ft, the average thickness of the Maha aquifer beneath of the project area, results in a storage coefficient of 3.8×10^{-4}.

2.3.3 Connectivity to Surface Water

Recharge to the *Kd/*Maha aquifer beneath the project area is limited to locations where the bedrock is close to the surface. This occurs most often along deeply-incised surface drainages. In other regions of the *Kd/*Maha aquifer, recharge occurs via infiltration of precipitation along exposed outcrops or shallow subcrops (Helgesen et al., 1993).

Connection to surface water features is limited to where outcrops of the *Kd* are in direct contact with streams at the surface or where permeable bedrock and or fractures are separated from the surface streams by highly permeable streambed sediments.

2.3.4 Connectivity to other Aquifers

Communication with overlying buried glacial outwash aquifers likely occurs, but specific quantification of these fluxes is not known. Gosselin et. al (2001) identified geochemical groundwater signatures that indicated a source from overlying glacial outwash. The degree of communication between the Quaternary and Cretaceous groundwater flow systems is not well understood and likely varies considerably due to local, ambient vertical gradients or through influence of pumping that occurs from both aquifers. Upward vertical communication of groundwater from underlying bedrock units is also possible. The highly saline sources in the *Kd*/Maha aquifer southeast of the project area in Lancaster County have been attributed to sources from the underlying Paleozoic units (Helgesen et al., 1993).

2.4 Water Quality

A total of 740 historic water quality samples were analyzed from the USGS National Water Information System (NWIS) to determine water chemistry characteristics of the project area, — 423 water samples from 184 stream-valley or alluvial wells, 192 water samples from 62 glacial-fill wells, 32 water samples from 31 High Plains aquifer wells, and 93 water samples from 29 wells tapping Cretaceous strata (most likely *Kd*). The water-quality samples from the High Plains aquifer wells likely were collected from wells screened in or open to the *To*. The High Plains aquifer also includes Quaternary deposits.

Median specific electrical conductance for all groundwater samples was 718 µS/cm (Table 2-2). Median calcium, sodium, chloride, and total dissolved solids (TDS) were 99.5, 25.9, 3.6, 39.0, and 448 mg/L, respectively (Figure 2-9 [sulfate not shown], Table 2-2). The maximum specific conductance value was 4,710 µS/cm and the maximum calcium, sodium, chloride, sulfate, and TDS concentrations were 527, 281, 110, 1,390, and 2,470 mg/L, respectively. The maximum value for both specific conductance and TDS was from a sample in a shallow glacial well open to loess or till deposits. Specific conductance values averaged 2,550 µS/cm from 5 water samples. So the 4,710 µS/cm reading would appear as or approach an outlier value.

Water quality data plots are included in Appendix 5 and all water quality data is provided in the data deliverables.

Table 2-2: Statistical results of water-quality analyses from groundwater samples collected in or near the project area, from all wells. Units in milligrams per liter unless stated otherwise. Data are from the US Geological Survey NWIS database; (NA- not analyzed; N- number of samples).

	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum	NA's	N
Water temperature (°C)	8.3	11.5	12.5	12.9	13.9	143	18	723
Specific conductance (µS/cm at 25 °C)	96	597	718	764.1	889.8	4710	2	739
pH (standard units)	5.9	7	7.2	7.309	7.6	8.5	83	658
Dissolved oxygen	0.1	0.2	0.7	2.438	4.1	17.2	384	357
Bicarbonate, as CaCO3	37	390	440	465	494	1,240	628	287
Calcium	10.1	82	99.5	103.9	120	527	0	741
Magnesium	1.9	16	21.9	23.63	29	90.5	0	741
Sodium	4.34	17	25.9	30.73	36	281	0	741
Sodium adsorption ratio	0.13	0.4	0.6	0.6956	0.8	3.52	0	741
Potassium	1.41	4.1	6.345	7.136	9	29	18	723
Chloride	1	27	93.5	102.6	162.8	267	2	739
Sulfate	0.18	16	39	77.88	89	1390	1	740
Fluoride	1	19	23	28.7	35	93	213	528
Silicate	8.2	27.75	33	32.5	39	66.8	200	541
TDS	85	355	448	483.2	571	2460	23	718

