TABLES

Table 1. Results of Monitor Well Samples, February 2011

Well ID	**MW-12**	**MW-9**	**MW-14**	**MW-108**	**MW-109**	**MW-74**	**MW-43R**	**MW-110**	**MW-111**
Sample Date	**2/11/2011**	**2/11/2011**	**2/11/2011**	**2/12/2011**	**2/12/2011**	**2/10/2011**	**2/12/2011**	**2/10/2011**	**2/10/2011**
Analyte	**Lang Draw**					**Northern Pathway**			
Major Ions (mg/L)									
Calcium	883	883	824	868	552	686	739	769	520
Chloride	371	334	358	302	89	233	254	290	102
Magnesium	544	200	343	179	137	175	154	156	90
Nitrogen Nitrate + Nitrite as N	0.01	0.81	<0.01	0.06	0.13	4.4	0.05	0.01	0.04
Phosphorus Total as P	<0.005	0.006	0.058	0.013	0.029	0.008	0.009	0.064	0.01
Potassium	18	6	11	9	10	14	16	17	7
Sodium	297	257	268	180	127	122	66	43	24
Sulfate	2810	1880	2280	1620	1900	2000	1530	1720	1190
Metals Dissolved (mg/L)									
Aluminum	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1
Arsenic	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Barium	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Beryllium	<0.001	N/A	N/A	N/A	N/A	<0.001	N/A	N/A	N/A
Cadmium	<0.001	N/A	N/A	N/A	N/A	<0.001	N/A	N/A	N/A
Chromium	<0.001	N/A	N/A	N/A	N/A	<0.001	N/A	N/A	N/A
Iron	0.41	1.14	1.46	0.55	0.53	4.62	0.59	9.92	0.19
Manganese	6.62	0.18	1.19	0.43	0.04	2.11	1.04	0.53	<0.01
Molybdenum	<0.001	N/A	N/A	N/A	N/A	<0.001	N/A	N/A	N/A
Nickel	0.035	0.018	0.04	0.043	0.013	0.042	0.017	0.006	0.004
Selenium	0.002	<0.001	0.004	N/A	N/A	0.021	0.003	N/A	N/A
Silica	28	23.7	25.9	26.2	14.1	29	19.6	23.6	18.1
Uranium (pCi/L)	420	195	439	135	61.3	15.4	38	1.6	17.6
Metals Total (mg/L)									
Aluminum	<0.1	<0.1	<0.1	1.2	3.1	<0.1	0.3	3	2.1
Iron	0.57	1.25	1.55	1.53	2	4.96	1.55	12.9	1.23
Manganese	6.72	0.19	1.21	0.49	0.03	2.14	1.16	0.54	0.02
Silica	31.6	25.9	27.3	18.5	29	30.9	20.8	38.7	28.2
Radionuclides Dissolved (pCi/L)									
Radium-226	0.62	0.3	0.09	0.41	0.5	2.2	1.8	2.9	0.42
Radium-228	2.4	1.9	0.8	1.6	1.3	4	3.1	7.6	1.4
Thorium-230	-0.3	-0.06	<0.1	-0.1	-0.05	-0.09	-0.07	<0.02	-0.06
Total Dissolved Solids (mg/L)	5770	4390	5050	3980	3050	3700	3410	3340	2260
pH (s.u.)	6.56	7.00	7.16	6.75	7.34	7.26	6.72	7.28	7.60

Table 2. Saturation Indices for Water Samples on Lang Draw Flow Path, 2011

Phase	Formula	MW-108	MW-109	MW-12	MW-14	MW-9
(UO2)3(PO4)2:4w	(UO2)3(PO4)2:4H2O	-36.01	-33.17		-36.37	-38.16
Al(OH)3(a)	Al(OH)3		-0.7			
Calcite	CaCO3	0.74	0.49	0.37	1.17	1.02
Chalcedony	SiO2	0.2	-0.07	0.23	0.2	0.16
CO2(g)	CO2 pressure (atmos.)	-0.91	-2.13	-0.74	-1.22	-1.11
Ferrihydrite	Fe(OH)3	2.23	2.49	1.97	2.86	2.69
Gypsum	CaSO4:2H2O	-0.01	-0.05	0.02	0.04	0.04
Magnesite	MgCO3	-0.19	-0.36	0.01	0.55	0.13
MnHPO4	MnHPO4	-0.28	-0.63		0.79	-0.97
Schoepite	UO2(OH)2:H2O	-7.67	-6.33	-6.64	-7.72	-7.88
Siderite	FeCO3	-7.03	-7.99	-7.12	-6.71	-6.77
U3O8(c)	U3O8	-38.21	-34.19	-35.12	-38.37	-38.83
UO2(OH)2(beta)	UO2(OH)2	-7.21	-5.87	-6.18	-7.27	-7.42
Uraninite(c)	UO2	-26.43	-25.09	-25.4	-26.48	-26.63

Note: SI less than 0 indicates undersaturation and SI greater than 0 indicates supersaturation.

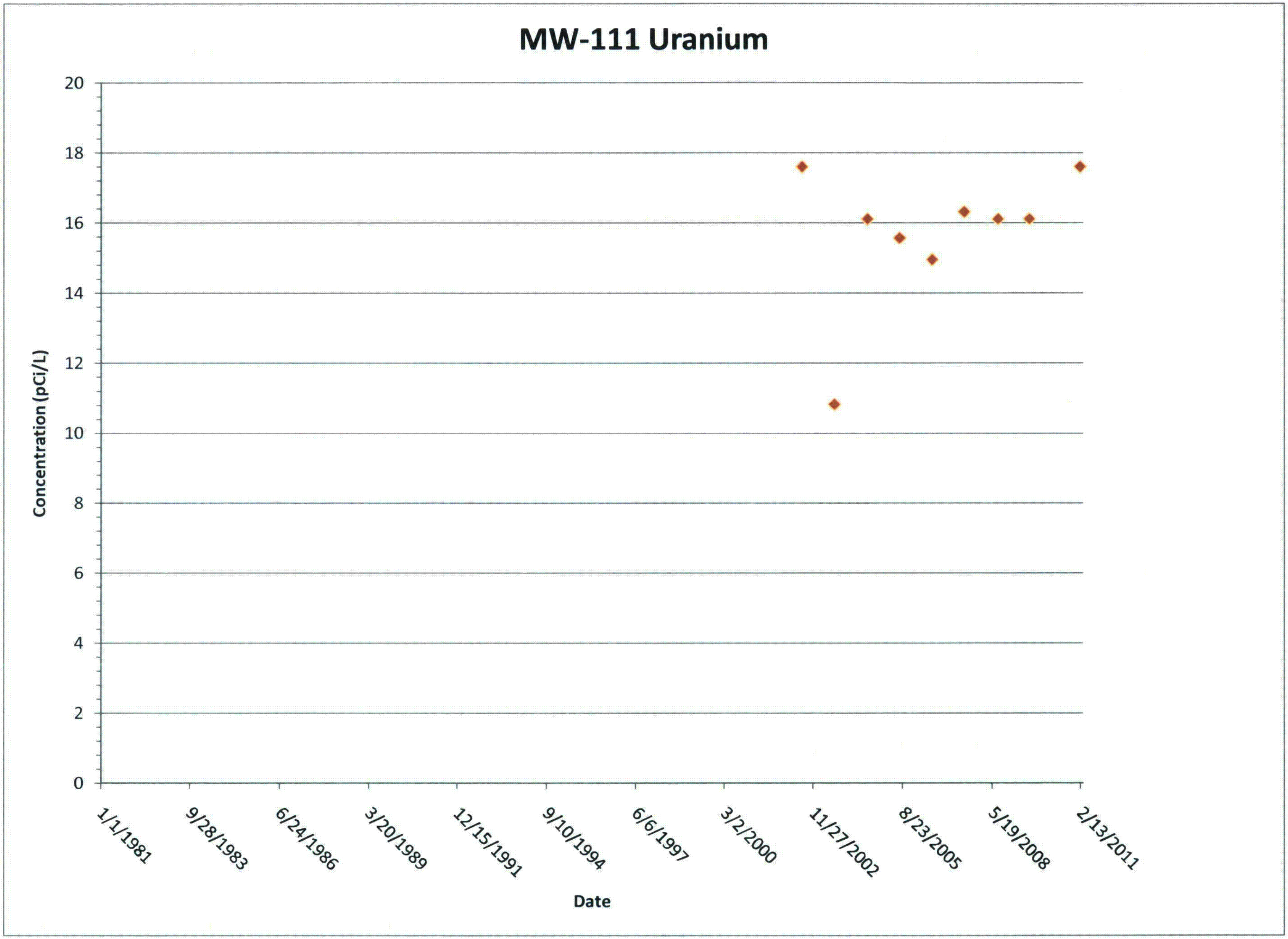
Table 3. Saturation Indices for Water Samples on Northern Pathway

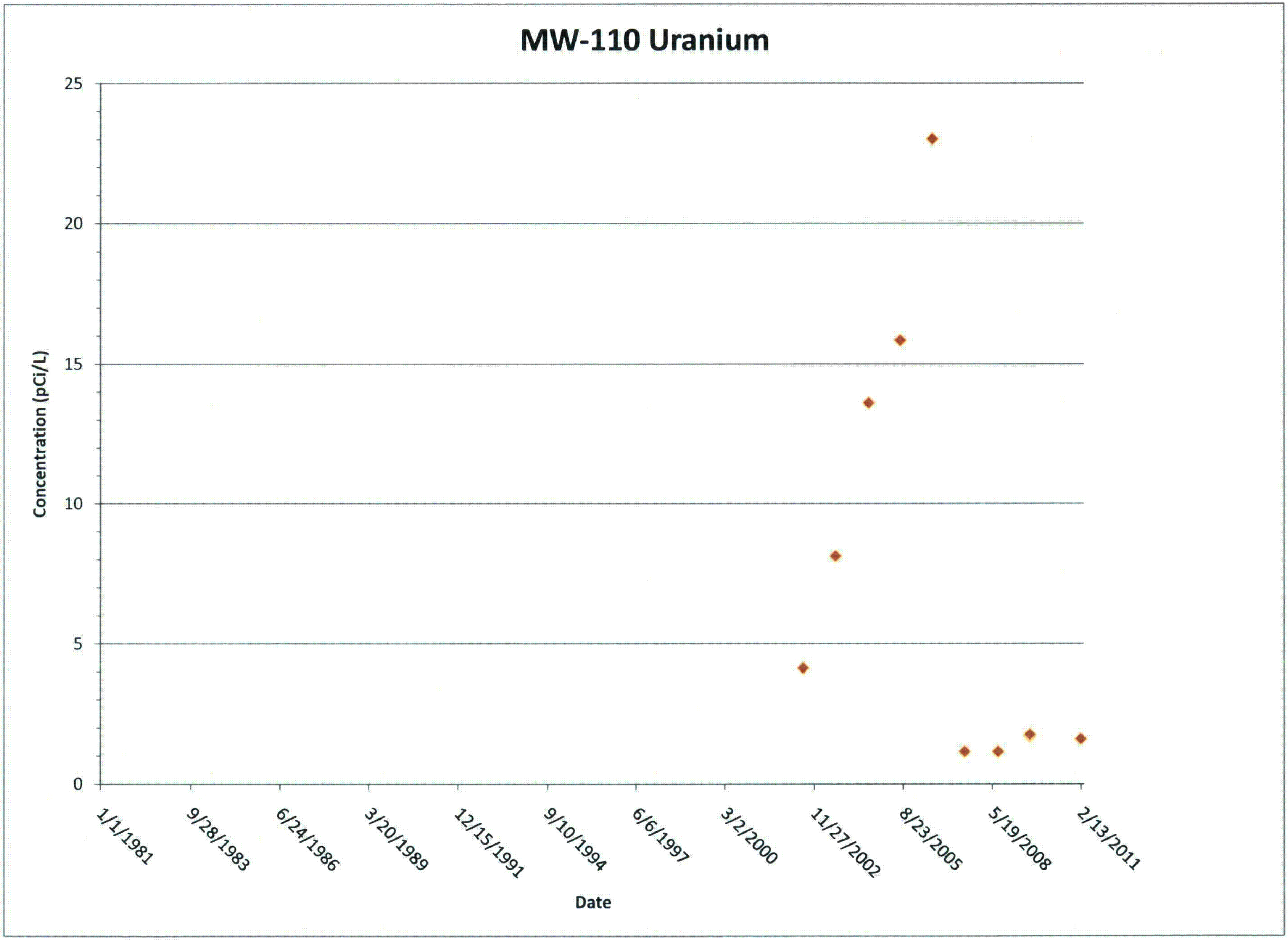
Phase	Formula	MW-110	MW-111	MW-43	MW-74
(UO2)3(PO4)2:4w	(UO2)3(PO4)2:4H2O	-40.91	-39.97	-35.5	-36.95
Calcite	CaCO3	0.93	1.05	0.44	0.59
Chalcedony	SiO2	0.15	0.03	0.07	0.24
CO2(g)	CO2 pressure (atmos)	-1.73	-2.14	-1.1	-1.96
Ferrihydrite	Fe(OH)3	3.74	2.1	2.24	3.4
Gypsum	CaSO4:2H2O	0.01	-0.19	-0.04	0.02
Magnesite	MgCO3	-0.01	0.04	-0.48	-0.25
MnHPO4	MnHPO4	0.7		0.03	0.45
Schoepite	UO2(OH)2:H2O	-9.16	-7.96	-7.45	-7.28
Siderite	FeCO3	-6.34	-8.39	-7.2	-6.91
U3O8(c)	U3O8	-42.69	-39.1	-37.54	-37.04
UO2(OH)2(beta)	UO2(OH)2	-8.71	-7.51	-6.99	-6.82
Uraninite(c)	UO2	-27.92	-26.72	-26.2	-26.04

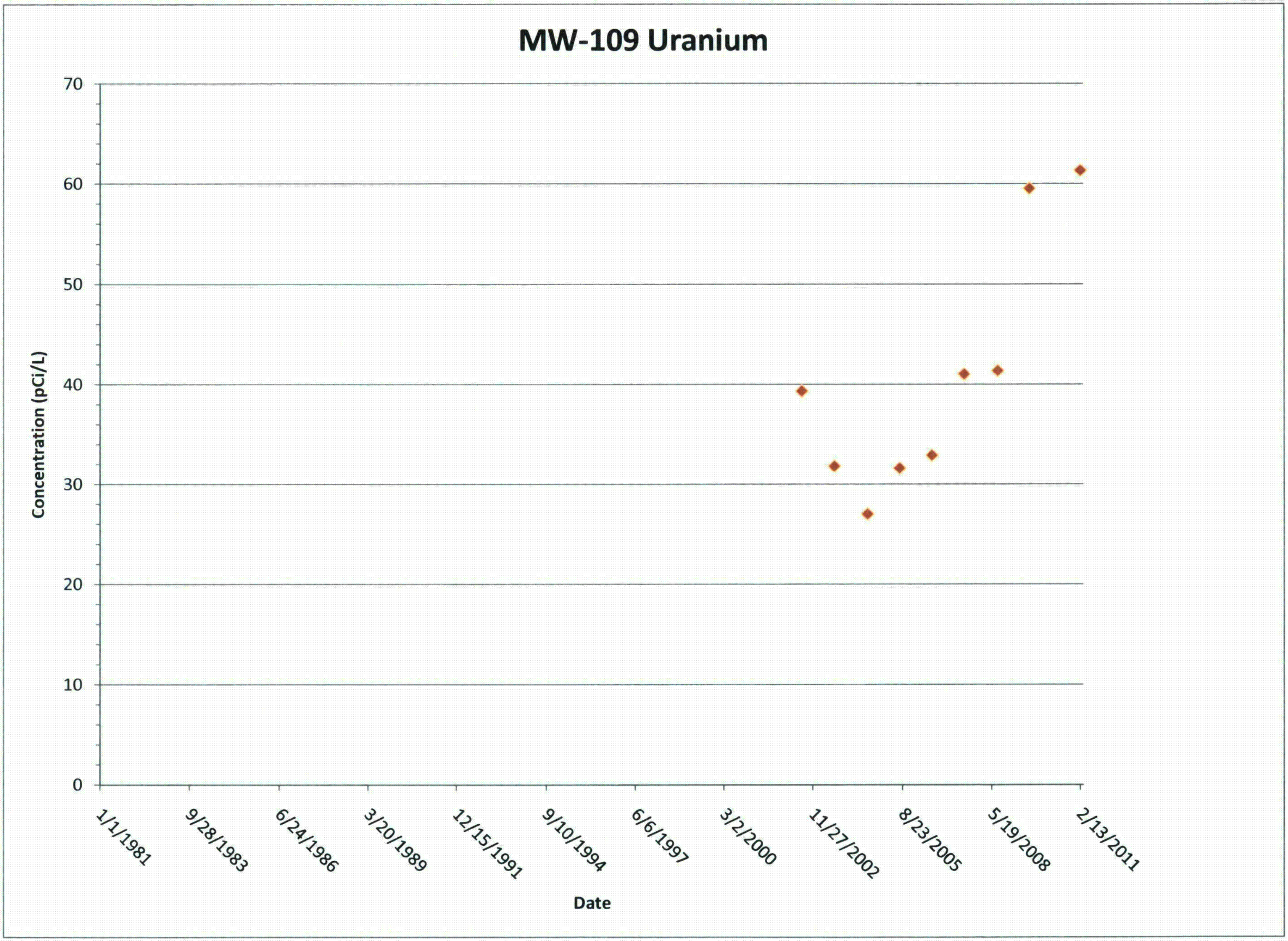
Note: SI less than 0 indicates undersaturation and SI greater than 0 indicates supersaturation.

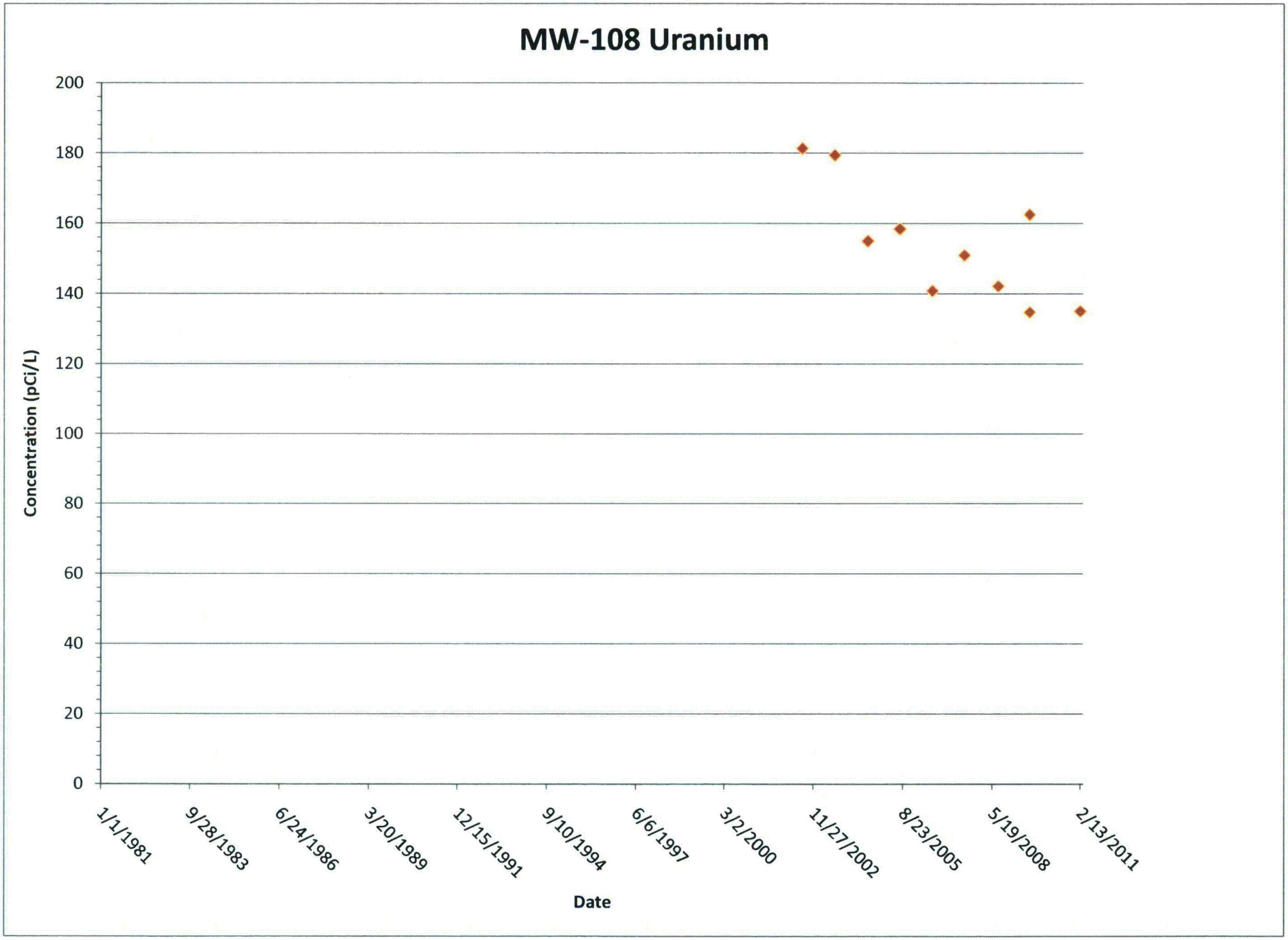
ATTACHMENT I

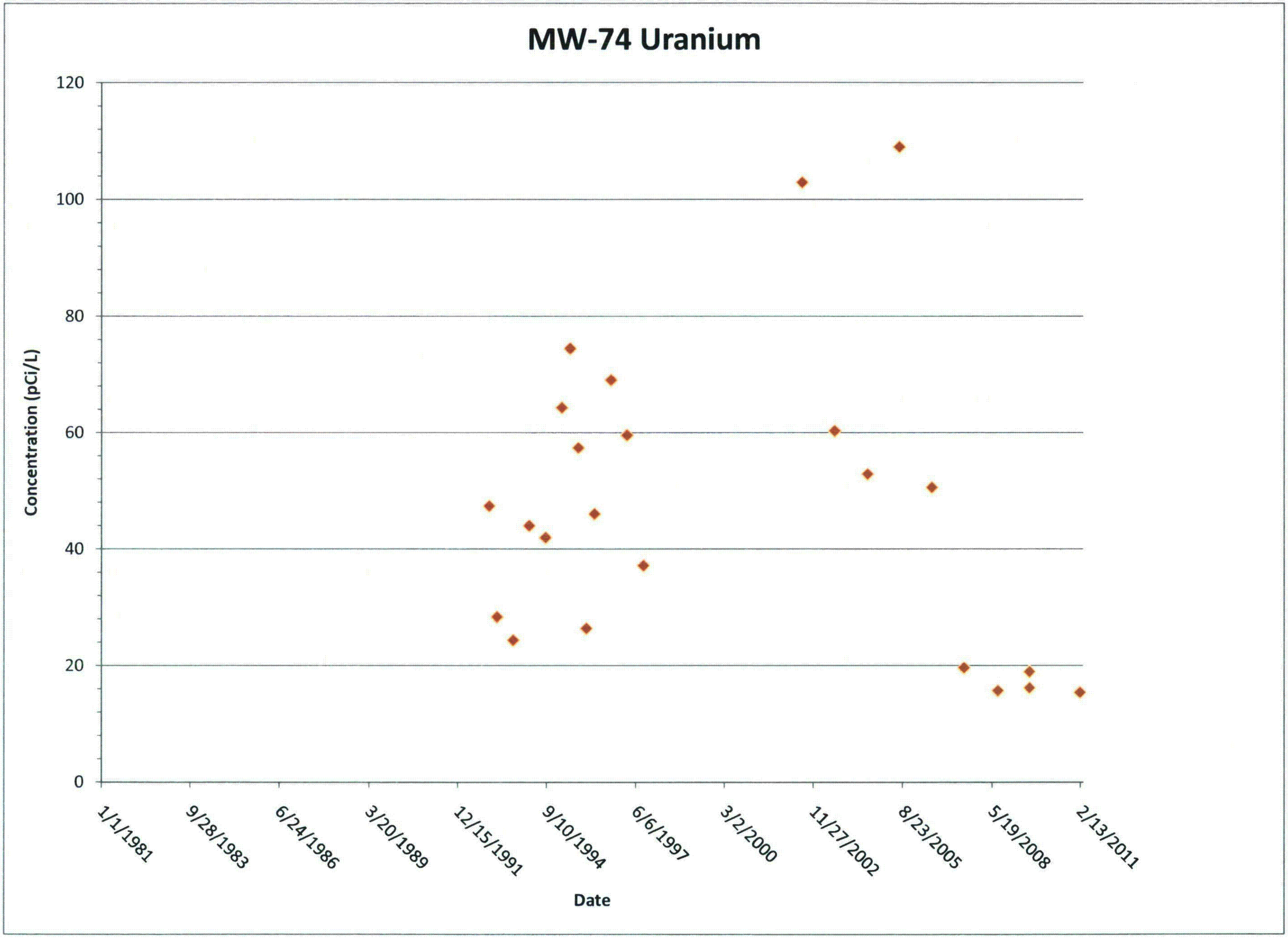
Temporal plots of
chemical parameters measured
in monitoring wells

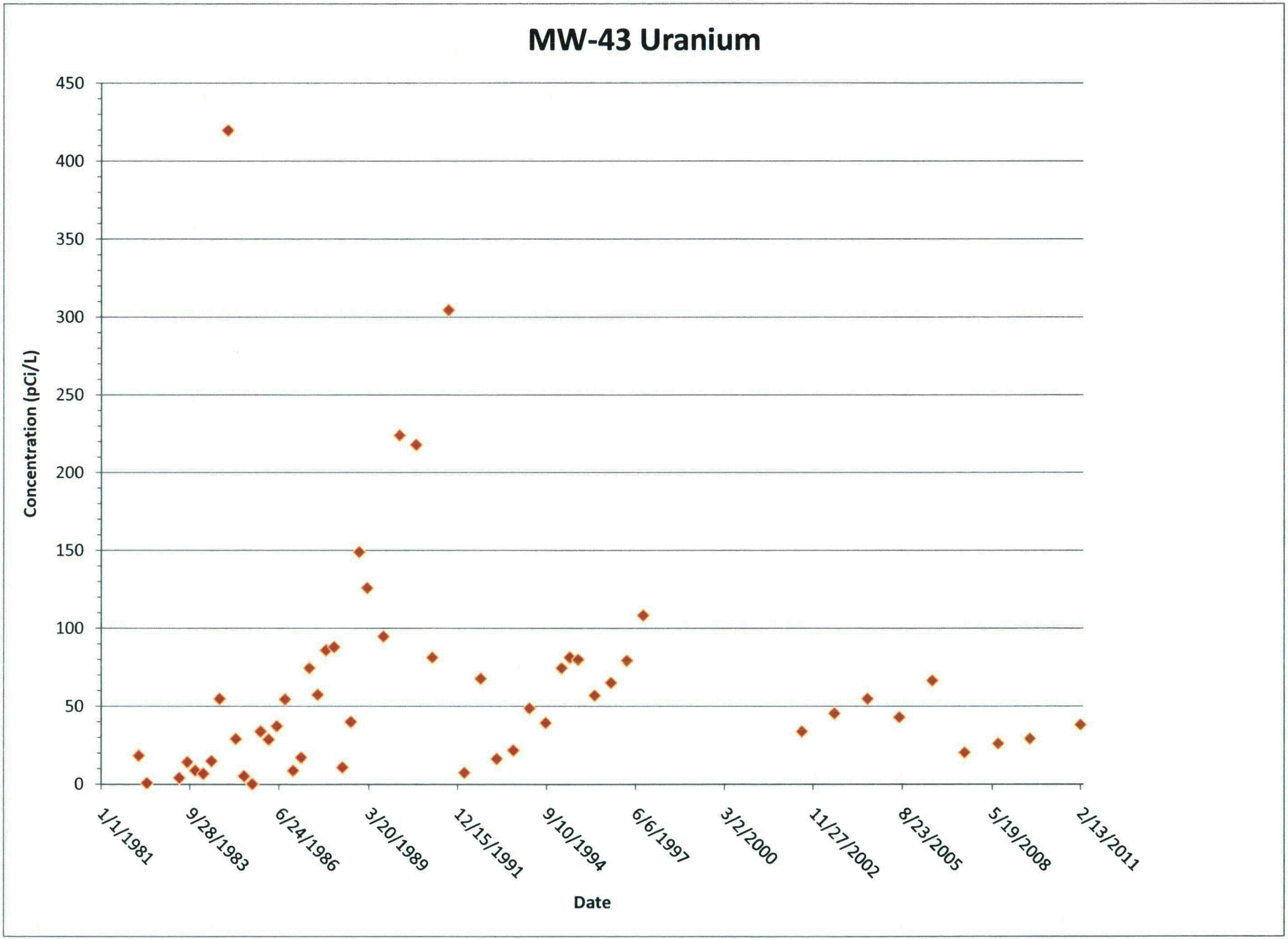

MW-111 Uranium
Concentration (pCi/L)
20
18
16
14
12
10
8
6
4
2
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

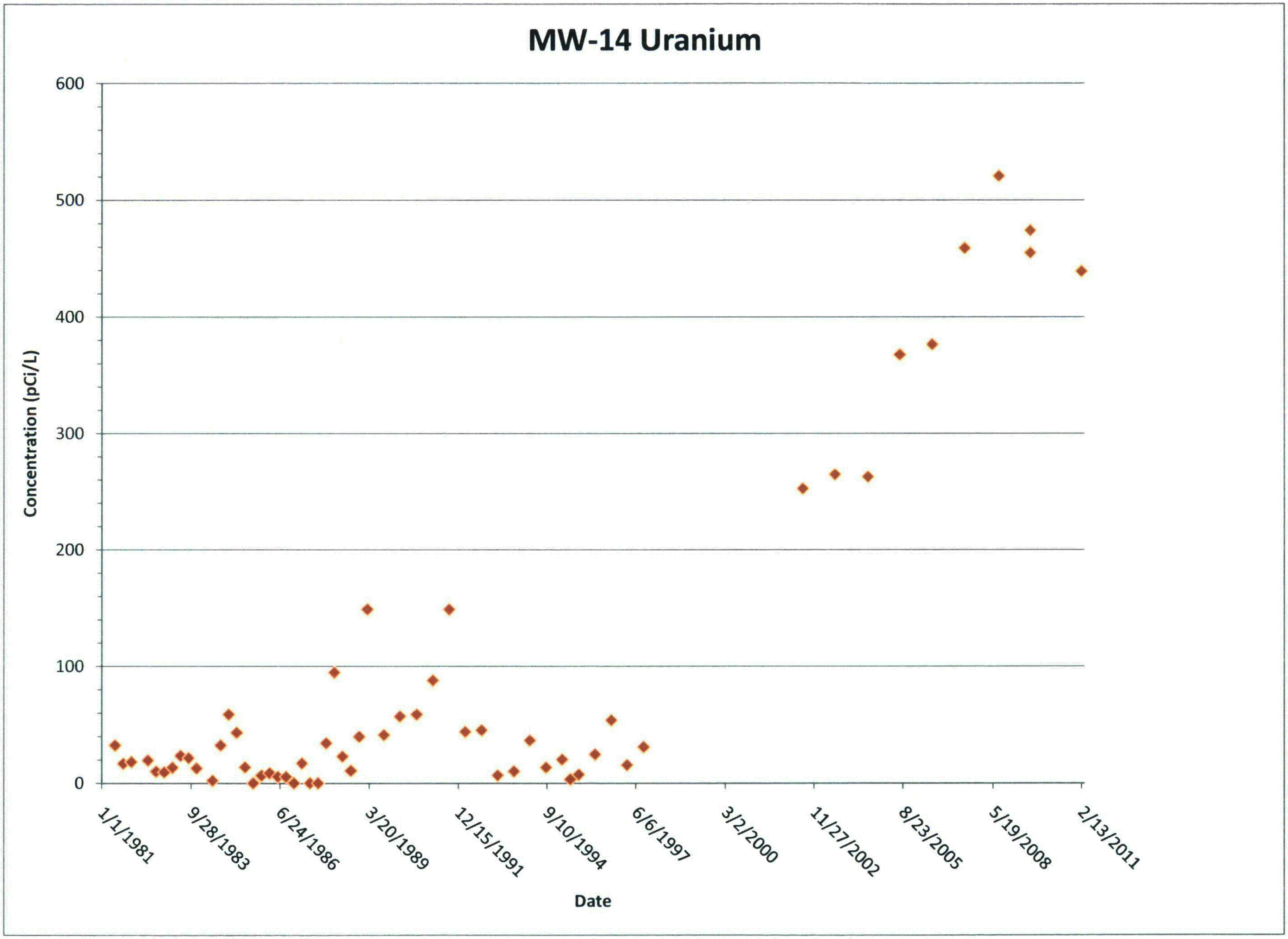

MW-110 Uranium
Concentration (pCi/L)
25
20
15
10
5
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

