/2002	<5.2	10/22/2002	<5.2	10/22/2002	<5.2
04/15/2003	<5.2	04/15/2003	<5.2	04/15/2003	<5.2
10/22/2003	<5.2	10/22/2003	5.5	10/21/2003	<5.2
05/04/2004	<5.2	05/04/2004	<5.2	05/04/2004	<5.2
10/19/2004	<5.2	10/19/2004	<5.2	10/20/2004	<5.2
04/19/2005	<5	04/19/2005	<5	04/19/2005	<5
10/11/2005	5.2	10/11/2005	6.5	10/11/2005	<5
04/26/2006	7.3	04/26/2006	5.8	04/26/2006	7.4
10/10/2006	<5.1	10/10/2006	<5	10/10/2006	<5
03/19/2007	<5.2	03/19/2007	<5.2	03/19/2007	<5.2
08/29/2007	<5.2	08/29/2007	<5.2	09/05/2007	<5.2
03/11/2008	<5.2	03/11/2008	<5.2	03/11/2008	<5.2
09/10/2008	<5.2	09/10/2008	5.9	09/10/2008	8.9
03/10/2009	<5	03/10/2009	<5	03/10/2009	<5
08/18/2009	<7.7	08/18/2009	<7.7	08/18/2009	<7.7
03/10/2010	<5	03/10/2010	<5	03/31/2010	<5
08/10/2010	5.5	08/25/2010	5.9	08/25/2010	<5

^a Determined to be a false positive through resampling^b Multiple laboratories used; this value is average of Lionville Laboratory only

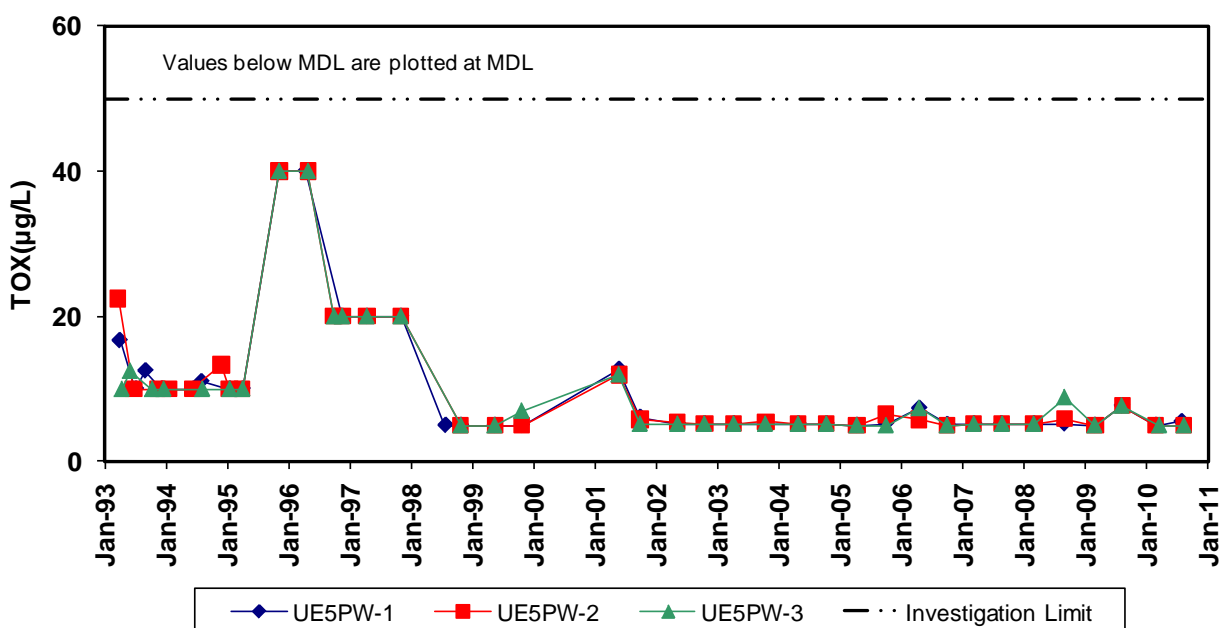


Figure 2-4. Area 5 RWMS Time Series Plot of TOX

2.2.5 Tritium

All tritium results from 2010 water samples were below the IL of 2,000 pCi/L and below the laboratory MDC of approximately 20 pCi/L (Table 2-6). In 2010, duplicate samples were collected from each well on each sample date. Table 2-6 reports the average of these two results. Tritium values have remained relatively stable and below the IL and MDC throughout the monitoring period (Figure 2-5). No groundwater contamination is indicated by the tritium results.

Table 2-6. Area 5 RWMS Tritium Values in pCi/L

UE5PW-1		UE5PW-2		UE5PW-3	
Date	Tritium	Date	Tritium	Date	Tritium
03/31/1993	0.442	03/24/1993	-4.28	04/14/1993	1.96
12/07/1993	-1.58	11/15/1993	32.2	06/02/1993	-2.74
No Sample		01/19/1994	3.69	12/20/1993	-0.459
06/15/1994	-2.04	06/07/1994	1.29	05/24/1994	1.13
08/01/1994	1.86	11/29/1994	0.015	08/08/1994	1.04
04/04/1995	2.80	04/04/1995	-0.920	04/05/1995	1.50
04/16/1996	-1.72	04/30/1996	-1.91	04/30/1996	-2.29
04/16/1997	3.15	04/16/1997	0.189	04/16/1997	3.69
05/13/1998	-2.35	05/13/1998	-1.95	05/13/1998	-4.71
10/28/1998	-1.09	10/28/1998	-1.85	10/28/1998	-8.25
05/19/1999	5.17	05/19/1999	4.24	05/19/1999	4.60
10/27/1999	-1.36	10/27/1999	-3.37	10/27/1999	1.08
04/26/2000	-2.56	04/26/2000	1.17	04/26/2000	-0.080
08/09/2000	-1.48	08/09/2000	6.97	08/09/2000	4.35

Table 2-6. Area 5 RWMS Tritium Values in pCi/L (continued)

UE5PW-1		UE5PW-2		UE5PW-3	
Date	Tritium	Date	Tritium	Date	Tritium
05/29/2001	-1.90	05/29/2001	-11.5	05/29/2001	-12.4
10/03/2001	-2.93	10/03/2001	-2.82	10/03/2001	2.46
05/15/2002	-2.82	05/15/2002	0.150	05/15/2002	-3.26
10/22/2002	-4.15	10/22/2002	0.113	10/22/2002	-1.17
04/15/2003	-1.13	04/15/2003	-5.22	04/15/2003	1.62
10/22/2003	0.952	10/22/2003	11.4	10/21/2003	0.405
05/04/2004	-2.69	05/04/2004	-6.17	05/04/2004	-6.04
10/19/2004	-1.50	10/19/2004	-10.0	10/20/2004	-6.39
04/19/2005	3.67	04/19/2005	3.76	04/19/2005	3.56
10/11/2005	8.83	10/11/2005	5.24	10/11/2005	-4.78
04/26/2006	0.480	04/26/2006	-2.70	04/26/2006	-6.71
10/10/2006	7.42	10/10/2006	9.35	10/10/2006	13.8
03/19/2007	-10.3	03/19/2007	-7.96	03/19/2007	-4.15
08/29/2007	-7.25	08/29/2007	-5.61	09/05/2007	-5.60
03/11/2008	5.33	03/11/2008	7.63	03/11/2008	-1.41
09/10/2008	4.53	09/10/2008	-2.03	09/10/2008	-4.98
03/10/2009	5.36	03/10/2009	11.80	03/10/2009	-3.77
08/18/2009	3.38	08/18/2009	1.62	08/18/2009	11.9
03/10/2010	-6.55	03/10/2010	-25.15	03/31/2010	-22.6
08/10/2010	-4.25	08/10/2010	0.08	08/10/2010	2.08