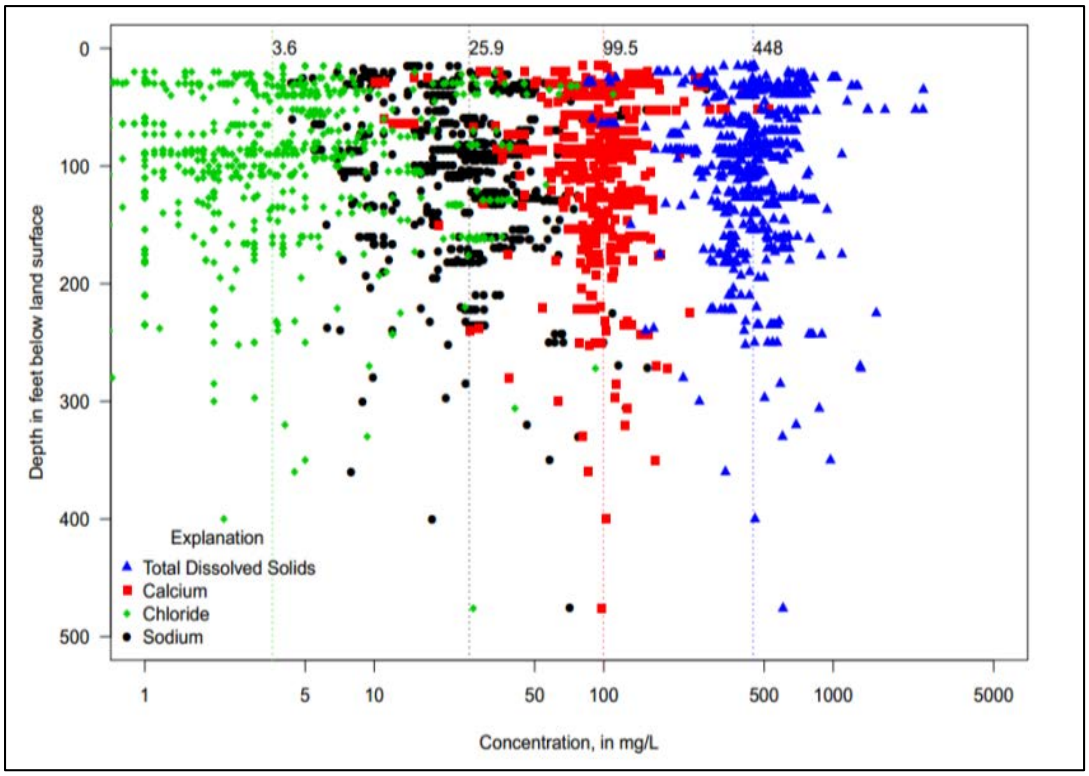


Figure 2-9: Concentrations of TDS, calcium, chloride, and sodium (x-axis) in water samples verses depth (y-axis) Data are from the USGS NWIS.

Most groundwater in the area appears fresh. In some locations, larger specific conductivity, sulfate, and TDS concentrations were observed. The quality of the groundwater in the project area should pose no interference for interpretation of AEM data.

2.4.1 Quaternary Aquifer Water Quality

Groundwater quality in both stream-valley and glacial-fill (Quaternary surficial aquifers) depends largely on overlying deposits. In areas where low yield deposits (i.e., till and loess) overlie aquifers, groundwater quality largely is less impacted than those where sand and gravel deposits are near land surface. In stream-valley systems, groundwater is in close proximity to the land surface and therefore subject to water quality changes due to land use/land cover.

Median specific conductance values from water-quality samples collected from stream-valley and glacial wells were 663 µS/cm (Table 2-3) and 779 µS/cm (Table 2-4), respectively. These values are lower than water samples from the *Kd* wells where median specific conductance was 845 µS/cm (Table 2-5). For stream-valley wells the median calcium, sodium, chloride, sulfate, and TDS concentrations were 91.0, 20.2, 3.20, 40.0, and 413 mg/L, respectively (Table 2-3). The maximum specific conductance value was 1,930 µS/cm and the maximum calcium, sodium, chloride, sulfate, and TDS concentrations were 237, 116, 56.0, 875, and 1,540 mg/L, respectively (Table 2-3). For glacial-fill wells the median calcium, sodium, chloride, sulfate, and TDS concentrations were 104, 33.4, 3.37, 29.0, and 468 mg/L, respectively (Table 2-4). The maximum specific conductance value was 4,710 µS/cm and the maximum calcium, sodium, chloride, sulfate, and TDS concentrations were 527, 281, 110, 1,390, and 2,470 mg/L, respectively (Table 2-4).

Generally, median concentrations of ions and TDS in groundwater were slightly higher in water samples from glacial-fill wells than from stream-valley wells. Sulfate was the only exception where the stream-valley systems contained higher sulfate concentrations than glacially-derived systems. This is thought to be due to the larger dissolved oxygen concentrations observed in the glacial systems than the stream-valley aquifers (2.50 to 0.65 mg/L). Small dissolved oxygen concentrations would help promote oxidation-reduction reactions (redox), which can increase SO_4 concentrations. Dissolved oxygen, however, was not collected in most stream-valley groundwater samples.

