

GROUNDWATER QUALITY BENEATH A BURIED OIL AND GAS RESERVE PIT IN WESTERN NORTH DAKOTA

(1980 – 2014)

by

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Introduction

In the 1980s, the North Dakota Geological Survey led the Rocky Mountain Region and the Northern Plains in the study of the impacts of buried drilling fluid on shallow groundwater (Murphy and Kehew, 1984; Murphy, 1988). As a result of this work, it was recognized that buried drilling mud could adversely impact the environment even when buried above the water table in a semi-arid environment. The 1984 report proved that drilling mud leachate was being generated at these sites and this leachate had the potential to negatively impact shallow groundwater in vulnerable settings. Both the 1984 and the 1988 reports recommended drilling mud not be disposed of in floodplains and other areas with high water tables and permeable sediments. That recommendation was repeated at a number of presentations throughout western North Dakota as well as nationally regarding the safe disposal of drilling mud. It was pointed out that it did not make sense to place a synthetic liner in a reserve pit only to rip out one side of the pit and push the drilling mud into deeper, unlined trenches upon reclamation. In environmentally sensitive settings, this traded a potential surface problem for a potential subsurface problem.

In response to the concerns generated by the initial reserve pit study, industry attempted to reduce the potential for leachate by, among other things, solidifying drilling mud in the pit and discontinuing the use of chromates in drilling fluid additives. Rules and policies regarding reserve pits were also amended. The practice of trenching was discontinued and drilling mud from wells located in environmentally sensitive settings could no longer be buried on site and had to be hauled to a special waste disposal site. More recently, Bakken wells must be drilled using a semi-closed system and the stabilized cuttings disposed of in an engineered waste disposal site within that spacing unit (approved by the North Dakota Oil and Gas Division) or a more remotely located special waste disposal site approved by the North Dakota Department of Health. As noted in the 1988 report, these disposal sites have to be carefully chosen to prevent contamination due to the concentration of waste.

The Apache Corporation drilled the Federal 1-5 in 1979 (figs. 1-7). The well is located on the floodplain of the Little Missouri River in northern Billings County, less than 1,000 feet (305 m) from the boundary of the

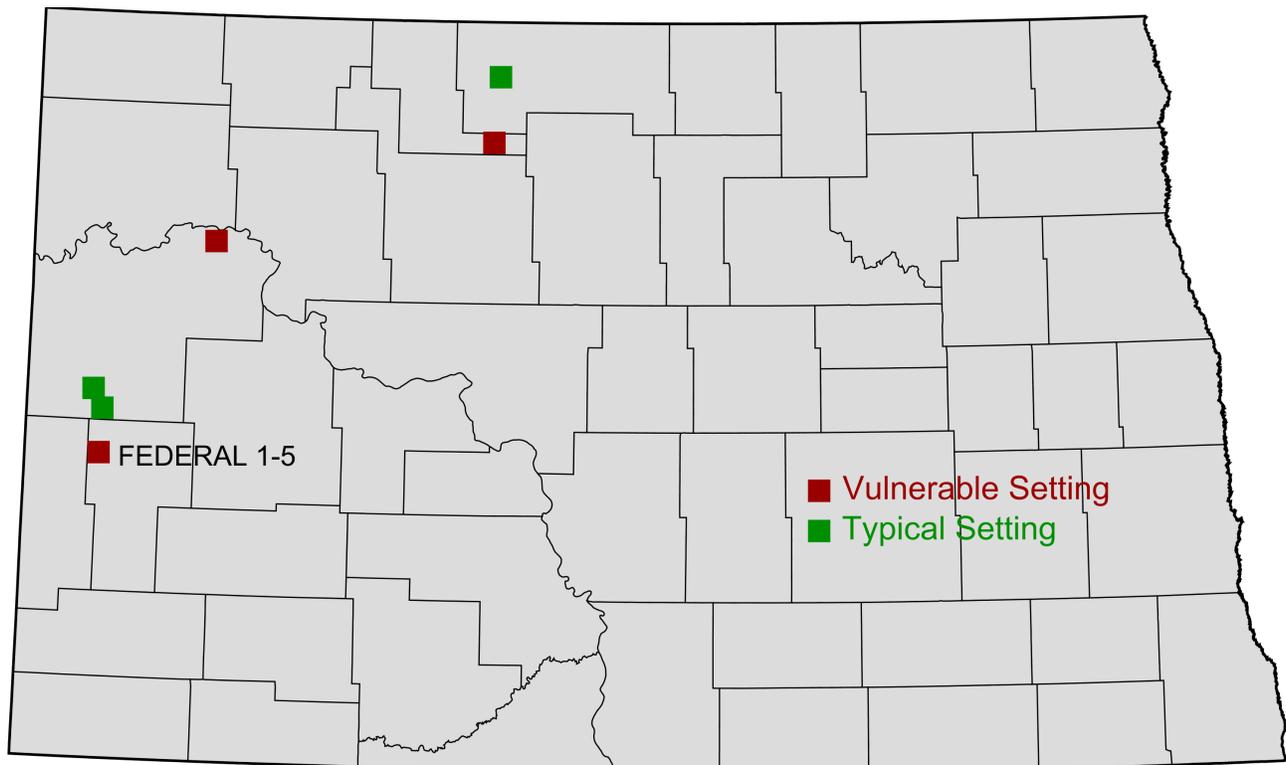


Figure 1. The locations of the six North Dakota study sites.



Figure 2. An aerial photograph of the area surrounding the Apache Federal 1-5 study site. The GoogleEarth Pro photo covers an area of 6.5 x 3.4 miles (10.5 x 5.5 km). The Apache drilling pad is outlined in red.



Figure 3. Looking east-southeast across the reclaimed well pad of the Apache Federal 1-5 in September 2014. The edge of the pad is about 75 feet (23 m) from where the photograph was taken and is marked by the change in slope and the increase in sagebrush.

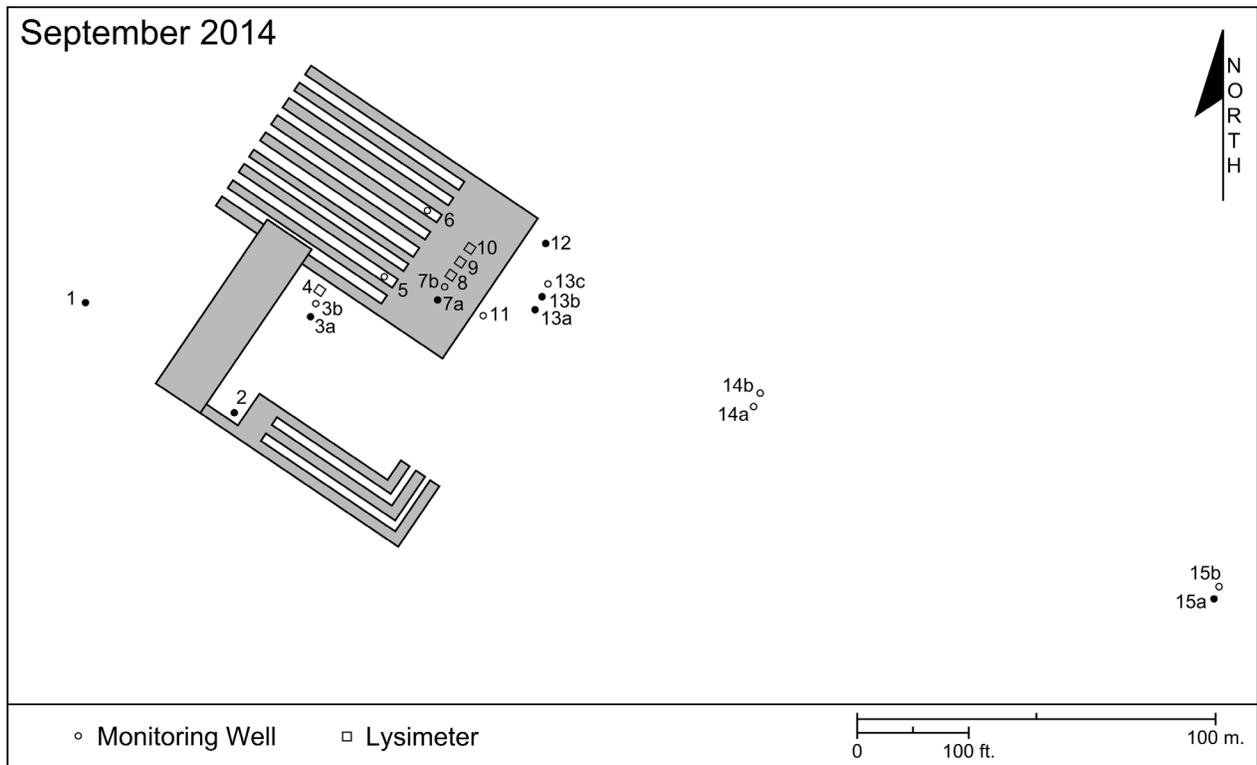


Figure 4. Monitoring well and lysimeter locations at the Apache Federal 1-5 site in Billings County, ND. The monitoring wells sampled in 2014 are shown with a black dot. No lysimeters were sampled in 2014.



Figure 5 Barbed wire fencing protects monitoring wells 7a and 7b and lysimeters 8-10. The photograph was taken in 2014 looking north-northeast. The trees in the background mark the southern edge of the Elkhorn Ranch Unit of the Theodore Roosevelt National Park.



Figure 6 Photographs of the 1981 trenching of the Apache Federal 1-5 re-entry reserve pit.





Figure 7. Monitoring wells in close proximity to buried drilling fluid. Above: Survey summer employees installing monitoring well no. 2 in 1981. Previously installed monitoring wells 3a and 3b are visible in the background. Below: Heavy equipment levels the reserve pit pushing drilling mud into the trenches. Wells 3a and 3b in the foreground.



Elkhorn Ranch Unit of the Theodore Roosevelt National Park. This location was one of four sites chosen in 1980 to study the long-term impact of buried oil and gas drilling mud on shallow groundwater in western North Dakota (Murphy and Kehew, 1984; Murphy, 2014). The Apache and one of the other study sites were chosen because they were located in environmentally sensitive settings i.e., near-surface sands and gravels and a high water table (water table less than 50 feet (15.2 m) below the surface). The environmentally sensitive sites in western North Dakota are primarily located in floodplains of the Missouri, Little Missouri, Little Muddy, Knife, Green, Heart, and Cannonball Rivers and their associated tributaries. The two other study sites were chosen because they were in typical western North Dakota settings i.e., Paleocene bedrock (alternating layers of mudstone, claystone, sandstone, siltstone, and lignite) with a low water table (water table more than 75 feet (22.9 m) below the surface).

Six monitoring wells were installed in the summer of 1980 at the reclaimed Apache well site. The following spring the Apache Corporation deepened the well destroying three of the monitoring wells. In the summer of 1981, 11 additional monitoring wells and four lysimeters (soil water samplers) were installed at the site. As a result of the 1981 re-entry, there are two reserve pits on location (Figs. 3-5). The 10-foot-deep (3.1 m) reserve pits were excavated into clayey silt and lined with a plastic liner. Upon reclamation, the pits were trenched and a significant portion of the drilling mud was buried in the unlined trenches (Fig. 6). The trenches were excavated to a depth of 21 feet (6.4 m). The majority of monitoring wells at this site were placed within a 50-foot (15.2 m)-radius of the buried drilling mud. They were constructed in close proximity to the buried waste because some in industry argued that little, if any, of the chemical constituents would leach from the buried waste due to the high clay content of the drilling mud. The close proximity of the monitoring wells to the waste gave us a better chance of detecting any leachate that was being generated (Fig. 7).



Figure 8. Geological Survey geologists Mark McDonald (left) and Tim Nesheim (right) collect water from monitoring well number 2. The cottonwood trees were not there when water samples were last collected in 1986.

After a 28 year absence, we returned to the site in the fall of 2014 to take water samples prior to monitoring well reclamation (Fig. 8). We were able to find all but two monitoring wells (14a and 14b) even though prairie grasses and sage had overtaken much of the location. Unfortunately well 14a, located 240 feet (73.2 m) down gradient from buried drilling mud, is essential to determining the maximum extent of leachate migration in the shallow groundwater system at this site. Six sets of water samples were taken from the Apache Federal 1-5 site over a span of 34 years (September 3, 1980; January 1, 1981; June 29, 1981; October 12, 1981; April 24, 1986; and September 17, 2014). The results from the 1980 and 1981 sampling rounds were reported in Murphy and Kehew (1984) and the 1986 samples were reported in Murphy (1988).

Geology of the Apache Federal 1-5

The Apache Federal 1-5 is underlain by 40 feet (12.2 m) of alluvium (Fig. 9). At a depth of 11-14 feet (3.4 – 4.3 m), the alluvium transitions from clayey silt to silty clay. This lens of silty clay is likely a better attenuator of leachate than is the overlying clayey silt layer. The water table is at a depth of approximately 35 feet (10.8 m) beneath the well pad and approximates the contact between the silty clay and underlying layer of sand and gravel. The upper half of this ten-foot-thick sand and gravel layer is sand, the lower half is gravel. This sand lens thickens to the east. Because this saturated sand and gravel layer was thought to be the most likely avenue of leachate migration, the majority of monitoring wells were screened through this interval (monitoring wells 1, 2, 3a, 5, 6, 7a, 11, 12, 13a, 13b, and 14a). The alluvial sediments are underlain by claystone and sandstone of the Bullion Creek Formation (Paleocene). Monitoring wells screened within the Bullion Creek Formation include 3b, 7b, 13c, 14b, 15a, and 15b (Fig. 9).