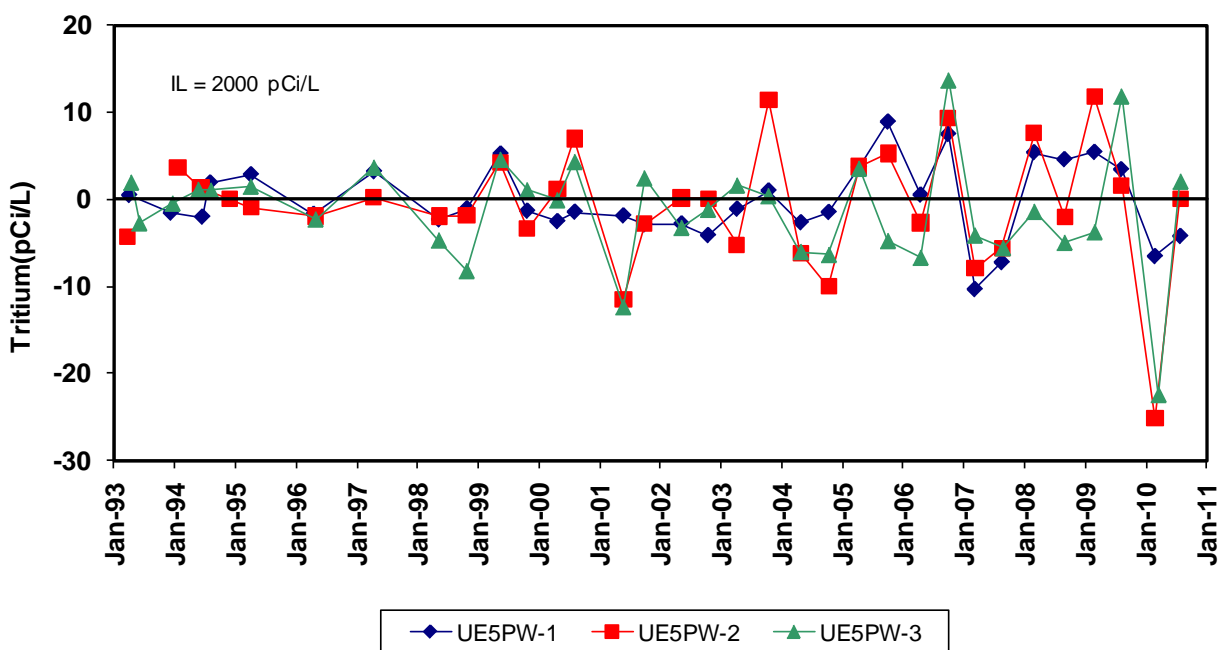


Figure 2-5. Area 5 RWMS Time Series Plot of Tritium

2.2.6 General Water Chemistry Parameters

General water chemistry analyses during 2010 for cations (Ca, Mg, Na, K, Fe), anions (Cl, F, SO₄, HCO₃), and SiO₂ indicate similar groundwater in all three wells and no changes in groundwater chemistry (Table 2-7, Table 2-8, and Table 2-9). Stiff plots for 2009 and 2010 indicate similar groundwater chemistry for all three wells and no changes in the groundwater chemistry (Figure 2-6). A piper diagram for the same water chemistry data from 2007 through 2010 indicates that the groundwater is a sodium-bicarbonate type (Figure 2-7).

Groundwater temperatures measured in March 2010 ranged from 17.5°C to 18.9°C (63.5°F to 66.0°F) and in August 2010 ranged from 21.9°C to 29.1°C (71.4°F to 84.4°F). Temperature measurements are collected at the ground surface and are influenced by the ambient air temperature.

Table 2-7. UE5PW-1 General Water Chemistry Values in mg/L

Date	Ca	Mg	K	Na	Mn	Fe	SiO ₂	SO ₄	HCO ₃	Cl	F
03/31/1993	No analysis	No analysis	No analysis	48	<0.006	0.013	No analysis	32	167	9.2	1.2
06/06/1993	No analysis	No analysis	No analysis	58	<0.001	0.059	No analysis	37	161	9.7	1.4
09/01/1993	No analysis	No analysis	No analysis	56	0.0066	0.027	No analysis	No analysis	158	8.4	5.7
12/07/1993	No analysis	No analysis	No analysis	57	<0.0012	0.012	No analysis	36	150	9.9	1.5
06/15/1994	No analysis	No analysis	No analysis	61	<0.004	0.01	No analysis	No analysis	No analysis	No analysis	No analysis
08/01/1994	No analysis	No analysis	No analysis	53	<0.0012	0.021	No analysis	36	No analysis	10.0	No analysis
04/04/1995	No analysis	No analysis	No analysis	58	<0.01	<0.05	No analysis	34	No analysis	9.9	No analysis
04/16/1996	No analysis	No analysis	No analysis	61	<0.001	0.02	No analysis	34	No analysis	9.9	No analysis
04/16/1997	15.1	5.3	5.9	54.5	<0.001	0.012	No analysis	32.2	156	9.3	1.3
11/05/1997	15.5	5.6	6.4	57.8	No analysis	0.012	No analysis	35.2	151	10.2	1.2
05/13/1998	14.0	5.4	5.2	55.8	0.0015	0.034	54.2	34.6	151	9.6	1.1
10/28/1998	14.9	5.6	6.9	57.6	0.0015	0.024	60.5	34.0	160	9.7	1.1
05/19/1999	12.5	5.3	6.9	61.0	<0.0025	<0.05	68.5	34.0	146	10.0	1.0
10/27/1999	14.5	6.0	6.6	63.5	<0.008	<0.009	62.0	35.0	159	8.8	1.1
04/26/2000	12.8	4.8	6.7	53.7	0.001	0.0326	58.4	35.7	165	10.0	1.0
08/9/2000	15.0	4.9	6.6	52.0	0.00045	<0.0164	59.9	37.1	146	10.4	1.1
05/29/2001	14.4	4.9	6.0	59.0	<0.025	0.01215	61.7	No analysis	143	No analysis	No analysis
10/03/2001	13.7	4.8	6.7	51.0	0.00020	<0.0156	58.3	36.0	151	10.2	1.0
05/15/2002	14.3	5.1	7.0	54.5	0.00053	0.02845	60.9	35.9	155	10.7	1.0
10/22/2002	14.6	5.2	6.4	50.0	0.0002	0.0181	60.7	35.6	143	10.1	1.0
04/15/2003	13.7	5.0	6.2	58.0	<0.0005	0.011	59.2	32.9	150	12.3	1.0
10/22/2003	14.0	5.0	6.0	58.1	<0.0016	0.0141	61.2	36.6	No analysis	9.5	1.1
05/04/2004	12.9	4.6	6.4	55.3	0.0027	0.0374	54.4	34.4	154	9.8	1.1
10/19/2004	13.1	5.2	6.0	56.2	<0.0003	0.0279	59.9	37.3	168	10.1	1.0
04/19/2005	13.8	4.8	6.6	55.1	<0.0006	0.007	58.6	39.6	149	10.5	1.0
10/11/2005	13.4	5.0	6.1	50.5	<0.0002	<0.026	61.2	35.7	156	9.7	1.0
04/26/2006	14.6	5.3	6.3	60.4	<0.0032	<0.0054	63.3	35.4	149	10.7	1.2
10/10/2006	14.0	5.2	5.9	58.8	0.0007	<0.0048	61.4	33.8	148	9.9	0.9
03/19/2007	15.7	5.4	6.0	57.4	<0.0036	0.0124	64.0	37.7	151	10.5	1.0
08/29/2007	15.4	5.4	6.2	59.0	0.00046	0.0058	64.6	35.9	148	10.0	1.2
03/11/2008	14.0	5.4	6.3	60.4	<0.00045	0.0066	63.1	37.4	149	11.1	1.2
09/10/2008	14.3	5.5	6.4	59.1	<0.0009	<0.045	62.5	34.7	155	11.0	1.2
03/10/2009	13.4	5.3	6.1	58.1	<0.005	<0.100	58.6	35.7	174	10.1	1.1
08/18/2009	13.4	5.3	6.0	58.3	0.00113	0.0168	61.8	37.1	160	11.0	1.0
03/10/2010	13.3	5.3	6.0	59.6	<0.005	<0.100	65.2	38.5	151	10.7	1.0
08/10/2010	12.8	5.2	5.9	57.6	0.00054	<0.050	44.1	35.7	162	11.0	1.0

