Groundwater Monitoring Evaluation for the Shirley Basin South, Wyoming, UMTRCA Title II Disposal Site

June 2011

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Abbreviations

ACL	alternate concentration limit
ALARA	as low as reasonably achievable
CAP	corrective action program
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
HEL	health effects level
MCL	maximum concentration limit
mg/L	milligrams per liter
NRC	U.S. Nuclear Regulatory Commission
Petrotomics	Petrotomics Company
POC	point of compliance
POE	point of exposure
s.u.	standard units
TDS	total dissolved solids
UCL 95	upper confidence limit
UMTRCA	Uranium Mill Tailings and Radiation Control Act
UPL	upper prediction limit

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1.0 Purpose

Groundwater at the Shirley Basin South, Wyoming, Uranium Mill Tailings and Radiation Control Act (UMTRCA) Title II Disposal Site (site) is being monitored by the U.S. Department of Energy (DOE) Office of Legacy Management in accordance with the approved Long-Term Surveillance Plan (DOE 2004). The monitoring well network for the site is shown in Figure 1. Aquifers in the Upper Sand (wells have the suffix "SC") and Main Sand (wells have the suffix "DC") units of the Wind River Formation are being monitored.

DOE acquired the site under the U.S. Nuclear Regulatory Commission (NRC) general license in 2005 and began annual groundwater monitoring that year. Monitoring results have indicated the exceedance of approved alternate concentration limits (ACLs) for radium-226, radium-228, and cadmium. This report provides an evaluation of groundwater monitoring results, existing ACLs and how they were established, and a recommendation for revising compliance monitoring.

2.0 Site History

The Petrotomics Company (Petrotomics) uranium mill began operation at the site in 1962 as a 500-ton-per-day mill. In 1968, the mill was expanded to 1,000-tons-per-day production by the addition of thickeners, leach tanks, and another solvent extraction circuit. The mill was expanded again in 1970 to a capacity of 1,500 tons per day (Getty 1981).

The ore being processed through the mill came from open pit mines in the immediate vicinity of the mill. The mill was a conventional acid leach uranium ore processing plant (Getty 1981). Chemical reagents used in the milling and solvent extraction process included ammonia, sodium chlorate and chloride, and sulfuric acid.

The tailings from milling operations were placed in the tailings pond from the beginning of operation in 1962. In 1977, an amendment to the NRC license allowed a new dam to be constructed over the original dam. The new dam, completed in 1979, raised the elevation of the tailings impoundment 35 feet (Getty 1981).

In 1985, due to the depressed uranium market, the mining and milling operations were shut down and mill decommissioning commenced. Mill components that were not salvaged and sold were buried or placed in the disposal cell (Petrotomics 2001).

NRC approved the reclamation plan in 1989. Reclamation included remediation of the contaminated aquifer underlying the impounded tailings. Groundwater was pumped from numerous extraction wells until the tailings and the aquifer were essentially dewatered. The pumped water was evaporated in lined ponds. Further remediation was impractical; therefore, Petrotomics applied for ACLs in 1996 and was granted NRC concurrence in 1998. The cell cover was completed in 2000, and final site reclamation was completed in 2001 (Petrotomics 2001).
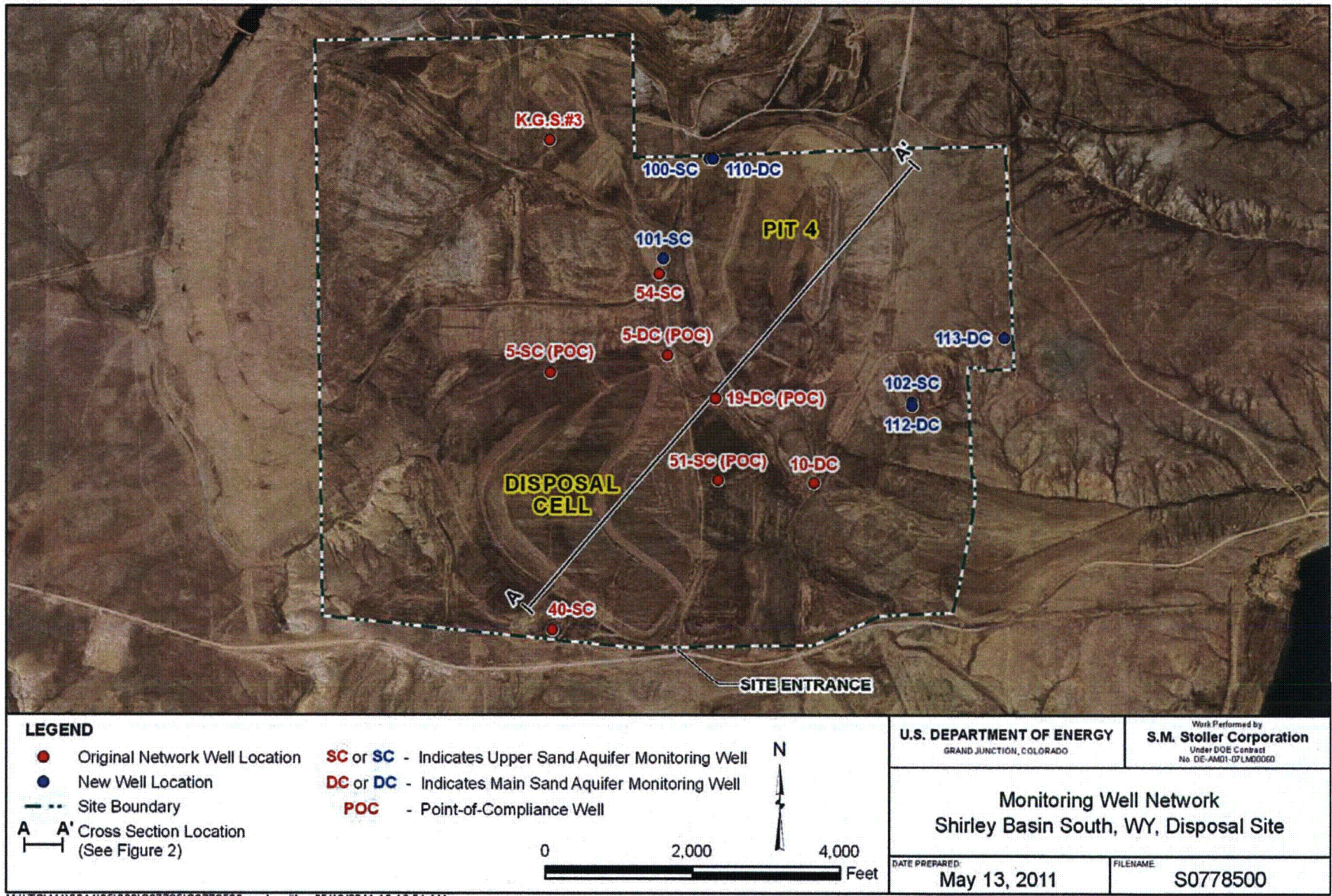
Figure 1. Monitoring Well Network at the Shirley Basin South, Wyoming, Disposal Site

3.0   Site Geology

The Shirley Basin is a southward extension of the Wind River Basin and lies between the Sweetwater Arch and the Laramie Range. The Laramie Mountains are to the northeast, and the Shirley Mountains are to the southwest. It is an area of low to moderate relief (Getty 1981).

The Eocene-age Wind River Formation is the uppermost geologic formation at the site. It was deposited in large streams that drained the Granite Mountains highland to the southwest and consists of poorly cemented layers of sandstone, conglomerate, siltstone, and claystone. The characters and thicknesses of the beds vary greatly and are subject to abrupt lateral changes (Getty 1981, Petrotomics 1997a). Well lithologic logs show that the formation dips approximately 1 degree to the northeast in the immediate vicinity of the disposal cell (Figure 2).

Roll-front uranium deposits are found in major sandstone beds, or units, throughout the Wind River Formation. Although numerous sandstone units and locally isolated lenses occur within the Wind River Formation at the site, only three have hydrogeologic significance: the Upper Sand, Main Sand, and Lower Sand units.

The Upper Sand unit crops out immediately south of the disposal cell and is the shallowest continuous sandstone unit under the cell. It ranges from 10 to 40 feet thick and averages about 15 feet thick downgradient of the cell until it coalesces with the underlying Main Sand unit in the northeast portion of the site. Drilling logs in areas near Pit 4 suggest that the Upper Sand unit is not homogeneous at that location. There appears to be two or more sandstone layers separated by claystone lenses, or there may be isolated sandstone lenses. These conditions are typical for fluvial environments as noted above.

Generally, the Main Sand unit is separated from the overlying Upper Sand unit by 10 to 40 feet of claystone composed of volcanic ash-derived swelling clays. The claystone layer, however, is absent beneath the northern tip of the disposal cell and pinched out in the area of Pit 4. The Main Sand unit crops out south of the site and has an average thickness of about 50 feet in the vicinity of the disposal cell. This unit contained the uranium ore body that was open-pit mined at the site. At the mine location, the Main Sand unit was at its greatest thickness and coalesced with the Upper Sand unit, resulting in a combined average thickness of approximately 140 feet. This entire thickness was mined in Pit 4 (Figure 2).

Interbedded claystones, siltstones, and thinly bedded sandstones totaling more than 50 feet thick separate the Main Sand unit from the underlying Lower Sand unit. The Lower Sand unit is approximately 100 feet thick at the site and was unaffected by uranium mineralization.

4.0   Groundwater Conditions

The uppermost aquifers at the site are in the Upper Sand and Main Sand units of the Wind River Formation. Both aquifers originate at outcrops near the southern boundary of the site, and neither is used as a source for drinking water or for any other beneficial purposes on or downgradient of the site. The groundwater quality is generally poor because of naturally occurring uranium mineralization and human activities related to uranium exploration and mining that occurred in the area from the late 1950s to the early 1990s.

SOUTHWEST

NORTHEAST

SOUTHWEST
CHANNEL

DAM
OUTSLOPE

PMF CHANNEL

DISPOSAL CELL

PIT 4

LAND
SURFACE

UPPER SURFACE

LOWER SURFACE

~TAILINGS~

APPROXIMATE
BOTTOM OF CELL

UPPER
SAND

7200

7100

7000

6900

6800

ELEVATION
(FEET ABOVE SEA LEVEL)

MAIN SAND

ORE BODY

~BACKFILL~

APPROXIMATE
LIMIT OF EXCAVATION

0   500   1000   1500   2000   2500   3000   3500   4000   4500   5000   5500   6000   6500   7000   7500   8000

A

DISTANCE (FEET)

A'

CROSS SECTION A-A'
NOT TO SCALE

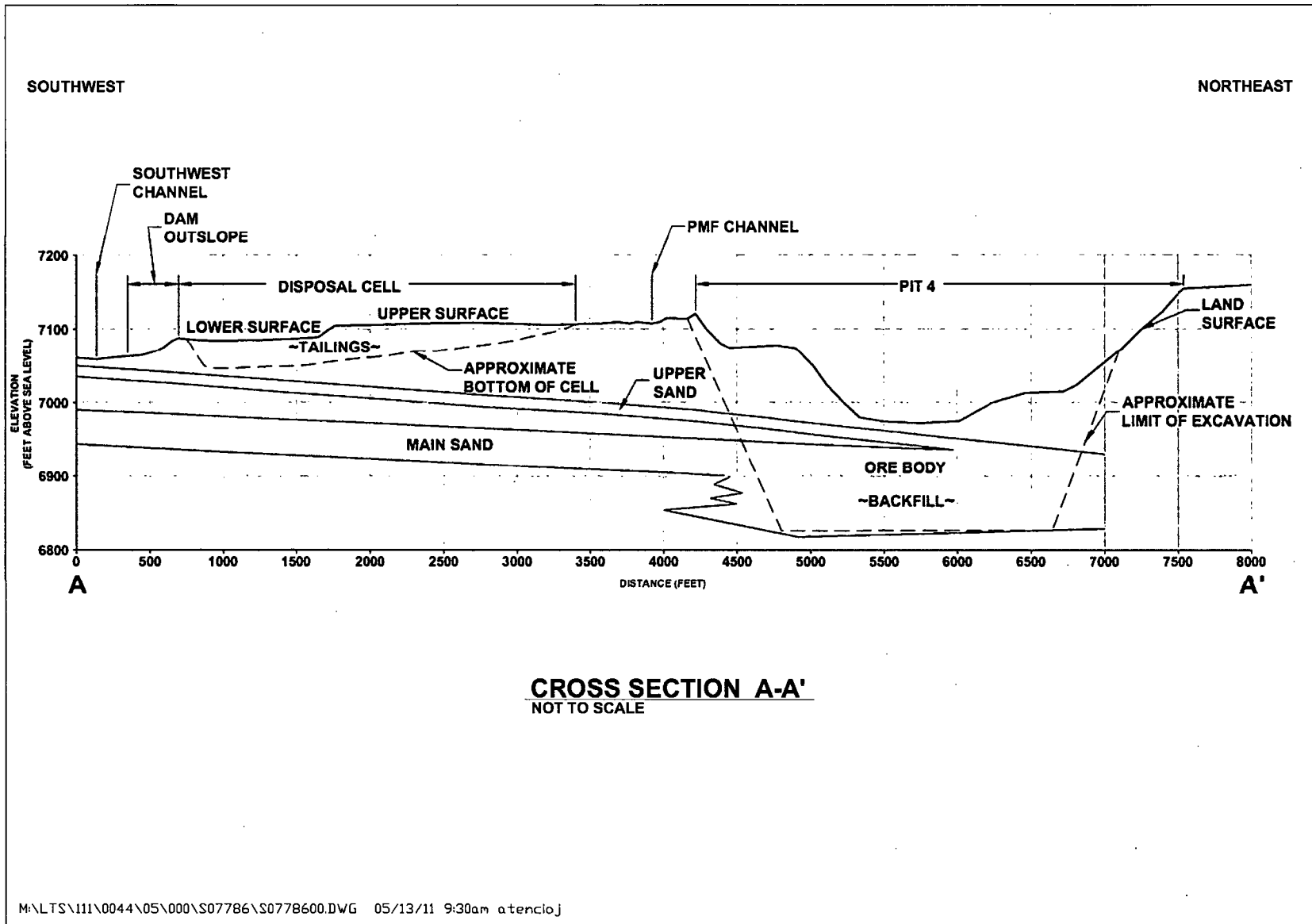M:\LTS\111\0044\05\000\S07786\S0778600.DWG   05/13/11 9:30am atencioj

Figure 2. Cross Section A-A' of the Shirley Basin South, Wyoming, Disposal Site

Although these aquifers are hydraulically distinct units over portions of the site, leakage may occur from the Upper Sand aquifer to the Main Sand aquifer where the claystone aquitard between them is not present (such as near the northern tip of the disposal cell). The natural groundwater flow direction follows the dip of the Upper Sand and Main Sand units to the northeast. Pit 4 is located directly along the flow path of groundwater from the disposal cell area.

These aquifers were affected by seepage from the tailings impoundment during milling operations. Although the recovery of tailings seepage water had been ongoing for a number of years, the groundwater corrective action program (CAP) formally began in 1988. The CAP was designed to recover contaminated groundwater and to control and minimize the spread of the tailings seepage (Petrotomics 1996). Site seepage recovery and groundwater remediation activities essentially dewatered the Upper Sand aquifer and the impounded tailings, thus reducing the source term. The extracted water was evaporated on site in lined ponds; the liners and accumulated evaporates eventually were disposed of in the cell.

The CAP was able to significantly reduce constituent concentrations but not achieve the site cleanup standards because continued efforts to dewater the aquifer proved to be unproductive. The results of the CAP, consequently, were considered to be as low as reasonably achievable (ALARA). Therefore, Petrotomics applied to NRC for ACLs in 1996 (Petrotomics 1996). After discussion and amendments to the application, NRC concurred with the request for ACLs in October 1998 (NRC 1998). ACLs were granted for constituents of concern as discussed later in this report.

As part of the reclamation plan, Pit 4 was partially backfilled to a bottom elevation several feet higher than the former top of the Upper Sand unit (Figure 2). This was done to prevent ponding of groundwater by keeping the water table below the bottom of the pit. Water that ponds at the bottom of the pit is ephemeral and is from rainfall and snowmelt. The backfill effectively acts as a sump for meteoric water captured in the pit, which may recharge the aquifer and alter its quality according to the quality of the runoff water and leached minerals from the backfill. Alternatively, the bottom of the pit may act as an evaporation area for the aquifer.

Mining operations at Pit 4 not only dewatered the Upper Sand and Main Sand aquifers in the vicinity of the pit, but also removed the confining layers of the aquifers. This removal reduced the potentiometric surface of the aquifers at that location. This factor, plus the subsequent partial backfilling of the pit, permanently altered the hydrogeologic character of the combined Upper Sand/Main Sand unit at that location.

Groundwater levels in the Upper Sand aquifer in the vicinity of the disposal cell continue to decline, perhaps because groundwater is draining along the bottom of the sandstone unit toward the Pit 4 area (Figure 3). Water levels in the Main Sand aquifer are recovering from the dewatering activities at the pit (Figure 4). Because of the hydrogeologic alterations of the Main Sand and Upper Sand aquifers caused by mining and reclamation operations at Pit 4 and north of the site, however, the aquifers at the site are not expected to return to pre-mining conditions.