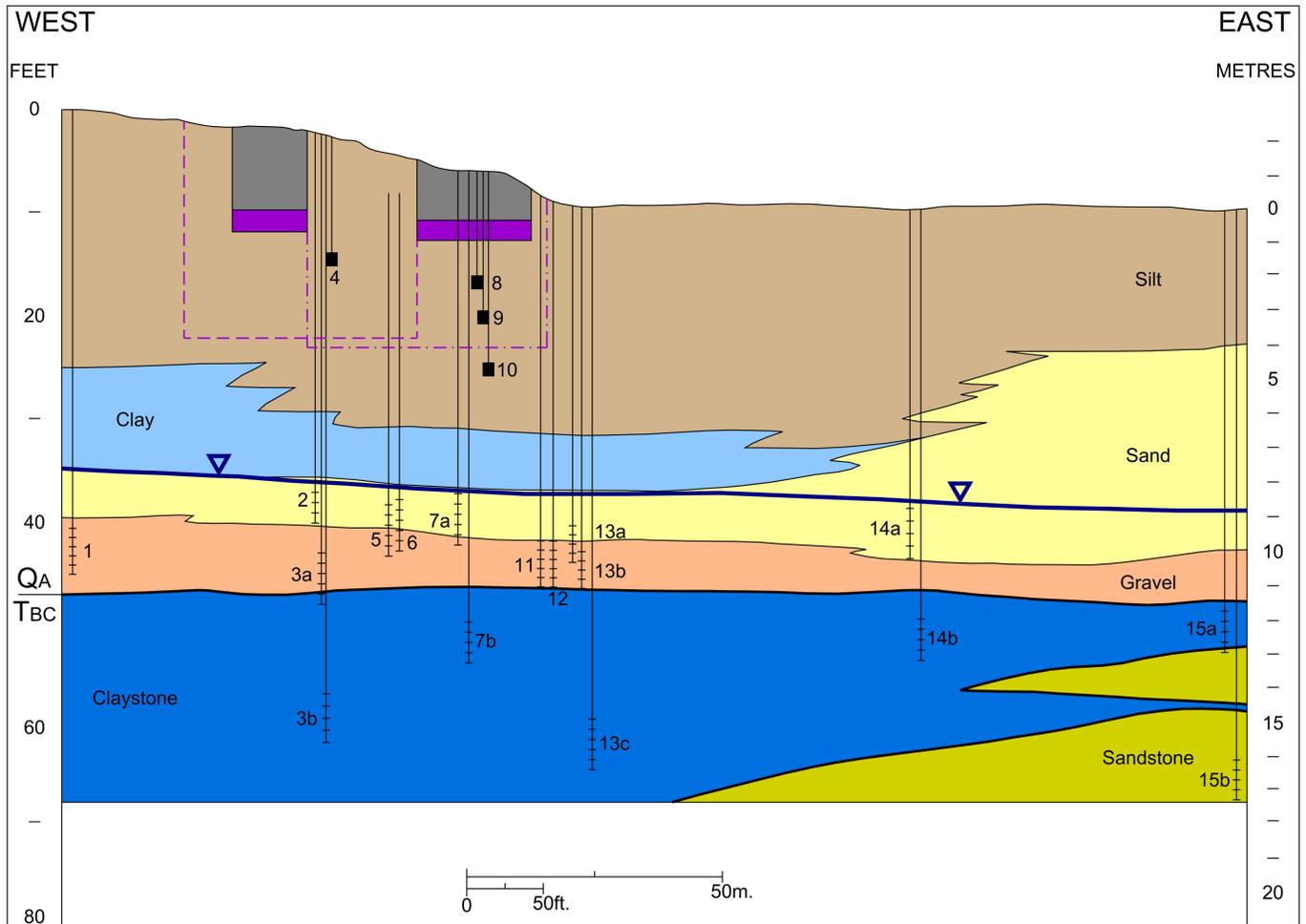


Figure 9. Geologic cross section of the Apache Federal 1-5 study site. Monitoring wells were placed in two primary horizons, 1) a sand and gravel unit at the base of the Quaternary sediments and 2) in the underlying Bullion Creek Formation (Paleocene).

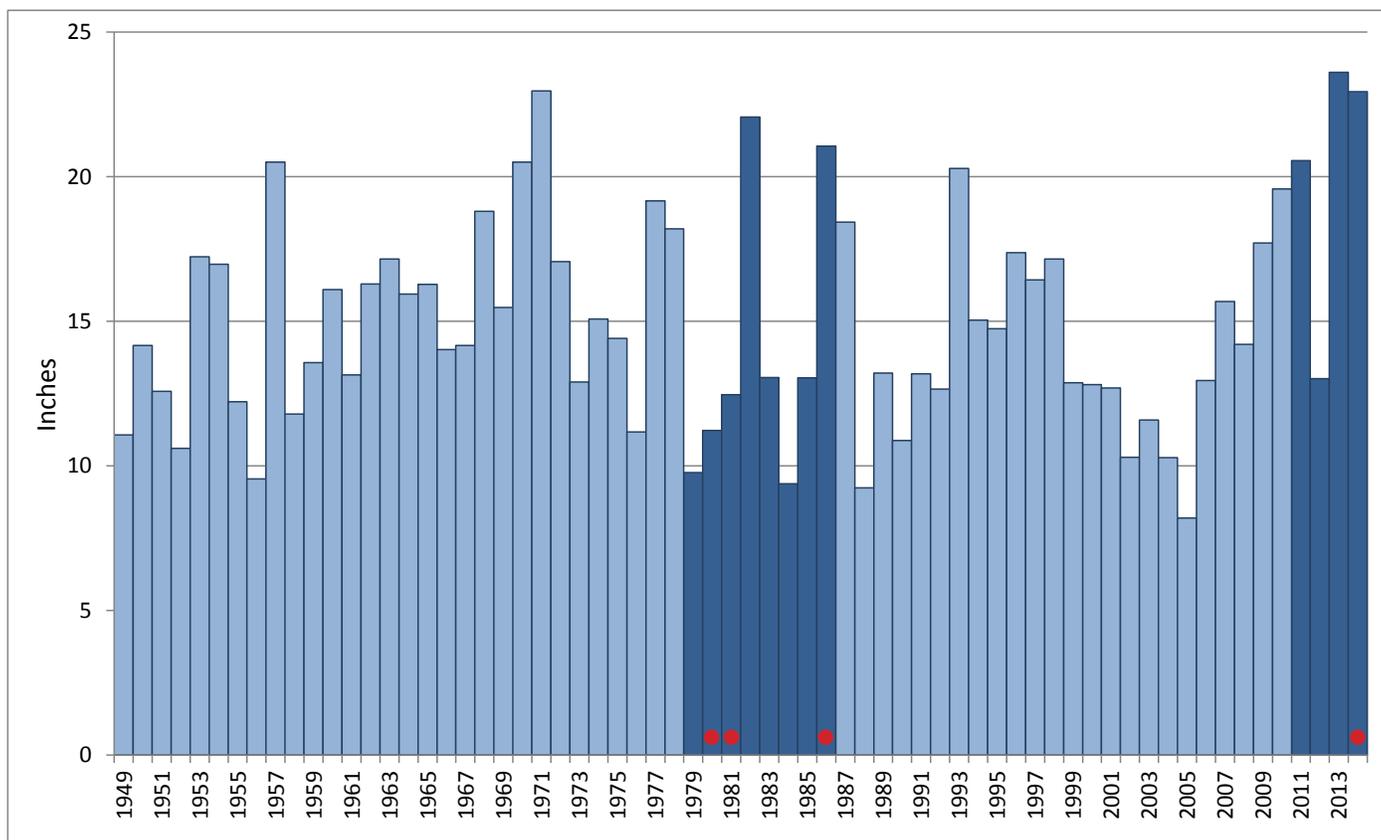


Figure 10. Annual precipitation for the Medora monitoring station (325813) from 1949 to 2014. Red dots denote sampling years.

Precipitation

The Medora weather station (325813) is approximately 23 miles (37 km) south-southeast of the Apache Federal 1-5 site. The average precipitation for the Medora station from 1949 through 2014 is 14.98 inches (38.05 cm). Based on the Medora station, water samples obtained in the 1980s from the Apache Federal 1-5 site were collected under much drier condition than those collected in 2014 (Fig. 10). Annual precipitation for the seven years between 1979 and 1985 averaged 13.0 inches (33.02 cm). Two of those years, 1979 and 1984, received less than 10 inches (25 cm) of annual precipitation. In contrast, 2010 to 2014 averaged 19.9 inches (50.5 cm) of precipitation and only one year (2012 at 13.2 inches or 33.5 cm) fell below the 66 year station average.

The majority of precipitation in western North Dakota generally comes in the spring and early summer with the wettest months typically being June, July, and May, in that order. Thunderstorms can produce significantly different rainfall totals over a relatively small area. Therefore, it is best to evaluate data from a couple of weather stations when one is not located in close proximity to the study site. The Sidney, Montana weather station is located 38 miles (61 km) northwest of the Apache Federal 1-5 site. The precipitation patterns for both the Medora and Sidney reporting stations indicate 1979-1986 primarily reflect a dry cycle and 2010-2014 a wet cycle.

Groundwater Chemistry

The North Dakota Department of Health and Consolidated Laboratories performed the analyses on all six sets of water samples for this project (1980-2014). The major ion and trace metal analyses in the 1980s included total dissolved solids (TDS), iron, manganese, calcium, magnesium, total hardness, potassium, sodium, chloride, sulfate, total alkalinity, bicarbonate, carbonate, fluoride, percent sodium, arsenic, barium, cadmium, chromium, lead, selenium, zinc, and nitrate. The 2014 major ion and trace metal analysis included all of the earlier parameters and added ammonia as nitrogen, nitrogen (total), nitrogen (total-Kjeldahl), hydroxide, silicon dioxide, phosphorus, bromide, boron, aluminum, beryllium, nickel, silver, antimony, and thallium (Appendix A).



Figure 11. Filtering was often done off the back of a pickup truck. Photograph taken October 1981.

All of the water samples collected in the 1980s were filtered through 0.45 micron filters (Fig. 11). The water to be analyzed for major ions was placed in quart containers and that portion of the sample to be analyzed for trace metals was placed in pint containers and acidified with concentrated nitric acid before placing on ice and transporting to the ND Health Department Lab. In 2014, none of the samples were filtered, but the sample portion for trace metal and nitrate analysis were acidified and placed on ice. As a result, the 1980, 1981, and 1986 analyses reflect the dissolved metals concentrations of the groundwater samples, the 2014 analyses reflect the total metal concentrations.

A series of isoconcentration maps and graphs were generated for many of the parameters using the wells screened in the sand and gravel horizon (monitoring wells 1, 2, 3a, 5, 6, 7A, 11, 12, 13a, 13b, and 14a). Isoconcentration maps of dissolved and total TDS, chloride, sodium, potassium, arsenic, barium, chromium, and lead were generated from water samples collected in 1981, 1986, and 2014 (Figs. 12 – 19). The values are plotted on the maps for wells 1, 14a, and 15a. Wells 1, 15a, and 15b were established as the background wells and wells 14a and 14b to determine maximum leachate migration. Isoconcentration maps were generated from the 2014 results for total aluminum, cadmium, nickel, bromide, phosphorus, total nitrogen, calcium, magnesium, and manganese (Figs. 20 – 22).

From the beginning, one of the focal points of the Apache Federal 1-5 study has been the chloride ion. Chloride ion concentrations are very low in shallow groundwater in western North Dakota, typically less than 30 mg/l. In contrast, chloride levels are at or near-saturated concentrations in salt-based drilling muds. The drilling mud from the Apache Federal 1-5 re-entry contained 175,000 mg/l of chloride. The chloride ion is generally not attenuated or slowed to any appreciable degree as it moves through shallow groundwater in this area and therefore is a good indicator of maximum leachate migration relative to the other ions. In general, chloride levels decreased in groundwater over time (Fig. 13). Because the drilling mud was buried above the water table this is likely more a reflection of recharge than anything else.

