Radium occurs in private wells in Minnesota groundwater

Radium in Private Wells and the Maximum Contaminant Level

Radium (Ra) is a naturally occurring radioactive element, originating from rocks containing uranium and thorium, like quartz sandstone and granitic and metamorphic crystalline rocks (Vinson et al., 2012). Radium occurs in Minnesota groundwater, most commonly in the sandstone bedrock aquifers, especially in the Cambrian Mount Simon Sandstone aquifer. The extent of the radium is localized with a shorter spread spatially and not transported long distances (Vinson et al., 2012). In groundwater there are three isotopes of radium: radium-224, radium-226, and radium-228. The most common species in groundwater is radium-226, which is from the uranium-238 decay series, and has a comparatively long half-life of 1,600 years. Both radium-228 and radium-224 are from the thorium-232 decay series, with radium-228 (half-life 5.8 years) decaying to radium-224 (half-life 3.6 days) (Vinson et al., 2012).

There is little data for radium in private wells. Radium is not a required test for new private well construction, so the impact of radium on private wells is unknown. Combined radium includes the isotopes radium-226 and radium-228. The isotope radium-224 has a short half-life of 3.6 days and does not have a Maximum Contaminant Level in drinking water, so there is little, if any, data for radium-224 in public water supplies. Public water suppliers are required to test for combined radium 226/228, and there are some public water supplies in southeastern Minnesota that have elevated combined radium 226/228. The Environmental Protection Agency (EPA) has a Maximum Contaminant Level (MCL) for combined radium 226/228 of 5 picocuries per liter (pCi/L), based on an elevated risk of bone cancer. Radium behaves like calcium in the body and can replace calcium in the tissues, especially the bones. Private well users may not be aware they have radium in their well water because radium does not change water taste, color, or smell. Analyzing water for radium at a private water testing laboratory is the only way to know if radium is present and there are no certified water testing labs in Minnesota that will test a private well for radium. Developing a greater understanding of radium occurrence in private water supply wells and identifying whether other surrogate analytes with more readily available labs and lower analytical costs will help protect private well users' health.

Approach

The scope of this project is to determine if private wells users are being exposed to elevated radium in their drinking water and to provide some basic tools for them to determine if their well water may be at risk. The assumption is that the private well user has no geology background and only has a well construction record for their well.

The objectives of this study are:

1.) Determine if private wells have geologically sourced radium in the drinking water. Are there any private wells in Minnesota that have concentrations of radium greater than the MCL?

2.) Can well construction and/or aquifer help determine the presence of radium in well water?

3.) Are public wells with known concentrations above the MCL good indicators for the location of private wells in Minnesota that may exhibit concentrations of radium above the MCL?

4.) Can the presence of radium be inferred from the presence of gross alpha?

Private water-supply wells completed in the Mt. Simon and Jordan aquifers may exhibit measurable concentrations of radium in groundwater. Previous research in Minnesota shows that groundwater collected from public water-supply wells completed in the Mt. Simon and Jordan aquifers can exceed the EPA combined radium MCL (Lively et al., 1992; Lundy, 2010). In addition, the gross alpha test detects radioactive alpha ions and is a cheaper test and easily available for private well users to test.

Methods

There are two phases in the study, the first phase consisted of sampling 97 private drinking water wells in five different study regions in Minnesota. These study regions are referred to as sites in this paper and are shown below in Figure 1a. Private wells in the five study regions were selected if the wells were within 6 miles of a previously sampled public water supply well that had combined radium 226/228 elevated above the MCL; in each site, approximately 20 private wells were sampled that fell within the six-mile buffer. The private wells were completed in different aquifers, including the Mt. Simon, Prairie du Chien-Jordan aquifer system, Quaternary sands and gravels, Tunnel City-Wonewoc aquifer system, and the Sioux Quartzite. The first sampling round tested the 97 wells for gross alpha, along with general water chemistry parameters (arsenic, iron, manganese, nitrate, sulfate, calcium, potassium, magnesium, sodium, alkalinity, and chloride).

The second phase of sampling tested all wells with any detectable level of gross alpha in the phase 1 sampling, since gross alpha detects some level of radioactivity in the water. The assumption is that radium is more likely to be found in wells exhibiting higher concentrations of gross alpha. Of the 97 wells from phase one, 48 wells were sampled again (see Figure 1b below), this time for combined radium, barium, and general water chemistry constituents. Barium is a chemical analogue of radium, radium may co-precipitate with barium in barite. Barium is correlated with radium-226 (Lively et al., 1992). Geochemistry was not analyzed as part of the scope of this project but it can be analyzed in future work (Table 5 and 6 in the Appendix).

Samples that required filtering were dissolved arsenic, barium, iron, manganese, nitrate+nitrite, magnesium, sodium, calcium, and potassium. These samples were field-filtered using a 0.45-micron in-line filter. In addition to the samples submitted for laboratory analysis, field parameters were collected while purging the wells. Once the field parameter readings stabilized and remained constant, the water samples were collected. The field parameters included: dissolved oxygen (DO), temperature, specific conductivity, redox potential, and pH.

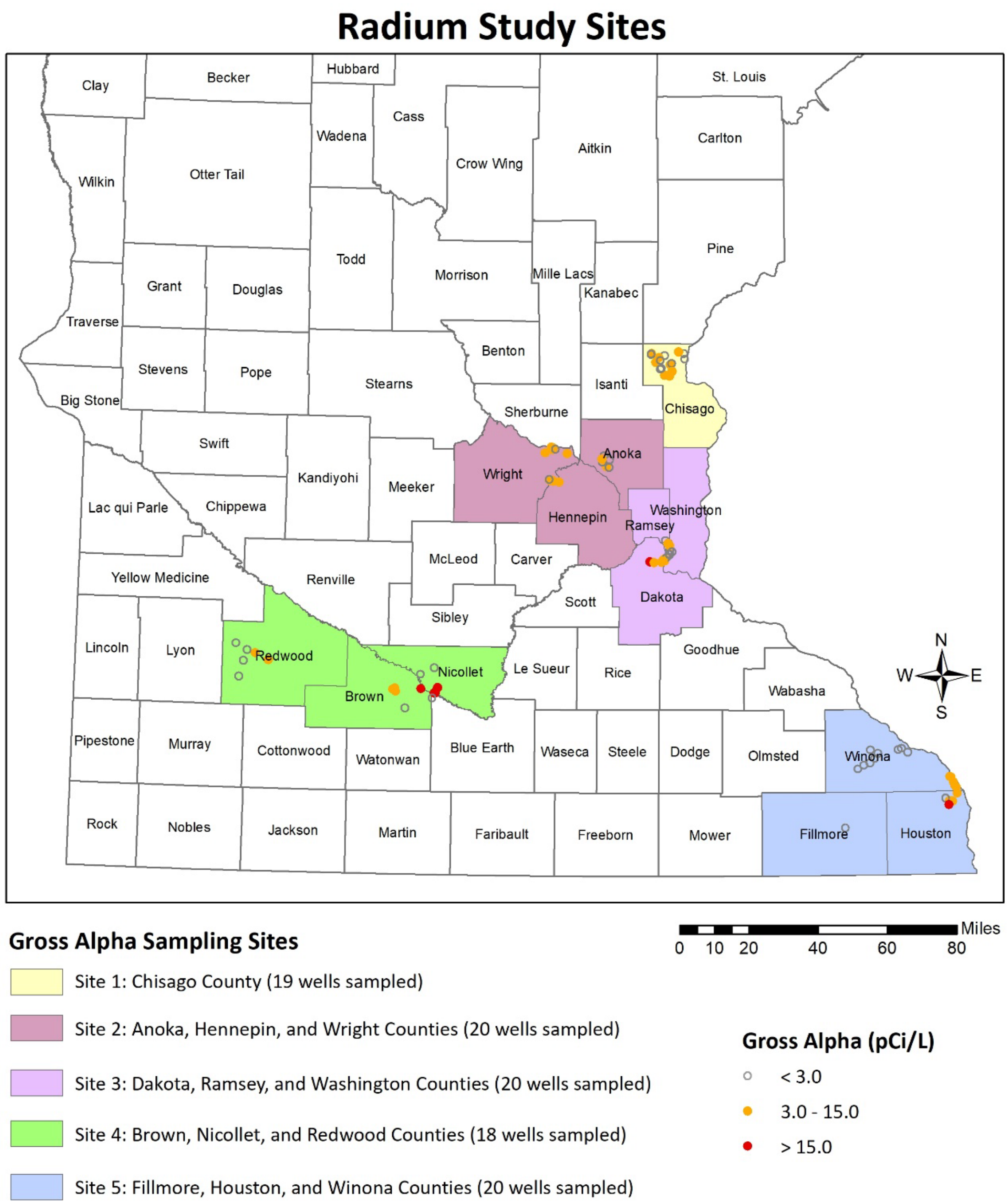


Figure 1a: Study sites with 97 private wells sampled for gross alpha as part of phase 1.

Site	Counties in Site	Number of Wells Sampled Phase 1	Number of wells **<3 pCi/L** Radium 226/228	Number of Wells **3.0 - 15 pCi/L** Radium 226/228	Number of Wells **>15 pCi/L** Radium 226/228
Site 1	Chisago	19	10	9	0
Site 2	Anoka, Hennepin, and Wright	20	8	12	0
Site 3	Dakota, Ramsey, and Washington	20	8	11	1
Site 4	Brown, Nicollet, and Redwood	18	8	5	5
Site 5	Filmore, Houston, and Winona	20	11	8	1

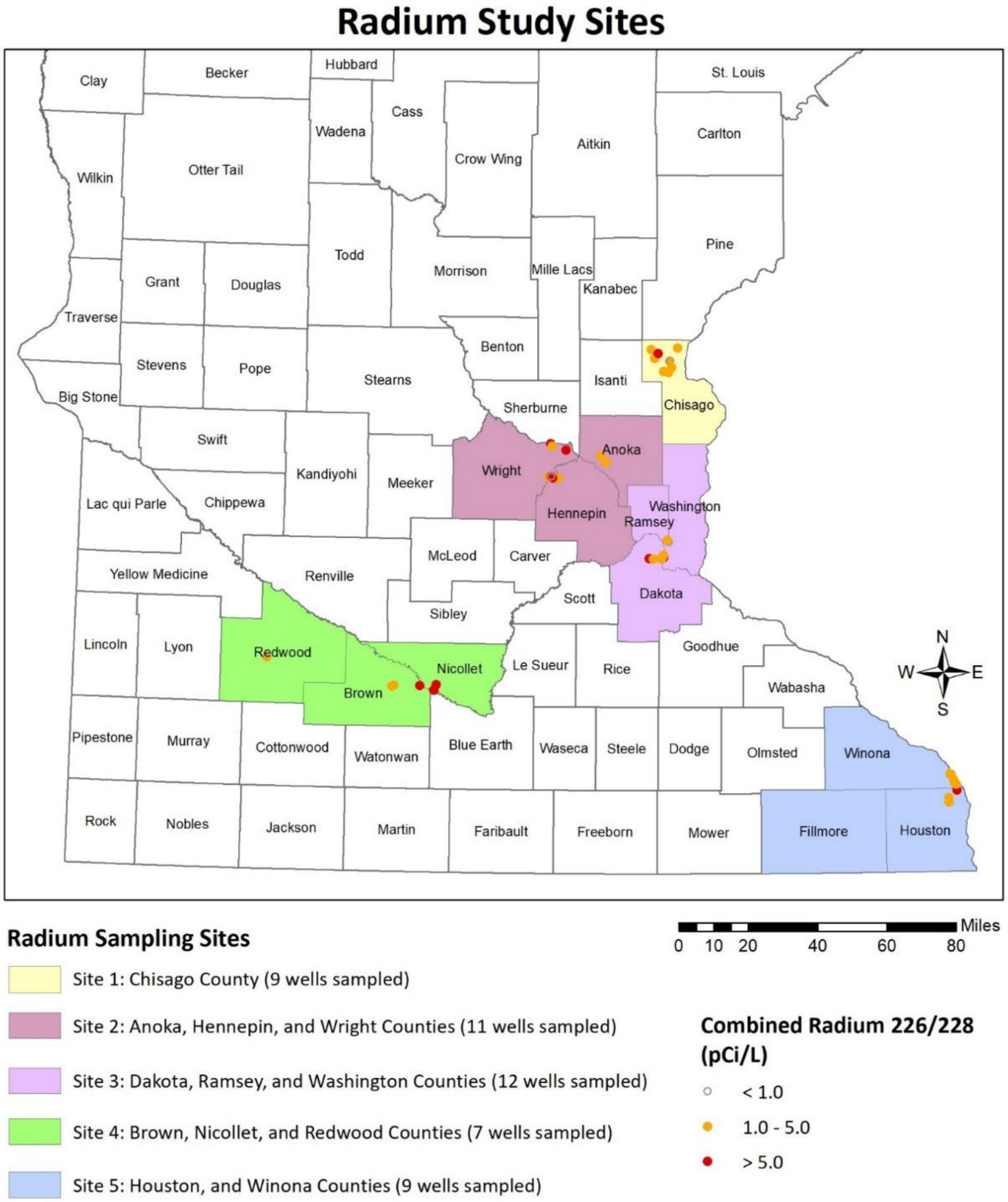


Figure 1b: Study sites with 48 private wells sampled for combined radium 226/228 as part of phase 2. Fillmore County had wells that were sampled but did not have detected gross alpha and were not resampled for radium 226/228.