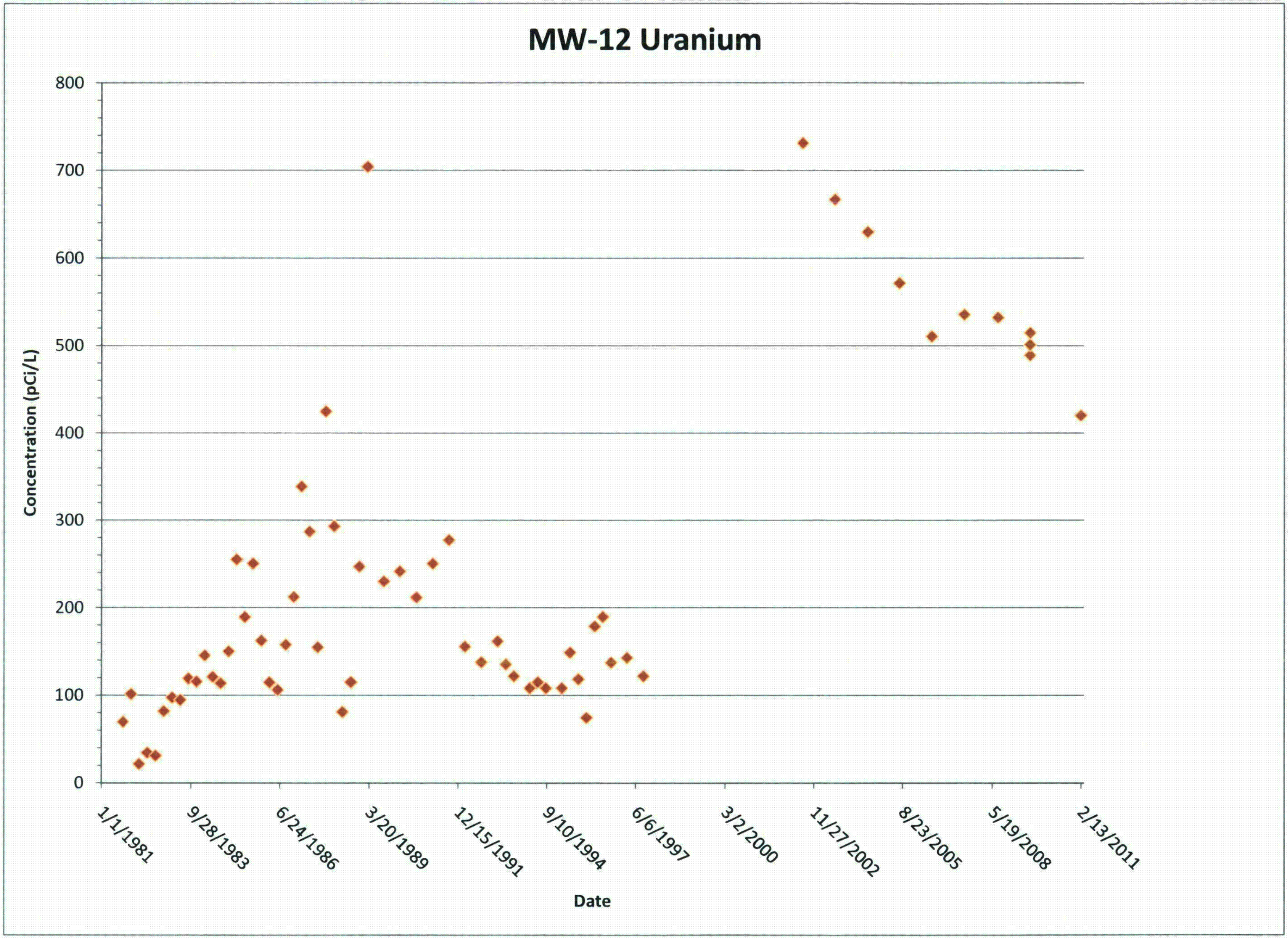

MW-109 Uranium
Concentration (pCi/L)
70
60
50
40
30
20
10
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

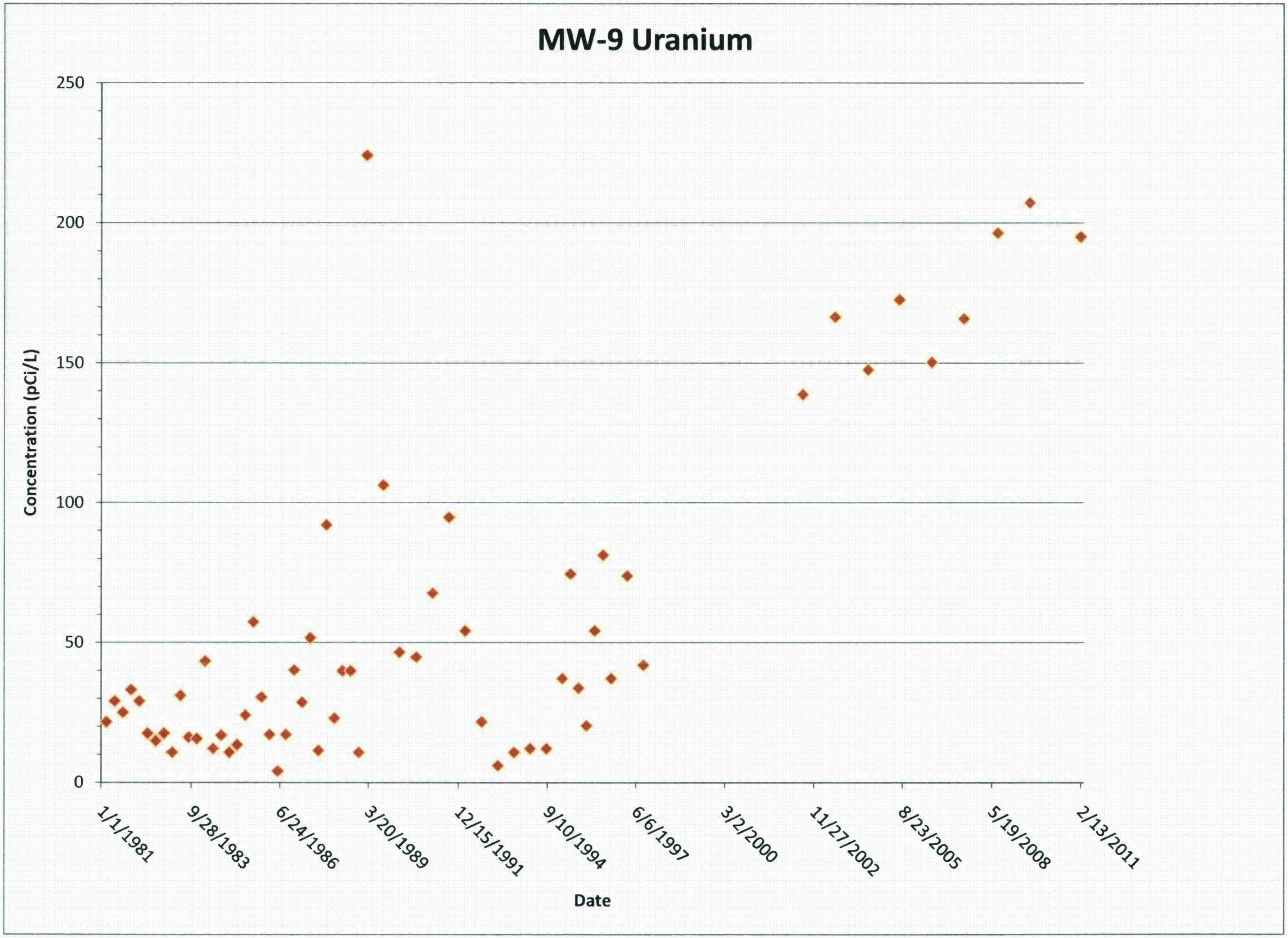

MW-108 Uranium
Concentration (pCi/L)
200
180
160
140
120
100
80
60
40
20
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

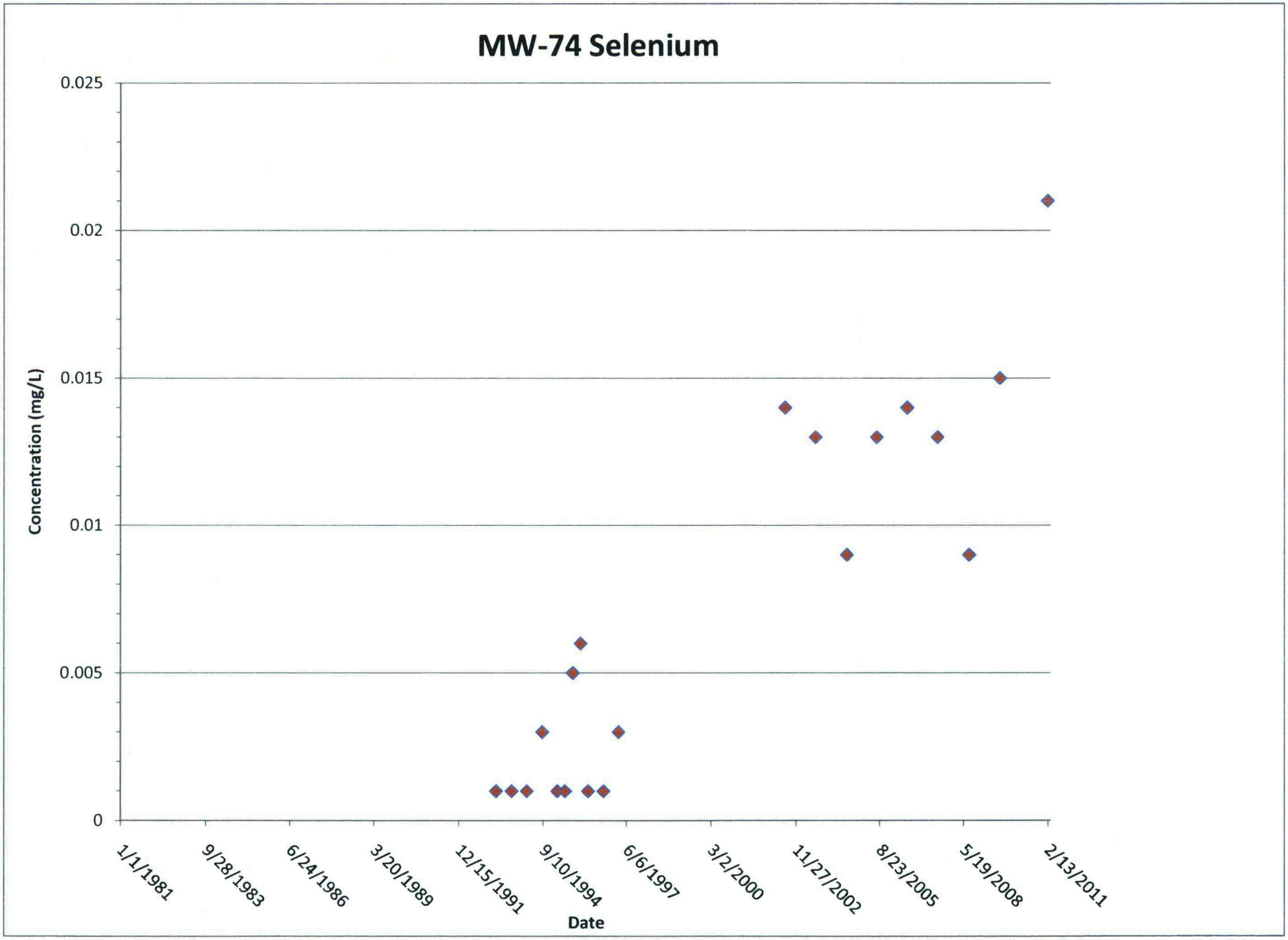

MW-74 Uranium
Concentration (pCi/L)
0
20
40
60
80
100
120
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

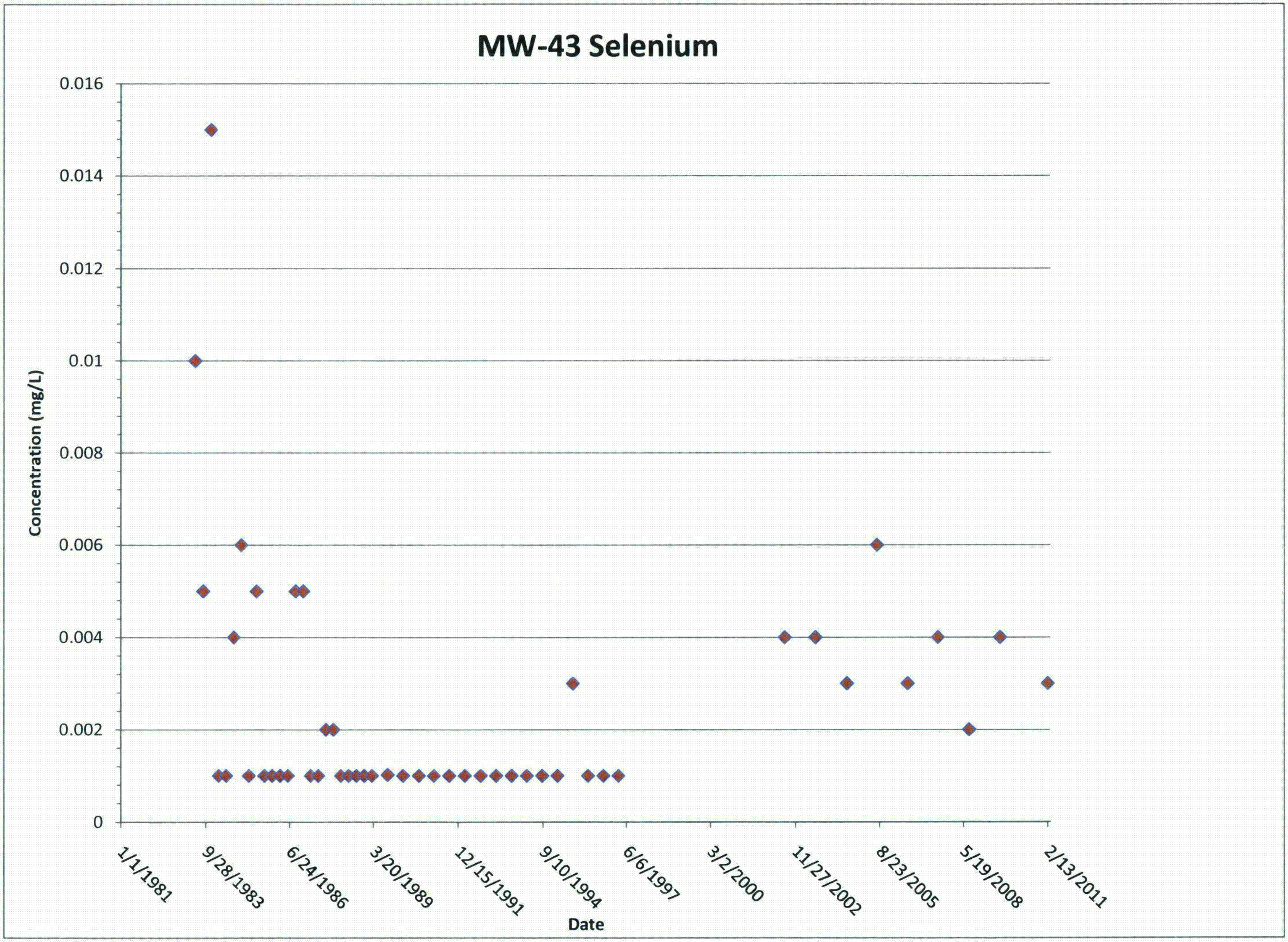
MW-43 Uranium
Concentration (pCi/L)
450
400
350
300
250
200
150
100
50
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

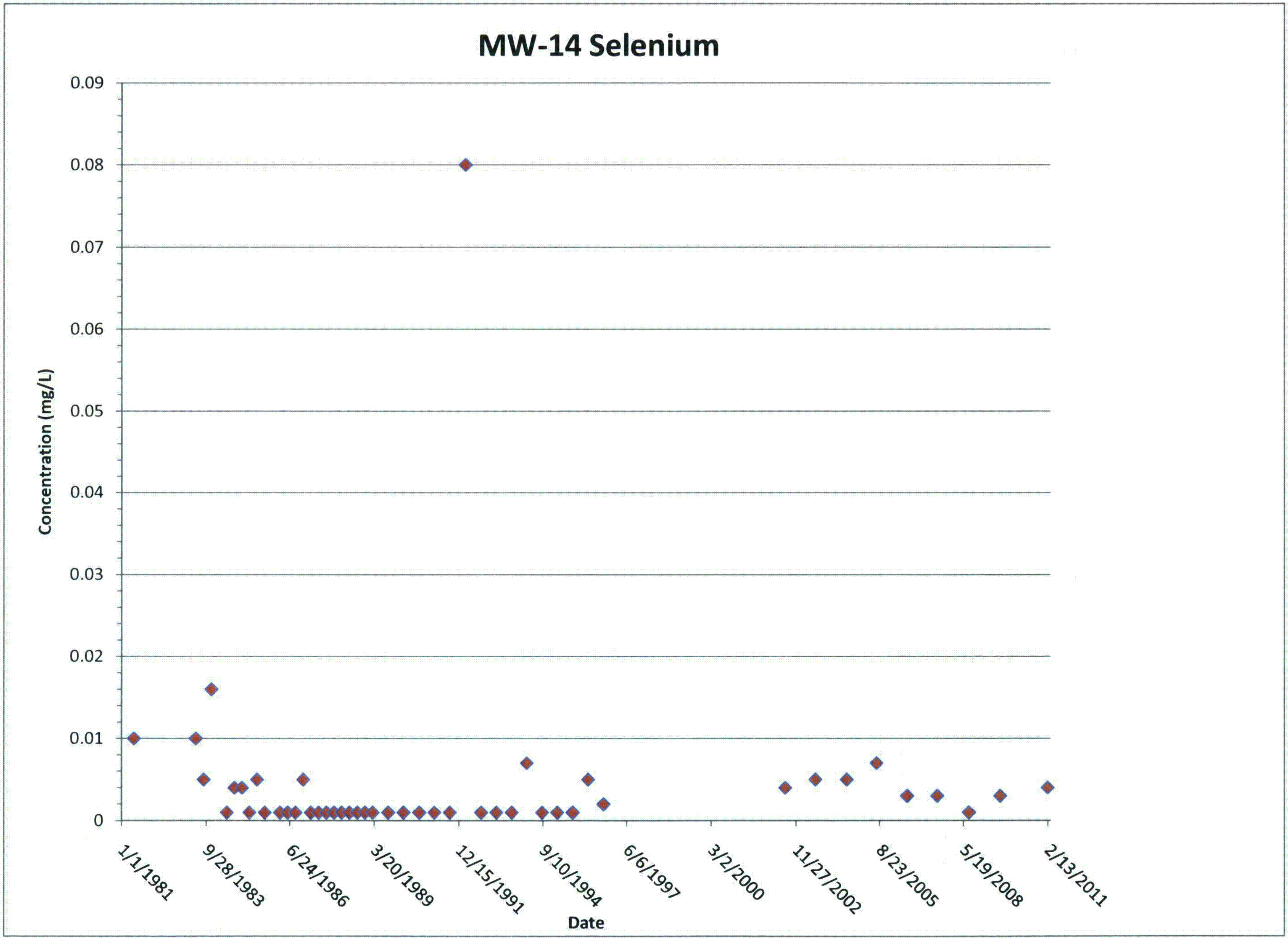

MW-14 Uranium
Concentration (pCi/L)
600
500
400
300
200
100
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

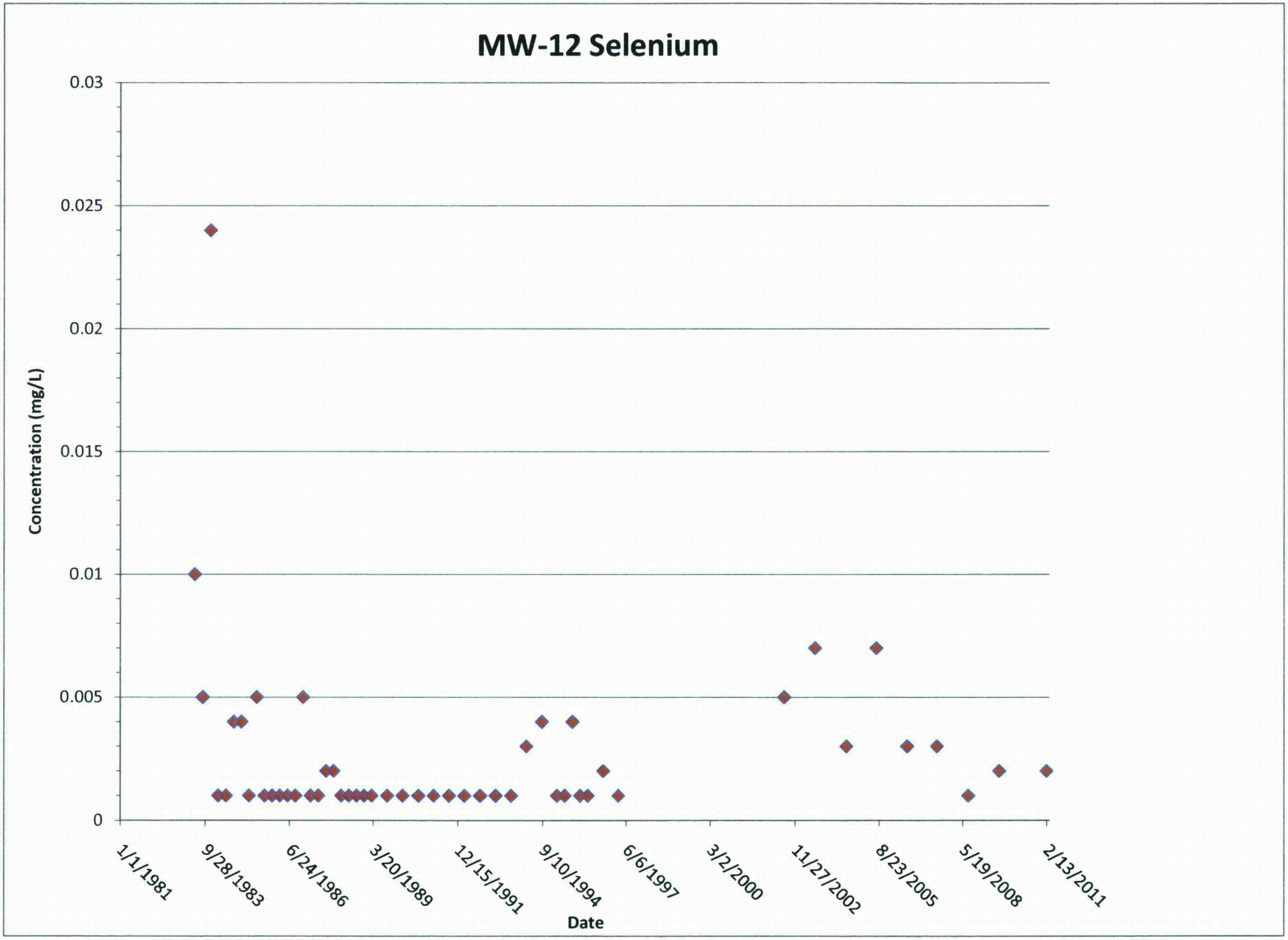

MW-12 Uranium
Concentration (pCi/L)
800
700
600
500
400
300
200
100
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

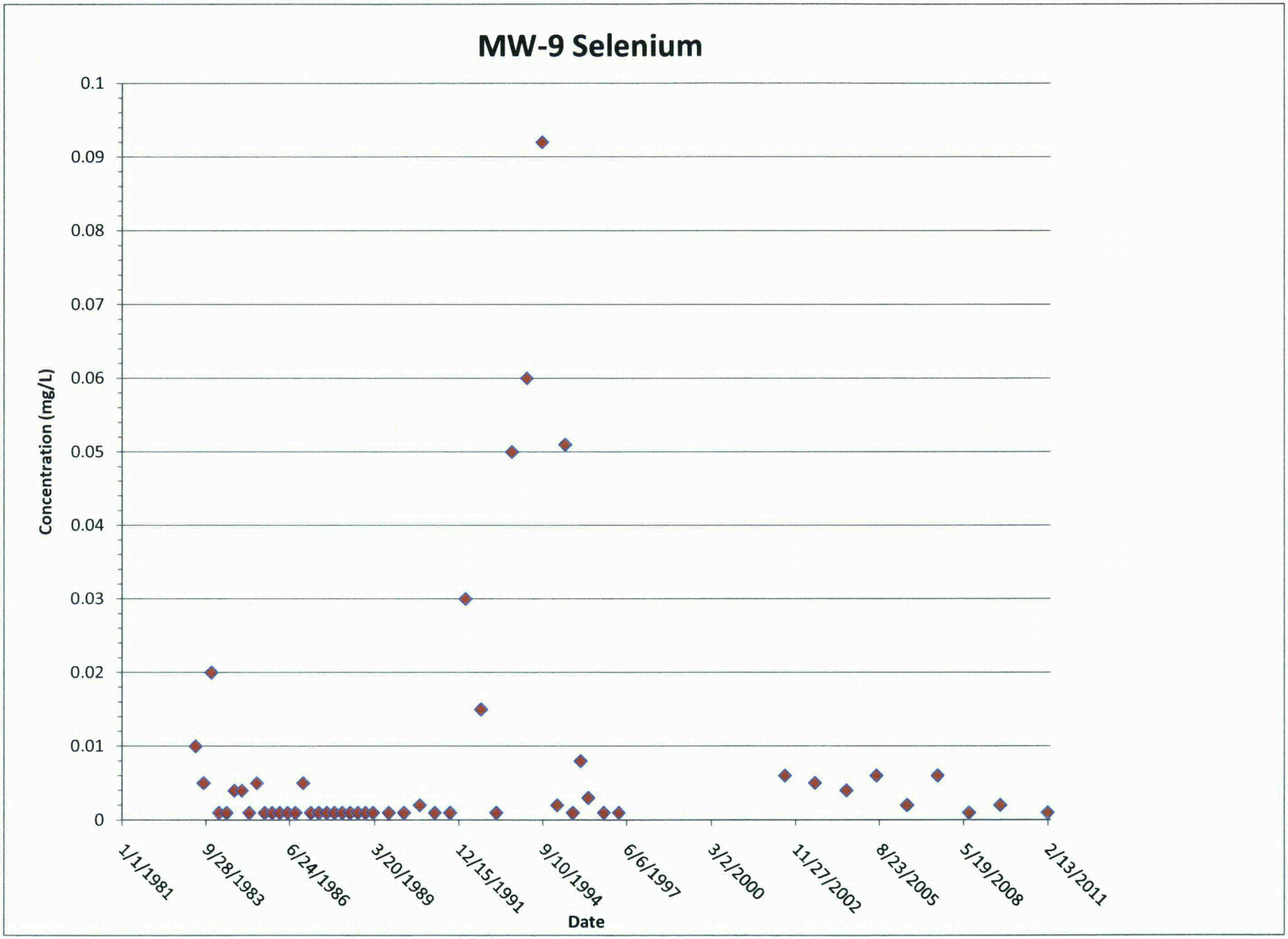

MW-9 Uranium
Concentration (pCi/L)
250
200
150
100
50
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date


MW-74 Selenium
Concentration (mg/L)
0.025
0.02
0.015
0.01
0.005
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

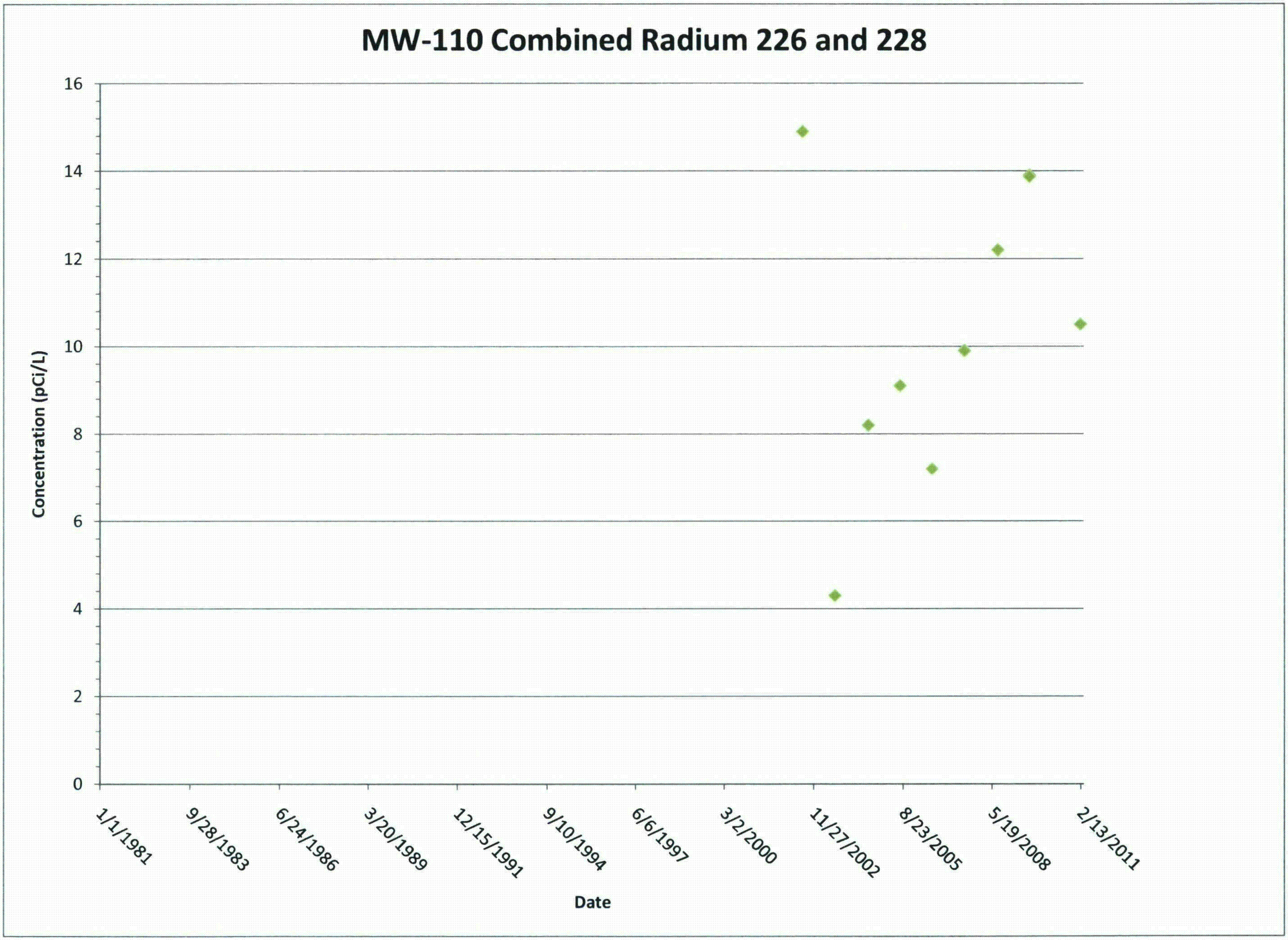

MW-43 Selenium
Concentration (mg/L)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date


MW-14 Selenium
Concentration (mg/L)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