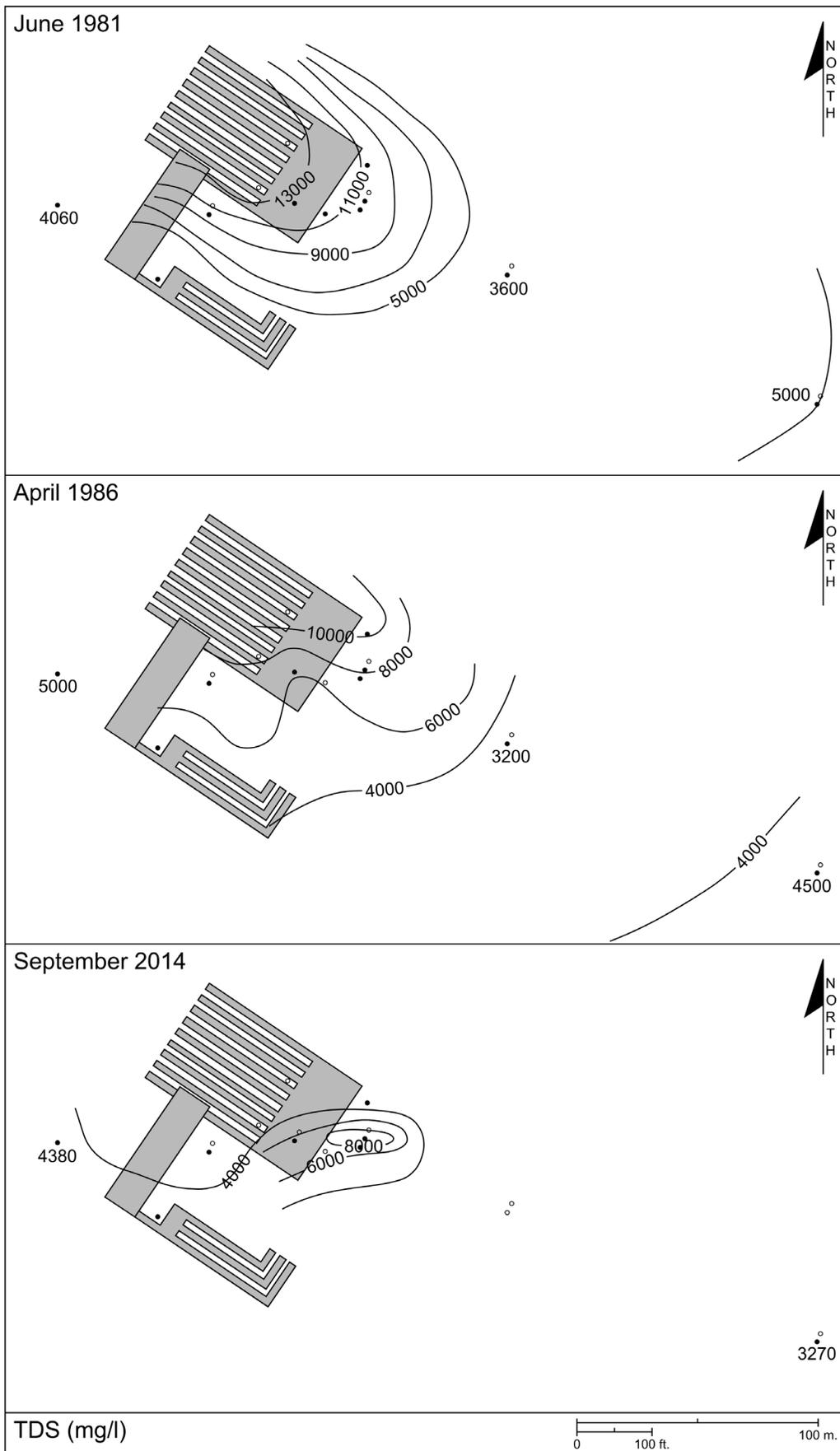


Figure 12. Total dissolved solids (TDS) isoconcentration maps from water samples collected June 1981; April 1986; and September 2014. Wells that were used to generate the maps are shown with a solid black dot.

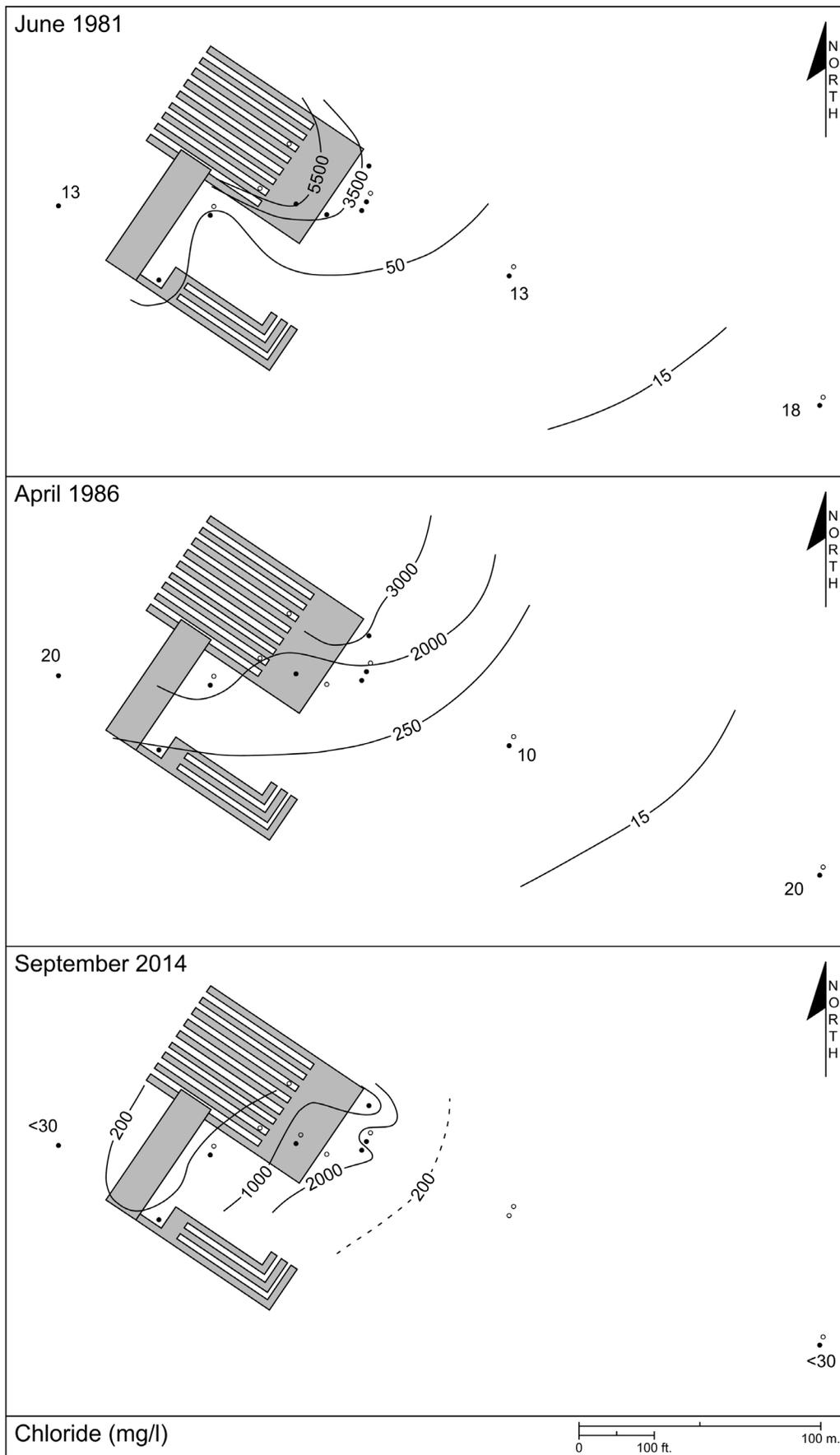


Figure 13. Chloride isoconcentration maps from water samples collected June 1981; April 1986; and September 2014.

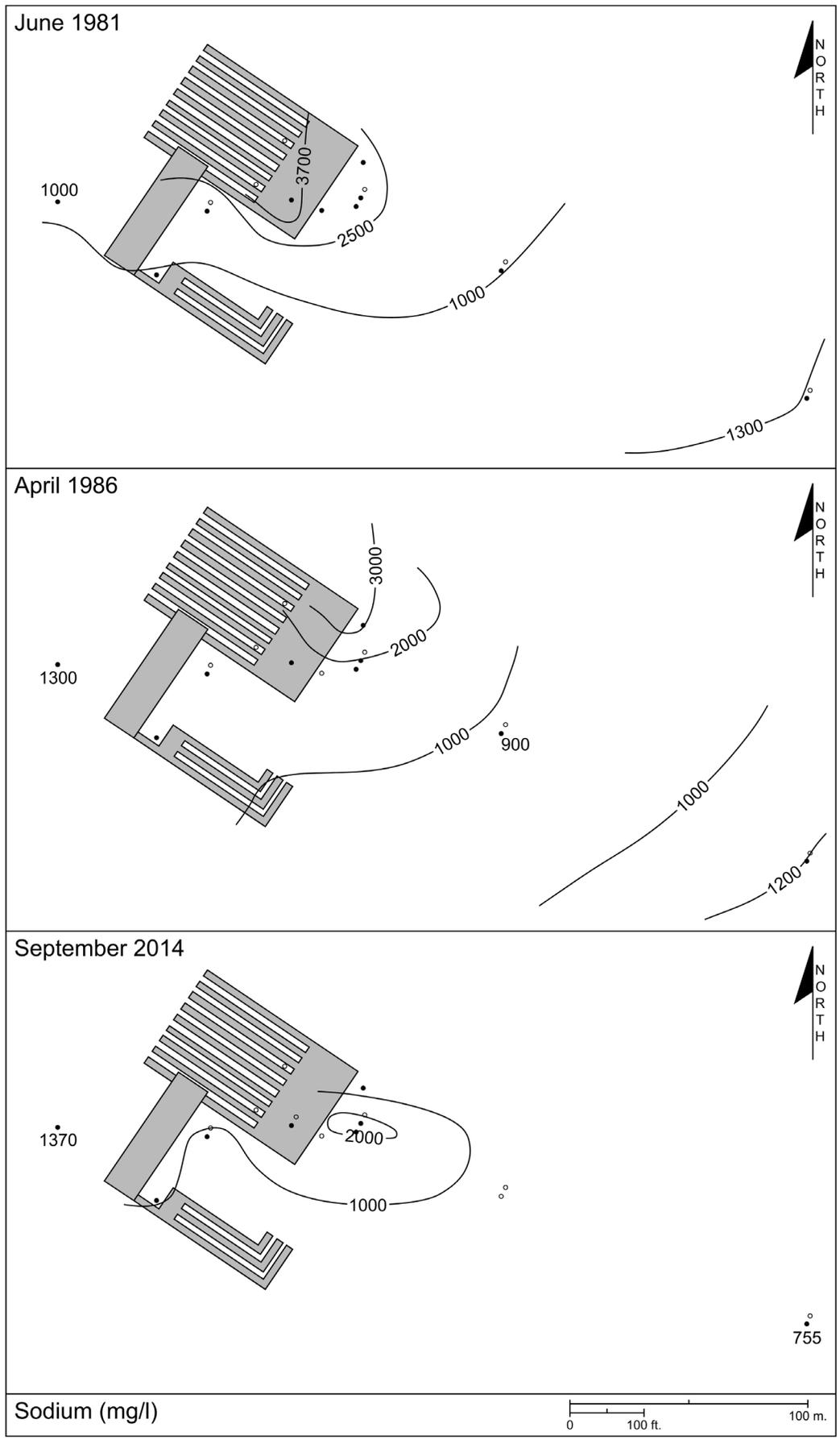


Figure 14. Sodium isoconcentration maps from water samples collected June 1981; April 1986; and September 2014.