Site	Counties in Site	Number of Wells Sampled Phase 2	Number of wells **>5 pCi/L** Radium 226/228	Number of Wells **1 - 5 pCi/L** Radium 226/228	Number of Wells >**1 pCi/L** Radium 226/228	Number of Wells <**1 pCi/L** Radium 226/228
Site 1	Chisago	9	1	7	8	1
Site 2	Anoka, Hennepin, and Wright	11	4	6	10	1
Site 3	Dakota, Ramsey, and Washington	12	2	9	11	1
Site 4	Brown, Nicollet, and Redwood	7	4	3	7	0
Site 5	Houston and Winona	9	1	7	8	1

Results

Is There Radium in Private Wells in Minnesota Groundwater?

Site	Number of Wells Sampled Round 2	Number of wells **>5 pCi/L** Ra 226/228	Percent **>5 pCi/L** Ra 226/228	Number of Wells **1 - 5 pCi/L** Radium 226/228	Percent **1 - 5 pCi/L** Ra 226/228	Number of Wells >**1 pCi/L** Radium 226/228	Percent of Wells >**1 pCi/L** Radium 226/228	Number of Wells <**1 pCi/L** Radium 226/228
Site 1	9	1	11%	7	78%	8	89%	1
Site 2	11	4	36%	6	55%	10	91%	1
Site 3	12	2	17%	9	75%	11	92%	1
Site 4	7	4	57%	3	43%	7	100%	0
Site 5	9	1	11%	7	78%	8	89%	1
Total	**48**	**12**	**25%**	**32**	**67%**	**44**	**92%**	**4**

Table 1: Combined radium 226/228 results in private wells - phase 2 sampling

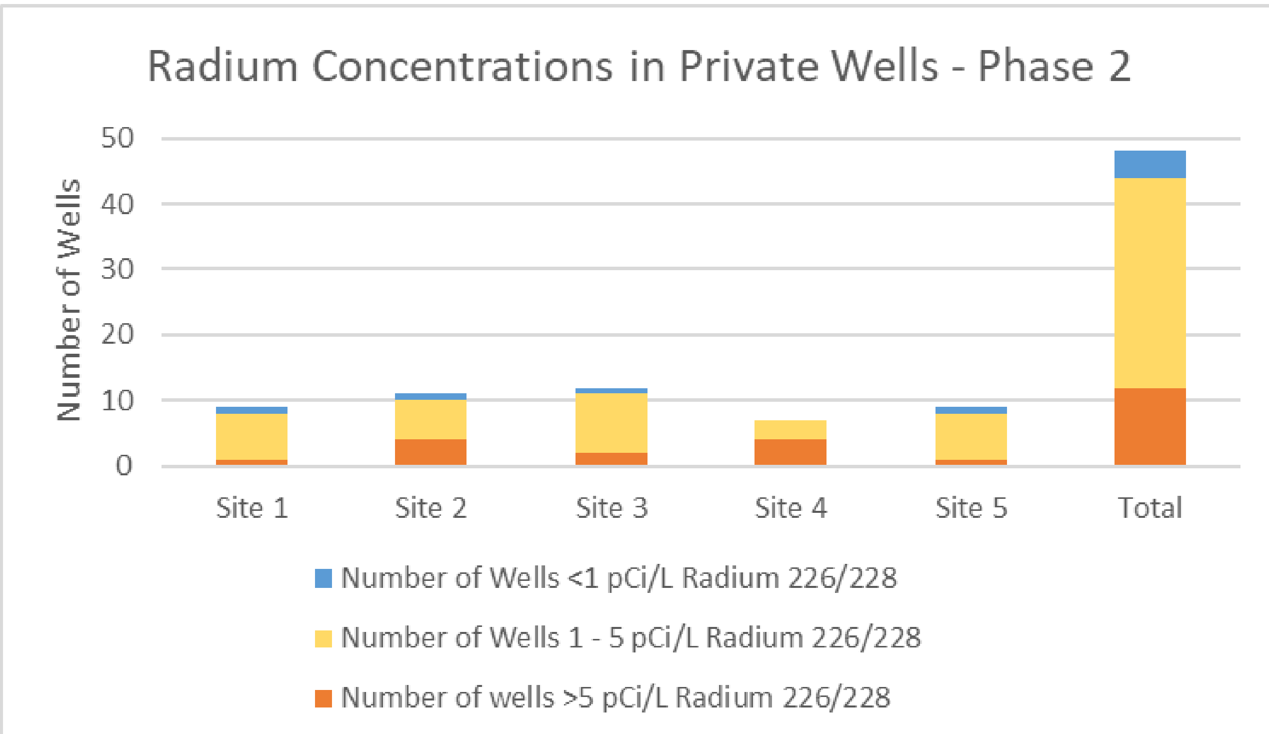


Chart 1: Combined radium 226/228 results in private wells - phase 2 sampling.

Radium was detected in private wells in the study; 92% of the private wells sampled in phase 2 have combined radium 226/228 above 1 pCi/L and 25% of private wells sampled had radium above the MCL of 5 pCi/L, as shown in Table 1 and Chart 1. Twelve households' drinking water was above the drinking water standard for combined radium 226/228. Site 2 and Site 4 had the highest concentrations of radium in well water, with 36% of wells above the MCL at Site 2 and 57% of wells above the MCL at Site 4. Sites 1, 3, and 5 had fewer wells above the MCL but radium was still detected.

Can well construction and/or aquifer help determine the presence of radium in well water?

Site 1

Public Water Supply Well	Well Depth	Aquifer	Combined Radium 226/228	Pumping Rate (gpm)
217928	104	Multiple (QBAA-Mt. Simon)	14.0	503
151559	220	Mt. Simon	14.0	600
612116	219	St. Peter-Prairie Du Chien-Mt. Simon	20.0	540

Private Well Unique ID	Well Depth	Aquifer	Combined Radium 226/228	Pumping Rate (gpm)
404938	110	Mt. Simon	4.7	10
680191	176	Mt. Simon	4.6	NA
629090	155	Mt. Simon	4.1	15
704590	128	Mt. Simon	2.5	12
627774	160	Mt. Simon	2.4	12
448245	156	Mt. Simon	< 1.0	12
672830	161	Eau Claire/Mt. Simon	5.2	12
664448	220	Eau Claire/Mt. Simon	3.8	NA
464413	186	Wonewoc Sandstone	3.5	10

Site 2

Public Water Supply Well	Well Depth	Aquifer	Combined Radium 226/228	Pumping Rate (gpm)
171011	601	Mt. Simon	12	900
415932	525	Mt. Simon	12	800
453792	490	Mt. Simon	19	2200
645355	401	Mt. Simon	22	NA

Private Well Unique ID	Well Depth	Aquifer	Combined Radium 226/228	Pumping Rate (gpm)
602052	290	Tunnel City Group	1.1	20
450343	320	Tunnel City Group	1.1	15
554881	263	Tunnel City/Wonewoc	7.6	NA
544595	260	Tunnel City/Wonewoc	3.7	NA
583152	255	Tunnel City/Wonewoc	<1.0	20
479430	280	Wonewoc/Eau Claire	4.8	10
137718	253	Eau Claire/Mt. Simon	11.7	NA
530268	405	Eau Claire/Mt. Simon	5.5	NA
471312	250	Mt. Simon	8.0	10
570309	281	Wonewoc Sandstone	4.7	40
140176	288	Wonewoc Sandstone	4.0	12

Site 3

Public Water Supply Well	Well Depth	Aquifer	Combined Radium 226/228	Pumping Rate (gpm)
655940	542	Jordan	10.0	1400
759561	510	Jordan	10.0	2000
200664	484	Jordan	23.0	1730

Private Well Unique ID	Well Depth	Aquifer	Combined Radium 226/228	Pumping Rate (gpm)
402553	320	Jordan	6.1	10
401865	360	Jordan	5.6	10
427027	220	Jordan	4.8	10
426390	420	Jordan	3.6	10
451601	420	Jordan	3.1	10
436443	380	Jordan	1.9	12
425267	400	Jordan	1.8	10
649665	485	Jordan	1.7	18
670708	502	Jordan	1.4	15
626608	500	Jordan	1.4	10
625964	480	Jordan	1.4	12
546240	415	Jordan	<1.0	10

Site 4

Public Water Supply Well	Well Depth	Aquifer	Combined Radium 226/228	Pumping Rate (gpm)
102025	130	Quaternary Buried Artesian Aquifer	11	66
437623	140	Cretaceous	14	85
430604	247	Mt. Simon	27	150
241335	219	Mt. Simon	34	NA

Private Well Unique ID	Well Depth	Aquifer	Combined Radium 226/228	Pumping Rate (gpm)
653550	121	Cretaceous	3.2	NA
731426	219	Cretaceous	1.5	12
543003	247	Mt. Simon	24.8	12
662632	180	Mt. Simon	17.3	10
592783	192	Mt. Simon	15.6	12
784246	376	Mt. Simon	6.2	10
660754	104	Quaternary Buried Artesian Aquifer	2.6	NA

Site 5

Public Water Supply Well	Well Depth	Aquifer	Combined Radium 226/228	Pumping Rate (gpm)
221197	550	Multiple (Eau Claire-Mt. Simon)	12	1000

Private Well Unique ID	Well Depth	Aquifer	Combined Radium 226/228	Pumping Rate (gpm)
475531	640	Wonewoc Sandstone	4.8	NA
770645	620	Wonewoc Sandstone	4	10
751016	652	Wonewoc Sandstone	3.3	NA
779134	627	Wonewoc Sandstone	1.2	12
107728	640	Wonewoc Sandstone	<1.0	NA
564610	740	Mt. Simon	5.6	25
758800	224	Mt. Simon	4.3	NA
660632	223	Mt. Simon	2.7	NA
625736	206	Mt. Simon	1.3	NA

Table 2: Public water supply wells and nearby private wells used in the study. Comparison for well depth, combined radium 226/228, aquifer, and pumping rate identified on the initial well construction record.

Table 2 shows the results for the well depth, aquifer completed in, combined radium 226/228 results and pumping rate written on the initial well record. Private wells are typically constructed differently than public water supply wells and pumped at different rates; private wells have different completed well depths than public water supply wells, have smaller casing diameters, and smaller pumping rates of 10-20 gpm. The public water supply wells in this study have larger diameters and pumping rates ranging from 500 to 2,000 gpm, depending on the city. The private well depths in this study ranged from 100 to 800 feet deep. Table 3 shows the radium concentrations at the different well depths. Elevated radium results, above the MCL, primarily occurred at depths 100 ft to 400 ft. Radium just above detection but below the MCL also primarily occurred at well depths 100 to 500 ft deep and 600-700 ft deep.

Well Depth (ft)	Number of Wells at Each Depth	Percent of Wells at Each Depth	Number of Wells **>5 pCi/L** Radium 226/228	Percent of Wells **>5 pCi/L** Radium 226/228	Number of Wells **1 - 5 pCi/L** Radium 226/228	Percent **1 - 5 pCi/L** Ra 226/228	Number of Wells **<1 pCi/L** Radium 226/228	Percent of Wells **<1 pCi/L** Radium 226/228
100-200	12	25%	3	25%	8	67%	1	8%
201-300	16	33%	4	25%	11	69%	1	6%
301-400	6	13%	3	50%	3	50%	0	0%
401-500	7	15%	1	14%	5	71%	1	14%
501-600	1	2%	0	0%	1	100%	0	0%
601-700	5	10%	0	0%	4	80%	1	20%
701-800	1	2%	1	100%	0	0%	0	0%
Total	48	100%	12	25%	32	67%	4	8%

Table 3: Private well radium 226/228 results compared to well depth (feet).

