




# Water Appropriation Requirements, Current Water Use, & Water Availability for Energy Industries in North Dakota:

## A 2010 Summary

Response to House Bill 1322, Section 2
of the 61st Legislative Assembly
of North Dakota

Prepared by W. M. Schuh

Water Resources Investigation No. 49
North Dakota State Water Commission

August 2010

# Water Appropriation Requirements, Current Water Use, & Water Availability for Energy Industries in North Dakota:

# A 2010 Summary

**Response to House Bill 1322, Section 2**
**of the 61st Legislative Assembly**
**of North Dakota**

**Prepared by W. M. Schuh**

**Water Resources Investigation No. 49**
**North Dakota State Water Commission**

**August 2010**

# ACKNOWLEDGEMENT

The content of this report has involved the work and consultation of many individuals in state and federal government, energy industries, and research institutions, so that it will be impossible to acknowledge all contributors on an individual basis. Many contributing individuals are cited in footnotes.

I first acknowledge Mike Fladeland who served as the Commerce Department Liaison with the Energy Policy Commission and was very helpful in coordinating all communications with Commission members.

Second, I acknowledge the contributions from members of the Energy Policy Commission, including: Ron Day (Tesoro), Terry Goerger (farmer representative), Shane Goettle (Commerce Commissioner), Paul Goulding (Goulding Oil), Eric Mack (ADM), Ron Ness (ND Petroleum Council), Curtis Jabs (Basin Electric), Mark Nisbet (Xcel Energy), Randy Schneider (ND Ethanol Producers), Andrea Stromberg (Montana Dakota Utilities), David Straley (Coteau Properties Company), Sandi Tabor (Lignite Energy Council), and John Weeda (Great River Energy), who provided valuable advice and access to technical resources and personnel within their respective industries, and facilitated review of report sections related to their industries.

Within the State Water Commission, all hydrologists in the Water Appropriations Division contributed time, effort and expertise in delineating and describing ground-water and surface-water bodies best suited for future water development within their management areas. Special thanks are offered to Alan Wanek, who contributed many of the figures and some of the narrative related to oil-field water development and the Fox Hills aquifer; Rod Bassler, who developed all of the major maps used in this report; and Michael Hove who spent many days reviewing and correcting water permit and water use data to help assess water availability for future development. His work is summarized in Appendix F. Tim Freije and Michelle Klose provided much assistance in evaluating potential use of SWPP and NAWS water. Thanks also to Appropriations Director, Bob Shaver, for resource assistance and technical and editorial review, and Brenda Hove for her long and patient work in editorial review.

Among contributors from state and federal agencies, Lynn Helms (Director of the Oil and Gas Division of the Industrial Commission) and Dave Hvinden provided valuable information and guidance regarding oil-field practices and water use; John Harju (Associate Director for Research of the Energy and Environmental Research Center) provided access to the expertise of several EERC personnel and some valuable editorial comments; Dan Stepan (EERC) provided a review for selected report sections, and contributed a summary of EERC research on water and energy which was incorporated, with slight modification, in the report; Mike Morohl and Jim Weigel of the U.S. Bureau of Reclamation provided valuable information concerning waters managed by the Bureau; and Phil Brown of the Corps of Engineers was very helpful in defining problems and procedures related to Corps permitting. Kathy Duttenheffner (ND Parks and Recreation) and Bruce Kreft (ND Fish and Game) were particularly helpful in providing information incorporated in the access maps for the Missouri River system. Thanks also to Fred Anderson of the North Dakota Geological Survey who provided the cross-section map of North Dakota’s bedrock aquifers.

# EXECUTIVE SUMMARY

During the 2009 legislative session, the 61st Legislative Assembly of the State of Dakota required that the North Dakota State Water Commission, in cooperation with the Energy Policy Commission, conduct a study of water use by energy industries in North Dakota. To meet legislature's requirements, State Water Commission (SWC) project leaders met with representatives of the Department of Commerce on May 26, 2009, to develop a study plan. It was agreed that the SWC would assume the lead role in the study. It was also agreed that the report would include the following items:

(1) A description of the water appropriation process, with the purpose of assisting potential water-permit applicants in understanding actions and time frames required to obtain a water permit;

(2) An evaluation of water use for each of the specified industries, including: a description of water use, water quality requirements, and unit water use, as required by the bill;

(3) A review of surface-water supplies available for potential use in development of the energy industry;

(4) A review of ground-water supplies available for potential use in development of the energy industry; and

(5) A review of water reuse.

## General Principles

- It is essential that any industry, which requires a substantial and reliable source of water, consider the water supply in the earliest stages of planning for locating a new facility. Among many critical factors that will affect planning are: (1) the location of surface or ground-water bodies having an adequate supply; (2) competition for water by other users at a prospective location; (3) the legal framework and processes which must be complied with in order to obtain the water, and the time frames involved and their effects on other planning schedules; and (4) the quality of local waters and their suitability for the specified use.

- Water in North Dakota is obtained from surface water and ground-water sources that are limited and usually local. It is not equally available at all locations, and in many locations it is sparse.

- There is really only one truly “plentiful” and reasonably stable source of unappropriated water in the state, and that is the Missouri River. All smaller rivers are nearly fully appropriated. Most of the state’s good quality ground water is found in glaciofluvial deposits, mostly in the eastern, central and northern portions of the state. Many of these aquifers are now nearly or fully appropriated and are unavailable for additional future allocations, or may require the deployment of special storage techniques to retain waters from limited periods of high flow.

- Some other areas of the state are underlain by bedrock aquifers. But water quality is often problematic, with brackish, saline or hypersaline waters, high sodium, high iron or high alkalinity. It is essential that planners for any prospective new industry requiring a large-scale reliable water supply consider the locations where suitable water supplies are probable.

## Obtaining a Water Permit

It is important that planners for water-using facilities be aware of legal and regulatory processes required for obtaining water rights. It is also important to understand that most of the time-consuming steps of the water permit process are required by law and cannot be circumvented, and that the Water Appropriation Division of the North Dakota State Water Commission will apply "due diligence" in assuring that the requirements of state law are met and that a reasonable certainty of a robust water supply will be assured to the applicant. Inadequate planning on the part of an applicant can be very costly, as water permits are not guaranteed, and denial of a water permit is a real possibility. The water permit process and a list of problems commonly encountered through improper application procedures are summarized in the report. A few key points are:

- Under the Doctrine of Appropriations water permits are granted on a "first-apply first-priority" basis.

- The water permit process, following application, requires a public notification, a public comment period (usually 30 days), an evaluation by a state hydrologist (may take a few days or as much as a couple of years depending on circumstances), and a recommended decision to the State Engineer. A hearing may be granted if parties which have submitted written objections during the comment period disagree with the decision. After a final decision by the State Engineer a "conditional" water permit is granted. The holder of the "conditional" water permit must complete works and begin beneficial use of the water within a reasonable period of time (usually three years), or the permit is subject to cancellation. Exceptions may be granted for good reasons. After works have been completed and beneficial use has begun, the works for the conditional permit are inspected. The time scale involved for completing a conditional permit may vary. If all conditions of the conditional water permit are met, the State Engineer issues a "perfected" water permit. This time scale may vary from as little as six months to an indefinite time, depending on competition for water in the area, local hydrologic conditions, the amount of data collection needed for evaluating the permit, and the backlog of permit applications to be evaluated. These are explained in more detail in the report.

- The managing hydrologist must evaluate: effects of the proposed use on prior water appropriators; the adequacy of the proposed point of diversion; whether the water use is beneficial; and whether the appropriation is in the public interest. Public interest criteria include: benefit to the applicant; effects of economic activity resulting from the appropriation; effects on fish, game and recreation; the effects of lost alternate uses within a reasonable period of time; harm to others from the proposed appropriation; and the intent and ability of the applicant to complete the appropriation.

## Water Use for Energy Industries in North Dakota

**Ethanol:** Biomass has overtaken hydropower as the largest domestic source of renewable energy. Biomass currently (2007) supplies over 3 percent of the nation's total energy consumption, and represents nearly half of all U.S. renewable energy use. National bioethanol production capacity was reported to be 34 billion gallons per year as of July 2008, and was projected to be 57 billion gallons per year by 2015 (National Research Council 2008).

With respect to water consumption Chiu and others (2009) draw a distinction between *imbedded* water and *process* water. Imbedded water includes irrigation water used for feedstock production as well as process water. North Dakota was estimated to be near the national median with respect to imbedded water, with 59 gal/gal (gallons of water used per gallon of denatured product), of which 31 gal/gal were attributed to ground water and 28 gal/gal were attributed to surface water.

Process water for the dry milling process is used for slurring, boiling, fermentation, distilling, system reject water and water, released from evaporators outside of the system. The largest use of water is for cooling. Cooling may be accomplished using *once-through*, *wet-recirculating*, or *dry-recirculating* processes. The distinction of water *withdrawal* and *consumption* discussed for thermoelectric power applies for ethanol production as well, with largest *withdrawal* and lowest *consumption* for once-through cooling systems, and largest consumption and lowest withdrawal for *wet-recirculating* systems.

- Estimates of process water-use efficiency have varied widely in the literature, and generally range from about 2 to 7 gal-water /gal-denatured product.

- In North Dakota there are or have been six ethanol-producing plants in operation. The time of operation varies from more than 20 years to a few months.

- Historical unit water use for North Dakota ethanol plants varies from as low as 2.5 gal/gal to as high as 6 gal/gal. However, the high use number is from the oldest plant, which is no longer in operation. All currently operating ethanol plants have unit water use of less than 3.7 gal/gal, with a state median of 3.06 gal/gal. Water-use efficiency for North Dakota's ethanol plants rates high on the national scale. Many of the plants are new, and reported efficiencies are expected to increase as plants refine operations.

- Using published design capacities for currently operating facilities, a total of 335,000,000 gal/year of ethanol production is projected for the state. From this production estimate, **current total water use at full capacity would be expected to range from about 3,100 acre-feet to 3,600 acre-feet per year.** The addition of four proposed facilities (Buffalo Creek Energy, Lakota Biofuels, Dakota AgEnergy, and Yellowstone Ethanol) would increase capacity by about 270,000,000 gal/year. **Additional water use would be expected to range from 2,500 to 2,900 acre-feet per year.** Total water use from full current and future combined production would be between 5,600 and 6,500 acre-feet per year.

Innovative process designs with respect to industrial and municipal water reuse are contributing to overall water-use efficiency within the ethanol industry.

- Filtrate and cooling-tower blowdown from Blue Flint Ethanol are returned to the Coal Creek Station for reuse in coal-fired thermoelectric power generation.

- Tharaldson Ethanol is reusing Fargo's wastewater as its main water supply.