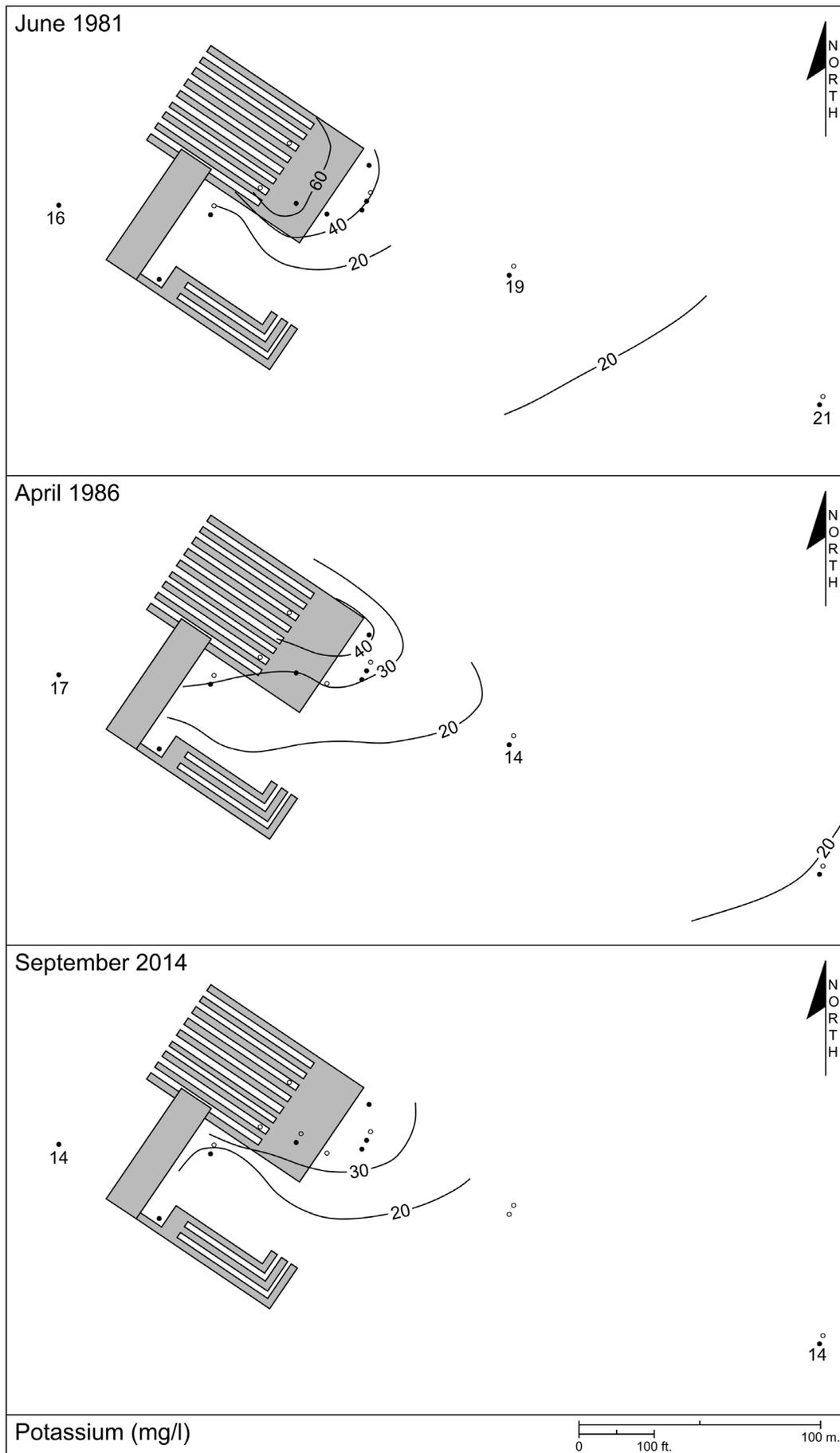


Figure 15. Potassium isoconcentration maps from water samples collected June 1981; April 1986; and September 2014.

Concentrations in Excess of the Maximum Contaminant Level

Dissolved arsenic exceeded the 10 ug/l maximum contaminant level (MCL) multiple times in monitoring wells 1, 2, 3a, 7a, 7b, 11, 12, 13b, 13c, 14a, and 15a as well as lysimeter 10. The average value of the dissolved arsenic samples above the MCL was 15.8 ug/l with a high of 43.4 ug/l (Fig. 16). The highest dissolved arsenic value (43.4 ug/l) came from a pore water sample collected from lysimeter 10 in October 1981. Although this high value in the unsaturated zone beneath the reserve pit points to an association with drilling fluid leachate, arsenic was not listed as a known constituent of drilling mud additives. At the time, representatives of the American Petroleum Institute speculated the source of arsenic was Wyoming bentonites in the bentonite additives. The source of arsenic in the background and downgradient wells (1, 14a, and 15a – Fig. 16) is not known. Total arsenic values exceeded the MCL in monitoring wells 1, 2, 3a, 7a, 7b, 12, 13a, and 13b. The average value of total arsenic above the MCL was 39.8 ug/l with a high of 118 ug/l. The highest value was a groundwater sample from monitoring well 13a, 40 feet (12.2 m) east of the edge of buried drilling mud (Fig. 16).

Barium was one metal that did not see a consistent increase in concentrations from the dissolved values in the 1980s to the total values in 2014. However, a 2014 water sample from monitoring well 12 contained 1,130 ug/l of total barium, more than half the 2,000 ug/l MCL (Fig. 17).

One of the primary impetuses for the original study was chromium. Area ranchers, in the late 1970s, were concerned that sodium chromate, a drilling fluid additive, might result in chromium leaching out of the drilling mud and contaminating surface water and groundwater. Drilling mud additives containing chromates were used at both the original Apache Federal 1-5 as well as the re-entry (Murphy and Kehew, 1984). The maximum contaminant level (MCL) for chromium (50 ug/l) was established for hexavalent chromium, the most toxic and mobile form of this metal. Dissolved chromium was not found in groundwater at the Federal 1-5 site above the 50 ug/l limit in the 1980s samples. However, in 2014, the total chromium values of four groundwater samples (C7a, C12, C13a, and C13b) exceeded the MCL with concentrations ranging from 82.6 -114 ug/l (Fig. 18).

Dissolved lead values exceeded the 15 ug/l MCL in eight monitoring wells (1, 3b, 7a, 7b, 11, 12, 13a, and 13b) and in lysimeter 10 (Fig. 19). The exceeded dissolved values in groundwater averaged 36 ug/l with a high of 92 ug/l in monitoring well 11. The pore water sample contained 188 ug/l of dissolved lead. There was an apparent problem with the 1986 lead analysis, all but two of the samples (monitoring well 1 at 0.1 ug/l and well 13a at 16.8 ug/l) were reported with zero concentrations. Total lead concentrations exceeded the MCL in monitoring wells 1, 2, 3a, 3b, 7a, 7b, 12, 13a, 13b, and 15b. The exceeded total lead values averaged 55 ug/l with a high of 192 ug/l occurring in well 13a.

The 5 ug/l MCL for cadmium was exceeded as dissolved cadmium in two monitoring wells (1 and 13b) and one lysimeter (10). Values for these three water samples ranged from 5.6 to 16.3 ug/l. The highest dissolved cadmium concentration was found in lysimeter 10, 15 feet (4.6 m) below the base of buried drill mud. A 2014 water sample from monitoring well 13a had a total cadmium concentration of 8.9 ug/l (Fig. 20). This was the only water sample collected in 2014 to exceed the MCL for cadmium.

The groundwater at the Apache site was never tested for organic pollutants because the monitoring wells were constructed of pvc and solvents and cements were used during well construction. The use of these materials could have resulted in false organic readings.

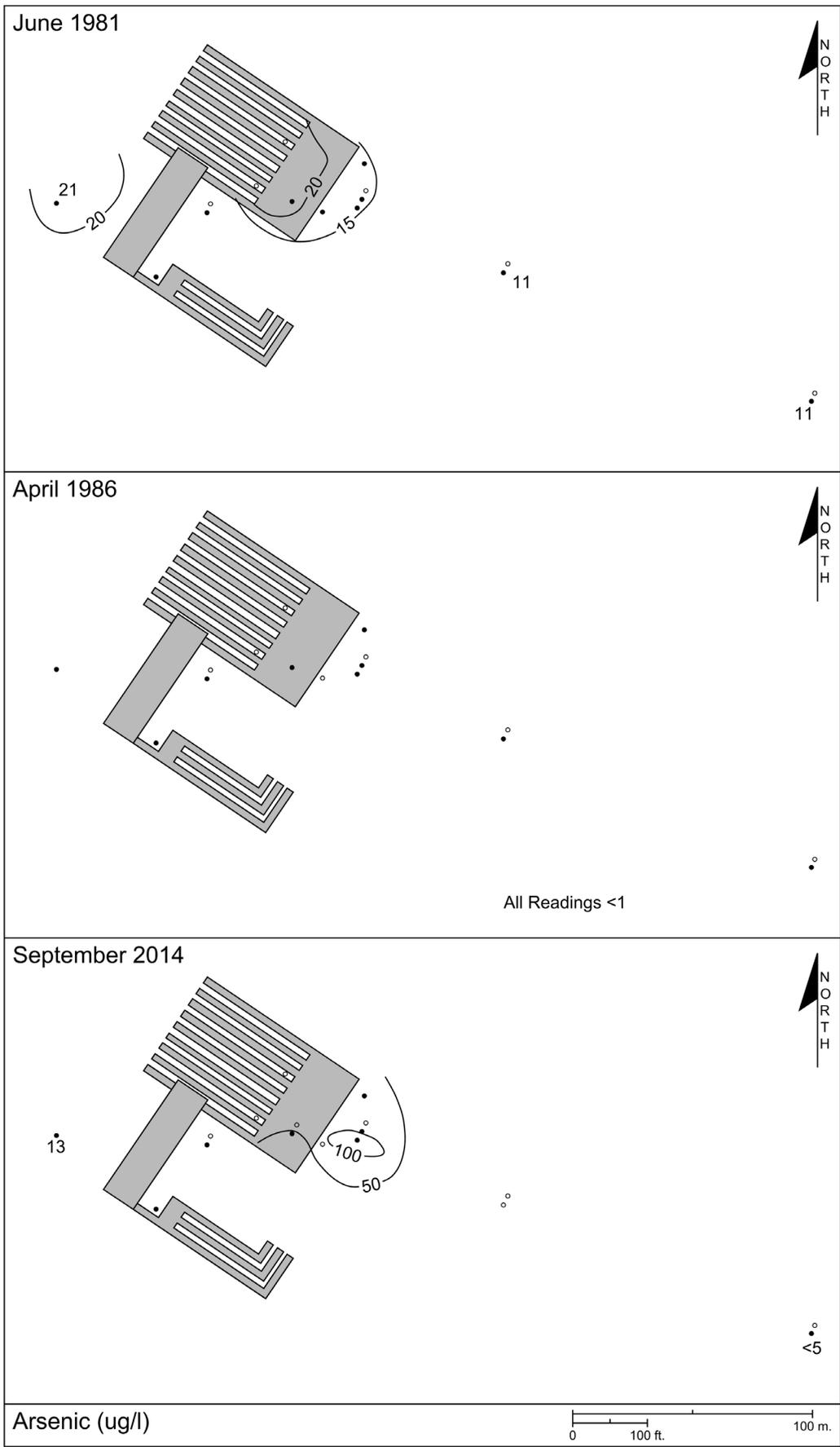


Figure 16. Isoconcentration maps for dissolved arsenic from water samples collected June 1981 and April 1986 and an isoconcentration map of total arsenic for water samples collected September 2014.

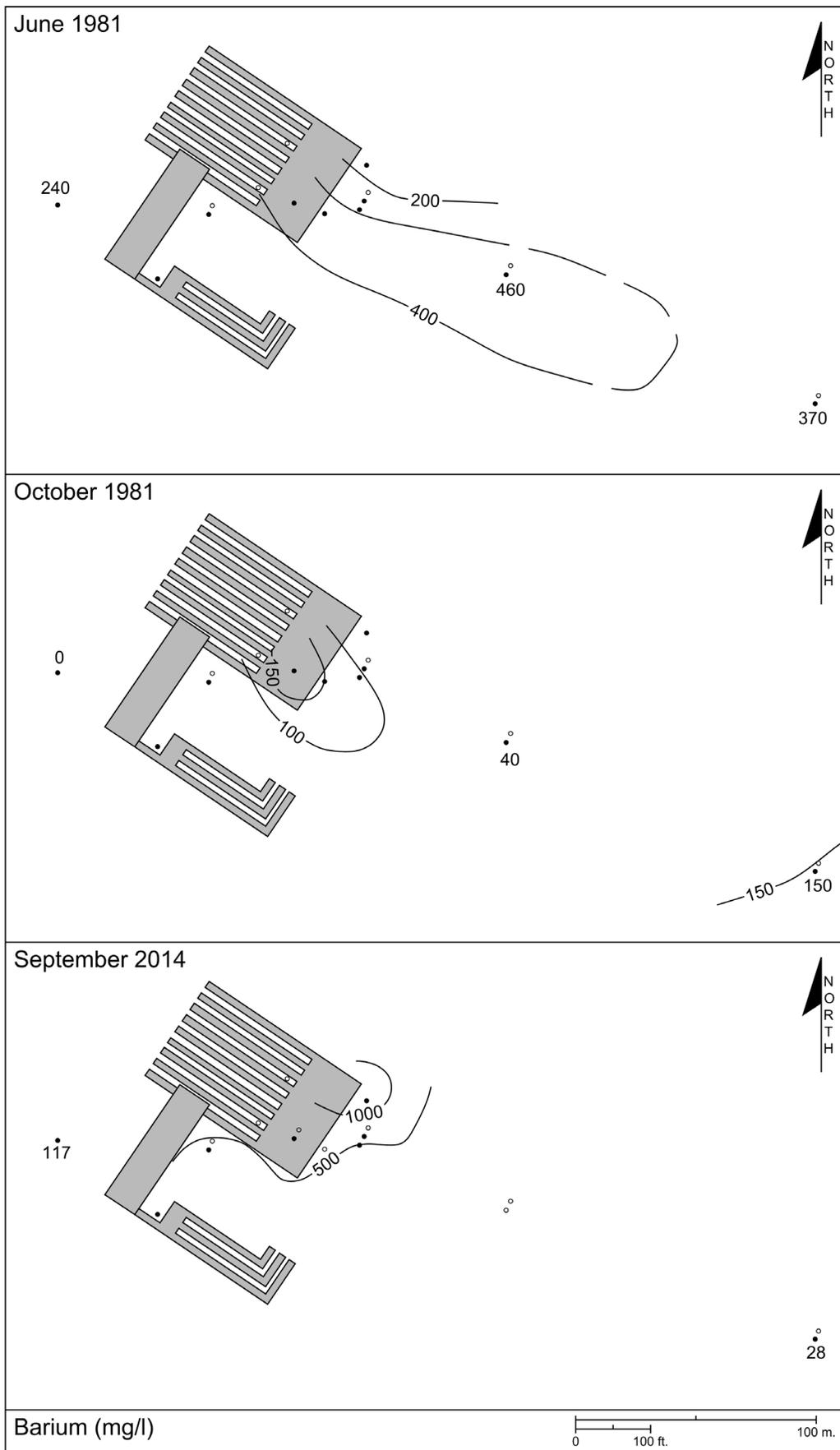


Figure 17. Isoconcentration maps for dissolved barium from water samples collected June 1981 and April 1986 and an isoconcentration map of total barium for water samples collected September 2014.