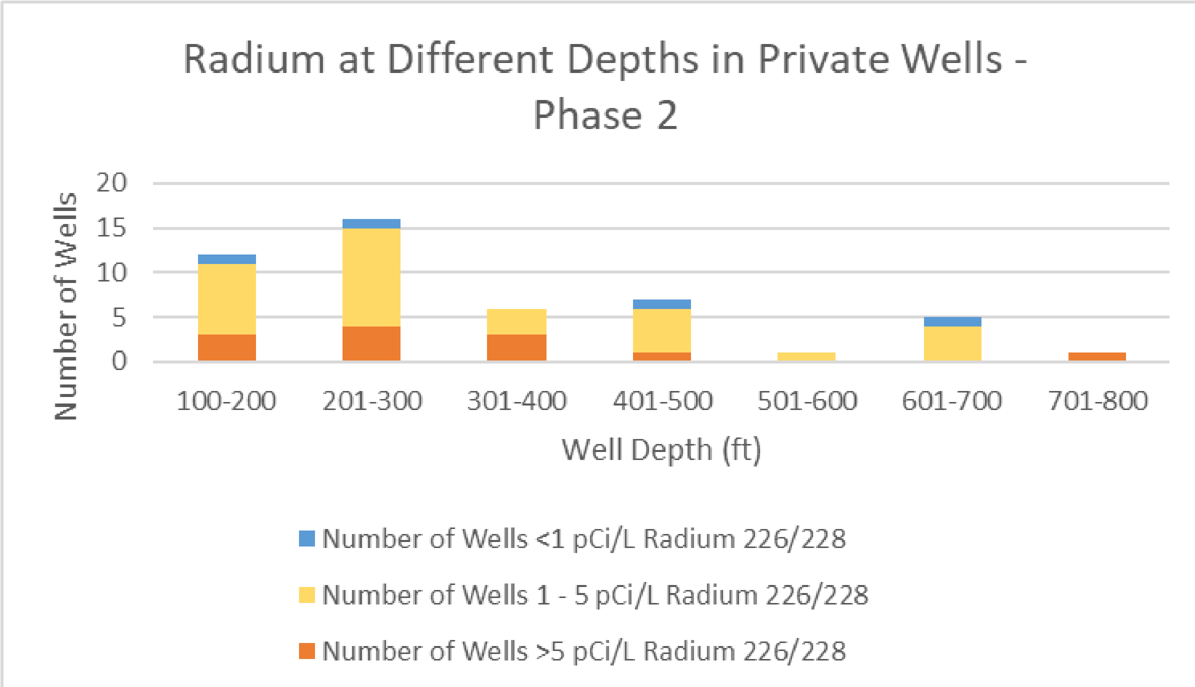


Chart 2: Private well radium 226/228 results compared to well depth (feet).

The private wells sampled were in different aquifers, but the majority sampled in the study were in the Mt. Simon/Eau Claire and Tunnel City-Wonewoc aquifers, as show below in Table 4. Table 4 shows the descriptive statistics for radium concentrations in each aquifer. The results support previous research that the sandstone Mt. Simon aquifer has the highest concentrations of radium, followed by the sandstone Tunnel City-Wonewoc and sandstone Jordan aquifer systems. The Mt. Simon has a mean concentration of 6.91 pCi/L, which is more than twice the means in the other aquifers, with the maximum radium result of 24.8 pCi/L. The Tunnel City-Wonewoc has a mean concentration of 3.27 pCi/L with the second highest maximum of 7.60 pCi/L. The Tunnel City-Wonewoc and Jordan aquifers have similar statistics, with slightly lower average radium concentrations in the Jordan. All the Paleozoic aquifers sampled for radium in this study (the Mt. Simon, Tunnel City-Wonewoc, and Jordan aquifers) had at least one private well with total radium concentrations above the MCL.

Aquifer	# of Wells	Mean	Median	Minimum	Maximum	Standard Deviation
Mt. Simon/Eau Claire	19	6.91	4.70	< 1.00	24.8	6.21
Tunnel City-Wonewoc	14	3.27	3.60	<1.00	7.60	1.98
Jordan	12	2.82	1.85	<1.00	6.10	1.80
Cretaceous	2	2.35	2.35	1.50	3.20	1.20

Table 4: Summary statistics for combined radium 226/228 by aquifer.

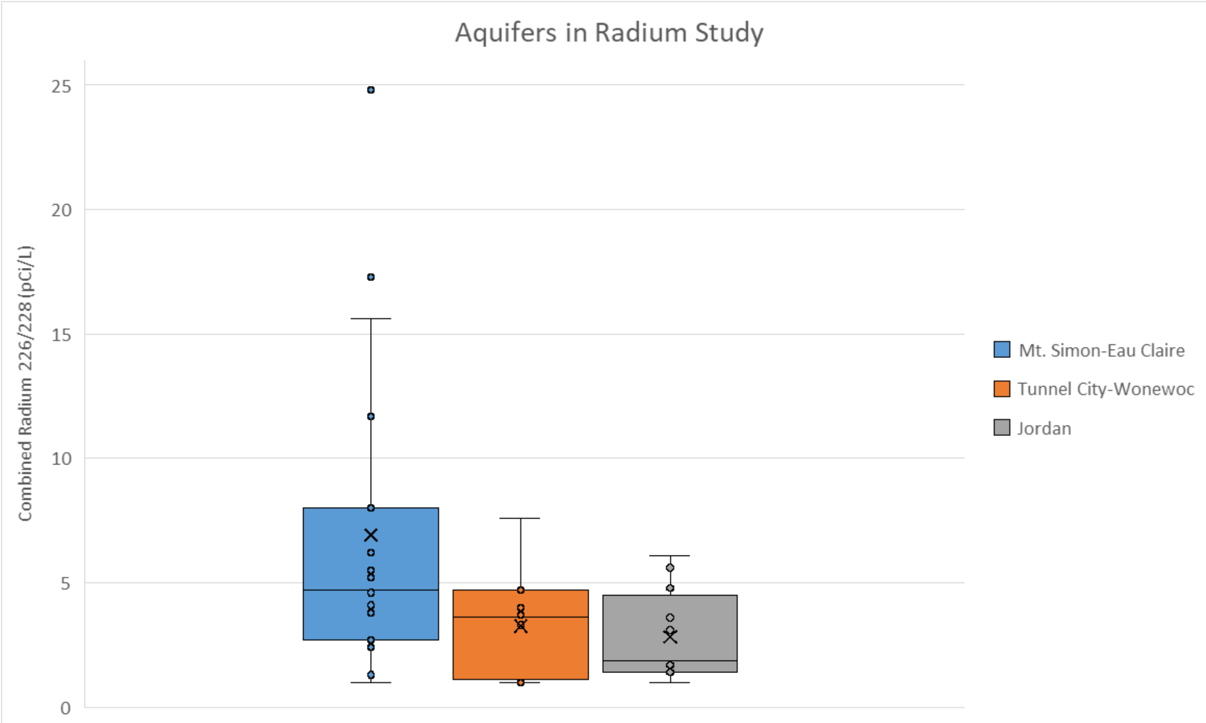


Chart 3: Combined radium 226/228 statistics.

Chart 3 shows the distribution of radium 226/228 data in the Mt. Simon-Eau Claire, Tunnel City-Wonewoc, and Jordan aquifers. The Mt. Simon-Eau Claire aquifer has a greater spread of data with a higher median and the Jordan aquifer has the smallest spread of data and lowest median value. The greatest maximum value is substantially higher in the Mt. Simon, followed by the Jordan aquifer.

There was only one Quaternary well of the original 97 wells sampled in Phase 1 that had gross alpha detected. The radium concentration in that Quaternary well was 2.6 pCi/L. The rest of the Quaternary wells did not have gross alpha detected so they were not resampled. Historically radium concentration data is not found in glacial geology and are not in most of the Quaternary public water supply wells, therefore most of the wells in this study were bedrock wells, Quaternary wells were not a focus of this study.

Are private wells nearby public water supplies with elevated radium also likely to have radium in their drinking water?

Public water supply wells have a greater casing diameter and pumping rate compared to private wells; however, elevated radium concentrations were found in private wells near a public water supply well with elevated combined radium 226/228, especially if the wells were in the same aquifer (Table 4). The magnitude of radium in private wells is less than the public water supply wells, but still at levels that pose a health risk to private well users.

Figures 2,3,4,5, and 6 show simplified geologic cross sections of the five study areas, comparing private well construction to public water supply well construction. Sandstone aquifers, like the Mt. Simon and Jordan aquifers, are more likely to have radium sources that mobilize into the groundwater, especially from the cementing between the grains in these aquifers (Vinson et al., 2012). Public wells with elevated radium completed in sandstone aquifers also have nearby private wells with radium detected in those sandstone aquifers. In the geologic cross sections below, the hatching is an estimate of the extent of the Mt. Simon Sandstone. Older well records do not have clear aquifer interpretations, for example, unique # 404938 was constructed in 1984 and the well record shows the last geologic unit is “Medium Fine Sand” that’s white in color. But in the Minnesota Well Index (MWI), it states the well was completed in the “CMTS”, Mt. Simon aquifer. The analysis in the previous sections uses the MWI aquifer codes but the following geologic cross sections only use the geologic information from the well record, which may or may not identify the aquifer. Public water wells also utilize multiple aquifers, whereas a private well is typically only completed in one aquifer.