- The proposed Dakota Spirit AgEnergy cellulosic ethanol plant, currently in planning for possible construction in the Jamestown, ND Spiritwood Industrial Park, plans to use steam from the Spiritwood Energy Station, currently in construction, for its fermentation process. Because the steam water for Spiritwood Energy is already drawn from the wastewater of the City of Jamestown, the multiple reuses of water in the Jamestown Energy Park are expected to serve as prototypes for a very high level of water-use efficiency.

**Biodiesel Fuel:** In North Dakota there are or have been only two biodiesel fuel producing plants in operation, and the operational periods of record are short, less than two years. The only currently operating biodiesel fuel plant is Archer-Daniels Midland (ADM) at Velva, ND.

- The common national range of unit process water consumption for biodiesel fuel production is between 1 and 3 gal/gal. Future technologies, which include the possibility of using recycled wastewater with various degrees of treatment, may increase water-use efficiency.

- The combined bulk water use (gal), per unit (gal) of biodiesel fuel produced for a single full production year (2008) at ADM was about 1.5 gal/gal. Water use in this calculation includes both feedstock crushing and biodiesel fuel processing combined. The calculated unit water use is within the lower range of national use estimates.

- Annual water use for biodiesel fuel production in North Dakota is currently less than 300 acre-feet. A reasonable estimate for unit water use would be about 1 to 1.5 gal/gal for future production. However, there are no current plans for additional biodiesel plants in North Dakota.

**Natural Gas:** The Oil and Gas Division of the Industrial Commission has listed 29 natural gas processing plants in North Dakota. Of these, 16 are listed as inactive and 13 are listed as operational.

- For the most part, little water is used by the natural gas industry. Uses and supplies vary between individual facilities. Water is used for boiler water and for wet sulfur scrubbers at some plants. At others it is used only for office, personnel and cleaning purposes. Industrial water permits for two plants authorize 25 and 29 acre-feet per year, a relatively small amount. Other plants are supplied as domestic users through community or rural water supply associations. Some are metered, others not. Some facilities truck their water from other locations.

- Most plants have residual produced water from the wet gas that is disposed of, in most cases, by trucking it to centralized well sites, where it is injected into the Dakota Formation. One plant evaporates the produced water.

- The median unit water use for measured plants is around 0.4 gal/MCF. Because of the relatively small amount of water used, natural gas plants should be serviceable by local ground-water wells, surface-water sources, water user associations, municipalities, or water depots with little difficulty.

**Oil-Field Development:** The recent increase in oil-field development in western North Dakota brings with it a demand for more water use. At the end of 2009, about 4,606 pumping wells were in operation in the North Dakota portion of the Williston Basin, with an additional 500 wells capable of producing but not currently in operation for various reasons. The Bakken-Sanish-Three-Forks (B-S-TF) play has greatly accelerated plans for oil drilling in western North Dakota. As of February 8, 2010, drilling activity of up to 1,800 wells per year has been predicted.

Williston Basin oil production in western and north-central North Dakota requires water during the construction and completion of oil wells, occasionally as oil is produced, and as part of secondary recovery operations in older oil fields. Oil-field water use includes: *(1) drilling fluid, (2) mixing concrete grout for surface casing, (3) formation fracturing (or fracing), (4) waterflooding, and (5) operation.*

- Drilling Fluid: Oil well surface casing is set from land surface to a few hundred feet below the deepest fresh-water aquifer. Recent estimates indicate that the quantity of fresh make-up water for drilling an oil well and mixing cement is about 133,000 gallons, about an order of magnitude higher than previous estimates.

- Hydraulic Fracturing Fluid: Hydraulic fracturing is used to enhance oil-recovery from low-permeability rock formations. It is an important tool for extracting oil from the Bakken Formation. Reported frac-water use per well for 2009 ranged from 0.004 to 9.82 acre-feet per well, with median and mean both of 2 acre-feet per well. The North Dakota Industrial Commission has estimated common current frac-water use at about 1.5 to 4 million gallons per well.

- Critical water quality factors for fracing fluid include water components that can impair polymer cross-linking and biological agents that can deteriorate the geochemical environment of the formation, particularly in the evolution of $H_2S$ gas. Scaling is also a potential problem. Hydraulic fracturing generally requires a high-quality water source.

- Brine Dilution Fluid: Freshwater for brine dilution is needed on about 10% of producing wells in North Dakota. Salty produced water is frequently entrained with produced oil. As produced water is pumped from deep formations with initial high temperatures, it cools as it rises, causing precipitation of salts, plugging the tubing. Freshwater is added to dilute the salts and prevent clogging. Although variable, depending on the amount of produced saltwater, the quantity of water used in an oil well for saltwater dilution is typically on the order of one gallon per minute (526,000 gallons, or 1.6 acre-feet per year).

- A secondary recovery technique called *waterflooding* is used to maintain fluid pressure in oil-bearing zones. Waterflood operations typically require some tens or hundreds of gallons of water per minute and may last for years. Because of the large quantity of water used in waterflooding, the source of water for pressure maintenance operations is restricted to the Dakota aquifer or underlying zones having low-quality water.

- Total estimated annual freshwater requirements for the B-S-TF play are about 13,000 to 23,000 acre-feet per year initially, depending on the number of wells drilled and the amount of frac-water required per well, and as much as 28,000 acre-feet per year at ten to 15 years from now. The annual amount of water used should decrease substantially as development of the B-S-TF play approaches completion, although it is possible that oil wells in the B-S-TF play will require "re-fracing" to enhance long-term oil recovery, thereby sustaining higher water demand.

- Ground water supplies in western North Dakota are limited. Glaciofluvial and other shallow aquifers and the Fox Hills – Hell Creek bedrock aquifer are insufficient to supply the requirements of the B-S-TF play at the proposed rate of development. It is critical that ground-water supplies be conserved for the use and sustenance of towns, homes, local industries, and farms and ranches, after the completion of oil development. As of December of 2009 there were 28 water depots, for a total allocation of 2,340 acre-feet per year serving the oil industry in western North Dakota. Thirty more water permits for water depots are pending, for an additional 5,534 acre-feet per year. Not all of these will likely be approved. Even if all were approved, water supplies from ground water would fall far short of needs for the B-S-TF play. **The only plentiful and dependable supply of water for the oil industry in western North Dakota, at projected rates of extraction, is the Missouri River system, including Lake Sakakawea.**

- The problem of water for oil-field use is distributional as well as quantitative. Large traffic caused by movement of millions of gallons of water for each of 1,800 wells per year will strain road infrastructure and pose serious safety issues. Lynn Helms, Director of the Oil and Gas Division of the North Dakota Industrial Commission, proposed a general model delineating five water-supply zones north and south of Lake Sakakawea to provide an adequate distribution of water.

- There are currently nine water permits pending for water from the Missouri River/Lake Sakakawea, for a total of 38,540 acre-feet per year submitted by six applicants. Of these, International Western Company of Forth Worth, TX, has applied for 28,900 acre-feet from seven points of diversion under three water permits. Steve Mortenson of Williston has applied for 5,370 acre-feet at two points of diversion under two water permits, and the Penningtons, of Newtown, have applied for 800 acre-feet from four points of diversion under one water permit. All applications are in various steps of processing, except for one water permit for 18,000 acre-feet for International Western Company, which has been granted.

- Access to water from Laka Sakakawea requires permits issued by the U.S. Army Corps of Engineers. The two permits required are a real estate and a regulatory permit. The real estate permit requires the applicant to "submit detailed plans and specifications indicating any effects on Corps managed lands." As a part of this submission the applicant must "identify current and future water volume needs." This requirement for what is, in essence, a "market analysis" was first incorporated into the permitting application process in late 2009. The requirement adds additional time delays in the permitting process.

- In May 2010, the U.S. Army Corps of Engineers announced that a three-to seven-year storage availability study would be required before any additional water access permits could be approved from Lake Sakakawea. If the study indicates storage is available, the Corps plans to levy "surplus water" storage fees for all industrial water users withdrawing water from Lake Sakakawea. As of July, 2010, the Corps indicates that the permitting process for four water permit applications currently before the Corps (which includes an 18,000 acre-feet application from the International Western Company) will be processed simultaneously with the storage availability study and a study to determine "surplus water" storage fees. No timeline for permit completion has been provided by the Corps.

- Currently, the North Dakota State Water Commission has approved 55 water permit applications to divert water from Lake Sakakawea for irrigation purposes. Some of these permits holders would like to temporarily forego irrigation and divert water for industrial (water depot) use for oil well fracing. The Water Appropriation Division of the State Water Commission has developed an internal policy to accommodate this change in purpose of use with the authorization of a temporary water permit. As of July 2010, this request is under study by the Corps with regard to their permitting process.

**Petroleum Refining:** The U.S. Department of Energy has estimated that unit water use for oil refining is about 1.5 gal/gal. There is currently only one oil refinery operating in North Dakota, the Mandan Tesoro Refinery, which processes about 60,000 barrels of crude oil per day (bpd). There are currently proposals for three new refineries: Northwest Refining at Williston (for 100,000 bpd), Dakota Oil Processing at Trenton (for 20,000 bpd), and the Three Affiliated Tribes Refinery at Makoti (for 15,000 bpd). There is also a proposal for expanding the Tesoro Refinery to produce low-sulfur diesel fuel from coal.

- The Tesoro Refinery uses about 1.5 million gallons of water per day from the Missouri River. About a million gallons are consumed, mainly through evaporation. The rest is returned to the stream.

- The approximate use distribution is: boiler water (10-15%), desalting crude oil (30-40%), and cooling water (approx. 35%).

- Since Tesoro replaced British Petroleum as the owner and operator of the refinery in 2003, the median water withdrawal (through 2008) has been 2,100 acre-feet per year, and median water consumption has been 1,275 acre-feet per year.

Consumptive water use has ranged narrowly from 0.46 to 0.53 gal/gal liquid product, with a median of 0.48 gal/gal. Total water withdrawal has ranged narrowly from 0.78 to 0.85 gal/gal liquid product with a median of 0.8 gal/gal. Estimated unit water use is low by national standards.

- If an additional 137,000 barrels were to be refined, at a range of 1 to 2 gallons of water per gallon of refined product, additional water use of 6,900 to 13,800 acre-feet would be required – for a total of 8,200 to 15,100 acre-feet per year.

**Coal-Fed Syngas and Liquid Fuels Synthesis:** The extraction of synthesis gas (syngas) from coal or methane can be used to produce several different energy fuels, from hydrogen to natural gas and diesel fuel. Syngas production, or planned production in North Dakota, uses lignite exclusively as a carbon and hydrogen feedstock. The Dakota Gasification plant at Beulah uses lignite to produce methane. A proposed synfuels plant at South Heart plans to produce hydrogen gas to directly fuel thermoelectric power generation. A joint venture between Tesoro and an area utility has been proposed to use coal from the Falkirk mine with steam from the Tesoro refinery at a facility managed with the Tesoro refinery, to produce aircraft fuel or diesel fuel using the Fischer-Tropsch process. American Lignite Energy is also planning another coal-to-liquid facility for future construction.