The Lower Sand aquifer yields the largest quantity and best quality of groundwater in the Shirley Basin (Petrotomics 1996). The groundwater quality of the aquifer was unaffected by mining and milling operations. A well (K.G.S. #3) completed in this aquifer at the site provided a potable water supply for mine operations.

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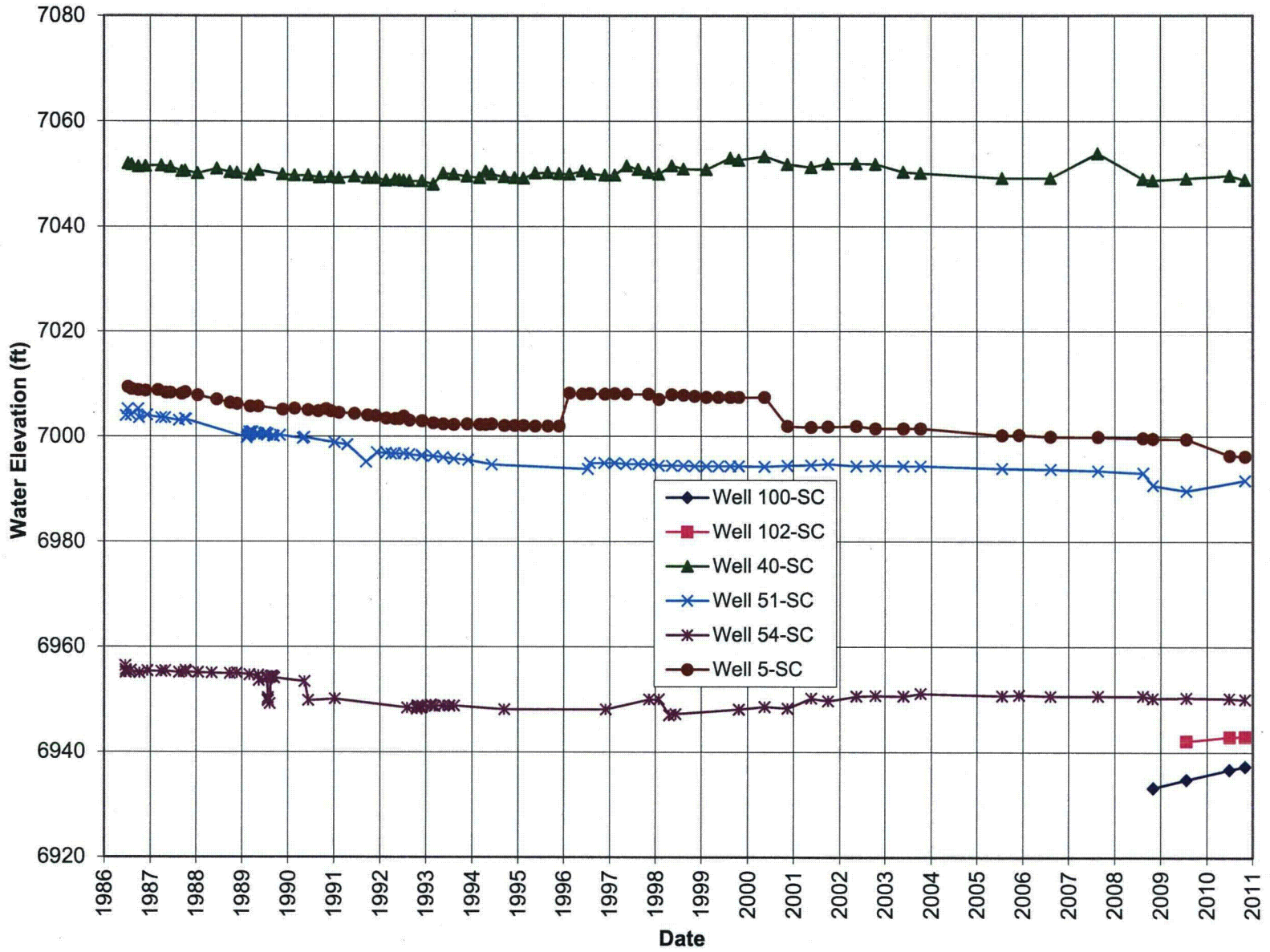June 2011   Doc. No. S07784
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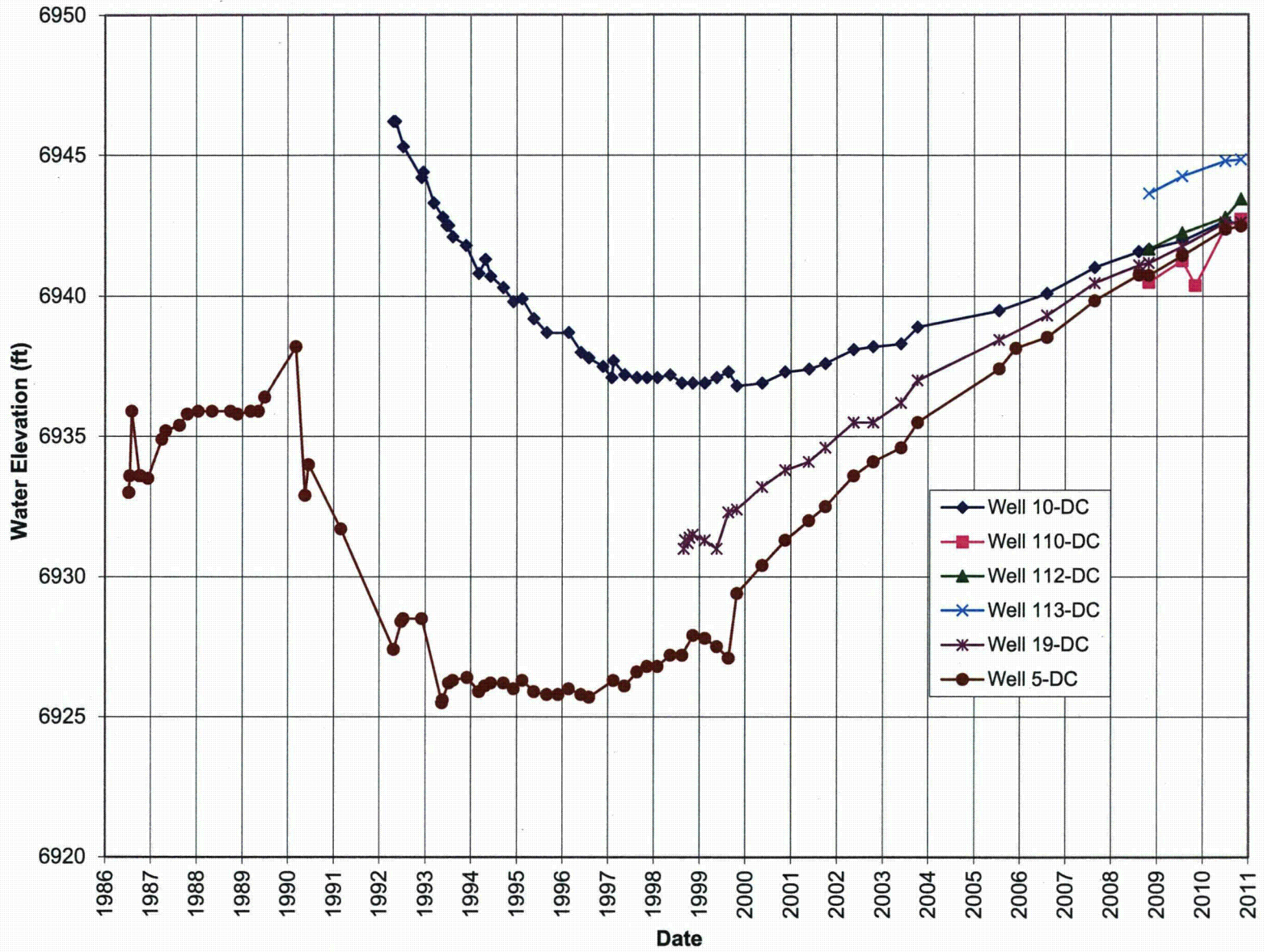Figure 3. Hydrographs of the Upper Sand Aquifer Monitoring Wells

Figure 4. Hydrographs of the Main Sand Aquifer Monitoring Wells

5.0 ACL History

Petrotomics originally submitted an application for ACLs in September 1996 (Petrotomics 1996). ACLs were proposed for all hazardous constituents for which on-site groundwater concentrations exceeded background or a U.S. Environmental Protection Agency (EPA) maximum concentration limit (MCL). The rationale for establishing the ACLs was complex. Petrotomics demonstrated that concentrations of metals at the site were controlled by a combination of pH levels and sulfate concentrations. A statistical analysis of site-wide chemical data showed that groundwater samples with pH levels greater than 4 standard units (s.u.) and sulfate concentrations less than 6,000 milligrams per liter (mg/L) had low concentrations of metals that were shown to meet protective health effects levels (HELs) for the assumed off-site water use, which is livestock watering (Table 1, Column 5). It was therefore assumed that if those criteria for pH and sulfate could be met at the site boundary, off-site water quality would be acceptable for the most likely use.

Table 1. ACLs and Values for Point of Exposure and HELs

	1	2	3	4	5	6
Constituent	Originally Proposed ACL Values (1996)[a]	Revised ACL Values (1997)[b]	POE Predicted Values (1997 data)[c]	POE Predicted Values (all data)[c]	Proposed HEL[d]	Final ACLs Approved in License Amendment[e]
Cadmium (mg/L)	0.15	0.079	0.040	0.038	5.0	0.079
Chromium (mg/L)	2.1	1.83	0.098	0.077	1,000	1.83
Lead (mg/L)	0.55	--	0.0097	0.18	30	0.05
Nickel (mg/L)	6.2	6.15	1.19	1.32	50	6.15
Radium-226 (pCi/L)	610	91.3	272	148	400	91.3
Radium-228 (pCi/L)	170	25.7	36	39.9	300	25.7
Selenium (mg/L)	0.12	0.023	0.0054	0.038	2	0.12
Thorium-230 (pCi/L)	2,700	2,409	11	20.7	400	2,409
Uranium (mg/L)	28	9.20	0.92	1.25	40	9.2

Key: ACL = alternate concentration limit; HEL = health effects level; mg/L = milligrams per liter; pCi/L = picocuries per liter; POE = point of exposure
[a] Derived from historical data for wells 5-SC, 51-SC, 5-DC, and 12-DC
[b] Data from January 1995 to 2nd quarter 1997 for wells 5-SC, 51-SC, and 5-DC
[c] Data with sulfate <6,000 mg/L and pH >4 s.u.
[d] Petrotomics 1996
[e] NRC 2002

Unlike a number of other sites where ACLs have been established based on transport modeling of constituent attenuation between the point of compliance (POC) and point of exposure (POE), assumed to be the site boundary, the protectiveness demonstration in the ACL application is based strictly on meeting pH and sulfate criteria at the site boundary. Transport modeling was completed for sulfate to show that it would attenuate with distance from the disposal site and meet the 6,000 mg/L criterion at the site boundary. Existing plume maps for the site also showed that the 6,000 mg/L sulfate contour was well ahead of the pH 4 s.u. contour; therefore, it was assumed that pH criteria would be met if sulfate remained below 6,000 mg/L. This issue was covered in depth in response to questions by NRC in its review of the initial ACL application (Petrotomics 1997b). Transport modeling was also completed for uranium as a conservative and representative metal to demonstrate that significant attenuation would occur between the disposal cell and the site boundary. The initially proposed ACLs were based on calculating the 95 percent

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upper confidence limit (UCL 95) of the mean of all data collected for the designated POC wells at the time the application was completed (5-SC, 51-SC, 5-DC, and 12-DC; Table 1, Column 1).

In its review of the ACL application, NRC determined that the proposed ACL values were not ALARA, as is required by 10 CFR 40 (NRC 1997). Their reasoning was that the demonstration of protectiveness at the POE was based only on data collected during 1995, while the data set for determining ACLs included older historical data that did not take into account the effects of remediation. NRC further indicated that well 12-DC was located within the tailings impoundment and was therefore not suitable as a POC well. Consequently, the licensee revised the ACLs, using only the most recent data (January 1995 through the second quarter of 1997) collected for the three remaining POC wells. These data were collected during corrective action prior to termination of remediation activities. The revised ACLs were also based on the UCL 95 of the mean for this data set. NRC approved the revised ACLs in 1998 (Table 1, Column 2).

Following approval of the revised ACLs in 1998, selenium was observed to routinely exceed its ACL in POC well 5-SC. Petrotomics subsequently requested that the selenium standard be raised to the originally proposed ACL value. Additional transport modeling was performed, demonstrating that even higher POC concentrations would be acceptable based on predicted concentrations at the long-term care boundary. NRC approved the revised selenium ACL, and the license was subsequently amended with the final ACLs shown in Table 1, Column 6 (NRC 2002). These ACLs were in the license at the time of termination when the site was transferred to DOE in 2005. The ACL history, predicted POE concentrations, and HELs for livestock are provided in Table 1.

The ACLs for the site, if exceeded, are intended to signal the potential for unacceptable disposal cell leakage. The final ACL for radium-228 was exceeded at POC well 5-DC and non-POC well 54-SC beginning with DOE's first sampling event in 2005, and continues to be exceeded (Figure 5). The cadmium concentrations also exceeded the ACL in well 5-SC during sampling events in 2005, but they have since returned to levels below the ACL (Figure 6). In response to these ACL exceedances, DOE began evaluating site groundwater conditions and installed six new monitoring wells to provide a better understanding of site hydrogeology and groundwater quality at the site boundary (POE). New downgradient well 110-DC at the site boundary exceeded the final ACL for radium-226 the second time it was sampled (in 2009), and the ACL continues to be exceeded (Figure 7). However, no results have exceeded the ACLs originally proposed by the licensee in 1996 (Table 1, Column 1).

6.0   Groundwater Constituents

6.1   Hazardous Constituents

According to 10 CFR Part 40, Appendix A, Criterion 5B(2), a constituent becomes a "hazardous constituent" regulated by NRC at a licensed facility if it meets three tests:

   (a)   The constituent is reasonably expected to be in or derived from the byproduct material in the disposal area;

   (b)   The constituent has been detected in the ground water in the uppermost aquifer; and

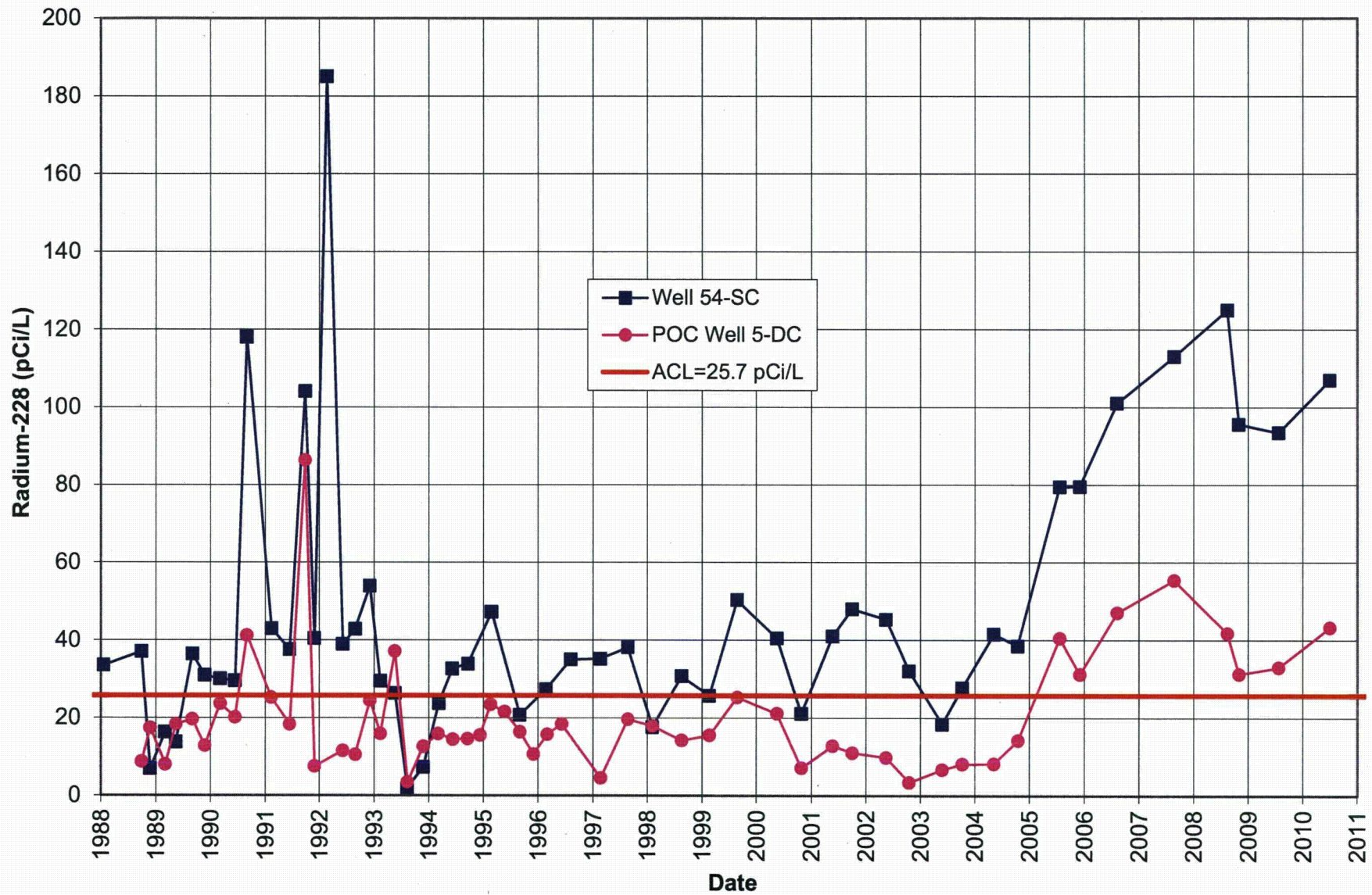   *(c)   The constituent is listed in Criterion 13 of this Appendix.*