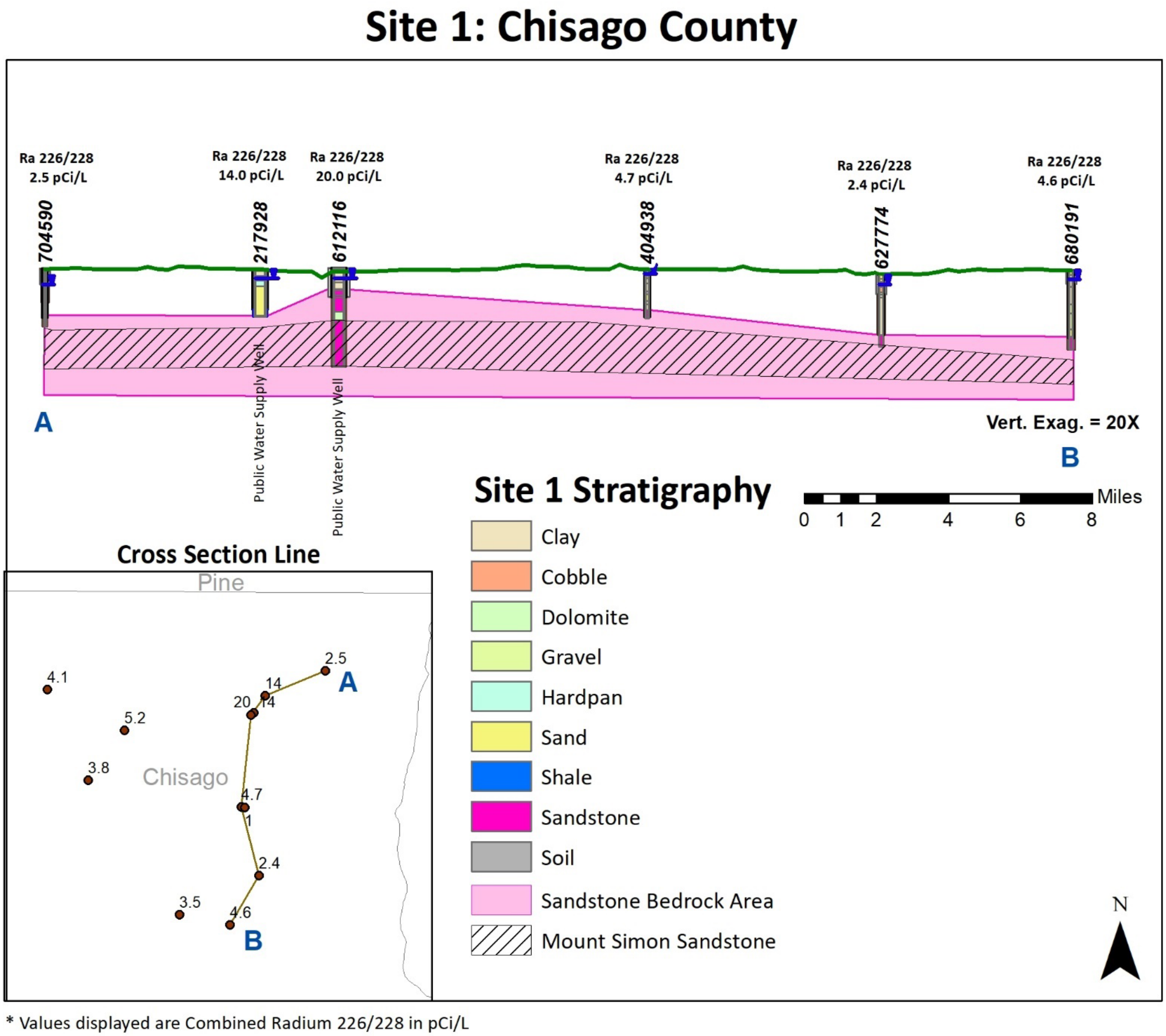
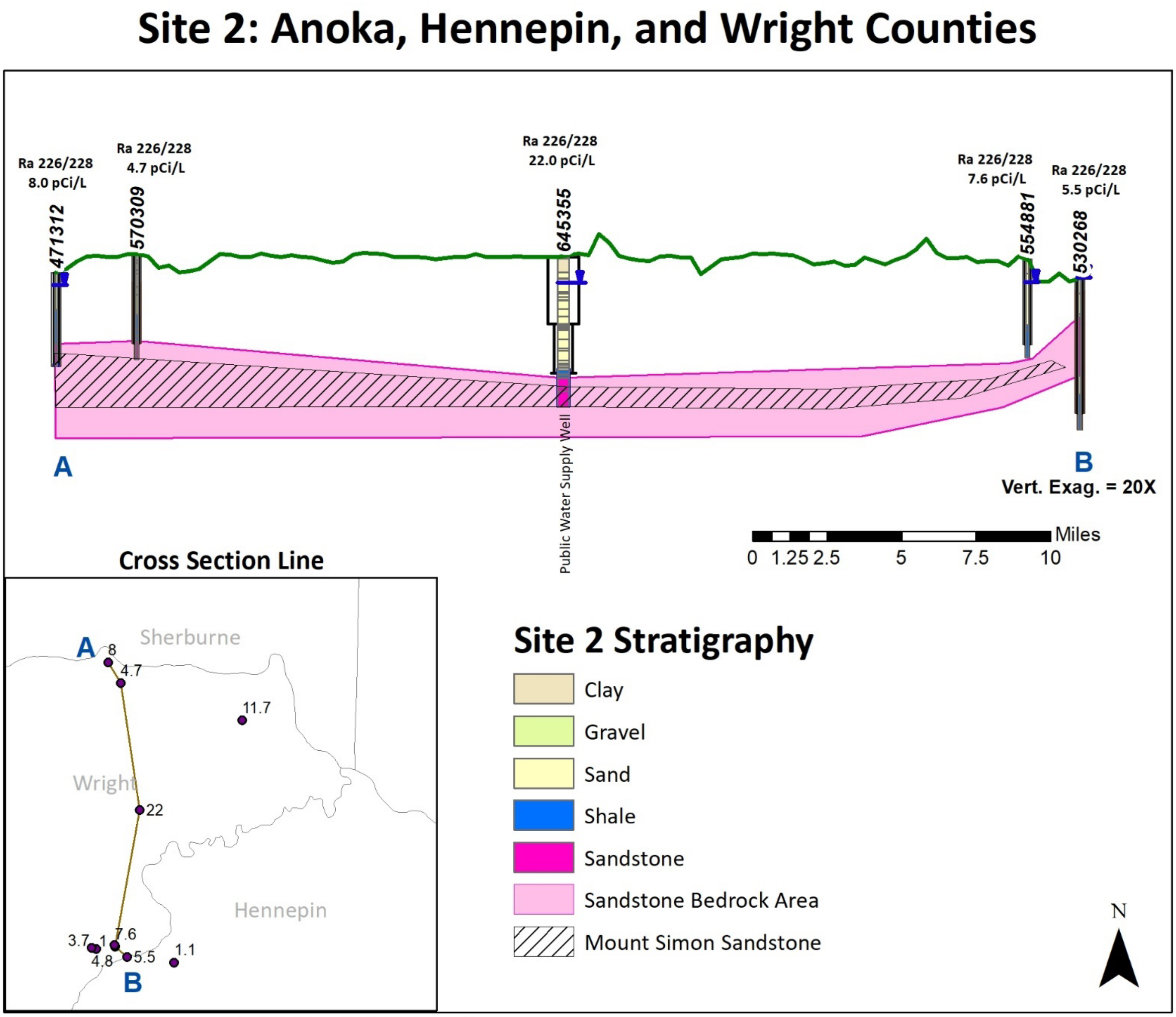


Figure 2: Geologic cross section.

In Site 1 (shown on Figure 2), the public water supplies have the highest concentrations of combined radium 226/228, with 14.0 pCi/L in the Multiple aquifer well, 14.0 pCi/L in the Mt. Simon well and 20.0 pCi/L in the St. Peter-Prairie Du Chien-Mt. Simon well. Nearby private wells are shallower and have smaller well diameters and pumping rates, but also have detected radium in the well water. The Minnesota Well Index (MWI) also identifies these as Mt. Simon sandstone aquifer wells, but the concentrations of radium 226/228 are lower than in the public wells. These wells range over 8 miles from each other. Distance from the public water supply wells isn't strongly correlated to radium concentration for wells in the same aquifer. In this site the Mt. Simon aquifer is shallower than at sites 2, 3 and 5, with the deepest public water supply well 219 ft deep.



* Values displayed are Combined Radium 226/228 in pCi/L

Figure 3: Geologic cross section.

In Site 2 (shown on Figure 3), the public water supply well has a combined radium concentration of 22.0 pCi/L, the surrounding private wells are less than half that level but still above the drinking water standard and pose a health risk. Some of the private wells are in the Mt. Simon aquifer but most are in the

Tunnel City/Wonewoc aquifer. The public water supply well is finished in the Mt. Simon aquifer. The private wells range up to 10 miles apart and many have elevated radium in the water, even in wells that are served by sandstone aquifers other than the Mt. Simon.

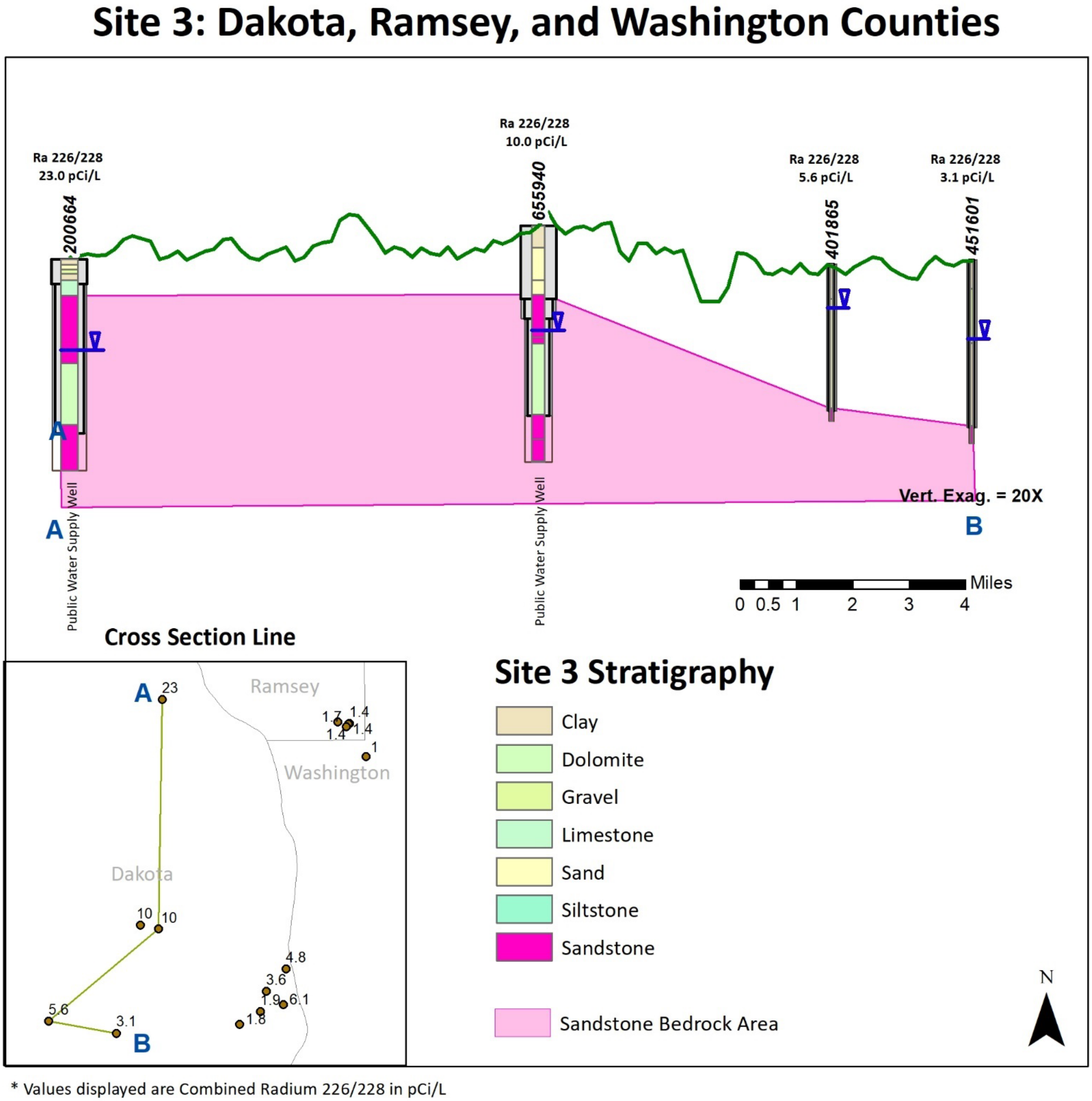


Figure 4: Geologic cross section. The sandstone unit is simplified to show the beginning of sandstone. Other geologic lenses and layers within the sandstone units are not shown in cross section.

In Site 3 (shown on Figure 4) there are no wells in the Mt. Simon sandstone units in this area. All the public and private wells are completed in the Jordan aquifers. The two public water supply wells have elevated combined radium 226/228. Private wells nearby also have radium to a lower magnitude. In the cross section, both public wells are wider diameter and have casing that goes a short way down, with over 300 ft open hole in the aquifer below that, whereas the private wells have much shorter open intervals. The two private wells shown on the cross-section have open holes ranging 20-36 feet.