The U.S. Department of Energy (USDOE 2006) has estimated unit water use at 4.6 to 6.9 gal/gal of liquid Fischer-Tropsch product, depending on the coal used. Other authors have presented a range of 1.5 gal/gal for a zero-discharge, air-cooled plant, to 5 to 7 gal/gal for a plant with water cooling and less recycled use of waste heat. Unit water use for production of hydrogen gas from methane has been estimated at about 4.5 gal/kg hydrogen produced.

- Eight-year unit water by Dakota Gasification was estimated at 0.049 gallons per standard cubic foot of methane gas. Efficiencies in water use are enhanced by the production of additional products, including anhydrous ammonia, ammonium sulfate, and various organic compounds.

- The proposed South Heart Energy Facility currently plans to produce syngas (hydrogen gas) from coal. The syngas will be used to power an integrated gas combined cycle power plant to produce electricity. The combined turbines will produce about 285 MW, of which about 118 MW is parasitic, leaving about 167 MW net power produced for sale. A $CO_2$ byproduct will be used for enhanced oil recovery in the Williston Basin. An average of 650 gallons per minute of raw water will be supplied by the Southwest Pipeline Project (SWPP), via an interconnect just upstream of the Dickinson Water Treatment Plant. Power plant cooling will be a combined air and water-cooled system so that water supplementation for cooling will be needed mainly in the summer. South Heart

Energy Development has considered using water from dewatering of the coal as a part of their water supply, but a well field would be required which could adversely affect local wells. Another optional water supply currently being considered is the use of treated wastewater from the Dickinson Wastewater Treatment Plant. The amount of wastewater available would be insufficient to meet all demands, but could be supplemental.

- American Lignite Energy (LLC) plans to build and operate a coal-to-liquid (CTL) facility to produce 38,000 bpd of liquid fuel, using about 11.5 million tons of North Dakota lignite annually. Steam will be used in the production of syngas and in adjustment of the $H_2/CO$ ratio prior to production of methanol, which will then be converted to gasoline. The methanol to gasoline step is exothermic, and preliminary plans are to use the heat released to produce steam to run steam turbines. In addition, a portion of the syngas will be used to fuel gas-fired turbines in an integrated gas combined cycle (IGCC) power plant. Because plans for the proposed CTL plant are incomplete, evaluation of unit water use and total potential water use is somewhat speculative. A major factor will be the design of the cooling system for the electrical generation component.

**Thermoelectric Power Generation:** Thermoelectric power accounts for about 39% of all surface-water withdrawals, about 3% of all water consumption, and about 53% of all water returns to surface waters in the United States. Aside from water used in the mining and beneficiation of coal for power generation, water is used for flue gas desulfurization (FGD), cooling, boiler water, and facility water (bathrooms, drinking water, etc.). Of these, most of the water consumption is used for cooling. In evaluating and comparing water use, an important distinction cited by most sources is between *withdrawn* water and *consumed* water. *Withdrawn* water is returned to the source stream after it is used and has little effect on the source waters. *Consumed* water is not returned to the source stream after it is used. Cooling water systems in electric power generation are of three basic types: (1) *once-through*, (2) *wet-recirculating*, and (3) *dry-recirculating*. A *once-through* system *withdraws* significantly more water, but a *wet-recirculating* system can *consume* ten times more water than a *once-through* system. W*et-recirculating* systems use large cooling towers, or in some cases ponds and canals to recycle the cooling water. *Dry-recirculating* systems have low water requirements, but have parasitic power needs and high capital costs. Larger consumption for *wet-recirculating* cooling systems result mainly from evaporative losses in the cooling towers, and make-up water to replace water drained during *blowdown*. Water used in boilers must be purified and treated to inhibit scale formation, corrosion, and impurity contamination of steam. A wide range of water chemistries has been used for cooling. But the main concerns for cooling water are *scaling*, *corrosion* and *biological fouling* of cooling towers in *wet-recirculating* cooling systems (Mortenson 2003). Scale can be prevented or controlled by reducing calcium by water softening, or by pH adjustment.

- There are seven coal-fired thermoelectric power plants in North Dakota. Four of the power plants (Heskett, Leland-Olds, Stanton, and Milton R. Young) employ *once-through* cooling systems, while three (Coal Creek, Antelope and Coyote) employ *wet-recirculating* cooling systems. All boilers used are *subcritical*.

- All of the North Dakota power plants draw water from the Missouri River system, including Lake Sakakawea, with the exception of the Milton R. Young Station, which draws its main supply from Square Butte Creek, with a supplemental supply from the Missouri River.

- The total water permitted for coal-fired electricity generation in North Dakota is about 1.8 million acre-feet. This includes both withdrawn water (non-consumed) and consumed water. The mean annual long-term water use for each station is summarized in Columns 12 (consumptive use) and 13 (non-consumptive use). The mean long-term consumptive use is about 28,500 acre-feet per year, while non-consumptive use is about a million acre-feet, for a combined total of almost 1.1 million acre-feet, or about 60% of the permitted use.

- Long-term mean unit water withdrawal for power stations employing *once-through* cooling systems (Table 8, Col. 10) ranged from 22 to 38 gal/kWh, compared with 37.7 gal/kWh cited by Feeley and others (2006), shown on Table 7. As expected, unit water withdrawal for stations employing *wet-recirculating* cooling systems were negligible.

- Unit water consumption for stations employing *wet-recirculating* cooling systems (Antelope Valley, Coal Creek and Coyote Stations) are about 0.5 gal/kWh, compared with 1.1 gal/kWh cited by U.S. Department of Energy sources.

- The only new coal-fired thermoelectric electric generation plant currently planned in North Dakota is the Spiritwood Station, which is under construction near Jamestown by Great River Energy. The Spiritwood Station is designed to generate 64 annual MWh of baseload electricity and 35 annual MWh of peaking electricity for the regional energy market. The Spiritwood Station was originally planned to operate in conjunction with a new ethanol plant, and with the existing Cargill Malting Plant located at Spiritwood, which would purchase low-pressure steam from the Station. Water requirements for power-plant operation are 325 gpm for the full 64 MWh power production capacity. With continuous operation, this would be equivalent to 524 acre-feet per year. The water supply is *grey water*, purchased from the city of Jamestown and from the Cargill lagoons. With reuse of Jamestown and Cargill water, the Spiritwood Station is expected to provide an example of very high water-use efficiency.

- Two potential practices that may increase water-use efficiency are: (1) use of more efficient boilers (supercritical or ultra-supercritical boilers), and (2) use of natural gas simple cycle (NGSC), combined cycle (NGCC), or syngas (integrated) combined cycle (IGCC) production facilities. NGCC and IGCC plants produce about 2/3 of their power using gas turbines, and about 1/3 using steam turbines powered by the steam heated in the gas combustion phase. A water-use efficiency enhancement of about 2/3 would be expected. However, water use in the production of natural gas or syngas would have to be factored into the water budget for a true comparison of water-use efficiency.

- Another efficiency factor would be the use of supercritical or ultra-supercritical boilers, which operate at higher efficiency and therefore require less water per unit of electrical power produced. The U.S. Department of Energy estimates that about 75% of future coal-fired power plants will be equipped with supercritical boilers.

**Carbon Capture Effects on Thermoelectric Power Generation:** The impact of carbon capture and sequestration on the use of water for any form of fossil-fuel based thermoelectric power generation is very large, ranging from about 50% to 100% additional water use. Current goals of the DOE National Energy Technology Laboratory (NETL) are to develop carbon capture technologies "that offer significant cost reductions" by 2014, and to initiate large-scale field testing by 2018. **Effects of prospective new technologies on water use are ill-defined at this time, but by any current indications, impacts of $CO_2$ capture technology on water consumption by fossil-fuel fed thermoelectric power generation are likely to be large.**

**Wind Energy:** Both U.S. Department of Energy sources and discussions with representatives of Nextera, a subsidiary of Florida Power and Light, which has managed the construction and operation of several North Dakota wind-power projects, and with representatives of Ottertail Power Co. have indicated that after construction, the wind turbines themselves use virtually no water. After construction water is mainly used for employee consumption, sanitation and cleaning, in a maintenance shop. Water requirements are sufficiently low that municipal, and rural water systems and local private local wells should provide sufficient supplies of water nearly anywhere in the state.

**Summary of Total Water Use for Energy:** Based on design capacities, total water use for the energy industry in North Dakota, with full capacity ethanol production in existing facilities, would be expected to be about 53,000 to 65,000 acre-feet per year. If four additional ethanol plants were added, total water use would be about 55,000 to 68,000 acre-feet per year. With carbon capture, total water use would likely expand to as much as 85,000 to 93,000 acre-feet per year, mainly due to increased water use for coal gasification and coal-fired thermoelectric power generation. With four additional ethanol plants, the total would be about 88,000 to 96,000 acre-feet per year. If three additional proposed petroleum refiners were added, total water use for energy would be about 95,000 to 110,000 acre-feet per year.

## Potential Surface-Water Sources for Use by The Energy Industry

Surface-water sources in North Dakota consist of rivers, lakes, potholes and wetlands. Of these, wetlands, potholes and freestanding lakes (not maintained as reservoirs of streams) do not provide viable sources for large-scale dependable water supplies. A large expanding and contracting lake, like Devils Lake, and associated lakes and potholes should not be considered as viable long-term water supplies.

North Dakota has eight major rivers. They are: the Missouri River, the Red River, the Sheyenne River, the Little Missouri River, and the Cannonball, Heart, Knife and James Rivers. Of these, the Missouri River and the Red River and their tributaries carry 98.4% of the surface water leaving the state (Ripley 1990). Most of the state's surface waters are heavily appropriated for their normal (year-round) flows, so there is little water available for additional appropriation and use. An exception is the Missouri River system (including the Lake Sakakawea and Lake Oahe reservoirs), which has an average annual outflow from the state of about 16.9 million acre-feet.

**Potential Water Supplies From the Missouri River System:** Several state, federal, local and tribal entities are involved with access to the Missouri River and its reservoirs and will need to be involved with proposed water-use projects. Ownership or lease agreements will be needed for properties required for conveyance works. Appropriate local governments should be consulted, including local county and city planning and zoning commissions, and tribal authorities if access and construction are to be undertaken on tribal lands.

- A sovereign lands permit will be required for free-flowing reaches of the Missouri River. If any alteration of the channel (dredging, excavation, construction of works) is required, a regulatory permit will be required from the U.S. Army Corps of Engineers (Corps). For reservoir reaches, including Lake Sakakawea and Lake Oahe, and for free-flowing reaches of the Missouri Rivers with federally owned shorelines, access would require both real estate and regulatory permits from the Corps. If the intended works for an intake intend to access the main channel of the Missouri River within the reservoir, a sovereign lands permit will also be required from the state.