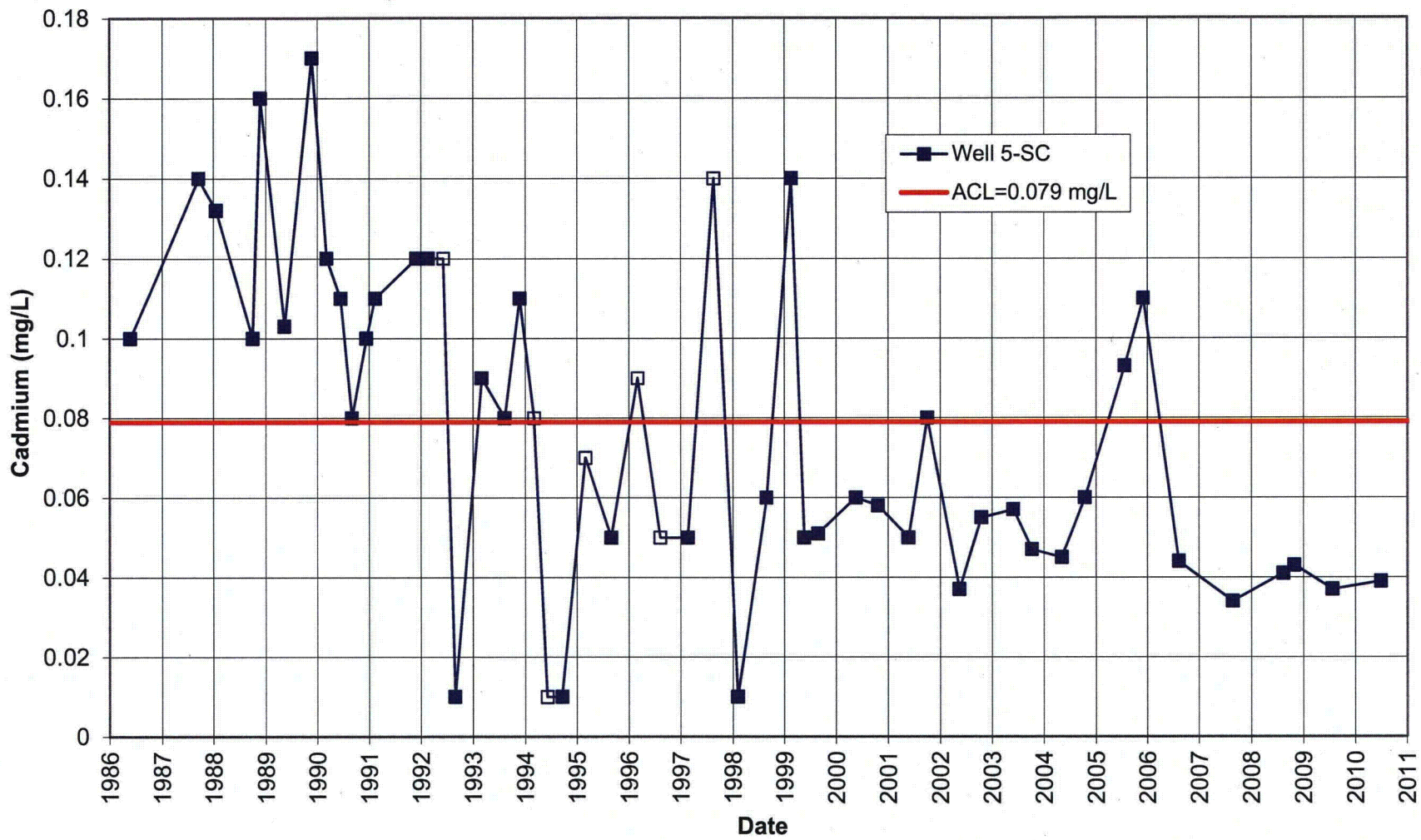Figure 5. Radium-228 Concentrations in Wells 5-DC and 54-SC

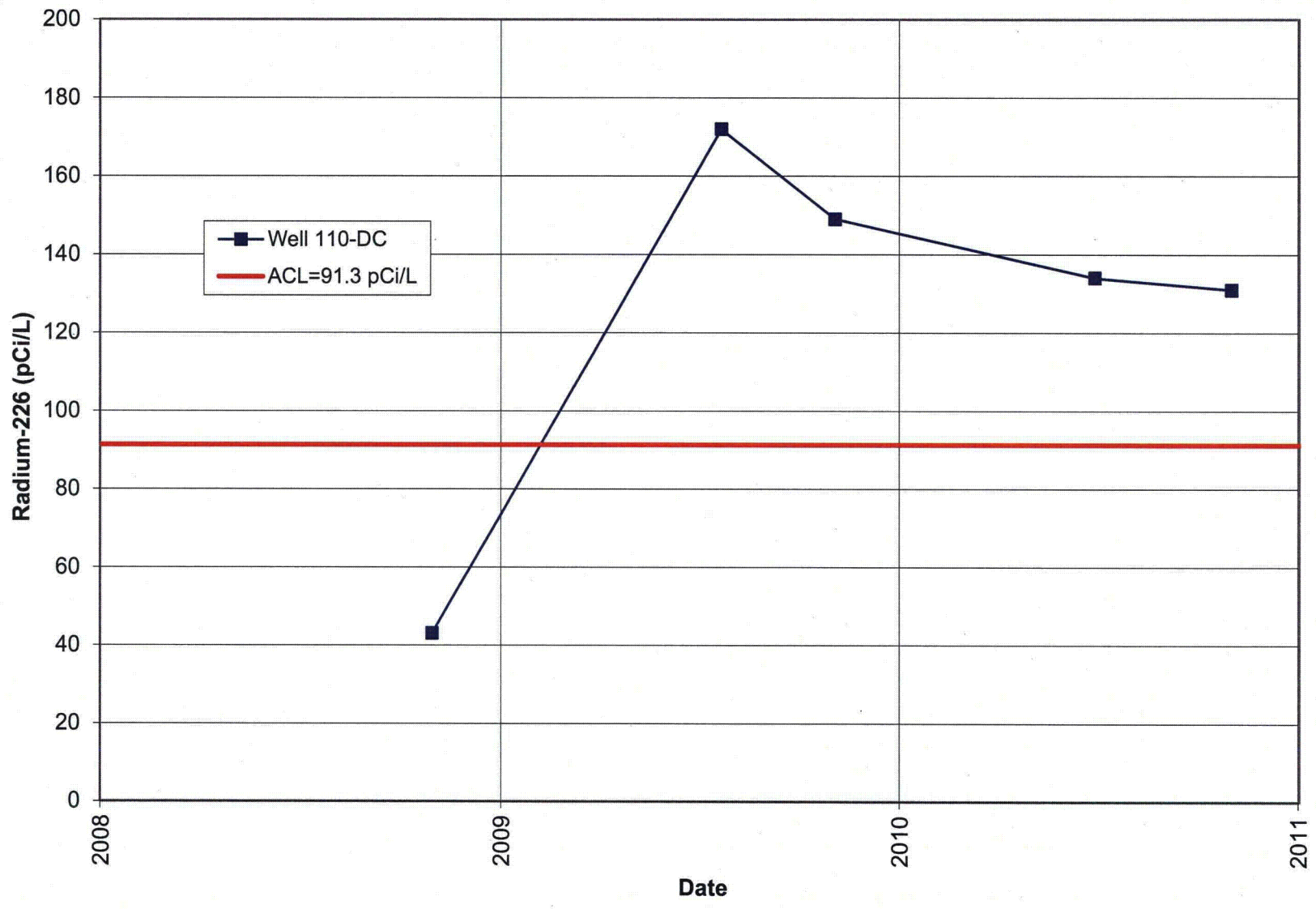*Figure 6. Cadmium Concentrations in Well 5-SC*

Figure 7. Radium-226 Concentrations in Well 110-DC

The regulation further states:

> *5B(3)—Even when constituents meet all three tests in paragraph 5B(2) of this criterion, the Commission may exclude a detected constituent from the set of hazardous constituents on a site specific basis if it finds that the constituent is not capable of posing a substantial present or potential hazard to human health or the environment.*

Nine factors are then provided that may be considered in excluding a detected constituent, including the potential for waste migration, site hydrogeological characteristics, and potential groundwater uses in the area.

Background data for two Upper Sand wells were presented in the ACL application (39-SC and 41-SC; Table 2). These data, at least in part, were apparently compared with tailings-related data for use in identifying hazardous constituents and setting the site standards originally specified in the license (Table 2). Sulfate and chloride were designated as indicator constituents. Analyses from mill liquids, tailings wells, and tailings pond water indicate that concentrations of all hazardous constituents identified in the license exceeded background levels or MCLs in at least one sample and are associated with the milling process (Table 3, Table 4, and Table 5), even if in low levels (i.e., designation of hazardous constituents meets 10 CFR 40 Appendix A, 5B(2) criteria). However, it is unclear if these background concentrations take into account water quality in the mineralized zones and are, therefore, representative of the site as a whole. Various reports have indicated that elevated levels of selenium, uranium, radium-226, and radium-228 have been observed in groundwater in these highly mineralized areas (DOE 1993, Harshman 1972). It was also noted in the ACL application that concentrations of radium-226 observed in former well 16-DC at the site were anomalous with respect to sulfate and chloride concentrations and were "likely attributed to high uranium mineralization in this area" as opposed to leachate from the cell (Petrotomics 1996, Section 2.2.3.2.6, page 34).

Table 2. Background Water Quality Data for Wells 39-SC and 41-SC
(Second Quarter 1995–First Quarter 1996)

Constituent[a]	Range of Concentrations	Site Standards[a]
pH (s.u.)	6.78 – 4.50	None
Cadmium (mg/L)	<0.001– 0.05	0.05
Chromium (mg/L)	<0.05 – 0.06	0.05
Lead (mg/L)	<0.005 – 0.024	0.05
Nickel (mg/L)	<0.05 – 0.28	0.22
Selenium (mg/L)	<0.002– 0.009	0.01
Uranium (mg/L)	<0.001 – 3.24	0.16
Radium-226 + Radium-228 (pCi/L)	1.5 – 18.8	5.00
Thorium-230 (pCi/L)	1.9 – 13.70	3.94

Key: mg/L = milligrams per liter; pCi/L = picocuries per liter; s.u. = standard units .
[a] As specified in original source materials license SUA-551

Table 3. Water Quality Data for Mill Liquids
(Petrotomics 1996, Table 2-5)

Constituent	HG-1L[a]	HG-2L[a]	HG-3L[a]	LG-1L[b]	LG-2L[b]	LG-3L[b]
Cadmium (mg/L)	<10	<10	<10	<10	<10	<10
Chloride (mg/L)	1,400	950	1,364	725	675	948
Chromium (mg/L)	<10	<10	<10	<10	<10	<10
Lead (mg/L)	<10	<10	<10	<10	<10	<10
Nickel (mg/L)	<10	<10	<10	<10	<10	<10
pH s.u.	2.20	2.27	1.94	1.90	2.35	2.15
Selenium (mg/L)	<10	<10	<10	<10	<10	<10
Sulfate (mg/L)	14,000	11,000	13,500	9,250	6,750	9,000
TDS (mg/L)	25,800	24,100	27,100	26,394	17,460	21,773

Key: mg/L = milligrams per liter; s.u. = standard units; TDS = total dissolved solids
[a] Liquid from high-grade mill runs
[b] Liquid from low-grade mill runs

Table 4. Groundwater Quality Data for Tailings Monitoring Wells
(Petrotomics 1996, Table 2-7)

Constituent	PT3 11/22/88	TW4 11/22/88	TW4 2/14/91	TW4 2/20/92	TW4 2/9/93	TW4 3/8/94	TW4 3/8/94	TW4 2/16/95
TDS (mg/L)	37,352	26,288	27,388	27,445	27,814	27,800	28,600	28,400
Chloride (mg/L)	456	354	357	340	356	475	425	375
Sulfate (mg/L)	17,600	16,200	15,100	17,000	17,400	21,500	19,600	19,200
Cadmium (mg/L)	0.17	0.17	0.12	0.12	0.15	0.13	0.13	0.12
Chromium (mg/L)	2.8	0.50	0.27	0.30	0.28	0.26	0.24	0.37
Lead (mg/L)	0.75	0.59	0.28	<0.05	<0.05	0.01	<0.01	<0.005
Nickel (mg/L)	3.7	3.3	4.9	5.2	4.44	5.65	5.41	5.34
Selenium (mg/L)	0.23	<0.001	<0.001	0.002	<0.001	<0.002	<0.002	0.28
Uranium (mg/L)	14.0	3.2	4.3	0.74	2.82	8.74	9.34	8.59
Radium-226 (pCi/L)	0.05	0.62	80	83	79	1,360	1,290	312
Radium-228 (pCi/L)	0.85	1.5	16.1	33	9	8	7	25
Thorium-230 (pCi/L)	23,500	938	1,872	985	1,904	11,900	11,100	7,160

Constituent	TW6 11/22/88	TW7 11/22/88	TW10 11/22/88	TW21 2/27/90	TW21 2/14/91	TW21 2/20/92	TW21 3/1/93	TW21 3/7/94	TW21 2/16/95
TDS (mg/L)	31,082	48,054	22,270	31,919	29,184	34,566	26,560	26,900	28,800
Chloride (mg/L)	363	527	359	378	355	422	325	350	345
Sulfate (mg/L)	18,800	29,000	13,600	20,400	16,400	17,200	19,200	22,800	19,200
Cadmium (mg/L)	0.15	0.23	0.13	0.12	0.13	0.14	0.16	0.09	0.11
Chromium (mg/L)	0.89	3.1	0.08	2.5	1.8	6.3	1.68	0.39	0.78
Lead (mg/L)	0.64	0.88	0.57	0.04	0.28	<0.05	<0.5	0.05	<0.005
Nickel (mg/L)	2.6	4.7	3.0	3.9	4.3	7.5	5.70	4.81	4.21
Selenium (mg/L)	0.008	0.17	<0.001	0.37	0.22	0.12	<0.001	0.01	0.02
Uranium (mg/L)	11.0	28	6.1	21	13.5	11.9	5.98	5.42	3.93
Radium-226 (pCi/L)	1.0	1.2	0.55	2.5	0.54	0.49	0.021	311.0	112.0
Radium-228 (pCi/L)	2.0	2.3	1.5	7.1	0.00	10.5	0.00	5	4
Thorium-230 (pCi/L)	1,170	52,500	1,135	16,395	8,140	4,948	8,483	4,190	2,840

Key: mg/L = milligrams per liter; pCi/L = picocuries per liter; TDS = total dissolved solids

Table 5. Water Quality Data for Tailings Pond Water
(Petrotomics 1996, Table 2-6)

Constituent	Concentration
Cadmium (mg/L)	0.074
Chloride (mg/L)	420
Chromium (mg/L)	2.1
Lead (mg/L)	<1.2
Nickel (mg/L)	4.4
Radium-226 (pCi/L)	151.2
Radium-228 (pCi/L)	Not reported
Selenium (mg/L)	2.3
Sulfate (mg/L)	42,000
Thorium-230 (pCi/L)	170,100
Uranium (mg/L)	16.5

Key: mg/L = milligrams per liter; pCi/L = picocuries per liter

Another consideration in the selection of constituents for long-term monitoring is the objective of POC monitoring, which ". . . is to provide the earliest practicable warning that the impoundment is releasing hazardous constituents to the ground water" (NUREG 1620, 4.2.3(2)). The appropriate monitored parameters, therefore, should be indicative of tailings materials and not significantly affected by retardation reactions. NUREG 1620 (Appendix D2.2.3(b)) suggests that total dissolved solids (TDS), chloride, or sulfate may be appropriate in this regard.

