Buried Sand and Gravel Aquifers of the Breckenridge/Wahpeton Area, Minnesota and North Dakota

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Introduction and Purpose

Located on the border between North Dakota and Minnesota, the communities of Wahpeton, North Dakota and Breckenridge, Minnesota meet at the confluence of Bois de Sioux and Ottertail rivers; these rivers form the beginning of the Red River of the North. In addition to sharing these surface water resources, residents of these communities have long understood that they share buried sand and gravel and sandstone aquifers that straddle the border beneath these rivers.

This report provides updated maps showing the distribution of the buried sand and gravel aquifers as well as insights into the recharge characteristics of these aquifers. These insights are based on a limited amount of geochemical evidence (isotopic and general chemistry of water samples collected from wells) and apparent hydrostratigraphic connections (hydraulic connections from surficial aquifers to the buried sand and gravel aquifers).

Management of these limited cross-border resources has been a contentious issue between local and state government entities in the past and could be again in the future. Continued mapping and monitoring of these aquifers will be a key component of successful management strategies.

History of Water Use and Investigations

In 1969, at the request of the Wahpeton City Council, the North Dakota State Water Commission (NDSWC) began a general investigation of groundwater resources in the area by drilling 52 test holes to depths up to 400 feet (Froelich, 1974). Most of the boreholes were completed as observation wells; water samples were collected from them for general chemistry, and one aquifer test was completed. The general thickness and boundaries of a major northwest-southeast trending buried sand aquifer were defined in this report and was named the Wahpeton Buried Valley (WBV) aquifer. With an approximate thickness of 200 feet, an approximate length and width of 16 miles and two miles, respectively, the WBV was recognized as a major and valuable natural resource in the area. Above the top of the Wahpeton Buried Valley aquifer (at a depth of approximately 100 feet beneath the City of Wahpeton), another thinner (approximately 20-40 foot thickness) aquifer was identified as the Wahpeton Sand Plain (WSP) aquifer. In the report, Froelich describes the WSP aquifer as consisting of two units; he believed the Ottertail Unit originated from eastern melt-water channels and the Colfax Unit from western melt-water channels. These two units were described as coalescing in the northern portion of the study area. Froehlich also stated “There are no irrigation or industrial wells developed in the area at the present time (1974)”.

In 1974 the Minn/Dak Coop Sugar Beet processing plant (Minn/Dak) went into operation approximately three miles north of the Wahpeton City limits near the three Wahpeton city wells (Ripley, 1988). From 1974 until 1985 Minn/Dak used the Wahpeton City wells for their supply. The city wells pumped water from the Wahpeton Buried Valley aquifer. For many years, Minn/Dak disposed of their process water into open lagoons within approximately 900 hundred feet of the Wahpeton city well #2. According to Ripley (1988), the water quality of samples from the Wahpeton city well #2 (near the disposal lagoons) was becoming progressively worse with increasing total dissolved solids (TDS) and hardness from 1980 through 1985. Additional drilling, observation well installations, sampling, and testing by the NDSWC determined that the source of the city well #2 contamination was, in fact, the sugar beet processing water that was disposed in the lagoons near city well #2. The pathway of water from the surface disposal lagoons to the Wahpeton Buried Valley aquifer was apparently through a particularly thick portion of surface sand; this surface sand was a conduit to the WSP aquifer that was apparently connected to the WBV aquifer in which city well #2 was completed. This surficial sand unit was called the Wahpeton Shallow Sand (WSS) aquifer.

The remediation of this contamination problem first began in 1986 with lining the disposal lagoons to stop water from seeping underground. The second step was remedial pumping from two newly installed wells; one of these two wells was located in the shallower WSS aquifer and the other was located in the deeper WBV aquifer. In addition, a third well, city well #2, was pumped to clean up the WBV aquifer in the vicinity of city well #2. During this period of high-capacity pumping at the Minn/Dak and Wahpeton city well sites north of Wahpeton, production from the City of Breckenridge wells, located approximately 3.5 miles to the southeast, was reduced by 50 gallons per minute in both wells. This reduction, caused by remediation pumping at the Minn/Dak site between 1986 and 1987, clearly showed that the WBV aquifer that straddled the state border was the same aquifer used by the City of Breckenridge (Dan Zwilling, unpub. report, 1990).

By 1990, with observation well water level and water use data provided by the NDSWC, it became generally understood that a cone of depression (with a maximum depth of approximately 50-60 feet) had been created by the combined effects of high capacity pumping in the area. In 1995, an increase in groundwater pumping by Minn/Dak and a proposal for the construction of a ProGold corn processing facility in Wahpeton that would also require large groundwater appropriations, prompted the Minnesota Department of Natural Resources (DNR), Division of Waters to write a letter to the NDSWC State Engineer and request "additional study and evaluation of this potential impact" of the proposed groundwater appropriations by the ProGold Plant (Minnesota DNR, written communication, 1995).

Due to these concerns, the NDSWC, Minnesota DNR, and Wilkin County Environmental Services collaborated from 1995 through 1998 on an area groundwater investigation that included:

- Collection of groundwater samples from 42 wells in Richland (North Dakota) and Wilkin (Minnesota) counties to be analyzed for stable isotopic analysis of ^{18}O and deuterium (Table 2), and general chemistry (Table 3).
- Drilling through the entire glacial section into Cretaceous bedrock at 11 locations in Minnesota with North Dakota drilling equipment and staff. Eighteen observation wells were installed at these locations with eight of these sites completed with two or more closely spaced wells of different depths (well nests).
- Completion of water level synoptic measurement events in June and October of 1995.

Since the results of this investigation have never been summarized, one of the objectives of this report is to summarize these data and integrate them with all the data available from this area, including approximately 70 new wells that have been drilled in this area since 1995.

Geologic Mapping Methods

Buried sand and gravel aquifers are an important groundwater resource throughout the study area for domestic, municipal, and industrial use. The locations of buried sand and gravel aquifers, however, are often difficult to map. Knowledge of these aquifers primarily depends on drill hole information, and the reliability of the aquifer maps depends on the spatial density of that information. A mapping method using closely spaced cross sections has become a standard method for mapping buried sand and gravel aquifers in Minnesota since it was first used for geologic atlases (Berg, 2006) and other reports (Thorleifson and others, 2005). This method was also used to produce the maps on Plates 1 and 2 of this report. A brief description of the assumptions and methods used for this report is provided to help the user understand the strengths and limitations of these maps.

The aquifer systems in the study area were mapped by constructing 40 west-east geologic cross sections with a 1-kilometer north-south spacing across the project area. Well information from the Minnesota County Well Index (CWI) and NDSWC within 500 meters on either side of each cross section line was projected to the line. The cross sections were constructed by first creating "stick diagrams" using a custom ArcGIS extension. Each stick diagram consists of a colored representation of the driller's log of geologic materials encountered during drilling plotted at the correct elevation. This basic diagram also included profile lines representing the land surface and the bedrock surface. The surface geologic unit boundaries from Thorliefson and others (2005) were generalized and added to all the cross sections.

The correlation process (matching sand layers from individual boreholes) between the plotted drill hole information mostly involved drawing stratigraphic boundaries (including aquifer boundaries) as line shapefiles in ArcGIS. The stratigraphic and aquifer boundaries were primarily based on all sand occurrences within similar elevation ranges. These sand occurrences were assumed to be indicators of boundaries between successive glacial events. Correlations were first completed from west to east within each cross section, and then these lines were compared north to south by superimposing adjacent sets of cross-section line shapefiles within the same ArcGIS dataframe. The sand boundaries for each aquifer system and each cross section were matched to a sketch map of the aquifer system boundaries to ensure that aquifer boundaries were consistent in both map and cross-section views.

Surficial Geology

The maps and cross sections on Plates 1 and 2 show one surficial sand aquifer and three buried sand and gravel aquifers. Saturated Holocene and Quaternary sand and gravel deposits comprise the surficial sand aquifer. The surficial geology from a regional geologic compilation (Thorliefson and others, 2005) is shown on Figure 1, Plate 1. The distribution of surficial sand indicated by this map matched the drillers log data from existing boreholes in the area for the Qha and Qgr units at most locations. Therefore, surface sand is indicated on the corresponding cross sections at these locations. However, well records from the Qaa areas usually did not indicate that surface sand was present at these locations so none is shown on the cross sections. Surface sand may still be present in these Qaa areas, but possibly not as widespread as the map suggests or occurrences may be so thin that they commonly were not noted on drillers logs. One of the significant geologic characteristics of this area is the partial coverage by fine-grained Lake Agassiz sediments in the study area; these sediments are distinct when compared to the complete coverage by thick lake clay that occurs to the north in the Fargo, ND and Moorhead, MN area. The thick lake clays in the Fargo-Moorhead area at the land surface in that area prevent recharge of the buried aquifers (Ripley, 2000).

Subsurface Geology

The surficial geologic map from Thorliefson and others (2005) also contains interpretations indicating group names for the till units (non-aquifer gray colored layers) that are shown on the maps and cross sections of Plates 1 and 2. The upper till unit, with a loamy texture (roughly equal parts sand, silt and clay) corresponds to the lower Goose River group. The till layer beneath aquifer 1 (till 2) probably corresponds to the Otter Tail River group. This group also has a loamy texture. Aquifers are shown as patterned colored and non-colored areas. Plate 1 shows area-wide features at a scale of 1:250,000. Plate 2 shows more detail of the Breckenridge/Wahpeton area at a scale of 1:100,000.

The aquifer names of this report probably correspond to the earlier North Dakota names in the following manner:

Table 1. Aquifer names

Aquifer names used in North Dakota publications	Aquifer names used in this report
WSS	Surficial sand
WSP	Aquifer 1
WBV	Aquifers 2 and 3

Groundwater Flow Directions

Groundwater flow directions can be estimated by comparing water level elevations measured in wells. Groundwater will flow from high elevations to low elevations. The elevations shown on Figures 2-4, Plate 1, are the static (non-pumped) water levels from the Minnesota County Well Index (CWI) that were recorded by the driller at the time the wells were drilled. The dates of these measurements range over the past 50 years, so only very general conclusions can be made regarding groundwater flow direction. The data show a general tendency of groundwater to flow northerly toward the Red and Ottertail rivers.

In 1995 water level measurements of wells in the local Breckenridge/Wahpeton area were made during a period of a few days (synoptic) to get a “snapshot” of these elevations and flow directions (Figures 1 through 4, Plate 2). When these measurements were made in June 1995, the groundwater flow directions and vertical gradients were significantly influenced by the pumping of the remediation well at the Minn/Dak location. Surficial aquifer data from this synoptic measurement were limited to the Minn/Dak location (Plate 2, Figure 1). With a few exceptions, most of these values were approximately 930 feet above sea level. The aquifer 1 data (Plate 2, Figure 2) suggests a cone of depression existed in an area bounded by the Minn/Dak location to the north and northern border of the Wahpeton city limits to the south. The aquifer 2 and 3 data (Plate 2, Figures 3 and 4) also suggest a cone of depression in the Minn/Dak location with water elevations of approximately 906 and 930 feet above sea level, respectively. When all of these water elevations are considered together, it appears that pumping from aquifer 2 created an induced gradient that resulted in water moving into aquifer 2 from both the shallow portions (surficial sand aquifer and aquifer 1) and the deeper portions (aquifer 3) of the system.

Geochemistry

Stable isotopes, ^{18}O, and deuterium

Isotopes of a particular element have the same number of protons, but different numbers of neutrons. Isotopes are called stable if they do not undergo natural radioactive decay. Stable isotopes are used to understand water sources or the processes that have affected them. The important stable isotopes are oxygen (^{16}O and ^{18}O) and hydrogen (^{1}H and ^{2}H). The hydrogen isotope ^{2}H is called deuterium. The mass differences between ^{16}O and ^{18}O or ^{1}H and ^{2}H can cause the concentrations of these isotopes to change (fractionate) during evaporation and precipitation, resulting in different ^{16}O /^{18}O and ^{1}H/^{2}H ratios in rain, snow, rivers, and lakes. The δ^{2}H and δ^{18}O values (the symbol “δ” denotes the relative difference from standard mean ocean water) in precipitation generally plot close to a straight line known as the meteoric water line (Figure 1). The departure of ^{18}O and deuterium values from the meteoric water line can indicate if water samples have been affected by evaporative processes or the mixing of water from different sources. Lake water typically shows an evaporative signature (a higher concentration of the heavier isotopes than precipitation). The effect of evaporative fractionation is that isotopic values from lake water samples plot with a slope that is less than the slope of the meteoric water line. Water that directly infiltrates the ground is not fractionated in this manner and has a meteoric signature with a higher concentration of the lighter, more prevalent isotopes.

Isotopic data collected from wells in the area are shown on Plates 1 and 2 as pink, yellow, green, and blue colors representing a continuum of conditions that relate to aquifer recharge and groundwater mixing conditions. The divisions between the classifications of stable isotope values in the glacial, mixed cold, and mixed warm classes are interpretative and are meant mainly to help visualize these data on the cross sections, graphs, and maps. Figure 1 shows a plot of ^{18}O and deuterium values from groundwater samples collected in the Breckenridge/Wahpeton area in 1995 (colored dots) compared to the meteoric water line, samples collected from the nearby Otter Tail Regional Hydrogeologic Assessment – Part B (Ekman and Alexander, 2002) and the

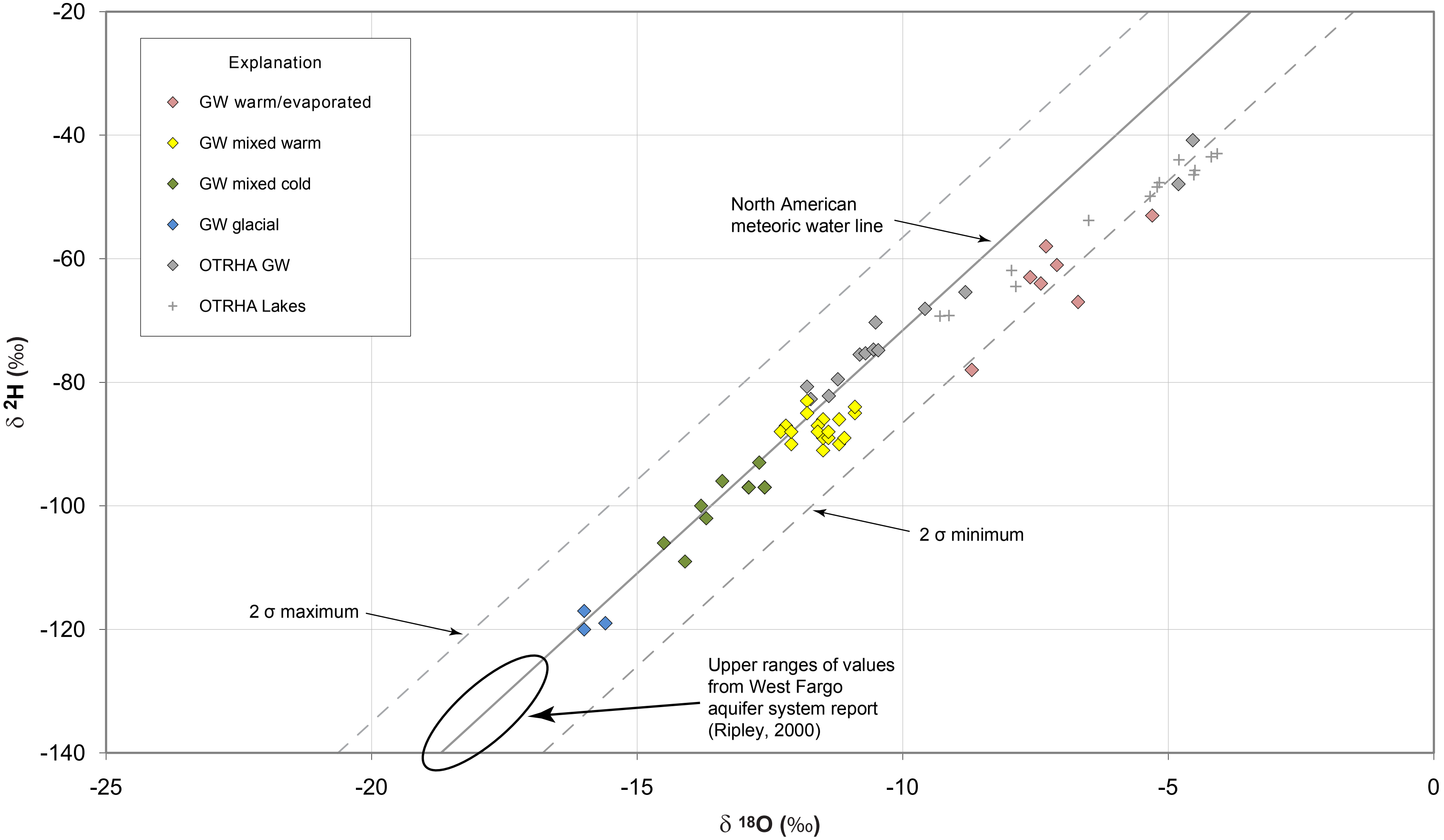

Figure 1. *Stable isotope data from Breckenridge/Wahpeton area compared with Otter Tail Regional Hydrogeologic Assessment(OTRHA) and West Fargo.*