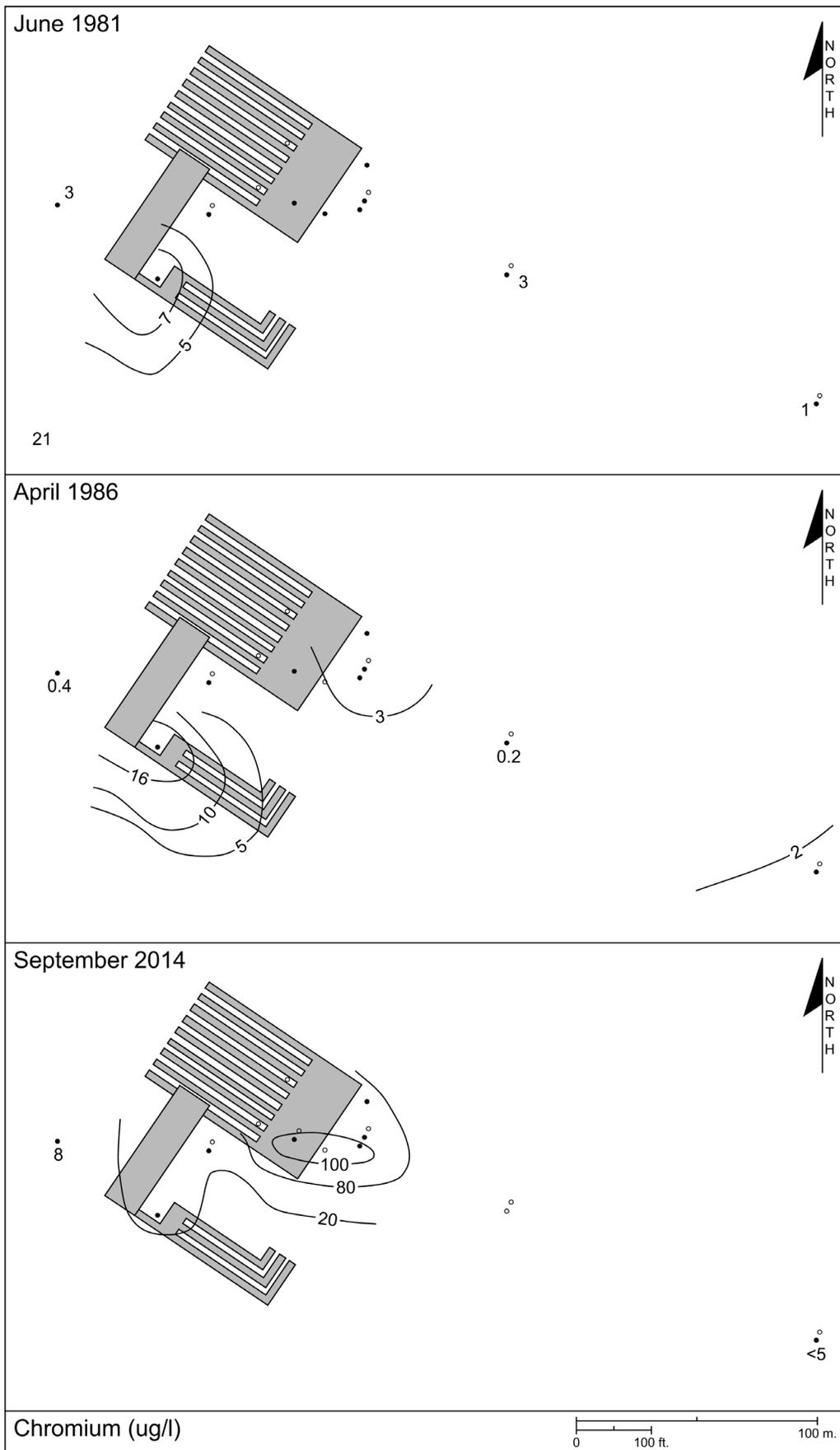


Figure 18. Isoconcentration maps for dissolved chromium from water samples collected June 1981 and April 1986 and an isoconcentration map of total chromium for water samples collected September 2014.

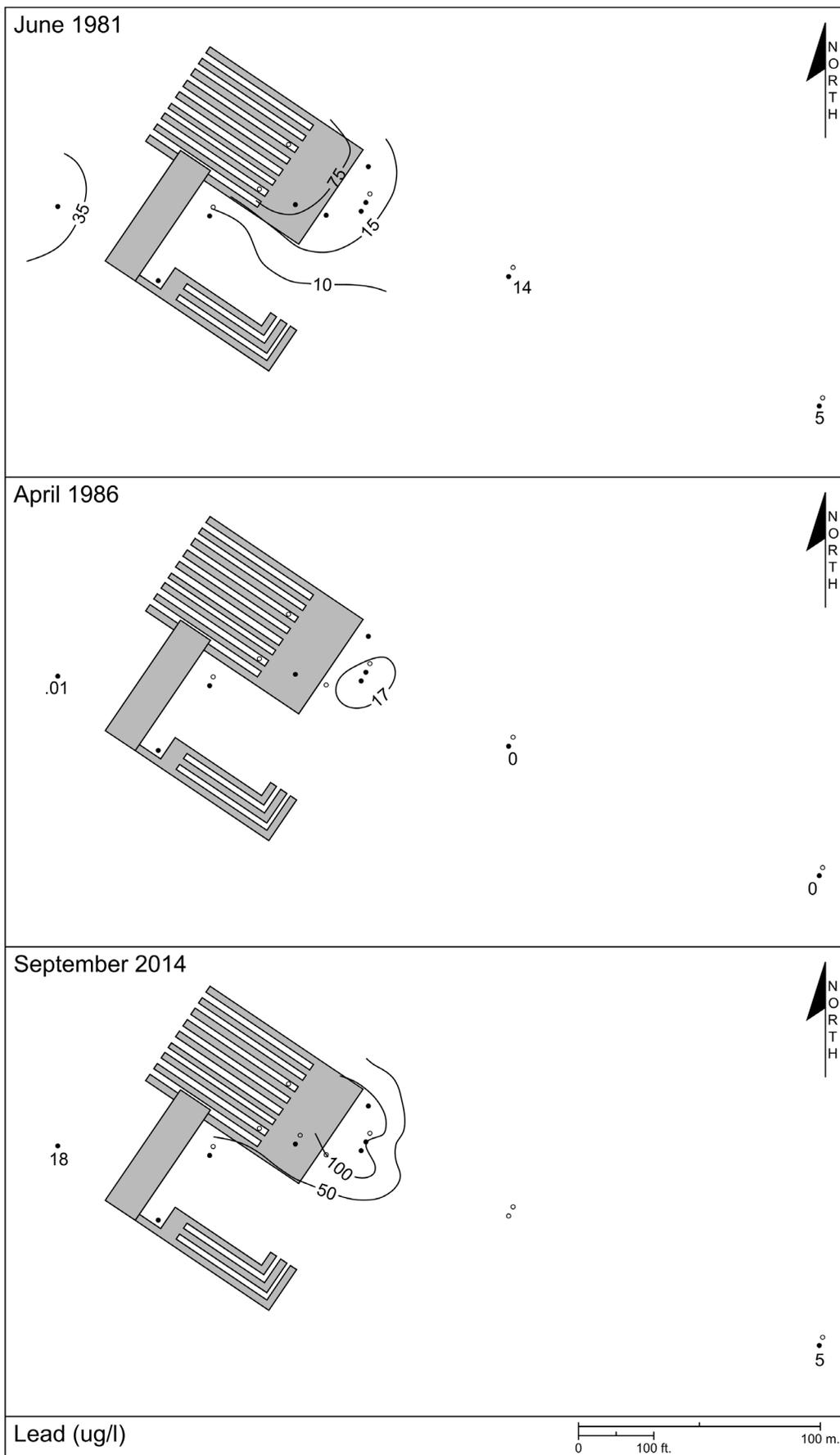


Figure 19. Isoconcentration maps for dissolved lead in water samples collected June 1981 and April 1986 and an isoconcentration map of total lead in water samples collected September 2014.

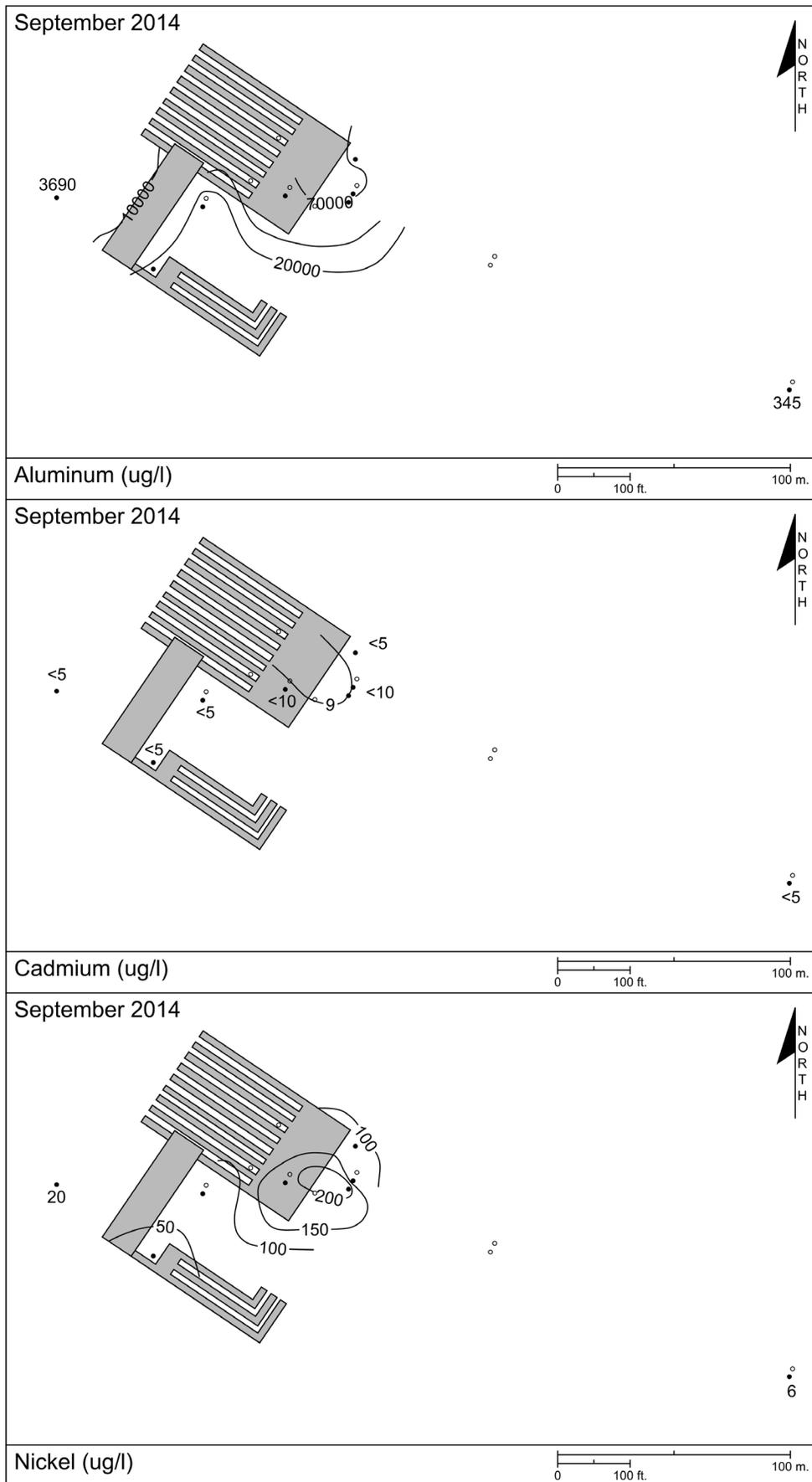


Figure 20. Isoconcentration maps for total aluminum, cadmium, and nickel in water samples collected September 2014.