- As of the beginning of 2010 the Corps has expressed reticence in allowing further points of diversion along its reservoirs in North Dakota without a “storage availability” study and a study to determine “surplus water” storage fees. These new developments indicate a likely greater degree of difficulty in obtaining regulatory and real estate permits for reservoir access.

- The Northwest Area Water Supply (NAWS) project design includes community and rural water system contracts and allowances for reasonable expansion of water use (2 to 3 million gpd) within the existing design capacity.

- Industrial use of NAWS water is allowed under the water permit, which is for multiple use. However, the project design does not include large-scale industrial use. There may be some potential for off-peak use for industrial applications, like oil-field development, that can utilize NAWS water at various outlet points at limited hours of the day, or during off-peak use seasons. Annual off-peak use would be limited to the difference between overall (average) use and permitted use (about 3,807 acre-feet). Daily off-peak use would be limited by maximum capacity (26 million gpd) and the actual pumping use by contract users. Where and when off-peak water would be available would also depend on the distribution of capacity and use within the NAWS system. An indirect effect of NAWS on potential industrial water use would be possible use of ground-water sources previously used by municipalities, but vacated by the use of NAWS water. Operation of NAWS is currently (July 2, 2010) under a court injunction and likely will not begin in the near future, pending resolution of the legal restrictions.

- The city of Parshall is expanding its water-supply capacity from 0.5 million gallons per day to 2.5 million gallons of treated water per day (gpd), expandable to 5 million gpd – from the Van Hook Arm of Lake Sakakawea. The planned intake will be capable of diverting as much as 5 to 10 million gpd of raw water. Some of the 2.5+ million gpd differential, or more than 2,500 acre-feet per year, may, upon completion, be available for industrial use as raw water. In addition, 0.5 million gpd of supplemental raw (untreated) water will be available for beneficial use from the original intake. (**As of July 15, 2010, Parshall and Fort Berthold Rural Water has applied for an industrial water permit (#1647) for 1,000 acre-feet per year from the new intake. The application is in processing. The status of Corps permission is uncertain.)**

- The BDW/Crosby and Ray/Tioga service areas will be served locally using ground-water sources. Because of limited ground-water supplies the BDW/Crosby area would provide a poor prospect for substantial industrial use, including the energy industry. **(As of June 30, 2010, the Ray/Tioga Water**

**Supply Association has signed a letter of support for a regional water system "centered on the Missouri River and the Williston Regional Water Treatment Facility as a source for the regional water demands," addressed to Governor Hoeven, and requesting cost share for an estimated $127 million water supply project.)**

- An expansion of McKenzie Rural Water is planned to provide about 4 million gpd to Watford City and other water users. It would include four water depots, including one at Watford City and three along a pipeline to Alexander. Some water could be available nine miles south of Williston by the summer of 2011, and the full project could be complete by 2012.

- With further expansion of Williston's water treatment plant capacity to 14-million gpd, additional "off-peak" water supplies of as much as 7-million gpd (7,800 acre-feet per year) to 11-million gpd (12,300 acre-feet per year) may be available for use by energy industries.

- While the statement of legislative intent for the Southwest Pipeline Project (SWPP) included industrial use, the initial SWPP water permit did not include industrial use. Additional water permits must be established for expanded industrial uses. An example is the Red Trail Energy ethanol plant, which obtained a water permit to use SWPP water and is currently supplied by SWPP. A proposed coal gasification plant at South Heart is considering use of SWPP water. A study was conducted to examine the required infrastructure and incremental costs for expanded water SWPP conveyance. It was estimated that additional annual conveyance ranging from 323 to 6,412 acre-feet could be achieved for additional costs ranging from $3.9 to $42.1 million.

- Residual capacity and off-peak water capacity may be sufficient to supply at least 1,000 gpm, or at least 1,300 acre-feet per year for oil-field use through turnouts at Dodge. The required infrastructure is being built, and is expected to be operational sometime during the summer of 2010.

- The "preferred alternative" for a Red River Valley Water Supply Project is to transfer up to about 82,345 acre-feet of Missouri River water per year. The simulated average future conveyance for use in the Red River Valley is about 30,000 acre-feet, based on 70 years of past climate data. A portion of this water will likely be available for industrial development, including the energy industry.

- More than 200,000 acre-feet of Missouri River water, currently permitted to the Bureau of Reclamation for irrigation development, may possibly be converted to use for an energy industry "corridor" along the McClusky Canal, and possibly expanded via the New Rockford Canal.

**Potential Water Supplies from the Heart River System:** The Bureau of Reclamation currently holds water permits for irrigation development from Lake Tschida, and for industrial, irrigation, and municipal development from Patterson Lake.

- Sufficient water to irrigate up to 5,800 acres from Lake Tschida, or conservatively about 5,800 acre-feet per year, may potentially be reallocated for industrial use by the energy industry under a water permit held by the Bureau of Reclamation.

- As much as 3,493 acre-feet could be applied for industrial, as well as municipal, recreation, and fish and wildlife use, under a water permit held by the Bureau of Reclamation for Patterson Lake. It also appears that a long-term median annual use of 2,470 acre-feet, with a maximum of 3,105 acre-feet, has been vacated by the city of Dickinson's shift to SWPP water and may be available under a Bureau of Reclamation permit for reallocation.

## Potential Use of Municipal Wastewater for Energy Industries

One substantial water supply that may be used for enhanced energy production is municipal wastewater. The minimum annual total wastewater supply from North Dakota's municipalities for 2004 through 2008 was 36,000 acre-feet. The median was 41,000 acre-feet. Much of this water may be available for beneficial use. An additional several thousand acre-feet may be available from industrial wastewater.

## Surface-Water Storage and Use

Except for the Missouri River system, most of the state's surface waters are heavily appropriated and are not good prospects for large-scale long-term sustainable water supplies. For many of the state's rivers, however, there are seasonal flows that are not being captured and used. With appropriate capture and storage these waters could be retained and used. Possible storage techniques would include surface storage and aquifer recharge and recovery.

## Potential Use of Ground Water for Energy Industries

Ground water supplies about 18% of municipal, 6% of rural, and about 8% of industrial water use in North Dakota. Some bedrock water may be used for energy industry development. However, because of limited recharge, and long distances to recharge sources, use of bedrock water for industrial development will likely be limited.

**Bedrock Aquifers – Dakota Aquifer:** The Dakota aquifer is a regional bedrock aquifer that underlies most of the Great Plains, and almost the entire state of North Dakota. It lies as deep as 4,000 to 6,000 feet in the Williston Basin, at 2,000 to 3,000 feet in north-central North Dakota, and shallow - just below the glacial drift and lacustrine materials in eastern North Dakota. The water quality is generally poor, with dissolved solids as high as 32,000 mg/L in the west, but more in the range of 2,000 to 4,000 mg/L in the southeast. Water is generally of the sodium-sulfate and chloride type. The Dakota Formation is used for injection disposal of oil-field brines in the west.

- The Energy and Environmental Research Center (EERC) of the University of North Dakota is currently working with an oil industry partner to examine the possibility of treating Dakota water for use in the oil fields.

- The EERC has proposed the possible treatment and use of Dakota water for municipal and industrial use in eastern North Dakota. The position of the SWC is that some industrial use of Dakota water may be feasible, and the cost of treatment is worth examining; but limitations and long-term water conservation concerns will likely limit the use of Dakota water in eastern North Dakota.

**Bedrock Aquifers – Fox Hills and Hell Creek Aquifer System:** The Fox Hills and Hell Creek aquifer system (FH-HC) underlies the western two-thirds of North Dakota at depths of up to 2,000 feet in the central part of the Williston Basin and trends to depths just below the glacial drift in central North Dakota. About 346 million acre-feet of water is stored in the Fox Hills - Hell Creek aquifer system. Water is usually of the sodium-bicarbonate type. Dissolved solids usually range from about 1,000 mg/L to 2,000 mg/L.

- Recharge zones for the FH-HC aquifer system are distant and travel times for recharge waters are slow. The FH-HC aquifer is the only reliable aquifer supplying very large portions of western North Dakota. It is important that water in the FH-HC aquifer be conserved for future use by its cities, towns, ranches and small industries.

- Many farms and ranches are dependent on flowing wells completed in the FH-HC aquifer for cost-effective water delivery to livestock and homes in areas where electrical transmission lines are sparse. Pressure heads are declining steadily, indicating that water is being mined. Accelerated loss of well pressure through increased local large-scale pumpage would likely cause a hardship for many water users.

- Since the 1980s it has been SWC policy to avoid use of FH-HC for large-scale industrial use whenever possible. With the large expansion of oil-field water use for fracing, it is clearly understood that the Fox Hills aquifer cannot supply a major portion of oil-field needs. The FH-HC aquifer may be capable of some additional development for energy industries. But it is expected to be a limited source.

**Shallow Glacial Aquifers:** An estimated 60 million acre-feet of water is stored in North Dakota’s glacial aquifers. The chemistry of shallow fluvial and glaciofluvial aquifers varies widely, but in general, it is fresher than bedrock water, although water near discharge areas can be highly saline. Glacial aquifers in eastern North Dakota also tend to be marginally high (just over the EPA-MCL of 10 μg/L) in arsenic, and often require treatment for municipal use. Shallow glaciofluvial aquifers provide excellent water supplies for many farms, homes, municipalities and industries, and provide the main water supply for irrigation. They are, however, subject to drought, and the water appropriation policy must consider the level of appropriation that can be sustained under a wide range of climatic conditions.

- Ground-water use in North Dakota has increased substantially over the last half century, and many of the state's shallow aquifers are fully appropriated or nearly fully appropriated. It is very important that planners for future development of the energy industry consider the local availability of water in the planning locations for their facilities.

- An inventory of the State’s shallow aquifers included in this report has estimated potential future water-use development from shallow ground water at somewhere between 58,000 and 110,000 acre-feet per year.

- An inventory of the state’s shallow ground water was conducted by dividing the state into 15 study areas. Maps of aquifer areas most likely to provide water for additional development were created for each area with descriptions of aquifer depth, thickness, water chemistry and potential development capabilities. The reader is referred to the report.

# TABLE OF CONTENTS

APPENDIX (Separate Document)

# LIST OF FIGURES

## Figure Addendum: *Shallow Glaciofulvial Aquifers*

The final major subsection titled *"Shallow Glaciofluvial Aquifers"* consists of physical, chemical, hydrologic and water-use profiles for each of 69 aquifers, divided within 15 study areas. For each study area a figure, which is a Piper Diagram showing the relative distribution of cations and anions determined from aquifer water samples, is included. Because of the large number of figures and the consistency of format, the figures are not included individually in the preliminary list (above). For each aquifer, however, the Piper Diagram figure is identified according to the following format: **Figure [Study Area].[aquifer number in study area].[figure number].** For example, the Piper Diagram for Aquifer 2 in Study Area 5 would be: **Figure 5.2.1.** The study areas and aquifers are listed in the Table of Contents for page number reference.