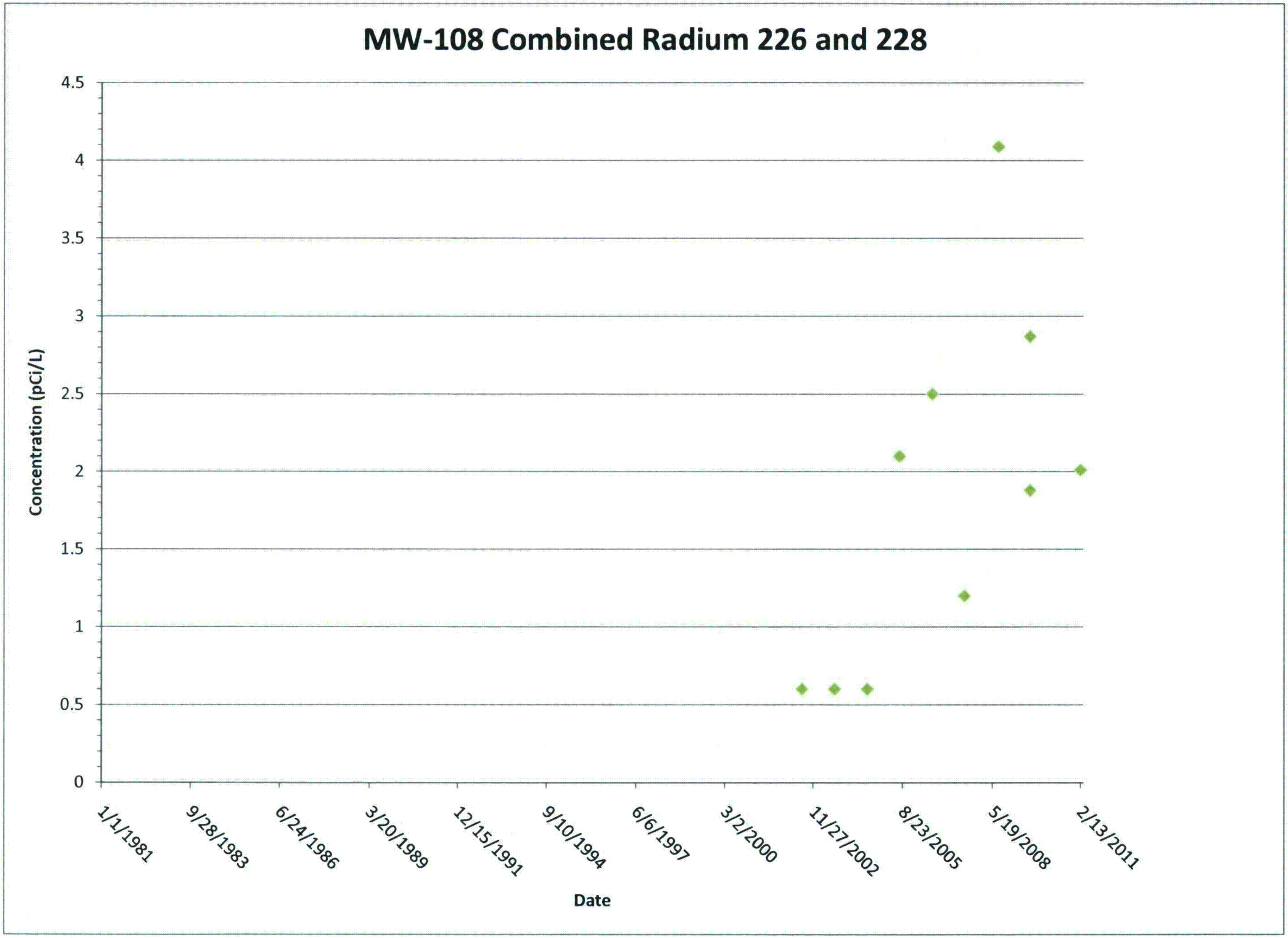

MW-12 Selenium
Concentration (mg/L)
0.03
0.025
0.02
0.015
0.01
0.005
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date



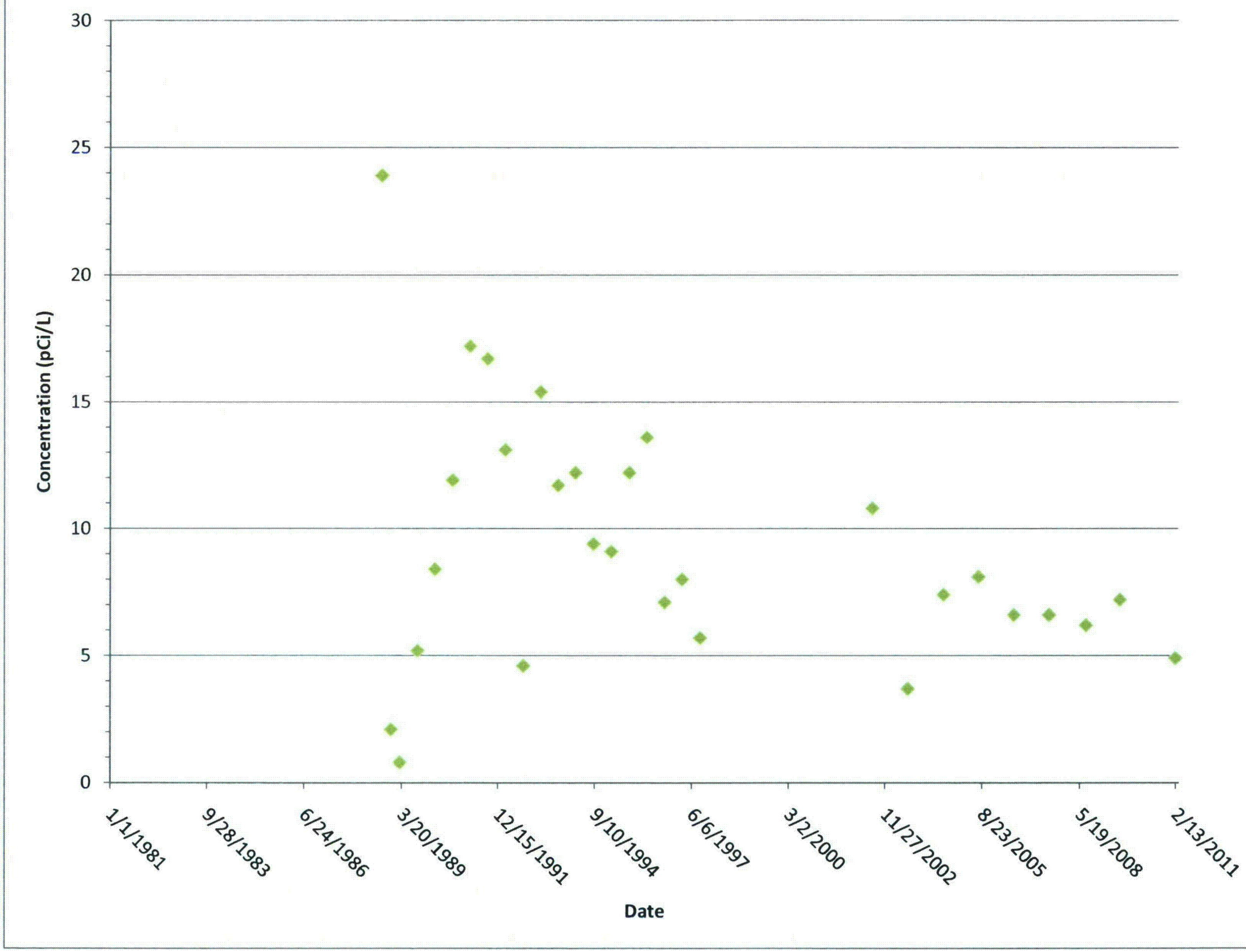
MW-9 Selenium
Concentration (mg/L)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

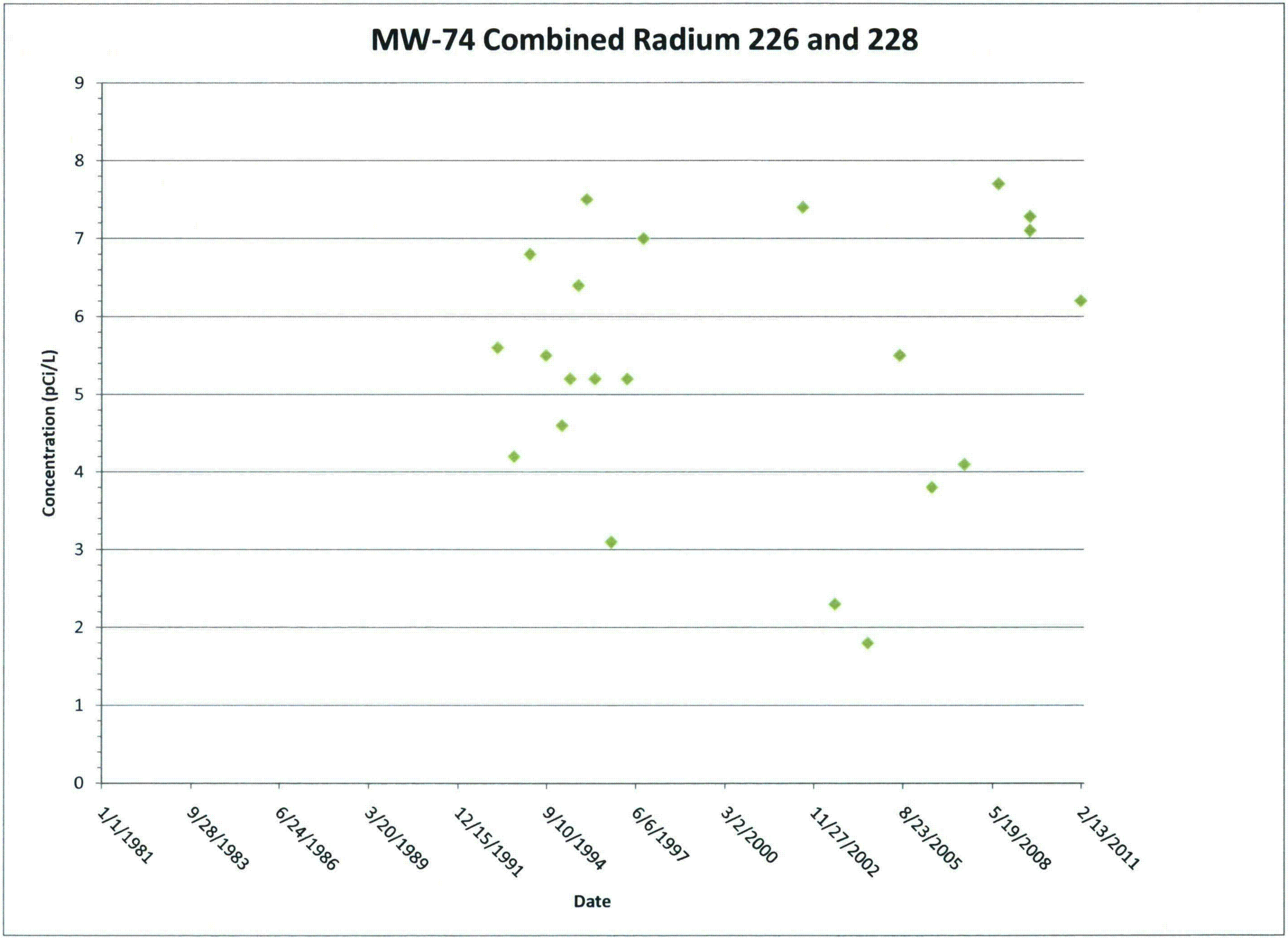


MW-110 Combined Radium 226 and 228

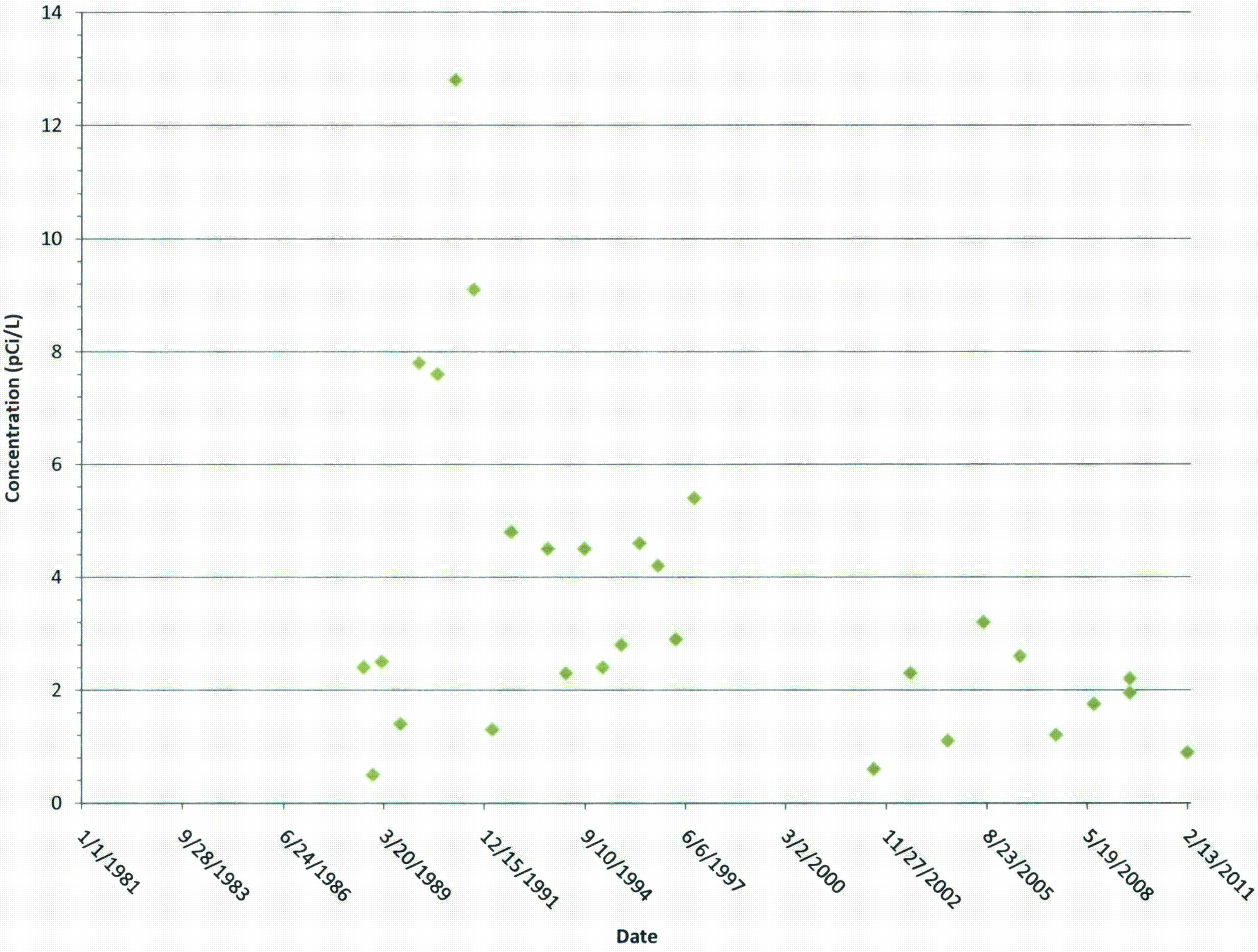

MW-108 Combined Radium 226 and 228
Concentration (pCi/L)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

MW-43 Combined Radium 226 and 228

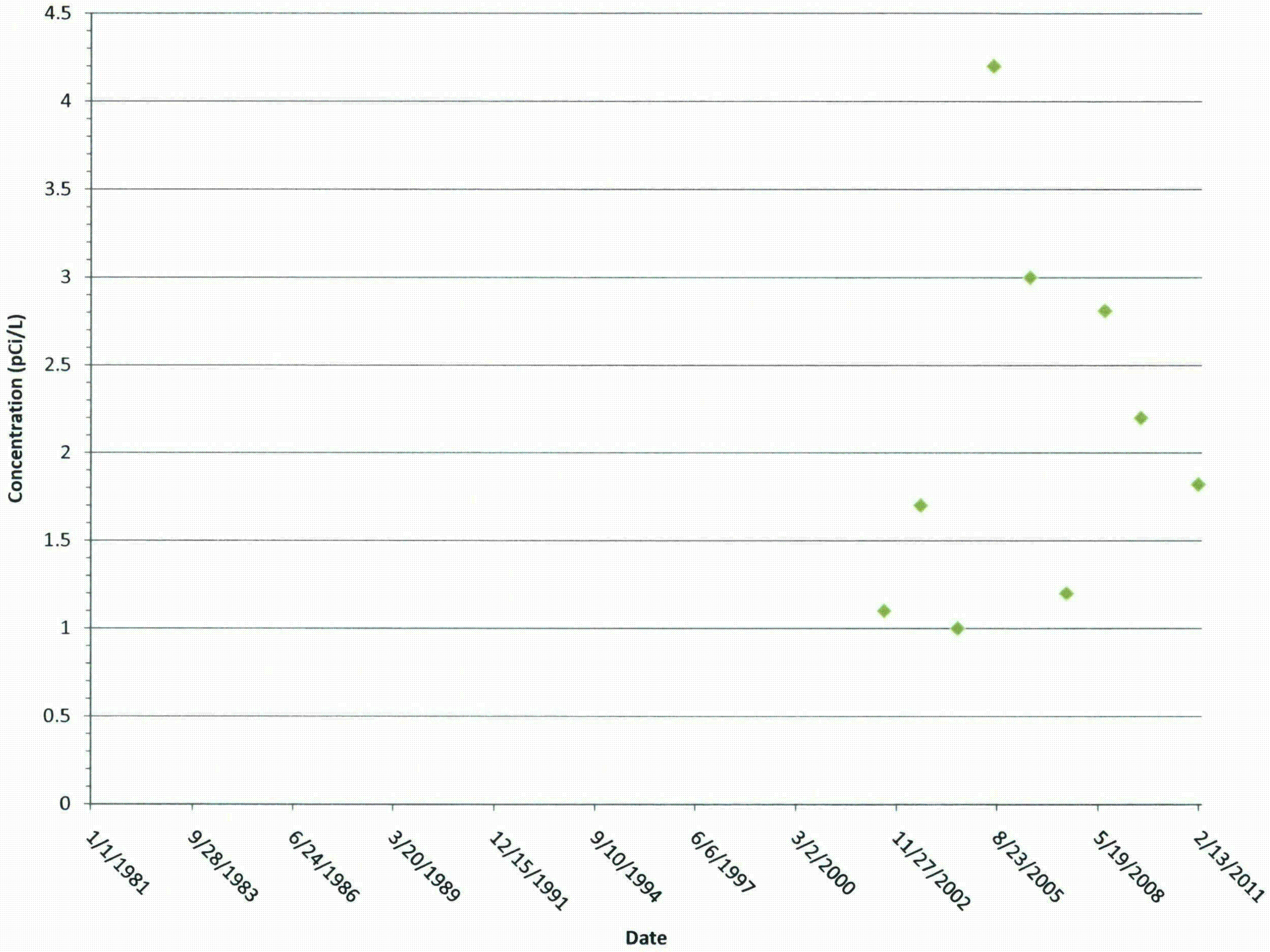


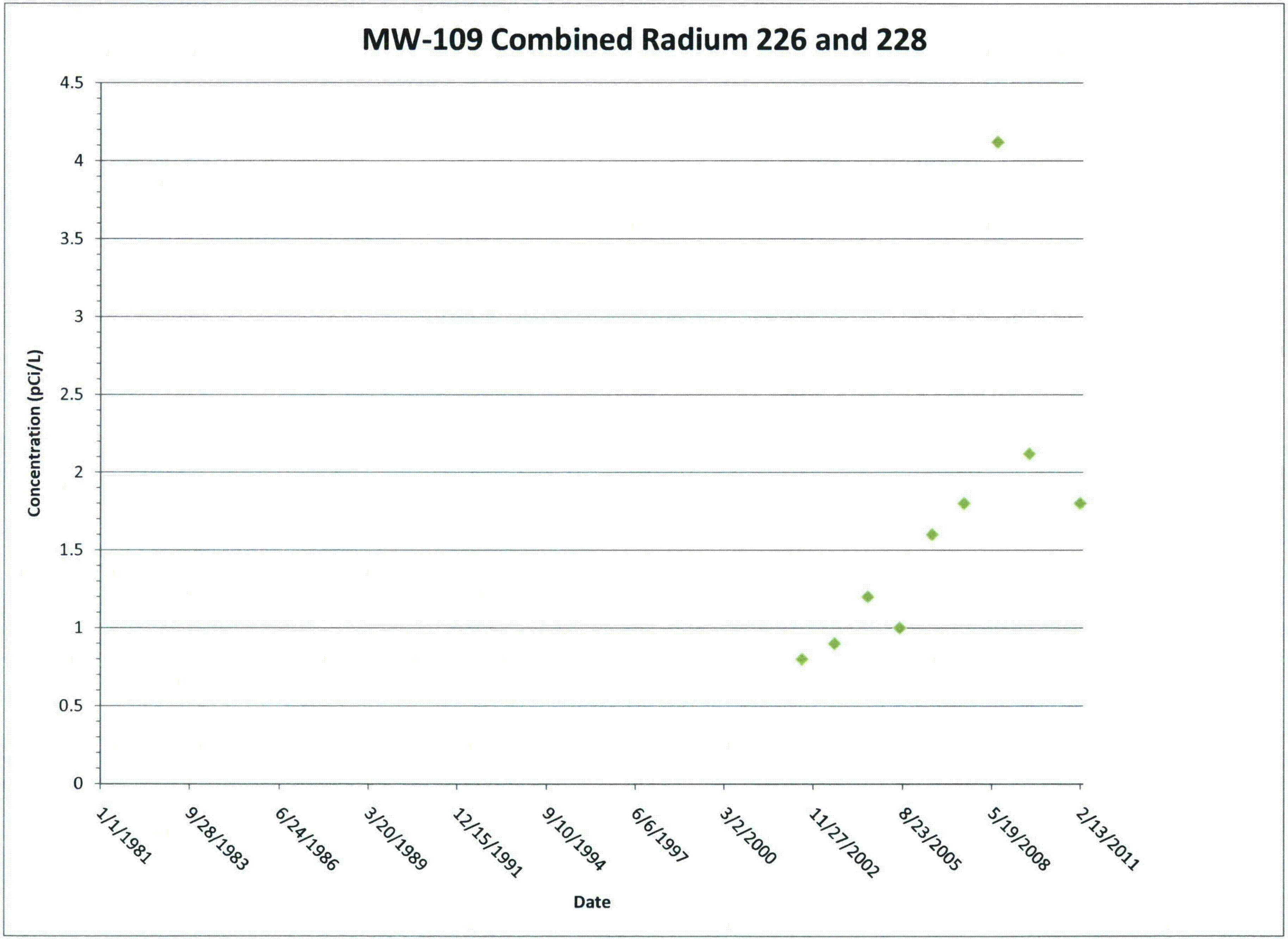
MW-74 Combined Radium 226 and 228
Concentration (pCi/L)
0
1
2
3
4
5
6
7
8
9
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