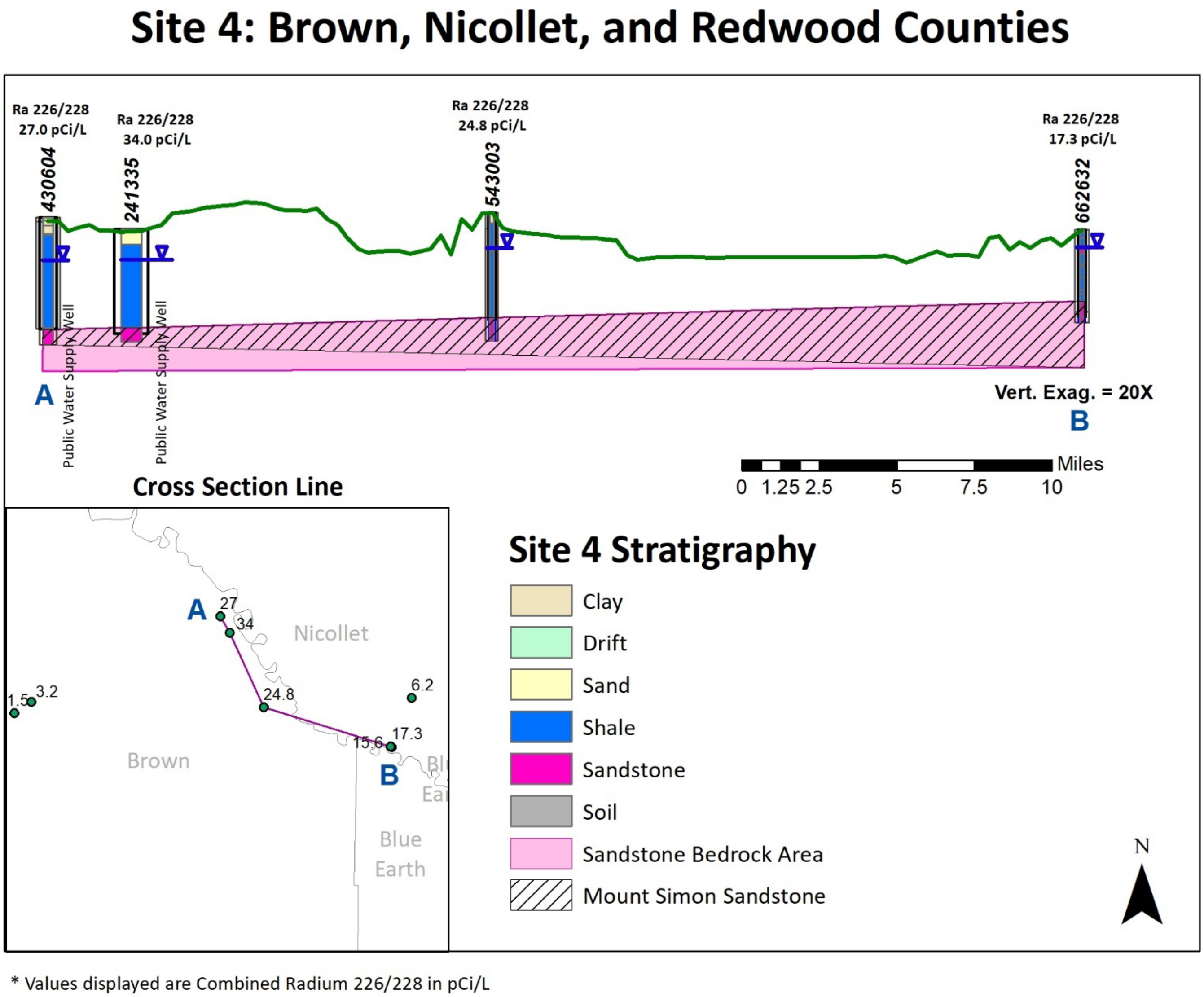


Figure 5: Geologic cross section.

In Site 4 (shown on Figure 5), both the public water supply wells and the private wells are in the Mt. Simon aquifer. Here the Mt. Simon is closer to the surface than at sites 2, 3 and 5 and elevated radium is present. As you move away from the river the private wells are constructed in shallower aquifers than the Mt. Simon and the radium concentration decreases. Private wells are constructed at similar depths to the public well near the river, and the radium concentration in the private wells is almost the same magnitude as the public water supply wells. The well furthest from the public water supply wells along the river is lower in radium magnitude but still very elevated above the 5 pCi/L radium 226/228.

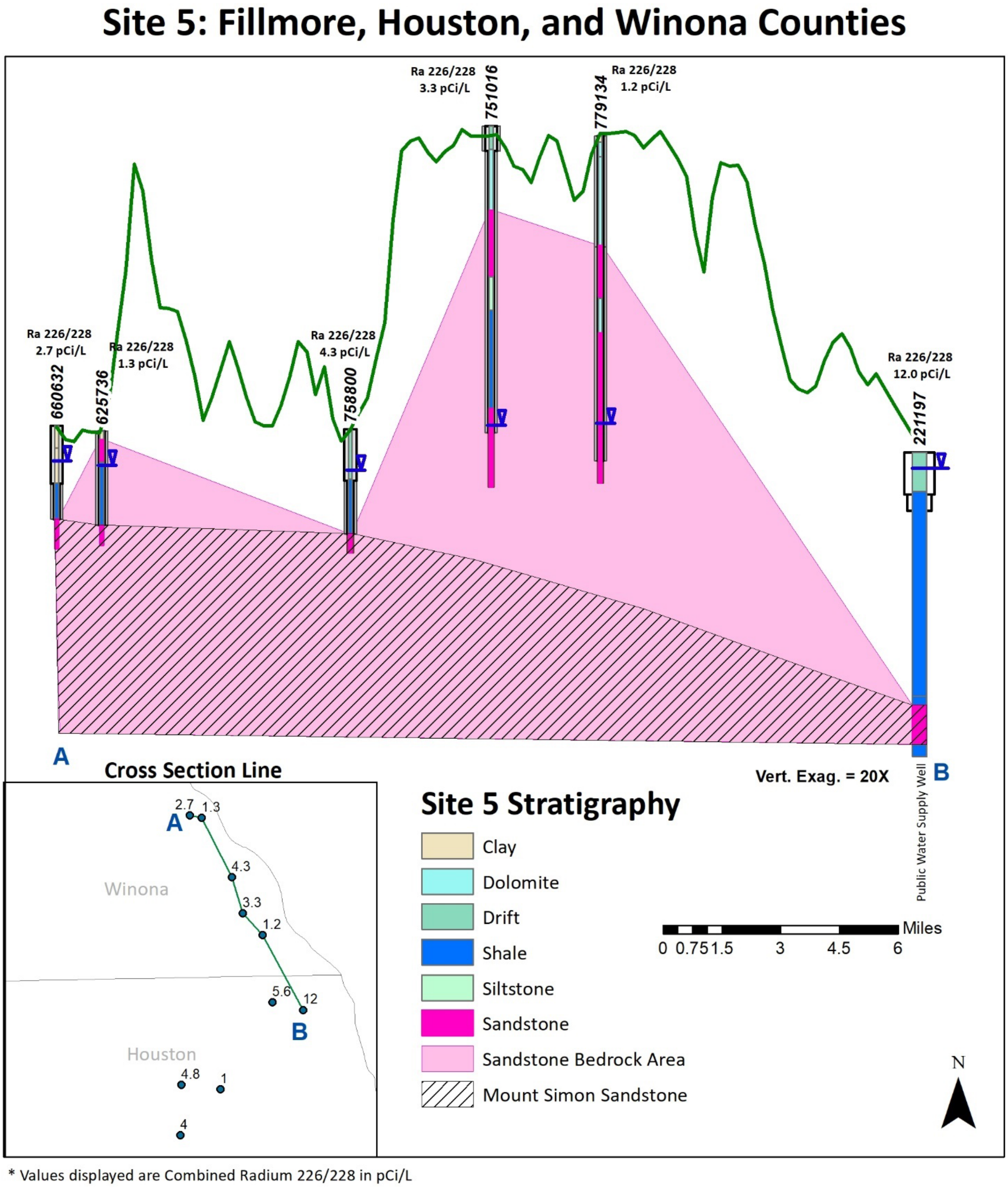


Figure 6: Geologic cross section. The sandstone unit is simplified to show the beginning of sandstone units. Other geologic lenses and layers within the sandstone units are not shown in cross section.

In Site 5 (shown on Figure 6), the public water supply well is a Multiple aquifer well, incorporating the Wonewoc Sandstone, the Mt. Simon, and other aquifer waters. None of the private wells are close in depth to the public well and none are above 5 pCi/L, although they do have radium detected. Three of the wells are in the Mt. Simon and the others are in the Wonewoc Sandstone, although there is not a big difference in the radium concentrations between these aquifers.

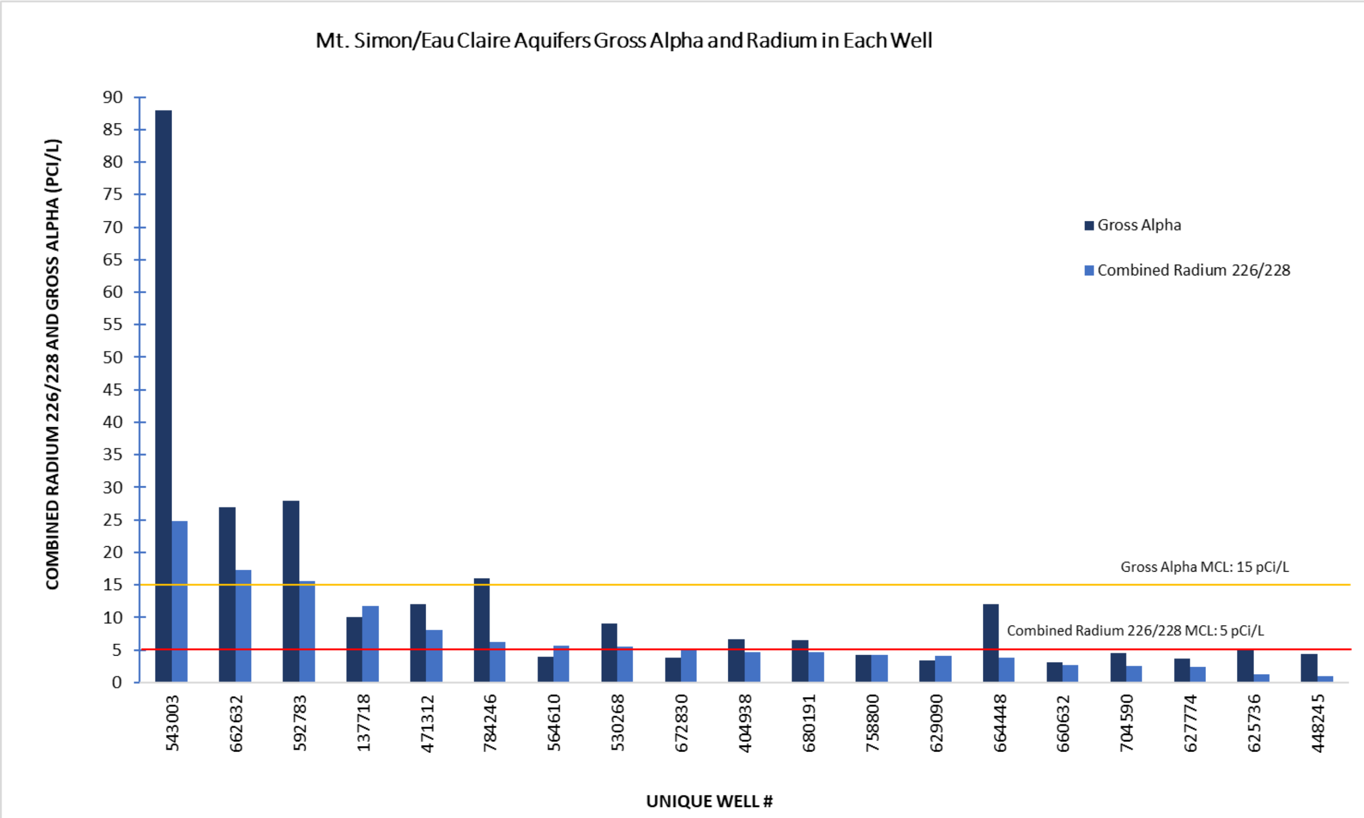
Is Gross Alpha a good indicator for the presence of radium?