# LIST OF TABLES

## **Table Addendum: *Shallow Glaciofulvial Aquifers***

The final major subsection titled "*Shallow Glaciofluvial Aquifers*" consists of physical, chemical, hydrologic and water-use profiles for each of 69 aquifers, divided within 15 study areas. for each study area there are included three tables summarizing the chemistry of water samples collected from the aquifer. Because of the large number of tables and the consistency of format, the chemistry summary tables for shallow glaciofluvial aquifers are not included individually in the preliminary list (above). For each aquifer, however, the chemistry summary tables are identified according to the following format: **Table[Study Area].[aquifer number in study area].[table number]**; where table numbers are **[1]** for general chemistry, **[2]** for use parameters (ex. hardness, alkalinity, etc.), and **[3]** for trace elements (ex. Arsenic, iron, manganese, selenium, etc.). For example, the trace elements table for Aquifer 2 in Study Area 5 would be: **Table 5.2.3.** The study areas and aquifers are listed in the Table of Contents for page number reference.

# INTRODUCTION

During the 2009 legislative session, the 61st Legislative Assembly of the State of Dakota required that the North Dakota State Water Commission, in cooperation with the Energy Policy Commission, conduct a study of water use by energy industries in North Dakota. Under 2009 Session bill H.B. 1322[1] the following requirements were specified:

**SECTION 2. WATER RESOURCES STUDY - REPORT TO LEGISLATIVE COUNCIL.**
1. During the 2009-10 interim, the state water commission shall conduct a study to:
a. Determine unit water use for each sector of energy production, including:
(1) Petroleum;
(2) Ethanol;
(3) Electrical generation; and
(4) Biodiesel;
b. Identify water quality constraints for each energy sector;
c. Estimate projected water use in each energy production sector based upon growth projections provided by the energy policy commission; and
d. Provide a qualitative assessment of the state's water resources and identify specific sources that have the potential of providing significant quantities of water for energy development.

To meet the legislature's requirements, State Water Commission (SWC) project leaders met with representatives of the Department of Commerce on May 26, 2009, to develop a study plan. It was agreed that the SWC would assume the lead role in the study. It was also agreed that the report would include the following items:

(1) A description of the water appropriation process, with the purpose of assisting potential water-permit applicants in understanding actions and time frames required to obtain a water permit;

(2) An evaluation of water use for each of the specified industries, including: a description of water use, water quality requirements, and unit water use, as required by the bill;

(3) A review of surface-water supplies available for potential use in development of the energy industry;

(4) A review of ground-water supplies available for potential use in development of the energy industry; and

(5) A review of water reuse.

---

[1] 2009 N.D. Sess. Laws ch. 192, § 2.

## Report Organization and Overview

The following report is organized into six sections, following the basic study outline described above. The first section, titled: *Considerations of Water Supply for Planning and Locating Energy Production Facilities in North Dakota*, provides an overview of water availability, and then describes in detail the steps for obtaining a water permit. A discussion of "effective water-permit acquisition" focuses on common problems and pitfalls that delay the water permit process. In addition, an approximate time-table for permit acquisition is presented.

The second section, titled: *Water Use by Energy Industries in North Dakota*, describes water use on an industry-by-industry basis as follows: biofuels, including biodiesel and ethanol production; natural gas processing; oil-field water use; petroleum refining; syngas production; coal-fired thermoelectric power generation; and wind energy. For each industry we review national water-use descriptions and unit water use, and then review in-state plants and/or enterprises on an individual facility or operational basis, based on a tabled summary of enterprises provided by the North Dakota State Department of Commerce (Appendix A). For each energy facility or operation we provide a brief summary of the facility and its products, its characteristic water use, water quality parameters, if known, and unit water use. Where possible, we provide a summary of projected total water requirements for future development of the energy. The section on oil-field water use focuses, in particular, on the current problem of obtaining sufficient water for use by the Bakken-Three Forks-Sanish play. The second section has been written with consultation and review by representatives of each individual enterprise within each industry.

The third section, titled: *Water and Energy Research Initiatives*, briefly reviews research projects related to water-use efficiency in the energy industry that are currently in progress at the Energy and Environmental Research Center of the University of North Dakota.

The fourth section, titled: *Potential Surface-Water Sources for Use by the Energy Industry in North Dakota,* provides a broad discussion of surface-water availability, principally from the Missouri River system (the free-flowing river, Lake Sakakawea and Lake Oahe) and the Heart River. In this section we have tried to review as thoroughly as possible the existing means of conveyance by which Missouri River water might be transported for beneficial use at other locations, including municipal and rural water systems, the Southwest Pipeline Project (SWPP), the Northwest Area Water Supply Project (NAWS), and the McClusky and New Rockford Canal with its associated water permits. The problem of access to the Missouri River is treated in some depth, including discussions of sovereign lands and federal regulatory and real estate permit requirements. A general map identifying areas in which applications are most likely to incur delays or difficulties in obtaining access permits is provided. In addition, we have examined the possibility for future allocations from Lake Tschida and Patterson Lake on the Heart River. We have also treated, briefly, the potential storage of surface-water in aquifers (aquifer recharge and recovery, or ARR) during periods of high flow, such as periods of spring runoff. Some of the options studied would require changes in state or federal law to authorize their use. But we have tried to examine as many potential sources as could be identified for consideration of future use. The fourth section has been written in consultation with surface-water hydrologists of the North Dakota State Water Commission, and with consultation and review of various portions by personnel and/or managers of the U.S. Bureau of Reclamation, the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, the SWPP and NAWS projects, the North Dakota Department of Game and Fish, the North Dakota Department of Parks and Recreation, the North Dakota Historical Society, Houston Engineering, AE2S Engineering, and many others.

The fifth section, titled *Potential Use of Wastewater for Energy Industry Development in North Dakota*, reviews, very briefly, the issues of wastewater reuse in relation to water appropriation laws and procedures, and potential municipal and industrial sources for reuse.

The sixth section, titled: *Potential Use of Ground-Water by the Energy Industry in North Dakota,* consists of an inventory of all of the state's ground-water sources, including bedrock aquifers and shallow glaciofluvial and fluvial aquifers. The ground-water section was written in consultation with each of the ground-water hydrologists of the North Dakota State Water Commission’s Water Appropriation Division. The procedure was:

(1) The state was divided into 15 ground-water study areas.

(2) Managing SWC hydrologists for each study area determined which aquifers and which areas of larger aquifers had potential for further development of the beneficial use of water. Development potential for each study area was represented on a map.

(3) Using county ground-water study publications and evaluations by managing hydrologists, aquifers within each study area were evaluated for: location and areal extent, description of depth and materials, water quality, level of current development, and potential for future development. A description is provided for each aquifer. The description includes a statistical summary of water-quality properties and parameters for all water samples currently in the SWC database for that aquifer. Examples of aquifer lithologies are provided in Appendix B.

**For both surface-water and ground-water maps and evaluations, it is important to understand that the assessments are to be used as an initial screening tool. A designation of *poor* potential for development does not mean that further development on some scale is impossible - only that it is more problematic and difficult, and that the probability of time delays and denial is higher. Similarly, a designation of *good* potential does not mean that a water permit is assured - only**

**that the probability of time delays, objections, and/or denials is relatively lower. Finding the locations within a good potential ground-water source is particularly critical for each case. After selecting a potential ground-water source an initial consultation with a managing SWC hydrologist is recommended as a good second step. The managing hydrologist can often provide valuable insights concerning which areas are least likely to cause problems. SWC hydrologists can be reached by calling 710-328-2754 and identifying the county in which development is planned.**

## Report Format

The organization hierarchy of this report is as follows:

**TITLE 1**
**Title 2**

**Title 3**
***Title 4***
Title 5

I have followed the hierarchy strictly, so that when describing water use for individual plants and industries, facilities of some industries are listed using **Title 3**, or ***Title 4*** headings, while some others use Title 5, depending on the nature of the discussion for that industry.

Because of wide range of sources and materials treated in this report, I have also used a variable citation format. In general, published books, articles, and government reports are cited using journal format (author year) - for example (Pate and others 2007), with citations at the end of each section under a **Title 2** format (**Citations**) heading. Information obtained from unpublished written memoranda, reports, or "white papers," e-mail communications and phone conversations are cited as footnotes, using a standard footnote format.

## Figures and Tables

Because of the wide ranges of materials and sources, and time limitations of a one-year study, variable formats have been used for both figures and tables. In addition to figures plotted specifically for this report, many have been adapted from federal and state publications, web sources, and contributions of other SWC personnel and personnel of other agencies. The variability of figure formats and types reflects the difference in contributing sources.

Figures and tables have followed a sequential format throughout the report, with the exception of the section on *shallow glaciofluvial aquifers*. Because of the extremely large number of tables and figures, and their organization by aquifer within 15 study areas, tables and figures have been organized separately and sequentially according to study area and aquifer within the study area. Thus, the first table of the first aquifer listed within the first study area would be labeled Table 1.1.1, and the second Table 1.1.2 and so on. Figures follow the same format. For example, the first figure for the third aquifer listed in the fifth study area would be labeled Figure 5.3.1. The normal sequence resumes after the shallow ground-water section.

## Location and Numbering System

The location and numbering system used in this report is based on the public land classification used by the U.S. Bureau of Land Management. The system is illustrated in Figure 1. The first number denotes the township north of a base line, the second number denotes the range west of the fifth principal meridian, and the third number denotes the section in which the well or test hole is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). For example, well 154-055-05ADD is located in the SE 1/4 SE 1/4 NE 1/4 Sec. 5, T. 154 N., R. 55 W. Consecutive terminal numerals are added if more than one well or test hole is located within a 10-acre tract.