Data source: Data before 10/27/1999 from BN, 2001

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Table 2-8. UE5PW-2 General Water Chemistry Values in mg/L

Date	Ca	Mg	K	Na	Mn	Fe	SiO ₂	SO ₄	HCO ₃	Cl	F
03/24/1993	No analysis	No analysis	No analysis	46	0.11	0.062	No analysis	28	159	8.4	1.0
06/22/1993	No analysis	No analysis	No analysis	54	0.032	0.25	No analysis	30	183	9.7	1.1
11/15/1993	No analysis	No analysis	No analysis	51	<0.004	0.180	No analysis	31	171	9.4	1.3
01/19/1994	No analysis	No analysis	No analysis	45	<0.0012	0.074	No analysis	29	159	No analysis	1.2
06/07/1994	No analysis	No analysis	No analysis	55	<0.004	0.14	No analysis	No analysis	No analysis	No analysis	No analysis
11/29/1994	No analysis	No analysis	No analysis	No analysis	No analysis	No analysis	No analysis	28	No analysis	8.0	No analysis
04/04/1995	No analysis	No analysis	No analysis	50	<0.01	<0.05	No analysis	28	No analysis	8.5	No analysis
04/30/1996	No analysis	No analysis	No analysis	51	<0.001	0.0127	No analysis	29	No analysis	8.3	No analysis
04/16/1997	15.9	6.0	5.0	47.6	<0.001	0.012	No analysis	26.4	149	7.9	1.2
11/05/1997	17.4	6.8	4.9	50.6	No analysis	0.018	No analysis	28.9	140	8.6	0.9
05/13/1998	14.8	5.7	3.8	45.2	<0.0011	0.073	50.8	28.2	151	8.1	1.0
10/28/1998	15.8	6.2	5.6	47.4	0.0009	0.018	55.9	28.4	157	8.3	1.0
05/19/1999	15.0	6.3	6.2	52.0	<0.0025	<0.05	62.0	27.5	134	8.7	0.9
10/27/1999	16.0	6.7	5.7	52.0	<0.0008	<0.009	55.6	28.0	152	7.4	1.0
04/26/2000	15.3	6.5	5.6	45.6	0.0007	0.0288	55.8	29.1	177	8.6	0.8
08/09/2000	17.0	6.6	5.3	44.5	<0.0002	<0.0164	59.2	28.8	155	9.3	0.9
05/29/2001	16.6	6.6	4.8	48.8	<0.0088	<0.0107	60.4	No analysis	152	No analysis	No analysis
10/03/2001	16.0	6.7	5.5	44.7	0.00017	0.0214	58.8	28.4	152	8.7	1.0
05/15/2002	16.5	6.8	5.6	46.1	0.00059	0.0603	60.1	28.7	155	9.3	0.9
10/22/2002	17.6	7.1	5.3	44.4	0.0031	<0.0181	63.0	28.7	149	8.7	0.8
04/15/2003	16.3	6.6	5.3	50.8	<0.0005	<0.0101	60.3	26.7	157	9.8	0.8
10/22/2003	16.1	6.6	5.2	49.6	<0.0016	0.0618	60.5	29.5	141	8.8	0.9
05/4/2004	16.0	6.3	5.4	47.2	<0.0007	0.0397	58.2	28.1	159	8.2	0.9
10/19/2004	15.7	6.7	5.1	48.6	<0.0003	<0.0279	59.7	29.6	169	8.9	0.9
04/19/2005	16.3	6.3	5.2	44.9	<0.0006	0.0115	58.6	31.3	133	8.4	0.9
10/11/2005	16.0	6.8	5.0	44.0	<0.0002	0.0270	62.2	29.0	167	8.1	0.9
04/26/2006	16.6	6.7	5.4	51.2	<0.0032	0.0612	62.5	28.1	152	8.8	1.1
10/10/2006	16.5	6.5	5.2	48.0	<0.0007	0.0170	61.2	27.2	156	8.6	1.1
03/19/2007	16.8	6.6	5.4	49.8	<0.0036	0.0387	62.9	42.2	149	11.3	0.9
08/29/2007	16.9	6.7	5.2	50.5	<0.00045	0.0098	63.7	27.9	151	9.0	1.1
03/11/2008	16.7	6.7	5.2	50.5	<0.00045	0.0159	60.3	30.7	149	10.0	1.0
09/10/2008	16.8	7.0	5.7	52.7	0.0020	<0.045	60.3	28.7	152	9.2	1.0
03/10/2009	15.9	6.7	5.0	50.0	<0.005	<0.100	61.6	28.9	165	8.4	1.0
08/18/2009	15.5	6.8	5.1	50.9	0.00066	0.0123	61.2	29.1	155	8.8	0.9
03/10/2010	15.6	6.6	5.0	51.2	0.00052	0.0199	62.2	30.9	156	8.9	0.9
08/10/2010	15.2	6.5	4.9	49.9	0.00074	0.0158	47.5	29.8	167	8.8	0.9