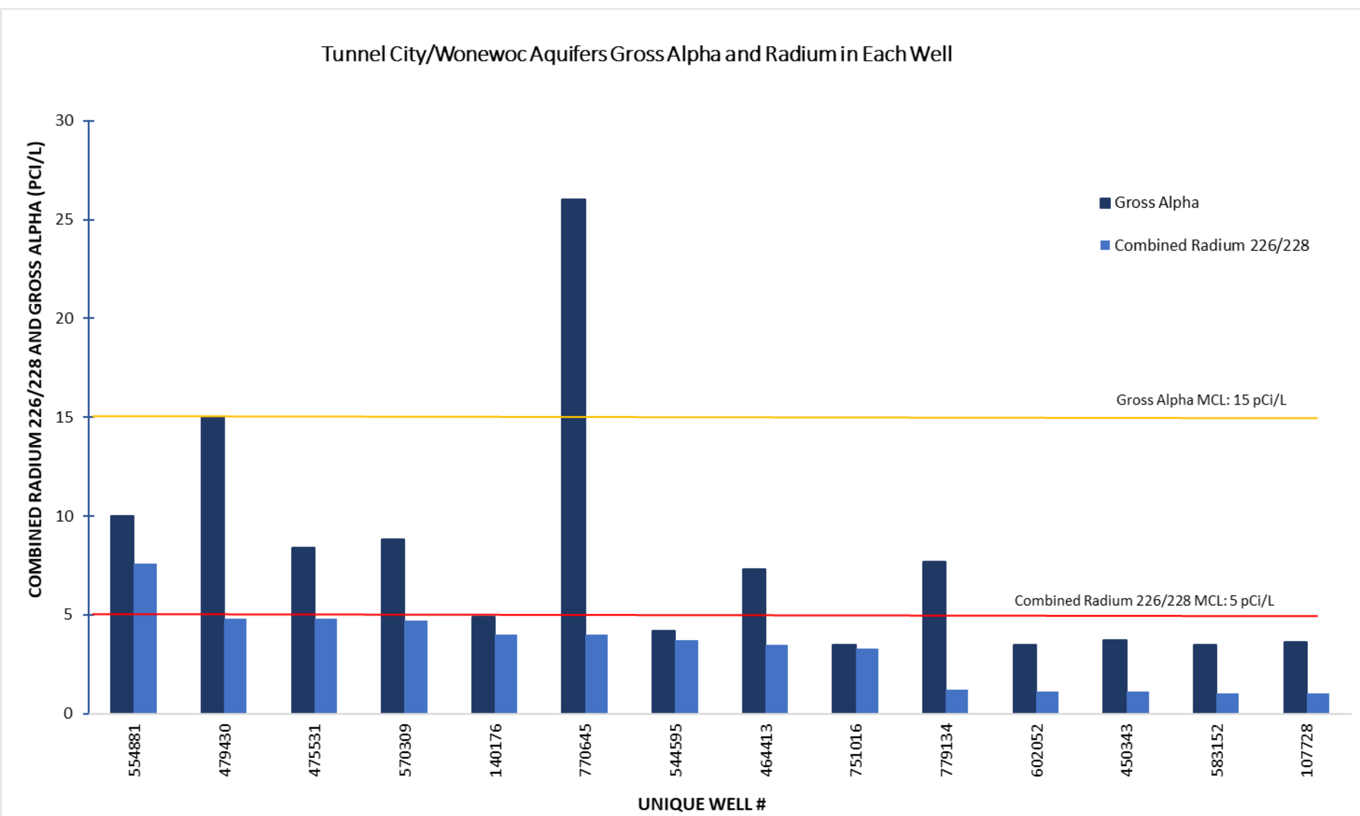
Comparing these results with historic data, it is inconclusive whether gross alpha is a good indicator for radium concentrations in well water. The gross alpha test measures alpha particles, so it will only detect radium-226 because it is the only alpha emitter of the radium ions. Therefore, a limitation of this data is bias towards wells that have some level of radium-226, it cannot confirm which radium isotope is dominant in the groundwater. Radium-228 and radium-224 are beta emitters and will not be detected in the gross alpha test. However, previous studies show radium-226 is the most common radium isotope in groundwater (Lively, 1992), so it should be more likely that some level of radioactivity will be detected by the gross alpha test. The results in Table 5 show gross alpha does not need to be elevated above the MCL (15 pCi/L) for there to be combined radium above the MCL (5 pCi/L) in the water.

Gross Alpha (Phase I) and Radium Results (Phase II)	Number of Wells
Wells sampled for **BOTH** Gross Alpha and Combined Radium 226/228	48
Detected Gross Alpha (**>3 pCi/L**)	48
>15 pCi/L Gross Alpha	6
>1 pCi/L Combined Radium 226/228	44
>5 pCi/L Combined Radium 226/228	12
>15 pCi/L Gross Alpha and **>5 pCi/L** Radium 226/228	5
>5 pCi/L Combined Radium 226/228 and Gross Alpha **3 - 15 pCi/L**	7
>5 pCi/L Combined Radium 226/228 and Gross Alpha **>3 pCi/L**	12
<15 pCi/L Gross Alpha and **>5 pCi/L** Combined Radium 226/228	7

Table 5: Summarize results for gross alpha and combined radium 226/228.

The results show 10.4% of wells in the study had both combined radium 226/228 elevated above the MCL and gross alpha elevated above the MCL. Only wells where gross alpha was detected (3.0 pCi/L detection limit for gross alpha) were sampled for Radium 226/228 in this study. Of those wells with gross alpha detected above 3 pCi/L, 92% of those wells had some level of radium above 1 pCi/L, and 25% had combined radium elevated above the 5 pCi/L MCL.


Mt. Simon/Eau Claire Aquifers Gross Alpha and Radium in Each Well
COMBINED RADIUM 226/228 AND GROSS ALPHA (PCI/L)
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Gross Alpha
Combined Radium 226/228
Gross Alpha MCL: 15 pCi/L
Combined Radium 226/228 MCL: 5 pCi/L
543003
662632
592783
137718
471312
784246
564610
530268
672830
404938
680191
758800
629090
664448
660632
704590
627774
625736
448245
UNIQUE WELL #


Tunnel City/Wonewoc Aquifers Gross Alpha and Radium in Each Well
COMBINED RADIUM 226/228 AND GROSS ALPHA (PCI/L)
30
25
20
15
10
5
0
Gross Alpha
Combined Radium 226/228
Gross Alpha MCL: 15 pCi/L
Combined Radium 226/228 MCL: 5 pCi/L
554881
479430
475531
570309
140176
770645
544595
464413
751016
779134
602052
450343
583152
107728
UNIQUE WELL #

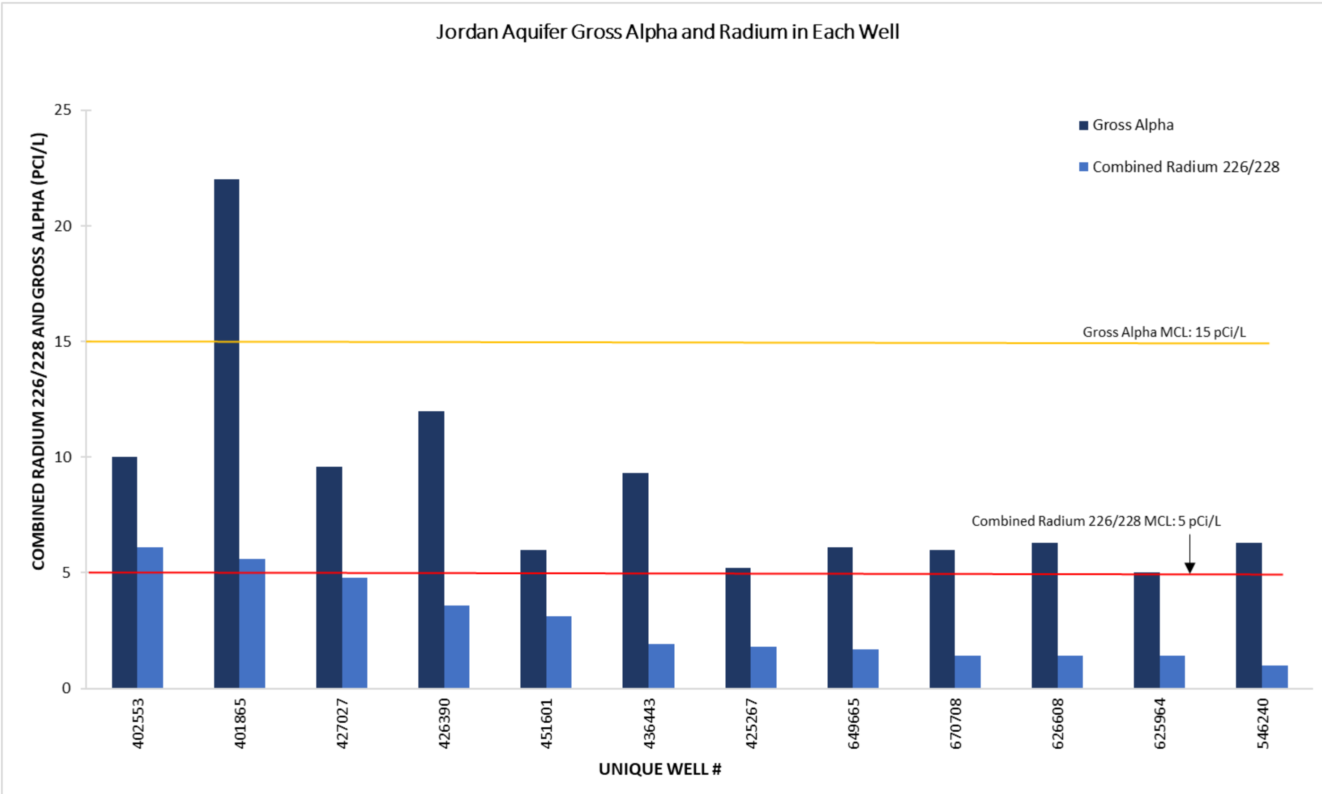


Chart 4: Combined radium 226/228 and gross alpha results in the three aquifers targeted in the study.

Chart 4 shows the combined radium 226/228 and gross alpha results in the three aquifers targeted in the study. They show gross alpha doesn't have to be elevated about the MCL of 15 pCi/L to be elevated above the combined radium 226/228 MCL of 5 pCi/L. There are also alpha emitters in groundwater that are not radium and can contribute to the gross alpha test.

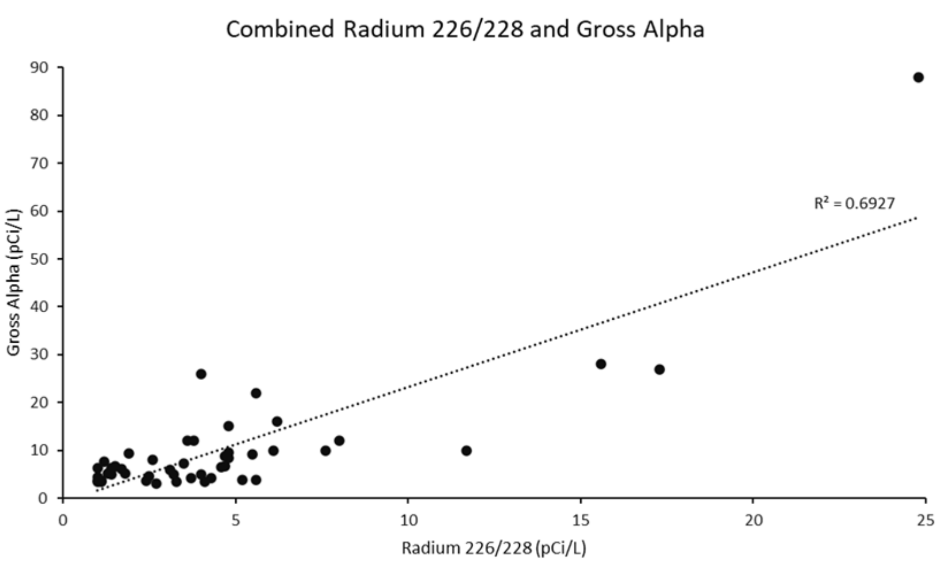


Figure 7: Radium 226/228 and gross alpha – all phase 2 samples.

In figure 7, combined radium 226/228 has a slight correlation with gross alpha, with R^2 of 0.6927. It's not a strong linear correlation, with more spread in gross alpha data at lower combined radium concentrations.

Conclusion

Private wells in Minnesota can have radium in their drinking water, and at levels above the MCL that can pose a long-term health risk to the private well user. Elevated radium, above the MCL 5 pCi/L, in the study occurred mainly in sandstone aquifers, like the Mt. Simon, Tunnel City-Wonewoc Sandstone, and Jordan aquifers. These aquifers were targeted based on public water supply well data and prior studies on radium in Minnesota ground water. Public water supply wells in other aquifers (like glacial aquifers) didn't have detected radium or elevated radium and weren't targeted for the study. Wells didn't need to be deep to have detected radium. Typical well depths where radium was detected ranged from 100-500 ft deep, suggesting the radium presence depends more on the geologic source than well depth. Most of the private wells in the study were shallower wells so the data is biased towards finding radium in well depths that are in the 100-500 ft deep range. Deeper wells can be very expensive for private well users to afford, so wells are more likely to be shallower due to economics and well construction costs. In the Mt. Simon aquifer, 47% of combined radium 226/228 results were above 5 pCi/L (9 of 19 wells), which of those elevated results, 8 of 9 wells were 100 ft deep to 500 ft deep and finished in the Mt. Simon aquifer, which is well known for the presence of dissolved radium in the drinking water (Vinson et al., 2012). In site one and site four, the Mt. Simon is closer to the land surface so wells can be finished in the Mt. Simon more easily. A couple Jordan wells in site 3 also had elevated radium but in slightly deeper wells around 360 ft, showing the geology is the more significant factor in predicting radium occurrence than well depth.

If higher radium aquifers like the Mt. Simon aquifer are closer to the surface, private wells are more likely to be constructed in the bedrock layers that can source radium in the water, and so have a higher chance of radioactivity in their well water. There was only one well, in the Mt. Simon, with a well depth of 740 ft deep, the rest were under 400 ft deep. The deepest well had a combined radium of 5.6 pCi/L, in the central part of site 4 in a Mt. Simon well.