In addition to identifying releases from the cell, it is also presumed that long-term monitoring should confirm that attenuation is occurring as predicted by transport/geochemical modeling. As noted previously, attenuation in the site groundwater is mainly dependent on absolute values of pH and sulfate in the vicinity of the site boundary and has little to do with constituent concentrations in the POC wells. Some measure besides a POC concentration, therefore, is necessary to evaluate the attenuation capacity of the aquifer.

Each of the hazardous constituents designated in source materials license SUA-551 are discussed briefly with respect to their applicability to long-term monitoring requirements for cell performance and plume migration.

6.1.1 Cadmium

Highest cadmium concentrations in tailings wells and pond waters are only a few times higher than the maximum background concentration. Therefore, this constituent would not be a good early indicator of cell leakage. Concentrations in tailings and POC wells have always been below values considered protective (Table 1, Column 5). With the additional attenuation that occurs as groundwater moves away from the cell, this constituent is not capable of posing a potential hazard at the site boundary. Cadmium concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A–1 in the Appendix.

6.1.2 Chromium

Chromium was regularly detected in tailings fluids at concentrations near the site standard (0.05 mg/L), although concentrations were still relatively low compared to some other site-related constituents. Chromium is readily attenuated, particularly at pH greater than 4.5 (Petrotomics 1996), and is, therefore, not a good early indicator of potential cell leakage. Concentrations in tailings and POC wells have always been below values considered protective

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(Table 1, Column 5). With the additional attenuation that occurs as groundwater moves away from the cell, this constituent is not capable of posing a potential hazard at the site boundary. Chromium concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A–2 in the Appendix.

6.1.3 Lead

Lead was only detected in about half of tailings wells and was generally within one order of magnitude of the site standard (0.05 mg/L). This constituent is strongly attenuated and, therefore, not a good early indicator of potential cell leakage. Concentrations in tailings and POC wells have always been below values considered protective (Table 1, Column 5). With the additional attenuation that occurs as groundwater moves away from the cell, this constituent is not capable of posing a potential hazard at the site boundary. Lead concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A–3 in the Appendix.

6.1.4 Nickel

There is evidence that nickel is elevated naturally in the area (Petrotomics 1996), although concentrations reported for background wells only ranged up to 0.26 mg/L. According to the ACL application, "Nickel concentration patterns are slightly different than the other heavy metals. A source of nickel other than tailings seepage is indicated, and therefore, this parameter may not be useful for defining the extent of tailings seepage" (Petrotomics 1996, Appendix E, "Review of Corrective Action in the Upper Wind River Sand at Petrotomics' Tailings Area," page 4). Concentrations in tailings and POC wells have always been below values considered protective (Table 1, Column 5). With the additional attenuation that occurs as groundwater moves away from the cell, this constituent is not capable of posing a potential hazard at the site boundary. Nickel concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A–4 in the Appendix.

6.1.5 Radium-226 and Radium-228

The following statements were excerpted from the ACL application (Petrotomics 1996):

- "The radium-226 plus radium-228 concentration contours indicate that a source different from Petrotomics' tailings is probably responsible for most of the elevated radium values. It is likely that this source is natural because the Wind River sands are the uranium ore-bearing unit in the Shirley Basin. Natural radium concentrations of up to 1,700 pCi/l have been observed in the Wind River water where the sand is mineralized (Harshman 1972). Since radium contours do not reflect the effects of tailings seepage on the Upper Wind River sand, they should not be used to define the extent of contamination" (Petrotomics 1996, Appendix E, "Review of Corrective Action in the Upper Wind River Sand at Petrotomics' Tailings Area," page 18).

- "Radium concentrations are naturally occurring from the ore-bearing Wind River sands, which makes radium a poor constituent for definition of areal extent of radionuclide seepage from the tailings. Radium concentrations have varied over a larger range than most parameters. Radium is therefore questionable as a hazardous constituent for this site, because radium occurs in high concentrations naturally" (Petrotomics 1996, Appendix E, "Review of Corrective Action in the Upper Wind River Sand at Petrotomics' Tailings Area," page 4).

As noted previously, high radium-226 concentrations observed in former well 16-DC have been attributed to localized uranium mineralization. This location was outside the restricted area boundary. Radium data from a number of other wells also display high and variable concentrations that are unlikely mill-related. Former wells 14-DC and 15-DC, also outside the restricted area boundary, had concentrations ranging between 200 and 800 pCi/L for combined radium-226 and radium-228. Even in proposing an ACL for radium, Petrotomics noted that natural radium concentrations can be substantial and that the influence of natural radium on groundwater quality would require "careful evaluation" (Petrotomics 1997b, page 3).

The ACL for radium-228 is being exceeded in wells 5-DC and 54-SC. Cell leakage does not appear to have caused the elevated concentrations. If the cell was leaking, other tailings-derived contaminants would also be expected to be elevated. Sample results show that only sulfate and TDS concentrations are increasing at wells 5-DC and 54-SC (the sulfate results remain within the range of concentrations predicted by Petrotomics' groundwater model for these locations). All other milling-related contaminant concentrations are remaining steady or are declining at these wells.

Radium-228 is a decay product of naturally occurring thorium-232, and Petrotomics attributed elevated concentrations at the site to natural thorium in the uranium ore. Because the half-life of radium-228 is relatively short (5.75 years), the increasing concentrations observed indicate that the radium is partitioning into the groundwater more quickly than it is decaying. This suggests a source of radium-228 that is in close proximity to the affected wells, such as in the dewatered solid aquifer materials. As the aquifer rebounds hydrologically from dewatering activities, geochemical rebound is likely occurring as well. Consequently, increases in some constituent concentrations in the groundwater, such as radium-228, may represent a reestablishment of equilibrium of groundwater with naturally occurring constituents in the sand units.

There are insufficient data to definitively determine why radium-226 is elevated at well 110-DC. The next highest result in the monitoring network during the June 2010 sampling event was 16.7 pCi/L in well 54-SC, which is between the disposal cell and well 110-DC and not designated as a cell performance compliance well. The highest radium-226 concentration for all POC wells (5-SC, 51-SC, 5-DC, and 19-DC) was 9.68 pCi/L in well 5-DC. This information suggests that the elevated radium-226 concentrations at well 110-DC do not represent a contaminant plume migrating off site; rather, they more likely represent natural conditions within the ore-bearing sand unit.

Based on monitoring results by DOE over the last several years, it can be concluded that radium-226 and radium-228 are not very good indicators of disposal cell performance or plume movement/attenuation. Radium-226 and radium-288 concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A–5 and Figure A–6, respectively, in the Appendix.

6.1.6 Selenium

Concentrations of selenium in the majority of tailings fluid samples were quite low but showed some variability. Selenium attenuates readily and is not likely to be an early indicator of potential cell leakage. Transport modeling performed specifically for selenium indicated that it would attenuate below the MCL of 0.05 mg/L at the site boundary. Concentrations in tailings and POC

wells have always been below values considered protective (Table 1, Column 5). With the additional attenuation that occurs as groundwater moves away from the cell, this constituent is not capable of posing a potential hazard at the site boundary. Selenium concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A-7 in the Appendix.

Results of the modeling for selenium help support the case for attenuation of cadmium, chromium, and lead. Distribution coefficients for those constituents range from a low that is similar to selenium, to highs that far exceed selenium values. Higher distribution coefficients correspond to proportionally higher retardation of contaminants in an aquifer. Therefore, movement of cadmium, chromium, and lead must be attenuated at least as much as or more than selenium.

6.1.7   Thorium-230

According to the ACL application, "Uranium and thorium-230 well define the extent of radionuclide seepage impact" (Petrotomics 1996, Appendix E, "Review of Corrective Action in the Upper Wind River Sand at Petrotomics' Tailings Area," page 4). Thorium-230 concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A-8 in the Appendix.

6.1.8   Uranium

According to the ACL application, "Uranium and thorium-230 well define the extent of radionuclide seepage impact" (Petrotomics 1996, Appendix E, "Review of Corrective Action in the Upper Wind River Sand at Petrotomics' Tailings Area," page 4). Uranium concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A-9 in the Appendix.

6.2   Indicator Constituents

Chloride and sulfate concentrations in tailings fluids were extremely high (Table 3, Table 4, and Table 5), and these constituents are good markers for the extent of site-related contamination (although maybe not as early indicators of further cell leakage). Chloride concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A-10 in the Appendix. Sulfate and pH are critical in controlling the attenuation capacity of the aquifer and must meet values less than 6,000 mg/L and greater than 4 s.u., respectively, at the site boundary. Sulfate and pH concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A-11 and Figure A-12, respectively, in the Appendix.

Ammonia was used in the milling process, and nitrate, which is a common degradation product of ammonia, tends to be mobile in groundwater systems. Due to the absence of other sources of nitrate in the area and because of the use of large quantities of ammonia during processing, nitrate should be an early discriminator of cell leakage. DOE measures nitrate in the form of nitrate plus nitrite as nitrogen. Nitrate concentrations in all wells completed in the Upper Sand and Main Sand aquifers since DOE began sampling in 2005 are shown in Figure A-13 in the Appendix. Petrotomics measured nitrate as nitrogen; its results are shown in Figure A-14 in the Appendix.

Tailings wells monitored by Petrotomics had TDS concentrations ranging from 22,270 mg/L to 48,054 mg/L (Table 4). Therefore, TDS is considered to be an indicator for the extent of site-related contamination. TDS concentrations in all wells completed in the Upper Sand and Main Sand aquifers are shown in Figure A–15 in the Appendix.

Based on the above evaluation, the hazardous constituents that are most likely to provide useful information about potential cell leakage and plume movement appear to be uranium and thorium-230. Both of these constituents exceed site standards and, therefore, require the establishment of ACLs. Chloride, sulfate, pH, nitrate, and TDS would also be useful indicators in distinguishing cell-related contamination. However, these indicator constituents and parameters do not require ACLs because they are not designated hazardous constituents. It is considered essential to monitor sulfate and pH to ensure that the attenuation capacity of the aquifer is maintained.

7.0 Evaluation of ACL Values

The groundwater data used for the revised ACL calculation were collected during active groundwater remediation (see Section 5.0). These data represent a short period of time during which the groundwater system was actively disturbed by pumping activities, which artificially affected the natural variability of the system. The Upper Sand aquifer in the vicinity of the disposal cell was essentially dewatered during this timeframe. It has been well established that after cessation of pumping activities, a rebound in groundwater concentrations is commonly observed as the groundwater and soil/rock matrix materials reequilibrate (EPA 1992). This was not accounted for in the revised ACLs.

The revised ACLs were based on an estimate of the population mean (i.e., UCL 95). A mean estimator based on data collected at the end of a remedial action is not an appropriate statistic for detecting unacceptable increases in concentration that need further investigation. By definition, the use of a mean statistic indicates that exceedances are to be expected (but can be minimized), even in the absence of system rebound. A more appropriate statistic to use is an estimate of an upper threshold concentration. EPA suggests using an upper prediction limit (UPL), an upper percentile value, or a UCL on an upper percentile as a maximum estimator or "not to exceed" value for a set of background or baseline data (EPA 2009). NRC's standard review plan for Title I UMTRCA sites indicates that "DOE will often use a statistical maximum in establishing an ACL" (NRC 1993). This approach is consistent with EPA's recommendations.

Consequently, an alternative approach is suggested for establishing ACLs for the site. If, as discussed above, the attenuation capacity of the aquifer is not dependent on contaminant reductions achieved during remediation, then use of the full historical data set in establishing ACLs may be justified. While it might be expected that remedial activities should result in contaminant reductions below historical maximum observations or predictions, some rebound of concentrations above the lowest achieved levels would also likely occur. In this case, it might be reasonable to use a mean estimator. The approach initially used by Petrotomics in calculating ACLs—UCL 95 of the mean of all data—did take into account the full variability of historical data in estimating an average that is unlikely to be exceeded. Although this approach did not result in ACLs that were considered ALARA, using an estimator of the population mean is more conservative than using an estimator of the population maximum while still providing a

reasonable assurance that ACL values will not be exceeded without actual cause for concern. If the originally proposed ACLs had been accepted, there would have been no exceedances of ACLs to date.

An alternative ACL approach could be to use a more recent post-remediation data set. However, in this case a predicted upper threshold, instead of a mean, would be the more appropriate statistic for comparison to account for system rebound and natural variability. Statistics were computed for uranium and thorium-230 data collected starting in 2000 (2 years after remediation ceased) using EPA's ProUCL 4.00 statistical package. Data were not normally distributed for either constituent, so nonparametric statistics are appropriate. Two different nonparametric UPLs were calculated (a 95 percent UPL based on the 95th percentile and a 95 percent Chebyshev UPL). The UPL and Chebyshev UPL computed for thorium-230 were 600.9 pCi/L and 1,227 pCi/L, respectively. For uranium, the UPL and Chebyshev UPL were 6.352 mg/L and 13 mg/L, respectively. These results suggest that the current ACL for uranium (9.2 mg/L) is in an appropriate range to serve as an upper threshold value for post-remediation data. The current thorium-230 ACL (2,409 pCi/L), however, is much higher than a UPL based on post-remediation data and reflects the high variability observed in this constituent during active remediation.

A key assumption in the establishment of ACLs is that if an ACL is exceeded, there is a reasonable likelihood that this occurrence is due to cell leakage and that further investigation is warranted. Therefore, the combination of the value assigned as an ACL and the test used for comparing monitoring data to an ACL must be meaningful in this respect. The cell is assumed to be performing satisfactorily unless monitoring data indicate otherwise. Because of the limited number of wells at the site and the hydrogeologic complexity of the site, it is necessary to compare sampling results for individual wells with ACLs instead of comparing the mean of several wells. However, considering the site history, a single exceedance of an ACL at a single well is unlikely to be sufficient grounds for contemplating corrective action. Several types of testing strategies can be used as alternatives to single-measurement comparisons with a threshold value. These strategies include sequential pooling of data, incorporating retesting strategies, and employing a test of trend. Using one or more of these approaches in addition to a simple ACL comparison would minimize triggering a more extensive evaluation when one is not necessarily warranted.

Simply ensuring that ACLs are not exceeded at POC wells at the site does not guarantee protectiveness at the POE. The attenuation/protectiveness argument has little to do with concentrations at the POC, except that maximum values of about 16,000 mg/L sulfate and 7 mg/L uranium were used as initial source concentrations in the modeling; higher concentrations than those modeled have been observed in POC wells. The source loading in the model is assumed to decline over time, so sulfate and uranium at the POC wells should logically decline in order to validate model predictions. Key to the attenuation argument, however, is that sulfate levels decline to below 6,000 mg/L and pH levels increase to greater than 4 s.u. with increasing proximity to the site boundary. The current ACLs and the general monitoring approach do not address this attenuation requirement. A comprehensive approach to long-term monitoring, therefore, should include one component for identifying possible unacceptable cell leakage and another for evaluating the continued attenuation capacity of the aquifer.

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8.0   Recommended ACLs and Compliance Monitoring

It is recommended that two hazardous constituents—uranium and thorium-230—be retained for long-term disposal site monitoring. Chloride, nitrate, sulfate, TDS, and pH should also be monitored as indicator constituents and parameters. Although the basis for the establishment of ACLs for uranium and thorium-230 may be questionable, they have already received NRC approval and appear to be reasonable for long-term monitoring needs. It is not likely, based on post-remediation observations, that use of these values would trigger unwarranted evaluations, especially using the monitoring approach outlined below. It is recommended, therefore, that the ACLs for those two constituents remain as they are. Proposed monitoring constituents and concentration limits are provided in Table 6.

Table 6. Proposed Constituents, ACLs, and POE Concentration Limits for the Shirley Basin South, Wyoming, Disposal Site

Constituent	ACL	POE Concentration Limit
Thorium-230	2,409 pCi/L[a]	20.7[b]
Uranium	9.2 mg/L[a]	1.25[b]
Chloride	NA	2,000 mg/L[c]
Nitrate + Nitrite as N	NA	100 mg/L[c]
Sulfate	NA	6,000 mg/L[d]
TDS	NA	5,000 mg/L[c]
pH	NA	>4 s.u.[d]

Key: ACL = alternate concentration limit; mg/L = milligrams per liter; NA = not applicable; pCi/L = picocuries per liter; POE = point of exposure; s.u. = standard units; TDS = total dissolved solids
[a] Final ACL approved in License Amendment (NRC 2002)
[b] There is no Wyoming Class III (livestock) groundwater protection standard; predicted POE concentration (unregulated) from Table 1, Column 4
[c] Wyoming Class III (livestock) groundwater protection standard
[d] Concentration to ensure that concentrations of metals meet protective health effects levels for livestock watering (Petrotomics 1996 and 1997)

Monitoring data for hazardous and indicator constituents will be qualitatively evaluated for the presence of trends even if an ACL or other standard is not exceeded. The POE concentration limits for thorium-230 and uranium provided in Table 6 are predicted values calculated by Petrotomics (Table 1, Column 4), assuming the sulfate and pH criteria are met. They are not intended to be limits for triggering corrective action; instead, they are provided for verification of the groundwater model. To date, the maximum thorium-230 concentration in wells near the site boundary has been 0.99 mg/L (100-SC), and the maximum uranium concentration has been 0.25 mg/L (112-DC).