Table 2. Summary of stable isotope data for the Breckenridge/Wahpeton area.
[Data from North Dakota State Water Commission and Minn/Dak Farmers Cooperative]

Unique Minnesota*	Unique North Dakota	Sample Date	Aquifer	^{18}O	Deuterium	Isotope Classification	Town	Range	Section	SubSection	Elevation	Depth Drilled	Depth Completed	Dataset	Diameter
460	13304720AAD1	10/17/1995	2,3	-12.6	-97	mixed cold	133	47	20	AAD1	969.91	210.00	200.00	NDSWC	1.25
461	13304720AAD2	10/17/1995	2	-12.9	-97	mixed cold	133	47	20	AAD2	970.25	135.00	134.00	NDSWC	1.25
462	13304720AAD3	10/17/1995	1	-8.7	-78	warm/evap	133	47	20	AAD3	970.27	60.00	59.00	NDSWC	2.00
477	13304720ABD	10/19/1995	3	-11.6	-88	mixed warm	133	47	20	ABD	971.48	300.00	300.00	NDSWC	12.00
478	13304720ABDAC1	10/23/1995	3	-10.9	-85	mixed warm	133	47	20	ABDAC1	972.62	302.00	275.00	NDSWC	12.00
480	13304720ABDBA1	9/30/1997	surficial sand	-7.3	-58	warm/evap	133	47	20	ABDBA1	972.12	62.00	60.00	NDSWC	2.00
481	13304720ABDBA2	10/17/1995	2	-7.6	-63	warm/evap	133	47	20	ABDBA2	972.10	120.00	119.00	NDSWC	2.00
486	13304720ABDB1	10/18/1995	2	-7.1	-61	warm/evap	133	47	20	ABDB1	972.79	124.00	120.00	NDSWC	1.25
487	13304720ABDB2	10/18/1995	3	-11.6	-88	mixed warm	133	47	20	ABDB2	972.93	280.00	253.00	NDSWC	1.25
492	13304720ABDB7	10/23/1995	2	-7.4	-64	warm/evap	133	47	20	ABDB7	972.60	120.00	115.00	NDSWC	12.00
495	13304720ABDC1	10/17/1995	3	-5.3	-53	warm/evap	133	47	20	ABDC1	984.26	286.00	283.00	NDSWC	1.25
521	13304720ADD3	10/17/1995	2	-11.1	-89	mixed warm	133	47	20	ADD3	970.22	129.00	127.00	NDSWC	1.25
537	13304720BAD3	10/18/1995	2,3	-6.7	-67	warm/evap	133	47	20	BAD3	976.80	70.00	56.00	NDSWC	2.00
548	13304720BBA	10/19/1995	2,3	-11.5	-86	mixed warm	133	47	20	BBA	963.43	327.00	300.00	NDSWC	12.00
551	13304720BBBAB4	10/17/1995	2	-11.6	-87	mixed warm	133	47	20	BBBAB4	959.99	86.00	83.00	NDSWC	2.00
552	13304720BBBAB5	10/26/1995	1	-11.5	-91	mixed warm	133	47	20	BBBAB5	960.04	55.00	53.00	NDSWC	2.00
564	13304720DDD2	10/17/1995	1	-14.1	-109	mixed cold	133	47	20	DDD2	968.43	80.00	51.00	NDSWC	1.25
569	13304803ABB2	7/9/1996	2	-11.4	-89	mixed warm	133	48	3	ABB2	945.91	140.00	119.00	NDSWC	1.25
570	13304812BAA	7/9/1996	2	-11.4	-88	mixed warm	133	48	12	BAA	950.21	235.00	135.00	NDSWC	1.25
942	13304717CCC1	10/17/1995	2,3	-11.4	-88	mixed warm	133	47	17	CCC1	960.34	320.00	121.00	NDSWC	1.25
17523	13304720ADD4	10/17/1995	3	-11.4	-88	mixed warm	133	47	20	ADD4	970.33	280.00	273.00	NDSWC	2.00
129714	13304703CCCDCB	10/18/1995	3	-15.6	-119	glacial	133	47	3	CCCDCB	963.00	256.00	256.00	CWILOC	4.00
129742	13304726BCCDCB	10/18/1995	1	-11.1	-89	mixed warm	133	47	26	BCCDCB	967.00	68.00	68.00	CWILOC	4.00
130573	13304728DDAADB	10/18/1995	3	-11.5	-89	mixed warm	133	47	28	DDAADB	965.00	340.00	340.00	CWILOC	12.00
130574	13304727CCCBBD	10/18/1995	3	-11.2	-90	mixed warm	133	47	27	CCCBBD	965.00	300.00	300.00	CWILOC	12.00
419474	13304726CBBCAC	10/18/1995	1	-11.2	-86	mixed warm	133	47	26	CBBCAC	968.00	48.00	48.00	CWILOC	4.00
438372	13304726BCDCBA	10/18/1995	2	-10.9	-84	mixed warm	133	47	26	BCDCBA	968.00	125.00	125.00	CWILOC	5.00
521555	13204702ADD	10/18/1995	unknown	-12.6	-97	mixed cold	132	47	2	ADD	972.00	260.00	258.00	CWIUNLOC	4.00
567370	13404810ABD1	11/8/1996	3	-16	-120	glacial	134	48	10	ADBBBA	937.00	218.00	208.00	CWILOC	2.00
567372	13304727ADD2	11/8/1996	2	-12.9	-97	mixed cold	133	47	27	ADDDAD	966.00	120.00	115.00	CWILOC	2.00
567373	13304727ADD3	11/8/1996	1	-11.8	-85	mixed warm	133	47	27	ADDDCA	968.00	64.00	64.00	CWILOC	2.00
567374	13304716DDAC2	11/7/1996	3	-13.8	-100	mixed cold	133	47	16	DDBCDA	963.00	80.00	74.00	CWILOC	2.00
589078	13304619DDD1	11/8/1996	unknown	-12.2	-87	mixed warm	133	46	19	DDDDCD	973.00	368.00	358.00	CWILOC	2.00
589079	13304619DDD2	11/8/1996	unknown	-12.1	-88	mixed warm	133	46	19	DDDDDC	974.00	285.00	253.00	CWILOC	2.00
589080	13304619DDD3	11/8/1996	1	-12.3	-88	mixed warm	133	46	19	DDDDDD	973.00	44.00	39.00	CWILOC	2.00
589082	13304726AAA1	11/8/1996	unknown	-16	-117	glacial	133	47	26	AAAABB	970.80	230.00	228.00	CWILOC	2.00
589083	13304726AAA2	11/8/1996	2	-12.7	-93	mixed cold	133	47	26	AAAABA	968.00	145.00	145.00	CWILOC	2.00
589086	13204702DDA2	11/7/1996	Cretaceous	-13.4	-96	mixed cold	132	47	2	DDAAAC	972.00	300.00	300.00	CWILOC	0.00
589090	13304701ABC	11/7/1996	Cretaceous	-14.5	-106	mixed cold	133	47	1	ABBCDA	969.00	280.00	270.00	CWILOC	2.00
589098	13204608BCCD1	11/8/1996	3	-12.1	-90	mixed warm	132	46	8	BCCDCC	976.00	248.00	238.00	CWILOC	2.00
589099	13204608BCCD2	11/8/1996	1	-11.8	-83	mixed warm	132	46	8	BCCDCB	976.00	67.00	61.00	CWILOC	2.00
591781	13404836ACB3	11/8/1996	1	-13.7	-102	mixed cold	134	48	36	BDCADB	947.00	118.00	108.00	CWILOC	2.00

*Sequential numbers were generated for the North Dakota unique identification data so all the well record data in the area could be processed together to produce the products of these reports.

upper range of values reported from the West Fargo aquifer systems (Ripley, 2000). The Breckenridge/Wahpeton stable isotope data are also summarized in Table 2. Three types of information regarding the origin and history of these water samples can be interpreted from this graph: relative atmospheric temperature during source water precipitation, relative mixing of water from cold and warm sources, and evaporation of source water.

Source water temperature and mixing

Of the samples that plot along the same slope as the meteoric water line, the samples more depleted in heavy isotopes (samples that plot closer to the bottom left of the graph) suggest water that precipitated from a colder atmosphere. Deuterium and ^{18}O samples collected from snow and rain samples approximately 80 miles west of the Breckenridge/Wahpeton area (Shaver, 1995) show snow samples plotting beyond the far bottom left range of the graph (deuterium: δ -190 to -125, ^{18}O: δ -25 to -18); whereas, rain samples plotted in the upper right portion of the graph (deuterium: δ -75 to -25, ^{18}O: δ -12 to -2). Most groundwater samples collected from a Fargo area study (Ripley, 2000) had stable isotope values in the same range as the snow samples in Shaver (1995) and were, therefore, interpreted as aquifer recharge water from melting glaciers. The West Fargo Aquifer System is overlain by 70 to 90 feet of lake clay. This clay confining layer trapped Pleistocene water in the area aquifers. Three stable isotope samples from the Breckenridge/Wahpeton area were slightly outside the snow melt or glacial range. These samples, therefore, consist mostly of glacial water. Groundwater samples with stable isotope values in the mixed cold (green) and mixed warm (yellow) groups apparently represent groundwater that is a mixture of glacial and post-glacial precipitation. The difference in isotopic composition between these two groups (mixed cold versus mixed warm) is probably the relative amounts of post-glacial versus glacial water. Several possible mixing pathways are apparent from the cross sections and are described in the following sections.

Isotope hydrostratigraphy and aquifer distribution

The results of this investigation are shown on two plates at different scales to better illustrate regional and local conditions. On Plate 1, the 1:250,000 scale maps and cross sections show that the aquifers of the Breckenridge/Wahpeton area are connected to a much larger system of aquifers. On Plate 2, the 1:100,000 scale maps and cross sections show some of the more important geochemical and stratigraphic details in the Breckenridge/Wahpeton area. The 100,000 scale maps on Plate 2 contain the same map information that is shown on Plate 1, but different cross sections have been included that better illustrate the stable isotope data and local hydrostrati-graphy.

The isotopic data that were obtained from wells are shown on Plate 1 and within the detail area shown on Plate 2. Aquifers mapped on the cross sections for which isotope data are available are colored according to isotopic categories; these categories illustrate the connection between aquifers and groundwater movement. However, some isotopic data from aquifer 1 are shown on Plate 1, cross sections 18 and 32. The portion of aquifer 1 on cross section 18 (Plate 1) that exists under and just to the west of the Red River has a mixed cold signature suggesting some recharge from the river valley but probably not a direct connection. The mixed warm signature for the portion of aquifer 1 east of the Ottertail River (Plate 1, cross section 32) suggests a more direct recharge connection from the Ottertail River valley and connections that continue to the underlying aquifer 3.

Table 3. Common cations and anions in milligrams per liter.
[Data from North Dakota State Water Commission and Minn/Dak Coop Sugar Beet processing plant; dash marks (--) indicate no data available]

Unique Minnesota*	Unique North Dakota*	Sample Date	Source	Aquifer	Ca	Mg	Na	K	HC03	CO3	S04	Cl	N03	Fe	Mn	TDS
460	13304720AAD1	10/17/1995	SWC	2,3	77	31	82	9	453	0	130	20	–	0.45	0.08	573
461	13304720AAD2	10/17/1995	SWC	2	72	32	77	7	444	0	110	16	–	0.08	0.1	570
462	13304720AAD3	10/17/1995	SWC	1	160	100	46	5.6	580	0	410	41	–	0.08	0.31	1100
477	13304720ABD	10/19/1995	SWC	3	110	46	61	7.5	524	0	190	15	–	1.6	0.16	707
478	13304720ABDAC1	10/23/1995	Minn-Dak	3	125	56	56	10	419	–	202	20	0	1	–	–
480	13304720ABDBA1	9/30/1997	SWC	surficial sand	95	60	51	5.3	350	0	290	15	0.4	0.44	0.4	720
481	13304720ABDBA2	10/17/1995	Minn-Dak	2	109	58	43	11	305	–	261	18	0.05	0	–	–
486	13304720ABDB1	10/18/1995	SWC	2	83	51	42	6.6	340	0	220	19	1	0.02	0.08	583
487	13304720ABDB2	10/18/1995	SWC	3	130	49	76	8	550	0	250	21	1	0.02	0.19	835
492	13304720ABDB7	10/23/1995	Minn-Dak	2	104	55	45	6	308	–	237	25	0	1	–	–
495	13304720ABDC1	10/17/1995	Minn-Dak	3	131	46	52	8	400	–	191	11	0.07	0	–	–
521	13304720ADD3	10/17/1995	SWC	2	71	30	70	6.3	483	0	59	21	–	0.34	0.1	497
537	13304720BAD3	10/18/1995	Minn-Dak	2,3	466	242	313	34	1078	–	1459	362	0	20	–	–
538	13304720BBA	10/19/1995	SWC	2,3	110	42	59	7.3	495	0	170	13	–	1.4	0.14	654
551	13304720BBBAB4	10/17/1995	SWC	2	73	31	68	6.1	487	0	61	16	1	0.12	0.1	506
552	13304720BBBAB5	10/26/1995	Minn-Dak	1	554	368	391	20	348	–	3018	124	0	2	–	–
564	13304720DDD2	10/17/1995	SWC	1	340	140	170	13	417	0	1500	21	–	3.4	0.46	2480
569	13304803ABB2	7/9/1996	SWC	2	110	45	54	7.1	486	6	190	12	6.7	0.2	0.28	691
570	13304812BAA	7/9/1996	SWC	2	100	41	50	6.4	473	0	150	11	6.4	0.52	0.13	594
942	13304717CCC1	10/17/1995	SWC	2,3	77	34	66	6.9	496	0	76	15	–	0.15	0.11	530
17523	13304720ADD4	10/17/1995	SWC	3	110	44	55	7.6	498	0	180	12	5	0.14	0.17	664
129714	13304703CCCDCB	10/18/1995	SWC	3	48	16	190	19	429	0	200	59	–	2.2	0.13	739
129742	13304726BCCDCB	10/18/1995	SWC	1	64	25	140	10	464	0	190	22	1	0.84	0.06	680
130573	13304728DDAADB	10/18/1995	SWC	3	110	42	52	7.2	495	0	170	12	–	1.4	0.15	659
130574	13304727CCCBBD	10/18/1995	SWC	3	89	37	59	6.5	510	0	95	15	–	4.9	0.27	551
419474	13304726CBBCAC	10/18/1995	SWC	1	76	30	140	9.1	466	0	230	21	–	0.24	0.15	726
438372	13304726BCDCBA	10/18/1995	SWC	2	63	24	140	10	448	0	180	21	–	0.85	0.06	640
521555	13204702ADD	10/18/1995	SWC	unknown	13	5	250	15	543	0	99	42	1	0.06	0.01	653
567370	13404810ABD1	11/7/1996	SWC	3	31	18	430	8.3	522	0	620	42	9	0.16	0.16	1400
567372	13304727ADD2	11/7/1996	SWC	2	52	25	130	4.3	586	0	22	15	23	0.33	0.34	587
567373	13304727ADD3	11/7/1996	SWC	1	65	25	140	8.3	460	0	190	25	12	0.58	0.12	699
567374	13304716DDAC2	11/6/1996	SWC	3	140	39	130	7.5	341	0	460	34	17	0.06	0.44	1000
589078	13304619DDD1	11/7/1996	SWC	unknown	120	48	47	7.2	491	0	200	14	2.9	0.2	0.27	686
589079	13304619DDD2	11/7/1996	SWC	unknown	100	40	57	8.6	481	0	130	16	5	0.08	0.26	608
589080	13304619DDD3	11/7/1996	SWC	1	75	19	74	8.9	410	0	70	24	2.2	0.32	0.21	493
589082	13304726AAA1	5/17/2001	SWC	unknown	16	5.5	210	11	559	16	31	24	0.2	0.05	0.12	585
589083	13304726AAA2	11/7/1996	SWC	2	50	20	100	5.2	448	0	39	26	14	0.17	0.18	485
589086	13204702DDA2	11/7/1996	SWC	Cretaceous	17	8	240	13	652	3	2.1	57	35	0.07	0.04	659
589090	13304701ABC	11/6/1996	SWC	Cretaceous	44	13	210	12	436	0	210	67	13	0.19	0.11	785
589098	13204608BCCD1	11/7/1996	SWC	3	36	14	160	6.9	464	0	95	26	15	0.15	0.09	576
589099	13204608BCCD2	11/7/1996	SWC	1	59	21	100	6.6	460	0	70	21	13	0.04	0.06	517
591781	13404836ACB3	11/7/1996	SWC	1	270	150	180	12	403	0	1300	15	12	2.7	0.38	2220

Similar direct connections or possible connections from the surface to the deepest unconsolidated aquifers in the area are shown on cross section 3 (Plate 1) from the Red River alluvium, through aquifers 1 and 2, to aquifer 3 (labeled as Border aquifer, Thorliefson and others, 2005). Cross section 23 (Plate 1) shows another possible direct connection west of the Red River through all the aquifers to the Wahpeton Buried valley aquifer. However, no isotope samples were collected from these two locations to test these possible hydraulic connections.