Data source: Data before 10/27/1999 from BN, 2001

Table 2-9. UE5PW-3 General Water Chemistry Values in mg/L

Date	Ca	Mg	K	Na	Mn	Fe	SiO ₂	SO ₄	HCO ₃	Cl	F
04/14/1993	No analysis	No analysis	No analysis	46	0.042	0.024	No analysis	31	157	8.5	1.3
06/02/1993	No analysis	No analysis	No analysis	53	0.009	0.014	No analysis	31	162	9.1	1.2
10/12/1993	No analysis	No analysis	No analysis	57	<0.006	0.11	No analysis	30	156	7.9	1.2
12/20/1993	No analysis	No analysis	No analysis	48	<0.0012	0.1	No analysis	33	156	8.7	1.3
05/24/1994	No analysis	No analysis	No analysis	56	<0.0012	0.02	No analysis	No analysis	No analysis	No analysis	No analysis
08/08/1994	No analysis	No analysis	No analysis	51	<0.0012	<0.009	No analysis	33	No analysis	8.9	No analysis
04/05/1995	No analysis	No analysis	No analysis	55	<0.01	<0.05	No analysis	31	No analysis	8.8	No analysis
04/30/1996	No analysis	No analysis	No analysis	57	<0.001	0.0088	No analysis	32	No analysis	8.7	No analysis
04/16/1997	15.8	5.7	4.0	54.2	<0.001	<0.006	No analysis	29	155	8.4	1.3
11/05/1997	16.8	6.1	4.3	55.5	No analysis	0.0133	No analysis	32.1	140	9.2	1.1
05/13/1998	15.8	5.8	3.3	53.8	<0.0011	0.025	56.6	30.9	151	8.4	1.0
10/28/1998	15.6	5.7	4.2	53.7	0.0009	0.0154	57.1	31.8	156	8.7	1.0
05/19/1999	15.0	5.8	4.8	56.0	<0.0025	<0.05	66.3	30.5	146	9.2	0.9
10/27/1999	16.0	6.4	5.0	58.5	<0.0008	<0.009	59.9	31.0	159	7.7	0.9
04/26/2000	15.3	5.9	4.5	49.8	0.00033	0.0178	58.5	32.0	169	9.1	0.9
08/09/2000	16.0	5.8	4.3	48.3	<0.0002	<0.0164	57.8	32.6	162	9.9	1.0
05/29/2001	16.4	5.9	4.0	54.8	0.00180	<0.0107	60.5	No analysis	151	No analysis	No analysis
10/03/2001	15.6	6.0	4.5	48.4	0.00022	0.0237	57.9	31.5	154	8.9	1.0
05/15/2002	15.7	6.0	4.5	49.3	0.00027	0.0249	57.9	33.0	151	9.8	0.9
10/22/2002	17.2	6.2	4.3	47.6	<0.0002	<0.0181	60.5	32.2	143	9.3	0.9
04/15/2003	16.0	5.9	4.5	54.7	0.00083	0.0195	58.4	29.3	144	11.8	0.8
10/21/2003	16.3	5.8	4.1	54.4	<0.0016	0.0212	59.5	32.5	160	9.2	1.0
05/04/2004	16.1	5.6	4.7	52.2	0.0019	0.0453	58.2	31.1	155	8.7	1.0
10/20/2004	15.6	5.9	4.0	52.3	<0.0003	<0.0279	58.4	32.0	166	9.4	0.8
04/19/2005	16.2	5.6	4.5	50.9	<0.0006	0.0319	57.8	34.4	148	8.8	0.9
10/11/2005	16.1	6.1	4.3	48.5	<0.0002	<0.026	61.4	32.5	156	8.5	0.9
04/26/2006	16.6	6.1	4.2	58.1	<0.0032	0.0057	61.6	31.6	159	9.4	1.2
10/10/2006	15.9	5.5	4.0	49.7	0.0007	0.0114	57.3	30.1	152	9.0	1.0
03/19/2007	16.8	6.1	4.0	55.5	<0.0036	0.0921	61.2	19.9	149	9.3	0.8
09/05/2007	16.5	5.9	4.3	54.7	0.0012	0.0041	60.1	32.5	149	9.8	1.1
03/11/2008	16.7	6.1	4.2	57.2	<0.00045	0.0045	58.8	32.1	144	9.9	1.0
09/10/2008	16.4	6.1	4.5	56.4	<0.0009	<0.045	58.8	35.9	165	9.5	1.0
03/10/2009	15.9	6.0	4.2	55.6	<0.005	0.100	59.0	31.7	155	9.0	0.9
08/18/2009	15.4	5.9	4.0	54.7	0.00062	0.0112	58.4	32.5	152	9.4	0.9
03/31/2010	15.5	6.1	4.1	55.9	0.00111	0.0276	56.9	38.3	144	11.0	1.3
08/10/2010	14.9	5.6	4.0	54.6	<0.002	0.0154	49.4	31.5	162	9.5	0.9