Table 2-3: Statistical results of water quality analyses from groundwater samples collected in or near the project area, from stream-valley/alluvial wells. Units are in milligrams per liter unless stated otherwise. Data are from the US Geological Survey NWIS database (NA- not analyzed; N- number of samples).

	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum	NA's	N
Water temperature (°C)	8.3	11.7	12.9	12.9	14	22.2	10	413
Specific conductance (µS/cm at 25 °C)	96	513	663	682	857	1,930	2	421
pH (standard units)	5.9	7.1	7.3	7.44	7.8	8.5	17	406
Dissolved oxygen	0.1	0.2	0.65	1.77	1.82	9	343	80
Bicarbonate, as CaCO3	37	44	413	330	437	699	402	21
Calcium	10.1	68	91	93.7	120	237	0	423
Magnesium	1.9	14	20	21.8	28	89	0	423
Sodium	4.34	11	20.2	23.4	29	116	0	423
Sodium adsorption ratio	0.2	0.32	0.5	0.55	0.68	1.8	0	423
Potassium	1.53	4.1	6.1	6.42	8.1	17	9	414
Chloride	0.54	1.7	3.2	6.43	5.94	56	2	421
Sulfate	0.8	15	40	67.4	84.8	875	1	422
Fluoride	0.1	0.3	0.3	0.35	0.4	0.9	50	373
Silicate	12	29.8	33	33.8	39	53	46	377
TDS	85	320	413	434	537	1,540	13	410

Table 2-4: Statistical results of water quality analyses from groundwater samples collected in or near the project area from wells in glacially-derived deposits. Units are in milligrams per liter unless stated otherwise. Data are from the US Geological Survey NWIS database; (NA- not analyzed; N- number of samples).

	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum	NA's	N
Water temperature (°C)	9.1	11.6	12.3	12.5	13.2	20.8	7	185
Specific conductance (µS/cm at 25 °C)	418	687	779	910	915	4,710	0	192
pH (standard units)	6.5	6.9	7	7.08	7.2	8.2	48	144
Dissolved oxygen	0.1	0.4	2.5	3.51	6.4	17.2	24	168
Bicarbonate, as CaCO3	192	429	477	545	514	1,240	123	69
Calcium	63	94	104	122	117	527	0	192
Magnesium	11	19.2	24.4	27.7	29.9	90.5	0	192
Sodium	8.73	25	33.4	42.8	47	281	0	192
Sodium adsorption ratio	0.13	0.59	0.73	0.94	1.04	3.52	0	192
Potassium	1.41	3.81	5.44	7.67	8.98	29	0	192
Chloride	<1.00	1.58	3.37	7.76	5.99	110	0	192
Sulfate	<0.18	15.8	29	78.5	58.2	1,390	0	192
Fluoride	0.17	0.3	0.4	0.49	0.6	1.22	104	88
Silicate	14.9	30.8	33.6	32.5	37.6	50.4	104	88
TDS	261	408	468	576	618	2,470	1	191

2.4.2 Bedrock Aquifer Water Quality

Water quality within the bedrock aquifers varies considerably by location and depth. Quality in the *Kd* in eastern Nebraska varies from (1) a Ca(±Mg)HCO_3-type water associated with local precipitation and where the *Kd*/Maha aquifer is unconfined, (2) a $CaSO_4$ and Ca-Na SO_4-type water associated with meltwater from Pleistocene glaciers and where the confining unit is thick, or (3) mixed waters of either $CaSO_4$ and Ca-Na SO_4-type water or NaCl-type water, which represent a possible interaction of the first two types of water or recharge waters have been displaced by NaCl at depth (Gosselin et al., 2001). In the project area, water quality in the *Kd* likely is a $CaSO_4$ and Ca-Na SO_4-type water.

Groundwater can be potable in areas where the *Kd* is unconfined or subject to recharge from local precipitation. TDS concentrations at these locations can be 500 mg/L or less (Ellis, 1984). Elsewhere, groundwater in the *Kd* can be highly mineralized (Stanton et al., 2007).

Table 2-5: Statistical results of water quality analyses from groundwater samples collected in or near the project area from *Kd* wells. Units are in milligrams per liter unless stated otherwise. Data are from the US Geological Survey NWIS database; NA, not analyzed; N, number of samples.