Figure 4 (Plate 1) shows the known extent of the Wahpeton Buried Valley aquifer, the southern portion of the Border aquifer (northwestern portion of the map), a poorly defined portion of this aquifer system in Minnesota that seems to parallel the WBV, and an isolated portion of this aquifer system near Kent, Minnesota. The WBV aquifer may be a composite of sand bodies deposited as parts of the aquifer 2 and 3 systems where they are connected. Examples of these connections are shown west of the Red River on cross sections 18 and 23 (Plate 1). The Border aquifer of the aquifer 3 system is shown as a progressively narrowing feature on cross sections 3 through 8 (Plate 1). Cross section 12 (Plate 1) shows an example, just east of the Red River, where a glacial isotopic signature from that portion of aquifer 3 indicates little or no recharge at that location due to a lack of interconnections of the overlying sand layers.

A more detailed view of the WBV aquifer is shown on Figure 4 (Plate 2) and cross sections 20, 21, 24, 25, and 27 on Plate 2. The stable isotopic data shows that most of this aquifer contains mixed warm water, indicating that it is probably recharged from the surface through interconnected sand layers. Demonstrating the precise focused surface recharge locations in cross sections is sometimes difficult without an abundance of borehole data, but the combination of the mixed warm isotope signatures and stacked sand layers with only thin till separations is good evidence of focused surface recharge occurring in the area. These types of stratigraphic and isotopic relationships can be seen on all the cross sections on Plate 2, indicating a recharge condition common to the area aquifers.

Cross section 25 (Plate 2) crosses the Minn/Dak plant area and the location of the City of Wahpeton well that was affected by the Minn/Dak plant process water discharge. Samples from the surficial aquifer and the underlying aquifer 1 had stable isotope values with an evaporative signature from the infiltration of disposed process water that was described in the previous section “History of Water Use and Investigations”. The cross section also shows that the upper portion of the WBV aquifer also contains water with this evaporative signature. Even though a direct connection between aquifer 1 and the WBV aquifer is not shown on this cross section the occurrence of water with an evaporated signature in the WBV aquifer indicates a hydraulic connection does exist somewhere near the trace of this cross section. Infiltration of this type of water to a depth of approximately 100 feet was probably induced by remediation pumping from a well that was constructed near the affected city well.

Some isolated aquifer conditions are shown on cross sections 21, Plate 2, and 24 and on Figures 2, 3, and 4 of Plate 2. Glacial signature water was detected at two locations in aquifer 3 (Plate 2, Figure 4). One of those locations is shown on cross section 21 and on Figure 4 (Plate 2) in a portion of aquifer 3 that is apparently not connected to the WBV aquifer or any overlying aquifers. The other occurrence is shown only on Figure 4 (Plate 2) northeast of Breckenridge from an isolated sand body at approximately the same elevation as the aquifer 3 channel to the east.

Groundwater samples that contained mixed cold signatures were present in aquifers 1 and 2 (Plate 2, Figures 2 and 3). An example from aquifer 1 is shown on cross section 24 (Plate 2) just east of the Red River; this example illustrates the complexity of buried sand distribution in glacial sediments where sometimes relatively shallow sand bodies that might be expected to have hydraulic connections to the surface are actually found to be relatively isolated based on geochemical data.

Common cations and anions

Distinct source water types and mixing of these waters can be portrayed graphically by plotting the relative abundances of common cations and anions as ion concentrations and percentages of the total cations or anions per sample. Figure 2 shows the relative abundances of these common ions plotted on a Piper diagram which consists of three ternary plots. Table 3 shows the concentrations of these constituents in mg/l. The most common type of water in this area has Ca and Mg as the predominant cations, with bicarbonate ($-HCO_3$) as the predominant anions (points on the graph within the green circles). This type of water is common in glacial aquifers of the upper Midwest (Freeze and Cherry, 1979, p. 284) and is derived from dissolution of calcite and dolomite minerals in soil and glacial sediments by meteoric water.

A fewer number of samples on the opposite corners of the ternary plots show that some Na+K and/or sulfate waters are also present in the area. The elevated Na+K content of seven water samples is probably due to anthropogenic (i.e., caused by or related to human activities) processes. Three of these samples were collected near the Minn/Dak disposal lagoons in the surficial aquifer or aquifer 1 (ND537, ND552, and 567374 shown on Plate 2, Figures 1 and 2; and cross section 24 (Plate 2). The two samples nearest the lagoons (ND537 and ND552) also contained elevated concentrations of Cl (Table 2). Evaporated process water commonly has higher concentrations of these ions.

In addition to elevated concentrations of Na+K and Cl in water samples due to anthropogenic processes, water samples with elevated sulfate concentrations and high total dissolved solid (TDS) concentrations, likely due to anthropogenic processes, were identified in several wells. One well in aquifer 1 occurs approximately four miles northwest of the Minn/Dak site along the Red River (#591781, Plate 1, Figure 2 and cross section 18). Aquifer 1 at this location has an apparent indirect connection to the Red River sand and gravel which may allow water affected by anthropogenic processes to move to aquifer 1.

Four of the elevated Na+K or sulfate (SO_4) type waters in Figure 2 may have a deep bedrock origin. These occurrences are shown on cross section 12 and 32 (#567370 and #589098, Plate 1), cross section 21 (#129714, Plate 2) and Figure 4 (#589882) of both plates. Three of these samples (#567370, #129714, and #589082) are from deeper isolated portions of aquifer 3. Both of these aquifers appear hydraulically isolated from surficial sources and the stable isotopic char-

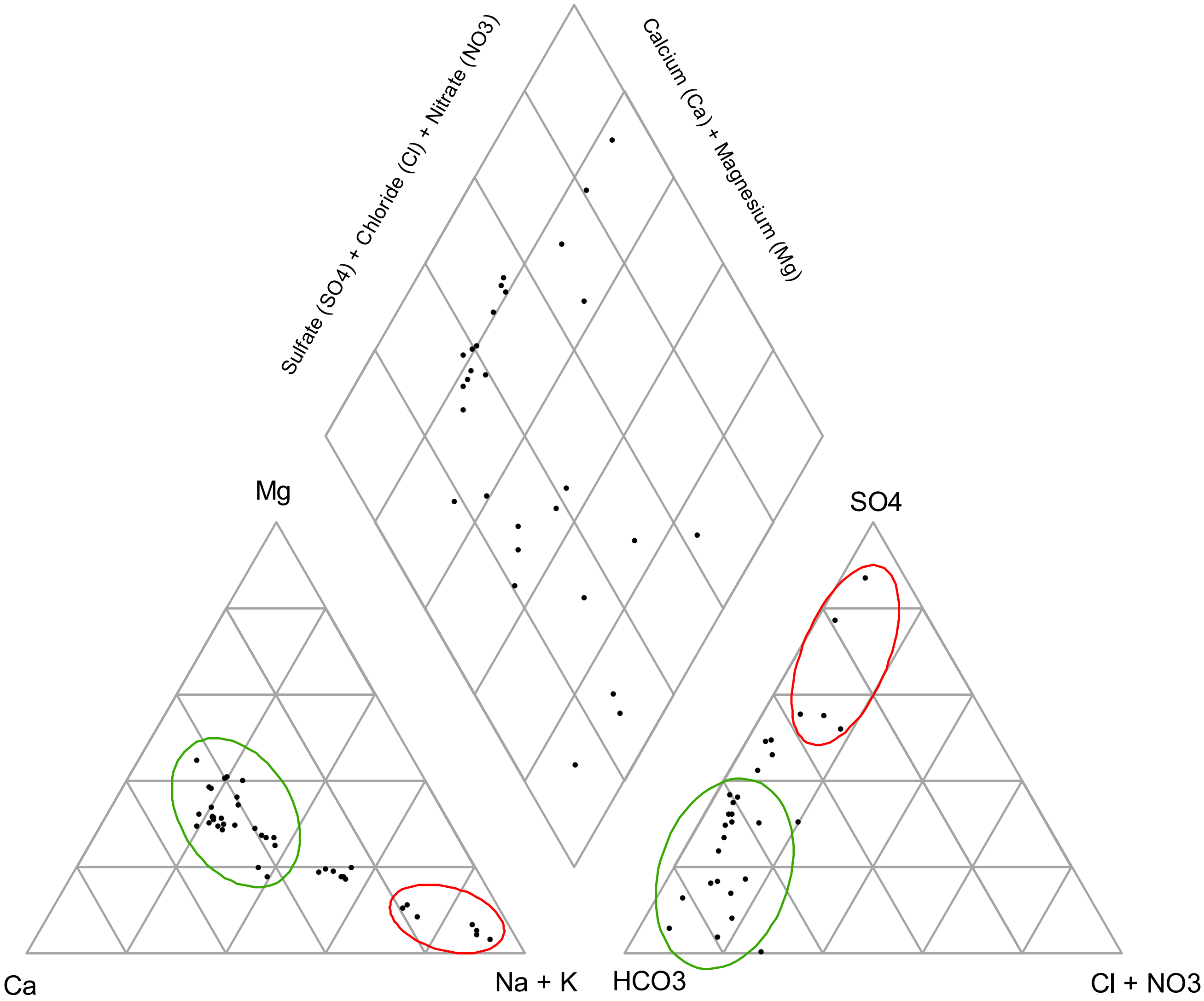

Figure 2. *Piper diagram of common cations and anions from selected wells in the Breckenridge/Wahpeton area. Ca-Mg bicarbonate is the most common type of groundwater in the area (points circled in green). Na+K sulfate groundwater is less common (circled in red).*

acteristics (glacial category) suggest little mixing with warmer meteoric sources. Therefore, the sources of the elevated Na+K and/or sulfate concentrations are apparently due to groundwater upwelling from deeper Cretaceous sandstone and shale bedrock.

The source of elevated Na+K ions (anthropogenic or Cretaceous bedrock) for the fourth occurrence (#589098, cross section 32, Plates 1 and 2) is less clear. While the sample is Na+K type water (but low sulfate), the stable isotope category for this sample is warm and mixed. Furthermore, the stratigraphy shown by the cross section suggests possible connections to surface sources.

Observation well hydrographs, climate, and sustainable water use

Industrial and municipal pumping in the area caused water levels in aquifers in the local Breckenridge/Wahpeton area to decline in the 1970s and 1980s from near surface levels to approximately 50 to 60 feet below ground surface (Dan Zwilling, unpub. report, 1990). Figure 2 shows the annual Wahpeton Buried Valley aquifer water use from 1978 through 2009. The spike in water use in the late 1980's was due to increased North Dakota industrial usage which subsequently declined and remained relatively steady from the 1990's through the 2009. The hydrograph from a Minnesota observation well (Minnesota observation well #84020, unique #475807, Plate 2, Figure 4), completed in the WBV aquifer shows that since the early 1990s the water levels of the WBV aquifer have been relatively stable. This hydrograph, which is located midway between the

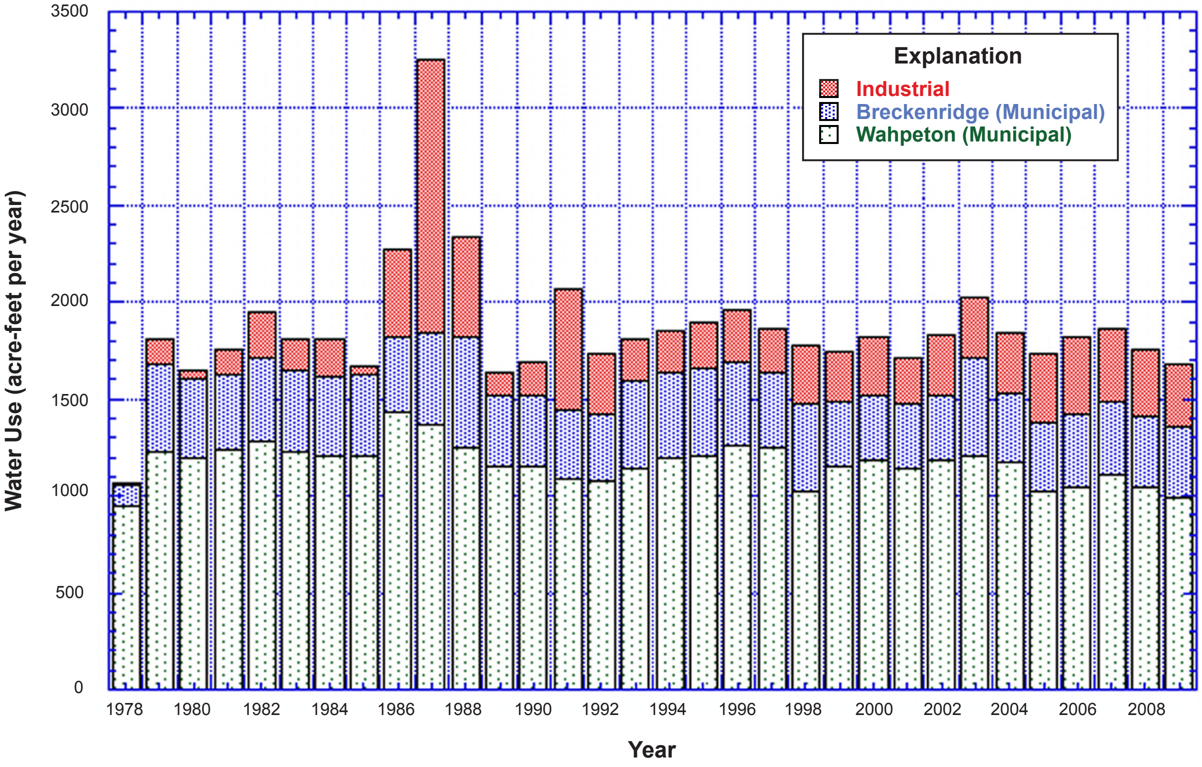

Figure 3. *Wahpeton Buried Valley aquifer water use from 1978-2009.*

Minnesota and North Dakota pumping centers, shows some yearly and seasonal fluctuation, but the overall trend appears flat with a slight rising trend from 2006 through 2009.

This slight rise in groundwater levels in recent years appears due to a wetter than normal precipitation pattern that is occurring in the area as shown by the rising brown line on this graph (cumulative 10-year departure from normal). Apparently, increased precipitation during those years resulted in some recharge of the WBV aquifer. Similar trends can be seen in other observation well data collected by the NDSWC in the area (Plate 2, Figure 2, unique #567373 and #589099; Figure 4, unique #589098). The stable isotope data, general chemistry data, and surface/subsurface sand distribution reviewed in this report provide evidence that shows some focused recharge of the WBV aquifer and other aquifers in the area is occurring.

Summary and Conclusions

The interstate border communities of Breckenridge, Minnesota and Wahpeton, North Dakota share a buried sand and gravel aquifer called the Wahpeton Buried Valley (WBV). Starting in 1986 efforts to remediate a groundwater contamination problem in Wahpeton by pumping contaminated water from the WBV aquifer led to water level declines in the City of Breckenridge water supply wells. From 1995 through 1998, to better understand the area aquifer recharge characteristics and long term sustainability, the NDSWC, Minnesota DNR and Wilkin County Environmental Services collaborated on a groundwater investigation. This investigation consisted of drilling new observation wells, collecting water samples from these wells for analysis of stable isotopes and common ions, and synoptic water level measurements. Until this report these data had never been published.

To help understand the geochemical and water level information generated by this investigation, area aquifers were mapped as part of this report with well log information from North Dakota and Minnesota databases. Closely spaced hydrogeologic cross sections of the area illustrating the distribution of isotopic groundwater types in buried sand aquifers provide evidence that shows hydraulic connections to surficial recharge water are common. Widespread occurrences of groundwater with a mixed warm isotopic type and gradually rising water levels from several observation wells indicate active recharge of area aquifers. The relatively open nature of the area aquifers suggests that water usage in this area appears sustainable at current water usage rates and quantities of precipitation. Should water usage or precipitation change significantly, the sustainability of aquifer usage in the area would need to be reevaluated. Long-term monitoring of the groundwater resources in this area should be continued.