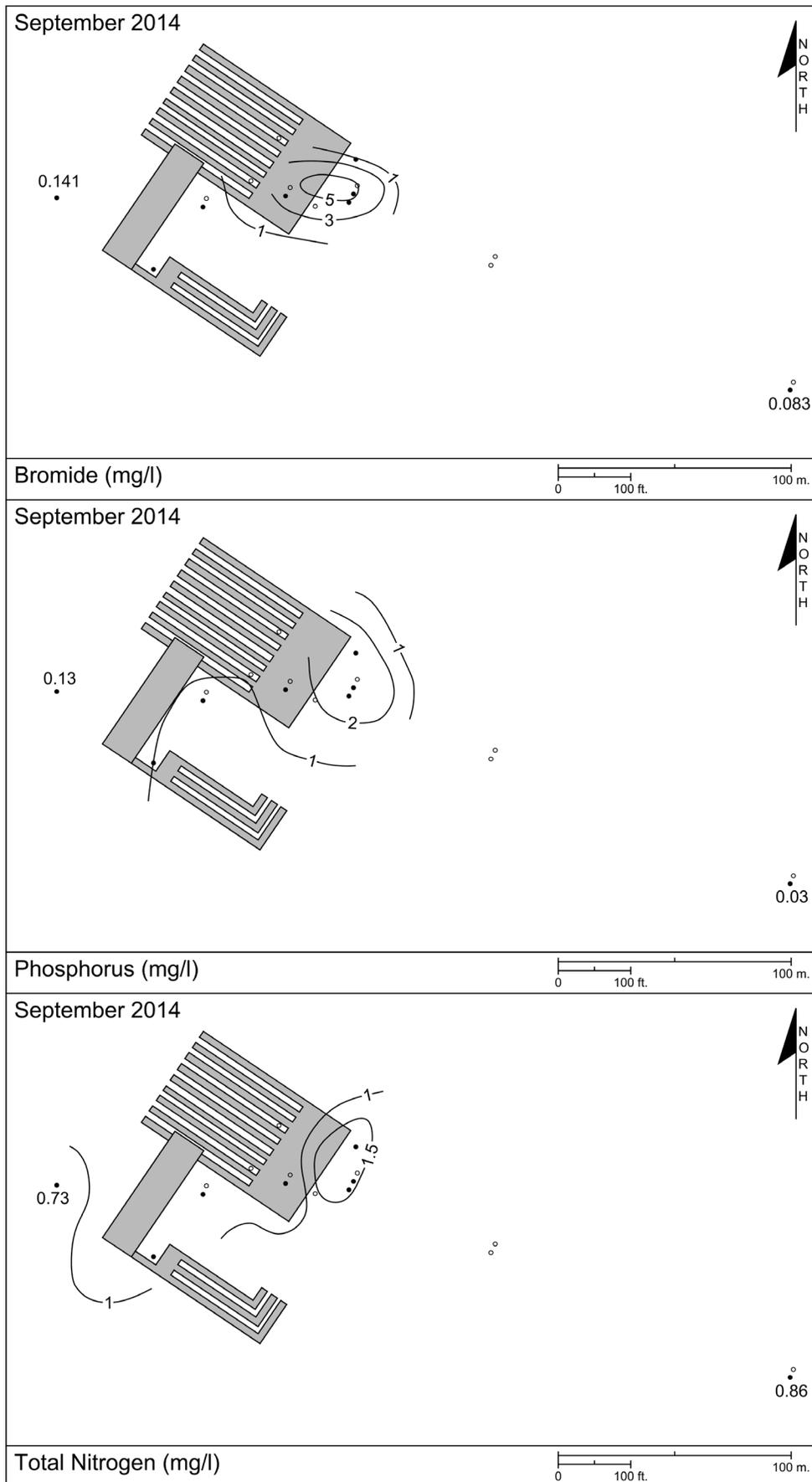


Figure 21. Isoconcentration maps for bromide, phosphorus, and total nitrogen in water samples collected September 2014.

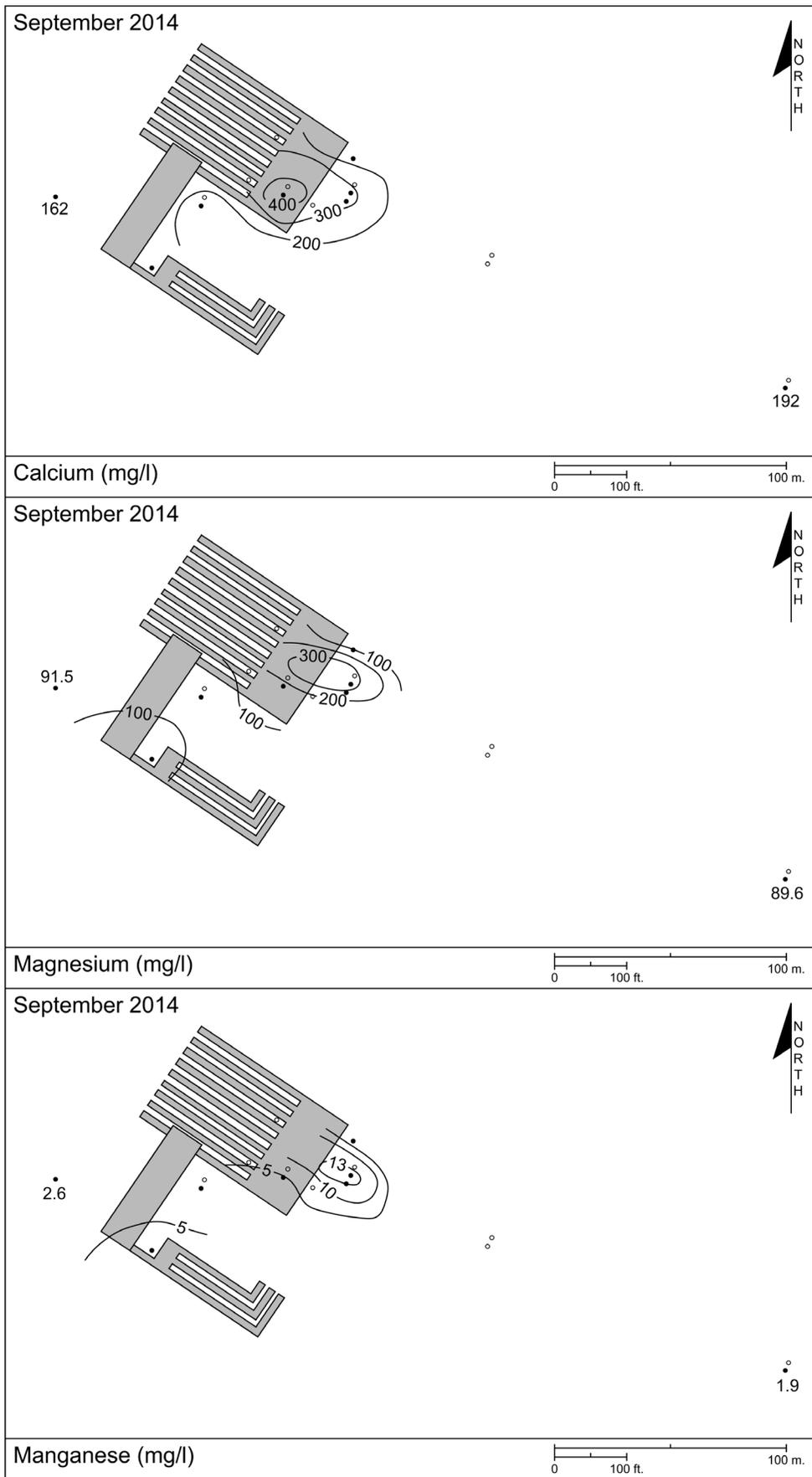


Figure 22. Isoconcentration maps for total calcium, magnesium, and manganese in water samples collected September 2014.

Conclusions

Through the course of the study, the TDS values and the concentrations of many of the major cations and anions in the groundwater surrounding the study site did not consistently increase. In fact, the groundwater in some monitoring wells showed a fairly consistent decrease in concentrations for many of the parameters (Fig. 23). A more consistent sampling routine may have revealed more fluctuations in chemical concentrations as slugs of drilling mud leachate made their way through the shallow groundwater system. The U.S. Forest Service permit allowed the Survey to retain the monitoring wells on federal land for more than thirty years because the original study plan envisioned sampling the site every five years. That schedule was adhered to in 1986, but after that time commitments to other projects or lack of funding resulted in only one round of sampling over a span of 28 years. The monitoring wells were plugged and reclaimed in November 2014.

Because the water samples were filtered during the 1980s and not filtered in 2014, metal concentrations from those two time periods could not be compared on a one to one basis. As would be expected, the total metals concentrations (2014 concentrations) were typically higher than the dissolved metal concentrations from the 1980s samples (Figs. 14-17). This was also true for the background monitoring wells. Metal concentrations increased in monitoring wells 12 and 13b in 2014 even though other parameters decreased (Fig. 23). Based on major ion concentrations, had the 2014 water samples been filtered, metal concentrations would likely have remained on par with 1980s levels (Figs. 24 and 25).

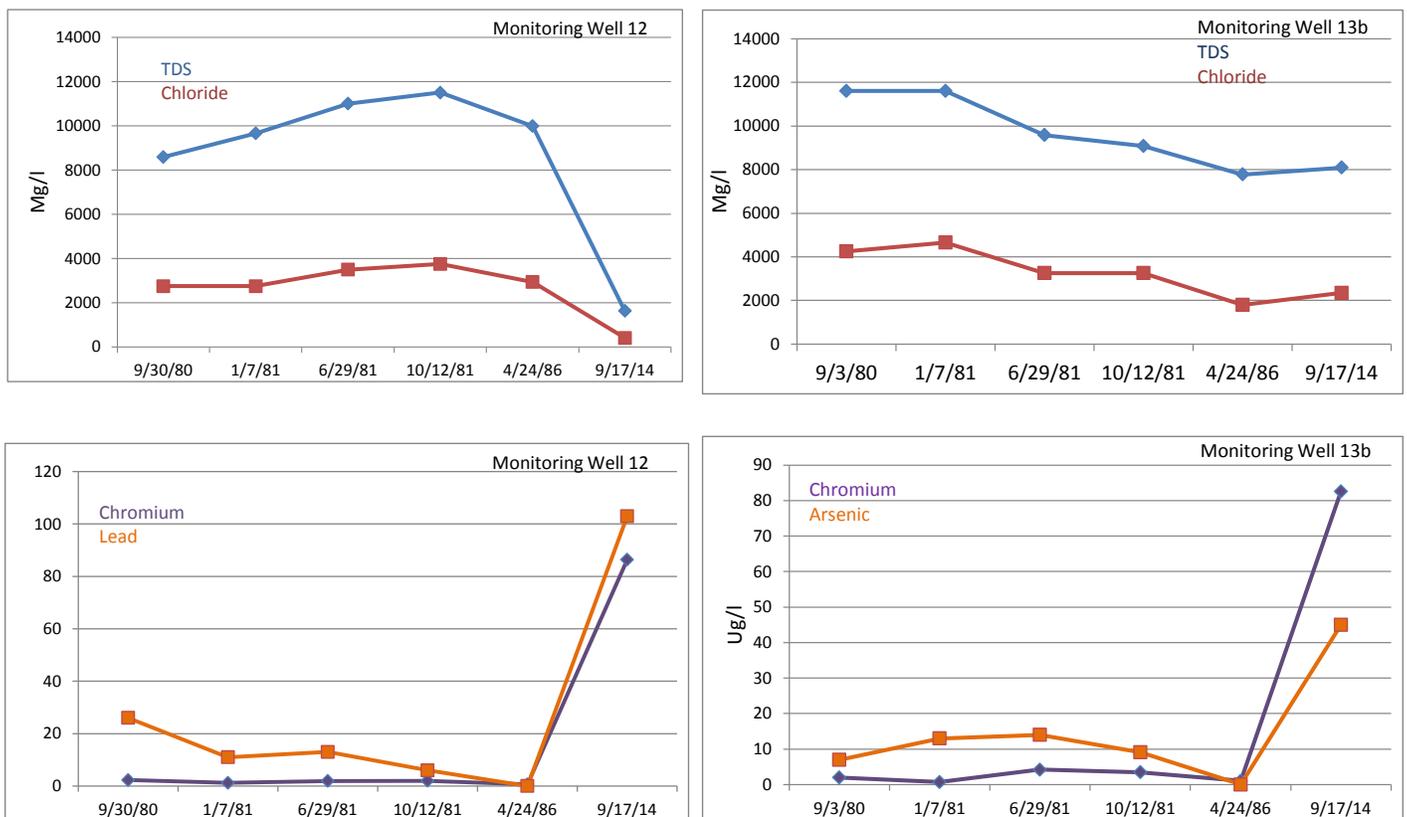


Figure 23. TDS, chloride, arsenic, lead, and chromium concentrations for monitoring wells 12 and 13b.

The leachate plume beneath the Apache Federal 1-5 site has remained relatively constant through time at approximately 200 feet x 200 feet (61 x 61 m). More frequent sampling may have resulted in a more variable leachate plume. Wet cycles resulting in more groundwater recharge events and dry cycles corresponding to little or no recharge would likely have been evident at this site had sampling been more frequent.

The leachate plume beneath the Apache Federal 1-5 site has not appreciably grown over the years and the documented impact area is relatively localized. Still, the 2014 sampling results demonstrate that leachate from drilling mud buried above the water table has the potential to degrade the groundwater for decades, perhaps longer. These results emphasize the importance of disposing of this waste in properly engineered facilities in areas that are geologically suited for waste disposal.