Private wells near a public water supply well with elevated radium are also likely to have radium in their drinking water, but at lower concentrations. Private wells can have radium that presents a health risk, above 5 pCi/L. Private wells in the same aquifer as the public water supply, or adjacent sandstone aquifers, were also more likely to have radium detected in the drinking water. Results from a public water supply well can be a good indicator that radium occurs in an area and that private wells constructed in sandstone aquifers in that area may also have an elevated risk for radium. Private wells near a public water supply don't necessarily mean the concentrations will be elevated, but for the private wells we tested within 6 miles of a public water supply well with radium, the private wells in the sandstone Mt. Simon, Wonewoc, or Jordan aquifers had a higher chance of also having radium than wells in other aquifers.

Gross alpha may be an indicator that radium is also present in drinking water, especially radium concentrations of health concern. The gross alpha does not need to be elevated, just detected, for radium to possibly be present at levels of a potential health concern. The radium concentration can still be above the MCL, even if the gross alpha is low, since radium-228 is not detected in the gross alpha test but can cause the combined radium 226/228 to go above the MCL for radium and pose a health risk. Gross alpha is a cheaper test and there are more private water testing labs in Minnesota that will do the gross alpha test for a private well user. Private well users can test their well water for gross alpha if they are concerned about radioactivity in their well water. If a well has gross alpha or radium, then a water softener is effective at removing radium from drinking water. Since radium behaves geochemically like calcium, it can be removed by a water softener designed to remove calcium.

Future projects could expand testing for private wells in bedrock aquifers near a public water supply with elevated radium, but without gross alpha levels detected. This is to see how many wells contain radium in the well water, even though the gross alpha test shows no detection, to see if there's more radium-228 present. A broader testing of private wells in bedrock aquifers, across a county or region, will provide more support for radium and gross alpha occurrence and which isotope is more common in Minnesota ground water, radium-226 and/or radium-228. If radium-226 is more common, then it shows the gross alpha test can be an effective tool to test for radioactivity in private wells. Future projects could look more in-depth at the geochemistry that mobilizes the radium into the groundwater and the redox processes, and other potentially correlated parameters, like barium. Doing more in-depth geological analysis can help determine radium sources and look at fractures and water movement through the layers to see how the aquifers might mix waters and allow recharge to influence radium mobilization and concentrations. Another project could examine the relationship between public water systems and private wells to understand why the magnitude of radium is so much greater in public wells than private wells. A study could also look at public water systems that don't have radium and randomly sample private wells to see if they do have radium, or gross alpha, to see if radioactivity is occurring, like in glacial and crystalline aquifers, or areas with higher uranium and thorium potential.

References

1. Lundy, James R, (2010), *Distribution of Radium in Minnesota Drinking Water Aquifers*, December 2010, Minnesota Department of Health, Source Water Protection Unit, pp. 1-13.
2. Lively, R.S., Jameson, R., Alexander, E.C., Morey, G.B., 1992. Radium in the Mt. Simon-Hinckley aquifer, east-central and southeastern Minnesota. Minnesota Geological Survey, Information Circular 36.
3. Vinson, D.S., Lundy, J.R., Dwyer, G.S., Vengosh, A., 2012. Implications of carbonate-like geochemical signatures in a sandstone aquifer: Radium and Strontium isotopes in the Cambrian Jordan aquifer (Minnesota, USA). Chemical Geology. 334, pp. 280-294.

Appendix

Table 5: Geochemistry Phase I Sampling

Unique ID	Date Sampled	Gross Alpha (pCi/L)	Alkalinity Total (mg/L)	Chloride (mg/L)	Dissolved Nitrate+Nitrite Nitrogen (mg/L)	Sulfate (mg/L)	Dissolved Arsenic (ug/L)	Dissolved Calcium (mg/L)	Dissolved Iron (ug/L)	Dissolved Potassium (mg/L)	Dissolved Magnesium (mg/L)	Dissolved Manganese (ug/L)	Dissolved Sodium (mg/L)
107728	9/25/2019	3.6	250	< 0.5	< 0.05	15	< 1	60	1720	1.01	30.3	42.3	1.56
137718	7/24/2019	10	320	0.601	< 0.05	15.1	< 1	83	2180	2.3	28.6	279	5.31
140176	6/13/2019	4.9	170	22.2	< 0.05	< 0.5	5.74	42	1420	1.74	13.9	102	19.5
187975	6/26/2019	< 3	110	0.512	< 0.05	6.35	2.77	33	917	0.76	8.42	336	3.11
193762	6/13/2019	< 3	280	11.3	< 0.05	< 0.5	19.1	75	1270	2.06	24.9	96.9	5.43
401865	6/6/2019	22	300	62.4	< 0.05	32.5	2.26	92	2940	2.19	36.8	223	19.6
402553	5/23/2019	10	270	13.4	1.9	20.8	< 1	74	< 20	1.77	30.8	454	4.29
404938	11/26/2018	6.6	320	8.06	< 0.05	10.7	< 1	72	261	2.07	36.5	579	7.89
416411	6/10/2019	< 3	160	8.5	< 0.05	< 0.5	2.96	43	1690	1.42	12.6	163	6.65
425267	5/23/2019	5.2	260	14.7	< 0.05	23.7	< 1	72	1020	2.23	28.3	219	4.76
426390	5/23/2019	12	280	24.2	2.5	23.4	1.95	78	< 20	1.57	32.9	231	4.65
427027	6/3/2019	9.6	240	1.11	< 0.05	10.2	1.29	62	591	2.98	22.7	144	6.02
429864	6/3/2019	< 3	200	1.33	< 0.05	8.58	< 1	53	2200	1.07	23.4	176	2.44
436443	5/23/2019	9.3	260	13.7	1.4	18	< 1	71	< 20	1.59	30.4	82.1	4.44
448245	11/26/2018	4.4	240	10.1	< 0.05	24.1	< 1	66	195	1.8	28.6	543	7.4
450343	6/26/2019	3.7	400	0.578	< 0.05	84.9	< 1	120	4490	2.13	43.3	86.8	10.3
451601	5/23/2019	6	280	5.27	< 0.05	13.6	< 1	72	990	1.68	25.8	205	3.66
452327	6/26/2019	< 3	290	0.704	< 0.05	7.38	< 1	75	740	1.9	29.5	124	4.89
452527	7/24/2019	7.8	270	0.719	< 0.05	< 2.5	3.32	66	1060	1.83	25.8	736	3.36
464413	6/6/2019	7.3	250	0.518	< 0.05	3.67	< 1	56	251	1.56	23.6	390	5.97
467714	6/6/2019	< 3	18	7.96	0.85	7.39	< 1	8.1	838	< 1	3	26.9	4.43
471312	6/10/2019	12	270	0.769	< 0.05	25.1	< 1	71	129	2.27	26.7	342	5.81
475531	9/25/2019	8.4	260	< 0.5	< 0.05	14.9	< 1	56	441	0.95	30.8	40.3	1.65
479430	6/26/2019	15	330	0.624	< 0.05	6.49	< 1	79	1750	2.36	33.9	278	3.99
479649	5/23/2019	< 3	220	0.52	< 0.05	10.4	< 1	56	770	1.18	21.1	52.9	2.18
485820	11/26/2018	< 3	320	1.76	< 0.05	10.2	< 1	80	427	1.6	33.4	405	4.65
493224	6/3/2019	< 3	240	1.13	< 0.05	23.6	< 1	63	1140	1.09	25.7	51.4	2.42
518697	5/23/2019	< 3	220	3.91	0.48	31.9	< 1	65	< 20	1.27	22	< 10	2.51
518810	6/3/2019	< 3	350	63.4	3.6	41.1	< 1	110	279	1.35	39.7	43.6	24.7
519096	6/3/2019	< 3	240	34.1	2.7	31	< 1	76	< 20	1.75	29.2	< 10	9.97
522421	6/6/2019	< 3	270	0.502	< 0.05	< 2.5	< 1	57	26.8	1.48	24.9	540	12.9
530268	6/26/2019	9.1	350	0.51	< 0.05	33	< 1	96	4790	2.75	33.3	85.3	5.06
537805	11/26/2018	< 3	370	0.513	< 0.05	0.52	< 1	63	79.1	1.94	53.7	667	5.81
543003	7/31/2019	88	400	13.3	< 0.05	410	< 1	180	2830	9.18	62.9	84.7	44
544507	7/24/2019	< 3	320	0.63	< 0.05	6.72	2.01	77	856	2.51	31.8	171	4.11
544595	6/26/2019	4.2	320	0.629	< 0.05	6.26	2.13	76	625	2.59	33.1	248	4.15
546240	6/3/2019	6.3	220	7.86	< 0.05	35.1	< 1	62	693	0.97	24.7	< 10	3.46
554749	6/3/2019	< 3	250	35.1	1.7	29.8	< 1	78	< 20	1.57	30.6	< 10	11.7
554881	6/26/2019	10	320	0.624	< 0.05	8.76	< 1	77	582	2.22	32.7	271	4.27
556280	9/19/2019	< 3	210	< 0.5	< 0.05	14.8	< 1	49	715	1.2	26.6	14.8	1.84
559043	6/10/2019	< 3	200	57.5	< 0.05	< 0.5	7.2	< 2	< 20	< 0.5	< 2	< 10	131
564610	9/25/2019	3.9	230	4	< 0.05	26.4	< 1	59	813	2.2	26.9	43.3	4.82
570309	7/24/2019	8.8	250	0.771	< 0.05	< 2.5	< 1	57	771	2.35	23.4	178	3.42
583152	7/24/2019	3.5	320	0.593	< 0.05	10.8	< 1	80	588	2.05	29.8	196	4.32
587312	10/9/2019	< 3	240	0.952	0.5	14.6	< 1	52	< 20	1.05	28.9	< 10	1.85
592783	7/31/2019	28	290	50	< 0.05	119	< 1	89	866	3.06	29.9	61.3	51.5
596147	8/21/2019	32	290	57.5	< 0.05	74.4	< 1	87	1220	2.33	32.4	99.8	40.5
602052	7/24/2019	3.5	190	38	< 0.05	2.29	< 1	54	1100	1.97	17.1	99.4	17.2
625707	10/9/2019	< 3	260	1.29	0.05	22.4	< 1	61	< 20	1.39	31.5	< 10	2.08
625736	10/7/2019	5.1	250	0.52	< 0.05	17.7	< 1	55	640	1.62	27.8	49.6	1.43
625964	6/3/2019	5	210	1.36	< 0.05	19.7	< 1	55	1430	1.05	22.4	36.9	2.78
626608	6/3/2019	6.3	200	2.19	< 0.05	22.1	< 1	55	950	1.13	21.5	30.4	2.6
627774	6/6/2019	3.7	230	4.21	< 0.05	2.35	< 1	< 2	< 20	< 0.5	< 2	< 10	111
629090	6/13/2019	3.4	270	< 0.5	< 0.05	< 2.5	20.9	54	2110	1.44	28.8	29.2	14.6
635315	6/26/2019	< 3	340	0.56	< 0.05	9.65	1.7	89	1070	1.49	31.2	51.7	5.02
644002	6/10/2019	< 3	63	3.88	2.2	5.82	< 1	18	< 20	1.19	8.41	< 10	2.93
649665	6/6/2019	6.1	200	3.68	< 0.05	30.2	< 1	57	956	< 1	22.6	24.1	2.69
653384	6/13/2019	< 3	63	4.35	3.6	6.64	< 1	21	< 20	1.08	8.52	< 10	2.79
653550	9/10/2019	5	420	1.55	< 0.05	79.4	< 1	85	1230	8.77	38.7	89.5	65.5
660632	10/7/2019	3.1	210	0.649	< 0.05	16.8	< 1	49	709	1.49	25.3	39.1	1.61
660754	8/21/2019	8	550	1.47	< 0.05	345	6.17	190	6480	5.72	75.7	721	42.6
662632	8/21/2019	27	290	34.6	< 0.05	134	< 1	92	1410	2.96	31.4	60	48.5
664448	6/6/2019	12	260	< 0.5	< 0.05	< 2.5	1.26	56	480	1.86	26	117	4.66