Data source: Data before 10/27/1999 from BN, 2001

Groundwater Monitoring Program
Area 5 Radioactive Waste Management Site

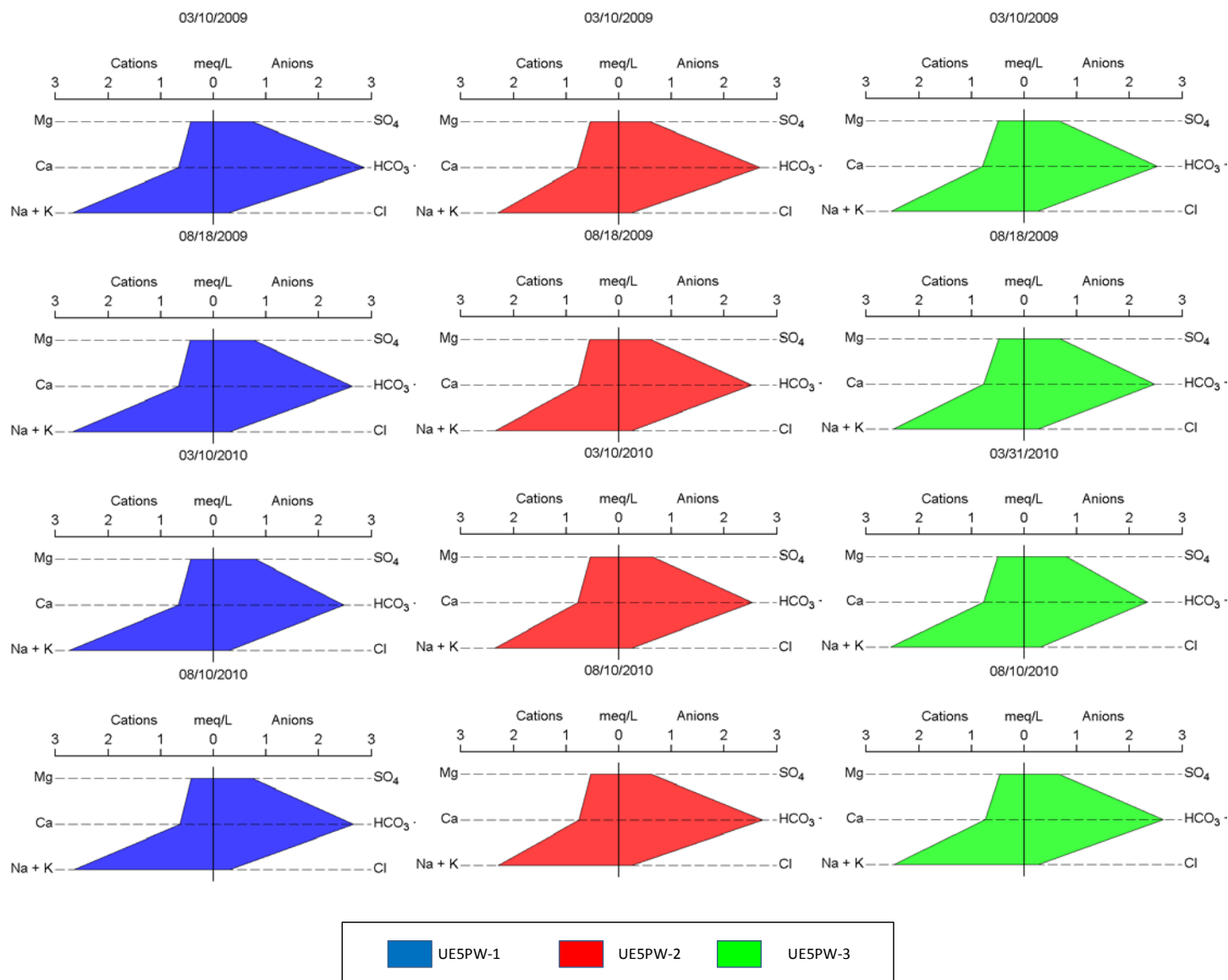


Figure 2-6. Area 5 RWMS Stiff Diagrams for 2009 and 2010

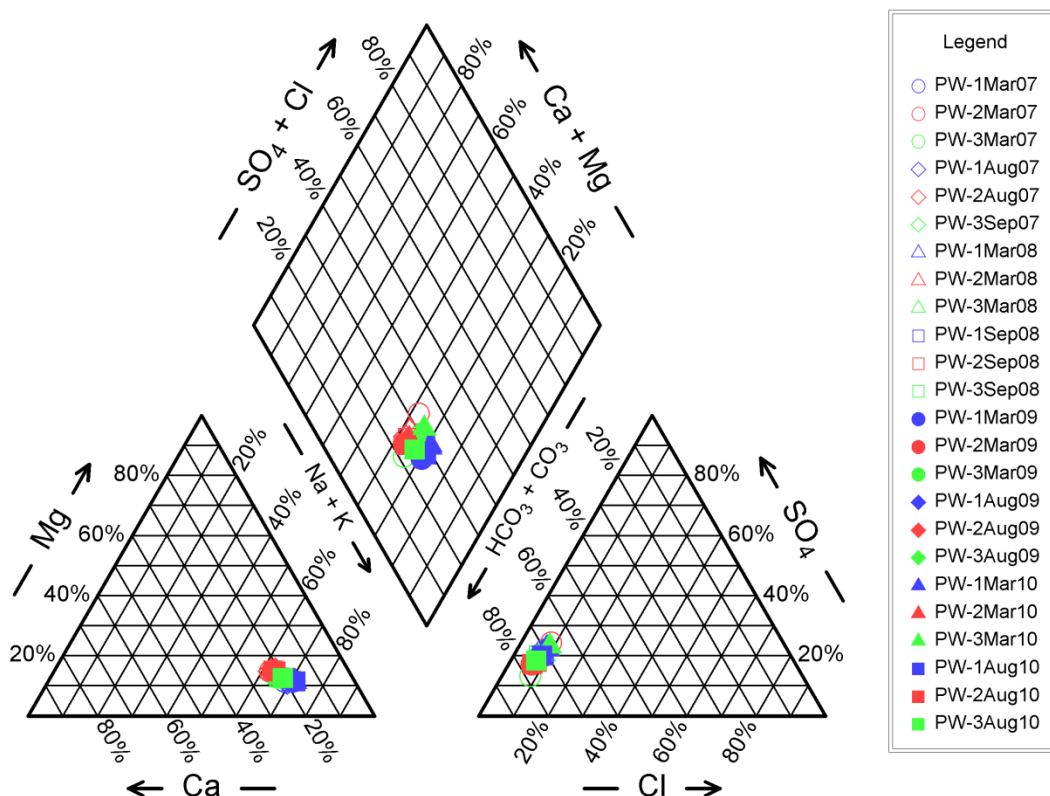


Figure 2-7. Area 5 RWMS Four-Year Piper Diagram

2.2.7 Groundwater Elevation

Groundwater elevations in UE5PW-1, UE5PW-2, and UE5PW-3 are measured quarterly using an electronic water-level tape (Table 2-10). The 2010 average depths to water from top of casing are 235.82 m (773.69 ft), 256.43 m (841.30 ft), and 271.54 m (890.88 ft) for UE5PW-1, UE5PW-2, and UE5PW-3, respectively. These measurements are corrected for borehole deviation (REECo, 1994).

The 2010 average groundwater elevations are 733.55 m (2,406.65 ft) AMSL, 733.69 m (2,407.11 ft) AMSL, and 733.69 m (2,407.11 ft) AMSL for UE5PW-1, UE5PW-2, and UE5PW-3, respectively. These measurements are corrected for borehole deviation (REECo, 1994). Based on the similar groundwater elevations, the groundwater table is essentially flat with little or no flow. Groundwater gradient, velocity, and flow direction are calculated from the groundwater elevations, borehole locations, and aquifer hydraulic properties (Table 2-13; Appendix B). The average calculated flow velocity during 2010 was 0.09 meters/year and the flow direction was south. The very low calculated flow velocities and the fluctuating flow directions indicate little or no groundwater flow.

Table 2-10. Area 5 RWMS Groundwater Elevation Data

Well Characteristics^a	UE5PW-1		UE5PW-2		UE5PW-3	
Northing ^b (m)	233,386.48		234,817.13		235,089.93	
Easting ^b (m)	216,357.08		216,376.00		214,415.04	
Well Casing Elevation ^c (m)	969.37		990.12		1,005.22	
Casing Stickup Height ^d (m)	0.72		0.68		0.76	
Land Surface Elevation (m)	968.73		989.54		1,004.50	
Borehole Deviation Correction (m)	0.08		0.21		0.02	
Date	Depth to Water (m below Top of Casing)	Water Table Elevation (m)	Depth to Water (m below Top of Casing)	Water Table Elevation (m)	Depth to Water (m below Top of Casing)	Water Table Elevation (m)
03/22/1993	235.55	733.82	256.38	733.74	271.69	733.53
03/23/1993	235.53	733.84	256.48	733.64	271.68	733.54
03/24/1993	235.53	733.84	256.36	733.76	271.69	733.53
03/25/1993	235.53	733.84	256.35	733.77	271.69	733.53
03/29/1993	235.59	733.78	256.38	733.74	271.73	733.49
03/30/1993	235.62	733.75	256.43	733.69	271.75	733.47
03/31/1993	235.62	733.75	256.44	733.68	271.74	733.48
04/01/1993	235.54	733.83	256.37	733.75	271.69	733.53
04/05/1993	235.51	733.86	256.35	733.77	271.67	733.55
04/06/1993	235.59	733.78	256.40	733.72	271.75	733.47
05/10/1993	235.64	733.73	256.46	733.66	271.76	733.46
05/11/1993	235.56	733.81	256.42	733.70	271.70	733.52
05/12/1993	235.54	733.83	256.40	733.72	271.72	733.50
05/13/1993	235.61	733.76	256.45	733.67	271.75	733.47
05/17/1993	235.61	733.76	256.45	733.67	271.74	733.48
05/18/1993	235.59	733.78	256.45	733.67	271.74	733.48
05/19/1993	235.59	733.78	256.44	733.68	271.73	733.49
05/20/1993	235.54	733.83	256.39	733.73	271.70	733.52
05/24/1993	235.60	733.77	256.43	733.69	271.74	733.48
05/25/1993	235.61	733.76	256.45	733.67	271.74	733.48
06/01/1993	235.58	733.79	256.43	733.69	271.73	733.49
06/07/1993	235.64	733.73	256.46	733.66	271.76	733.46
06/14/1993	235.61	733.76	256.46	733.66	271.74	733.48
06/21/1993	235.58	733.79	256.43	733.69	271.73	733.49
07/26/1993	235.59	733.78	256.45	733.67	271.74	733.48
08/03/1993	235.54	733.83	256.42	733.70	271.70	733.52
08/09/1993	235.62	733.75	256.46	733.66	271.75	733.47
08/16/1993	235.59	733.78	256.42	733.70	271.73	733.49
08/30/1993	235.58	733.79	256.43	733.69	271.72	733.50
12/28/1993	235.59	733.78	256.47	733.65	271.74	733.48
01/03/1994	235.57	733.80	256.44	733.68	271.70	733.52
02/02/1994	235.53	733.84	256.44	733.68	271.66	733.56
02/22/1994	235.60	733.77	256.43	733.69	271.71	733.51

Table 2-11. Area 5 RWMS Groundwater Elevation Data (continued)