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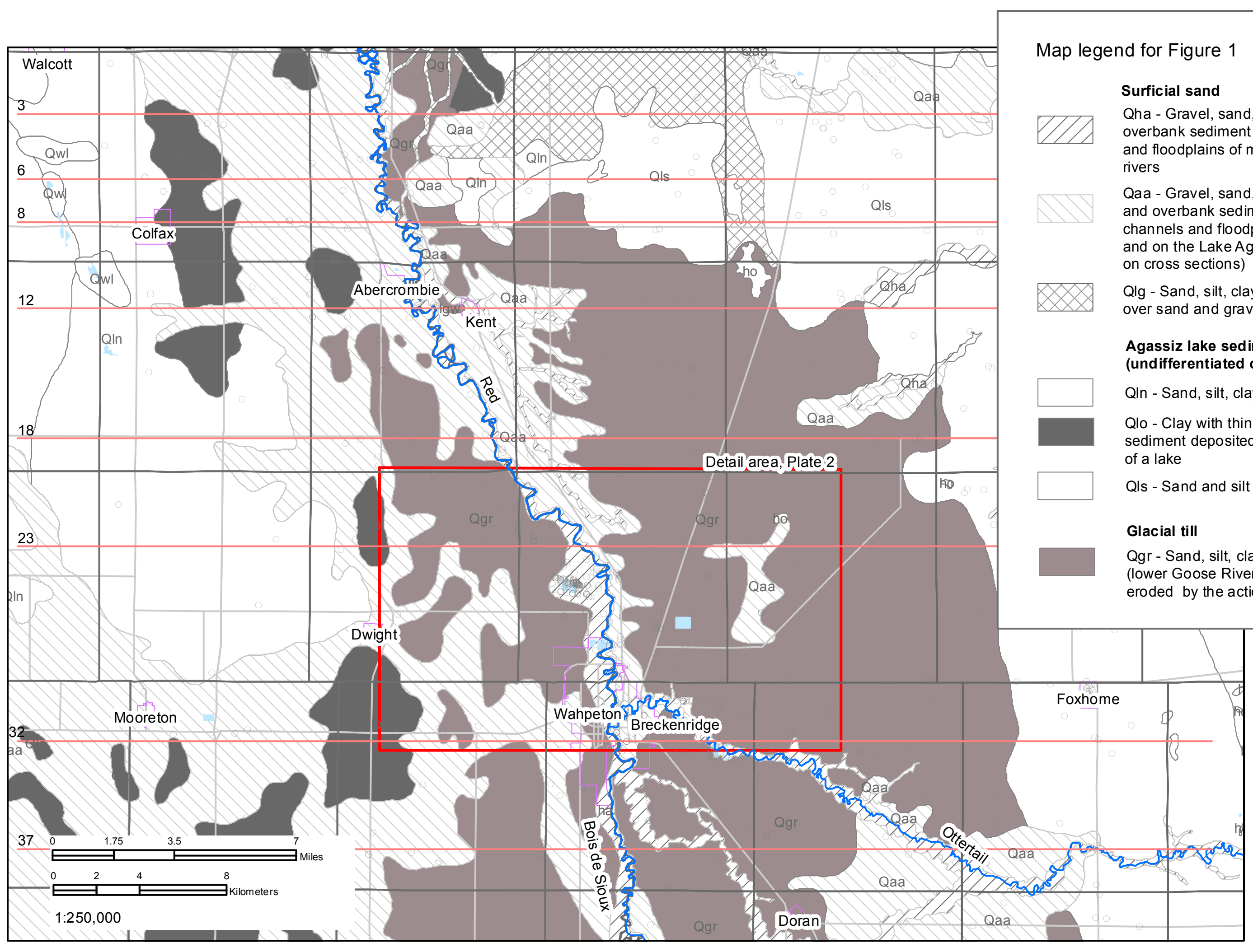
Buried sand and gravel aquifers of the Breckenridge/Wahpeton area, Minnesota and North Dakota

Plate 1. Surficial geology and distribution of buried sand and gravel



Map legend for Figure 1

Surficial sand

▨ Qha - Gravel, sand, silt, clay; alluvium and overbank sediment deposited in channels and floodplains of modern streams and rivers

▨ Qaa - Gravel, sand, silt, and clay; alluvium and overbank sediment deposited in channels and floodplains of ancient rivers and on the Lake Agassiz plain (not shown on cross sections)

▩ Qlg - Sand, silt, clay; thin lake sediment over sand and gravel (Buffalo aquifer)

Agassiz lake sediment (undifferentiated on cross sections)

☐ Qln - Sand, silt, clay

■ Qlo - Clay with thin silt laminae; offshore sediment deposited in deep quiet water of a lake

☐ Qls - Sand and silt with gravel ridges

Glacial till

■ Qgr - Sand, silt, clay; glacial till (lower Goose River group) that has been eroded by the action of waves in a lake

FIGURE 1. Surficial geology emphasizing distribution of surficial sand and gravel deposits (modified from Thorliefson and others, 2005).

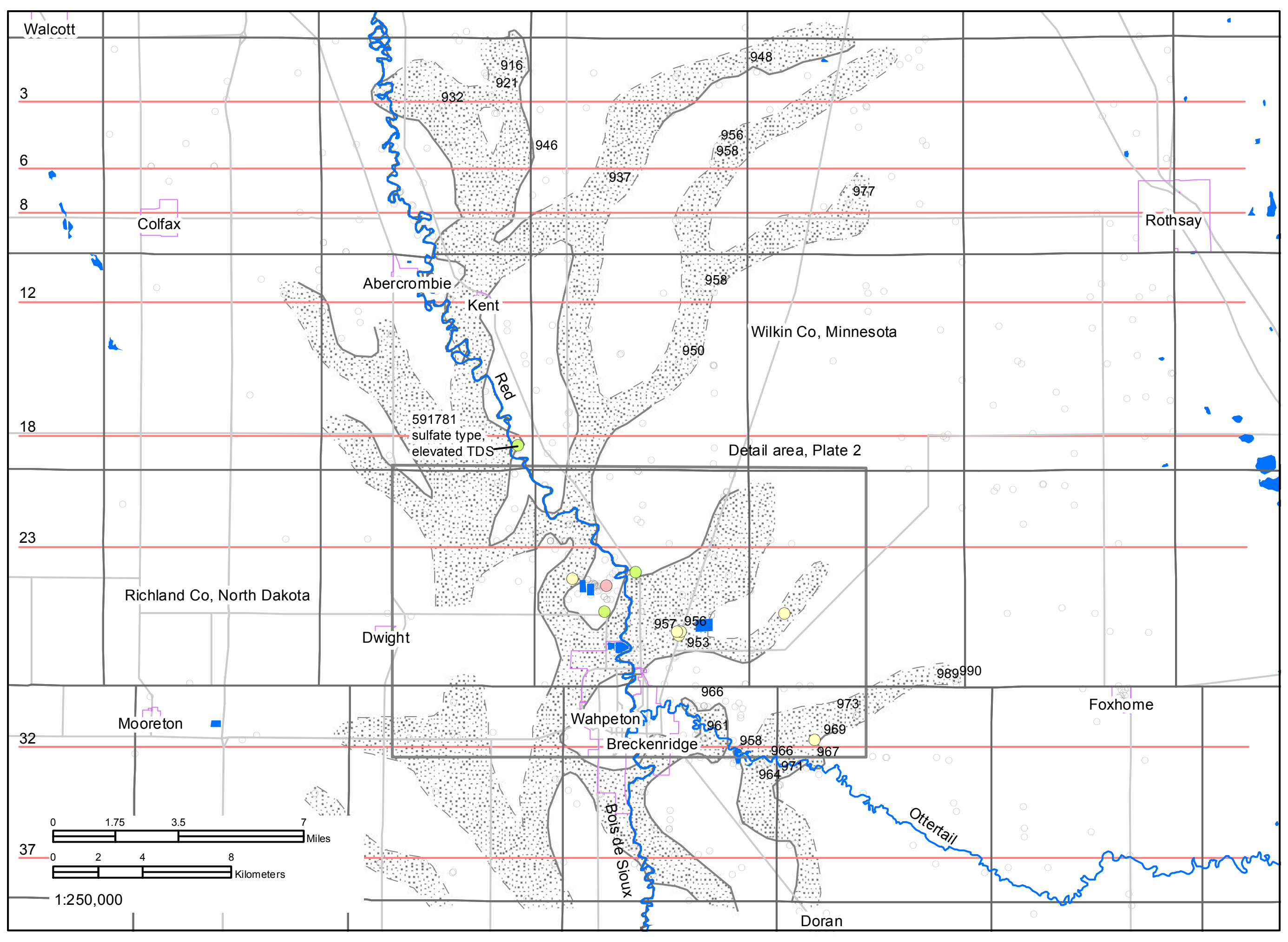


FIGURE 2. Buried aquifer 1 distribution. Also shown are the 18O/deuterium characteristics (October 1995 and November 1996) in groundwater samples in wells from this aquifer and static water elevations (Minnesota only) at the time each well was drilled.

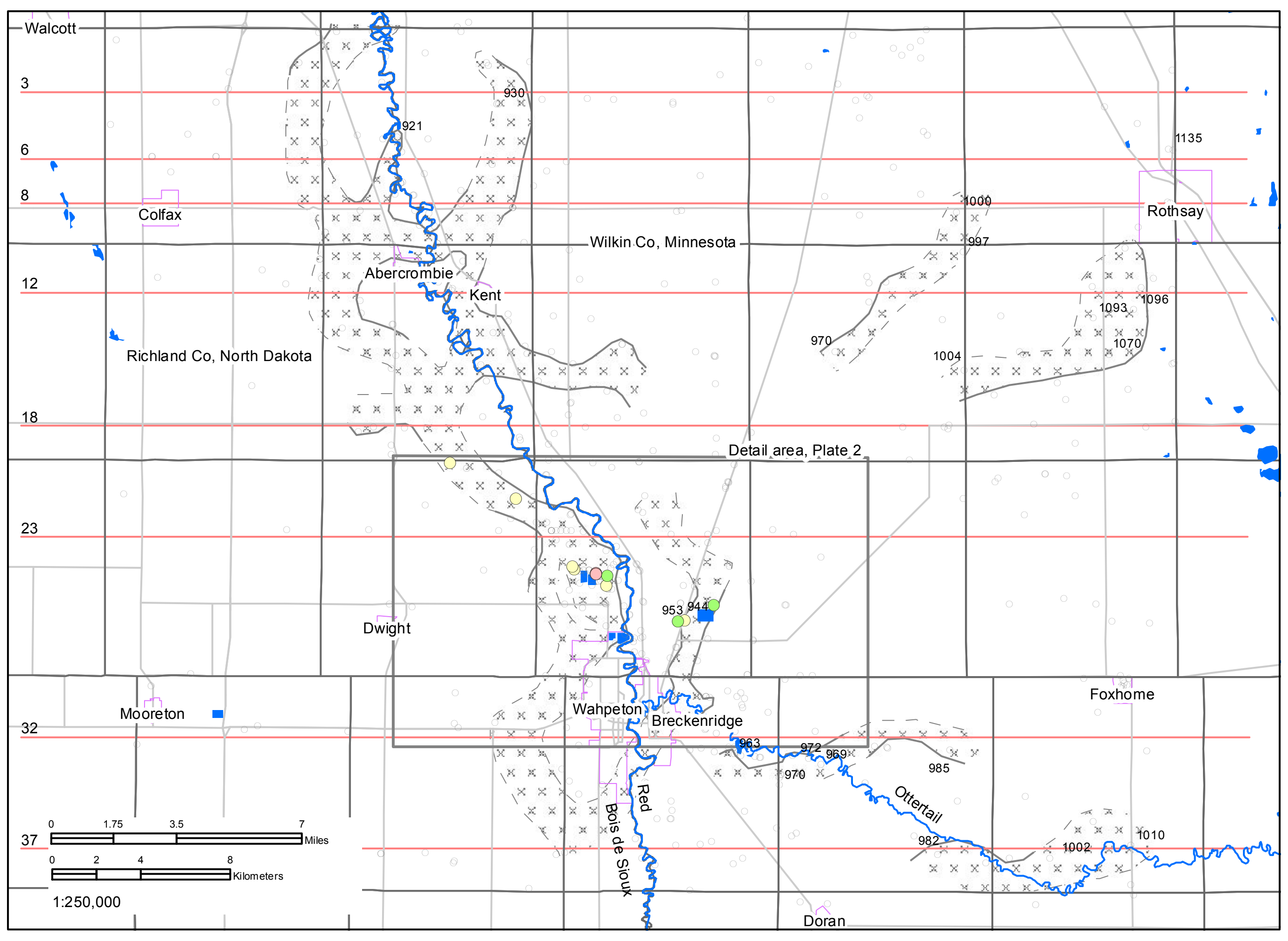


FIGURE 3. Buried aquifer 2 distribution. Also shown are the 18O/deuterium characteristics (October 1995 and November 1996) in groundwater samples in wells from this aquifer and static water elevations (Minnesota only) at the time each well was drilled.