Sulfate and pH will be tracked for wells downgradient of POC wells to ensure that attenuation criteria are maintained. If trends suggest that a groundwater standard or criterion may be violated at the site boundary, a statistical analysis may be performed to quantify these predictions and consider the need for an evaluative monitoring program. Sulfate and pH concentrations in new wells located along predicted groundwater flow paths and near the site boundary are shown in Figure 8 and Figure 9, respectively. As shown in these figures, sulfate concentrations are well below the 6,000 mg/L threshold, and pH concentrations are well above the 4 s.u. threshold.
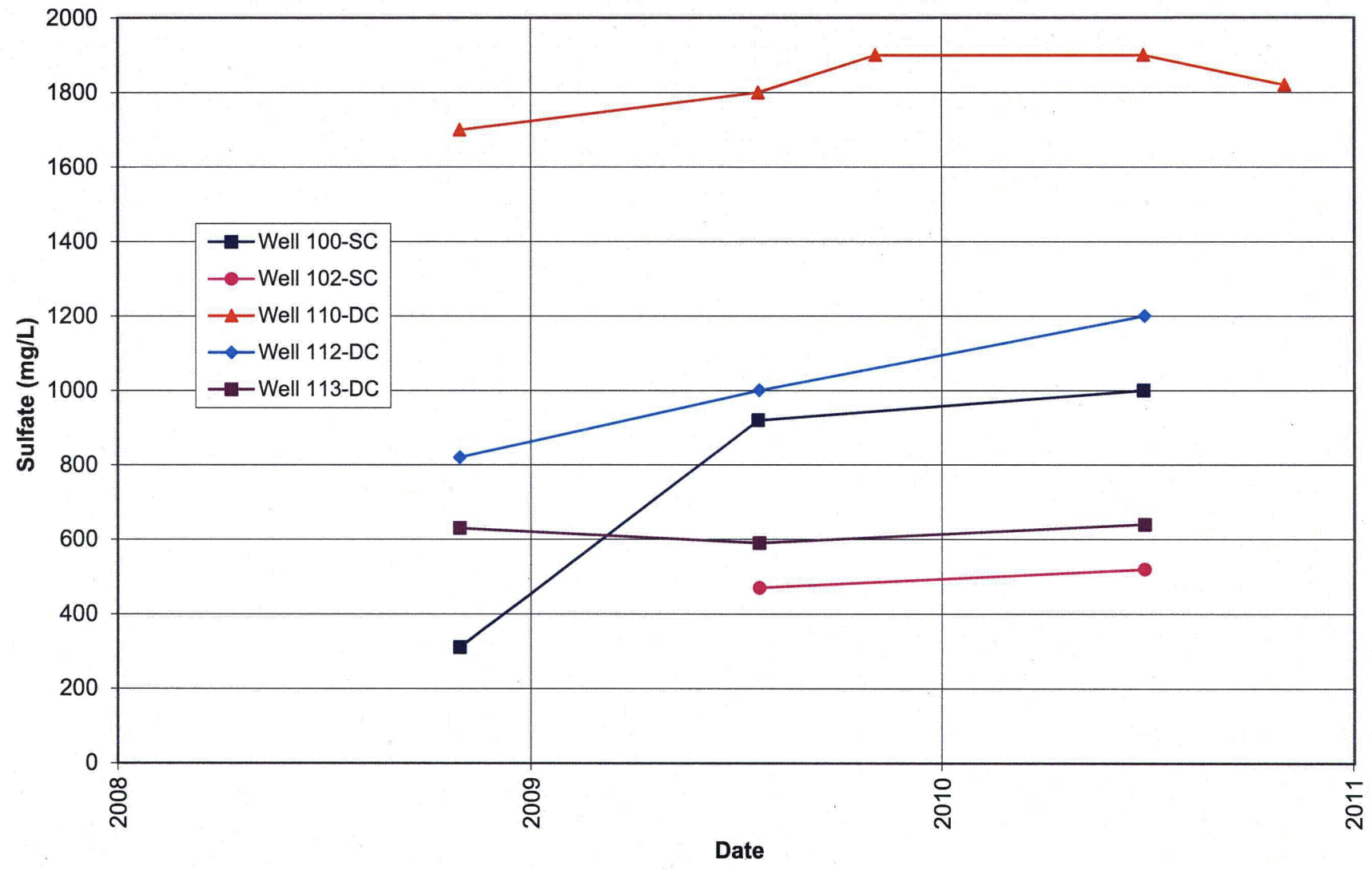
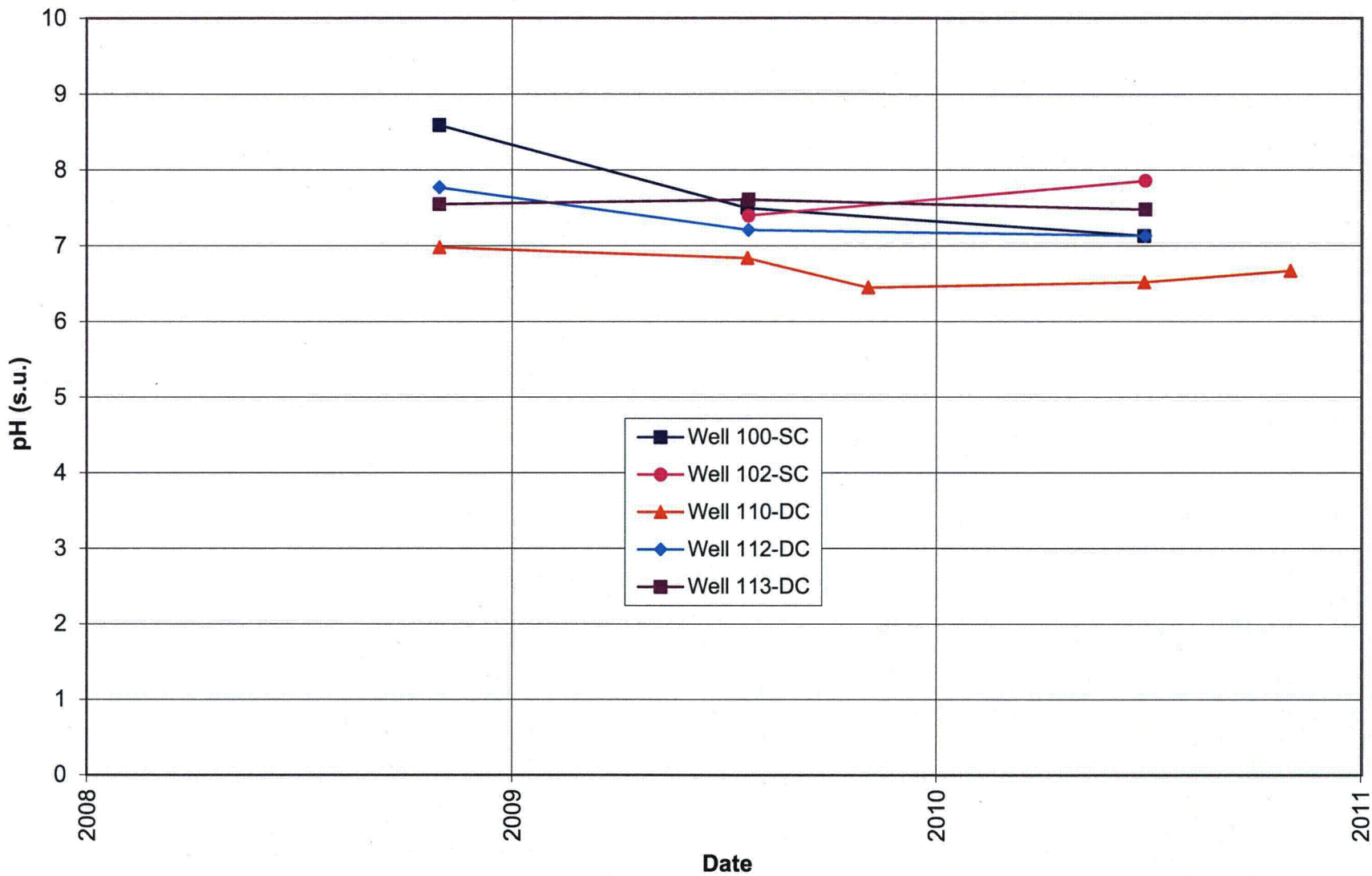*Figure 8. Sulfate Concentrations in the New Wells*

Figure 9. pH Measurements in the New Wells

If an ACL for a hazardous constituent is exceeded at a POC well, DOE will inform NRC and the Wyoming Department of Environmental Quality of the results. If results from the next two annual sampling events confirm that concentrations remain above an ACL (i.e., an exceedance is observed for 3 consecutive years), DOE will develop an evaluative monitoring work plan and submit it to NRC for review before implementing it. Results of evaluative monitoring will be used, in consultation with NRC and the Wyoming Department of Environmental Quality, to determine if corrective action is necessary.

Annual sampling of all site monitoring wells would continue for a minimum of 5 years after NRC approval of the revised compliance monitoring program. After the fifth sampling event, the groundwater monitoring program will be evaluated to determine if the disposal cell is performing as designed (i.e., no evidence of leakage) and if changes to the monitoring program are appropriate. Recommendations drawn from the evaluation will be submitted to NRC for concurrence and could include continuation of the monitoring program, revision of the program (i.e., changes to the analyte list or sampling frequency), or discontinuation of groundwater monitoring.