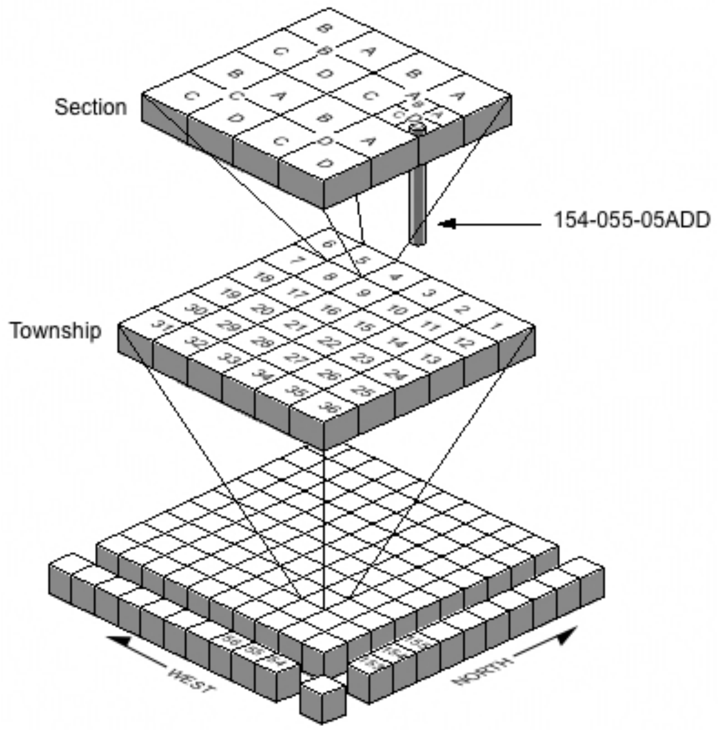


Figure 1. Description of U.S. Bureau of Land Management location system.

# Disclaimer

This report has been compiled using materials and verbal citations from a large number of people in widely different agencies, industries and enterprises, and a substantial body of published literature. The expertise of the author is water rather than energy, and water is the focus of the report. Nonetheless, in describing industrial water use, a great deal has depended on contributions from energy-industry specialists. The author has made every effort to report their contributions accurately, including substantiating phone calls to clarify points of confusion and the submission of industry descriptions to representatives of each subject enterprise. Almost all of the materials have been confirmed at least once. Each energy industry represented on the Energy Policy Commission was solicited for review. However, in such a varied and lengthy report it is always possible that some verifications may have been inadvertently neglected. Following publication, further corrections will be made, if necessary, in web posted versions of the report. With respect to potential water supplies discussed, the author warrants no guarantee of supply. The primary purpose of this report is to assist potential water users in their initial planning through directing them to water sources most likely to be available for further development.

# CONSIDERATIONS OF WATER SUPPLY FOR PLANNING AND LOCATING ENERGY PRODUCTION FACILITIES IN NORTH DAKOTA

It is essential that any industry, which requires a substantial and reliable source of water, consider the water supply in the earliest stages of planning for locating a new facility. Among many critical factors that will affect planning are: (1) the location of surface or ground-water bodies having an adequate water supply; (2) competition for water by other users at a prospective location; (3) the legal framework and processes which must be complied with in order to obtain the water, and the time frames involved and their effects on other planning schedules; and (4) the quality of local waters and their suitability for the specified use. The purpose of this section is to provide an overview of water supplies in North Dakota and some factors that may affect their use for expansion of energy industries. Locations of water supplies and water quality suitability of those supplies for specific industries will be considered in more detail later in this report.

## Water Availability for Energy Use in North Dakota

Water in North Dakota is obtained from surface-water and ground-water sources that are limited and usually local. It is not equally available at all locations, and in many locations it is sparse. Several federal reports have published general maps of water shortage and availability on a state-by-state basis. One of the maps was published by the General Accounting Office, and has been used in several U.S. DOE reports, including the 2006 Report to Congress. It indicates that North Dakota is one of six *non-shortage* states (AL, IA, IL, ND, UT, VT).

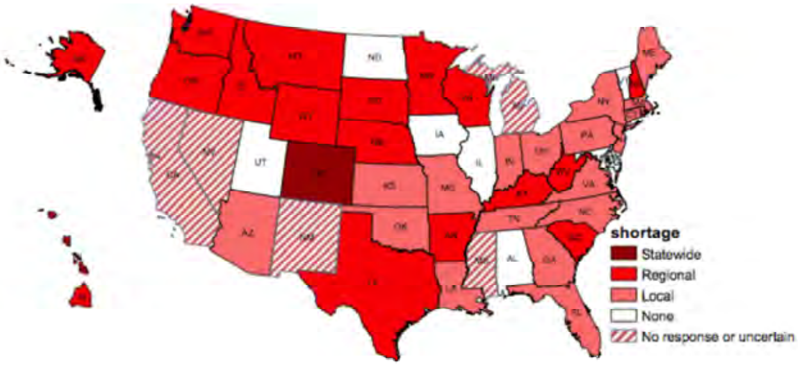


Figure 2. Assessment of national water shortages (Figure IV-1 from U.S. Department of Energy 2006)[2].

---

[2] Adapted by U.S. DOE (2006) from: GAO, (General Accounting Office 2003). Freshwater supply: state's views of how federal agencies could help them meet the challenges of expected shortages, July 2003, GAO-03-514.

Another map, published by Hoffman and others (2002) indicates that North Dakota ground-water availability is high throughout the state, in fact among the highest in the nation.

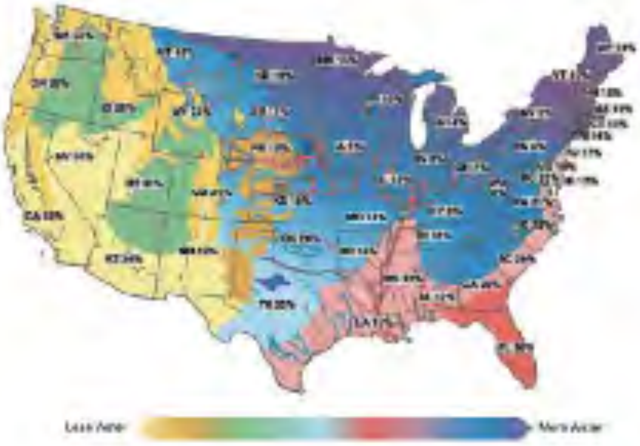


Figure 3. U.S. Department of Energy representation of national relative ground-water availability and projected population changes from 2000 through 2020 (Figure 7 from Hoffman and others 2002).

Both of these maps are misleading. There is really only one truly "plentiful" and reasonably stable source of unappropriated water in the state, and that is the Missouri River. All smaller rivers are nearly fully appropriated. Most of the state's good quality ground water is found in glaciofluvial deposits, mostly in the eastern, central and northern portions of the state. Many of these aquifers are now almost fully appropriated and unavailable for additional large-scale future use. A map of glacial aquifers and water availability for beneficial use as of 2009 is shown in Figure 4. Of 70,704 square miles of state area, only 9,589 square miles, or about 13.5% of the state area, overlie glacial aquifers. Of this, only about half (4,391 square miles), or about 6% of the state area has sufficient unappropriated ground water to be a good candidate for large-scale sustainable use from local water supplies. These are shown in green in Figure 4.

Some other areas of the state are underlain by bedrock aquifers. But water quality is often problematic, with brackish, saline or hypersaline waters, high sodium, high iron or high alkalinity**. It is essential that planners for any prospective new industry requiring a large-scale reliable water supply consider the locations where suitable water supplies are probable. It is also important to understand that generalized availability maps do not guarantee sufficient water or water of suitable quality at any given location. Further exploratory work for local siting must be conducted. This should include exploratory drilling of prospective sites, long-term aquifer tests, and collection of water samples to ascertain water quality.**

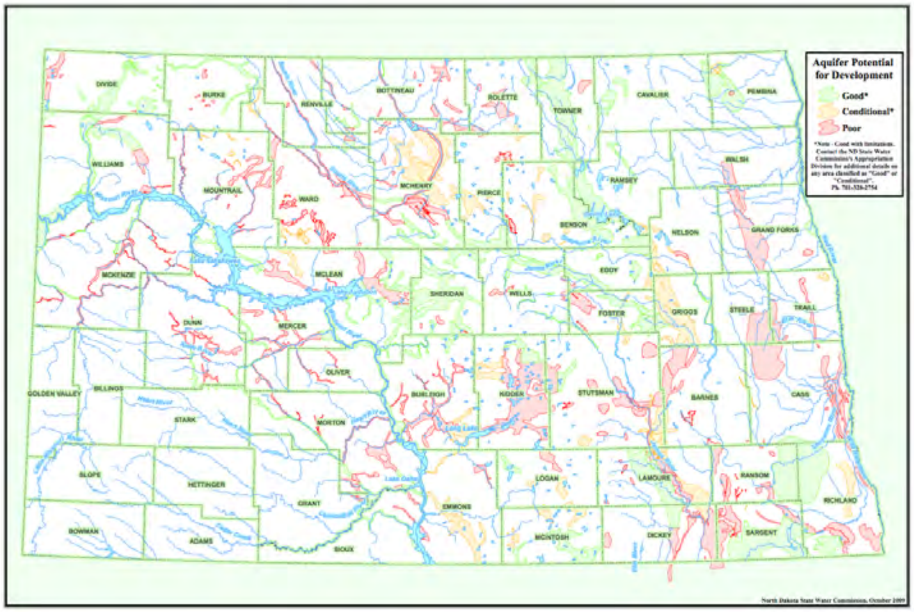


Figure 4. Relative availability of ground water from glacial aquifers in North Dakota.

## Obtaining Water Rights for Energy Development in North Dakota

It is important that planners for water-using facilities be aware of legal and regulatory processes required for obtaining water rights. These processes affect not only the potential for obtaining the desired waters, but the time scales on which they may be obtained. Planners need to be aware early of the plausibility of developing water supplies in desired locations, and of the steps required for obtaining a water permit. It is also important to understand that most of the time-consuming steps of the water permit process are required by law and cannot be circumvented, and that the Water Appropriation Division of the North Dakota State Water Commission will apply "due diligence" in assuring that the requirements of state law are met and that a reasonable certainty of a robust water supply will be assured to the applicant. The purpose of this section is to provide a basic and abbreviated outline of the steps and requirements for obtaining a water permit, and to point out some of the potential problems that may be incurred without proper attention to and understanding of the water permit process.

### Basic Steps of the Water Permit Process

The Constitution of the State of North Dakota, Article XI, states that:

> *"All flowing streams and natural watercourses shall forever remain the property of the state for mining, irrigation and manufacturing purposes."*

On this constitutional basis waters of the state are allocated for the beneficial use of its citizens according to the doctrine of Prior Appropriations, under provisions of Chapter 61-04 of the North Dakota Century Code, and Article 89-03 of the North Dakota Administrative Code, which govern water appropriation. In principle, water permits are granted for the beneficial use of water on the basis of priority date, established by the date of application. Water permits for competing applications, that is, those filed within 90 days of each other, are granted by preference in order of domestic, municipal, livestock, irrigation, industrial, and recreation, if the water source is insufficient to supply all applicants. The water permit process is summarized as follows:

(1) Water rights are established and protected by the order of priority.

(2) The order of priority is established by the date on which the completed application for a water permit is received by the office of the State Engineer.