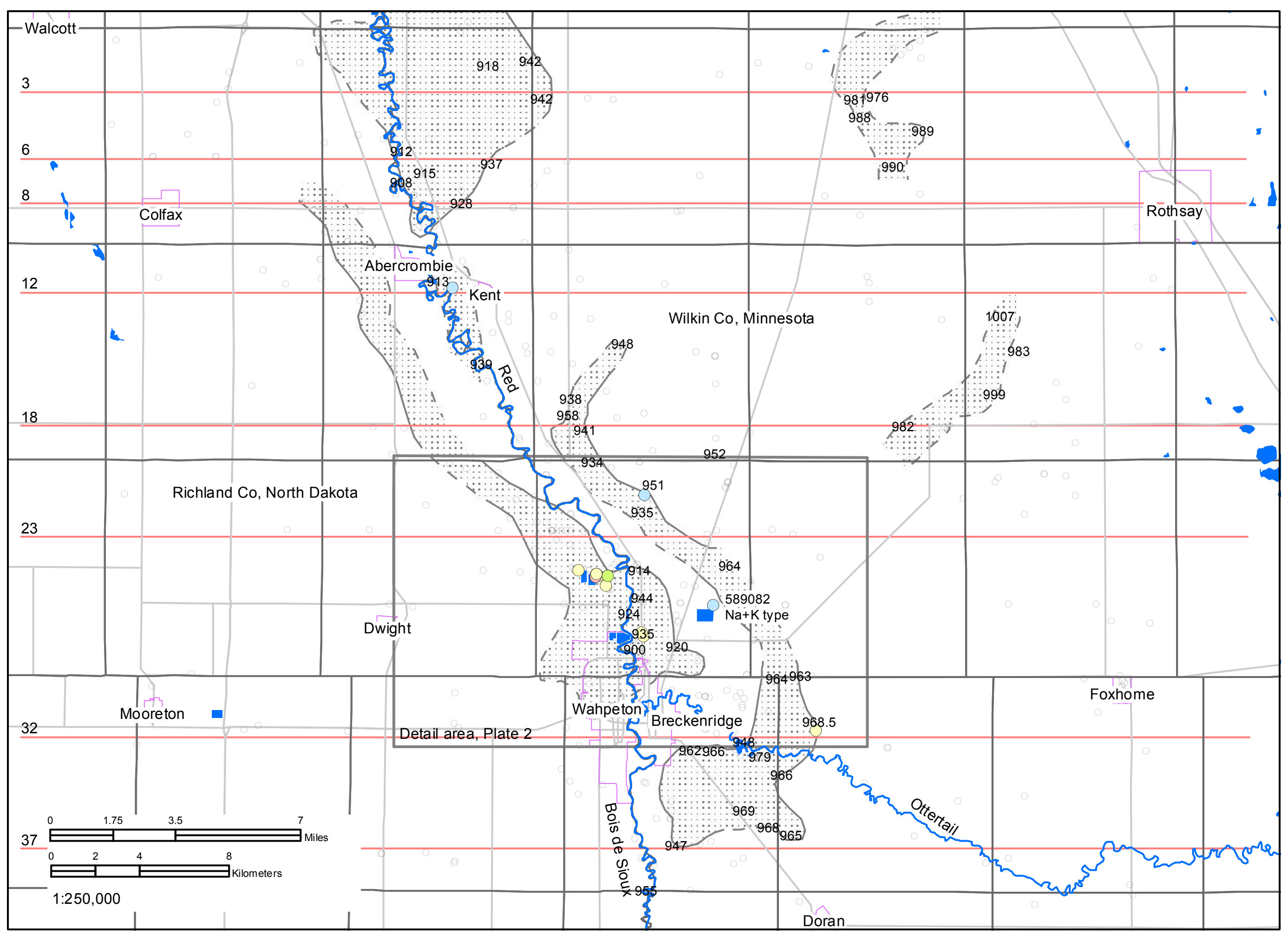
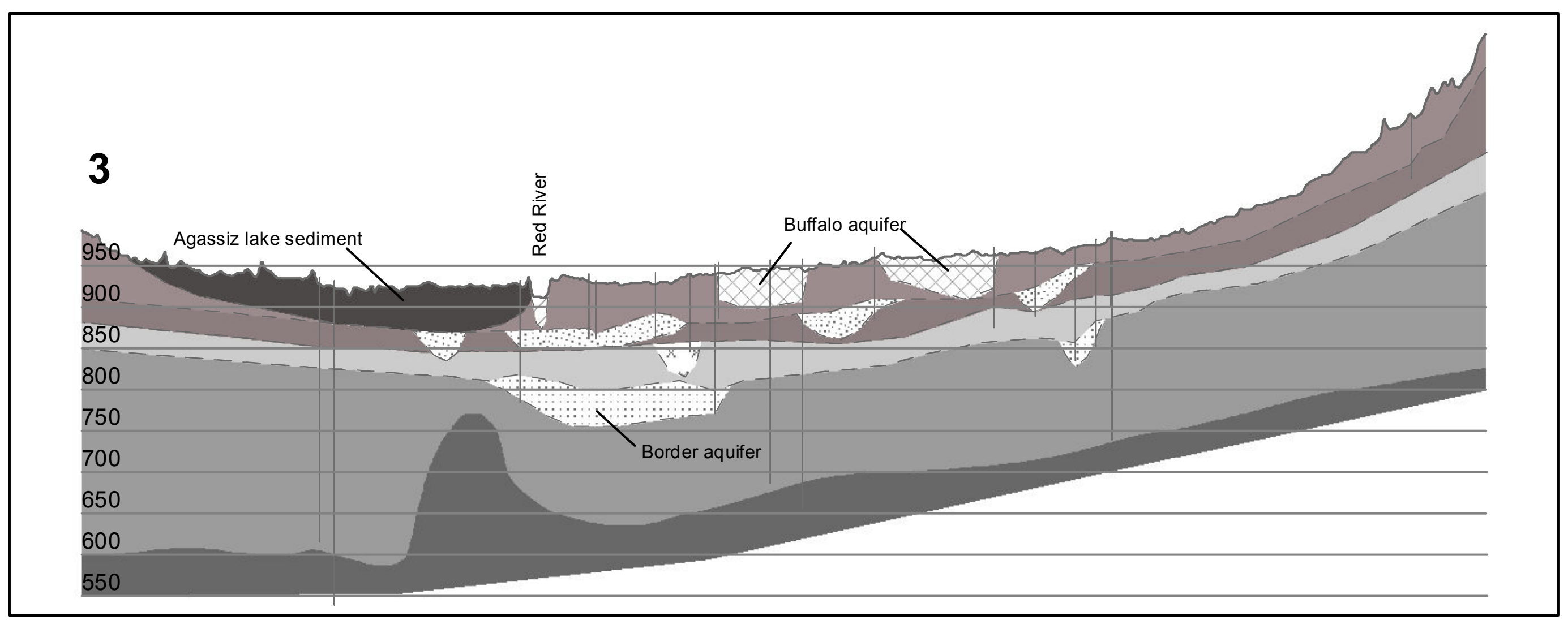
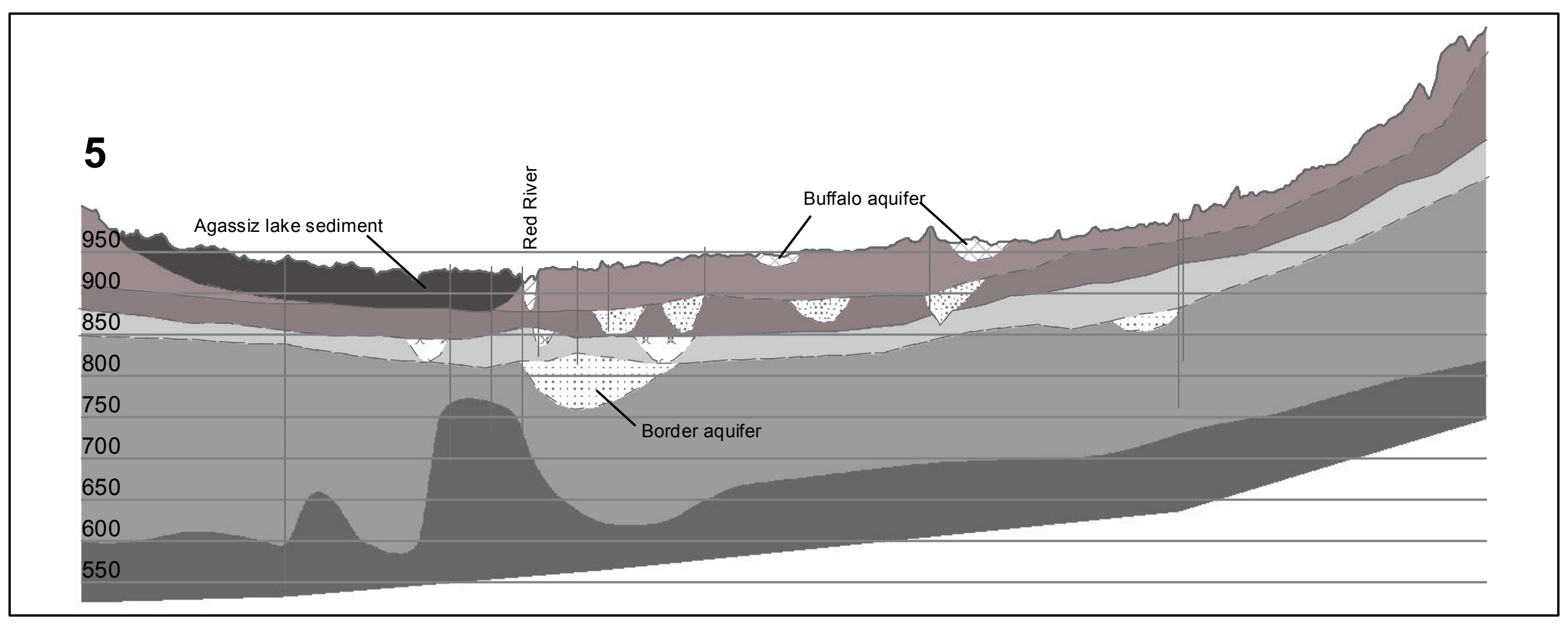
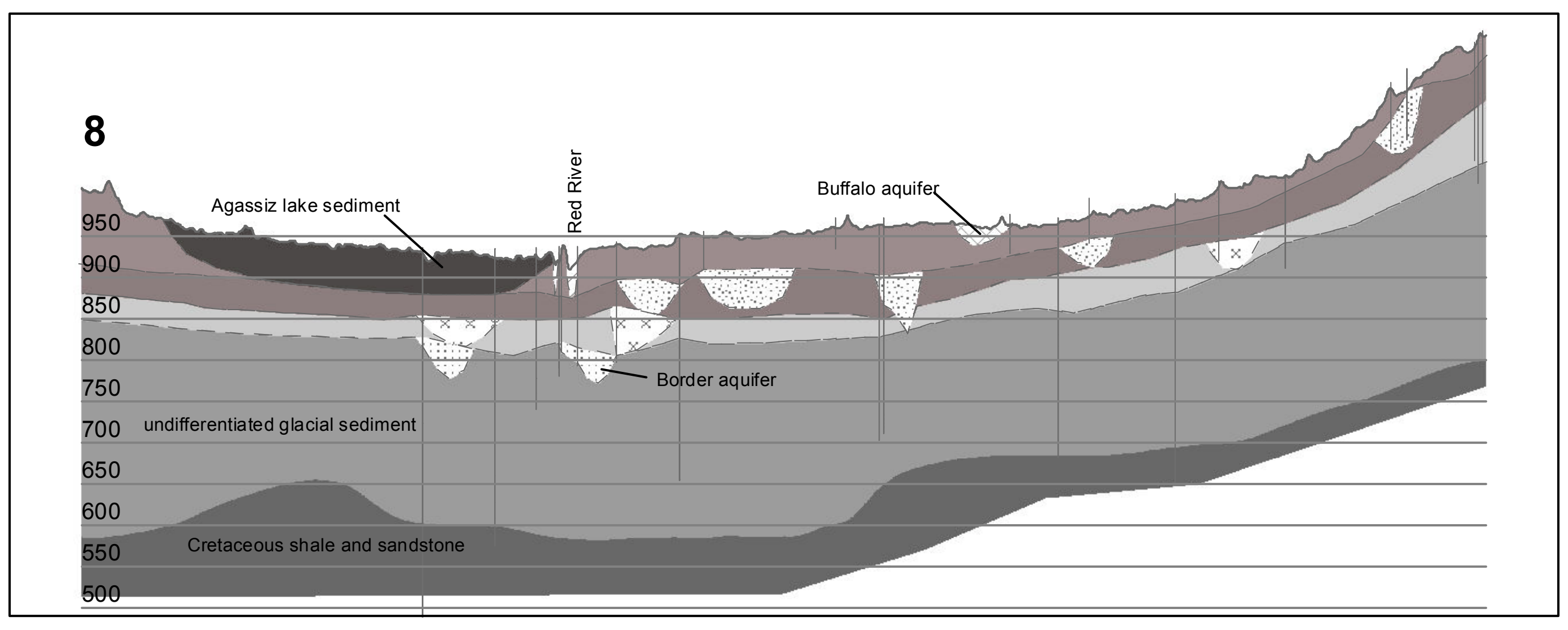
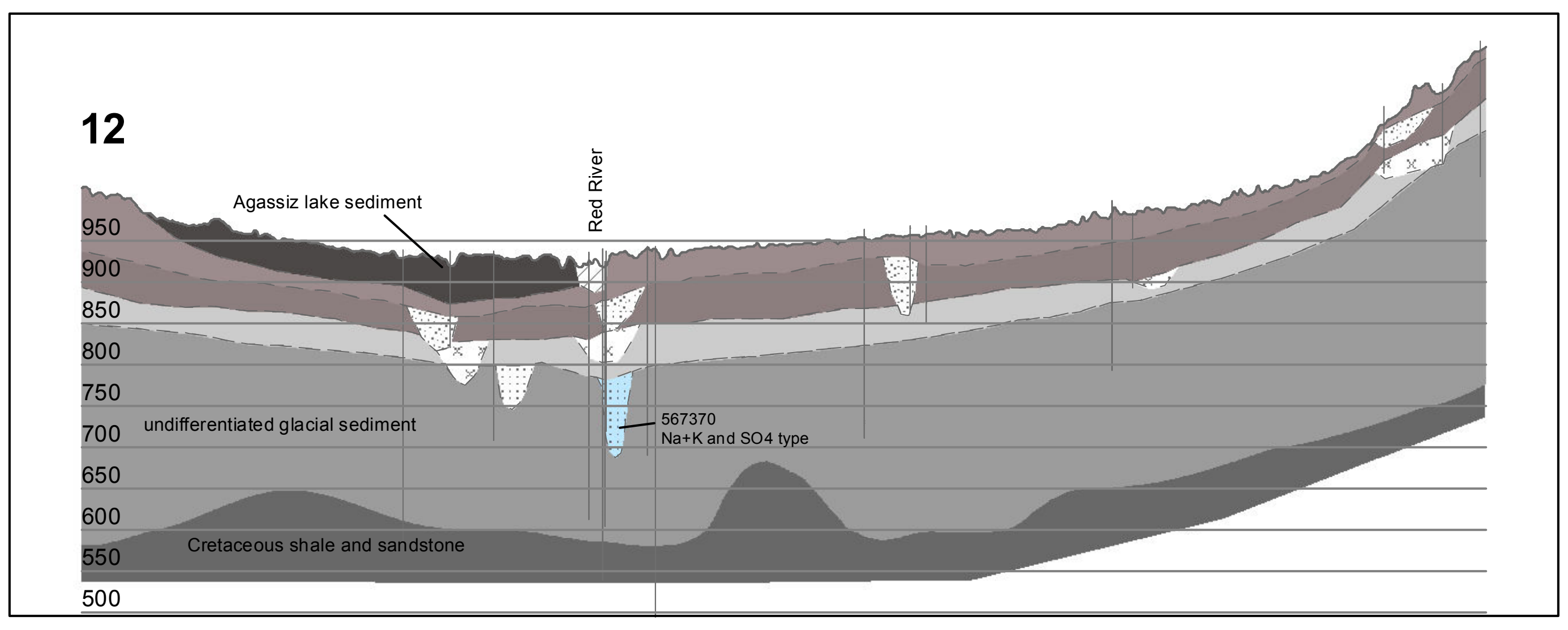


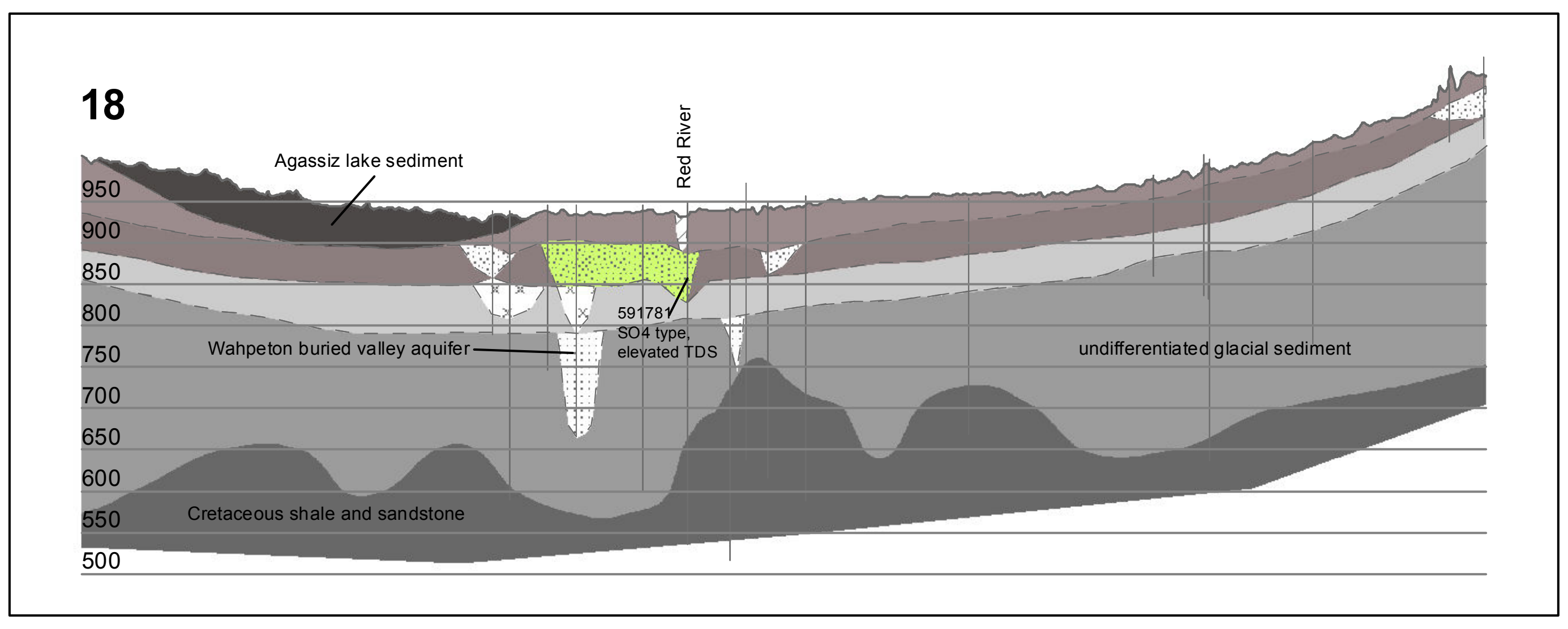
FIGURE 4. Buried aquifer 3 distribution. Also shown are the 18O/deuterium characteristics (October 1995 and November 1996) in groundwater samples in wells from this aquifer and static water elevations (Minnesota only) at the time each well was drilled.