	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum	NA's	N
Water temperature (°C)	10.8	11	11.5	13.4	13	143	1	92
Specific conductance (µS/cm at 25 °C)	582	755	845	880	938	2,050	0	93
pH (standard units)	6.7	7	7.1	7.1	7.2	7.7	18	75
Dissolved oxygen	0.1	0.1	0.3	0.48	0.6	2.4	11	82
Bicarbonate, as CaCO3	367	372	384	385	392	410	87	6
Calcium	70.1	104	119	118	129	215	0	93
Magnesium	14.2	21.5	23.7	25.3	29.7	47	0	93
Sodium	16	27.4	32.7	43.3	43.7	186	0	93
Sodium adsorption ratio	0.4	0.63	0.73	0.94	0.99	3	0	93
Potassium	<3.21	6.73	9.9	9.74	11.4	28	9	84
Chloride	<1.00	2	14	17.3	25.6	106	0	93
Sulfate	<2.00	68.9	90	127.3	157	755	0	93
Fluoride	0.71	0.87	0.92	1.1	1.1	2.8	59	34
Silicate	8.2	12.7	14	13.9	14.8	21.9	50	43
TDS	292	460	534	559	602	1,490	9	84

The median specific conductance value from water quality samples collected from *Kd* wells was 845 µS/cm (Table 2-5). As mentioned, this median value is higher than median specific conductance water samples from the stream-valley and glacial wells (Table 2-3 and Table 2-4). For *Kd* wells, the median calcium, sodium, chloride, sulfate, and TDS concentrations were 119, 32.7, 14.0, 19.0, and 534 mg/L, respectively (Table 2-5). These values are also larger than water samples collected from stream-valley and glacial wells. The single glacial well has large specific conductance and TDS values.

Maximum calcium, sodium, chloride, sulfate, and TDS concentrations from *Kd* wells were 215, 186, 106, 755, and 1,490 mg/L, respectively (Table 2-5). Maximum calcium, chloride, and TDS concentrations were

smaller than samples from glacial wells, a condition which is likely due to samples collected from the glacial wells discussed above.

2.5 Water Use

The public supply wells within the ENWRA area are displayed in Figure 2-10. The greatest concentrations of public wells are near the more populated area of northeast Madison County. Registered wells other than public supply wells are found throughout the ENWRA, with irrigation wells being the most numerous. The densest concentrations of irrigation wells are in the western third of the ENWRA as well as in smaller areas near the center and southeastern parts of the project area. Domestic wells are scattered throughout the ENWRA, with the greatest concentration surrounding the Norfolk, NE area.

Figure 2-11 displays the depth to groundwater in the registered wells. Relatively shallow groundwater (less than 50 ft below the subsurface) is present along the surface drainages that slope east/southeastward across the district, most notably along the Elkhorn and North Fork of the Elkhorn River valleys. Trending north/south through the middle of the project area is a zone of wells where groundwater is typically 150 ft deep or greater. In the western third of the area, depth to groundwater is slightly more variable, with the static levels typically between 50 and 150 ft. This variation could be due to wells tapping different aquifers, as the *To* is present in this area. Similar patterns in depth to groundwater are also apparent in the north-central portion of the project area.

Figure 2-12 demonstrates the increase in the number of registered irrigation wells across the northern ENWRA project area from the mid-20th century through 2014 (DNR registered well database, accessed May, 2015). Before the 1960s, irrigation wells were mainly prevalent along the valleys of the major river drainages where shallow groundwater levels typically persist. Over time, as technological advancements of pumps and center-pivot systems allowed for more widespread implementation of irrigation above deeper aquifers and more variable terrain, the number of wells across the northern ENWRA area increased rapidly. The 1970s witnessed the largest increase in the use irrigation wells, with the growth occurring primarily in the western one-fourth of the area, primarily within the LENRD. The increase in irrigation in these areas corresponds to where the High Plains aquifer (*To*) is present. Over the next two decades, the areas already developed continued to fill in with additional wells with isolated areas across the LENRD gaining more irrigation wells. Since 2000, a rapid increase in the number of irrigation wells within the northern LENRD and the LCNRD occurred, likely as a response to the 2001-02 drought that occurred across the High Plains. The irrigation well distribution maps inferentially demonstrate that in parts of the LENRD and the PMRNRD, aquifer resources are not suitable to support widespread groundwater irrigation. Even the maps within the most recent two decades show large areas of these two NRDs with only sparse distributions of irrigation wells in comparison to the surrounding areas. Supporting evidence of the subsurface conditions causing this lack of irrigation wells will be demonstrated in the AEM findings in following sections of this report.