Unique ID	Date Sampled	Gross Alpha (pCi/L)	Alkalinity Total (mg/L)	Chloride (mg/L)	Dissolved Nitrate+Nitrite Nitrogen (mg/L)	Sulfate (mg/L)	Dissolved Arsenic (ug/L)	Dissolved Calcium (mg/L)	Dissolved Iron (ug/L)	Dissolved Potassium (mg/L)	Dissolved Magnesium (mg/L)	Dissolved Manganese (ug/L)	Dissolved Sodium (mg/L)
665492	9/25/2019	< 3	240	< 0.5	< 0.05	22	< 1	56	873	1.42	32.1	13.8	1.87
668032	7/24/2019	< 3	300	0.702	< 0.05	3.9	< 1	71	2370	2.18	29.7	159	4.85
670708	6/3/2019	6	210	1.4	< 0.05	19	< 1	54	900	0.77	21.5	30.6	2.64
672627	9/19/2019	< 3	240	< 0.5	< 0.05	18.3	< 1	76	152	1.9	19.9	18.3	1.95
672830	6/10/2019	3.8	280	0.696	< 0.05	3.53	2.95	62	843	1.8	27.8	504	5.23
675658	7/31/2019	< 3	480	1.41	< 0.05	358	6.68	140	6070	3.15	53.6	164	105
675840	6/13/2019	< 3	300	< 0.5	< 0.05	< 2.5	< 1	< 2	< 20	< 0.5	< 2	< 10	139
677692	10/9/2019	< 3	240	< 0.5	< 0.05	26	< 1	55	945	1.42	28	14.4	1.6
678912	10/9/2019	< 3	290	< 0.5	< 0.05	24.5	< 1	59	804	1.5	34.6	12.4	1.72
678990	7/31/2019	< 3	470	0.7	< 0.05	115	10.1	130	4180	3.44	42.6	482	33.3
680191	6/10/2019	6.5	300	1.16	< 0.05	< 2.5	4.32	65	3970	1.43	27.2	1570	7.73
685919	9/25/2019	< 3	240	< 0.5	< 0.05	17.5	< 1	< 2	< 20	< 0.5	< 2	< 10	124
690287	6/13/2019	< 3	320	< 0.5	< 0.05	< 2.5	< 1	< 2	< 20	< 0.5	< 2	< 10	152
704590	6/6/2019	4.5	340	8.29	< 0.05	3.15	4.26	82	1490	2.38	31.1	133	10.3
712525	6/10/2019	< 3	230	1.6	< 0.05	4.45	1.64	48	236	1.39	27.7	492	4.29
725137	5/23/2019	< 3	220	0.501	< 0.05	11.7	< 1	58	2770	1.21	20.7	57.1	2.13
731426	9/10/2019	6.7	410	22.4	< 0.05	79.9	< 1	30	< 200	6.74	16	30.9	160
733089	9/19/2019	< 3	200	0.618	< 0.05	14	< 1	49	1900	0.88	23.4	55.5	1.85
737915	10/9/2019	< 3	250	< 0.5	< 0.05	24	< 1	65	431	0.96	25.2	25.1	2.67
740635	9/10/2019	< 3	310	25.4	< 0.05	790	< 1	90	1010	10.1	36.7	51.6	333
743634	8/21/2019	4.8	270	28.3	< 0.05	173	< 1	57	593	6.43	25.9	14.3	93.7
749513	7/31/2019	< 3	430	0.94	< 0.05	216	9.62	110	2000	3.98	42.9	475	74
751016	10/7/2019	3.5	270	1.07	< 0.05	31.3	< 1	67	74.7	1.15	30.8	15.5	1.74
758032	6/13/2019	< 3	320	0.665	< 0.05	< 2.5	< 1	68	< 20	1.96	37.5	1690	8.31
758800	10/7/2019	4.2	250	0.804	< 0.05	20.9	< 1	63	1020	1.79	29.3	62.4	1.48
760668	9/10/2019	< 3	440	0.899	< 0.05	211	7.12	120	1200	< 5	43.5	138	72.1
769179	9/10/2019	< 3	210	69.7	< 0.05	832	< 1	55	< 200	8.07	17.2	26.3	407
770645	9/25/2019	26	260	< 0.5	< 0.05	15.1	< 1	58	1430	1.01	29.7	38.1	1.6
775004	7/31/2019	10	410	< 0.5	< 0.05	< 1	8.46	98	5700	4.41	29.6	228	12.3
778537	9/19/2019	< 3	230	3.01	< 0.05	34.8	< 1	< 2	< 40	9.73	< 2	< 10	115
779134	10/9/2019	7.7	280	< 0.5	< 0.05	18	< 1	64	2190	0.73	30	45.8	1.54
784246	7/31/2019	16	410	0.666	< 0.05	321	1.04	180	< 60	6.09	63.7	136	9.1
786119	8/21/2019	< 3	350	16.3	< 0.05	590	< 1	160	222	7.58	56.7	1840	146
795738	9/10/2019	< 3	240	58.8	< 0.05	559	< 1	64	354	7.32	27	30.8	269

Table 6: Geochemistry Phase II Sampling

Unique ID	Date Sampled	Radium-226 (pCi/L)	Radium-228 (pCi/L)	Combined Radium-226/228 (pCi/L)	Alkalinity Total (mg/L)	Chloride (mg/L)	Dissolved Nitrate+Nitrite Nitrogen (mg/L)	Sulfate (mg/L)	Barium (ug/L)	Dissolved Calcium (mg/L)	Dissolved Iron (ug/L)	Dissolved Potassium (mg/L)	Dissolved Magnesium (mg/L)	Dissolved Manganese (ug/L)	Dissolved Sodium (mg/L)
107728	9/10/2020	< 1	< 1	< 1	250	< 0.5	< 0.05	15.4	< 20	57	1330	1.1	29.2	42.4	1.51
137718	8/18/2020	3.2	8.5	11.7	320	0.618	< 0.05	14.4	73	83	3520	2.64	28.9	296	5.87
140176	8/11/2020	1.1	2.9	4	180	20.7	< 0.05	< 0.5	64.8	41	1280	1.71	13.9	102	19.3
401865	8/4/2020	4.5	1.1	5.6	320	74	< 0.05	35.8	306	93	3250	2.3	37.8	244	23.1
402553	8/4/2020	6.1	< 1	6.1	280	13	1.6	21.9	374	72	< 20	1.86	31	487	4.52
404938	9/8/2020	2.4	2.3	4.7	310	9.66	< 0.05	18.5	95.2	70	385	2	35.8	610	7.38
425267	8/25/2020	1.8	< 1	1.8	270	16.4	< 0.05	26.3	237	73	939	2.32	29.5	241	5.71
426390	8/25/2020	3.6	< 1	3.6	280	28.9	2.7	24.9	381	83	< 20	1.85	34.2	160	4.9
427027	8/4/2020	2.6	2.2	4.8	250	< 0.5	< 0.05	8.85	123	61	2890	2.92	23.4	182	4.14
436443	8/4/2020	1.9	< 1	1.9	270	14.1	1.3	19.5	197	70	< 20	1.53	30.8	95.2	4.78
448245	9/4/2020	< 1	< 1	< 1	250	11.6	< 0.05	27.2	< 20	63	189	1.82	28.1	537	6.36
450343	8/11/2020	1.1	< 1	1.1	400	0.568	< 0.05	87.2	137	110	2940	2.11	41	81.7	11.4
451601	8/25/2020	2	1.1	3.1	290	5.87	< 0.05	14.3	183	74	1050	2.01	26.8	215	3.76
464413	9/4/2020	1.5	2	3.5	260	0.513	< 0.05	4.01	39.9	58	270	1.6	25.1	352	5.83
471312	8/11/2020	3.4	4.6	8	290	0.76	< 0.05	26.2	52.8	70	248	2.32	26.4	349	6.42
475531	9/10/2020	1.9	2.9	4.8	250	< 0.5	< 0.05	15.2	31.2	54	425	0.88	29.3	40.9	1.53
479430	8/18/2020	4.8	< 1	4.8	330	0.622	< 0.05	7.09	95.5	77	930	2.79	33.1	268	4.5
530268	8/11/2020	2.9	2.6	5.5	350	< 0.5	< 0.05	34.5	97.6	92	3520	2.8	32.5	87.4	4.99
543003	8/28/2020	17.3	7.5	24.8	400	13.8	< 0.05	412	113	180	2730	10.5	65.3	79.2	48.3
544595	8/11/2020	1.9	1.8	3.7	330	0.639	< 0.05	7.08	112	72	595	2.72	31.5	250	4.37
546240	8/4/2020	< 1	< 1	< 1	230	12.4	< 0.05	39.2	< 20	64	1250	1.1	26.6	11.8	4.5
554881	8/18/2020	2.8	4.8	7.6	330	0.613	< 0.05	9.21	115	78	495	2.55	31.1	277	4.52
564610	9/10/2020	2	3.6	5.6	220	4.17	< 0.05	26.4	56.9	55	1030	2.11	24.7	47.4	4.63
570309	8/11/2020	3.4	1.3	4.7	250	0.771	< 0.05	1.8	20.5	56	763	2.42	23.6	176	3.72
583152	8/18/2020	< 1	< 1	< 1	320	0.584	< 0.05	10.3	87	78	553	2.42	29.7	195	4.88
592783	8/28/2020	6.5	9.1	15.6	290	51.4	< 0.05	121	87	90	792	3.76	30.3	54.4	54.1
602052	8/18/2020	< 1	1.1	1.1	190	41.6	< 0.05	2.53	71.8	54	1500	2.41	17.3	104	19
625736	9/22/2020	1.3	< 1	1.3	230	0.543	< 0.05	18.3	31.1	53	593	1.59	27	51.1	1.35
625964	8/25/2020	1.4	< 1	1.4	220	0.841	< 0.05	15.6	< 20	55	2250	1.36	23.3	52	2.83
626608	8/4/2020	1.4	< 1	1.4	210	2.52	< 0.05	22.8	< 20	55	738	1.13	21.7	30.2	2.93
627774	9/4/2020	1.2	1.2	2.4	230	4.39	< 0.05	2.19	< 20	57	593	1.95	20.3	417	6.5
629090	9/8/2020	1.2	2.9	4.1	280	< 0.5	< 0.05	1.33	66.4	53	2070	1.49	28.3	30.7	13.8
649665	8/25/2020	1.7	< 1	1.7	210	3.1	< 0.05	28.9	< 20	56	505	0.94	22.8	18.6	2.92
653550	8/28/2020	1.3	1.9	3.2	420	1.57	< 0.05	81.5	42.4	78	1140	8.46	36.1	84	58.1
660632	9/22/2020	1.1	1.6	2.7	210	< 0.5	< 0.05	17.1	30.4	47	608	1.45	24.8	38.9	1.43
660754	9/1/2020	1.5	1.1	2.6	550	1.63	< 0.05	357	114	190	6030	6.83	77.3	661	42.2
662632	9/1/2020	6.6	10.7	17.3	290	36.1	< 0.05	137	112	92	990	3.78	30.7	55.1	48
664448	9/8/2020	1.7	2.1	3.8	270	< 0.5	< 0.05	2.2	< 20	58	649	1.87	27.2	131	4.97
670708	8/18/2020	1.4	< 1	1.4	210	0.947	< 0.05	18.3	< 20	55	518	0.88	22.1	26	2.77
672830	9/8/2020	1.2	4	5.2	290	0.69	< 0.05	3.79	119	64	644	1.89	29	542	5.28
680191	9/4/2020	1.7	2.9	4.6	310	1.22	< 0.05	< 0.5	31	67	3960	1.6	28.5	1520	7.97
704590	9/4/2020	1.3	1.2	2.5	350	8.85	< 0.05	3.29	39.5	81	1260	2.47	32	134	10.8
731426	8/28/2020	1.5	< 1	1.5	420	27.8	< 0.05	85.8	56.9	27	144	8	14	25.7	176
751016	9/22/2020	1.4	1.9	3.3	260	1.03	< 0.05	32	< 20	65	69.5	1.01	30.3	13	1.57
758800	9/10/2020	1.4	2.9	4.3	250	0.777	< 0.05	21.5	41.9	59	843	1.92	28.7	66.1	1.5
770645	9/10/2020	1.2	2.8	4	250	< 0.5	< 0.05	14.6	26.7	55	1140	0.85	29.2	33.2	1.44
779134	9/22/2020	1.2	< 1	1.2	260	< 0.5	< 0.05	20.8	< 20	63	918	0.68	28.2	32.5	1.4
784246	8/28/2020	1.3	4.9	6.2	410	0.62	< 0.05	271	26.7	160	< 40	6.63	58.3	118	10.8