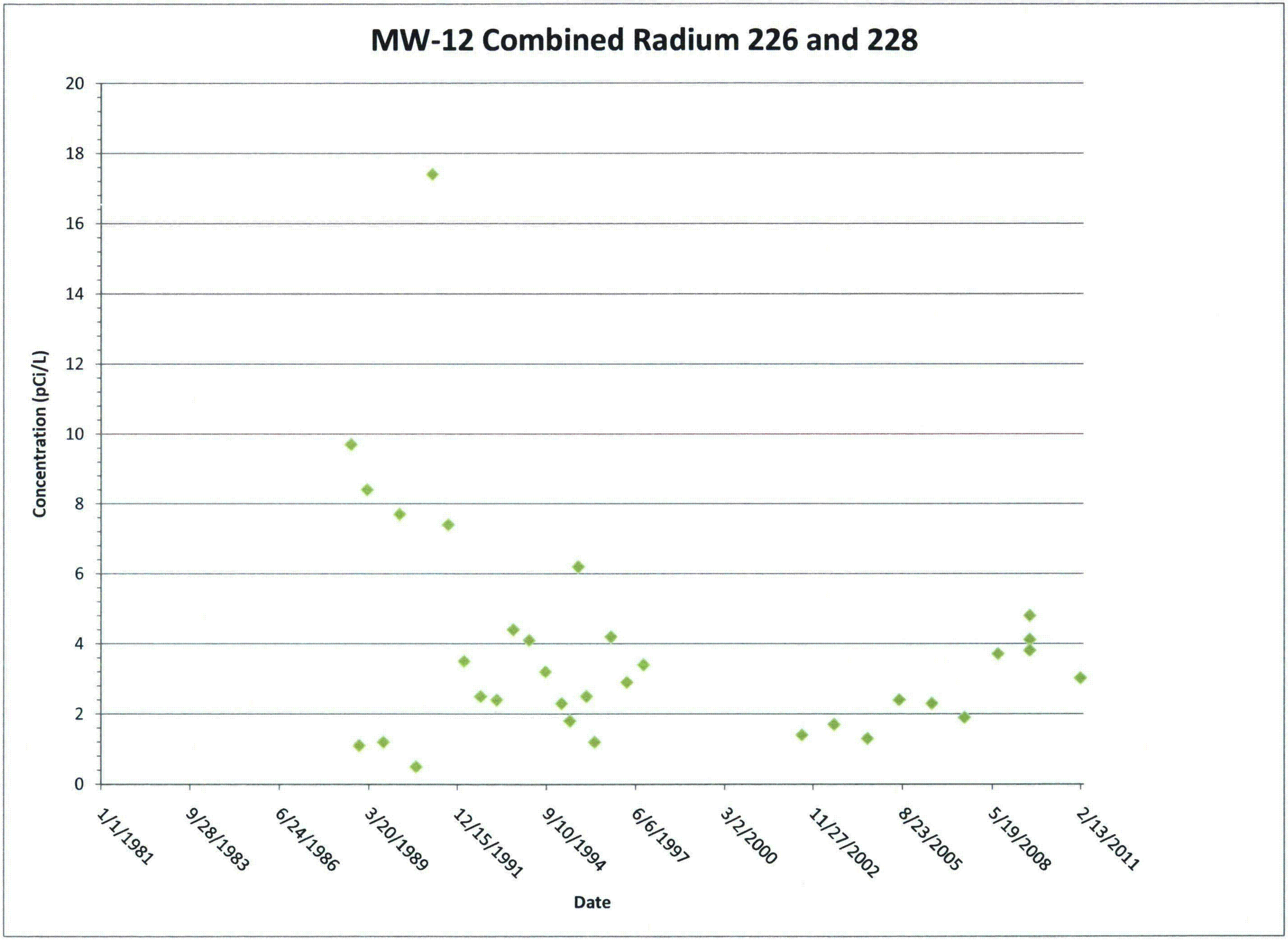
MW-14 Combined Radium 226 and 228

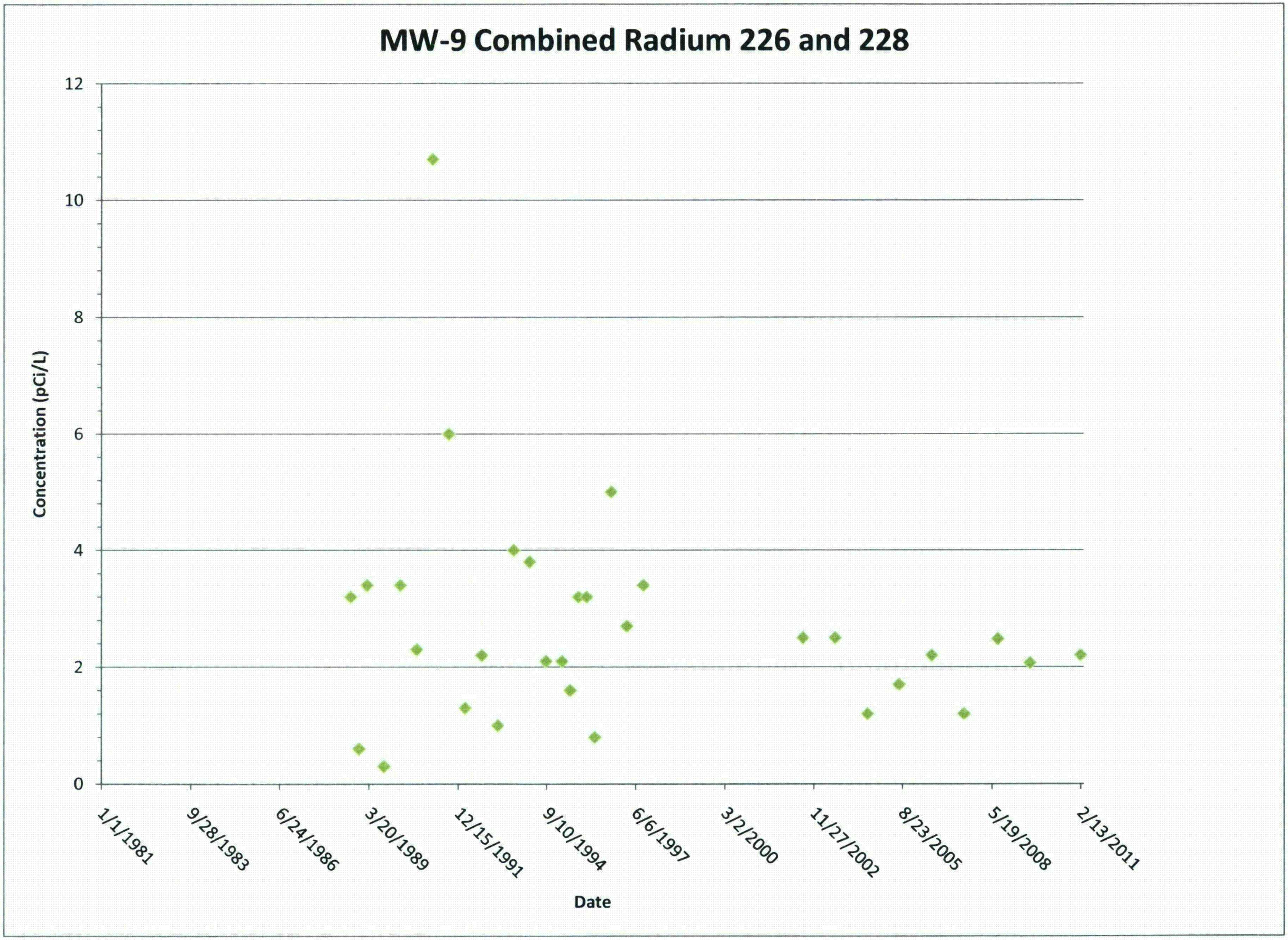


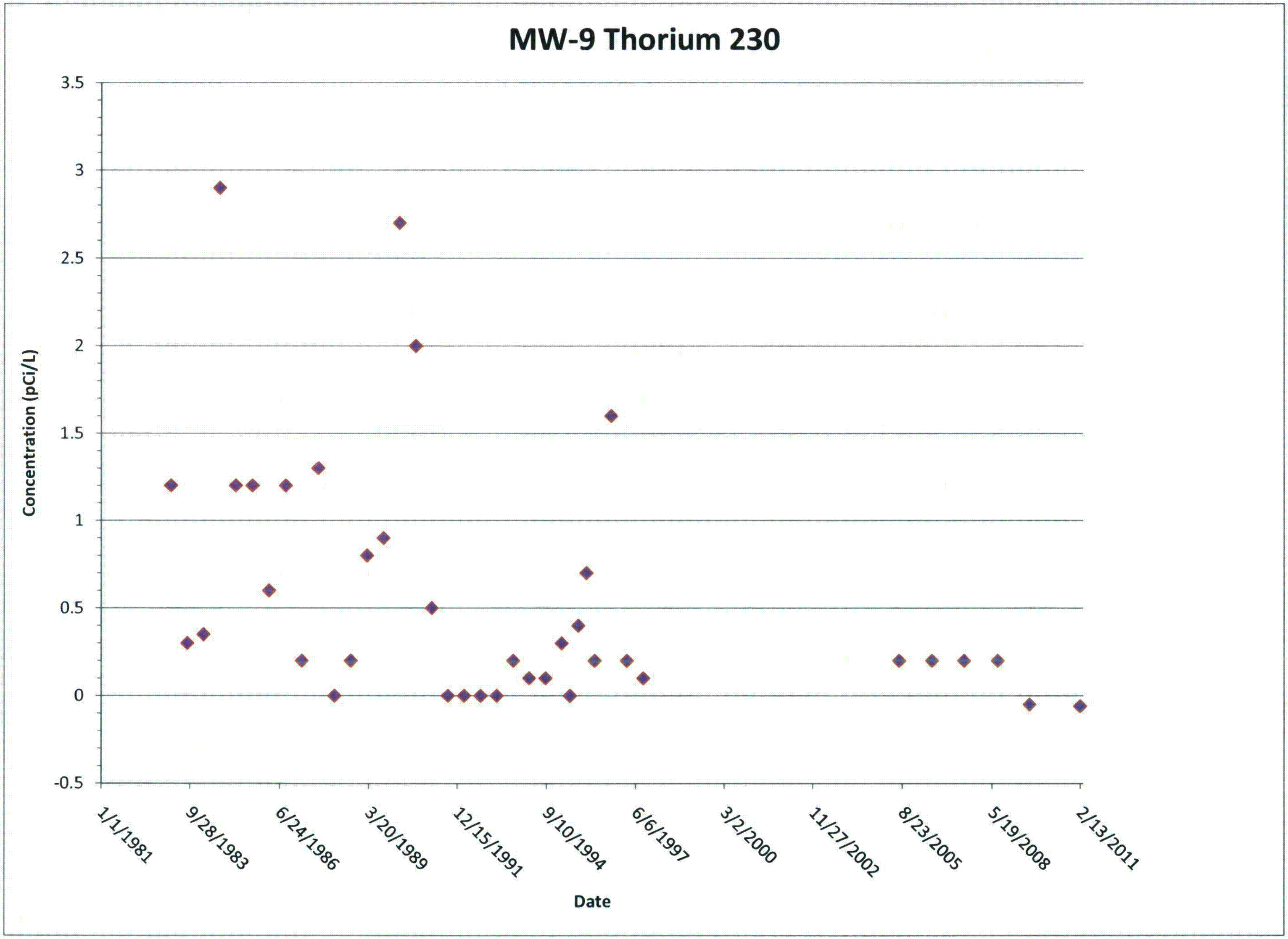
MW-111 Combined Radium 226 and 228

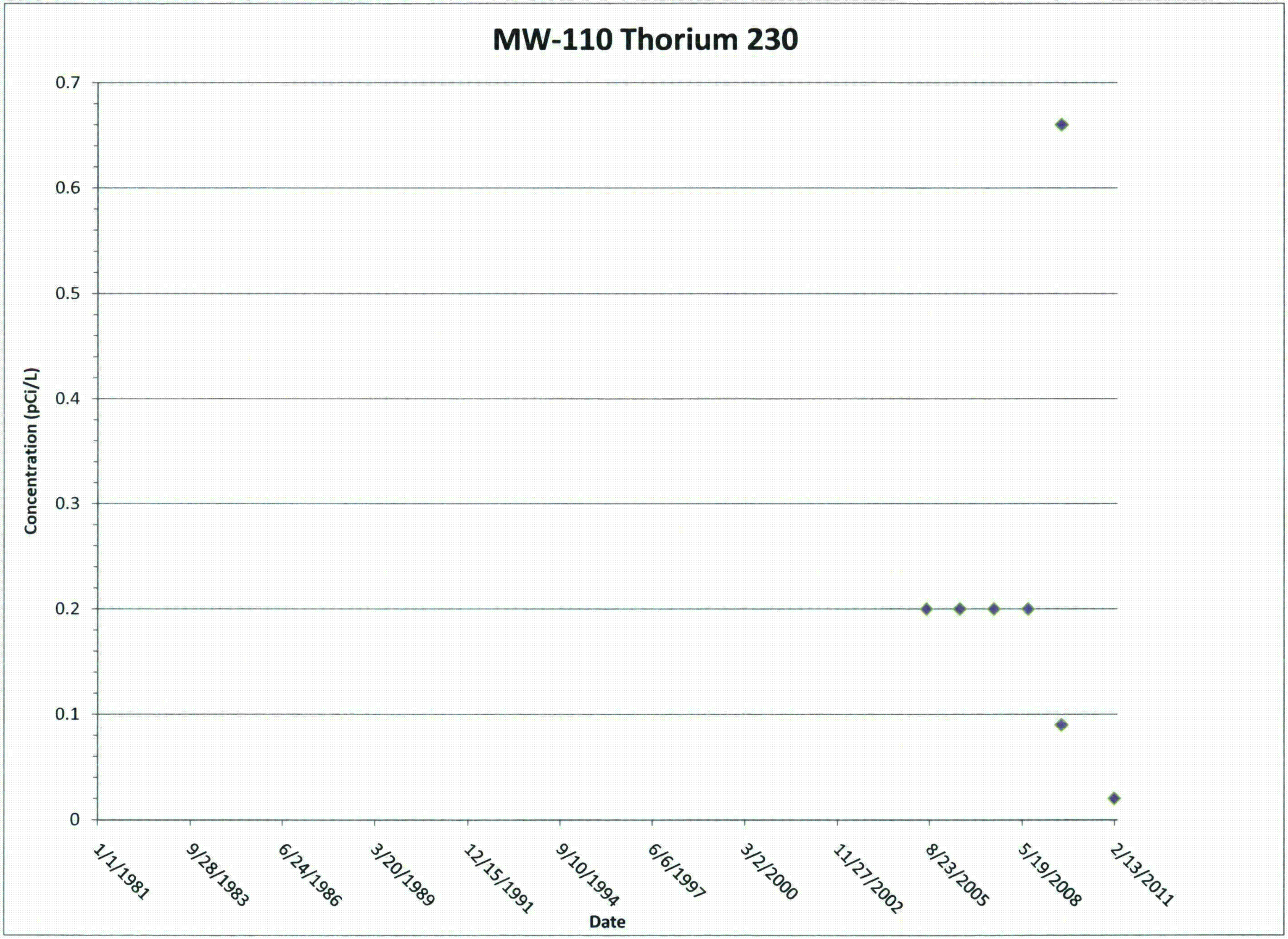


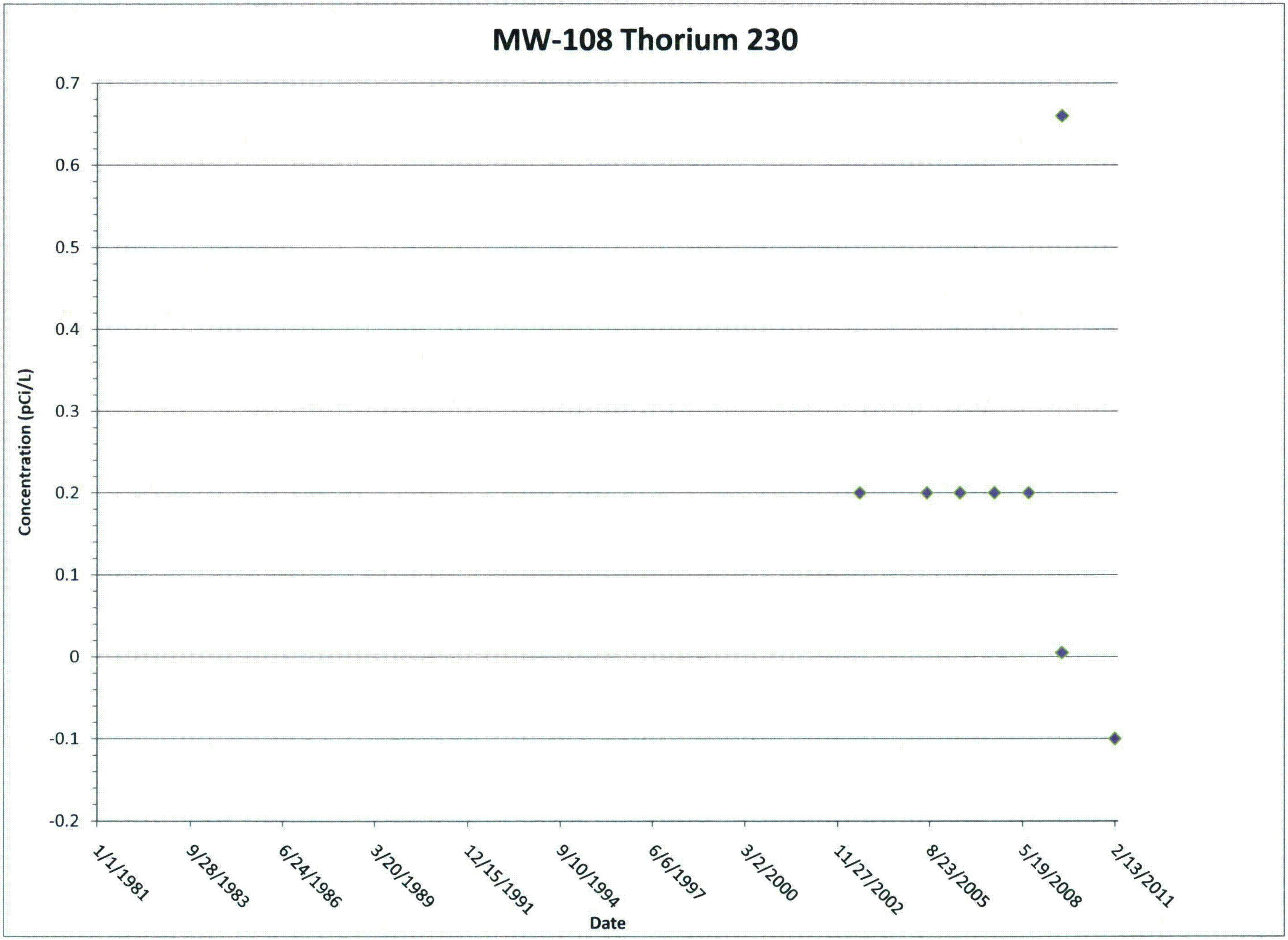

MW-109 Combined Radium 226 and 228
Concentration (pCi/L)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

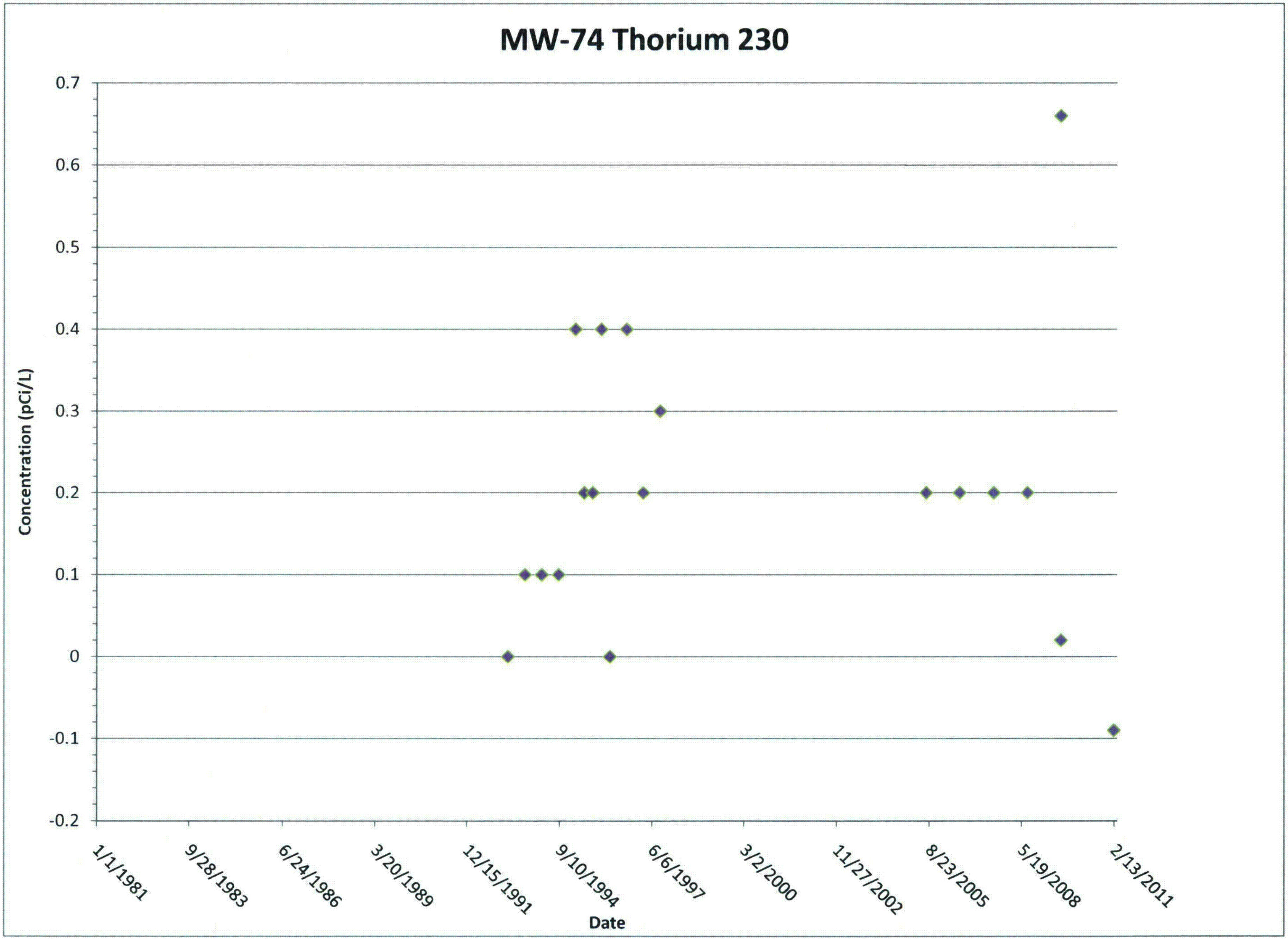

MW-12 Combined Radium 226 and 228
Concentration (pCi/L)
0
2
4
6
8
10
12
14
16
18
20
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

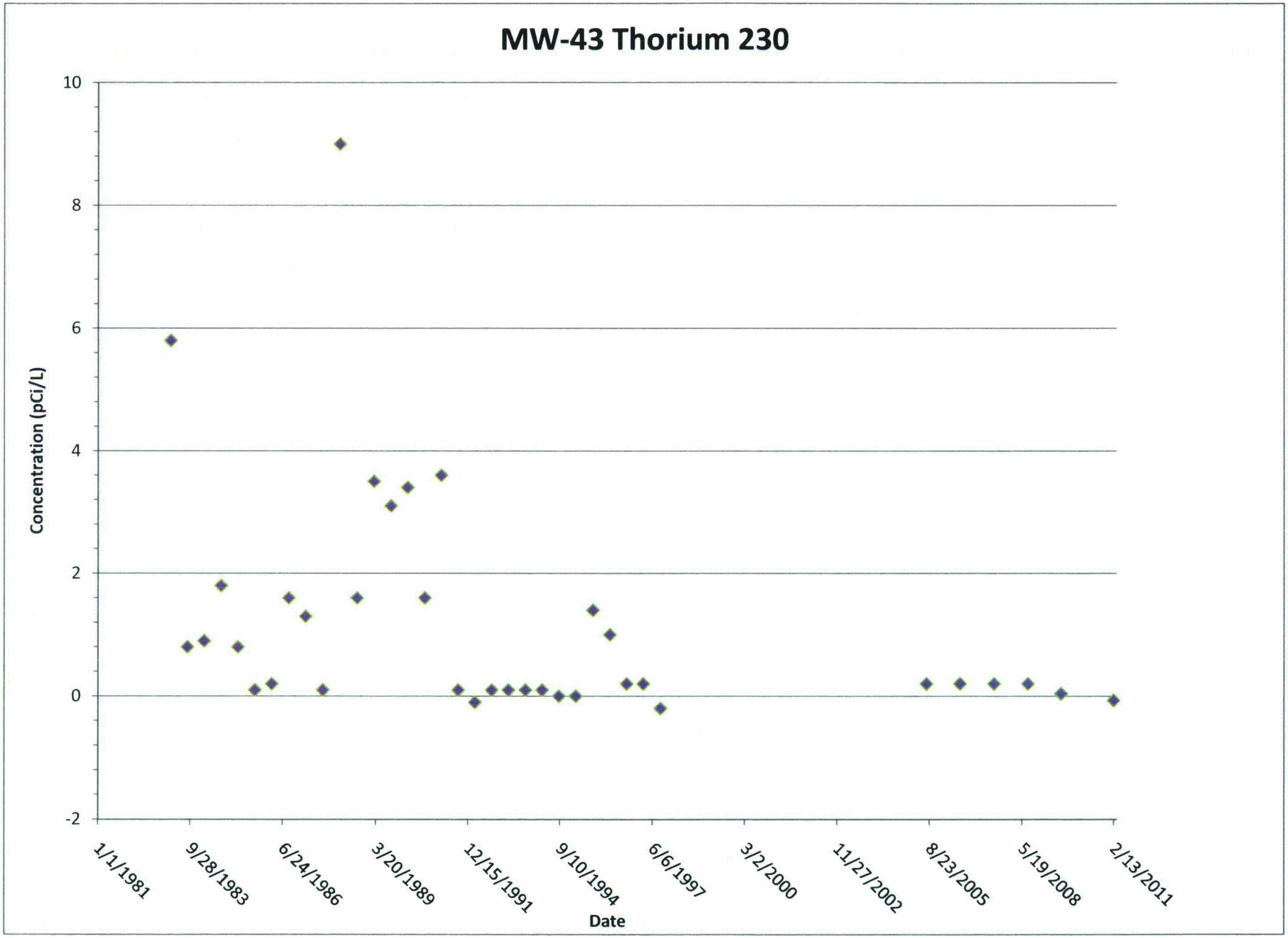

MW-9 Combined Radium 226 and 228
Concentration (pCi/L)
12
10
8
6
4
2
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

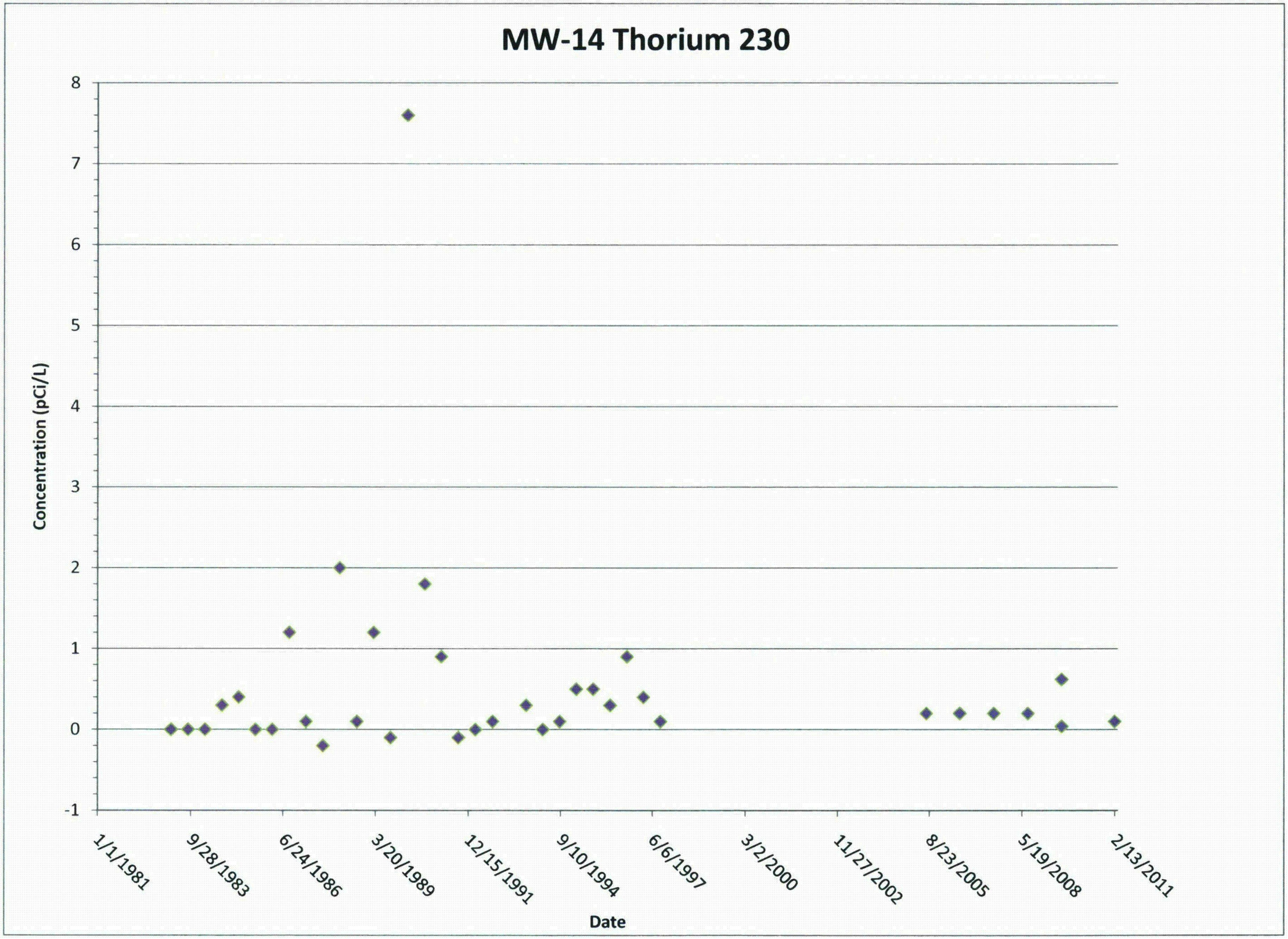

MW-9 Thorium 230
Concentration (pCi/L)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

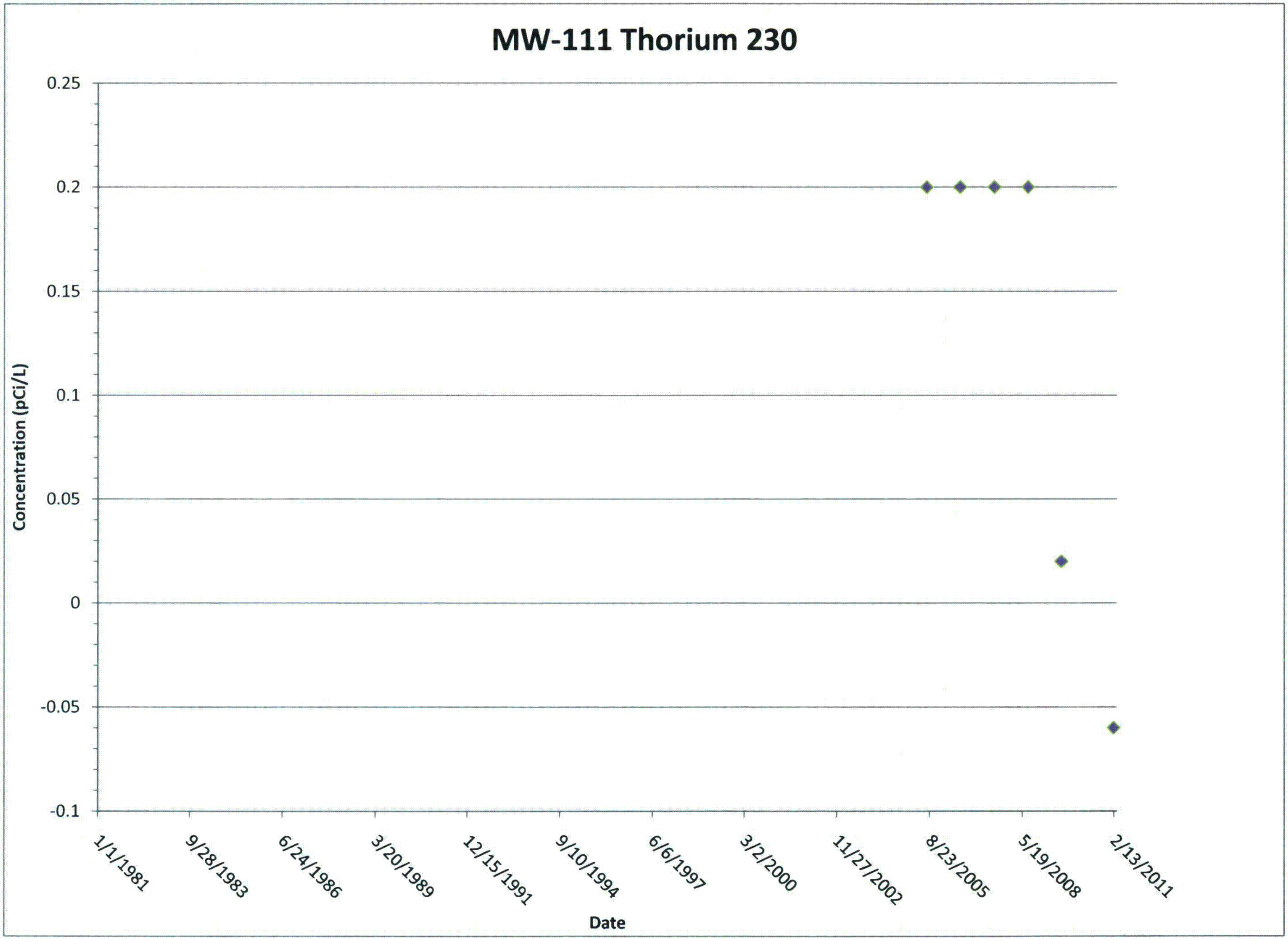

MW-110 Thorium 230
Concentration (pCi/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

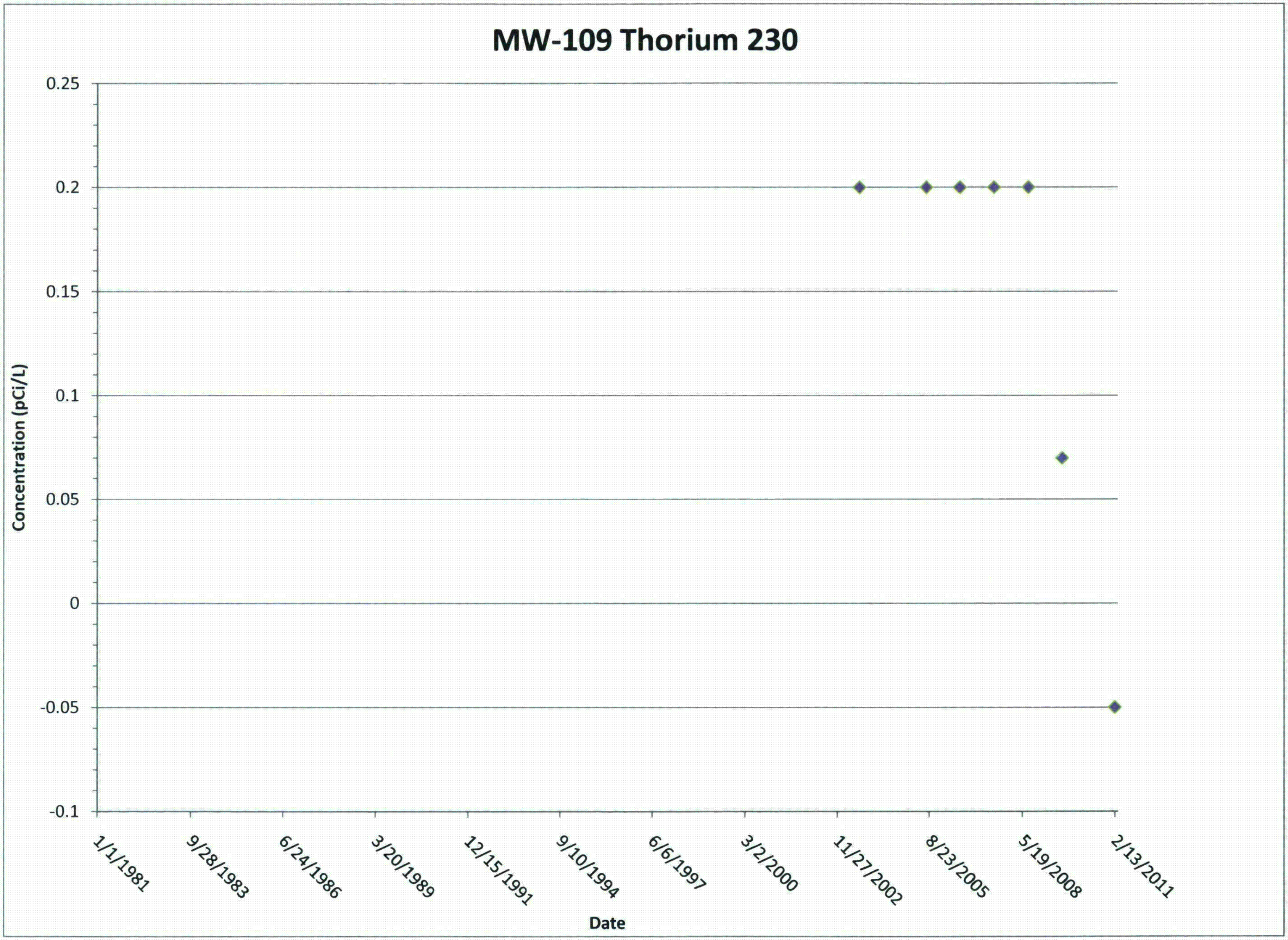

MW-108 Thorium 230
Concentration (pCi/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

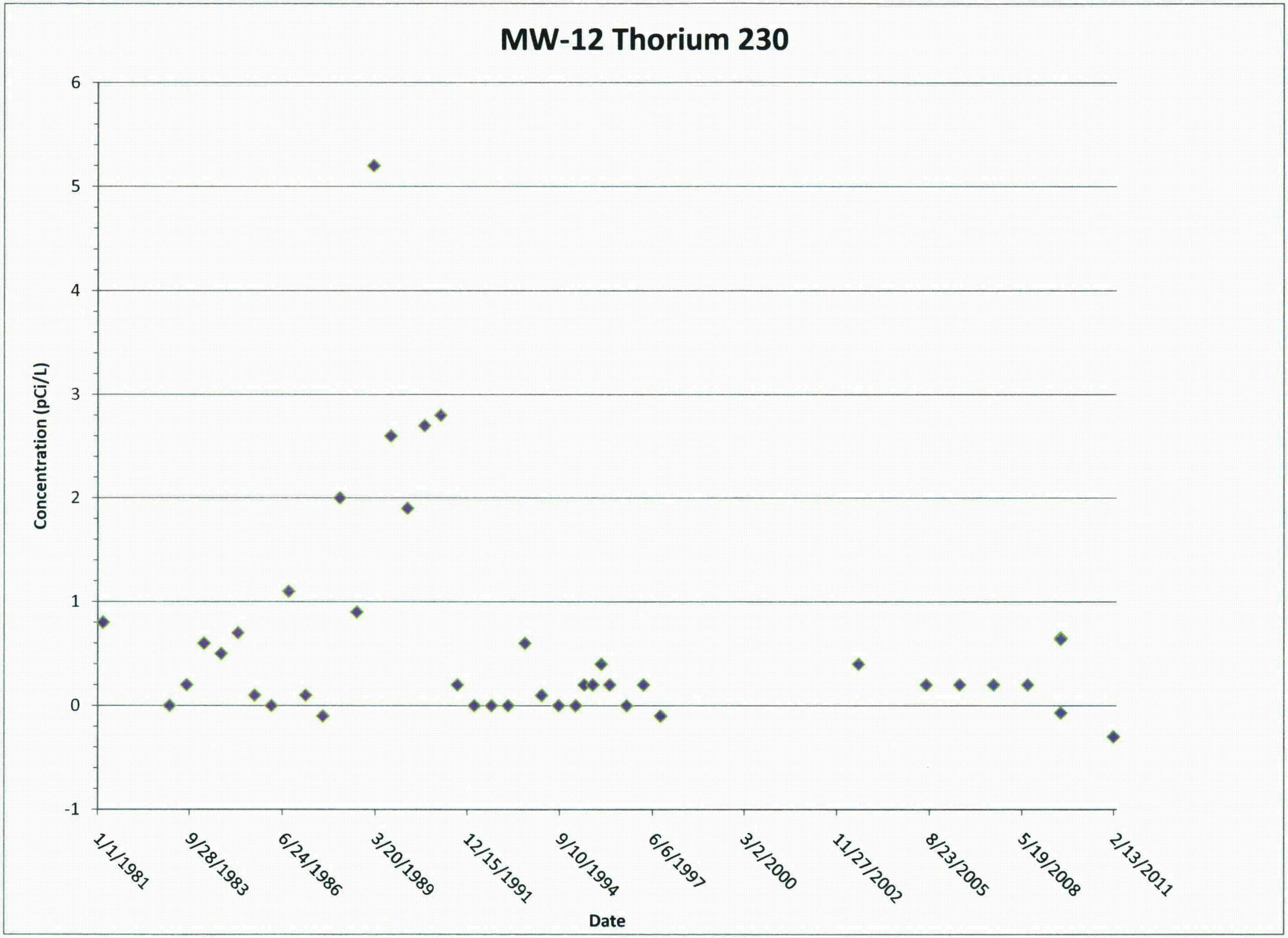

MW-74 Thorium 230
Concentration (pCi/L)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Date
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011