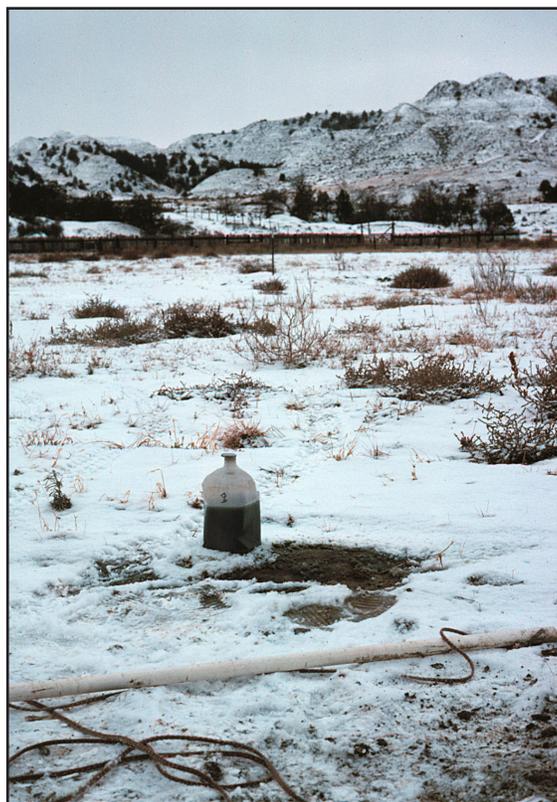


Figure 24. A water sample collected from the Apache study site in January 1981. The sample was filtered and acidified soon after this photograph was taken.

Figure 25. Filtered samples from the Apache study site (C designation) and the other reserve pit study sites in western North Dakota. The samples were collected in October 1981.



References

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- Murphy, E.C., 1988, Oil well reserve pits (Apache Federal #1-5, five years after): North Dakota Groundwater Quality Symposium, pp.199-204.
- Murphy, E.C., 2014, Reserve pit and brine pond studies in North Dakota, powerpoint presentation to Energy Development and Transmission Committee: North Dakota Geological Survey Geologic Investigations no. 175, 109 slides.

APPENDIX A

Monitoring Well	Units	1	1	1	1	1
Date		9/3/80	1/7/81	6/29/81	10/12/81	4/24/86
Conductivity	umhos/cm	6,200	5,400	4,460	5,280	5,645
TDS	mg/l	4,630	4,840	4,060	4,550	4,740
Fe	mg/l	0.12	0.2	1.3	2.47	0.059
Mn	mg/l	2.44	2.66	2.69	2.85	0.01
Ca	mg/l	188	181	150	177	84.2
Mg	mg/l	107	106	89	103	98.3
Total Hardness	mg/l	910	888	742	867	615
K	mg/l	18.8	17.8	16.2	19.0	17.1
Na	mg/l	1,310	1,130	1,030	1,400	1,310
C1	mg/l	25.0	11.0	13.0	30.0	21.4
S04	mg/l	2,260	2,650	2,130	2,130	2,540
Total A.	mg/l	1,180	1,240	1,040	1,120	1,110
HC03	mg/l	1,440	1,520	1,270	1,370	1,360
C03	mg/l	0.0	0.0	0.0	0.0	0.0
F	mg/l	0.6	0.7	0.5	0.5	0.6
%Na	%	75.8	73.3	75.0	77.7	82.2
As	ug/l	7.0	14.0	21.0	7.5	0.0
Ba	ug/l	260	160	240	0.0	---
Cd	ug/l	5.6	0.5	2.8	1.5	---
Cr	ug/l	1.2	1.4	2.6	1.6	0.44
Cu	ug/l	134	95.0	26.0	12.3	---
Pb	ug/l	27.0	7.0	36.0	6.0	0.1
pH	pH	7.1	---	6.8	7.5	7.8
Se	ug/l	3	---	---	2	0.00
Temperature	Celsius	10.1	8.0	11.0	10.0	
Turbidity	NTU	3.0	---	5.0	22.0	24
Zn	ug/l	120	119	35.0	49.0	---
SAR	%	19.0	16.4	16.4	20.7	23
N03	mg/l	2	2	2	2	0.3
Ammonia (N)	mg/l					
N (Total)	mg/l					
N (Total-Kjeldahl)	mg/l					
OH	mg/l					
SiO2 (ICP)	mg/l					
Hardness Total	grain/gallon					
P (Total)	mg/l					
Br	mg/l					
B	ug/l					
Al	ug/l					
Be	ug/l					
Ni	ug/l					
Ag	ug/l					
Sb	ug/l					
Tl	ug/l					

Sta.	1	2	2	2	2	3A	3A
Date-X	9/17/14	6/29/81	10/12/81	4/24/86	9/17/14	6/29/81	10/12/81
Cond.	5,380	4,230	4,180	5,504	5,360	4,320	4,410
TDS	4,140	3,740	3,470	4,390	3,990	3,720	3,790
Fe	11.6	0.25	0.08	0.0	37.1	0.47	1.27
Mn	2.64	2.82	0.14	0.471	5.73	1.81	1.86
Ca	162	154	80.0	150	240	150	149
Mg	91.5	80.0	76.5	106	122	76.5	79.0
Total H.	782	714	514	813	1100	689	698
K	13.8	16.6	14.2	15.9	16.7	17.3	13.8
Na	1,130	965	1,040	1,190	1,000	1,050	1,130
C1	30	55.0	13.0	257	205	33.0	33.0
S04	2,060	1,850	1,680	2,030	1,740	1,740	1,730
Total A.	1,080	1,030	929	1,070	1,090	1,020	1,080
HC03	1,320	1,250	1,130	1,300	1,340	1,300	1,330
C03	< 1	0.0	0.0	0.0	< 1	0.0	0.0
F	0.69	0.6	0.4	0.5	0.6	0.8	0.8
%Na	75.4	74.5	81.3	76	65.8	76.8	77.8
As	12.9	11.0	6.7	0.0	19.4	9.0	5.0
Ba	117	360	---	---	443	340	---
Cd	< 5	2.0	0.9	---	< 5	1.7	1.1
Cr	7.56	6.8	2.3	15.9	25.8	2.0	1.4
Cu	253	94.0	6.1	---	130	46.0	6.3
Pb	18	6.0	9.0	0.0	24.9	8.0	4.0
pH	7.81	6.8	7.5	7.5	7.72	6.9	7.7
Se	< 5	---	2	0.00	< 5	---	2
Temp.		11.0	10.0			11.0	10.0
Turb.	135	7.0	3.0	19	678	4.0	10.0
Zn	184	169	65.0	---	145	47.0	29.0
SAR	17.6	15.6	19.9	18.2	13.1	17.5	18.6
N03	0.07	2	2	0.0	0.09	2	2
NH3-N	0.31				0.16		
N (Total)	0.73				0.32		
N (Total-Kjeldahl)	0.66				0.23		
OH	< 1				< 1		
SiO2 (ICP)	38.8				90.3		
Hard Total	46				64		
P (Total)	0.13				0.96		
Br	0.141				0.45		
B	921				1,140		
Al	3,690				19,500		
Be	< 5				< 5		
Ni	20.3				65.6		
Ag	< 5				< 5		
Sb	< 5				< 5		
Tl	< 5				< 5		

Sta.	3A	3A	3B	3B	3B	5	5
Date-X	4/24/86	9/17/14	6/29/81	10/12/81	9/17/14	9/3/80	1/7/81
Cond.	10,340	4020	4,050	3,840	1,150	4,680	4,000
TDS	7,620	2,750	3,650	3,200	712	3,420	3,360
Fe	8.62	28	0.24	0.21	8.41	0.06	1.06
Mn	1.7	1.96	1.27	0.98	0.235	2.72	3.19
Ca	429	159	143	109	60.6	147	148
Mg	267	47.3	66.0	54.0	15.1	75.0	82.0
Total H.	2,170	592	630	494	214	677	707
K	28.7	14.7	16.8	12.4	9.8	15.1	76.5
Na	1,870	741	1,040	1,010	173	998	899
C1	2,070	278	23.0	28.0	23.9	105	70.0
S04	2,440	1,060	1,740	1,380	231	1,480	1,470
Total A.	852	743	1,020	999	326	981	1,010
HC03	1,040	906	1,250	1,220	398	1,190	1,230
C03	0.0	< 1	0.0	0.0	< 1	0.0	0.0
F	0.4	0.83	1.3	1.3	0.54	0.6	0.6
%Na	65	72.4	78.2	81.6	62.3	76.1	73.3
As	0.0	16.3	7.0	6.8	5.02	3.0	8.0
Ba	---	245	170	60.0	75.8	120	180
Cd	---	< 5	1.8	0.7	< 5	1.9	0.7
Cr	0.79	19.5	2.0	2.1	6.36	0.0	0.8
Cu	---	126	52.0	6.9	109	63.0	16.0
Pb	0.0	28.9	21.0	5.0	20.5	7.0	7.0
pH	7.7	7.87	7.0	7.8	7.76	6.8	---
Se	0.00	< 5	---	2	< 5	3	---
Temp.			11	10.0		10.5	8.0
Turb.	96.0	702	2.0	4.0	129	2	---
Zn	---	121	34	24.0	41.4	136	48.0
SAR	17.4	13.2	18.1	19.8	5.15	16.6	14.6
N03	0.0	0.07	2	2	0.22	2	2
NH3-N		0.24			0.3		
N (Total)		0.4			0.78		
N (Total-Kjeldahl)		0.33			0.56		
OH		< 1			< 1		
SiO2 (ICP)		70			27.2		
Hard Total		35			12		
P (Total)		0.74			0.29		
Br		0.582			0.092		
B		633			293		
Al		14,800			4,550		
Be		< 5			< 5		
Ni		37.8			9.53		
Ag		< 5			< 5		
Sb		< 5			< 5		
Tl		< 5			< 5		

Sta.	6	6	7A	7A	7A	7A	7B
Date- \bar{X}	9/3/80	1/7/81	6/29/81	10/12/81	4/24/86	9/17/14	6/29/81
Cond.	5,820	4,500	18,400	10,100	8,254	10,200	22,600
TDS	4,130	4,330	12,700	7,530	5,840	7,320	13,100
Fe	0.04	0.47	1.19	4.2	0.674	87.3	10.5
Mn	2.84	3.64	6.54	3.6	0.144	5.21	9.23
Ca	193	175	585	274	160	441	775
Mg	105	98.0	280	148	128	217	370.0
Total H.	917	840	2,610	1,290	926	2,000	3,460
K	16.5	18.2	61.5	36.6	28.4	36.4	61.0
Na	1,250	1,120	3,680	2,460	1,770	2,010	4,120
C1	150	53.0	5,500	2,000	1,190	1,710	5,000
S04	1,760	2,200	2,170	2,000	1,930	2,290	2,280
Total A.	1,080	1,110	803	1,000	1,050	1,030	817
HC03	1,330	1,360	981	1,220	1,280	1,250	998
C03	0.0	0.0	0.0	0.0	0.0	< 1	0.0
F	0.6	0.5	0.3	0.4	0.5	0.48	0.3
%Na	74.6	74.2	75.3	80.4	80.5	68.1	72.0
As	4.0	9.0	19.0	11.3	0.0	42.2	15.0
Ba	20.0	90.0	410	170	---	680	400
Cd	1.0	0.9	2.3	1.1	---	< 10	2.0
Cr	0.4	0.9	1.5	4.2	2.79	114	3.0
Cu	99.0	21.0	48.0	7.9	---	240	82.0
Pb	3.0	3.0	26.0	11.0	0.0	56.9	10.0
pH	6.6	---	7.0	7.3	7.6	7.68	6.8
Se	3	---	---	2	0.01	< 10	---
Temp.	10.5	8.0	12.0	10.0			12.0
Turb.	2.0	---	15.0	33.0	27.0	1,820	83.0
Zn	206	52.0	90.0	137	---	266	104
SAR	17.9	16.7	31.3	29.7	25.2	19.6	30.4
N03	2	2	2	2	0.1	0.1	2
NH3-N						0.18	
N (Total)						0.18	
N (Total-Kjeldahl)						0.08	
OH						< 1	
SiO2 (ICP)						122	
Hard Total						117	
P (Total)						1.15	
Br						3.2	
B						2,120	
Al						36,100	
Be						< 10	
Ni						178	
Ag						< 10	
Sb						< 10	
Tl						< 10	