	UE5PW-1		UE5PW-2		UE5PW-3	
Date	Depth to Water (m below Top of Casing)	Water Table Elevation (m)	Depth to Water (m below Top of Casing)	Water Table Elevation (m)	Depth to Water (m below Top of Casing)	Water Table Elevation (m)
02/28/1994	235.60	733.77	256.45	733.67	271.70	733.52
03/07/1994	235.54	733.83	256.38	733.74	271.66	733.56
03/14/1994	235.55	733.82	256.45	733.67	271.67	733.55
03/21/1994	235.56	733.81	256.38	733.74	271.68	733.54
03/28/1994	235.63	733.74	256.47	733.65	271.70	733.52
04/04/1994	235.53	733.84	256.40	733.72	271.66	733.56
04/13/1994	235.55	733.82	256.43	733.69	271.65	733.57
04/20/1994	235.51	733.86	256.38	733.74	271.64	733.58
04/26/1994	235.55	733.82	256.35	733.77	271.65	733.57
01/18/1995	235.63	733.74	256.45	733.67	271.62	733.60
04/03/1995	235.57	733.80	256.39	733.73	271.61	733.61
01/16/1996	235.36	734.01	256.13	733.99	271.35	733.87
04/15/1996	235.56	733.81	256.30	733.82	271.43	733.79
10/01/1996	235.54	733.83	256.32	733.80	271.51	733.71
11/19/1996	235.59	733.78	256.33	733.79	271.52	733.70
03/03/1997	235.54	733.83	256.30	733.82	271.41	733.81
04/15/1997	235.63	733.74	256.40	733.72	271.54	733.68
06/18/1997	235.61	733.76	256.40	733.72	271.52	733.70
07/28/1997	235.60	733.77	256.37	733.75	271.51	733.71
08/20/1997	235.52	733.85	256.29	733.83	271.44	733.78
09/25/1997	235.59	733.78	256.35	733.77	271.49	733.73
10/27/1997	235.57	733.80	256.34	733.78	271.48	733.74
11/03/1997	235.65	733.72	256.40	733.72	271.55	733.67
11/06/1997	235.57	733.80	256.36	733.76	271.48	733.74
11/12/1997	235.66	733.71	256.45	733.67	271.54	733.68
11/13/1997	235.60	733.77	256.29	733.83	271.49	733.73
11/19/1997	235.63	733.74	256.42	733.70	271.55	733.67
11/20/1997	235.65	733.72	256.43	733.69	271.57	733.65
11/25/1997	235.64	733.73	256.39	733.73	271.54	733.68
11/26/1997	235.50	733.87	256.27	733.85	271.45	733.77
12/03/1997	235.71	733.66	256.43	733.69	271.60	733.62
01/26/1998	235.72	733.65	256.47	733.65	271.60	733.62
05/12/1998	235.60	733.77	256.32	733.80	271.52	733.70
10/27/1998	235.52	733.85	256.21	733.91	271.36	733.86
12/22/1998	235.54	733.83	256.20	733.92	271.35	733.87
02/02/1999	235.61	733.76	256.34	733.78	271.42	733.80
05/18/1999	235.56	733.81	256.26	733.86	271.35	733.87
08/25/1999	235.56	733.81	256.26	733.86	271.38	733.84
10/26/1999	235.57	733.80	256.26	733.86	271.34	733.88
04/24/2000	235.64	733.73	256.34	733.78	271.52	733.70
08/07/2000	235.59	733.78	256.30	733.82	271.47	733.75
11/13/2000	235.66	733.71	256.34	733.78	271.45	733.77
02/22/2001	235.57	733.80	256.26	733.86	271.38	733.84
05/21/2001	235.67	733.70	256.35	733.77	271.49	733.73
08/01/2001	235.66	733.71	256.36	733.76	271.48	733.74
10/01/2001	235.66	733.71	256.35	733.77	271.45	733.77

Table 2-12. Area 5 RWMS Groundwater Elevation Data (continued)

	UE5PW-1		UE5PW-2		UE5PW-3	
Date	Depth to Water (m below Top of Casing)	Water Table Elevation (m)	Depth to Water (m below Top of Casing)	Water Table Elevation (m)	Depth to Water (m below Top of Casing)	Water Table Elevation (m)
02/26/2002	235.76	733.61	256.43	733.69	271.52	733.70
05/13/2002	235.65	733.72	256.39	733.73	271.44	733.78
08/19/2002	235.61	733.76	256.28	733.84	271.42	733.80
10/21/2002	235.61	733.76	256.31	733.81	271.44	733.78
02/26/2003	235.65	733.72	256.28	733.84	271.43	733.79
04/10/2003	235.61	733.76	256.30	733.82	271.41	733.81
09/10/2003	235.74	733.63	256.35	733.77	271.50	733.72
10/20/2003	235.73	733.64	256.42	733.70	271.53	733.69
02/25/2004	235.78	733.59	256.36	733.76	271.52	733.70
04/27/2004	235.72	733.65	256.43	733.69	271.52	733.70
08/18/2004	235.72	733.65	256.38	733.74	271.48	733.74
10/18/2004	235.71	733.66	256.29	733.83	271.47	733.75
01/26/2005	235.67	733.70	256.45	733.67	271.46	733.76
04/18/2005	235.66	733.71	256.33	733.79	271.44	733.78
07/27/2005	235.75	733.62	256.42	733.70	271.51	733.71
10/10/2005	235.77	733.60	256.44	733.68	271.54	733.68
03/08/2006	235.74	733.63	256.39	733.73	271.50	733.72
05/03/2006	235.69	733.68	256.41	733.71	271.62	733.60
08/23/2006	235.76	733.61	256.43	733.69	271.50	733.72
10/09/2006	235.69	733.68	256.38	733.74	271.44	733.78
02/28/2007	235.74	733.63	256.29	733.83	271.49	733.73
07/11/2007	235.77	733.60	256.41	733.71	271.50	733.72
08/28/2007	235.78	733.59	256.42	733.70	271.47	733.75
10/15/2007	235.76	733.61	256.40	733.72	271.49	733.73
01/22/2008	235.79	733.58	256.39	733.73	271.53	733.69
03/03/2008	235.80	733.57	256.38	733.74	271.53	733.69
06/16/2008	235.74	733.63	256.32	733.80	271.48	733.74
09/09/2008	235.73	733.64	256.39	733.73	271.47	733.75
02/17/2009	235.78	733.59	256.40	733.72	271.52	733.70
05/06/2009	235.80	733.57	256.41	733.71	271.52	733.70
08/17/2009	235.76	733.61	256.39	733.73	271.51	733.71
11/10/2009	235.81	733.56	256.46	733.66	271.55	733.67
03/01/2010	235.85	733.52	256.47	733.65	271.57	733.65
04/26/2010	235.78	733.59	256.44	733.68	271.52	733.70
08/09/2010	235.82	733.55	256.41	733.71	271.51	733.71
11/09/2010	235.82	733.55	256.40	733.72	271.54	733.68

^a Source for northings, eastings, well casing elevations, and deviation corrections: REECO, 1994

^b Coordinate System: Nevada (Central) State Plane NAD27

^c Measured from top of well casing

^d Measured from top of well casing to land surface

NOTE: All elevations are m above mean sea level

Table 2-13. 2010 Area 5 RWMS Groundwater Flow Calculations

Hydraulic Conductivity = 1.12E-03 cm/s (3.67E-05 ft/s) ^a			
Effective Porosity = 0.38 ^a			
Date	Hydraulic Gradient (m/m)	Velocity (m/yr)	Flow Direction (degrees East of North)
03/01/2010	9.16E-05	0.09	188
04/26/2010	6.29E-05	0.06	179
08/09/2010	1.13E-04	0.10	188
11/09/2010	1.24E-04	0.12	197