9.0   References

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Appendix A

Time-Concentration Plots for Groundwater Constituents

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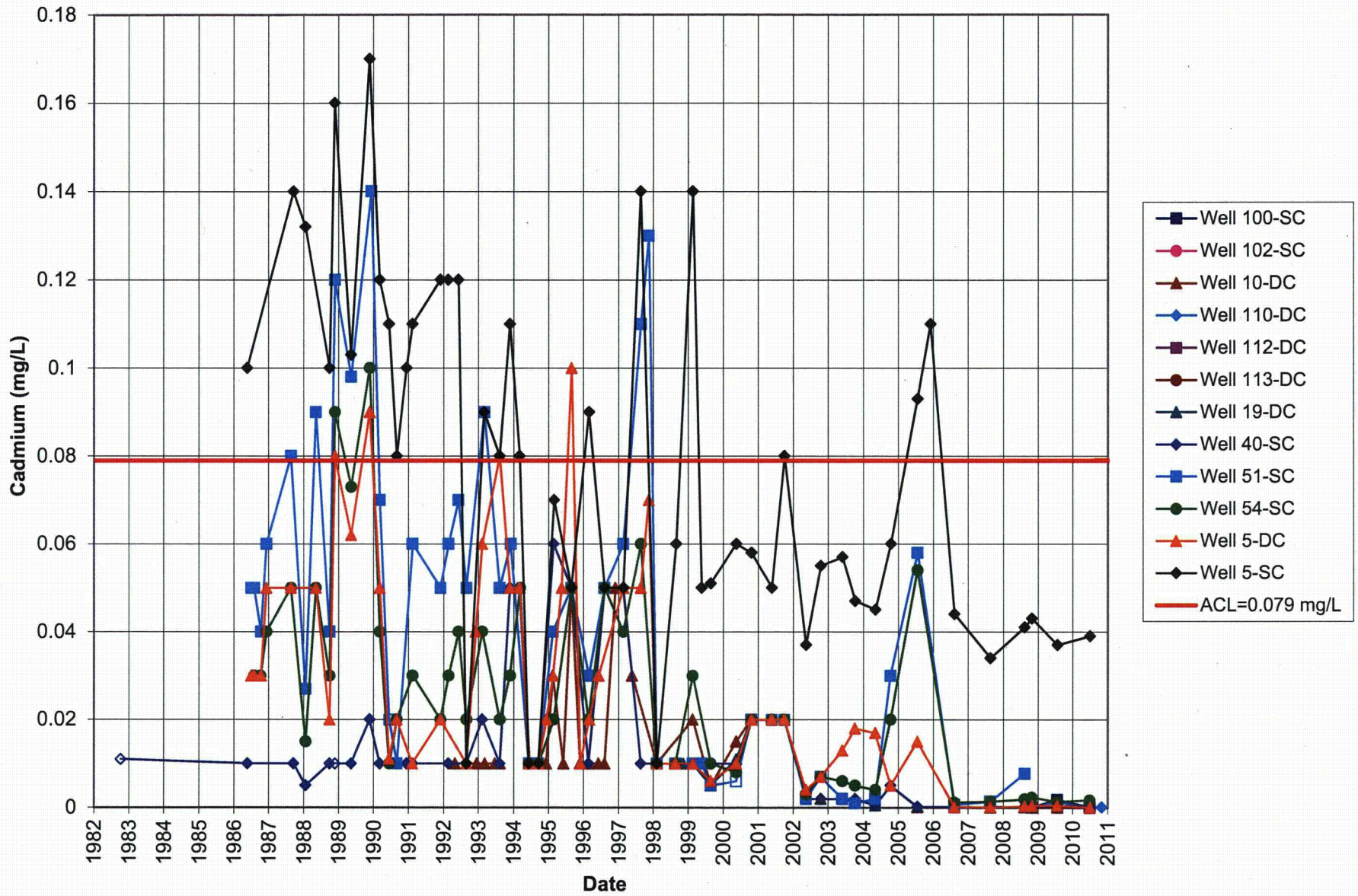
Figure A–1. Cadmium Concentrations in All Wells
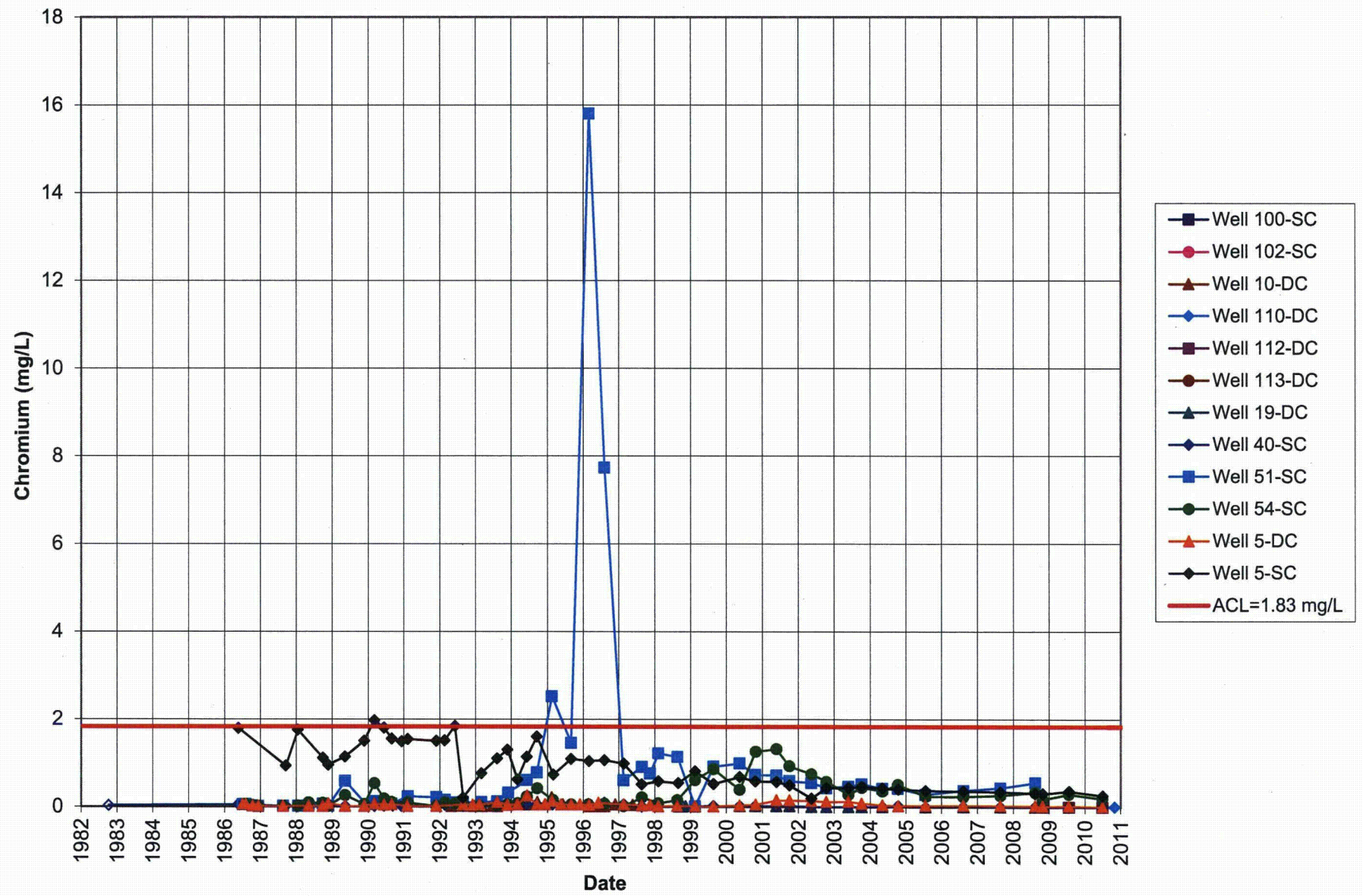
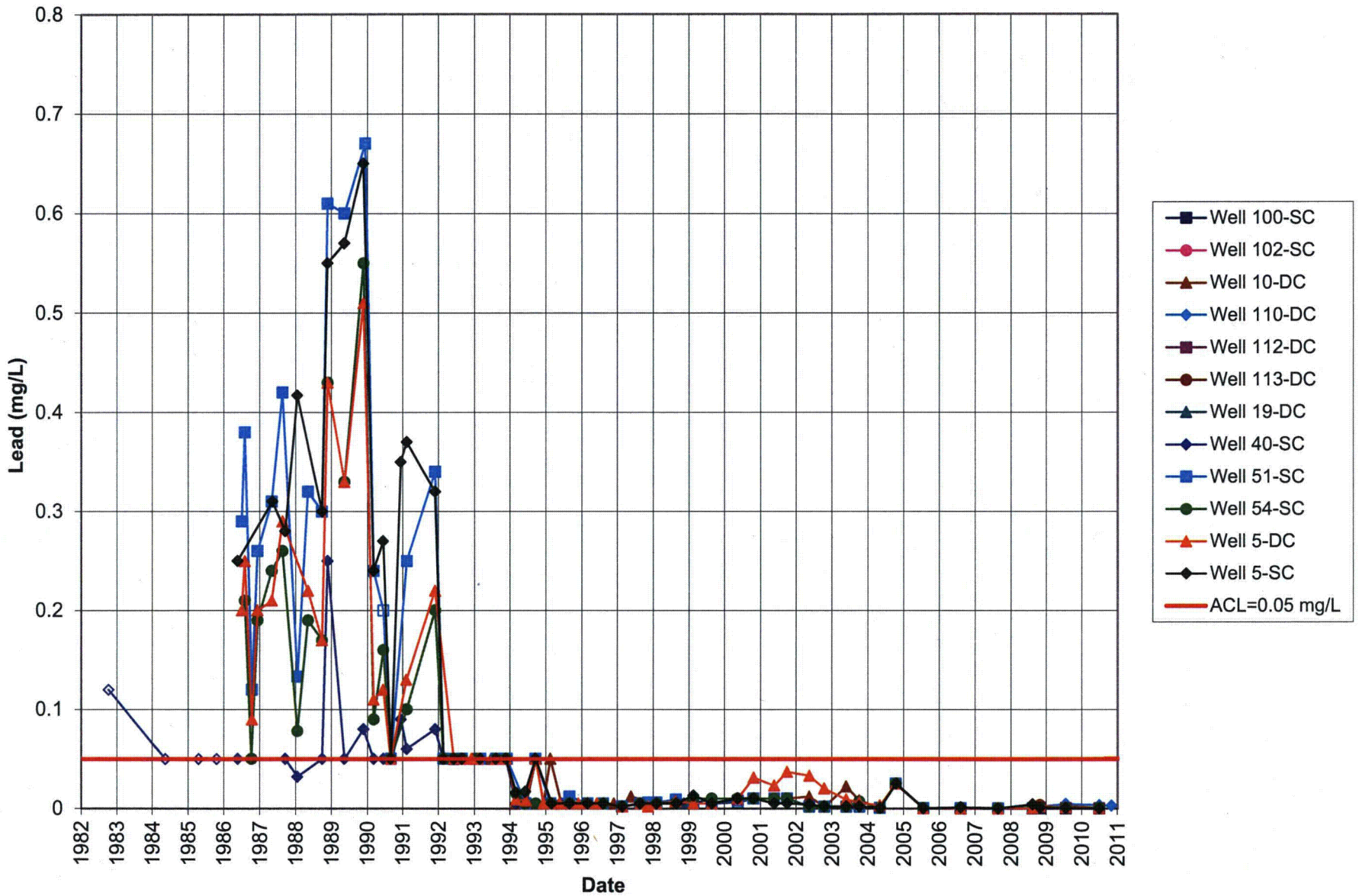*Figure A–2. Chromium Concentrations in All Wells*
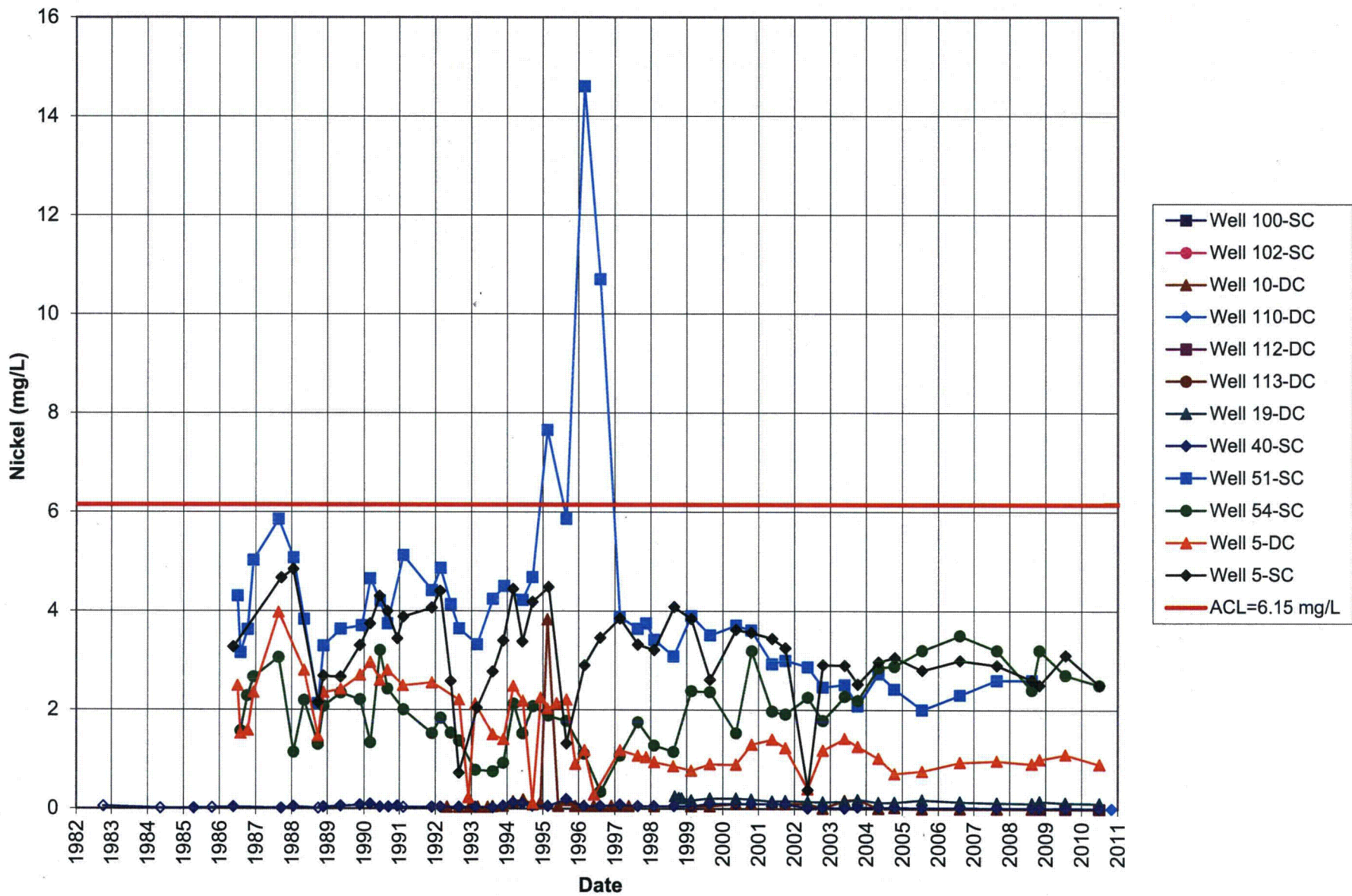
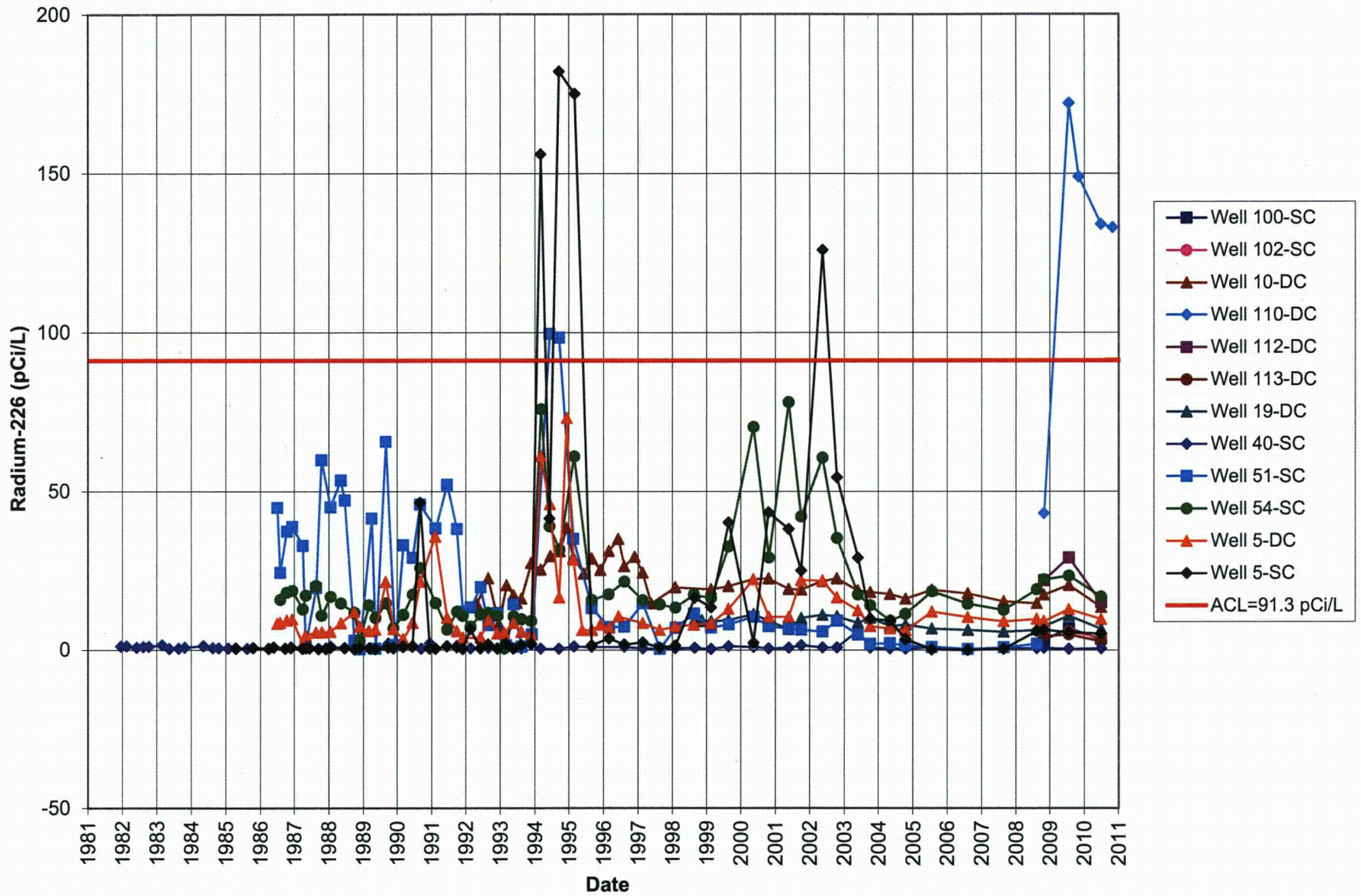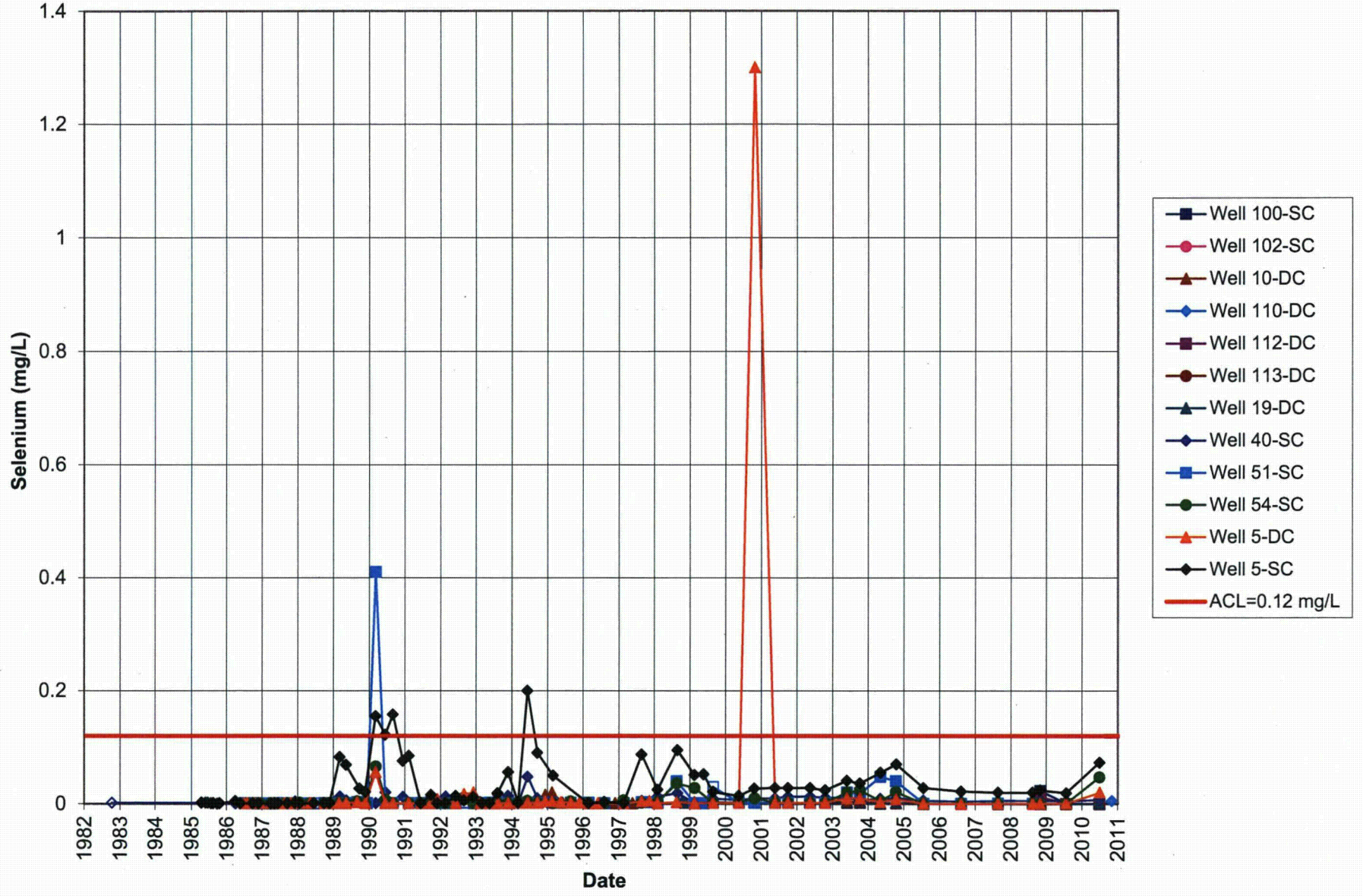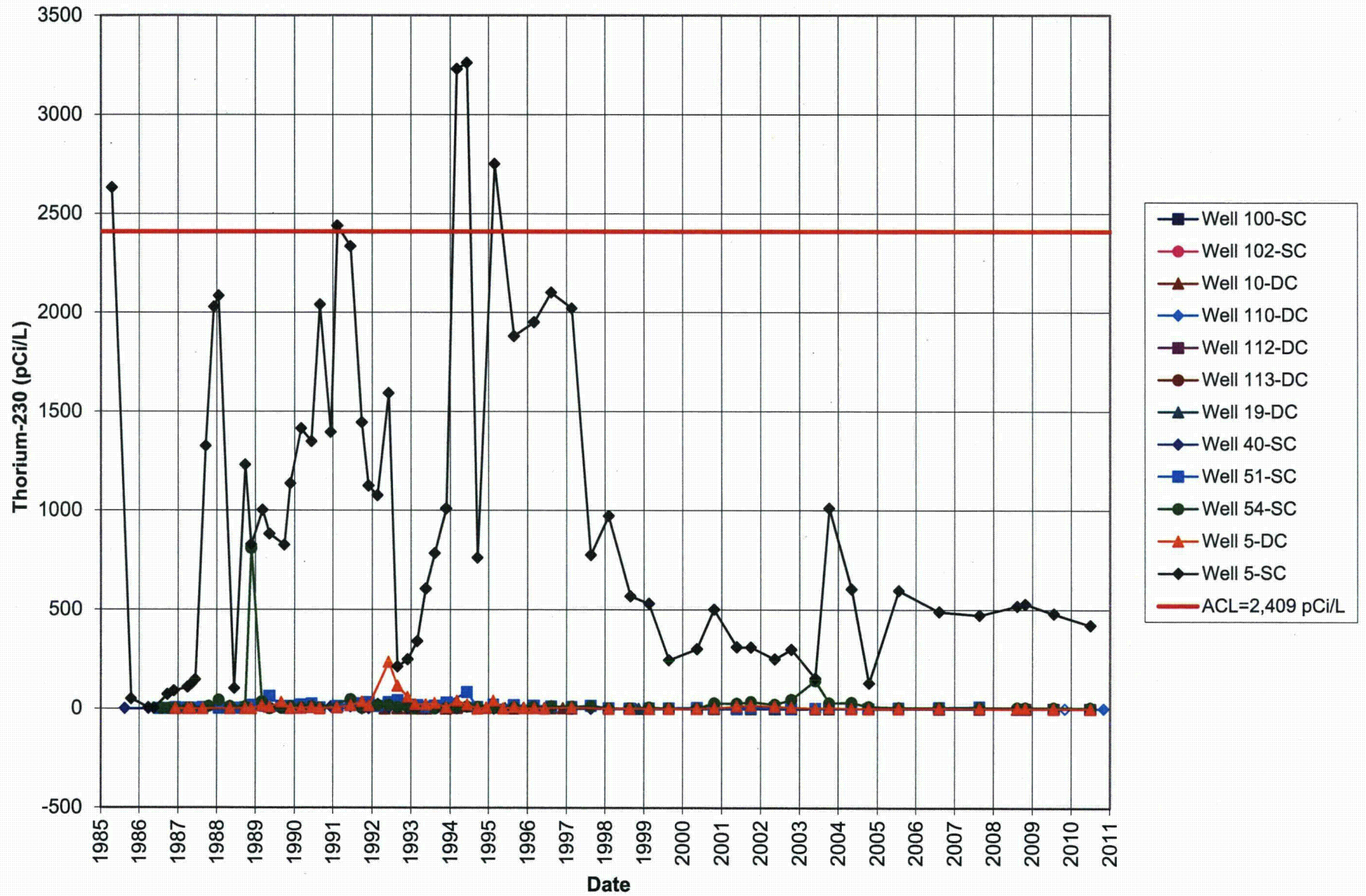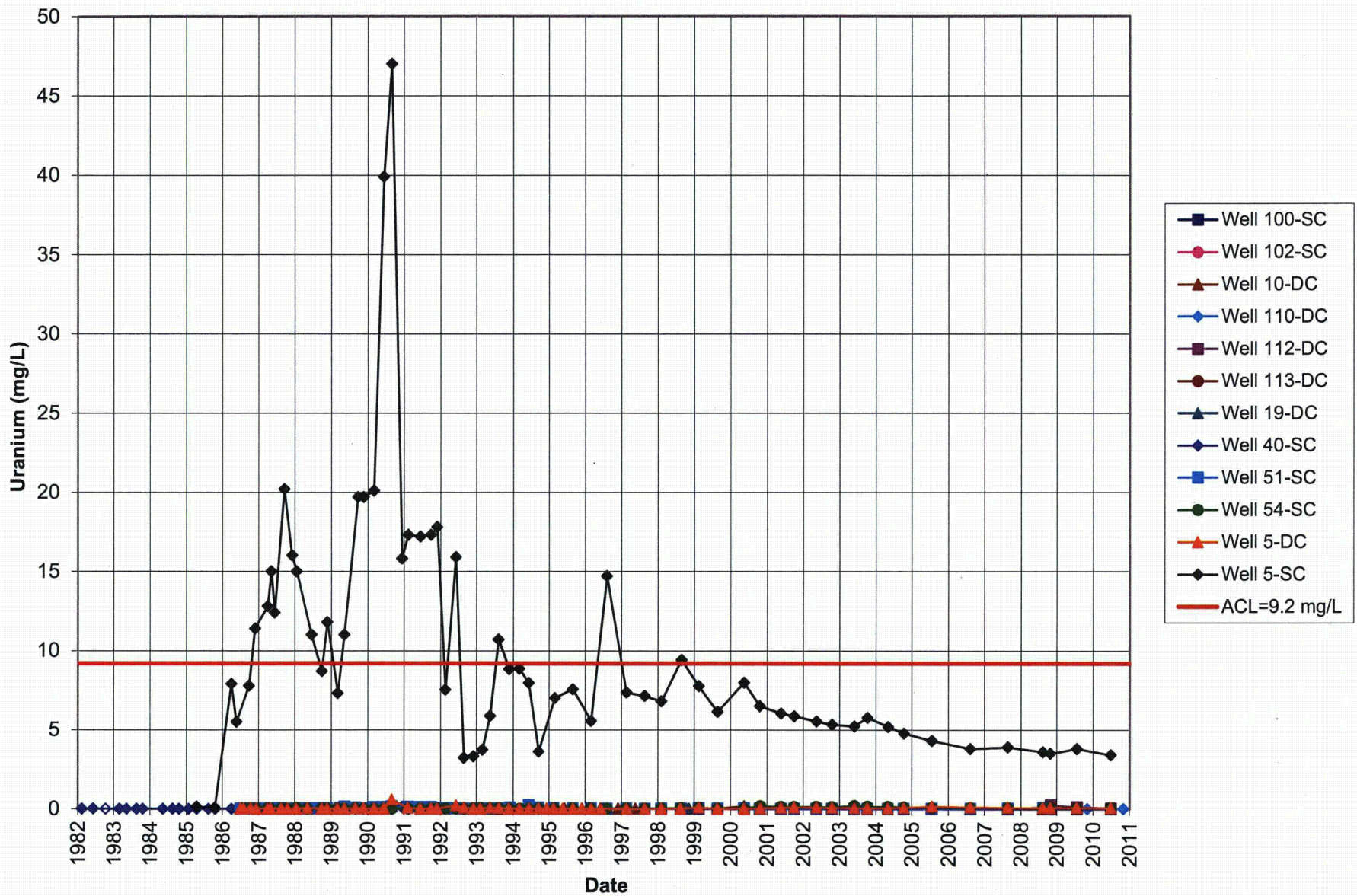*Figure A–3. Lead Concentrations in All Wells*