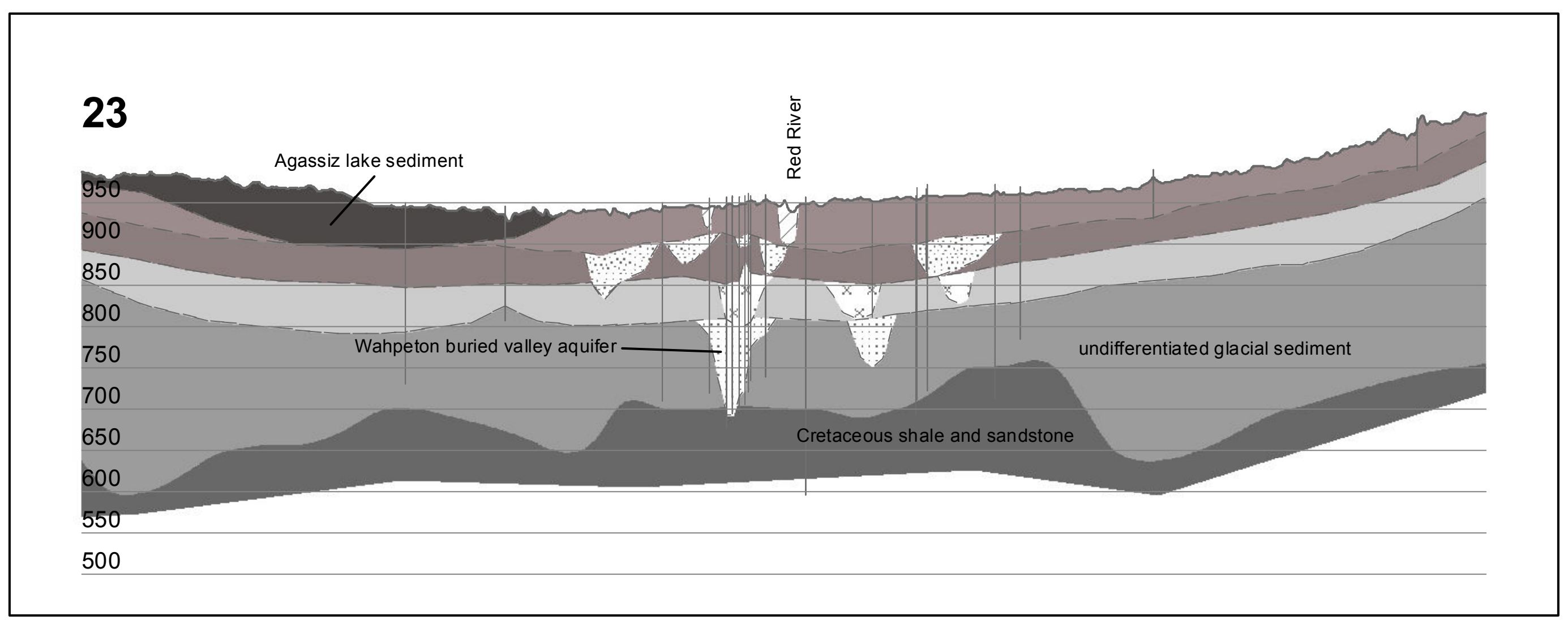


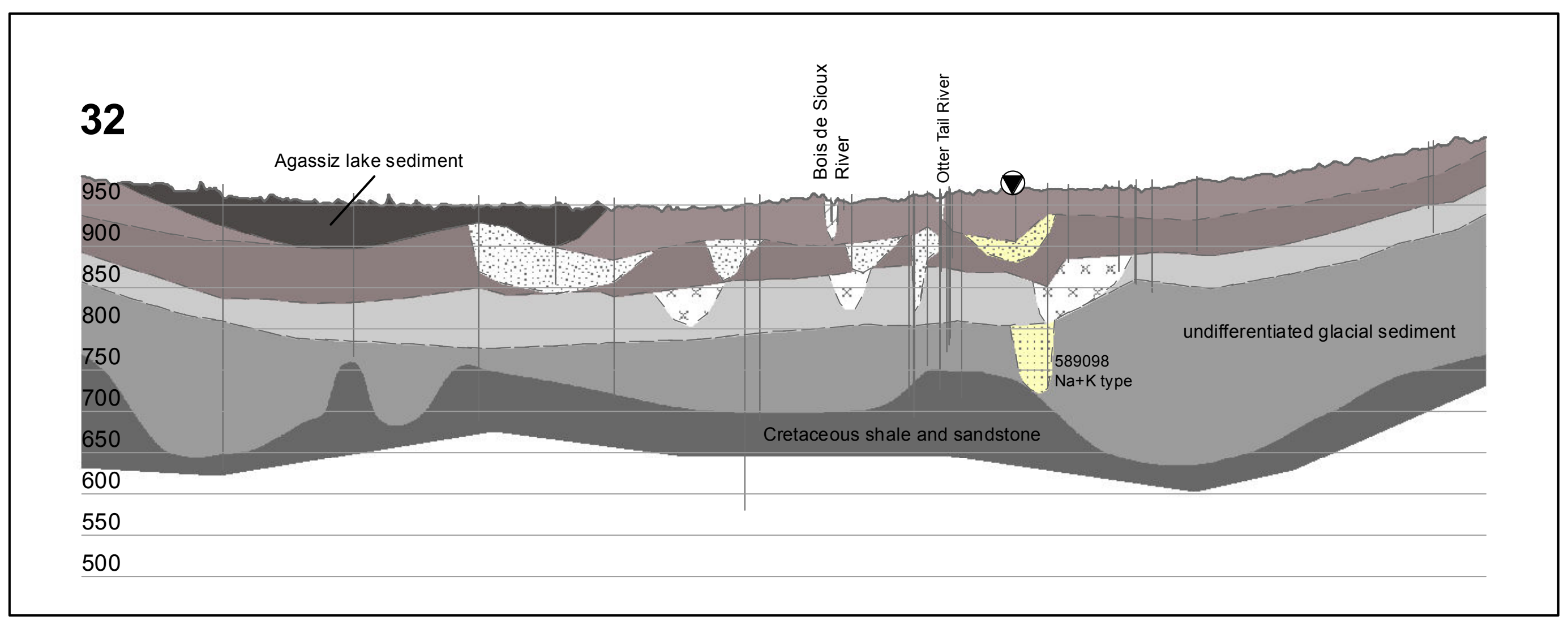


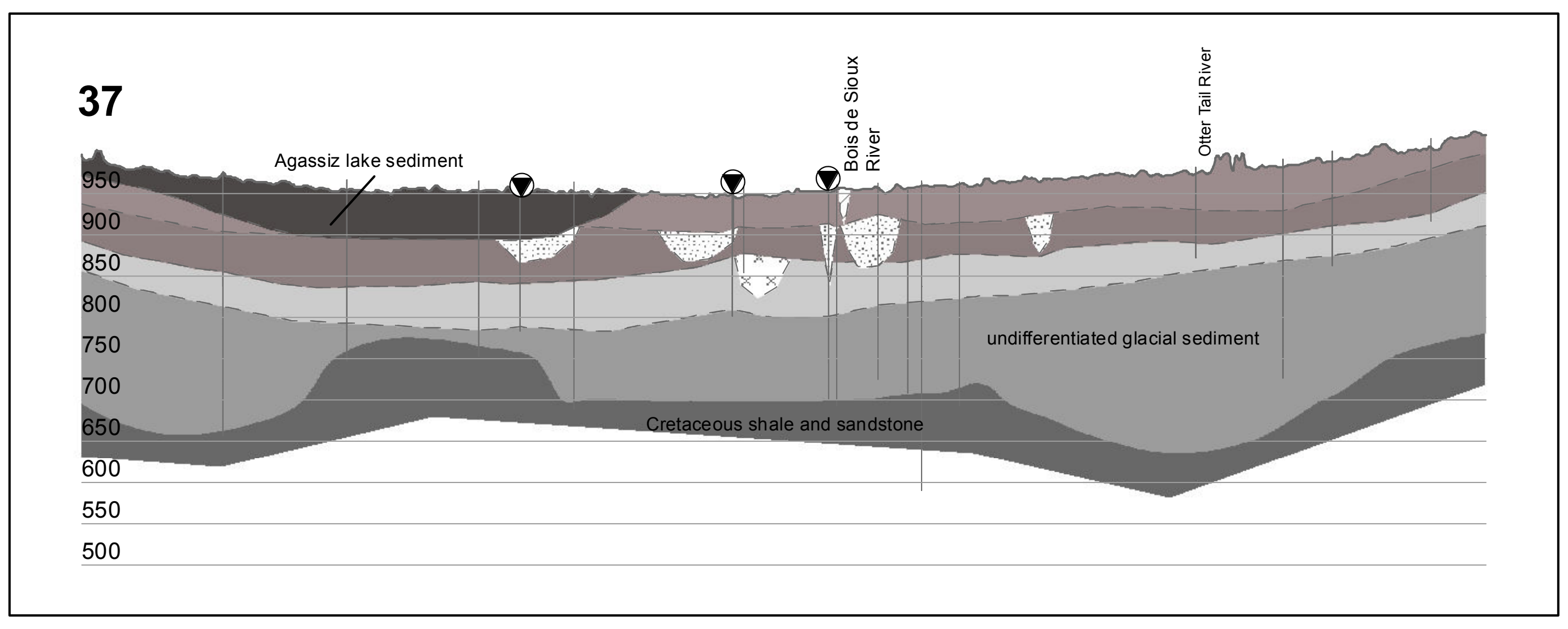












Vertical Exaggeration = X100

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2012

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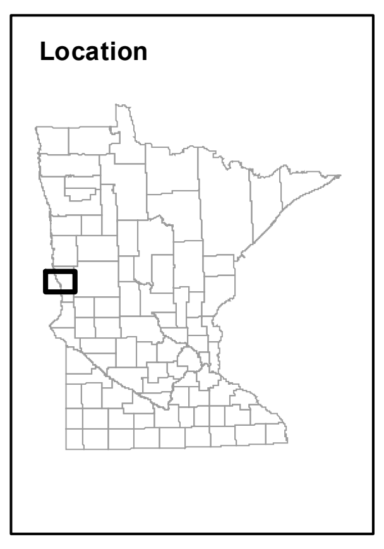


Map legend for Figures 2, 3, and 4

Buried sand and gravel aquifers

▒ Aquifer 1

× Aquifer 2

⁘ Aquifer 3

18O and deuterium categories

● Evaporative signature

● Mixed warm

● Mixed cold

● Glacial

○ Wells and soil borings used to map the aquifer shown on each figure

963 Static water elevation (feet above sea level)

■ Surface water body

Cross section legend

18O and deuterium categories

🟥 Evaporative signature

🟨 Mixed warm

🟩 Mixed cold

🟦 Glacial

▼ Selected water levels from 2007-2009

Aquifers

Surficial sand ▨

Aquifer 1 ▒

Aquifer 2 ×

Aquifer 3 ⁘

Confining layers

■ Agassiz Lake clay

■ Lower Goose River group till

■ Till 1 - undifferentiated

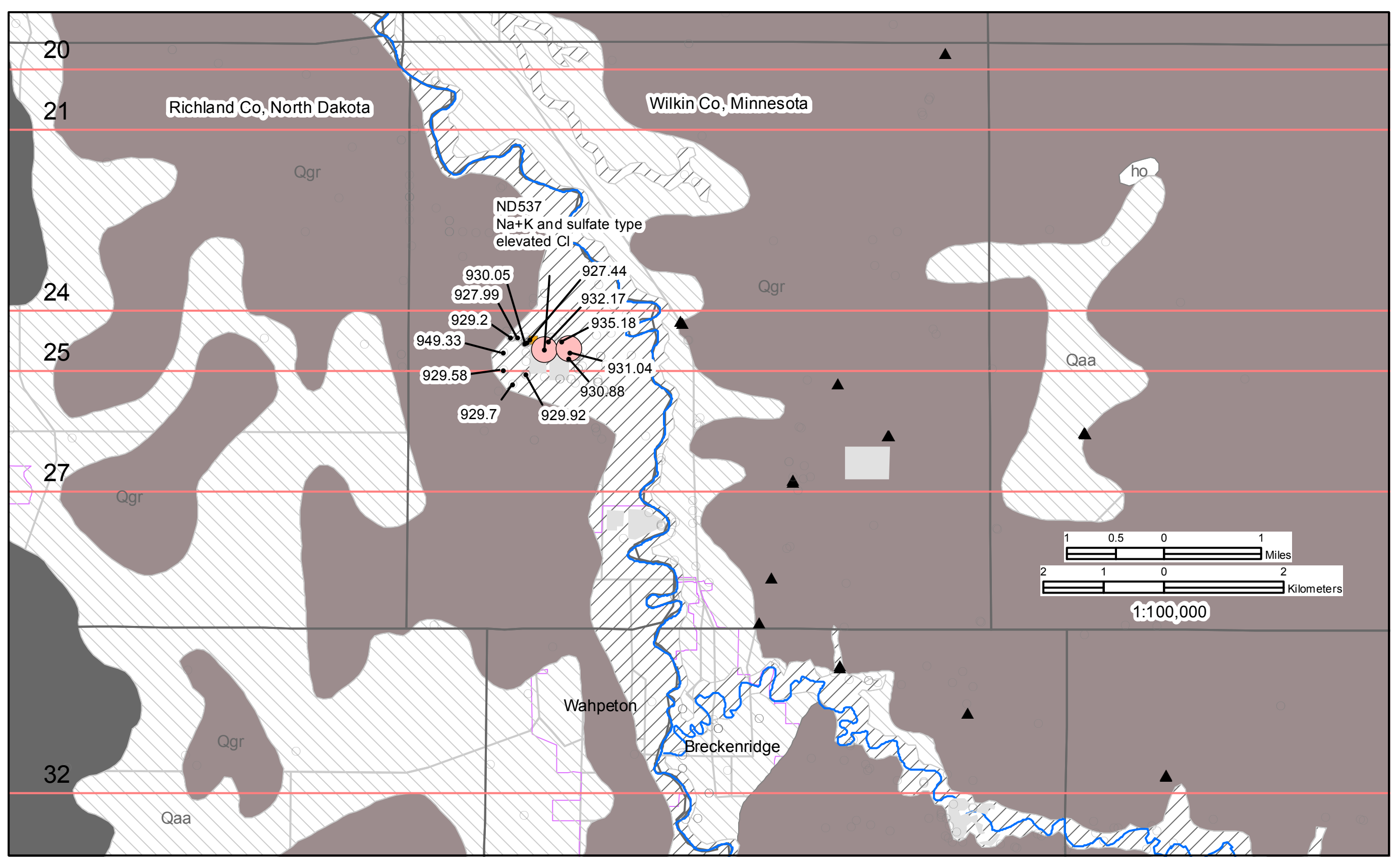
■ Till 2 - undifferentiated

■ Till 3 - undifferentiated

■ Cretaceous shale and sandstone

Buried sand and gravel aquifers of the Breckenridge/Wahpeton area, Minnesota and North Dakota

Plate 2. Detail area: Isotope hydrostratigraphy



Surficial sand

▨ Qha - Gravel, sand, silt, clay; alluvium and overbank sediment deposited in channels and floodplains of modern streams and rivers

▨ Qaa - Gravel, sand, silt, and clay; alluvium and overbank sediment deposited in channels and floodplains of ancient rivers and on the Lake Agassiz plain (generally not shown on cross sections)

Agassiz lake sediment

■ Qlo - Clay with thin silt laminae; offshore sediment deposited in deep quiet water of a lake

Glacial till

■ Qgr - Sand, silt, clay; glacial till (lower Goose River group) that has been eroded by the action of waves in a lake

● Water level elevations, June 1995

■ High capacity production wells

▲ NDSWC/MNDNR observation wells

○ Wells and soil borings used to map the aquifer shown on each figure

963 Static water elevation (feet above sea level)

FIGURE 1. Surficial geology emphasizing distribution of surficial sand and gravel deposits. Modified from Thorleifson, H., and others (2005). Also shown are the water level elevations (June 1995) and 18O/deuterium characteristics (October 1995 and November 1996) in the water table aquifer.

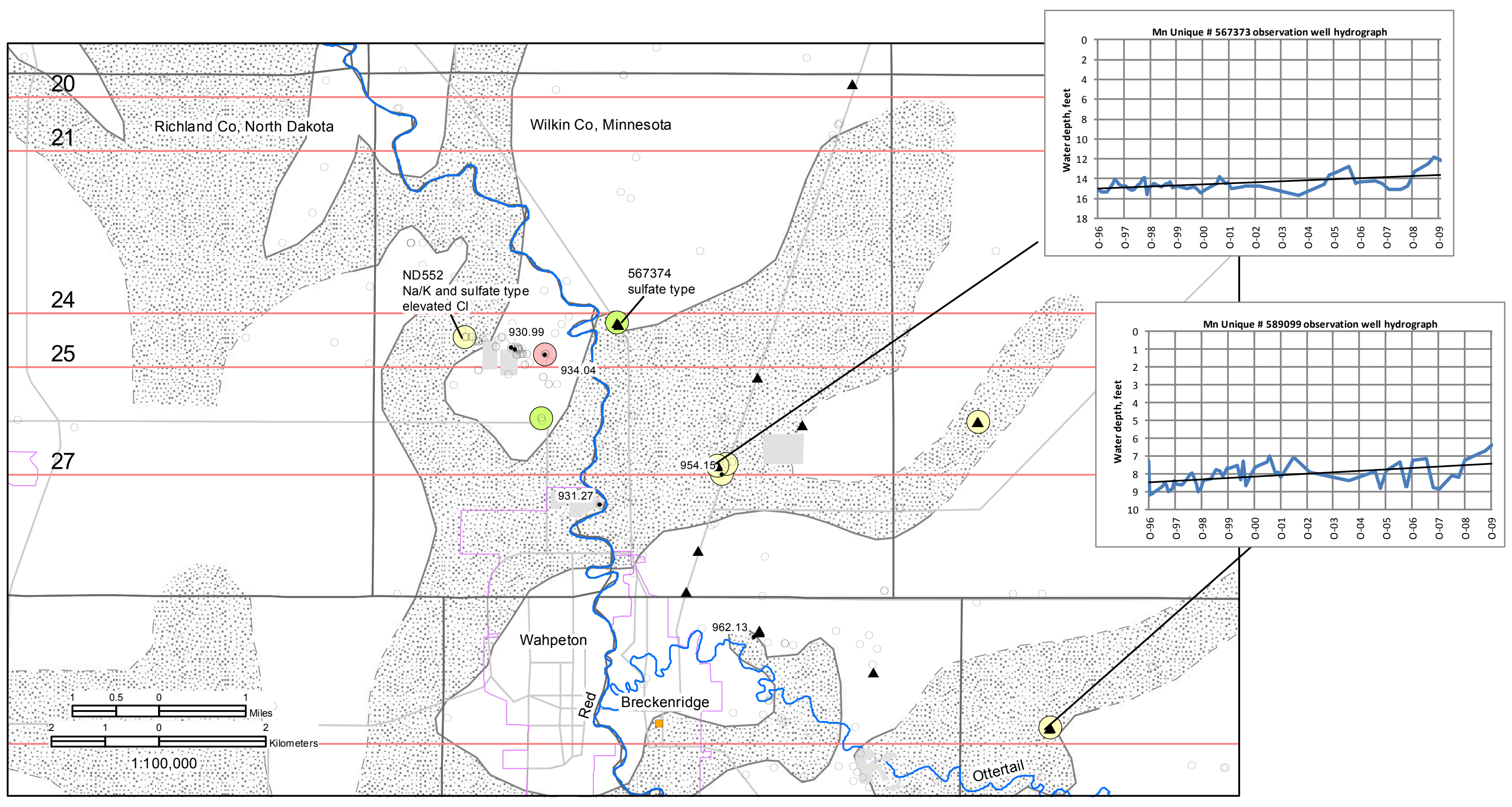


FIGURE 2. Buried aquifer 1 distribution. Also shown are the water level elevations (June 1995) and 18O/deuterium characteristics in aquifer 1. The observation well hydrographs indicate a slight rise in water levels since 1996. The black line on each hydrograph is a linear trendline that best fits the water level data