(3) Applications for water rights from the same water source that are filed within 90 days of each other are considered as *competing* water rights, when the water supply is insufficient to supply all applicants, and are given preference by the order of use priority. **The order of use priority is: 1) domestic, 2) municipal, 3) livestock, 4) irrigation, 5) industrial, and 6) recreation.**

(4) After receiving the completed application the State Engineer will instruct the applicant to give notice of the application by certified mail to all record title owners of real estate within a radius of one mile from the location of the proposed points of diversion, or in the case of municipalities or subdivisions, to the governing authorities of the municipality or subdivision. The applicant will also be instructed to notify by certified mail all persons holding water permits within one mile of the point of diversion, and will be provided a list of all municipal or rural water facilities within a 12-mile radius of the point of diversion, which must also be notified. The applicant has a maximum of 60 days, following notification by the State Engineer, to provide the State Engineer with an affidavit of notice by certified mail. After receiving the affidavit of notice, the State Engineer will publish the notice of application in the official newspaper of the county once a week for two consecutive weeks (NDCC 61-04-05).

(5) Following the notification, the State Engineer will establish a termination date for a 30-day comment period. Any party may file written comments before that date, and all comments filed before the specified final date will become a part of the official record. Those persons filing written comments become "parties of record" at the end of the 30-day comment period.

(6) The water permit application is assigned to a managing hydrologist for evaluation of compliance with criteria specified under NDCC 61-04-06. These include:

  a. The rights of a prior appropriator will not be unduly affected.
  b. The proposed means of diversion or construction are adequate.
  c. The proposed use of water is beneficial.
  d. The proposed appropriation is in the public interest. In determining the public interest the following "shall" be considered:
     i. The benefit to the applicant.
     ii. The effect of economic activity resulting from the proposed appropriation.
     iii. The effect on fish and game resources and public recreational opportunities.
     iv. The effect of loss of alternate uses of water that might be made within a reasonable time if not precluded or hindered by the proposed appropriation.
     v. Harm to others resulting from the proposed appropriation.
     vi. The intent and ability of the applicant to complete the appropriation.

Evaluation by the managing hydrologist is comprehensive, and may require several months in areas where water supplies are limited and critical, or where substantive issues have been raised in comments. Factors affecting the availability of water include the size of the water supply, the proximity of other prior water users, the locations of recharge and discharge areas, the nature of recharge and discharge areas, and probable long-term effects of climatic variation on local water supplies. Evaluations are usually concluded within a few months. In highly competitive settings or where hydrologic data are sparse, further exploratory drilling and data acquisition may be needed, and evaluations may require more than one, or even several years.

(7) After a recommended decision prepared by the hydrologist is approved by the State Engineer, all parties of record (those who filed written comments) receive a copy of the recommended decision for review. Parties of record who "would be aggrieved" by the decision then have 30 days to file additional comments or to request a hearing, or both. If a hearing is requested, the State Engineer must arrange a time and place for the hearing and serve a copy of notice of the hearing to the applicant and all parties of record at least 20 days before the hearing (NDCC 61-04-05.1). For this reason, the process of arranging the hearing must require at least 20 days.

(8) If no hearing is requested by an "aggrieved" party, or following a hearing, if requested, the State Engineer will render a final decision. If the application is denied, the applicant may appeal any perceived denial of a *substantial right* to the district court of the county in which the proposed diversion is situated within 60 days. In the absence of the appeal, the State Engineer's decision is final (NDCC 61-04-07). If the decision is favorable, a *conditional* water permit will be granted to the applicant.

(9) When issuing the conditional water permit, the State Engineer will specify a time by which works for diversion and commencement of beneficial use must begin (generally three years). State law specifies: "when the appropriator fails to apply it to the beneficial use cited in the permit or ceases to use it for the beneficial use cited in the permit for three successive years, unless the failure or cessation of use has been due to the unavailability of water, a justifiable inability to complete the works, or other good and sufficient cause, the State Engineer may declare the water permit or right forfeited" (NDCC 61-04-23). In areas where there are competing applications, an earlier beneficial use date (less than three years) may be imposed.

(10) If appropriate works have been constructed and beneficial use has commenced by the specified date, the works will be inspected by a representative of the State Engineer and, if satisfactory, a *perfected* water permit will be issued. If construction and use has not been completed within the specified time, the applicant has 60 days from the date of notification of default to comply with appropriate works, or to petition the State Engineer for an extension. The State Engineer may grant an extension for "good cause shown" (NDCC 61-04-14). "Good cause" has been further specified that; "failure or cessation of use has been due to the unavailability of water, a justifiable inability to complete the works, or other good and sufficient cause" (NDCC 61-04-23). An extension of the conditional water permit can be granted only if there are no pending applications in the vicinity of the proposed point of diversion and in competition with the proposed appropriation. It is important to understand the consequence of failure to develop the permitted beneficial use or file for an extension in a timely manner: i.e. "a conditional water permit, or any portion thereof, shall be considered forfeited, abandoned, and void if no request for renewal is received by the State Engineer within 60 days after the date the permitted is informed by certified mail that the period for applying water to the beneficial use cited in the conditional permit has expired. If a request to extend the time for application to beneficial use for any conditional permit, or portion thereof, is denied, such conditional permit, or portion thereof, shall be considered forfeited, abandoned, and void" (NDCC 61-04-14).

(11) A water right may not be transferred from a "higher" use to a "lower" use, as indicated by the order of priority presented above in Item 3 (NDCC 61-04-15.1). For example, water permitted for irrigation may not be transferred to industrial or recreational use. This is important, because most water uses in the energy industry would be classified as industrial.

Approximate time scales for various steps of the water permit process are summarized on Table 1. It is important to be aware that some steps, particularly Step 5, may be prolonged if extensive hydrologic analysis is required, or if further exploratory work is needed. It is also important to understand that approval of the water permit is not certain and that denial is possible, pending results of hydrologic analysis. A summary of potential problems that could delay or jeopardize the progress of a water permit is provided below.

## Considerations for Effective Water-Permit Acquisition

(1) Inadequate application: Under NDCC 61-04-04, in the case of an incomplete or otherwise unsatisfactory application, the State Engineer may return the form for revision. If the revised forms are returned within 60 days of notification, the priority date will be the same as the initial filing dates. The delay in the permit process would include the time for notification, and the time until the correction is filed. Failure to correct the application within 60 days would result in the corresponding time of delay, plus the priority date would be changed to the date of receipt for the corrected application. This is mandatory under state law.

(2) Competing permits with earlier priority dates: If a designated application is received and granted a priority date from a water source from which a number of competing permits have earlier priority dates, the water permits are, as a matter of policy, evaluated in the order of priority. Possible exceptions would be cases in which water supplies clearly exceed all uses for which water permits have been filed, such as the Missouri River, or where clearly evident hydrologic circumstances indicate that the designated application will not be in the area of influence, and thus competing with other prior appropriators. Such evidence might include hydrologic separation within a designated aquifer, or sufficient distance between applicants. Depending on the number of applicants, the complexity of the hydrologic circumstances, and the manpower available for evaluating and processing the permits, delays could be substantial, possibly years, if stress on the resource is critical. In any case, applicants need to be aware of potential additional delays in areas where the competition for water is great.

Table 1. Summary and generic time-table for the North Dakota water permit application process.

| **Step #** | **Time period*** | **Procedure** |
|---|---|---|
| | | |
| 1. | | Application, filing fee and map is received by State Engineer, priority date set. |
| | | |
| 2. | 2 weeks + | The applicant is instructed to send a "Notice of Application" by certified mail to all record title owners of real property within 1 mile radius, all permit holders within 1 mile radius, and municipal and/or rural water facilities with 12 mile radius. |
| | | |
| 3. | 1 to 2 weeks | After the Notice of Application has been mailed, the applicant completes an affidavit of notice and returns it to the State Engineer. |
| | | |
| 4. | 1 month from first notice in newspaper | Upon receipt of the completed affidavit, the State Engineer publishes a notice of the water permit application in the official county newspaper. Notice of water permit application is published once a week for two consecutive weeks. Public has 30 days to comment in writing with concerns about the application |
| | | |
| 5. | 1 to 6 months +<br>May require a year or more if further exploration and data acquisition or ground water models are required | Hydrologist prepares a "Recommended Decision" to the State Engineer recommending approval or denial of the application. The criteria from which the State Engineer must base his decision to grant or deny a water permit application are in NDCC §61-04-06. If the proposed point of diversion is located in a highly complex, competitive hydrologic setting, additional hydrological data and analysis may be required to prepare a recommended decision. This could significantly extend the time required to prepare the Recommended Decision. |
| | | |
| 6. | 1 month | The Recommended Decision is mailed to any person who filed written comments regarding the water permit application. Within 30 days of service of the Recommended Decision, the applicant and any person who would be aggrieved by the decision and who filed written comments may file additional written comments with the State Engineer or request a hearing on the application, or both. |
| | | |
| 7. | 6 month + | If hearing is granted, six months or more are typically added |
| | | |
| Total | 6 months to 1 year-may be more than one year if time for step 5 is longer. | |

* Approximation. Some steps may require longer times.

(3) Limited or critical water-source status: Applicants must understand that the process of water permit evaluation is NOT a "rubber stamp" procedure. The State Engineer is charged with protecting the water supplies of prior appropriators. But in addition, the needs of investors in the new enterprise applying for the water must be given responsible consideration. While a water permit might be granted for a "marginal" case where water would be available for a time, but where pumping would have to be curtailed to protect prior appropriators during a time of drought, it would be irresponsible to grant a permit to an applicant representing an enterprise with a large investment which is dependent on a steady reliable water supply, when supplies are known to be marginal. To do so would risk of damage to the investors, employees, and others in the local economy, and would establish a basis for future conflict. In some cases, extensive further work, including exploratory drilling, aquifer tests, or hydrologic modeling by state hydrologists, or, in some cases, by private contractors, may be needed. This may require further months, or in some rare cases, years. Water permits awaiting evaluation are held in "deferred" status until action on the application is taken. In some cases, a portion of the permit application request is granted and the remainder can be held in "abeyance" pending the acquisition of additional hydrologic data. In any case, the Water Appropriation Division is committed to the practice of "due diligence" by qualified hydrologists. Applicants should be aware that there is no guarantee of approval of a water permit request. A denial is a real possibility. The best way to avoid delays or denials is to apply for water permits with points of diversion in water-source areas where competition for water is minimal.

(4) Water rights follow priority dates: Under State law, water rights are protected in the order of priority date. The size of the economic interests involved does not influence the priority of water rights. If a period of scarcity or drought occurs, and if a water supply is insufficient to supply all permit holders, pumping for beneficial use will be curtailed in the reverse order of priority - not in the reverse order of economic interests. It is in the best interest of applicants considering large investments, that they expect and concur with a realistic assessment of the stability of future water supplies.