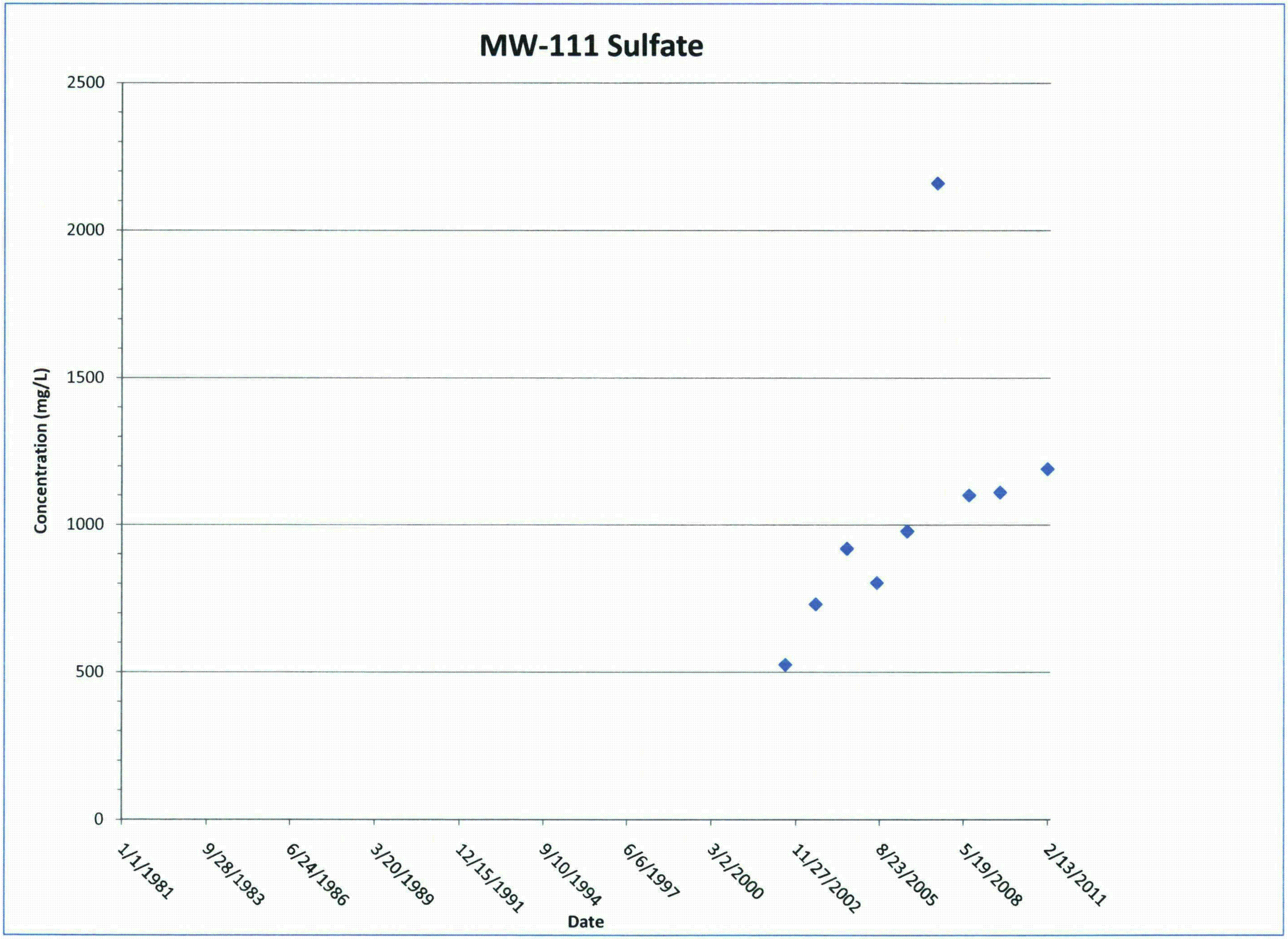

MW-43 Thorium 230
Concentration (pCi/L)
10
8
6
4
2
0
-2
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

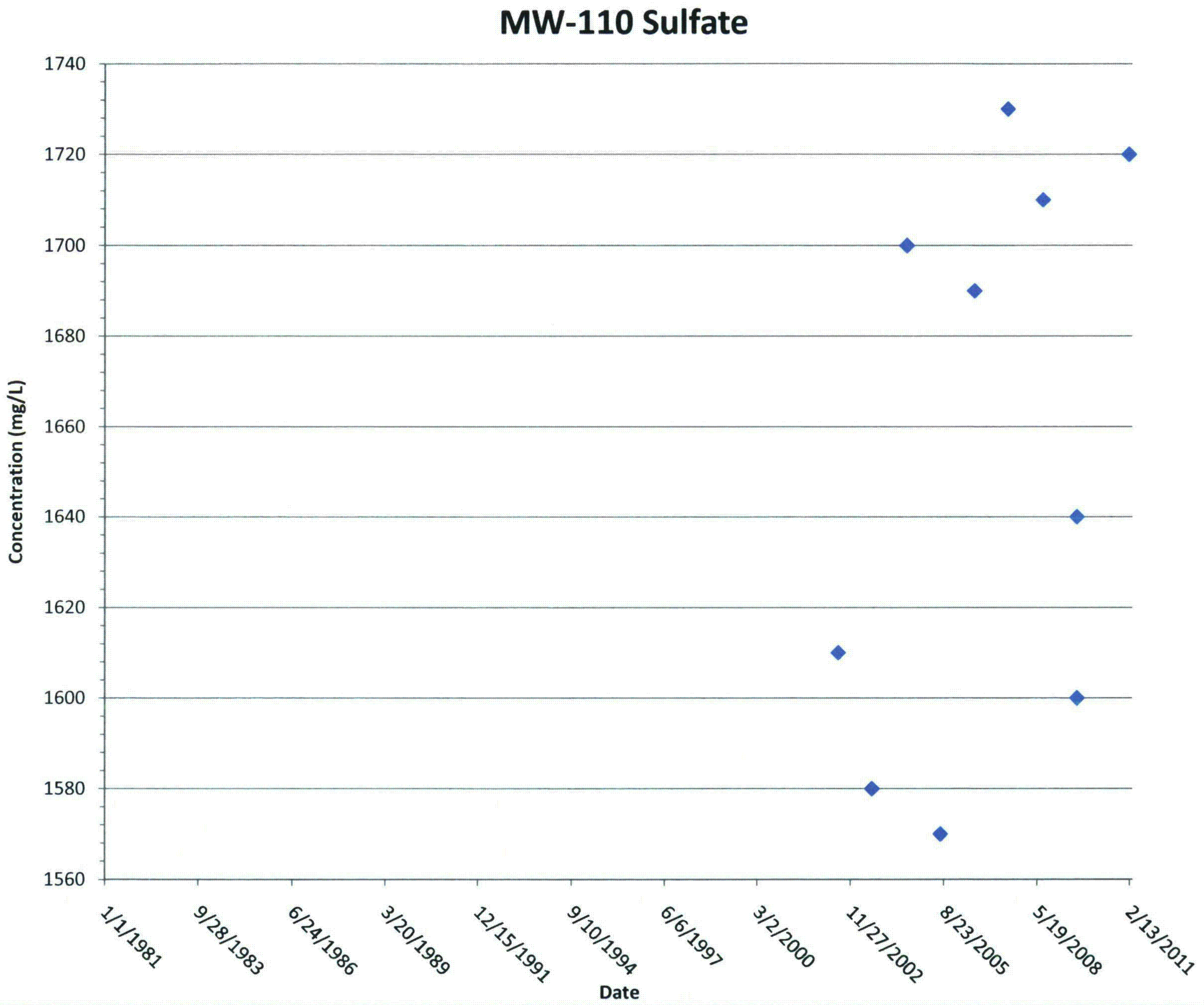

MW-14 Thorium 230
Concentration (pCi/L)
8
7
6
5
4
3
2
1
0
-1
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

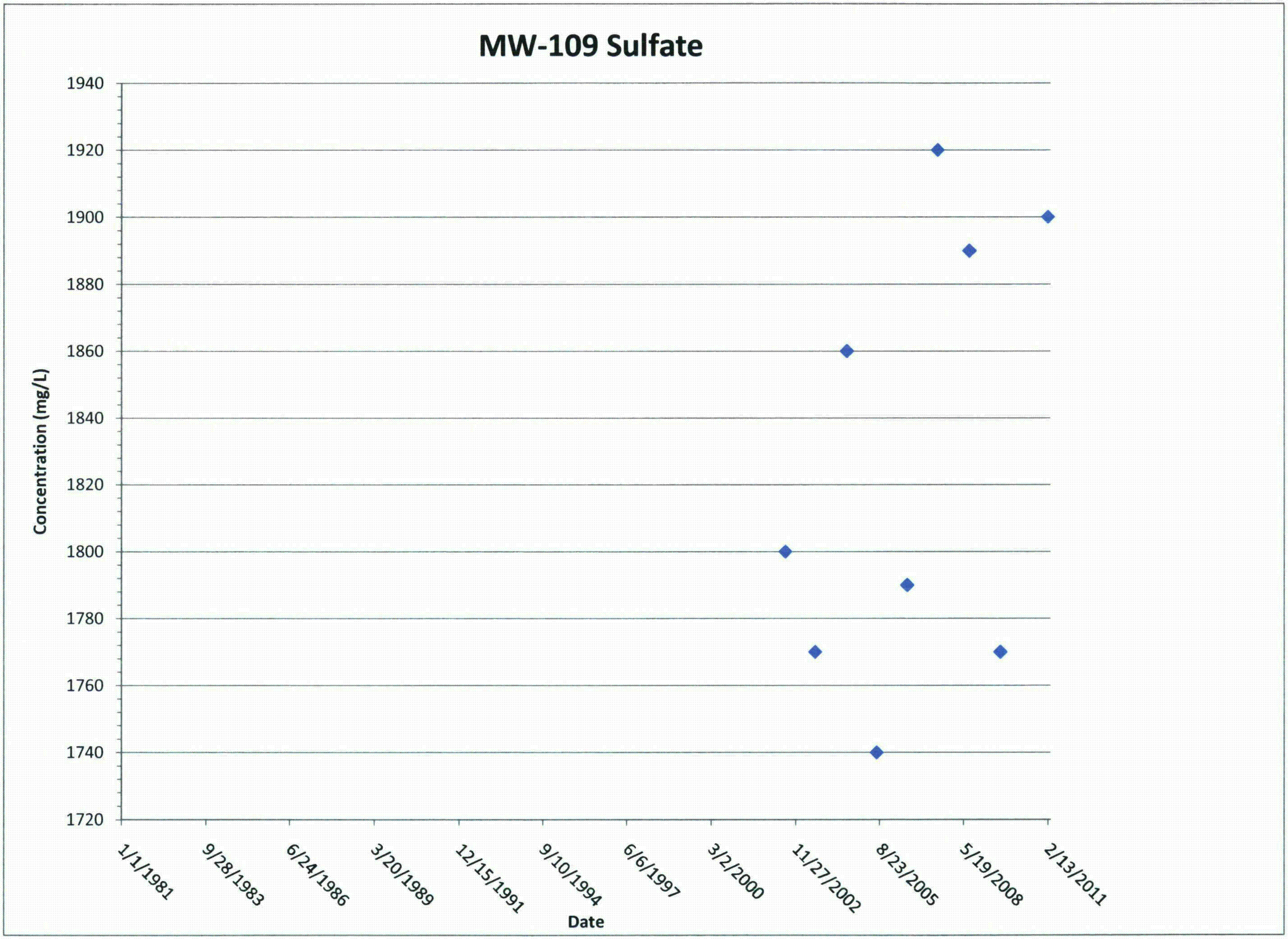

MW-111 Thorium 230
Concentration (pCi/L)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

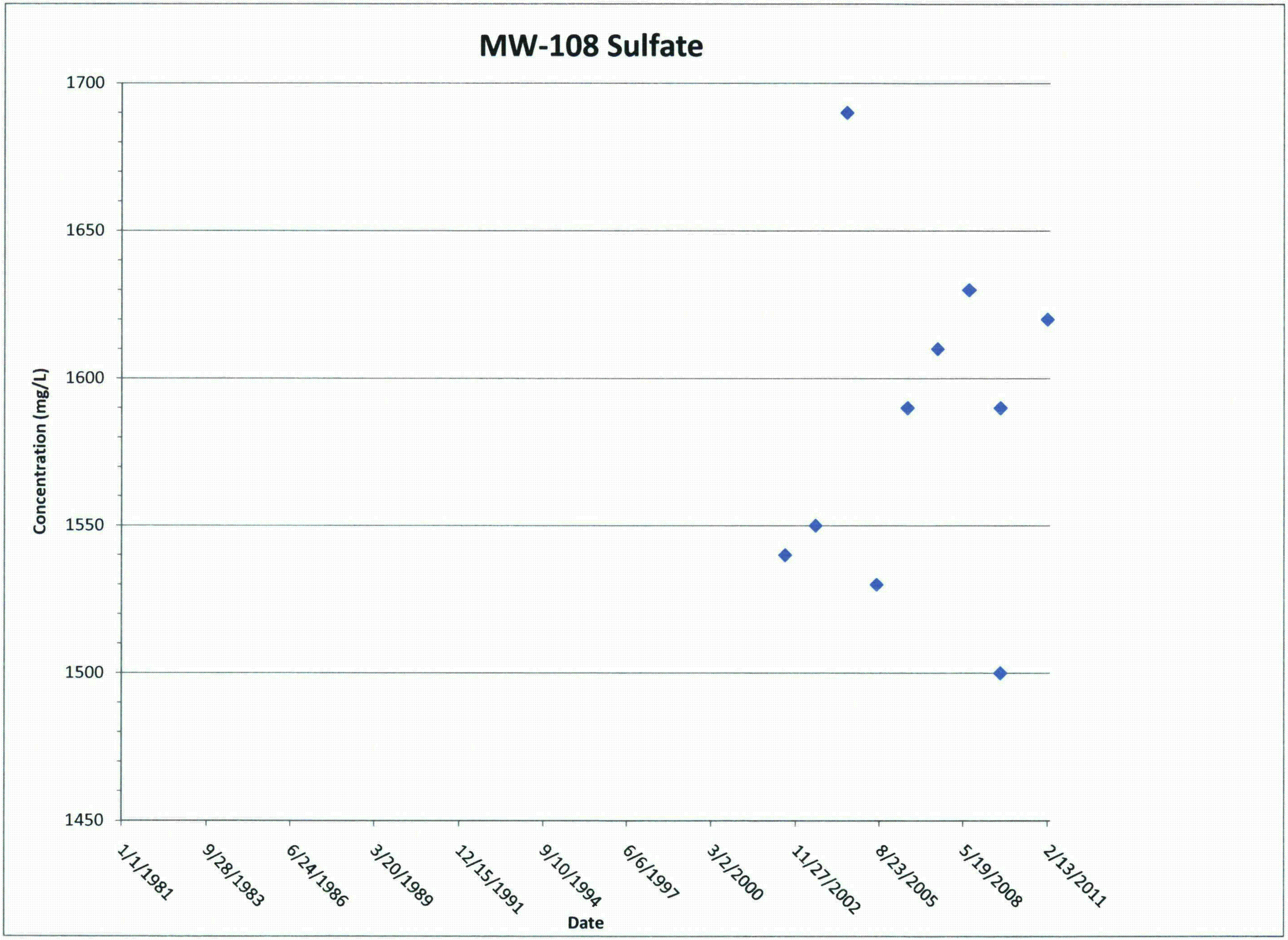

MW-109 Thorium 230
Concentration (pCi/L)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

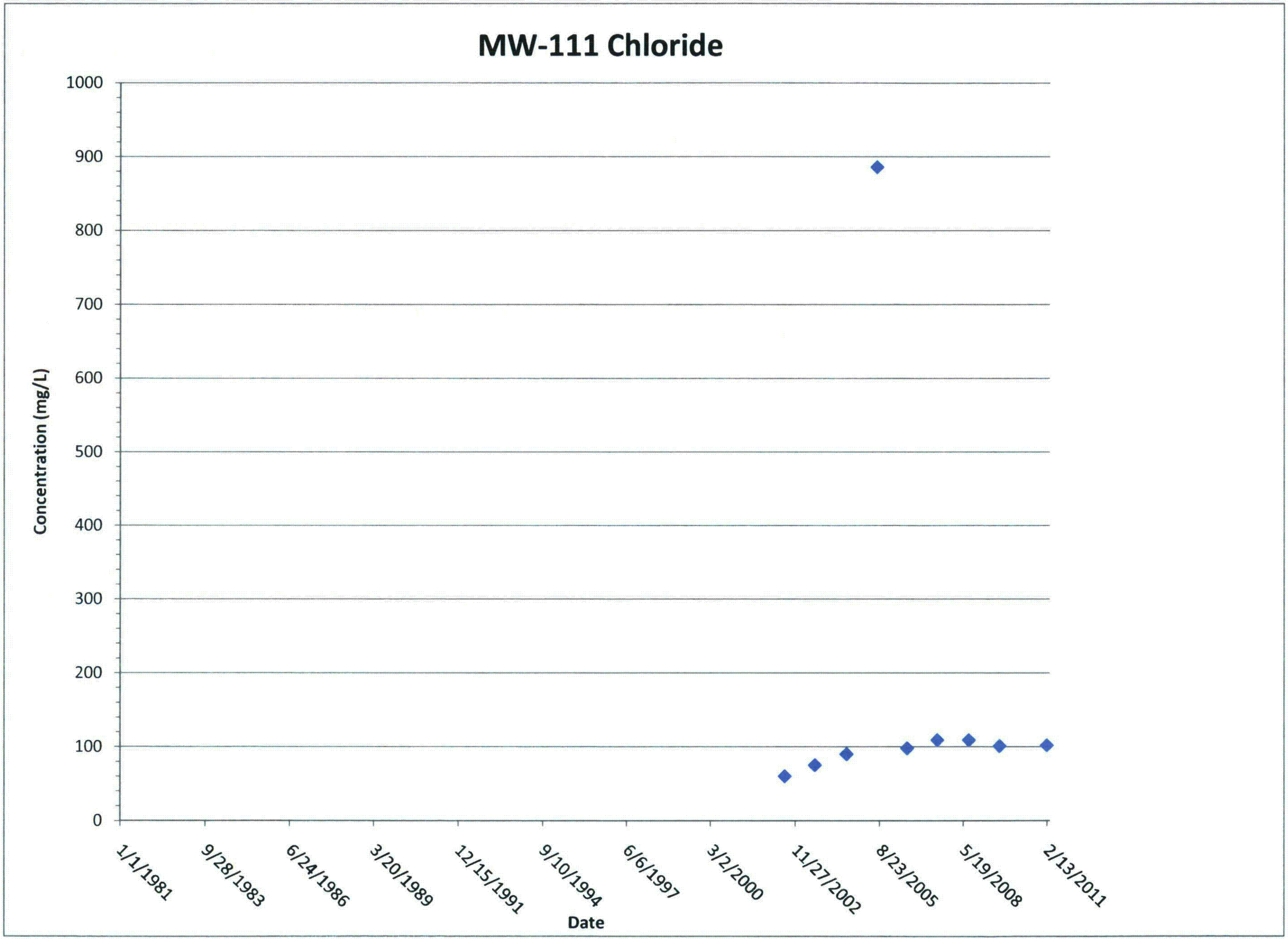

MW-12 Thorium 230
Concentration (pCi/L)
6
5
4
3
2
1
0
-1
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

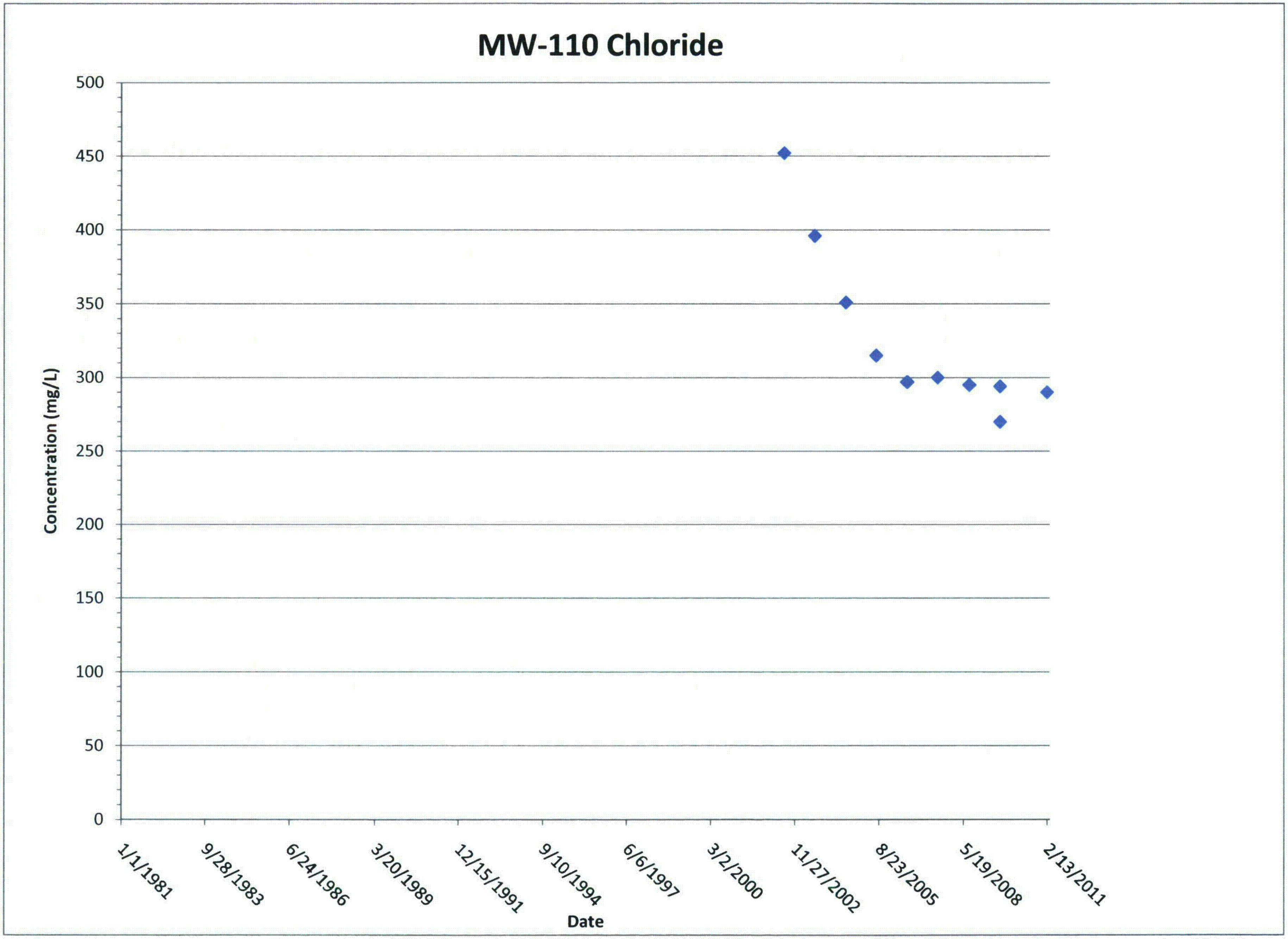
MW-111 Sulfate
Concentration (mg/L)
2500
2000
1500
1000
500
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date


MW-110 Sulfate
Concentration (mg/L)
1740
1720
1700
1680
1660
1640
1620
1600
1580
1560
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

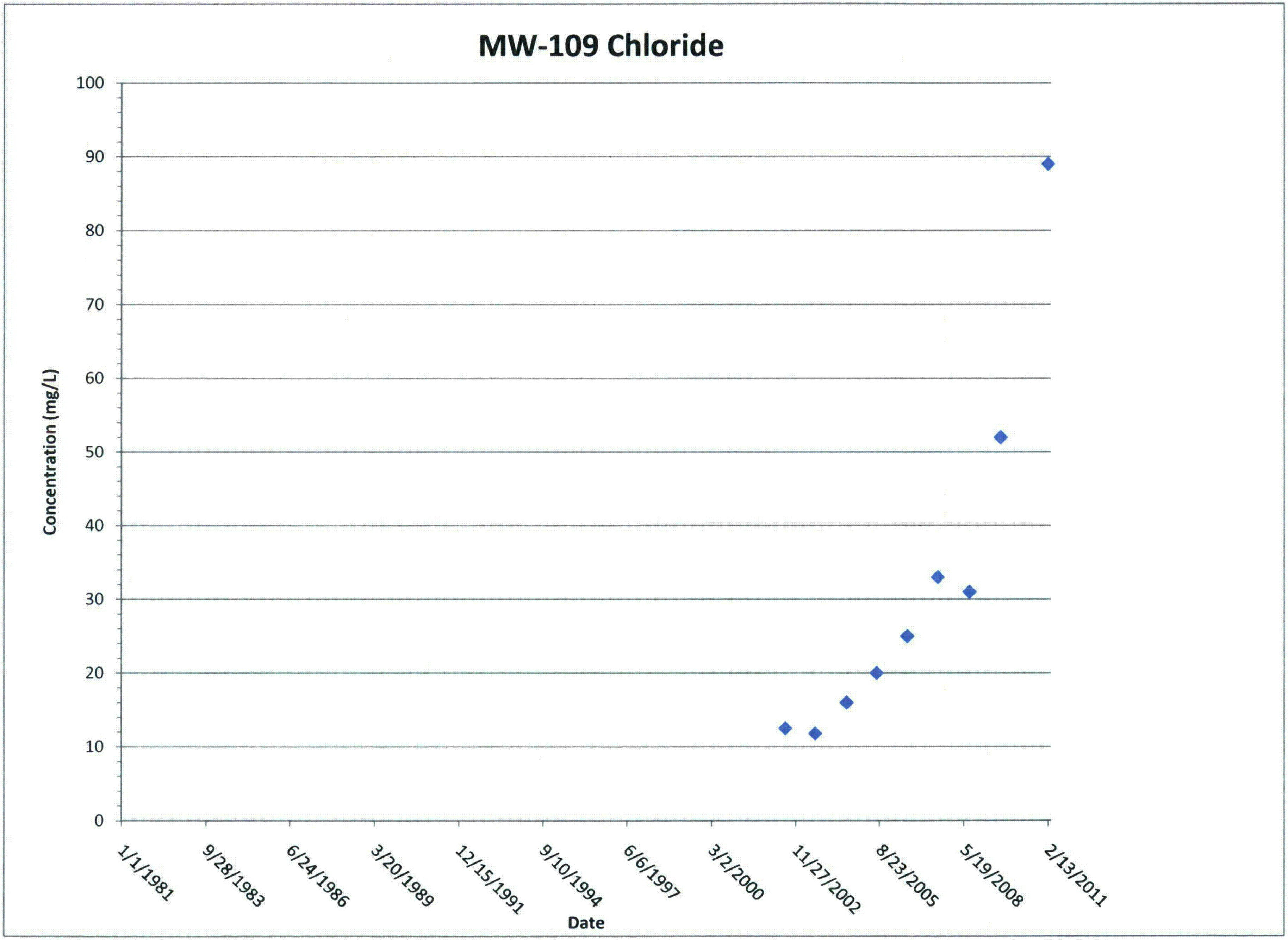

MW-109 Sulfate
Concentration (mg/L)
1940
1920
1900
1880
1860
1840
1820
1800
1780
1760
1740
1720
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

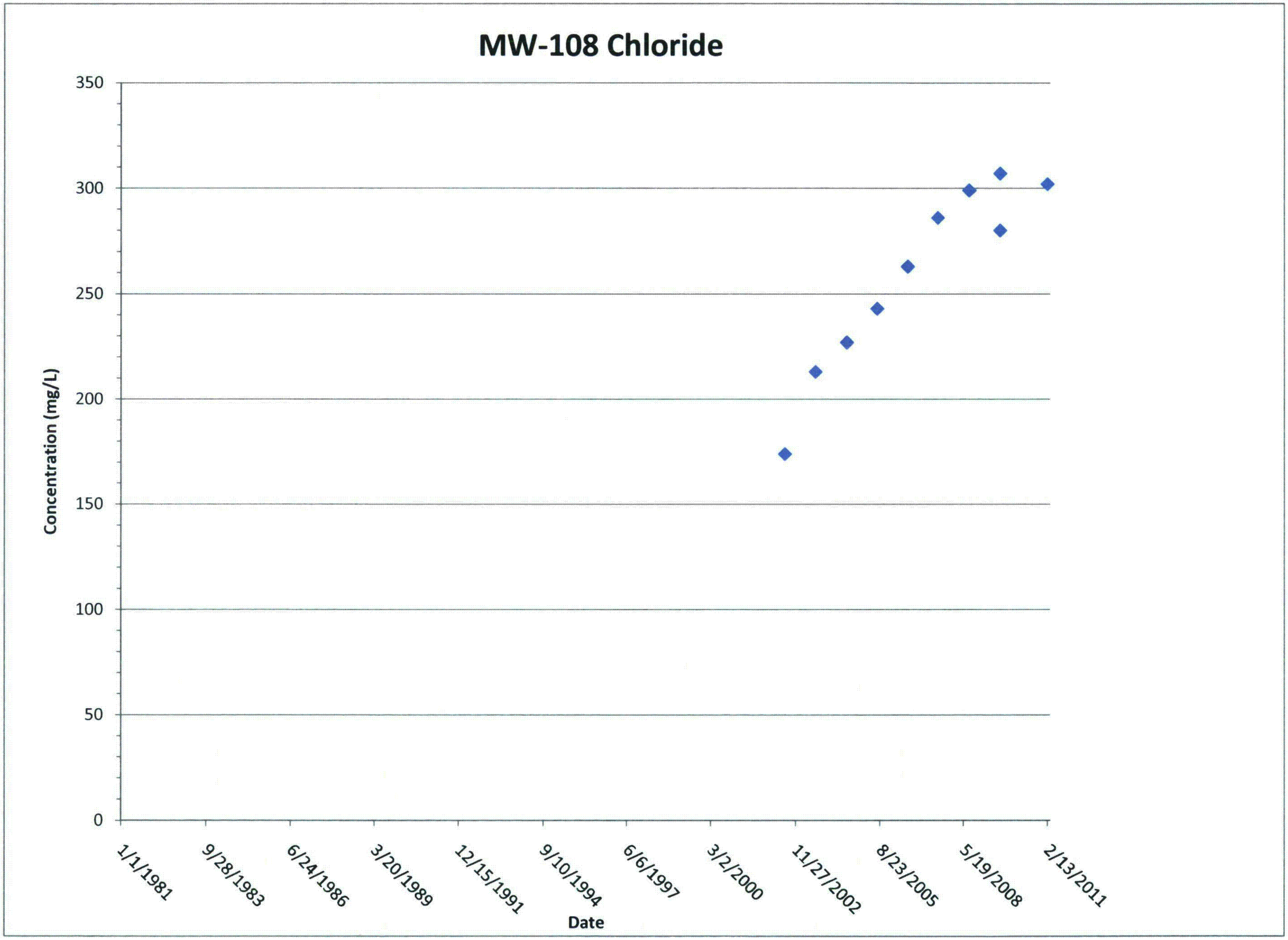

MW-108 Sulfate
Concentration (mg/L)
1700
1650
1600
1550
1500
1450
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

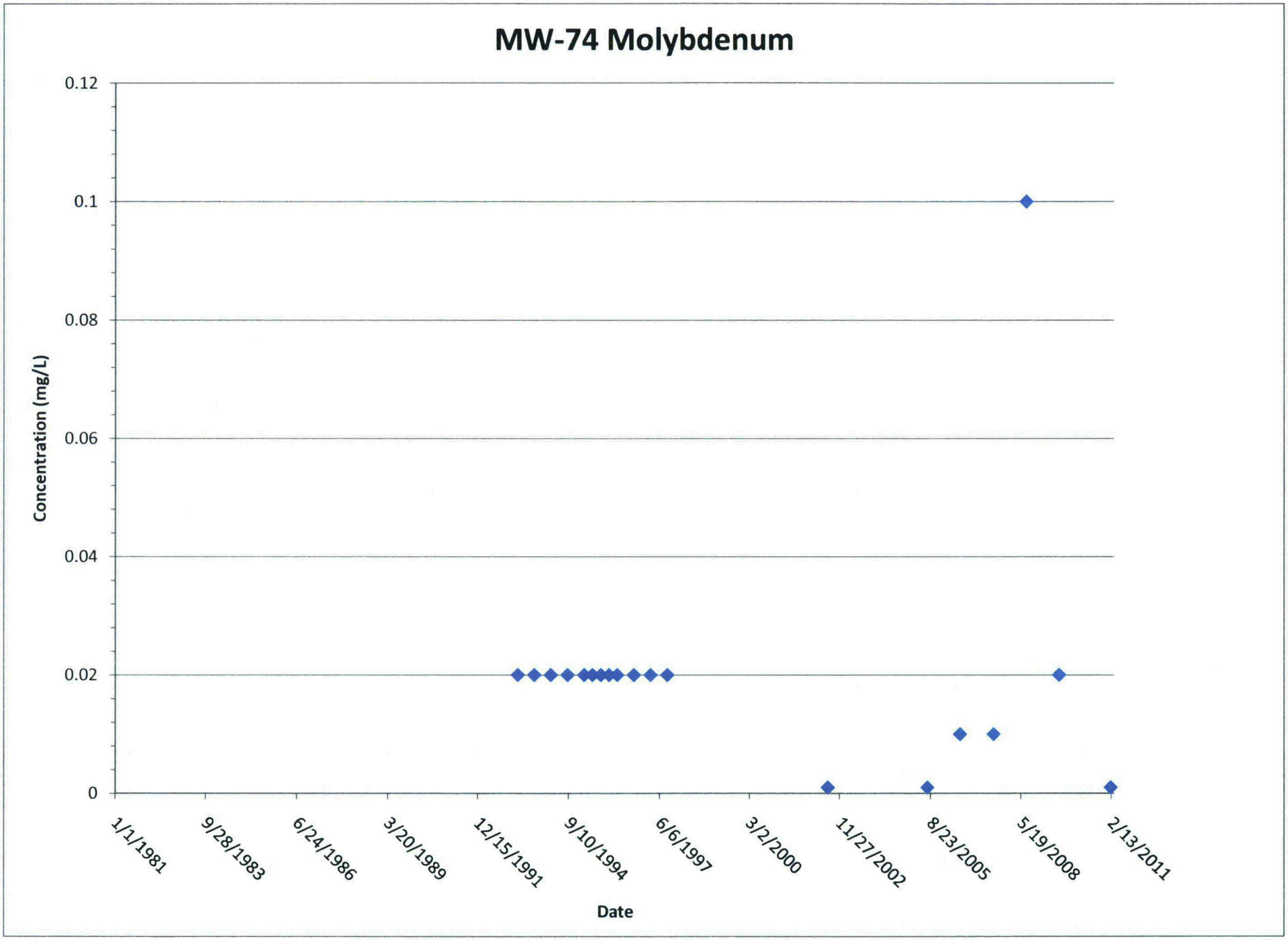

MW-111 Chloride
Concentration (mg/L)
1000
900
800
700
600
500
400
300
200
100
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