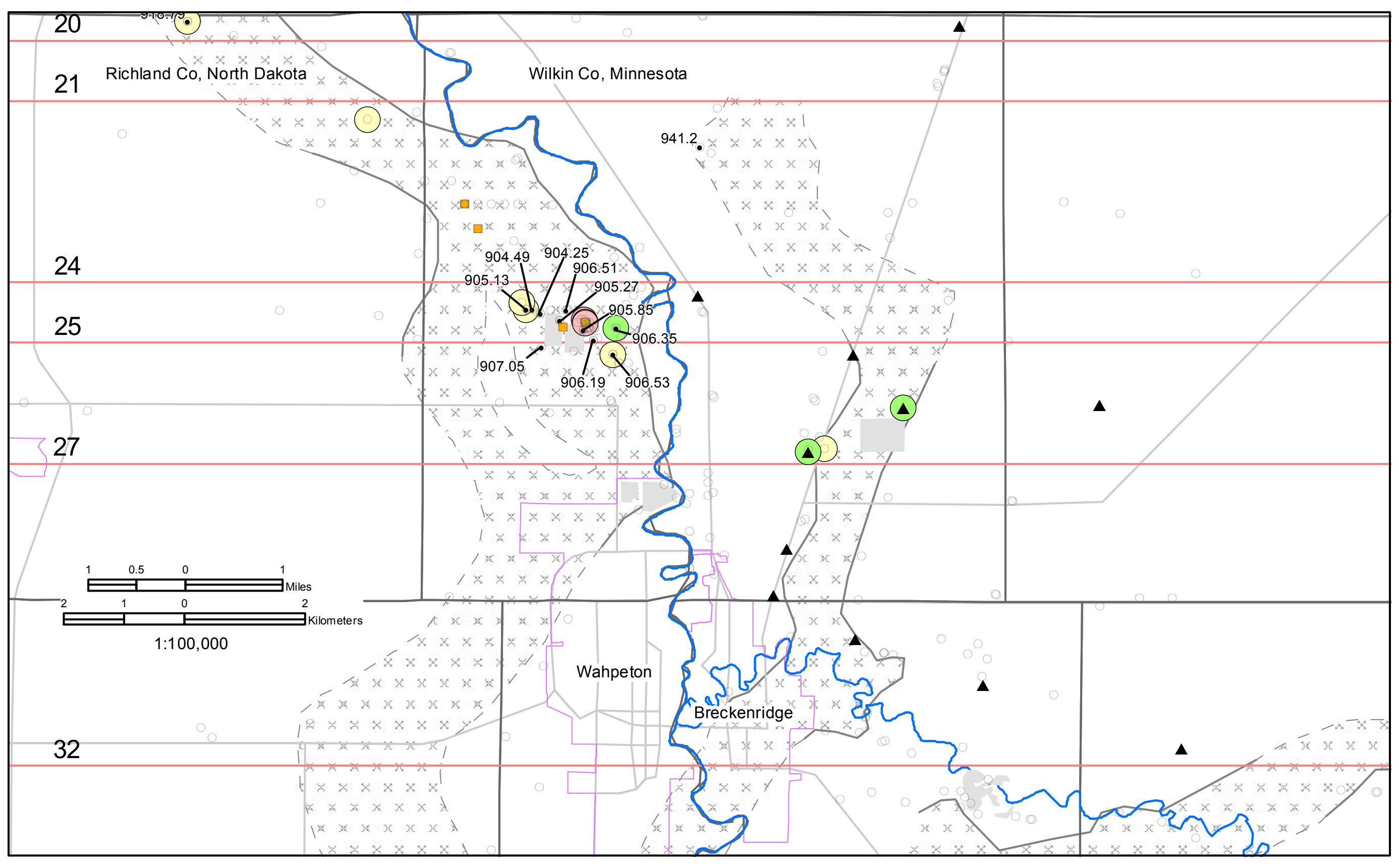


FIGURE 3. Buried aquifer 2 distribution. Also shown are the water level elevations (June 1995) and 18O/deuterium characteristics (October 1995 and November 1996) in aquifer 2.

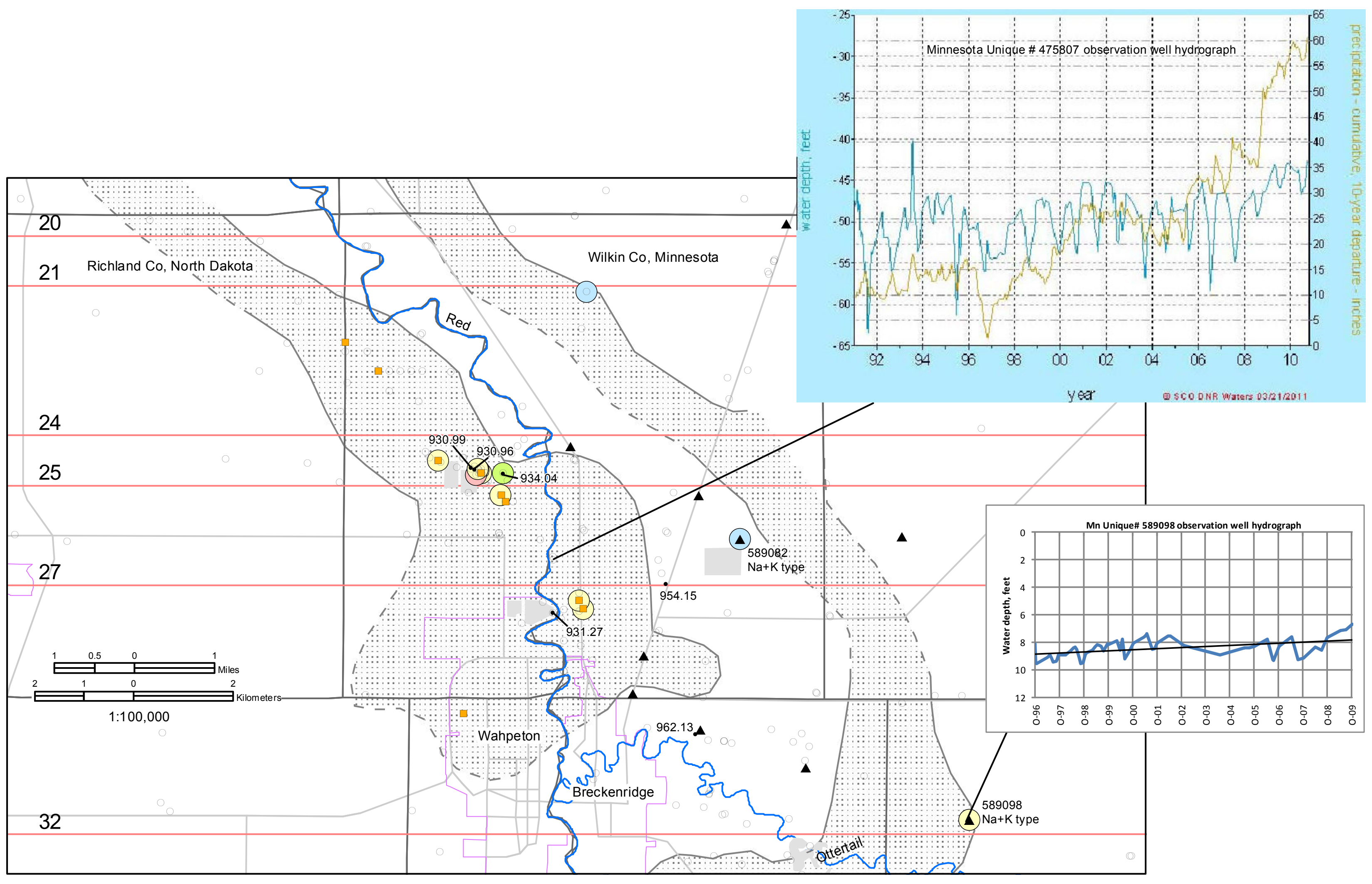
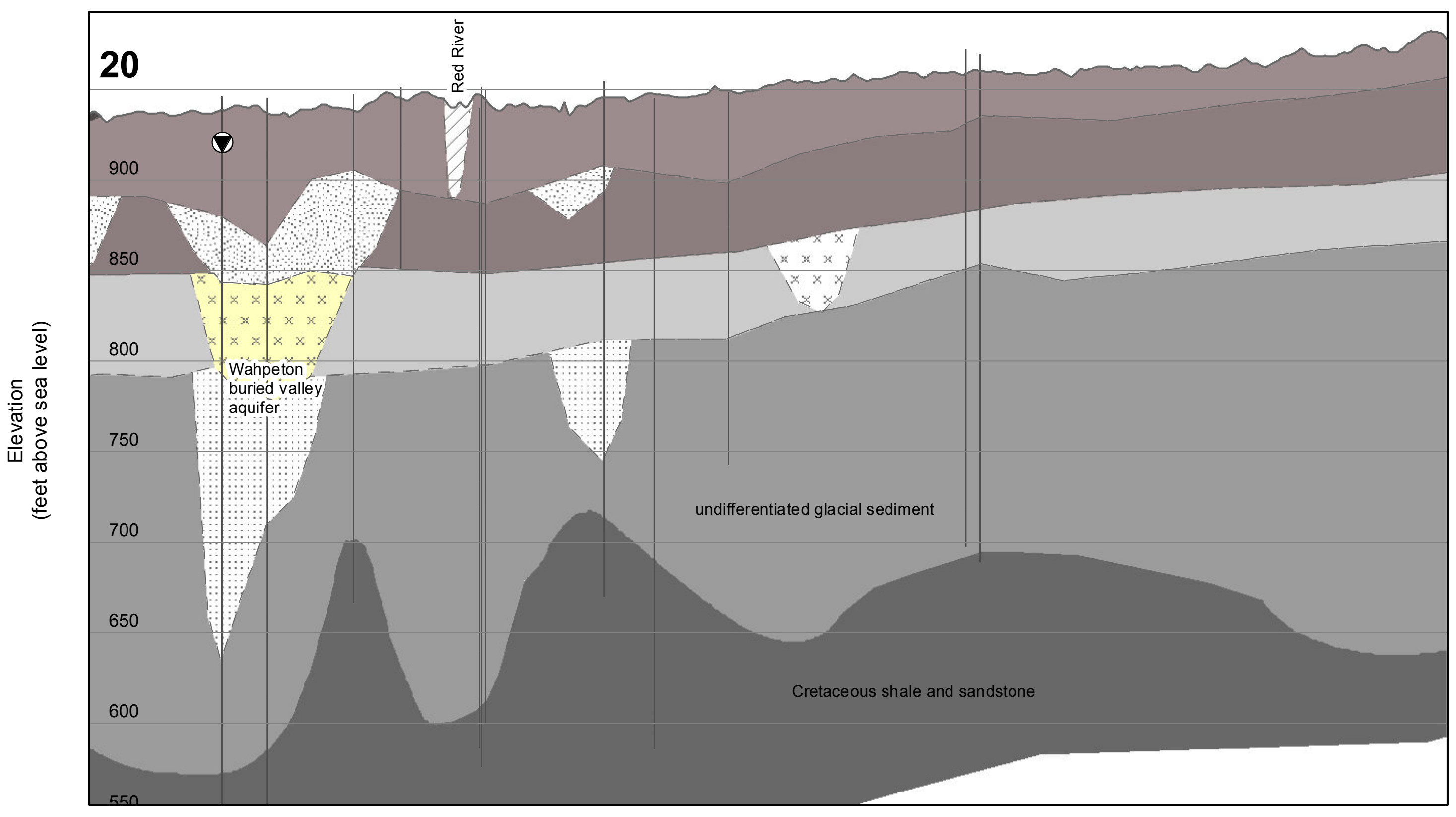
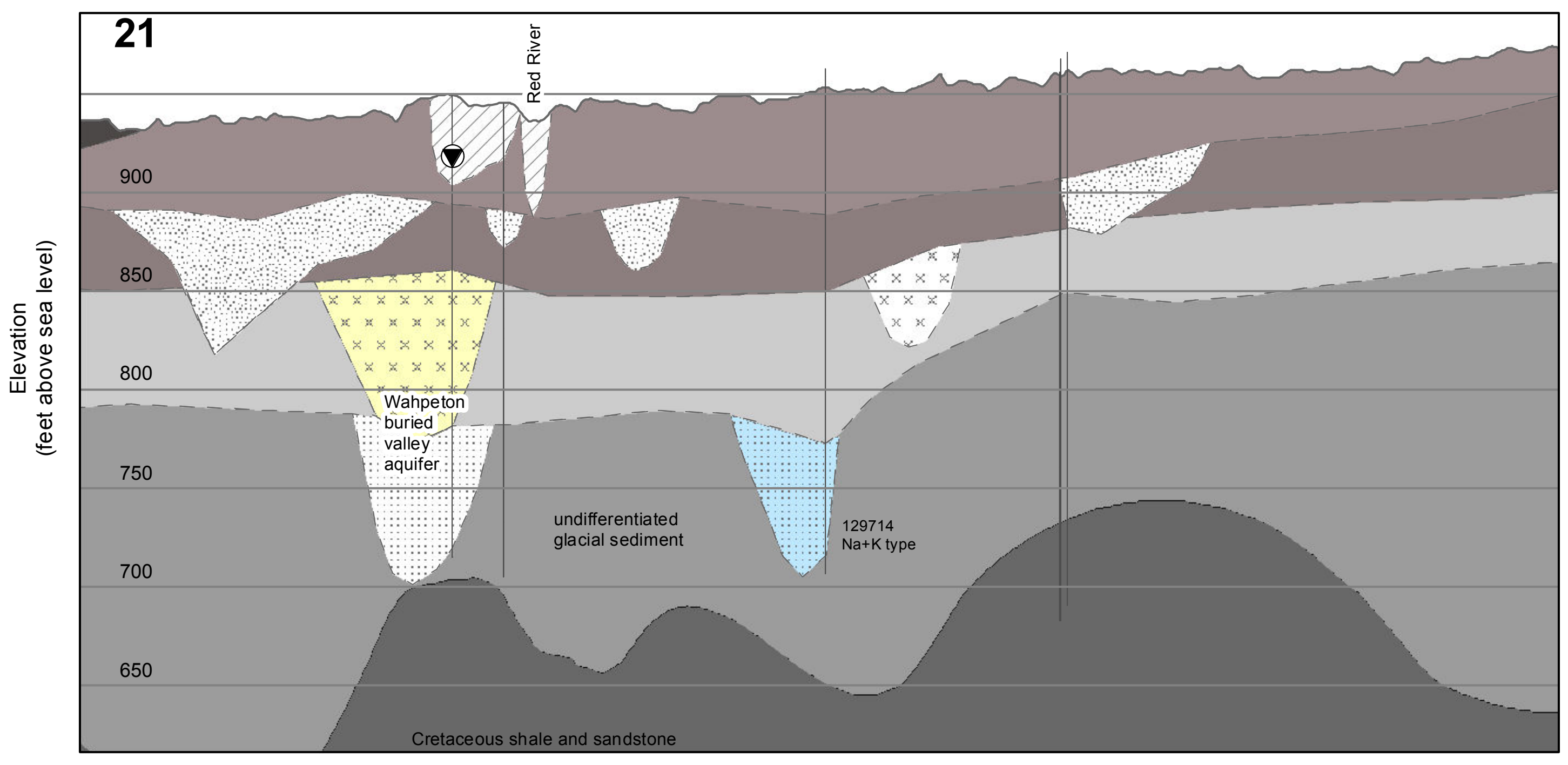
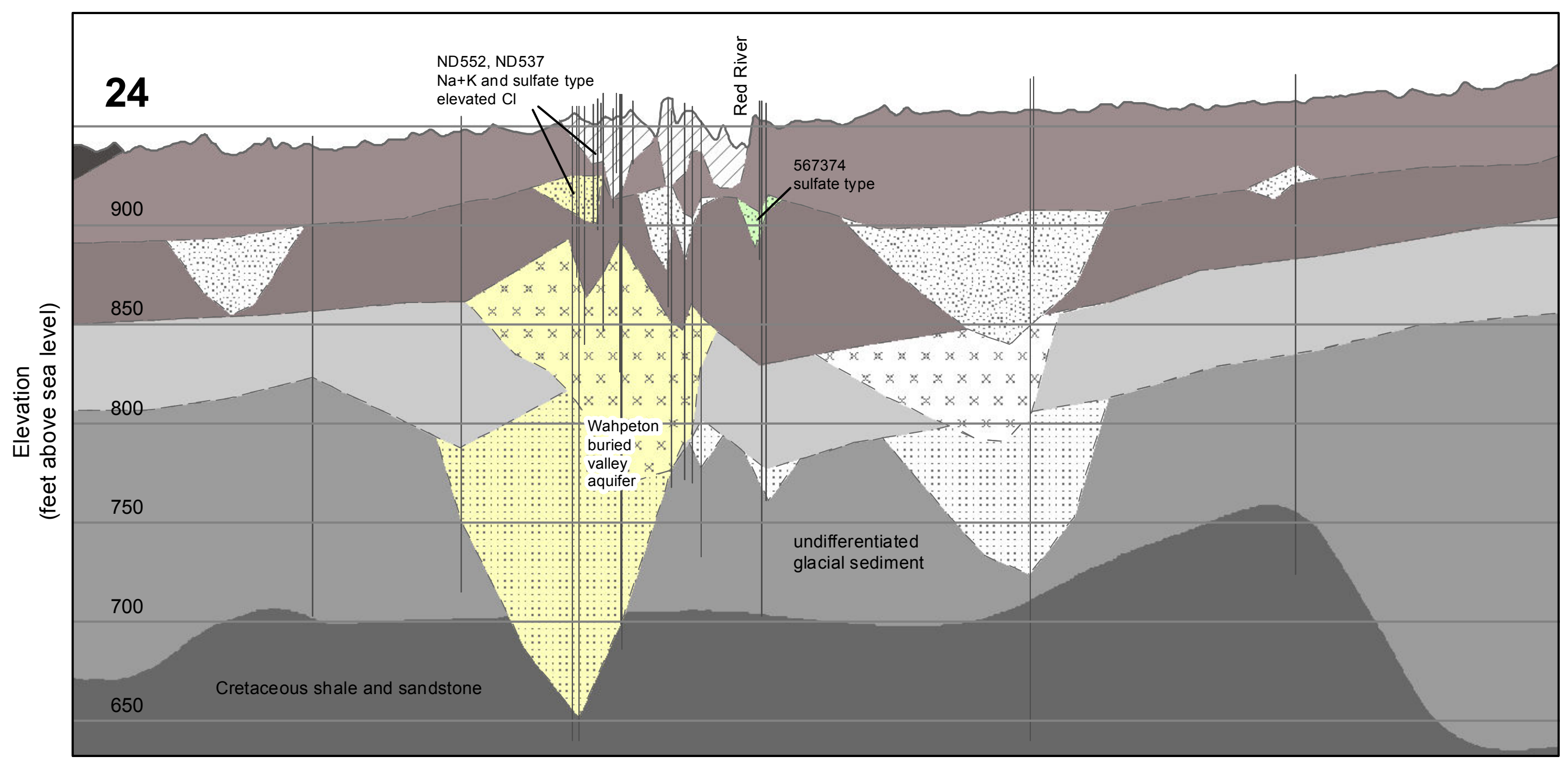
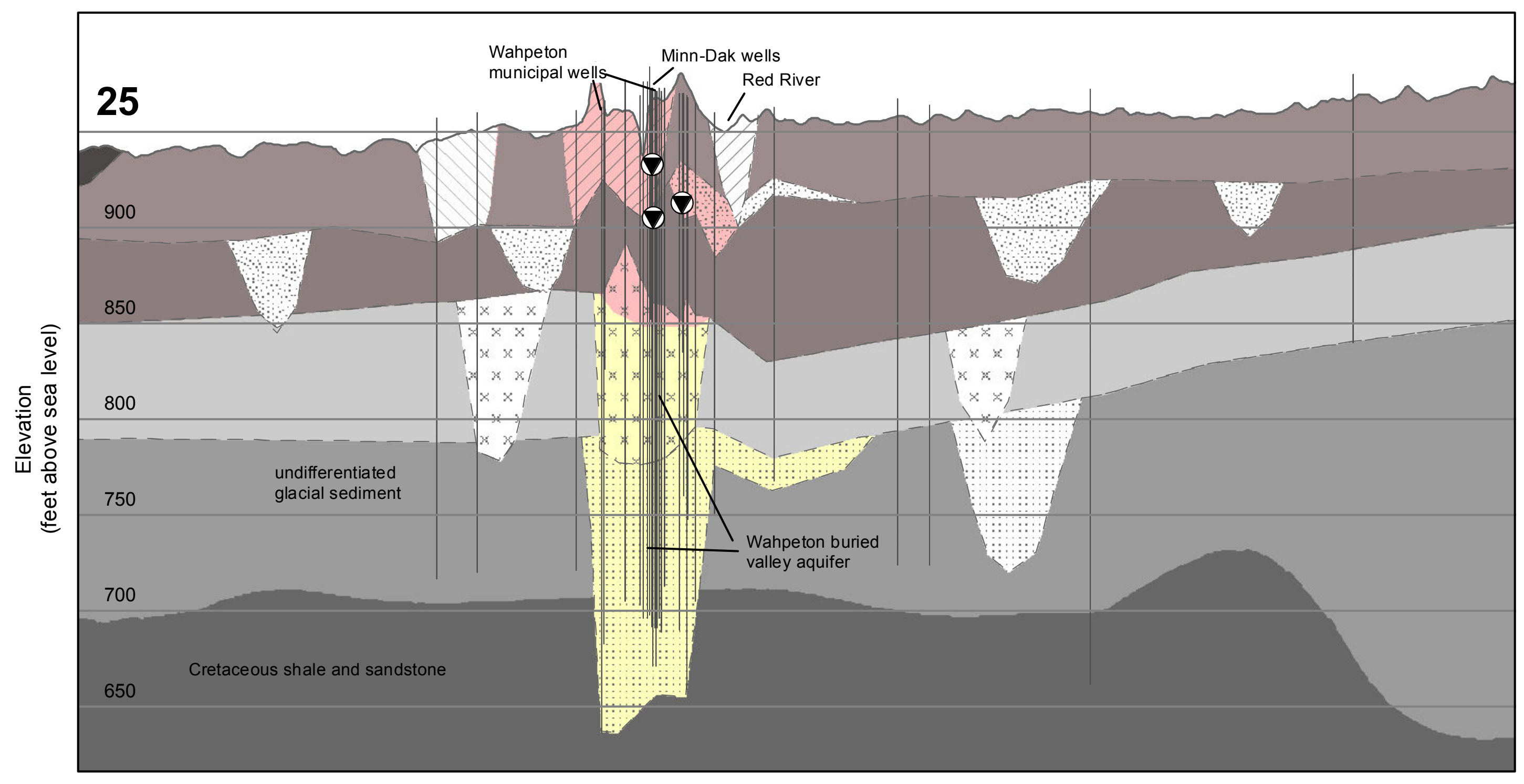