^a Source: REECO, 1994

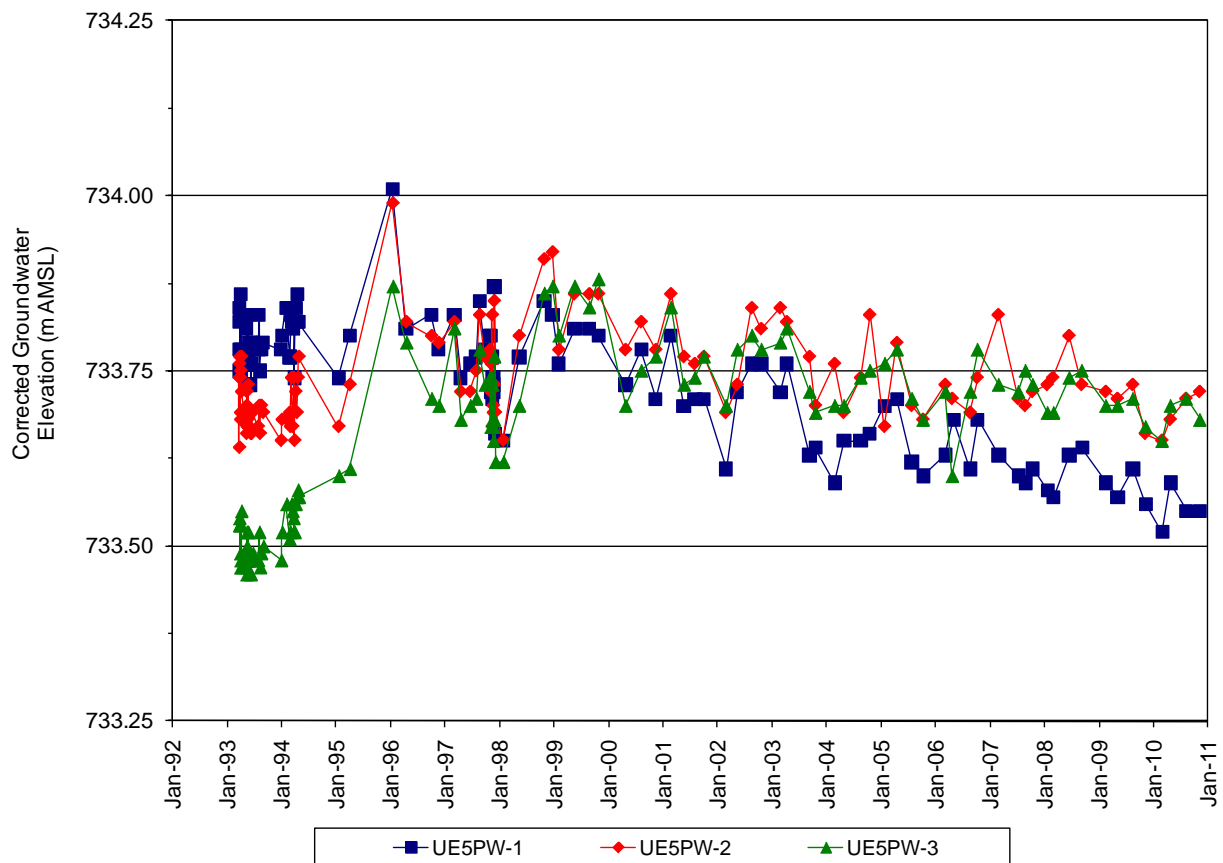


Figure 2-8. Area 5 RWMS Time Series Plot of Groundwater Elevations

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3.0 SUMMARY

The hydrologic conditions in the uppermost aquifer beneath the Area 5 RWMS remain stable. Groundwater flow in this uppermost aquifer is negligible. No significant changes were detected in the water chemistry, and all indicator parameters remain within the established ILs.

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4.0 CONCLUSION

There is no measurable impact to the uppermost aquifer from the Area 5 RWMS.

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Appendix A – Cumulative Chronology for the Area 5 Radioactive Waste Management Site Groundwater Monitoring Program

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Cumulative Chronology for Area 5 RWMS Groundwater (GW) Monitoring Program					
Date	UE5PW-1	Date	UE5PW-2	Date	UE5PW-3
03/20/1990	U.S. Department of Energy (DOE) letter requesting installation of monitoring wells near the Area 5 RWMS.				
03/13/1992	Drilling begins				
06/16/1992	Drilling ends	06/18/1992	Drilling begins		
09/11/1992	Well developed	09/04/1992	Drilling ends		
				09/16/1992	Drilling begins
				11/09/1992	Drilling ends
		03/24/1993	GW Sampling		
03/31/1993	GW Sampling	03/30/1993	Well developed	04/04/1993	Well developed
				04/14/1993	GW Sampling
06/06/1993	GW Sampling	06/22/1993	GW Sampling	06/02/1993	GW Sampling
09/01/1993	GW Sampling			10/12/1993	GW Sampling
12/07/1993	GW Sampling	11/15/1993	GW Sampling	12/20/1993	GW Sampling
12/17/1993	DOE letter to Nevada Department of Environmental Protection (NDEP) requesting to establish pilot wells located near the Area 5 RWMS as Resource Conservation and Recovery Act (RCRA) GW monitoring wells.				
02/24/1994	NDEP letter stating that the pilot wells appear to meet the applicable design, construction, and development criteria for RCRA GW monitoring wells.				
06/15/1994	GW Sampling	06/07/1994	GW Sampling	05/24/1994	GW Sampling
08/01/1994	GW Sampling			08/08/1994	GW Sampling
		11/29/1994	GW Sampling		
09/30/1994	DOE submits 1993 GW monitoring results from quarterly sampling effort.				
01/18/1995	UE5PW-3 GW resampling for 08/01/1994 total organic carbon (TOC) hit.				
02/23/1995	DOE transmits to NDEP GW Monitoring Program Outline.				
03/01/1995	1994 GW Monitoring Report submitted to NDEP.				
04/04/1995	GW Sampling				
11/09/1995	GW Sampling				
11/09/1995	UE5PW-1 pump snagged in hole, resulting in a bent shaft on the reel.				
01/18/1996	GW Sampling	01/25/1996	GW Sampling	01/18/1996	GW Sampling
01/22/1996	Bennett pump seals replaced at all three wells.				

Groundwater Monitoring Program
Area 5 Radioactive Waste Management Site

Cumulative Chronology for Area 5 RWMS Groundwater (GW) Monitoring Program					
Date	UE5PW-1	Date	UE5PW-2	Date	UE5PW-3
03/01/1996	DOE submits to NDEP the 1995 GW Monitoring Report.				
04/16/1996	GW Sampling	04/23/1996	GW Sampling		
		04/30/1996	GW Sampling		
10/02/1996	GW Sampling				
10/25/1996	NDEP requests clarifications/changes in the GW Monitoring Report.				
11/20/1996	GW Sampling				
03/01/1997	DOE submits 1996 GW Monitoring Report and revised GW Monitoring Program Outline.				
04/16/1997	GW Sampling				
08/12/1997	NDEP comments on 1996 GW Monitoring Report/Proposed Outline.				
10/22/1997	Pump and water-level meter lodge in UE5PW-1 during simultaneous operation, retrieved 10/23/1997.				
10/22/1997	Larger diameter air lines installed at all three wells.				
11/05/1997	GW Sampling				
03/01/1998	DOE submits to NDEP the 1997 GW Monitoring Report and new outline.				
03/31/1998	NDEP letter stating that they concur on the indicator parameters and investigation levels submitted in the GW Monitoring Outline.				
05/13/1998	GW Sampling				
06/22/1998	Total organic halides (TOX) detected in the 05/13/1998 samples and blanks from all three wells.				
07/10/1998	DOE and NDEP agree to resample UE5PW-1 to confirm no TOX.				
07/29/1998	GW resampling at UE5PW-1 for 05/13/1998 TOX hits.				
09/10/1998	Results from 07/29/1998 resampling are non-detect for TOX. TOX results from the 05/13/1998 sampling event are determined to be false positives.				
09/10/1998	Bennett pumps from three wells and spare pumps are sent to manufacturer for refurbishing.				
09/12/1998	Reels from three wells are returned to manufacturer for new tubing bundles.				
10/28/1998	GW Sampling				
09/12/1998	UE5PW-1 reel returned to manufacturer for repair of exhaust tube. Spare pump returned to manufacturer for the repair of a leaky seal.				
03/01/1999	DOE submits to NDEP 1998 GW Monitoring Report.				
03/31/1999	NDEP requests statistical analysis of data and states that values determined to be false positives through resampling do not need to be presented graphically.				
05/19/1999	GW Sampling				
10/27/1999	GW Sampling				
12/13/1999	Resample UE5PW-2 after TOC hit from 10/27/1999.				