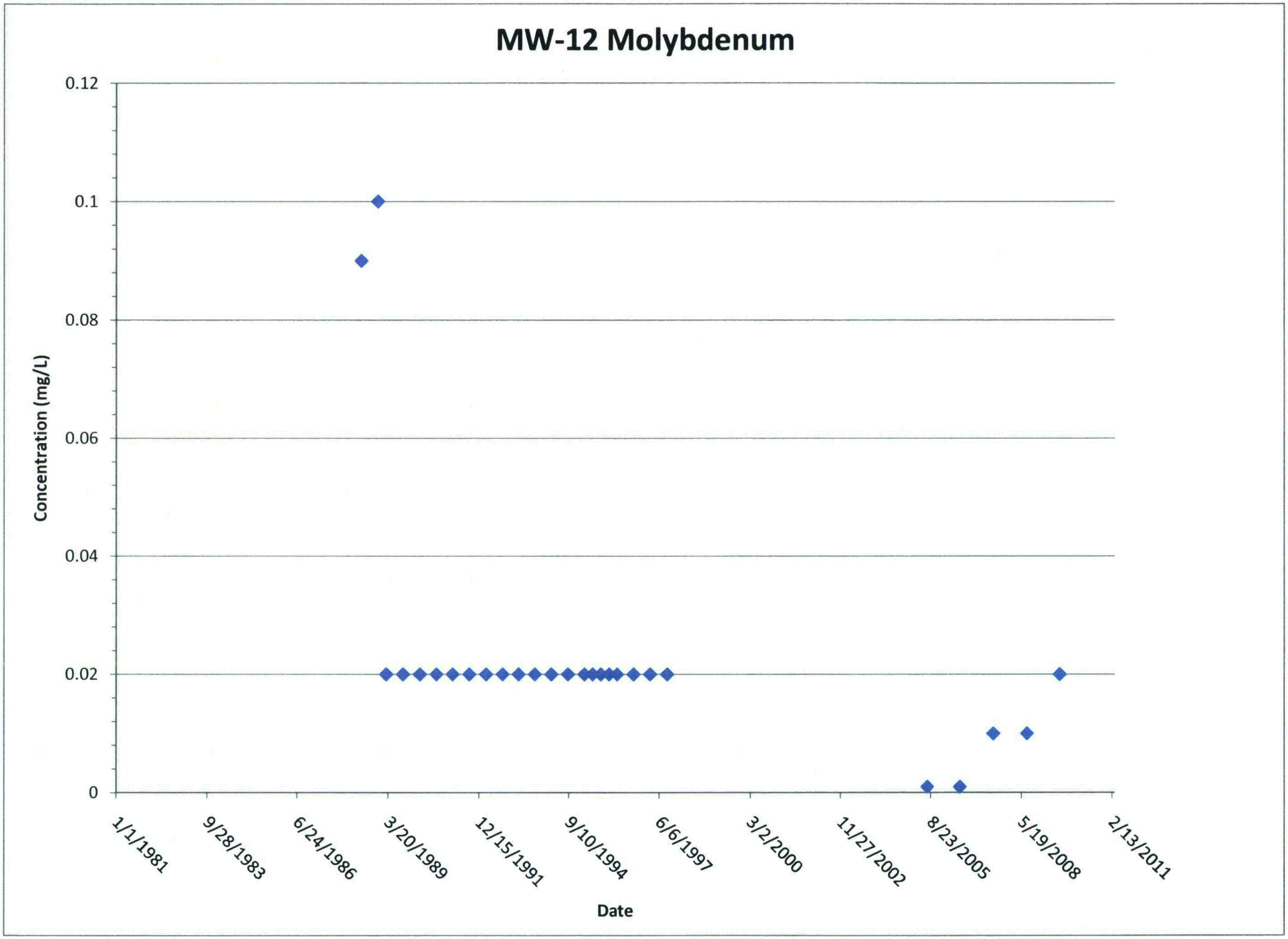


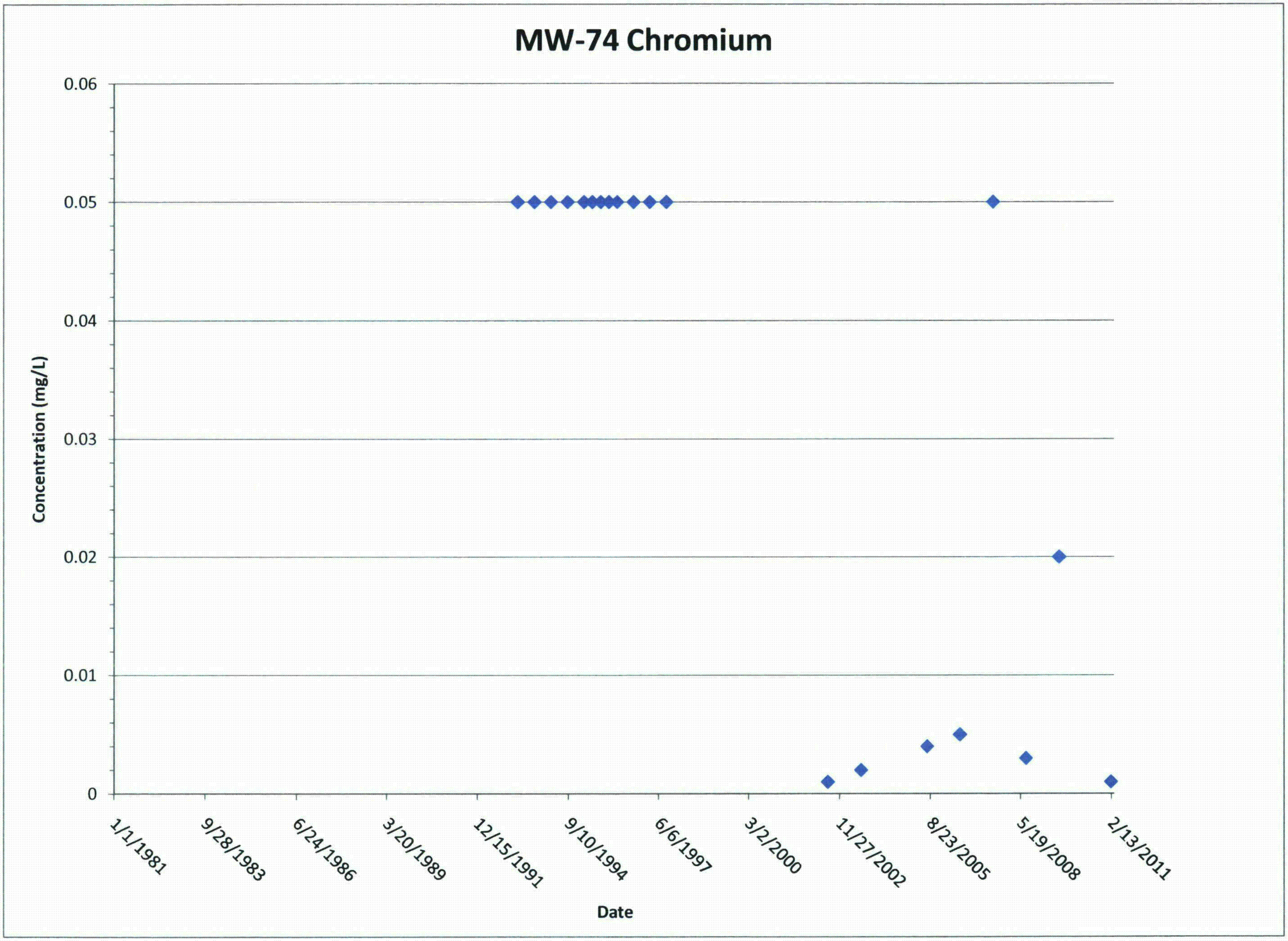
MW-110 Chloride
Concentration (mg/L)
500
450
400
350
300
250
200
150
100
50
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

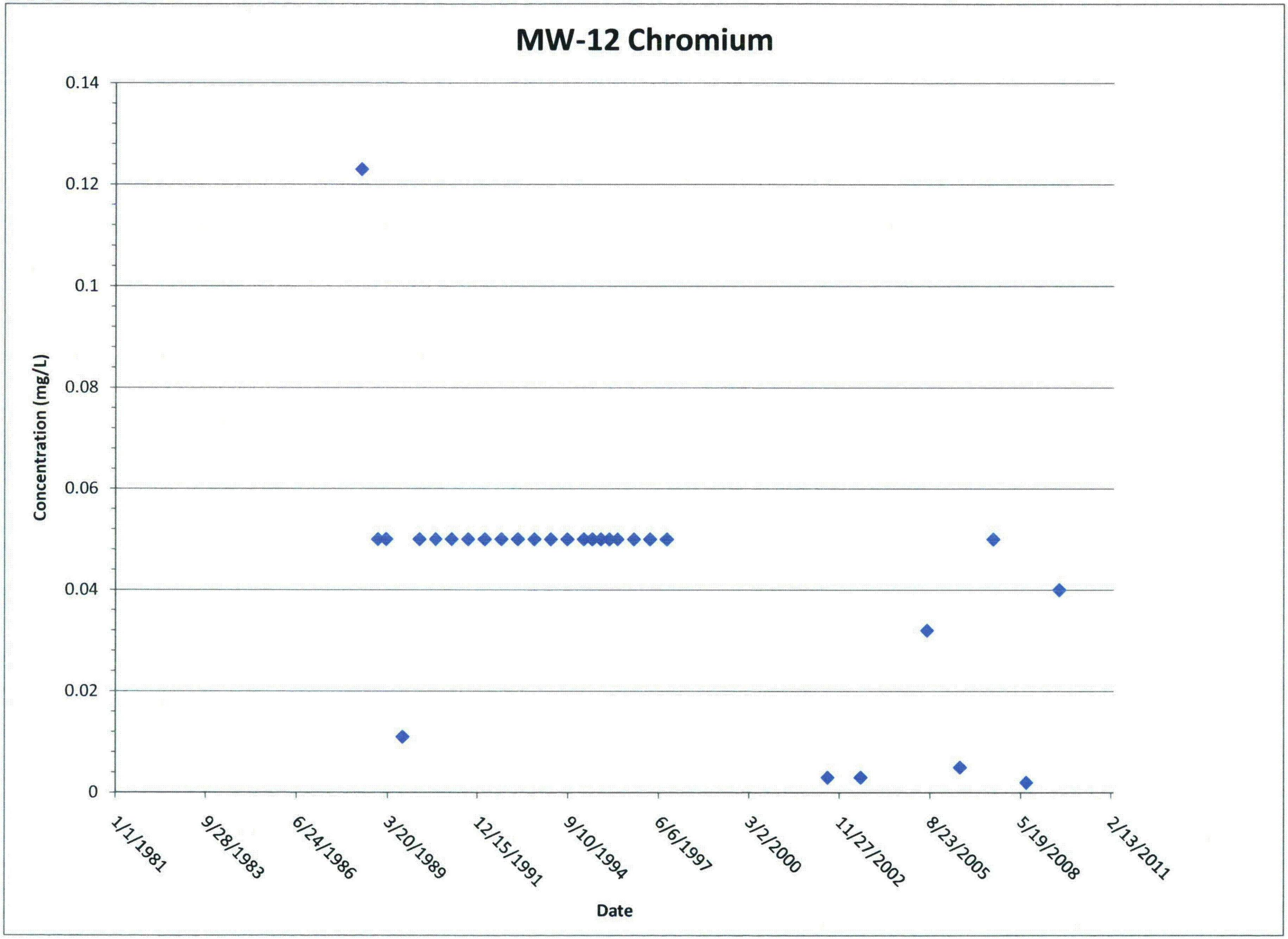

MW-109 Chloride
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

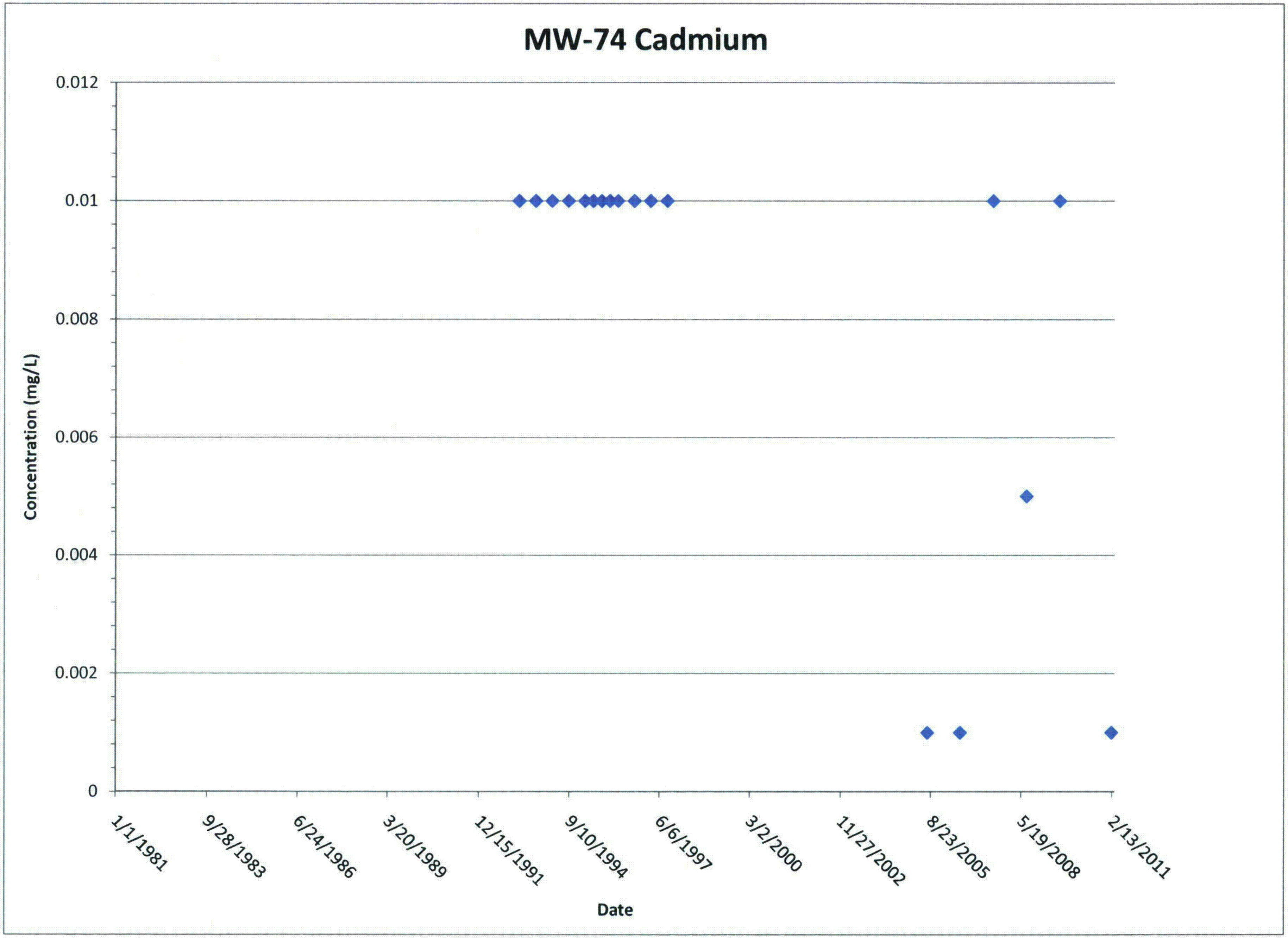

MW-108 Chloride
Concentration (mg/L)
350
300
250
200
150
100
50
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

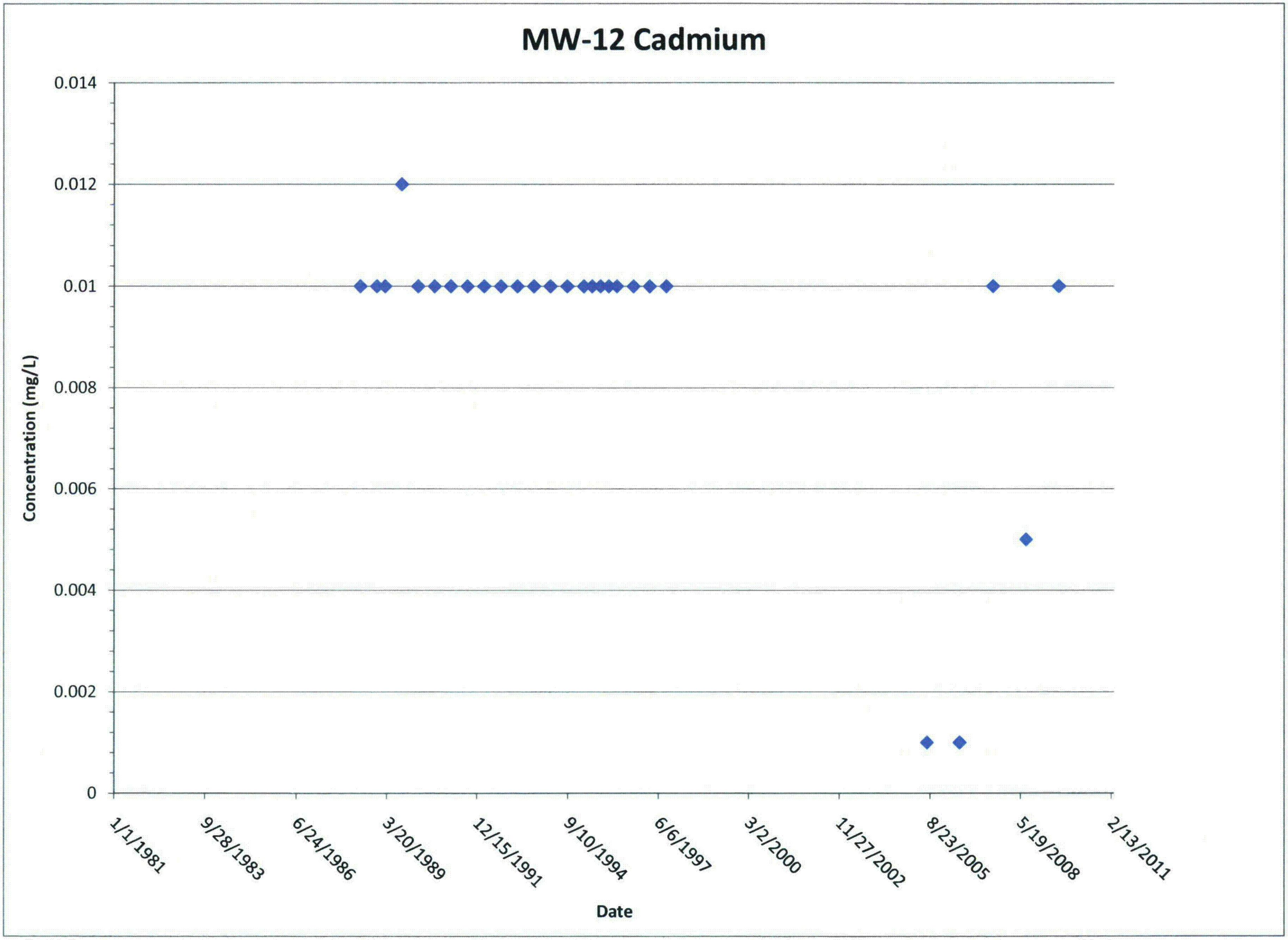

MW-74 Molybdenum
Concentration (mg/L)
0.12
0.1
0.08
0.06
0.04
0.02
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

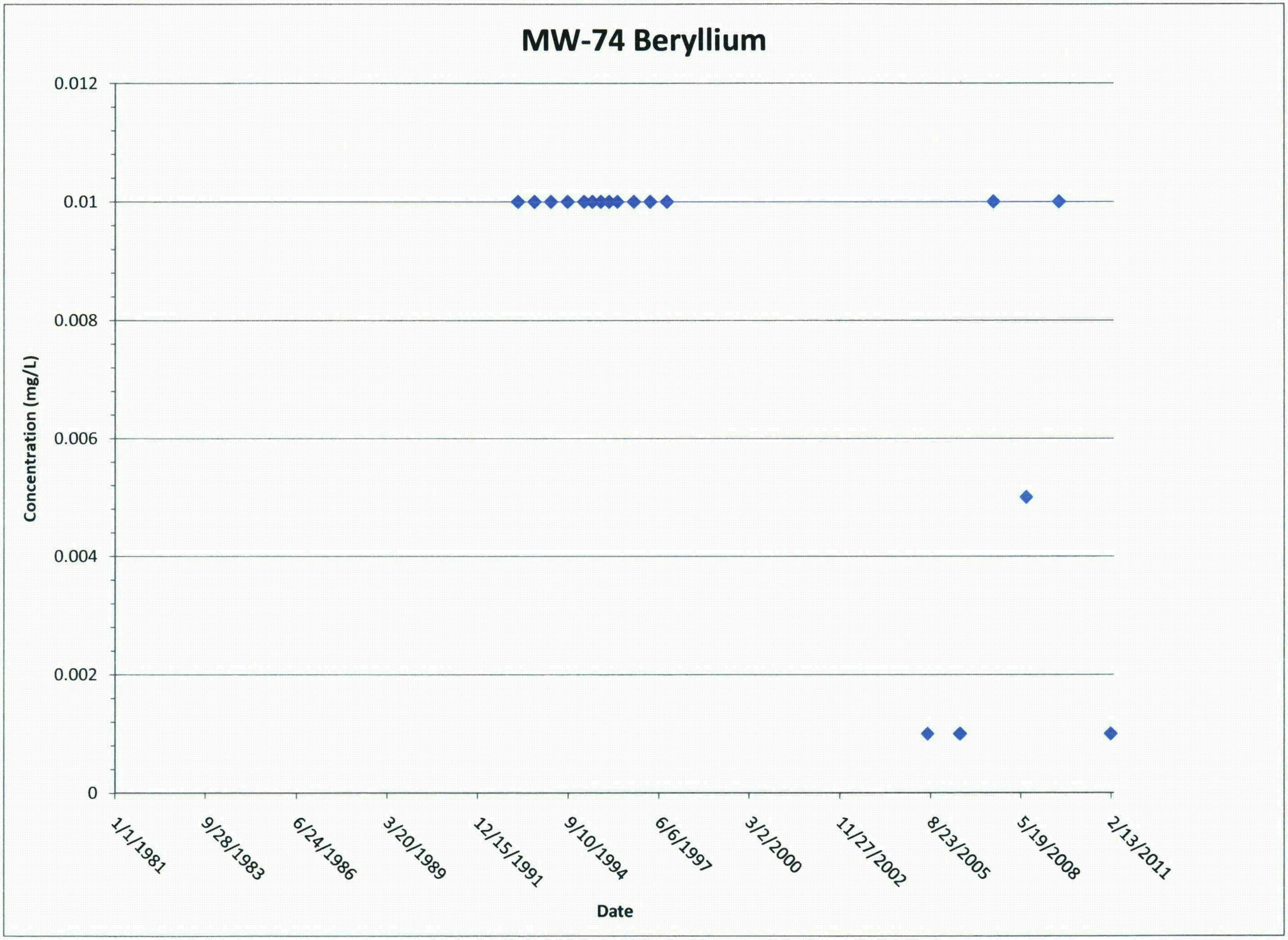

MW-12 Molybdenum
Concentration (mg/L)
0.12
0.1
0.08
0.06
0.04
0.02
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date


MW-74 Chromium
Concentration (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

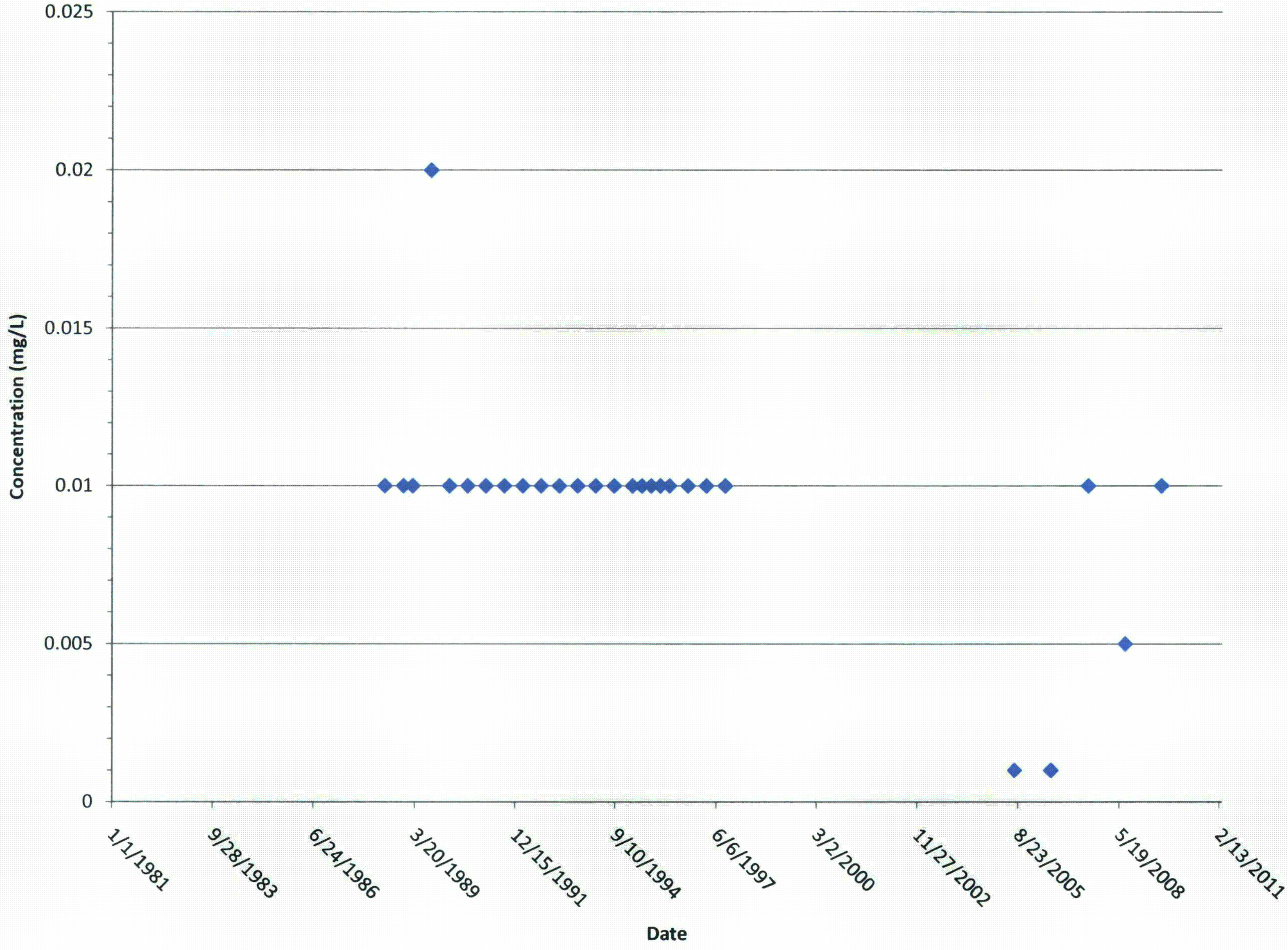

MW-12 Chromium
Concentration (mg/L)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

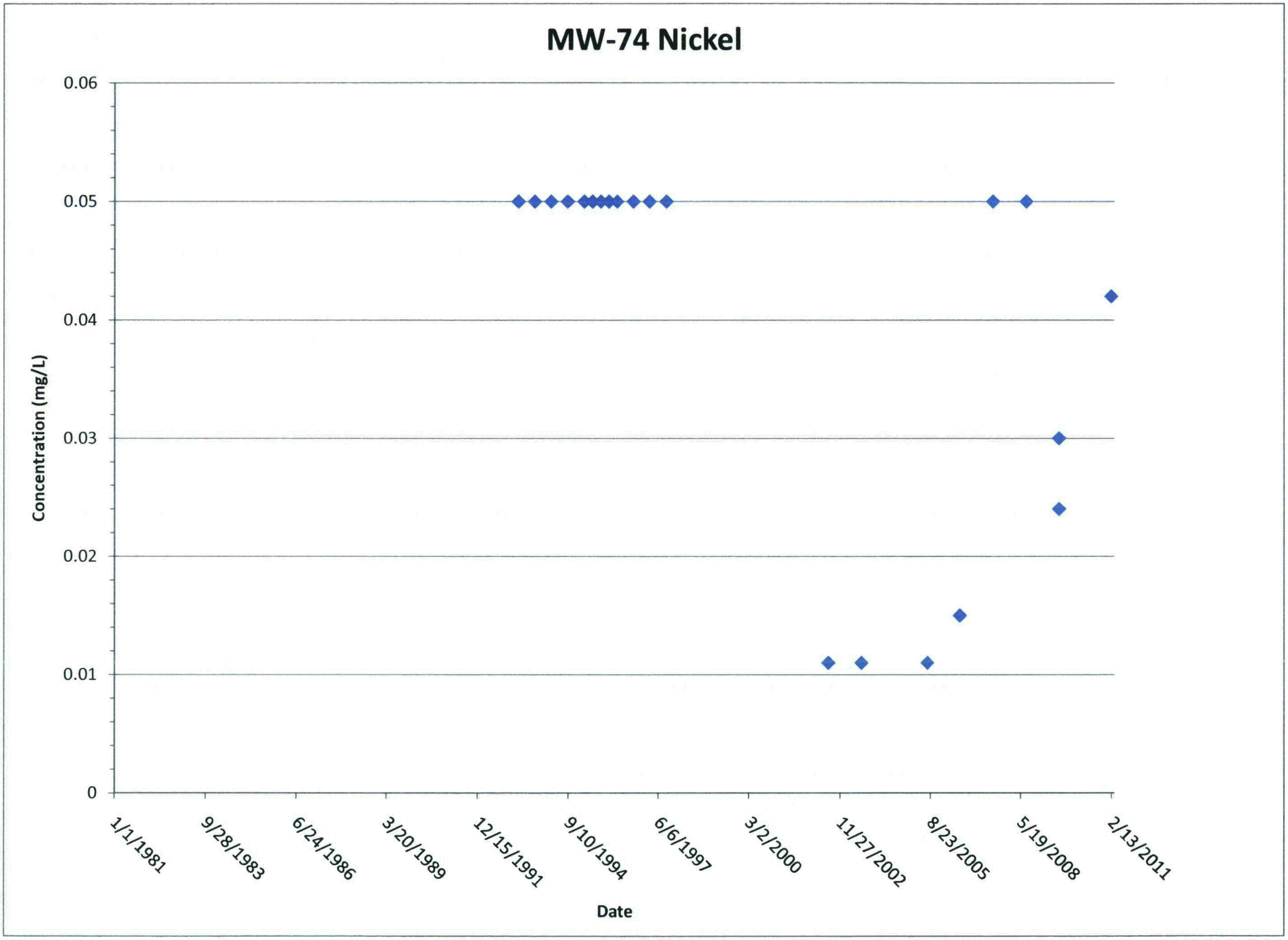

MW-74 Cadmium
Concentration (mg/L)
0.012
0.01
0.008
0.006
0.004
0.002
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