Figure A–4. Nickel Concentrations in All Wells

Figure A–5. Radium-226 Concentrations in All Wells

Legend:
- Well 100-SC
- Well 102-SC
- Well 10-DC
- Well 110-DC
- Well 112-DC
- Well 113-DC
- Well 19-DC
- Well 40-SC
- Well 51-SC
- Well 54-SC
- Well 5-DC
- Well 5-SC
- ACL=91.3 pCi/L
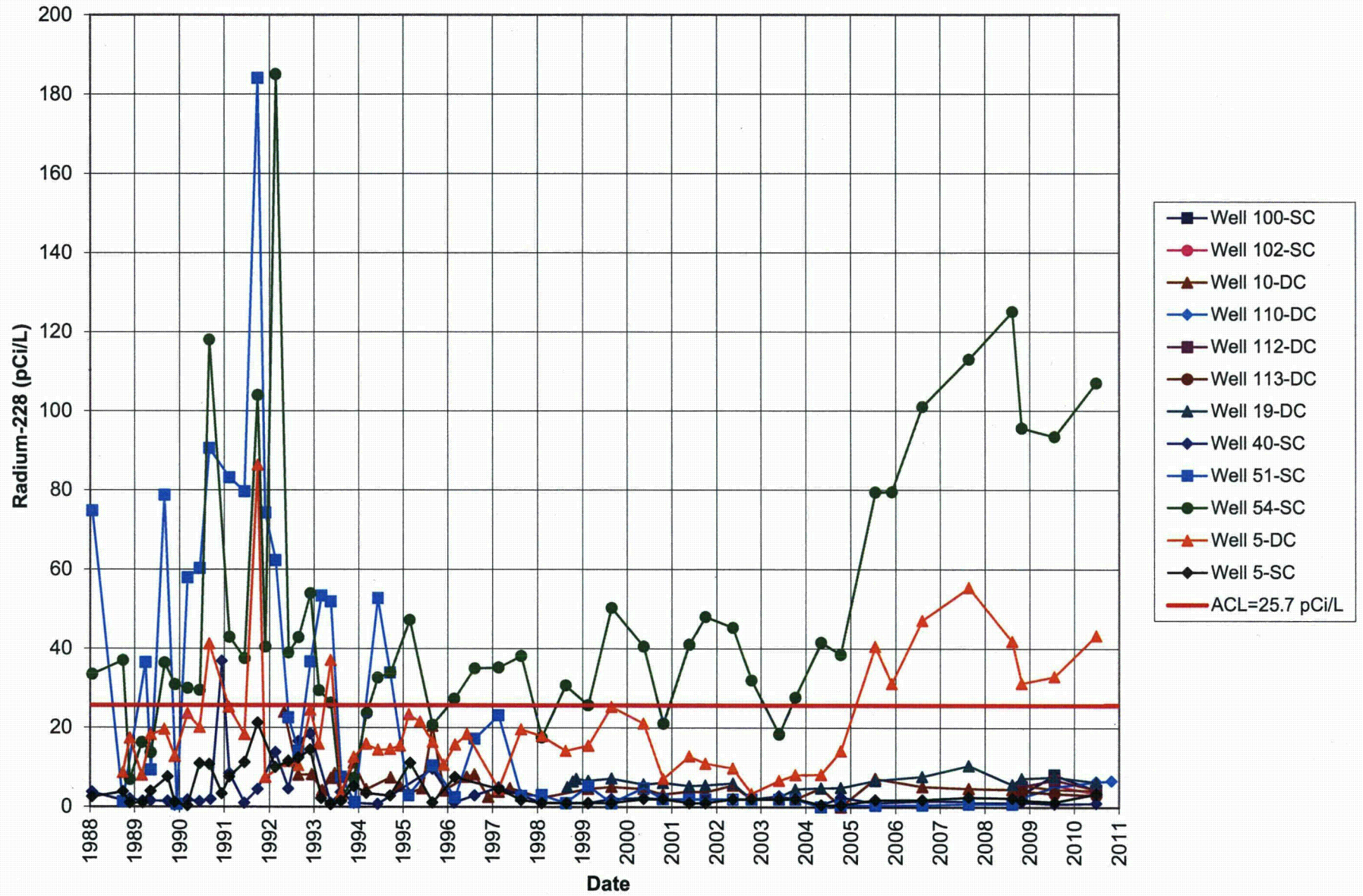
Figure A–6. Radium-228 Concentrations in All Wells

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Figure A-7. Selenium Concentrations in All Wells