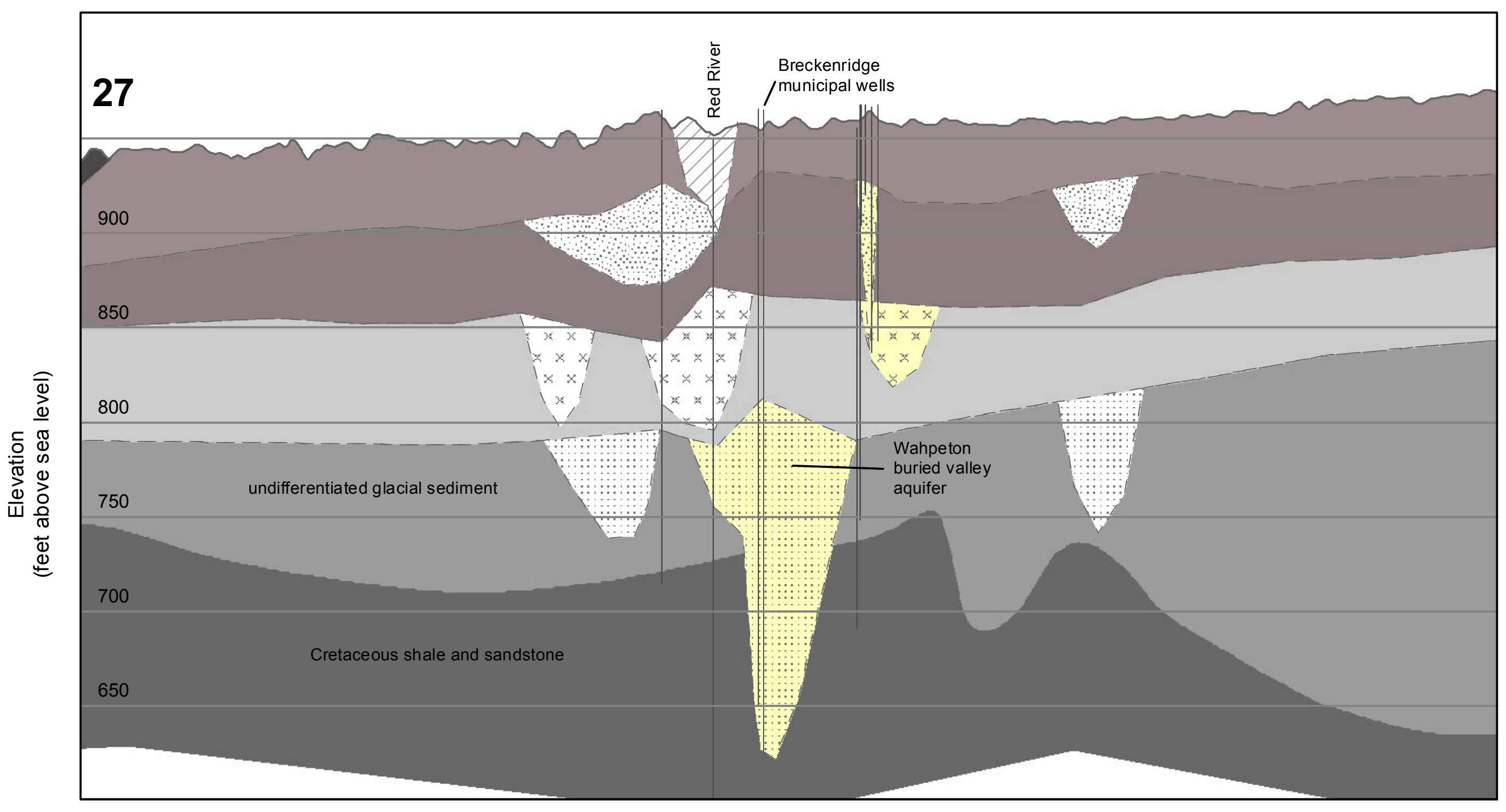
FIGURE 4. Buried aquifer 3 distribution. Also shown are the water level elevations (June 1995) and 18O/deuterium characteristics (October 1995 and November 1996) in aquifer 3. The observation well hydrograph #589098 indicates a slight rise in water levels since 1996. The black line on the hydrograph is a linear trendline that best fits the water level data. The #475807 hydrograph shows water levels from aquifer 3 since 1991 compared to cumulative changes in precipitation. Precipitation has increased since 2008 creating a slight rise in water levels.

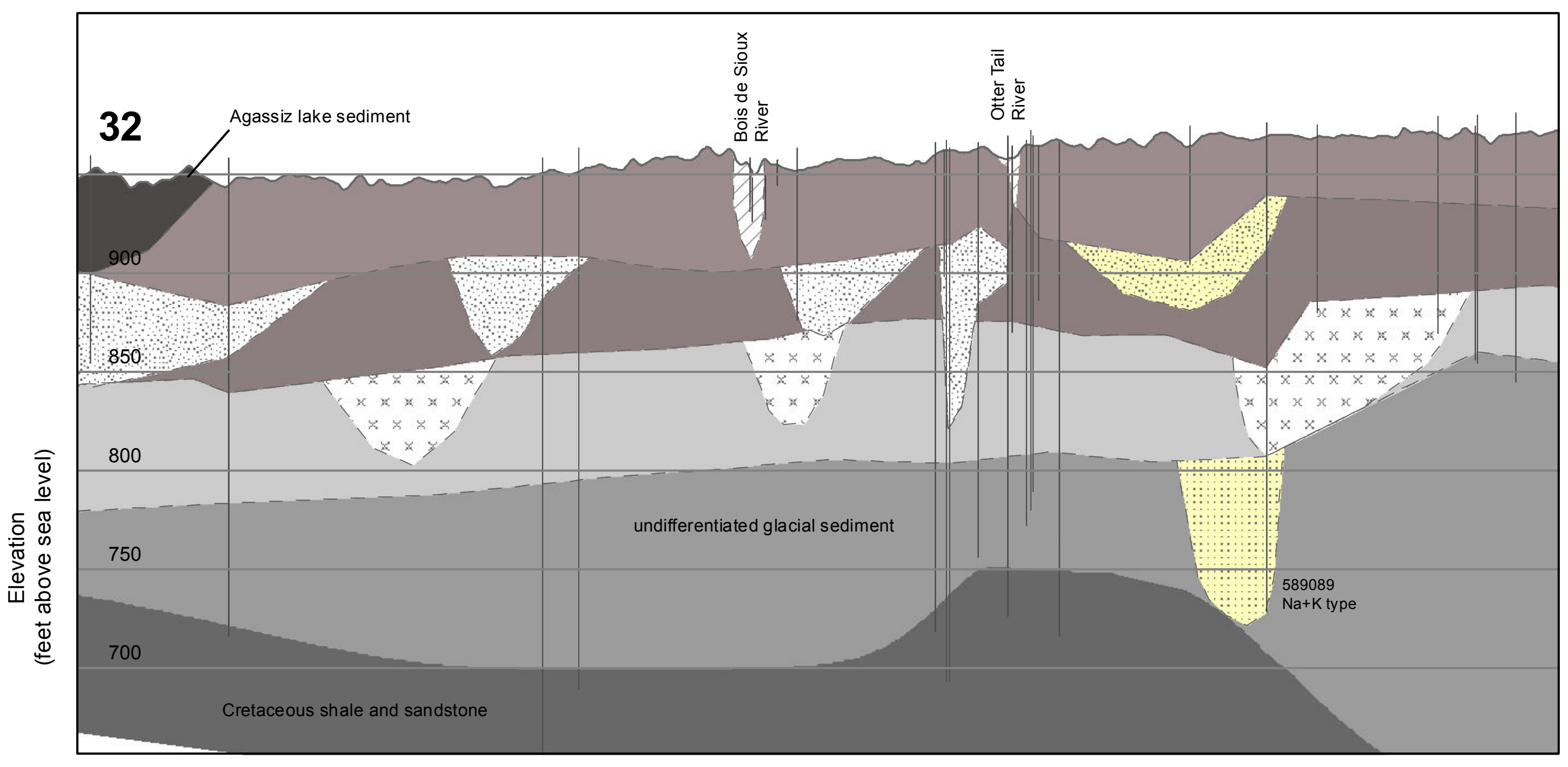












Vertical Exaggeration = X100

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Division of Ecological and Water Resources

2012

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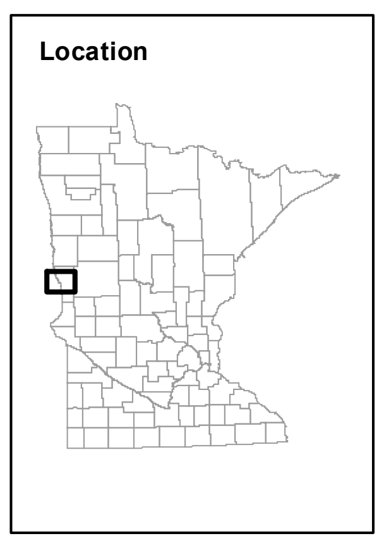

Map legend for Figures 2, 3, and 4

Buried sand and gravel aquifers

▨ Aquifer 1

× Aquifer 2

⁞ Aquifer 3

18O and deuterium categories

● Evaporative signature

● Mixed warm

● Mixed cold

● Glacial

● Water level elevations, June 1995

■ High capacity production wells

▲ NDSWC/MNDNR observation wells

○ Wells and soil borings used to map the aquifer shown on each figure

963 Static water elevation (feet above sea level)

▭ Surface water body

Cross section legend

18O and deuterium categories

🟥 Evaporative signature

🟨 Mixed warm

🟩 Mixed cold

🟦 Glacial

▼ Selected water levels from 2007-2009

Aquifers

Surficial sand ▨

Aquifer 1 ▨

Aquifer 2 ×

Aquifer 3 ⁞

Confining layers

■ Agassiz lake clay

■ Goose River group till

■ Till 1 - undifferentiated

■ Till 2 - undifferentiated

■ Till 3 - undifferentiated

■ Cretaceous shale and sandstone