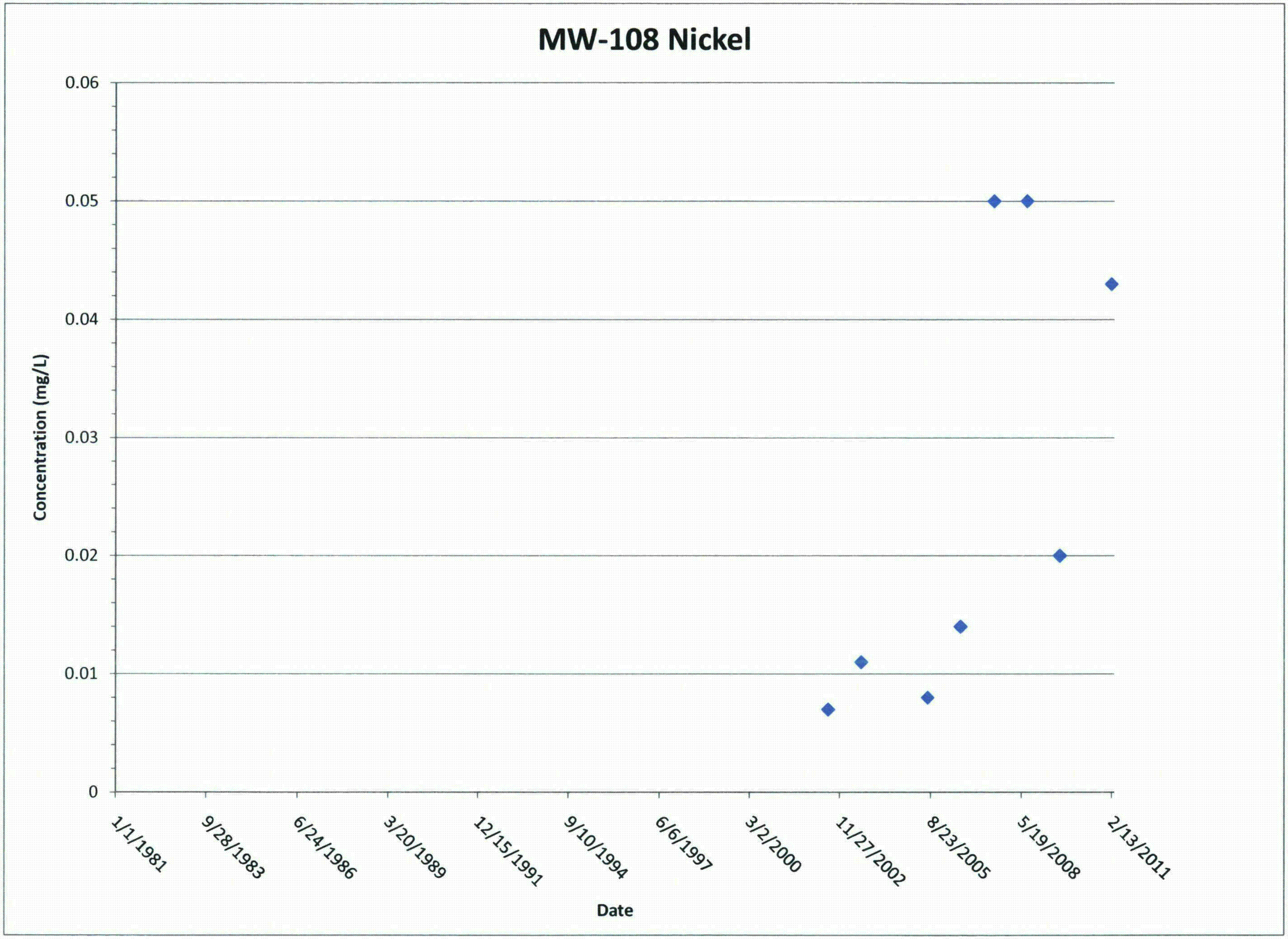

MW-12 Cadmium
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Concentration (mg/L)
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

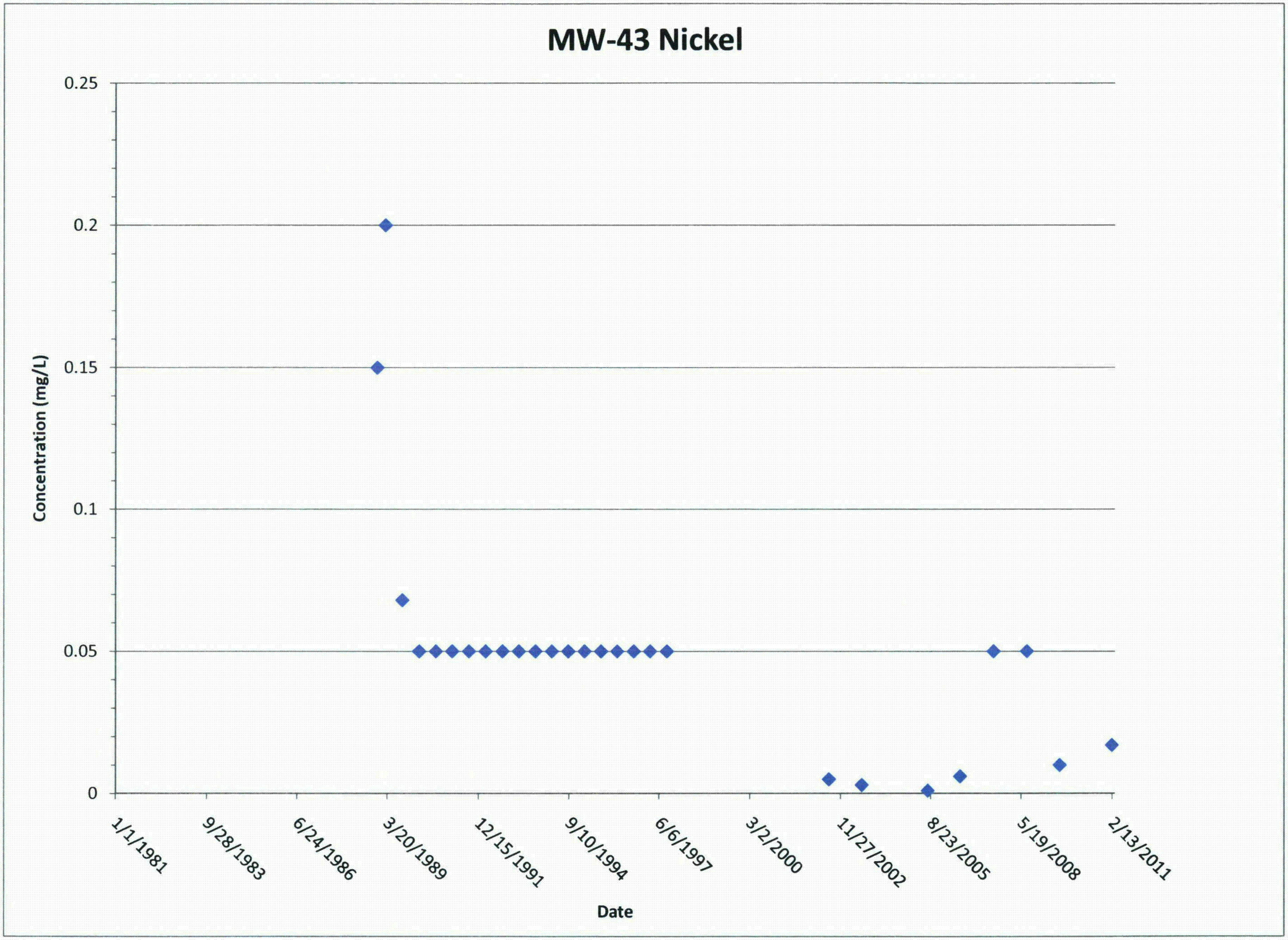

MW-74 Beryllium
Concentration (mg/L)
0.012
0.01
0.008
0.006
0.004
0.002
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

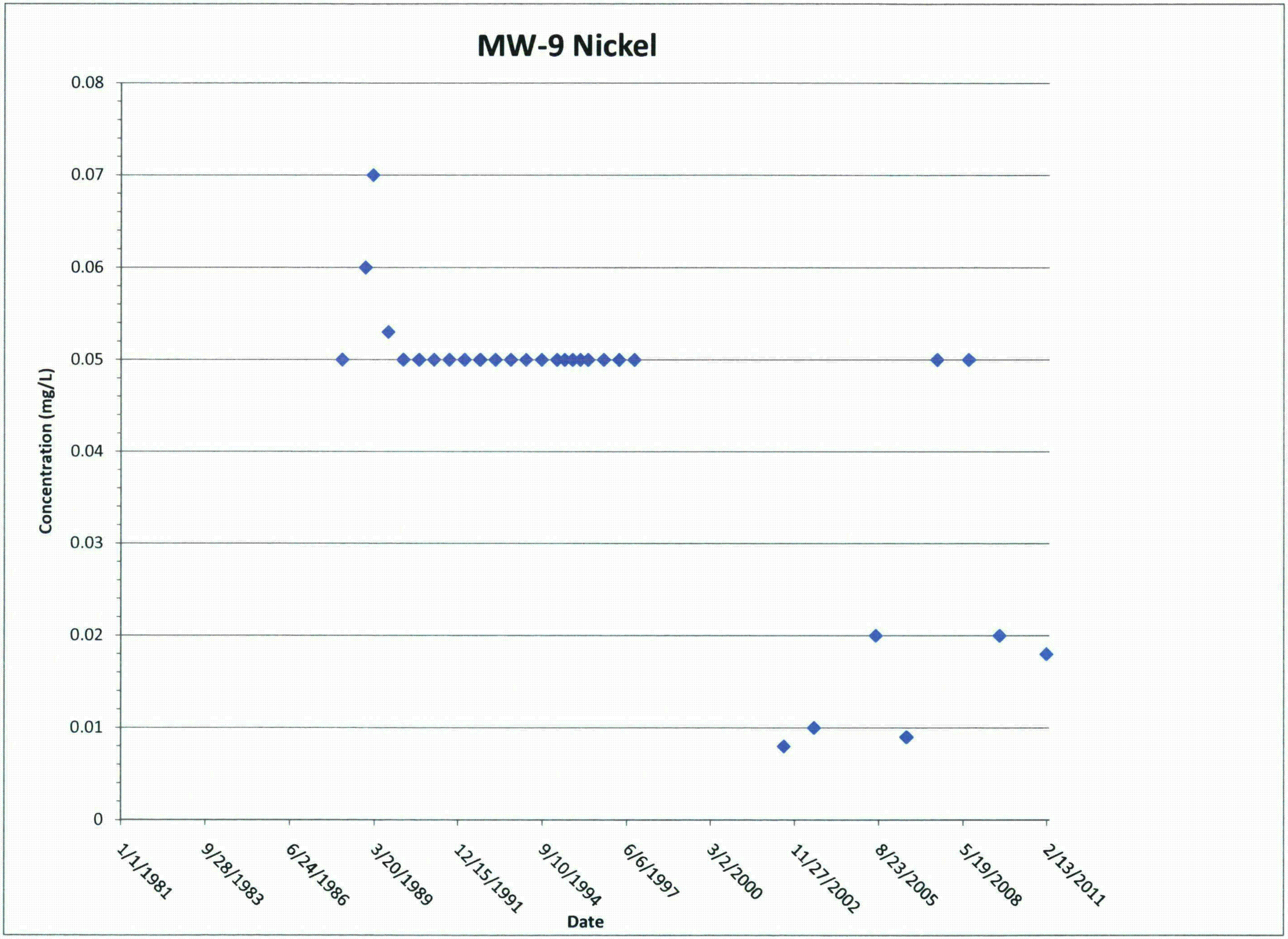
MW-12 Beryllium

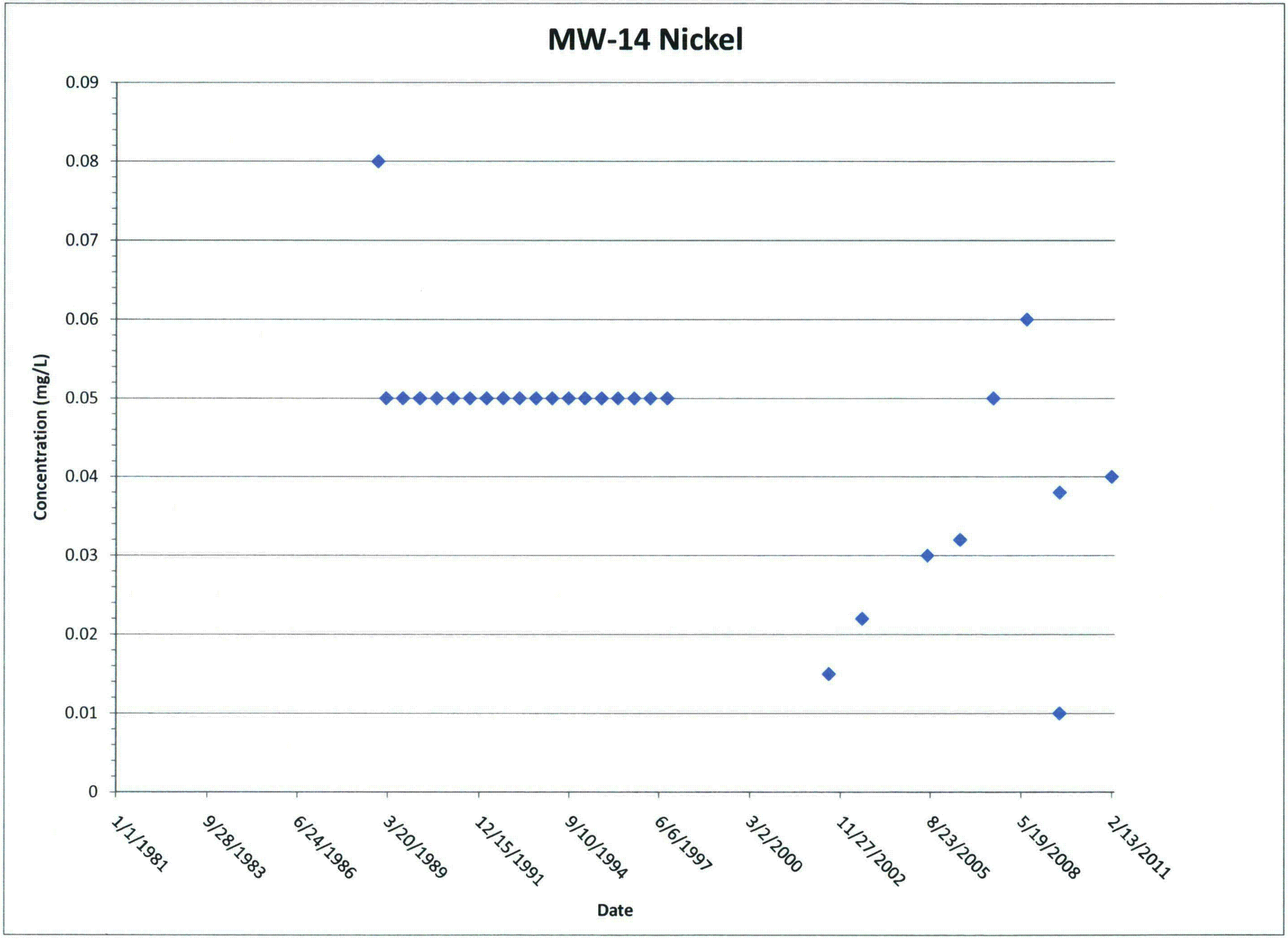


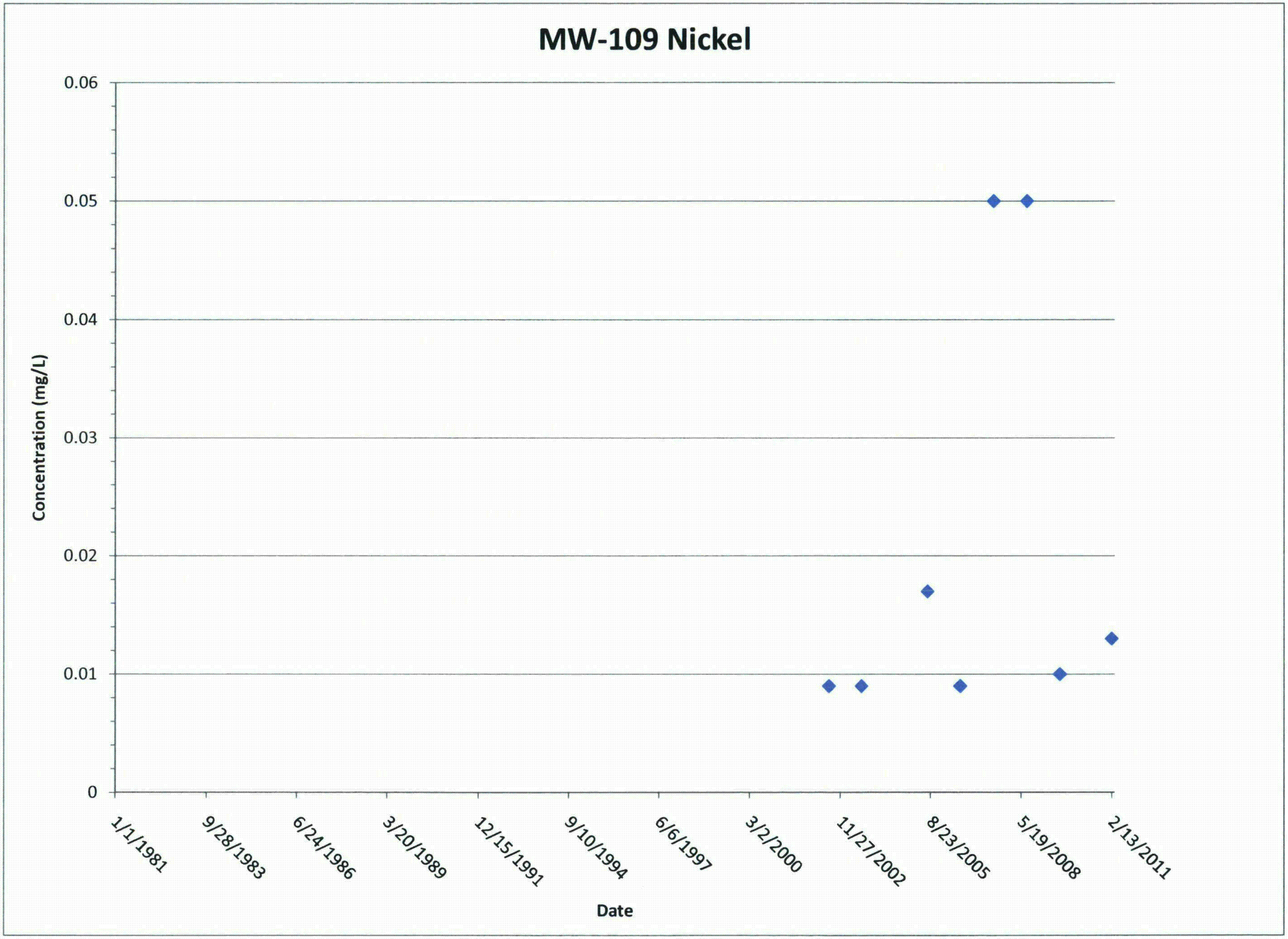

MW-74 Nickel
Concentration (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

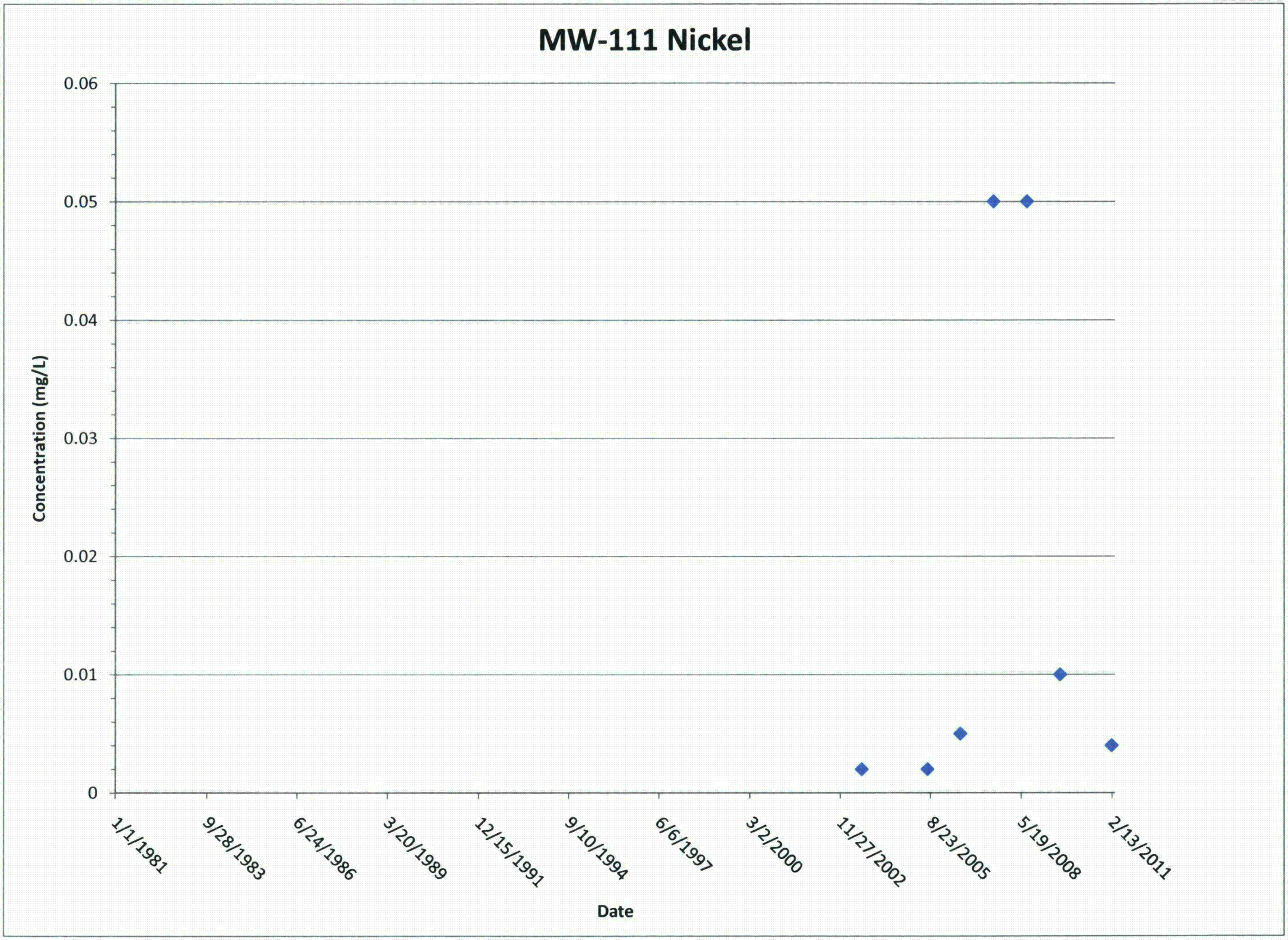

MW-108 Nickel
Concentration (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date


MW-43 Nickel
Concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

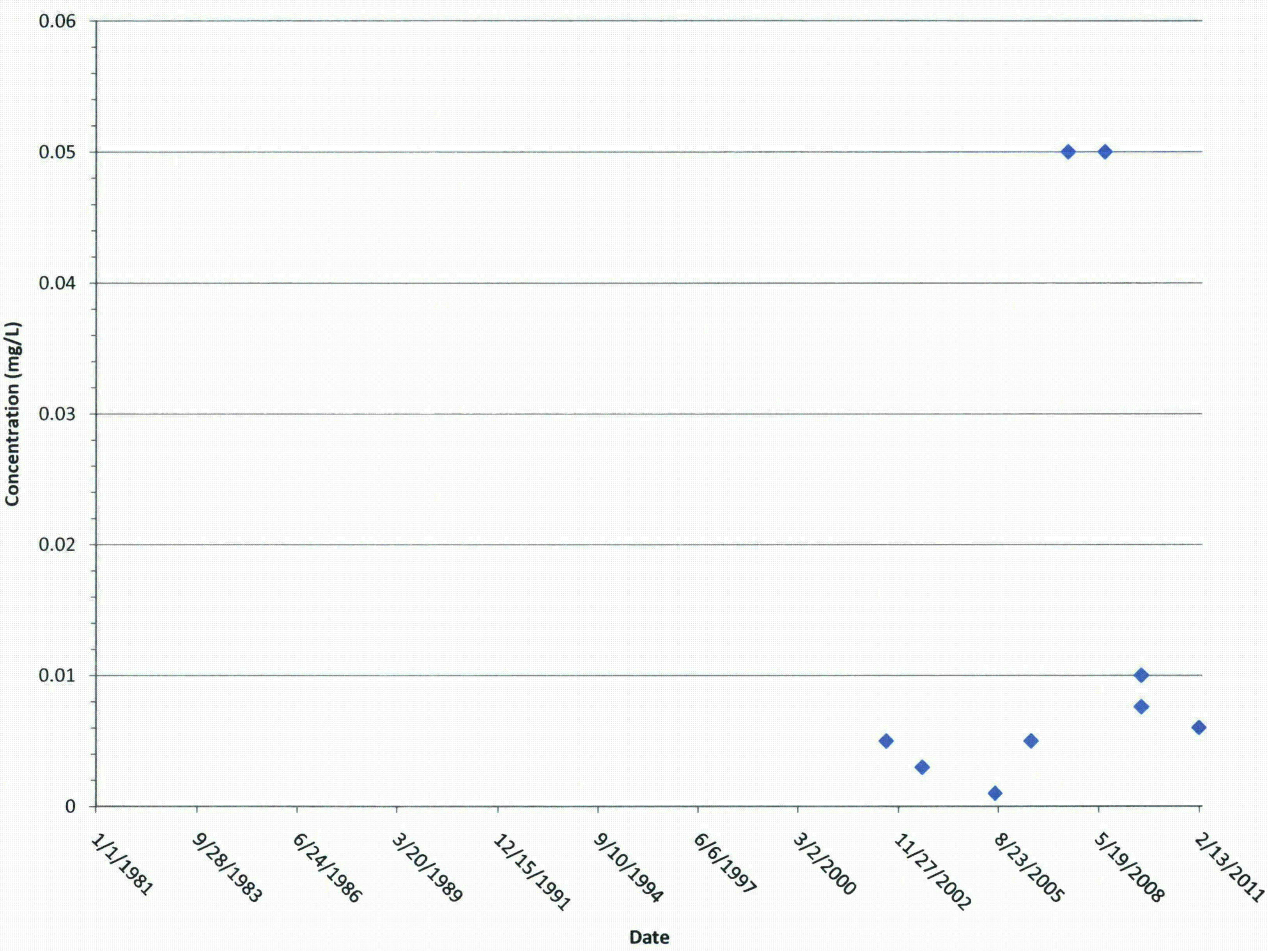

MW-9 Nickel
Concentration (mg/L)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

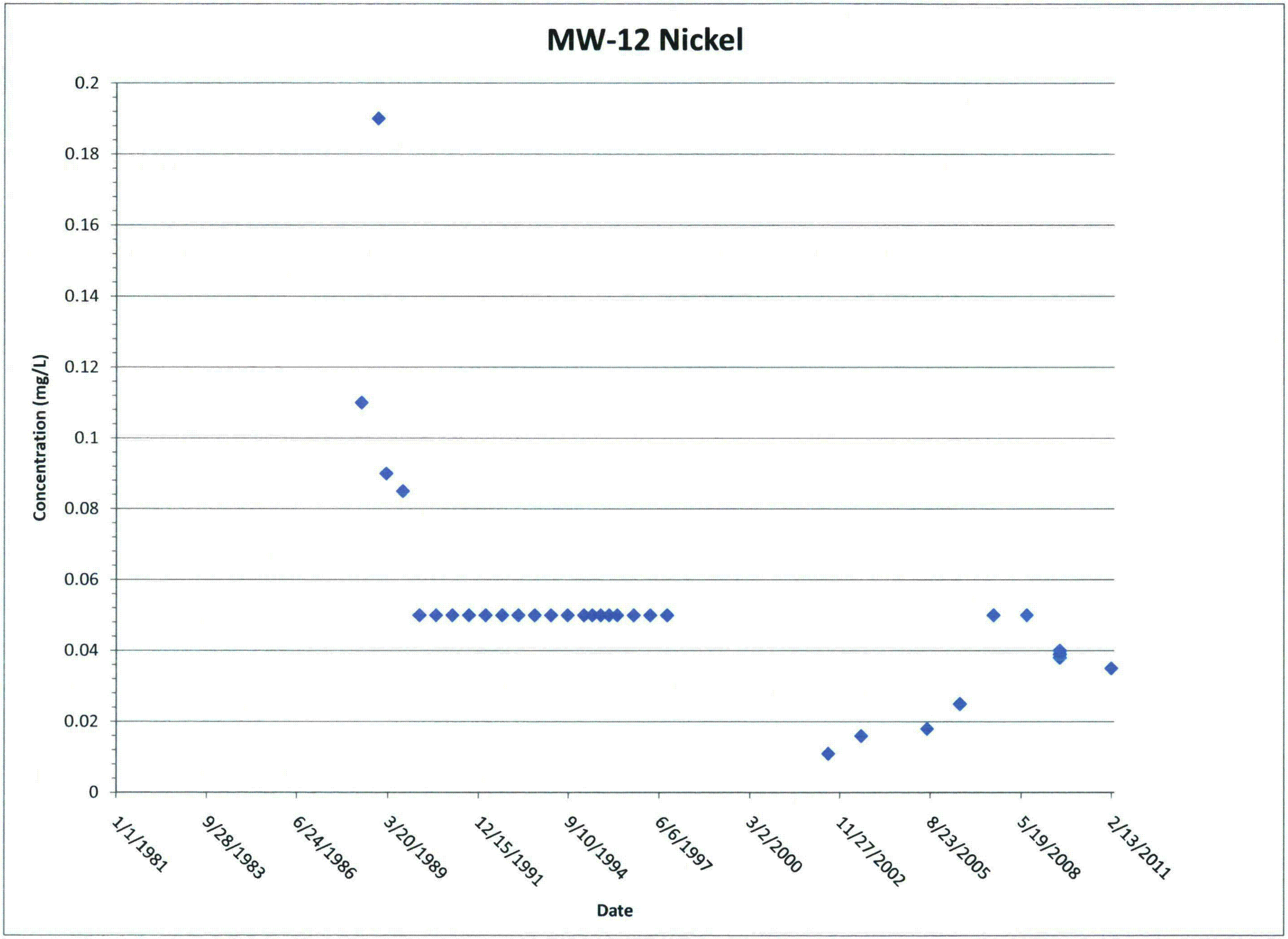

MW-14 Nickel
Concentration (mg/L)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date


MW-109 Nickel
0.06
0.05
0.04
0.03
0.02
0.01
0
Concentration (mg/L)
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date


MW-111 Nickel
Concentration (mg/L)
0.06
0.05
0.04
0.03
0.02
0.01
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

MW-110 Nickel




MW-12 Nickel
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1/1/1981
9/28/1983
6/24/1986
3/20/1989
12/15/1991
9/10/1994
6/6/1997
3/2/2000
11/27/2002
8/23/2005
5/19/2008
2/13/2011
Date