Figure A–8. Thorium-230 Concentrations in All Wells

Figure A–9. Uranium Concentrations in All Wells
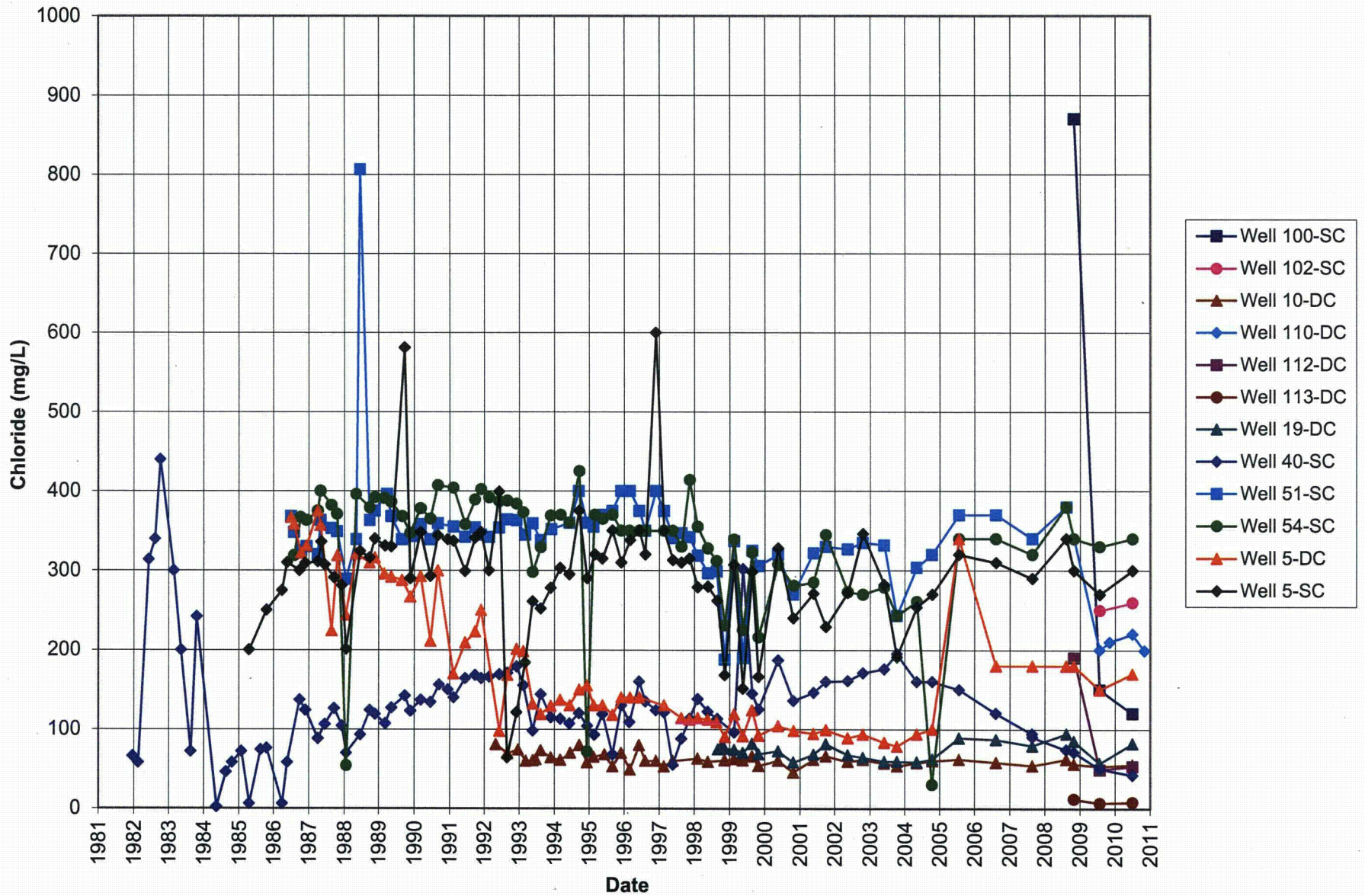
Figure A–10. Chloride Concentrations in All Wells
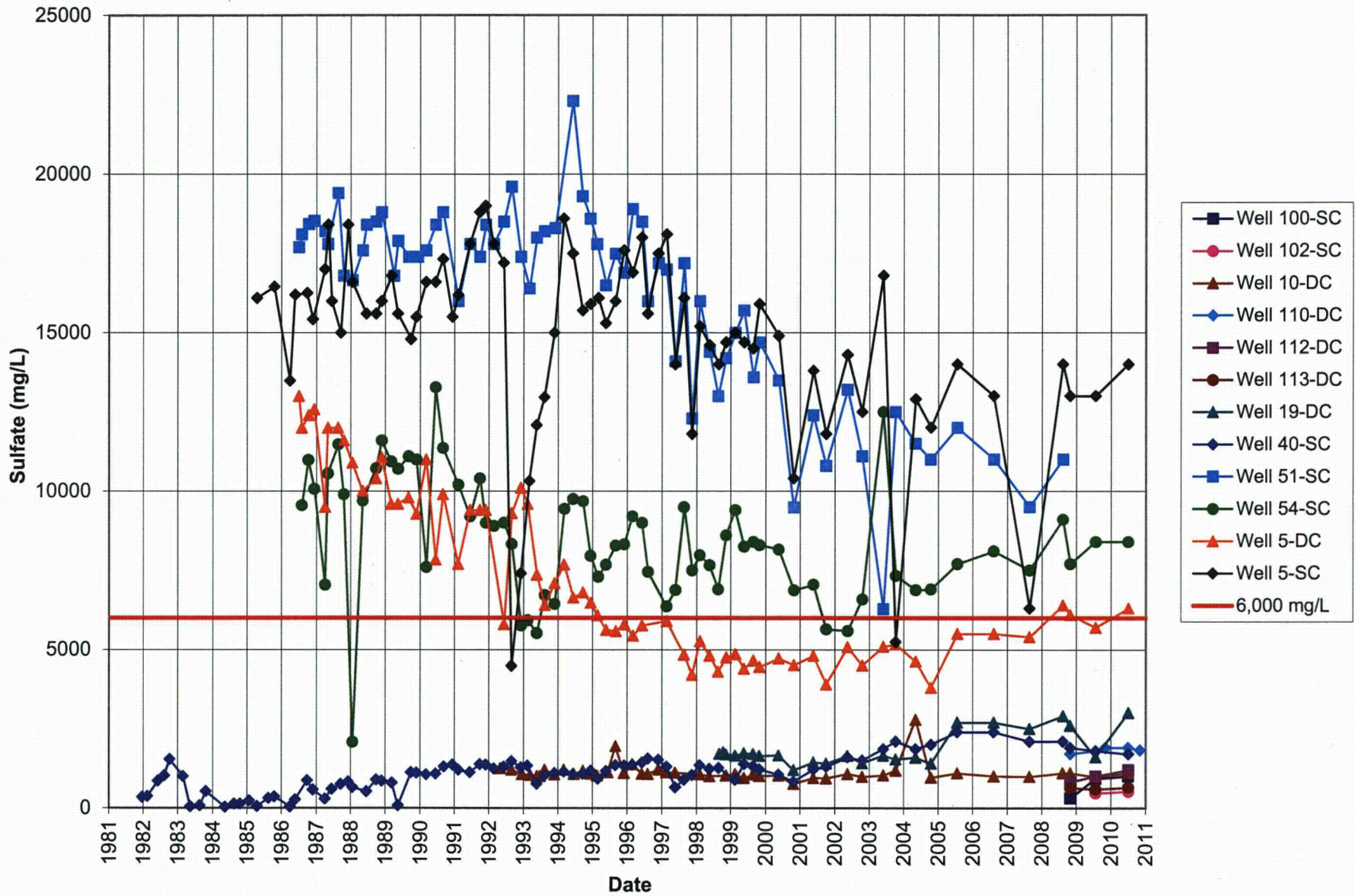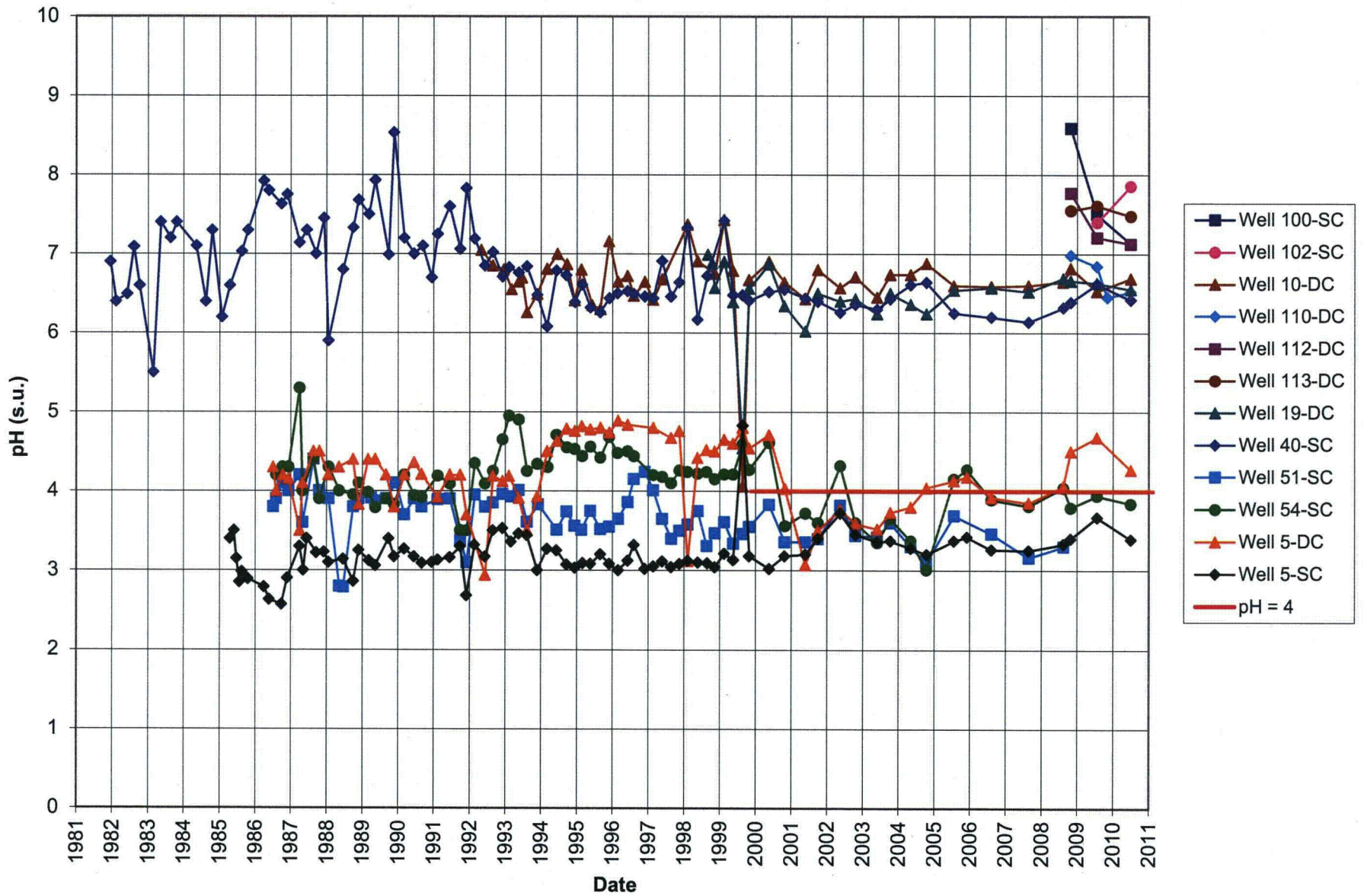
Figure A–11. Sulfate Concentrations in All Wells
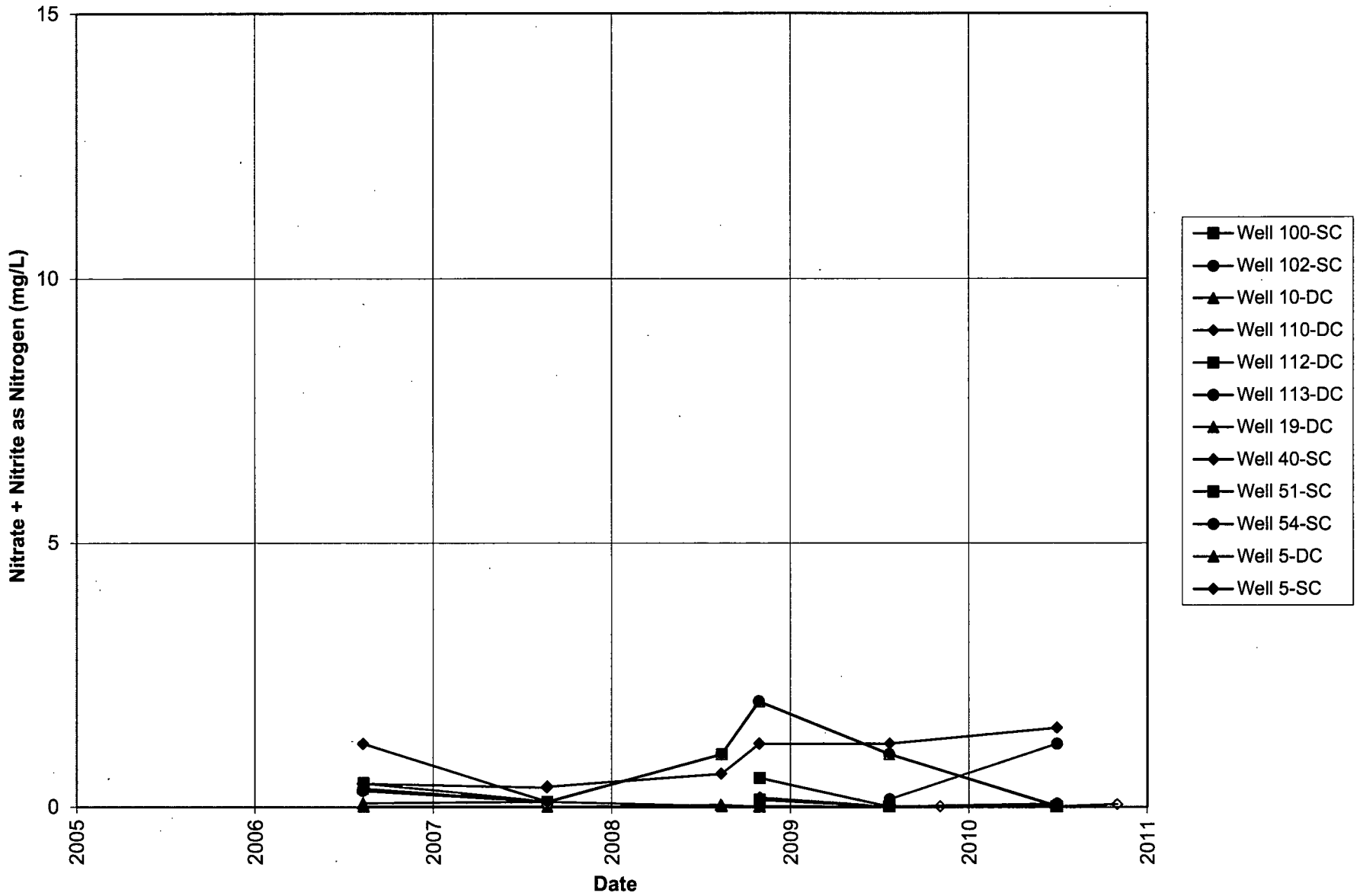
Figure A–12. pH Measurements in All Wells

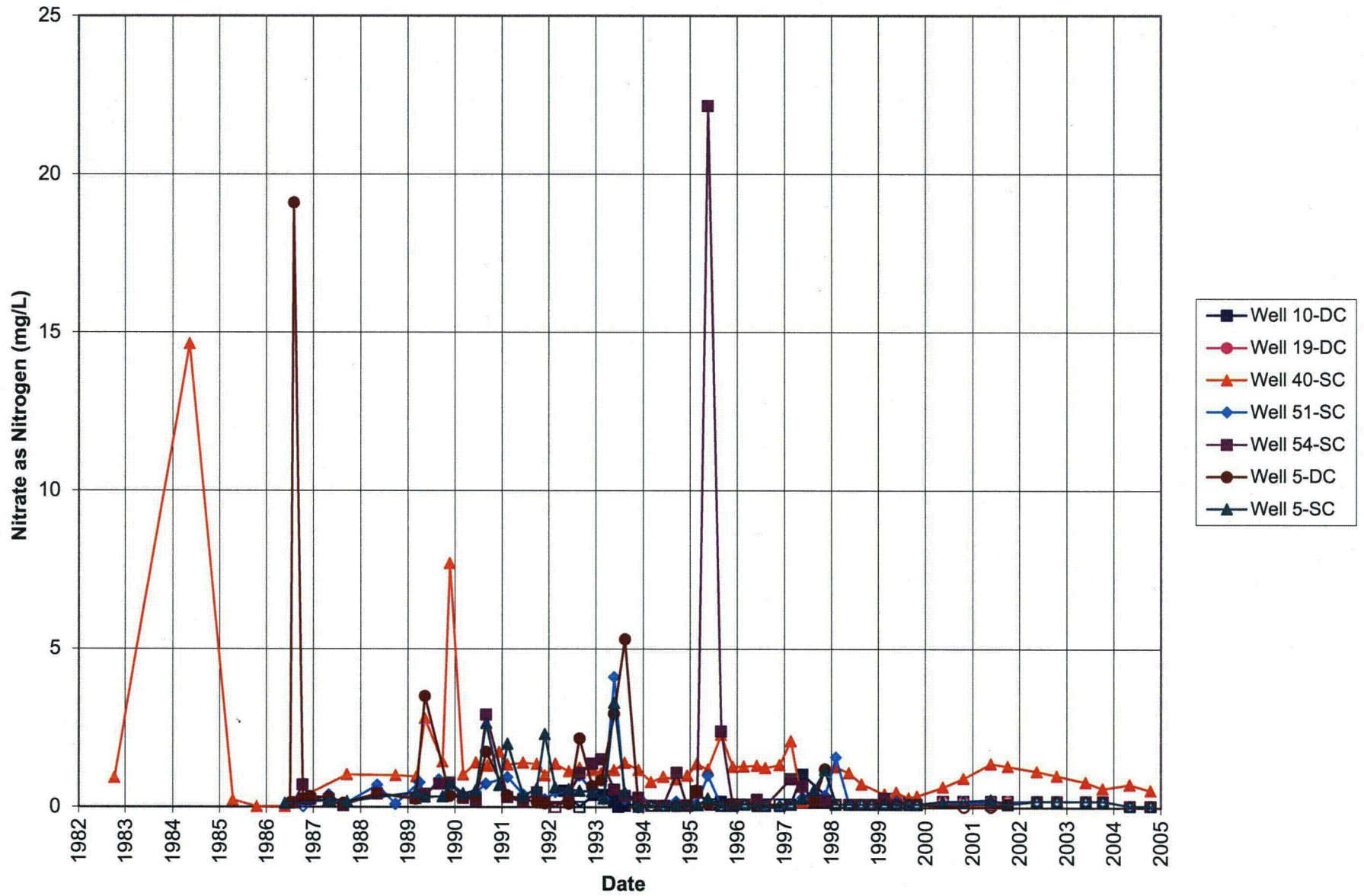*Figure A–13. Nitrate plus Nitrite as Nitrogen Concentrations in All Wells*

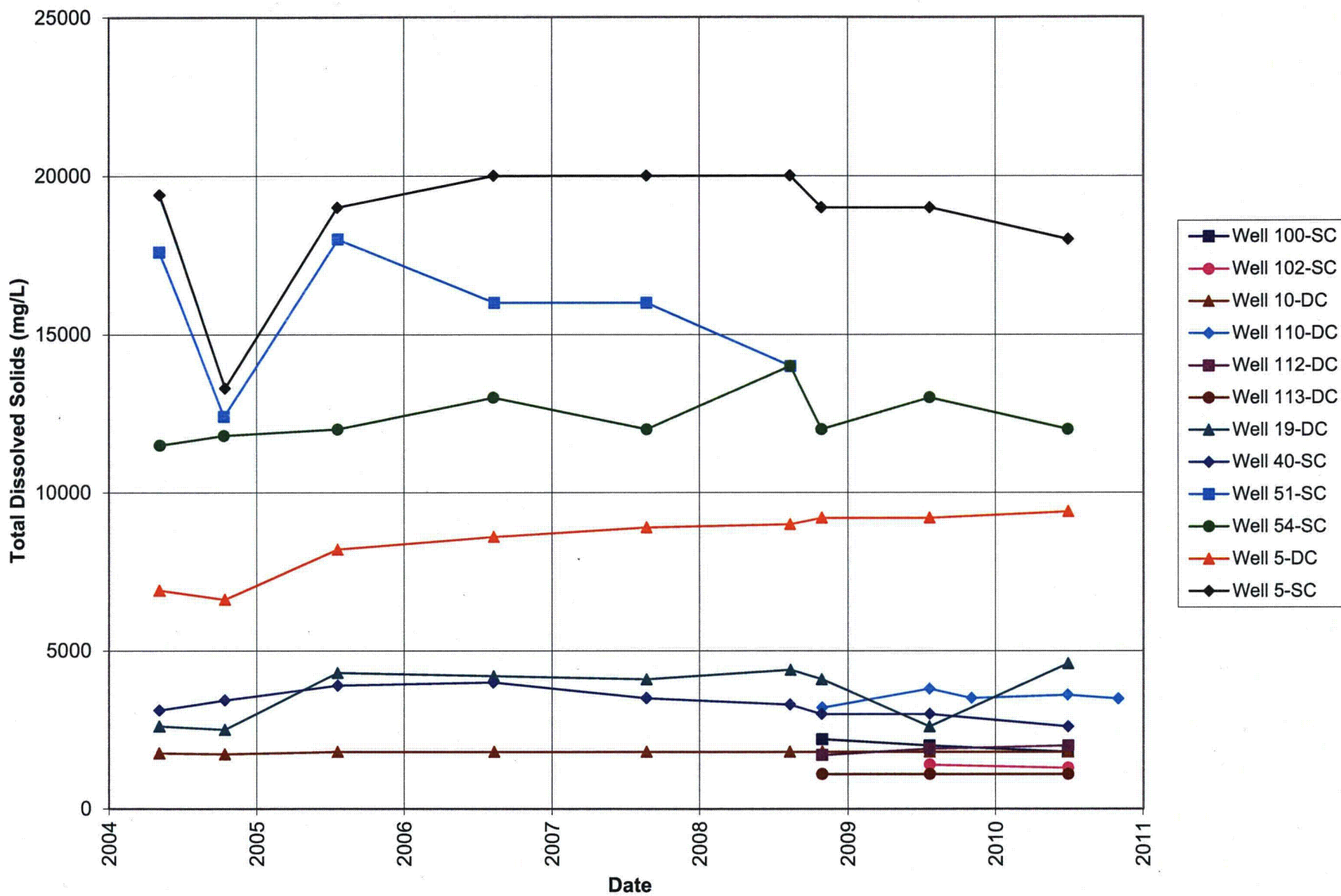Figure A–14. Nitrate as Nitrogen Concentrations in All Wells

Figure A–15. Total Dissolved Solids Concentrations in All Wells

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