Sta.	7B	7B	10	11	11	12	12
Date-X	10/12/81	9/17/14	10/12/81	9/3/80	1/7/81	9/30/80	1/7/81
Cond.	18,100	5,870	65,500	19,500	21,000	14,200	12,000
TDS	12,400	4,290	53,200	11,500	12,100	8,590	9,660
Fe	2.29	25.8	0.75	3.10	0.84	0.7	0.54
Mn	6.49	1.08	4.03	6.10	12.9	5.6	8.28
Ca	650	155	1,440	520	717	525	680
Mg	350	70.1	2,100	277	347	287	372
Total H.	3,060	676	12,200	2,440	3,220	2,490	3,230
K	45.2	14	144	39.0	44.7	38.7	34.7
Na	3,520	1,340	17,900	3,520	3,490	2,120	2,310
C1	5,500	525	25,000	4,000	4,500	2,750	2,750
S04	1,850	1,680	5,750	2,570	2,500	2,360	3,030
Total A.	817	841	1,140	968	923	846	814
HC03	998	1,030	1,400	1,180	1,120	1,030	994
C03	0.0	< 1	0.0	0.0	0.0	0.0	0.0
F	0.3	0.74	0.0	0.3	0.3	0.3	0.3
%Na	71.3	80.7	76.0	75.7	70.1	64.7	60.7
As	15.6	24.3	43.3	9.0	15.0	10.0	17.0
Ba	20.0	182	90.0	380	300	160	140
Cd	4.6	< 5	16.3	3.1	0.6	2.4	0.5
Cr	3.0	16.8	18.9	1.8	0.5	2.3	1.2
Cu	10.2	318	125	68.0	52.0	76.0	41.0
Pb	50.0	34.5	188	92.0	19.0	26.0	11.0
pH	6.8	7.64	6.5	6.4	---	6.5	---
Se	2	< 5	2.6	3	---	3	---
Temp.	10.0		10.0	10.7	8.0	9.7	8
Turb.	34.0	265	3.0	50.0	3.0	25.0	2.0
Zn	53.0	196	172	132	85.0	144	67
SAR	27.6	22.4	70.4	30.9	26.7	18.4	17.6
N03	2	0.09	203	2	2	2	2
NH3-N		0.79					
N (Total)		0.94					
N (Total-Kjeldahl)		0.85					
OH		< 1					
SiO2 (ICP)		41.6					
Hard Total		39					
P (Total)		0.3					
Br		1.31					
B		875					
Al		7,570					
Be		< 5					
Ni		28.4					
Ag		< 5					
Sb		< 5					
Tl		< 5					

Sta.	12	12	12	13A	13A	13A	13A
Date- \ddot{X}	10/12/81	4/24/86	9/17/14	6/29/81	10/12/81	4/24/86	9/17/14
Cond.	15,800	14,330	2,670	13,600	13,800	10,260	8,280
TDS	11,500	9,990	1,630	10,000	9,810	6,900	5,830
Fe	15.6	1.30	145	0.25	1.58	0.0	233
Mn	11.0	1.08	3.85	5.0	6.13	0.0	11.5
Ca	745	363	105	515	515	140	242
Mg	455	257	35	267	285	180	123
Total H.	3,730	1,960	407	2,380	2,460	1,090	1,110
K	35.7	37.9	34.9	33.5	31.7	29.3	36.1
Na	3,000	3,040	412	2,660	2,780	2,090	1,630
C1	3,750	2,940	406	3,250	3,250	1,740	1,330
S04	3,060	2,790	408	2,820	2,480	2,200	1,920
Total A.	804	947	370	761	781	879	904
HC03	982	1,160	451	930	954	1,070	1,100
C03	0.0	0.0	< 1	0.0	0.0	0.0	< 1
F	0.2	0.4	0.26	0.4	0.4	0.4	0.51
%Na	63.5	77.0	66.4	70.7	70.9	80.5	75.3
As	3.9	0.0	40	8.0	9.6	0.0	118
Ba	---	---	1130	470	110	---	447
Cd	0.5	---	< 5	3.9	0.4	---	8.92
Cr	2	0.64	86.4	2.6	3.2	3.54	114
Cu	10.3	---	221	72.0	9.2	---	756
Pb	6.0	0.0	103	27.0	7.0	16.8	192
pH	7.2	7.6	7.46	7.1	7.4	7.5	7.55
Se	2	0.0	< 5	---	2	0.0	9.62
Temp.	10			11.0	10.0		
Turb.	112.0	35.0	4,070	3.0	25.0	4.0	4,650
Zn	79	---	483	114	69	---	801
SAR	21.3	29.9	8.88	23.7	24.3	27.5	21.3
N03	2	0.2	0.73	2	2	0.3	0.25
NH3-N			0.36				0.87
N (Total)			1.38				1.06
N (Total-Kjeldahl)			0.65				0.81
OH			< 1				< 1
SiO2 (ICP)			209				197
Hard Total			24				65
P (Total)			2.87				2.59
Br			0.937				2.93
B			524				< 5000
Al			78,400				76,900
Be			6				8.26
Ni			115				230
Ag			< 5				< 5
Sb			< 5				< 5
Tl			< 5				< 5

Sta.	13A	13B	13B	13B	13B	13B	13B
Date-X	9/17/14	9/3/80	1/7/81	6/29/81	10/12/81	4/24/86	9/17/14
Cond.	8,280	18,800	17,500	14,000	12,700	11,170	11400
TDS	5,830	11,600	11,600	9,580	9,080	7,780	8090
Fe	233	0.10	1.93	0.75	1.53	0.005	114
Mn	11.5	9.10	14.7	11.2	9.9	0.123	12.9
Ca	242	760	780	565	495	190	333
Mg	123	400	390	280	265	154	307
Total H.	1,110	3,540	3,550	2,560	2,320	1,110	2,100
K	36.1	37.5	39.5	29.5	28.5	30.8	36.5
Na	1,630	3,130	2,930	2,510	2,510	2,540	2,240
C1	1,330	4,250	4,650	3,250	3,250	1,790	2,340
S04	1,920	2,610	2,370	2,390	1,970	2,410	2,200
Total A.	904	819	814	914	939	1,100	1,050
HC03	1,100	1,000	994	1,110	1,140	1,340	1,280
C03	< 1	0.0	0.0	0.0	0.0	0.0	< 1
F	0.51	0.3	0.2	0.3	0.3	0.4	0.51
%Na	75.3	65.6	64.0	67.9	70.0	83.2	69.4
As	118	7.0	13.0	14.0	9.1	0.0	45
Ba	447	240	190	310	90.0	---	760
Cd	8.92	5.8	0.8	1.8	2.0	---	< 10
Cr	114	2	0.7	4.2	3.5	1.02	82.6
Cu	756	106	73.0	49.0	12.6	---	249
Pb	192	78.0	25.0	10.0	21.0	0.0	52.4
pH	7.55	6.3	---	6.8	7.1	7.4	7.52
Se	9.62	3	---	---	2	0.0	< 10
Temp.		10.0	8.0	11.0	10.0		
Turb.	4,650	4.0	23.0	5.0	12.0	4.0	3,380
Zn	801	124	138	88.0	50.0	---	432
SAR	21.3	22.8	21.3	21.5	22.6	33.2	21.3
N03	0.25	2	2	2	2	0.0	0.19
NH3-N	0.87						0.9
N (Total)	1.06						1.47
N (Total-Kjeldahl)	0.81						1.28
OH	< 1						< 1
SiO2 (ICP)	197						165
Hard Total	65						122
P (Total)	2.59						2.27
Br	2.93						5.21
B	< 5000						< 5000
Al	76,900						66,200
Be	8.26						< 10
Ni	230						117
Ag	< 5						< 10
Sb	< 5						< 10
Tl	< 5						< 10

Sta.	13C	13C	13C	14A	14A	14A	14B
Date-X	6/29/81	10/12/81	9/17/14	6/29/81	10/12/81	4/24/86	6/29/81
Cond.	13,800	9,400	3,900	4,040	4,060	3,961	3,680
TDS	9,670	6,640	2,650	3,610	6,640	3180	3,310
Fe	0.60	0.68	2.53	0.10	0.26	0.826	0.07
Mn	5.43	3.59	1.31	0.88	0.8	1.25	0.69
Ca	487	281	25.2	148	126	144	115
Mg	245	155	10.6	77.0	71.0	76.1	51.0
Total H.	2,220	1,340	107	688	607	672	497
K	32.7	22.9	4.4	19.4	15.7	14	17.4
Na	2,590	2,080	901	973	944	867	933
C1	3,250	1,750	80.6	13.0	10.0	10.2	10.0
S04	2,610	1,880	1,090	1,890	1,640	1,500	1,670
Total A.	748	764	892	804	829	945	843
HC03	914	933	1,090	982	1,010	1,150	1,030
C03	0.0	0.0	< 1	0.0	0.0	0.0	0.0
F	0.4	0.5	1.73	0.6	0.5	0.5	0.8
%Na	71.5	77.0	94.6	75.3	77.1	73.6	80.2
As	16.0	0.0	< 10	11.0	4.6	0.9	8.0
Ba	450	20.0	72.4	460	40.0	---	420
Cd	1.9	0.9	< 10	0.9	0.6	---	0.7
Cr	1.6	2.3	< 10	3.1	2.6	0.22	1.9
Cu	56.0	9.4	95.6	50.0	10.0	---	37.0
Pb	12.0	10.0	14.5	14.0	4.0	0.0	---
pH	7.0	7.2	8.18	7.1	7.2	7.5	7.0
Se	---	2	< 10	---	2	0.0	---
Temp.	11.0	10.0		11.0	10.0		10.0
Turb.	3.0	6.0	44	5.0	3.0	12.0	1.0
Zn	65.0	38.0	50.7	78.0	30.0	---	37.0
SAR	23.8	24.7	37.9	16.1	16.6	14.5	18.1
N03	2	2	0.7	2	2	0.0	2
NH3-N			< 0.03				
N (Total)			0.84				
N (Total-Kjeldahl)			0.14				
OH			< 1				
SiO2 (ICP)			15.4				
Hard Total			6				
P (Total)			0.09				
Br			0.283				
B			625				
Al			1,850				
Be			< 10				
Ni			13.6				
Ag			< 10				
Sb			< 10				
Tl			< 10				

Sta.	14B	15A	15A	15A	15A	15B	15B
Date-X	10/12/81	6/29/81	10/12/81	4/24/86	9/17/14	6/29/81	10/12/81
Cond.	3,710	5,220	5,430	5,286	4,280	5,300	5,080
TDS	2,980	5,040	4,820	4,510	3,270	4,820	4,370
Fe	0.22	0.14	0.13	0.051	3.14	0.25	0.08
Mn	0.49	1.60	1.54	0.003	1.9	1.03	0.83
Ca	88.5	186	177	117	192	161	118
Mg	45.0	88.5	91.5	104	89.6	79.5	61.0
Total H.	406	830	820	721	849	730	546
K	13.7	21.0	18.4	19.6	14.1	19.6	13.5
Na	895	1,260	1,350	1,170	755	1,260	1,370
C1	10.0	18.0	20.0	20.2	30	18.0	3.0
S04	1,440	2,930	2,650	2,580	1710	2,760	2,280
Total A.	808	874	841	817	793	847	863
HC03	987	1,060	1,020	998	968	1,030	1,050
C03	0.0	0.0	0.0	0.0	< 1	0.0	0.0
F	0.7	0.7	0.6	0.5	0.45	0.8	0.9
%Na	82.6	76.7	78.1	77.8	65.3	78.9	84.4
As	5.2	11.0	0.0	0.3	< 5	9.0	0.0
Ba	70.0	370	150	---	27.9	350	120
Cd	0.7	1.3	0.7	---	< 5	1.0	0.3
Cr	2.4	1.1	1.7	1.94	< 5	1.8	2.3
Cu	6.9	47.0	10.3	---	69.3	32.0	5.4
Pb	5.0	5.0	3.0	0.0	5.28	5.0	4.0
pH	7.1	7.3	7.3	7.8	7.68	7.2	7.5
Se	2	---	2	0.0	< 5	---	2
Temp.	10.0	10.0	10.0			10.0	10.0
Turb.	4.0	1.0	2.0	12.0	29.5	1.0	1.0
Zn	34.0	80.0	48.0	---	71.1	45.0	27.0
SAR	19.3	19.1	20.5	18.9	11.3	20.3	25.4
N03	2	2	2	0.5	0.09	2	2
NH3-N					0.44		
N (Total)					0.86		
N (Total-Kjeldahl)					0.77		
OH					< 1		
SiO2 (ICP)					24.9		
Hard Total					50		
P (Total)					0.03		
Br					0.083		
B					638		
Al					345		
Be					< 5		
Ni					6.19		
Ag					< 5		
Sb					< 5		
Tl					< 5		

Sta.	15B	Winter Stock Well
Date-X	9/17/14	1/7/81
Cond.	3,250	1,700
TDS	2,170	1,200
Fe	4.25	0.09
Mn	0.636	0.02
Ca	12.7	1.5
Mg	5.7	1.0
Total H.	55	8.0
K	3.4	2.4
Na	725	477
C1	< 30	6.0
S04	876	169
Total A.	837	903
HC03	1,020	1,060
C03	< 1	17.0
F	2.38	4.5
%Na	96.3	99.2
As	< 5	---
Ba	54.6	---
Cd	< 5	---
Cr	< 5	---
Cu	78.7	---
Pb	16	---
pH	8.24	8.5
Se	< 5	---
Temp.		11.0
Turb.	55.8	1.0
Zn	54.2	---
SAR	42.4	73.9
N03	2	2.0
NH3-N	< 0.03	
N (Total)	2.06	
N (Total-Kjeldahl)	< 0.08	
OH	< 1	
SiO2 (ICP)	14.8	
Hard Total	3	
P (Total)	0.11	
Br	0.2	
B	612	
Al	1,700	
Be	< 5	
Ni	6.49	
Ag	< 5	
Sb	< 5	
Tl	< 5	