ATTACHMENT II

Input PHREEQC data set for Long Draw

```
DATABASE Phreeqcm.dat
# Input dataset for Lang Draw model

USER PUNCH
  -headings U pCi/L  Radium pCi/L  CELL DISTANCE m TIME YEARS  DATE step
  ALKALINITY U_ppm pH   Ferri  Cl_ppm S(6)_ppm Ra2(pCi/L)  Ni_ppm
 -start
5 USPECIES = MOL("Ca2UO2(CO3)3")+ MOL("CaUO2(CO3)3-2") + MOL("UO2+2")+
MOL("UO2CO3") + MOL("UO2Cl+") + MOL("UO2Cl2") + MOL("UO2(CO3)2-2")+
MOL("UO2(CO3)3-4") + MOL("UO2(OH)3-") + MOL("UO2(OH)2") + MOL("UO2OH+")+
MOL("UO2(OH)4-2")+MOL("UO2SO4")+ MOL("UO2(SO4)2-2") + MOL("(UO2)2(OH)2+2")
10 SURFCOMP =  MOL("Hfo_wOUO2+")+ MOL("Hfo_sOUO2+") + MOL("Hfo_wOUO2(CO3)2-3")
+ MOL("Hfo wOUO2CO3-")
15 PUNCH USPECIES*238*1000*.67*1000
#Uranium in pCi/L
20 PUNCH (TOT("Ra")*226*1000)/(226*2.8E-15*1600)
#Radium in pCi/L
25  PUNCH CELL NO
30  PUNCH CELL NO*4
35 PUNCH TOTAL TIME/(3600*24*365)
40 PUNCH (TOTAL TIME/(3600*24)+34578)                               # you
can install an actual date by  changing the 34578 value, WHICH is currently
set for Sept 1 1994.
45 PUNCH step no                                                     # puts
step number in column 7
50 PUNCH ALK*50000
55 PUNCH TOT("U")*238*1000
60 PUNCH -LA("H+")
65 PUNCH EQUI("Fe(OH)3(a)")
70 PUNCH TOT("CL")*1000*35.453
75 PUNCH TOT("S(6)")*1000*96.064
80 SURFCOMP =  MOL("Hfo_wOUO2+")+ MOL("Hfo_sOUO2+") + MOL("Hfo_wOUO2(CO3)2-3")
+ MOL("Hfo wOUO2CO3-")
85 PUNCH TOT("Ra")*226*1.0E12  # Ra in pCi/L
90 PUNCH TOT("Ni")*1000*58.69

 -end

TITLE   Transport: Bear Creek Lang Draw Model Phreeqc 2.0


 SOLUTION 1000 solution   MW-86         # Solution to mix with upgradient
        (MW-36) water for upgradient boundary condition
units mg/L
 # Samplename   MW-86
 pH      4.5
 pe      12
 temp    25
 Ca      420
 Mg      700
 Na      278 charge
 K       42
 Fe      926
 Mn      35.9
 Al      230
 S(6)    9040
 Cl      600
 C(4)
 F       0.1
 P       0.01
 Si      21.4                                                    #as SiO2
 Ni      0.08
 U       3.303662   # U-natural (pCi/L)  2038
 Ra      4.5e-09

END
```

```
SOLUTION 2000 MW-36 background groundwater      #THIS IS WATER FROM MW-36
clean water

units mg/L
# Samplename    MW-36
pH       7.8
pe       12
temp     25
Ca       158
Mg       21
Na       61
K        7
Fe       0.1
Mn       0.11
Al       0.5
S(6)     425
Cl       25
C(4)     153
Ni       0.01
U        0.003
Ra       0.5E-09


END

SOLUTION 3000 MW-14
units mg/L
# Samplename    MW-14
pH       7.4
pe       12
temp     25
Ca       440
Mg       59
Na       34 charge
K        2
Fe       0.1
Mn       0.49
Al       0.5
S(6)     1053
Cl       90
C(4)     331
Ni       0.01
U        0.054
# U-natural (pCi/L)
Ra       1.2E-09

END

MIX
1000    .594427
2000    .405573
SAVE SOLUTION 0-30
END


#  CELL SETUP STARTS HERE FIRST SIMULATION

EQUILIBRIUM PHASES 1-30
        Al(OH)3(a)   -1.36  0.0
        Fe(OH)3(a)    1.69  1.000000E-4
        Calcite       0.0   0.0
        Gypsum        0.0   0.2
        SiO2(a)       0.0   0.0

SURFACE 1-30
 -equilibrate with solution  1-30
```

```
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase  0.005


SAVE EQUILIBRIUM PHASES 1-30
SAVE SURFACE 1-30
SAVE Solution 1-30

END
SOLUTION 31-55 Initial solution for column THIS IS MW-15
        units   ppm
units mg/L
# Samplename    MW-15
pH      6.0
pe      12
temp    25
Ca      650
Mg      250
Na      212 charge
K       18
Fe      2.18
Mn      0.35
Al      1.33
S(6)    2420
Cl      375
C(4)    1450
F       0.3
P       0.01
Si      20.78                                                         #as SiO2
Ba      #
Ni      0.025
U       1.20000000
Ra      2.5312E-09


EQUILIBRIUM PHASES 31-55
        Al(OH)3(a)  -1.36  0.1
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.01
        Gypsum       0.0   0.2
        SiO2(a)      0.0   0.0

SURFACE 31-55
 -equilibrate with solution  31-55
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase 0.005


SAVE SURFACE 31-55
SAVE EQUILIBRIUM PHASES 31-55
SAVE Solution 31-55

END
SOLUTION 56-119 Initial solution for column  MW-12
units mg/L
# Samplename    MW-12
pH      7.0
pe      12
temp    25
Ca      450
Mg      150
Na      265 charge
K       14
```

```
Fe      0.69
Mn      0.07
Al      1.15
S(6)    2000
Cl      275
C(4)    878
F       0.3
P       0.01
Si      18                                                      #as SiO2
Ni      0.025
U       0.16
Ra      1.5E-09


EQUILIBRIUM PHASES 56-119
        Al(OH)3(a)  -1.36  0.01
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.4
        Gypsum       0.0   0.0
        SiO2(a)      0.0   0.0


SURFACE 56-119
 -equilibrate with solution 56-119
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase 0.005


SAVE EQUILIBRIUM PHASES 56-119
SAVE SURFACE 56-119
SAVE Solution 56-119

END

SOLUTION 120-162 Initial solution for column  MW-14
units mg/L
# Samplename    MW-14
pH      7.7
pe      12
temp    25
Ca      350
Mg      59
Na      34 charge
K       2
Fe      0.1
Mn      0.49
Al      0.5
S(6)    800
Cl      70
C(4)    331
F
P
Si
Ni      0.01
U       0.054
Ra      1.2E-09


EQUILIBRIUM PHASES  120-162
        Al(OH)3(a)  -1.36  0.01
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.4
        Gypsum       0.0   0.0
        SiO2(a)      0.0   0.0
```

```
SURFACE  120-162
 -equilibrate with solution 120-162
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase 0.005



SAVE EQUILIBRIUM PHASES  120-162
SAVE SURFACE 120-162
SAVE Solution 120-162

END

MIX
2000 0.5
3000 0.5
SAVE SOLUTION 163-210
END



EQUILIBRIUM PHASES  163-210
        Al(OH)3(a)  -1.36  0.01
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.4
        Gypsum       0.0   0.0
        SiO2(a)      0.0   0.0


SURFACE  163-210
 -equilibrate with solution 163-210
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase 0.005


SAVE SURFACE 163-210
SAVE Solution 163-210

END

MIX
2000 0.8
3000 0.2
SAVE SOLUTION 211-242
END


EQUILIBRIUM PHASES  211-242
        Al(OH)3(a)  -1.36  0.01
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.4
        Gypsum       0.0   0.0
        SiO2(a)      0.0   0.0

SURFACE  211-242
 -equilibrate with solution 211-242
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase 0.005
```

```
SAVE EQUILIBRIUM PHASES  211-242
SAVE SURFACE 211-242
SAVE Solution 211-242

END
PRINT
        -reset  false
   -surface  true
SELECTED OUTPUT
    -file                   BC_mod02.sel                                    #can
        be SEL or XLS
    -reset                  false
#    -step     true                                                          #this
prints the time step in the first column, set to "false" in order to eliminate
that column
                          #1995 through 1997      Plateau 2
MIX
1000    .594427
2000    .405573
SAVE SOLUTION 0
# 1994 through 1995
TRANSPORT
        -cells                  242                                         #235
        is total cells
        -length             4                                               #4
        meter cells  .10000000   40.000000
        -shifts                 9.00000                                     #6
        yrs*365*24*3600/2522880= 75 shifts; we start at the dam, John added a
        year for the diffence in length for the first water
        -time step              3155760.0                                   #This
        is 29.2 days in seconds and essentially indicates hydraulic
        conductivity
        -punch cells  1 20 52  98 121 159  181  242
        -punch frequency   1
        -flow direction       forward
        -boundary conditions  flux  flux
        -correct disp         true
        -dispersivity           235*30.0000
        -diffusion_coef       0.0e-0                                        #No
        diffusion
        -tempr  1.0                                                         #No
        heat retardation
END
#1995 through 1997      Plateau 2
MIX
1000    .349935
2000    .650065
SAVE SOLUTION 0                                                             #Over-
write Solution 0

TRANSPORT
 -shifts        20.0000

END
#1997 through 2000      Plateau 3

MIX
1000    .087363
2000    .912637
SAVE SOLUTION 0                                                             #Over-
write Solution 0.

TRANSPORT
 -shifts        30.0000
```

```
END

#2000 through 2010      Plateau 4

MIX
1000    .004258
2000    .995742
SAVE SOLUTION 0                                                         #Over-
write Solution 0.

TRANSPORT
 -shifts        60.0000

END

#2006 through 2010      Plateau 5

MIX
1000    1.25E-5
2000    .999988
SAVE SOLUTION 0                                                         #Over-
write Solution 0.

TRANSPORT
 -shifts                109.000

END


END
```

ATTACHMENT III

Input PHREEQC data set for Northern Pathway

```
DATABASE C:Phreeqcm.dat


USER PUNCH
  -headings U pCi/L  Radium pCi/L  CELL DISTANCE m TIME_YEARS  DATE step
  ALKALINITY U_ppm pH   Ferri  Cl_ppm S(6)_ppm RA_pCI/L  NI_ppm
 -start
3 USPECIES = MOL("Ca2UO2(CO3)3")+ MOL("CaUO2(CO3)3-2") + MOL("UO2+2")+
MOL("UO2CO3") + MOL("UO2Cl+") + MOL("UO2Cl2") + MOL("UO2(CO3)2-2")+
MOL("UO2(CO3)3-4") + MOL("UO2(OH)3-") + MOL("UO2(OH)2") + MOL("UO2OH+")+
MOL("UO2(OH)4-2")+MOL("UO2SO4")+ MOL("UO2(SO4)2-2") + MOL("(UO2)2(OH)2+2")
4 SURFCOMP =  MOL("Hfo_wOUO2+")+ MOL("Hfo_sOUO2+") + MOL("Hfo_wOUO2(CO3)2-3")
+ MOL("Hfo wOUO2CO3-")
5 PUNCH USPECIES*238*1000*.67*1000
#Uranium in pCi/L
7 PUNCH (TOT("Ra")*226*1000)/(226*2.8E-15*1600)
#Radium in pCi/L
11  PUNCH CELL NO                                                      #if
you want to eliminate a column, you remove it from the heading, then comment
out the line that applies to that column
13  PUNCH CELL NO*4
15 PUNCH TOTAL TIME/(3600*24*365)
17 PUNCH (TOTAL TIME/(3600*24)+34578)                                  # you
can install an actual date by  changing the 34578 value, WHICH is currently
set for Sept 1 1994.
19 PUNCH step no                                                       #puts
step number in column 7
21 PUNCH ALK*50000
23 PUNCH TOT("U")*238*1000
25 PUNCH -LA("H+")
26 PUNCH EQUI("Fe(OH)3(a)")
27 PUNCH TOT("CL")*1000*35.453
28 PUNCH TOT("S(6)")*1000*96.064
30 SURFCOMP =  MOL("Hfo_wOUO2+")+ MOL("Hfo_sOUO2+") + MOL("Hfo_wOUO2(CO3)2-3")
+ MOL("Hfo_wOUO2CO3-")

32 PUNCH TOT("Ra")*226*1.0E12  # Ra in pCi/L
33 PUNCH TOT("Ni")*1000*58.69

 -end

TITLE   Transport: Bear Creek North Path


SOLUTION 1000 solution   MW-86
units mg/L
# Samplename    MW-86
pH       4.5
pe       12
temp     25
Ca       420
Mg       700
Na       278 charge
K        42
Fe       926
Mn       35.9
Al       230
S(6)     9040
Cl       400
F        0.1
P        0.01
Si       21.4                                               #as SiO2
Ni       .1
U        0.6
Ra       1.51872E-08
END
```

```
SOLUTION 2000 MW-36 background groundwater

units mg/L
# Samplename    MW-36
pH      7.4
pe      12
temp    25
Ca      158
Mg      21
Na      61
K       7
Fe      0.1
Mn      0.11
Al      0.5
S(6)    425
Cl      25
C(4)    153
Ni      0.01
U       0.003
Ra      2.5312E-09


END

SOLUTION 3000 MW-43
units mg/L
# Samplename    MW-43 11/10/94
pH      7.7
pe      12
temp    25
Ca      974.
Mg      198.
Na      71. charge
K       17.
Fe      7.91
Mn      0.85
Al      0.01
S(6)    2080
Cl      575.
C(4)    854.
F       .2
Si      5.4
Ba      #
Ni      0.02
U       0.0581
Ra      5.164E-09


END

MIX
1000    .334046
2000    .665954
SAVE SOLUTION 0-54
END


#  CELL SETUP STARTS HERE FIRST SIMULATION

EQUILIBRIUM PHASES 1-54
        Al(OH)3(a)  -1.36  0.0
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.0
        Gypsum       0.0   0.2
        SiO2(a)      0.0   0.0

SURFACE 1-54
```

```
 -equilibrate with solution  1-54
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase  0.005


SAVE EQUILIBRIUM PHASES 1-54
SAVE SURFACE 1-54
SAVE Solution 1-54

END

MIX
1000    .334046
2000    .665954
SAVE SOLUTION 55-84
END


#  CELL SETUP STARTS HERE FIRST SIMULATION

EQUILIBRIUM PHASES 55-84
        Al(OH)3(a)  -1.36  0.0
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.1
        Gypsum       0.0   0.2
        SiO2(a)      0.0   0.0

SURFACE 55-84
 -equilibrate with solution  55-84
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase  0.005


SAVE EQUILIBRIUM PHASES 55-84
SAVE SURFACE 55-84
SAVE Solution 55-84

END


SOLUTION 85-125 Initial solution for column THIS IS MW-74
        units   ppm
units mg/L
# Samplename    MW-74 9/94
pH      6.7
pe      12
temp    25
Ca      450.
Mg      116.
Na      67. charge
K       12.
Fe      0.66
Mn      0.48
Al      0.96
S(6)    1900.
Cl      200.
C(4)    708.
F       0.2
P       0.01
Si      15.83                                                   #as SiO2
Ba      #
Ni      0.025                                                   #table 3-12
U       0.062
```

```
Ra      2.936E-09


EQUILIBRIUM PHASES 85-125
        Al(OH)3(a)  -1.36  0.1
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.4
        Gypsum       0.0   0.2
        SiO2(a)      0.0   0.0

SURFACE 85-125
 -equilibrate with solution  85-125
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase 0.005


SAVE SURFACE 85-125
SAVE EQUILIBRIUM PHASES 85-125
SAVE Solution 85-125

END
SOLUTION 126-170 Initial solution for column  MW-43
units mg/L
# Samplename    MW-43 11/10/94
pH      7.7
pe      12
temp    25
Ca      974.
Mg      198.
Na      71. charge
K       17.
Fe      7.91
Mn      0.85
Al      0.01
S(6)    2080
Cl      575.
C(4)    854.
F       .2
P
Si      5.4
Ba      #
Ni      0.02
U       0.0581
# U-natural (pCi/L)
Ra      2.5E-9


EQUILIBRIUM PHASES 126-170
        Al(OH)3(a)  -1.36  0.01
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.4
        Gypsum       0.0   0.0
        SiO2(a)      0.0   0.0

SURFACE 126-170
 -equilibrate with solution 126-170
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      # 0.2 sites per mole
of Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase 0.005


SAVE EQUILIBRIUM PHASES 126-170
SAVE SURFACE 126-170
SAVE Solution 126-170
```

```
END

MIX
2000 0.5
3000 0.5
SAVE SOLUTION 171-233
END

EQUILIBRIUM PHASES  171-233
        Al(OH)3(a)  -1.36  0.01
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.4
        Gypsum       0.0   0.0
        SiO2(a)      0.0   0.0


SURFACE  171-233
 -equilibrate with solution 171-233
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase 0.005



SAVE EQUILIBRIUM PHASES  171-233
SAVE SURFACE 171-233
SAVE Solution 171-233

END

MIX
2000 1.0
3000 0.0
SAVE SOLUTION 234-260
END



EQUILIBRIUM PHASES  234-260
        Al(OH)3(a)  -1.36  0.01
        Fe(OH)3(a)   1.69  1.000000E-4
        Calcite      0.0   0.4
        Gypsum       0.0   0.0
        SiO2(a)      0.0   0.0

SURFACE  234-260
 -equilibrate with solution 234-260
Hfo wOH  Fe(OH)3(a) equilibrium phase  0.2   53400      #0.2 sites per mole of
Fe(OH)3(a) present; 53400=600x89 (89 is formula weight for goethite) is
surface area per mole of iron hydroxide
Hfo_sOH  Fe(OH)3(a) equilibrium_phase 0.005


SAVE EQUILIBRIUM PHASES  234-260
SAVE SURFACE 234-260
SAVE Solution 234-260

END



END
PRINT
        -reset  false
   -surface  false
```

```
SELECTED OUTPUT
    -file                  BC_mod02.sel                                     #can
        be SEL or XLS
    -reset                 false
#    -step     true                                                         #this
prints the time step in the first column, set to "false" in order to eliminate
that column
                        #1995 through 1997      Plateau 2
MIX
1000    .334046
2000    .665954
SAVE SOLUTION 0
# 1994 through 1995
TRANSPORT
        -cells                260                                           #235
        is total cells
        -length                   4                                         #4
        meter cells  .20000000   20.000000
        -shifts               4.00000                                       #6
        yrs*365*24*3600/2522880= 75 shifts; we start at the dam, John added a
        year for the diffence in length for the first water
        -time step            6311520.0                                     #This
        is 29.2 days in seconds and essentially indicates hydraulic
        conductivity
  -punch cells   10 40 70 85 110 142 203 260
        -punch frequency   1
        -flow direction       forward
        -boundary conditions  flux  flux
        -correct disp         true
        -dispersivity           260*20.000000
        -diffusion_coef       0.0e-0                                        #No
        diffusion
        -tempr  1.0                                                         #No
        heat retardation
END
#1995 through 1997      Plateau 2
MIX
1000    .262052
2000    .737948
SAVE SOLUTION 0                                                             #Over-
write Solution 0

TRANSPORT
 -shifts        11.0000

END
#1997 through 2000      Plateau 3

MIX
1000    .166453
2000    .833547
SAVE SOLUTION 0                                                             #Over-
write Solution 0.

TRANSPORT
 -shifts        14.0000

END

#2000 through 2010      Plateau 4

MIX
1000    .069069
2000    .930931
SAVE SOLUTION 0                                                             #Over-
write Solution 0.
```

```
TRANSPORT
 -shifts        29.0000

END

#2006 through 2010      Plateau 5

MIX
1000    .010855
2000    .989145
SAVE SOLUTION 0                                                        #Over-
write Solution 0.

TRANSPORT
 -shifts        10 #00

END


END
```

ATTACHMENT IV

Modifications to the Thermodynamic Database for Uranium and Radium

Modifications to the Thermodynamic Database for Uranium and Radium

by

John J. Mahoney
Mahoney Geochemical Consulting LLC

DATABASE

The thermodynamic database used for these calculations (summarized in Table 1) was a modified version of the WATEQ4F database provided with PHREEQC (Parkhurst and Appelo, 1999). Modifications were primarily based upon changes to the reactions in the SOLUTION_SPECIES[1] portion of the database for the uranyl (UO_2^{+2}) component. Additionally, reactions for radium were also added to the database; the solution reactions were originally taken from the MINTEQ.V4.dat database also provided with PHREEQC.

Uranium

For uranium the revised data were from two sources. Reactions in solution were updated using the OECD NEA 2003 compilation (Guillaumont et al., 2003). This document is an update of an earlier compilation also done under the auspices of the NEA (Grenthe et al., 1992). The reactions that were updated primarily involved uranyl complexation reactions involving hydroxide and carbonate. Table 1 lists the NEA selected values along with the values in several of the unmodified databases included in the PHREEQC program package. The table also lists the values used in the revised database, called WATEQ_NEA.dat in Table 1.

In addition to the NEA update reactions, three ternary uranyl complexes were also added to database. These complexes included $CaUO_2(CO_3)_3^{-2}$, $Ca_2UO_2(CO_3)_3^{\circ}$, and $MgUO_2(CO_3)_3^{-2}$. The constants for these three reactions were reported in the literature after the 2003 NEA compilation was released. The values for these three complexation constants were taken from Dong and Brooks, (2006, 2008). The inclusion of these complexes will tend to increase

---

[1] The term SOLUTION_SPECIES is the keyword used in PHREEQC to define these reactions.

solubility concentrations estimates for uranyl and decrease adsorption of uranyl onto HFO in geochemical models (Mahoney et al., 2009b). Inclusion of the complexes improves model estimates by providing a more realistic set of complexation reactions in solution. Their presence will also tend to increase the model determined concentration of uranium in solution, which produces a more conservative model estimate. As this study was primarily aimed at adsorption reactions onto hydrous ferric oxide (HFO), no attempt was made to update uranyl bearing mineral phases in the database.

In addition to modifications to the SOLUTION_SPECIES portion of the database, the reactions that defined the surface complexation of uranyl onto hydrous ferric oxide (HFO) were updated based upon the recently published results of Mahoney et al. (2009a). This set of four reactions replaced the estimated values for the two reactions that were originally presented in Dzombak and Morel, (1990). The following surface complexation reactions were used to describe uranium (as uranyl) adsorption onto hydrous ferric oxide:

$$Hfo\_sOH + UO_2^{+2} = Hfo\_sOUO_2^{+} + H^{+} \qquad Log\,K_1^{int} = 3.736$$

$$Hfo\_wOH + UO_2^{+2} = Hfo\_wOUO_2^{+} + H^{+} \qquad Log\,K_2^{int} = 2.534$$

$$Hfo\_wOH + UO_2^{+2} + CO_3^{-2} = Hfo\_wOUO_2CO_3^{-} + H^{+} \qquad Log\,K_3^{int} = 9.034$$

$$Hfo\_wOH + UO_2^{+2} + 2CO_3^{-2} = Hfo\_wOUO_2(CO_3)_2^{-3} + H^{+} \qquad Log\,K_4^{int} = 15.28$$

These revised set of reactions correct the values reported by Dzombak and Morel for K_1^{int} and K_2^{int}, which were not based upon comparison to laboratory derived data. Rather Dzombak and Morel used a correlation between the log K for the first metal hydroxide complex and the log K_1^{int} and K_2^{int} values. When compared to experimental measurements the Dzombak and Morel estimated values for log K_1^{int} and K_2^{int} tended to significantly overestimate the amount of uranyl adsorption at low pH conditions and tended to underestimate uranium adsorption at high pH conditions particularly when carbonate was also present in solution. The newer values, published in Mahoney et al. (2009a), were based upon model based fits to laboratory measurements. Moreover, the revised data set included two surface complexation constants for uranyl carbonate complexes (the K_3^{int} and K_4^{int} reactions). Complexation constants for any type of uranyl carbonate surface complex were not included in the original Dzombak and Morel (1990) compilation that eventually became the basis for the surface complexation portion of the database included in the PHREEQC package. The existence of uranyl carbonate surface complexes has long been known, although various groups define them differently. The

Dzombak and Morel compilation was never meant to be a definitive treatise on surface complexation reactions involving uranium, and so this shortcoming can be excused. However, any detailed study involved with uranium adsorption must consider the reactions in some form or other. The revised database does consider these reactions.

In addition to the uranyl adsorption reactions, two additional surface complexation reactions were added to the database. These reactions are defined below:

$$Hfo\_wOH + CO_3^{-2} + H^+ = Hfo\_wOCO_2^- + H2O \qquad Log\ K^{int} = 12.78$$
$$Hfo\_wOH + CO_3^{-2} + 2H^+ = Hfo\_wOCO_2H + H2O \qquad Log\ K^{int} = 20.37$$

These final two reactions were defined by Appelo et al. (2002), and will influence sorption at higher partial pressures of $CO_2(g)$. Specifically, these two additional reactions will tend to occupy sites on the surface that could complex with uranium. This will produce a concomitant increase in uranium concentrations in the pore waters (Mahoney et al., 2009b).

Radium

Speciation reaction constants for radium were also added to this database. Values were obtained from Langmuir and Riese (1985). The following reactions were added to the database.

Species	Reaction	Log K
$RaOH^+$	$Ra^{+2} + H_2O = RaOH^+ + H^+$	-13.5
$RaSO_4$	$Ra^{+2} + SO_4^{-2} = RaSO_4$	2.76
$RaCO_3$	$Ra^{+2} + CO_3^{-2} = RaCO_3$	2.5
$RaCl^+$	$Ra^{+2} + Cl^- = RaCl^+$	-0.1
$RaCl_2$	$Ra^{+2} + 2Cl^- = RaCl_2$	-0.05

Surface complexation reactions onto HFO for radium (as Ra^{+2}) generally use the same values as Ba^{+2}. However, for this database values were recalculated and slight differences were noted. According to the model proposed by Dzombak and Morel, divalent cations form outer sphere complexes with the strong surface sites (designated as Hfo_sOH) and inner sphere complexes with the weak sites (Hfo_wOH). Using only Ca, Ba and Sr, the correlation between log K_{MOH} the strong site surface complexes was

$$\log K_1^{int} = -0.6592 * \log K_{MOH} + 5.6719$$

a log K_1^{int} of 5.3424 was noted for radium[2]. The log K_1^{int} value for Ba^{+2} was 5.46.

The value for the log K_2^{int} Reaction ($Hfo\_wOH + Ra^{+2} = Hfo\_wORa^{+} + H^{+}$) was based upon the overall regression equation defined in Dzombak and Morel. The calculated value for log K_2^{int} was -7.333. The log K_2^{int} value for Ba^{+2} was -7.2.

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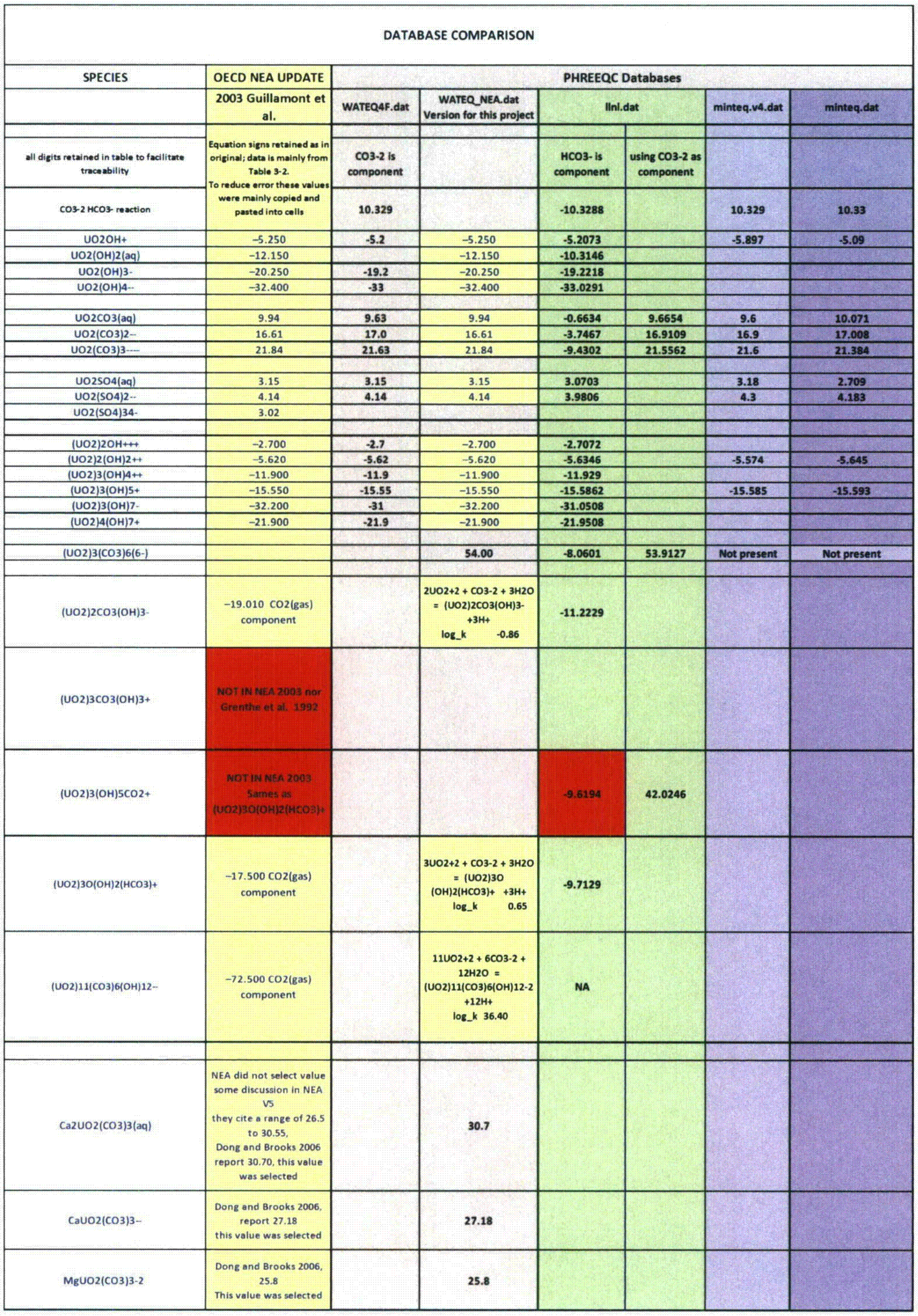
[2] Langmuir and Riese (1985) write the radium hydrolysis reaction as $Ra^{+2} + H_2O = RaOH^{+} + H^{+}$, however Dzombak and Morel removed water from their equations and used equations of the form $Ra^{+2} + OH^{-} = RaOH^{+}$, for their correlations. Therefore, for radium the log K_{MOH} becomes 0.5, and the corresponding log K_{MOH} for barium is 0.53.

Table 1. Continued. Surface complexation reactions for uranium adsorption onto HFO and solubility product constants for selected phases.

DATABASE COMPARISON							
SPECIES	OECD NEA UPDATE	PHREEQC Databases					
	2003 Guillamont et al.	WATEQ4F.dat	WATEQ_NEA.dat Version for this project	llnl.dat		minteq.v4.dat	minteq.dat
SURFACE COMPLEXES							
Hfo_sOUO2+	NEA does not discuss	5.2	3.736	We are using the Mahoney, Cadle and Jakubowski (2009) constants plus two reactions for carbonate surface complexation [Hfo_wOCO2-, and Hfo_wOCO2H]			
Hfo_wOUO2+		2.8	2.534				
Hfo_wOUO2CO3-			9.034				
Hfo_wOUO2(CO3)2-3			15.28				
PHASES (limited selection listed)							
UO2SO4	Free Energy provided no value for K given			1.9681			
UO2SO4:2.5H2O	1.589			-1.4912			
UO2SO4:3.5H2O	1.585			-1.4805			
UO2SO4:3H2O *	–0.831* 0.754 (recalculated)			-1.4028			
UO2SO4:H2O				-6.0233			
Schoepite (UO3:2H2O)	UO3 · 2H2O(cr) -> UO2 + 2 + 2 OH– + H2O(l) , 10 ,0 log s K = – (23.19 ± 0.43). Or 4.81 in proton form	5.404	5.404	4.8333		5.994	5.404

Table 1. Comparison of uranium solution complexation reactions in various databases provided with PHREEQC and selected values included in the updated database.



DATABASE COMPARISON							
SPECIES	OECD NEA UPDATE	PHREEQC Databases					
	2003 Guillamont et al.	WATEQ4F.dat	WATEQ_NEA.dat Version for this project	llnl.dat		minteq.v4.dat	minteq.dat
all digits retained in table to facilitate traceability	Equation signs retained as in original; data is mainly from Table 3-2. To reduce error these values were mainly copied and pasted into cells	CO3-2 is component		HCO3- is component	using CO3-2 as component		
CO3-2 HCO3- reaction		10.329		-10.3288		10.329	10.33
UO2OH+	–5.250	-5.2	–5.250	-5.2073		-5.897	-5.09
UO2(OH)2(aq)	–12.150		–12.150	-10.3146			
UO2(OH)3-	–20.250	-19.2	–20.250	-19.2218			
UO2(OH)4--	–32.400	-33	–32.400	-33.0291			
UO2CO3(aq)	9.94	9.63	9.94	-0.6634	9.6654	9.6	10.071
UO2(CO3)2--	16.61	17.0	16.61	-3.7467	16.9109	16.9	17.008
UO2(CO3)3----	21.84	21.63	21.84	-9.4302	21.5562	21.6	21.384
UO2SO4(aq)	3.15	3.15	3.15	3.0703		3.18	2.709
UO2(SO4)2--	4.14	4.14	4.14	3.9806		4.3	4.183
UO2(SO4)34-	3.02						
(UO2)2OH+++	–2.700	-2.7	–2.700	-2.7072			
(UO2)2(OH)2++	–5.620	-5.62	–5.620	-5.6346		-5.574	-5.645
(UO2)3(OH)4++	–11.900	-11.9	–11.900	-11.929			
(UO2)3(OH)5+	–15.550	-15.55	–15.550	-15.5862		-15.585	-15.593
(UO2)3(OH)7-	–32.200	-31	–32.200	-31.0508			
(UO2)4(OH)7+	–21.900	-21.9	–21.900	-21.9508			
(UO2)3(CO3)6(6-)			54.00	-8.0601	53.9127	Not present	Not present
(UO2)2CO3(OH)3-	–19.010 CO2(gas) component		2UO2+2 + CO3-2 + 3H2O = (UO2)2CO3(OH)3- +3H+ log_k -0.86	-11.2229			
(UO2)3CO3(OH)3+	NOT IN NEA 2003 nor Grenthe et al. 1992						
(UO2)3(OH)5CO2+	NOT IN NEA 2003 Sames as (UO2)3O(OH)2(HCO3)+			-9.6194	42.0246		
(UO2)3O(OH)2(HCO3)+	–17.500 CO2(gas) component		3UO2+2 + CO3-2 + 3H2O = (UO2)3O (OH)2(HCO3)+ +3H+ log_k 0.65	-9.7129			
(UO2)11(CO3)6(OH)12--	–72.500 CO2(gas) component		11UO2+2 + 6CO3-2 + 12H2O = (UO2)11(CO3)6(OH)12-2 +12H+ log_k 36.40	NA			
Ca2UO2(CO3)3(aq)	NEA did not select value some discussion in NEA V5 they cite a range of 26.5 to 30.55, Dong and Brooks 2006 report 30.70, this value was selected		30.7				
CaUO2(CO3)3--	Dong and Brooks 2006, report 27.18 this value was selected		27.18				
MgUO2(CO3)3-2	Dong and Brooks 2006, 25.8 This value was selected		25.8				

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