Cumulative Chronology for Area 5 RWMS Groundwater (GW) Monitoring Program					
Date	UE5PW-1	Date	UE5PW-2	Date	UE5PW-3
12/27/1999	Results from the resampling of UE5PW-2 are non-detect for TOC. TOC result from 10/27/1999 is determined to be a false positive.				
02/25/2000	DOE submits to NDEP 1999 GW Monitoring Report.				
04/17/2000	NDEP states that future reports do not need to include statistical analyses.				
04/26/2000	GW Sampling				
06/28/2000	DOE contacts State to report TOX/TOC hits from 04/26/2000. DOE and NDEP agree that the wells will be resampled in August, which would also constitute the Fall sampling event.				
08/09/2000	GW Sampling				
09/20/2000	DOE contacts NDEP to report TOX hits from 08/09/2000 sampling.				
11/07/2000	Letter from NDEP stating that DOE does not have a valid data set for TOX and possibly TOC and requests a plan to address contamination concerns prior to next sampling event.				
11/20/2000	Video log well			11/27/2000	Video log well
12/20/2000	DOE transmits to NDEP a proposed plan to address contamination issues.				
01/31/2001	Letter from NDEP generally concurring that the plan submitted to determine the cause of TOX and TOC hits is sound.				
02/21/2001	DOE submits to NDEP 2000 GW Monitoring Report.				
03/14/2001	Letter from NDEP stating that the 2000 GW Monitoring Report was received in a timely manner and contains all the data required by Title 40 Code of Federal Regulations Part 265.94. Letter also requests information regarding data in Appendix A of the 2000 GW Monitoring Report (Bechtel Nevada, 2001).				
04/19/2001	Letter from DOE responding to NDEP's 3/14/2001 request for information regarding presentation of TOX/TOC data in the 2000 report.				
04/30/2001	Letter from NDEP concurring with the approach to data presentation as outlined by DOE in the 4/19/2001 correspondence.				
05/29/2001	GW Sampling				
10/03/2001	GW Sampling				
03/01/2002	DOE submits to NDEP 2001 GW Monitoring Report.				
05/15/2002	GW Sampling				
10/22/2002	GW Sampling				
03/01/2003	DOE submits to NDEP 2002 GW Monitoring Report.				
04/15/2003	GW Sampling				
10/22/2003	GW Sampling			10/21/2003	GW Sampling

Groundwater Monitoring Program
Area 5 Radioactive Waste Management Site

Cumulative Chronology for Area 5 RWMS Groundwater (GW) Monitoring Program					
Date	UE5PW-1	Date	UE5PW-2	Date	UE5PW-3
02/27/2004	DOE submits to NDEP 2003 GW Monitoring Report.				
05/04/2004	GW Sampling				
10/19/2004	GW Sampling			10/20/2003	GW Sampling
02/25/2005	DOE submits to NDEP 2004 GW Monitoring Report.				
04/19/2005	GW Sampling				
10/11/2005	GW Sampling				
02/28/2006	DOE submits to NDEP 2005 GW Monitoring Report.				
04/26/2006	GW Sampling				
10/10/2006	GW Sampling				
03/01/2007	DOE submits to NDEP 2006 GW Monitoring Report.				
03/19/2007	GW Sampling				
08/29/2007	GW Sampling			09/05/2007	GW Sampling
03/01/2008	DOE submits to NDEP 2007 GW Monitoring Report.				
03/11/2008	GW Sampling				
09/10/2008	GW Sampling				
04/22/2009	DOE submits to NDEP 2008 GW Monitoring Report.				
03/10/2009	GW Sampling				
08/18/2009	GW Sampling				
03/01/2010	DOE submits to NDEP 2009 GW Monitoring Report.				
03/10/2010	GW Sampling			03/31/2010	GW Sampling
08/10/2010	GW Sampling				
		08/25/2010	GW Sampling		

Appendix B – Gradient/Velocity Calculations

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Calculation of Magnitude and Direction of Area 5 Alluvial Aquifer Gradient

Water level elevations measured at three wells near the Area 5 Radioactive Waste Management Site (UE5PW-1, UE5PW-2, and UE5PW-3) are used to calculate the magnitude and direction of the aquifer hydraulic gradient.

The locations of the three wells are given in Nevada State Central Zone coordinates in meters as northing (N) and easting (E) values. The coordinates of each of the three water elevation points define a plane that contains the water level points. The coordinates of the water elevation points are (E_i , N_i , e_i) where:

E_i is the East Coordinate of the i^{th} well (m)
 N_i is the North Coordinate of the i^{th} well (m)
 e_i is the water level elevation of the i^{th} well (m)

Assuming $i=1$ for UE5PW-1, $i=2$ for UE5PW-2, and $i=3$ for UE5PW-3, the vector **a** connecting the water level at UE5PW-1 to the water level at UE5PW-2 and the vector **b** connecting the water level at UE5PW-1 to the water level at UE5PW-3 are defined by:

$$\begin{aligned}\mathbf{a} &= (E_2 - E_1)\mathbf{i} + (N_2 - N_1)\mathbf{j} + (e_2 - e_1)\mathbf{k} \\ \mathbf{b} &= (E_3 - E_1)\mathbf{i} + (N_3 - N_1)\mathbf{j} + (e_3 - e_1)\mathbf{k}\end{aligned}$$

The aquifer hydraulic gradient is the cross product $\mathbf{a} \times \mathbf{b}$.

$$\begin{aligned}\mathbf{a} \times \mathbf{b} &= \text{DET} \begin{bmatrix} i & j & k \\ E_2 - E_1 & N_2 - N_1 & e_2 - e_1 \\ E_3 - E_1 & N_3 - N_1 & e_3 - e_1 \end{bmatrix} \\ &= [(N_2 - N_1)(e_3 - e_1) - (e_2 - e_1)(N_3 - N_1)]\mathbf{i} + \\ &\quad [(e_2 - e_1)(E_3 - E_1) - (E_2 - E_1)(e_3 - e_1)]\mathbf{j} + \\ &\quad [(E_2 - E_1)(N_3 - N_1) - (N_2 - N_1)(E_3 - E_1)]\mathbf{k} \\ &= A\mathbf{i} + B\mathbf{j} + C\mathbf{k}\end{aligned}$$

Where: $A = (N_2 - N_1)(e_3 - e_1) - (e_2 - e_1)(N_3 - N_1)$
 $B = (e_2 - e_1)(E_3 - E_1) - (E_2 - E_1)(e_3 - e_1)$
 $C = (E_2 - E_1)(N_3 - N_1) - (N_2 - N_1)(E_3 - E_1)$

Dividing hydraulic gradient by C gives the magnitude of the gradient in Easting (**i**) and Northing (**j**) for a unit change in elevation (**k**)

$$\frac{(\mathbf{a} \times \mathbf{b})}{C} = \frac{A}{C}\mathbf{i} + \frac{B}{C}\mathbf{j} + \mathbf{k}$$

The magnitude of the gradient is:

$$\sqrt{\left(\frac{A}{C}\right)^2 + \left(\frac{B}{C}\right)^2}$$

The direction of the gradient from north (θ) is calculated using the magnitudes of easting (E) and northing (N).

- If $B > 0$, then $\theta = \arctan (a/b)$
- If $B < 0$, then $\theta = 180^\circ + \arctan (a/b)$
- If $B = 0$ and $A > 0$, then $\theta = 90^\circ$
- If $B = 0$ and $A < 0$, then $\theta = 270^\circ$
- If $B = 0$ and $A = 0$, then the flow is straight down.

Calculation of Mean Groundwater Velocity

Groundwater flux is from calculated from Darcy's Law:

$$J = -K \left(\frac{\Delta e}{C} \right)$$

Where: J is groundwater flux (m/s)
 K is saturated hydraulic conductivity (m/s)
 $\frac{\Delta e}{C}$ is the hydraulic gradient (m/m)

The mean groundwater velocity is calculated from the flux:

$$V = \frac{J}{\phi}$$

Where: V is mean groundwater velocity (m/s)
 J is the groundwater flux (m/s)
 Φ is porosity (m^3/m^3)

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