(5) Low industrial priority in State Century Code: Industrial applicants, who would include most energy industry applicants, must recognize that they are low (fifth) on the priority of use list, behind domestic use, municipal use, livestock use, and irrigation use (NDCC 61-04-06.1). This means that after submission of a designated industrial-use water application, any applicant for domestic, municipal, livestock, or irrigation water use that files for a water permit within 90 days of the designated applicant will gain priority over the

designated applicant if the water source is insufficient to supply all applicants (NDAC 89-03-01-11). For this reason it is critical that industrial applicants file for water permits at the earliest time possible to prevent preemption by other applicants, which could extend the time of the permitting process, or in some cases, could potentially jeopardize the issuance of the water permit altogether.

(6) Do not undertake construction until the water permit is granted: It is illegal to "commence any construction for the purpose of appropriating waters of the state" without first receiving an approved "conditional" water permit (NDCC 61-04-02). The definition of works includes canals, ditches, pipelines, and other conveyance systems, irrigation facilities, wells, pumps, dams, dikes, reservoirs, and other devices used for the appropriation or storage of water" (NDAC 18-13-03-01.3). While the language does not specifically forbid initiation of construction for plant facilities, it is very unwise to begin construction without a water permit. A water permit will not be granted until "due diligence" by the reviewing hydrologist has been performed. It is rarely possible to predict the outcome of the investigation until it has been conducted and until the notification process has brought possible opposition to the surface. A denial is possible, if warranted.

(7) Temporary water permits are not used to "bridge" delays in the permit process: While the State Engineer, under NDCC 61-04-02.1 and NDAC 89-03-01-10 may grant temporary or emergency permits, which do not establish water rights, for one year; emergency permits are not used to enable premature operation of a water-using facility in which illegal or inappropriate works have been constructed, or to circumvent the water permit process. To do so would encourage construction without water permits, and would result, in some cases, in construction of works where a final water permit would not be granted. It would also raise a public question of circumventing the administrative process.

(8) Municipal water permits may not be used for industrial water permits: Municipalities may not pass their permitted waters to prospective local large-scale industrial water users. To do so would violate state law in several ways. First, transferring part of a city's permit would constitute transferring a water right from a higher use priority to a lower use priority. This is not allowed under state law (NDCC 61-04-15.1) . Second, transferring part of the water right would, in many cases, circumvent the priority date for the prospective industry. City water may be used by commercial enterprises or light industries requiring small amounts of water if they are "intrinsic" to the normal and essential commerce of the municipality.

(9) A municipal waste stream may, under some conditions, be used for a new industry: The use of a municipal waste stream is one of the "grey" areas in water appropriation law. Once a municipality has established a water right, it may use the water to "extinction." This means that it has no obligation to return water to the source or to another water body. Under current policy, once treated wastewater has entered a waterway it is considered to have returned to the status of "waters of the state," and is no longer under the jurisdiction of the original water permit holder. However, if treated wastewater is piped directly to another user of the city's choice, the city may sell the water to the subsidiary user. The subsidiary user, however, will be required to apply for a state water permit. Once designated by the municipality, there would be, in a practical sense, no competition for the water. The state water permit is required to assure appropriate evaluation of the status of the water and the appropriateness of its transfer on a case-by-case basis.

The best way to assure a high probability of success and smooth progress for the application is to contact the staff of the Water Appropriation Division of the North Dakota State Water Commission early in the consideration of a site or site alternatives. They will be more than willing to assist in evaluating the plausibility of obtaining suitable waters in a given area, and in providing the information and assistance needed to facilitate the application process.

## Citations

Hoffman, Jeffrey, Sarah Forbes, and Thomas Feeley. 2002. Estimating freshwater needs to meet 2025 electricity generating capacity forecasts. U.S. Department of Energy/National Energy Technology Laboratory. 12 pp.

U.S. Department of Energy. Dec. 2006. Energy demands on water resources: Report to congress on the interdependency of energy and water. 80 pp. http://www.sandia.gov/energy-water/congress_report.htm.

# WATER USE BY ENERGY INDUSTRIES IN NORTH DAKOTA

One of the legislature's requirements was that the State Water Commission "*determine unit water use for each sector of the energy industry, including: (1) Petroleum; (2) Ethanol; (3) Electrical generation; and (4) Biodiesel.*"[3] In this section we have treated *biodiesel* and *ethanol* as subcategories of *bioenergy*. The petroleum industry is treated in three separate categories, including: (1) oil-field production, (2) natural gas production, and (3) petroleum refining. We have added a section on *syngas* which, although not specified under HB 1322, is an important and expanding outgrowth of the lignite-based energy industrial sector in North Dakota, and which may comprise a major sector for future growth. We have treated coal-fired electrical generation as a separate category. We have also added a brief section on wind energy, although water use in the wind energy sector is very small. A list of planned and operational energy entities, provided by the North Dakota Department of Commerce, is included as Appendix A.

Our approach, for each sector of the energy industry, has been to: (1) briefly review the national literature on unit water use to provide a comparative standard; and (2) estimate the unit water use on a facility basis within each industry. Unit water use was calculated by dividing total water use for a number of sample years by total production for the same years. Sample production statistics were provided, in most cases, by industry personnel. In the case of natural gas, production statistics were provided by the North Dakota Industrial Commission Oil and Gas Division. For the most part, we avoid publishing the actual production numbers, respecting the reticence of some industries to do so, and publish only the derivative water use numbers.

Water-use estimates were derived from various sources. Where plants and facilities have state water permits, we used reported water-use statistics, with the assistance of industry personnel in interpreting their use. In many cases, water is purchased from other suppliers - municipalities, rural water systems, public water projects, or even other industries. In a few cases water is trucked between facilities, and multiple plants are served by a single source. Water supplies for these cases were estimated from information provided by the industry or from information provided by water suppliers. In some cases, where small quantities are used, there are no records separable from the gross use of the suppliers.

Units used are, for the most part, non-comparable between industries. Units include: gallons of water per gallon of product for biodiesel fuel (gal/gal); gallons of water per gallon of denatured product for ethanol (gal/gal); gallons of water per thousand cubic feet of natural gas processed as received from the well (gal/MCF), gallons of water per gallon liquid product (gal/gal) for petroleum refining; gallons per cubic foot of natural gas produced at standard temperature and pressure (gal/SCF) for the Dakota Gasification plant at Beulah, ND; and gallons of water per kilowatt-hour for thermoelectric and wind-driven power generation. For industries still in planning, unit water use was obviously unavailable and potential use was discussed in more general

---

[3] 2009 N.D. Sess. Laws ch. 192, § 2.

terms. Unit water use could not be calculated for the oil fields. The production practices are extremely complex and varied, including: different water qualities for different operations; large production times and indeterminate yields for individual oil wells; and constantly changing practices and water-use requirements for many oil-field operations, particularly fracturing. Also, syngas final products vary with individual plants: some producing natural gas, others producing liquid gases, others burning syngas for thermoelectric power production.

Finally, the water-use information is provided in the form of an industry-by-industry summary of individual plant or operational profiles. These profiles, or brief operational descriptions and their water use, were developed in collaboration with managers or engineers of each facility, or in some cases designated corporate representatives. Information was provided by phone interview or through e-mail exchanges. In each case, the profile was submitted by e-mail to the industry representative for review and correction. It is recognized that many of the energy industries in North Dakota are moving and developing quickly, and that their water requirements are somewhat of a "moving target." The disposition of water depots for use by the oil field, for example, is extremely dynamic at present (Spring 2010) and changes by the day. Omissions or inadequate reviews, moreover, are always possible, and the author, if contacted, is prepared to correct any omissions or errors that may have occurred.

## Water Use for Biofuels in North Dakota

According to Pate and others (2007), in recent years biomass has overtaken hydropower as the largest domestic source of renewable energy. Biomass currently (2007) supplies over 3 % of the nation's total energy consumption, and represents nearly half of all U.S. renewable energy use. A summary of unit water use and consumption for varying biofuels is reproduced on Table 2.

**Table 2. National water-use summary for biofuels. (Reproduction of Table 4, from Pate and others, 2007).**

| Fuel Type and Conversion Process | Biomass Feedstock | Processing Water Use Intensity (gal $H_2O$/gal fuel) | | Feedstock Water Use Intensity | | |
|---|---|---|---|---|---|---|
| | | Process Water Use | Process Water Consumption | Feedstock Water Demand Ac-ft / Acre | Biofuel Yield gal fuel / Acre | Feedstock Water Consumption[d] gal $H_2O$/gal fuel |
| Ethanol, Starch or sugar-based Wet mill or Dry Mill | Corn | ~ 2 - 6 | ~4 | ~ 1.2 | 400 | 980 |
| | Sorghum | | | ~ 1.0 | 170 | 1900 |
| | Sugar Cane | | | ~ 2.0 | 560 | 1160 |
| | Sugar Beets | | | ~ 2.3 | 550 | 1360 |
| Ethanol Cellulose-based[a] Biochem or Thermochem | Switchgrass | ~3 - 12[e] estimate | ~ 2 – 6[e] estimate | ~ 2.3 | 500 – 800 (700 estimated)[b] | Rain-fed |
| | Woody biomass | | | ~ 2.5 | 500 – 800 | Rain-fed |
| Biodiesel from Oil Extraction and Trans-Esterification | Soybeans | ~0.3 - 3 | ~ 1 | ~ 0.8 | 40 | 6500 |
| | Sunflower | | | ~ 1.5 | 80 | 6100 |
| | Oil Palm | | | ≥ 2.5 | 510 | Rain-fed |
| | Algae | ~0.3 - 3 | ~ 1 | Not determined[f] | 3,000 – 15,000[c] (5000 estimated) | Not determined[f] |

[a] Cellulose-based ethanol yields of 100 gal/dry ton based on laboratory data, processes are still experimental

[b] Switchgrass yields have exceeded 10 dry tons/acre experimentally, but more routinely range from 3 to 7 dry tons/acre

[c] Algal-based biodiesel production estimates based on laboratory and small scale test data: viable high-yield scale-up still uncertain

[d] Water consumption with irrigated feedstock production at per-acre water demand and per-acre biofuel yield levels shown

[e] Estimates based on unvalidated projections for commercial processing

[f] Non-fresh water used; losses mainly from evaporation

## Water Use for Ethanol Production

National bioethanol production capacity was reported to be 34 billion gallons per year as of July 2008, and was projected to be 57 billion gallons per year by 2015 (National Research Council 2008).

With respect to water consumption Chiu and others (2009) draw a distinction between *imbedded* water and *process* water. Imbedded water includes irrigation water used for feedstock production as well as process water. According to Chiu and others (2009) about 80% of all corn feedstock is grown, on a national basis, within about 64 km (38 mi) of the ethanol facility. Because irrigation requirements vary with climate, there is a wide variation in imbedded water [5 to 2,138 gal (ethanol)/gal ($H_2O$)], with least in humid areas, and most in arid areas. The largest imbedded water is in California. North Dakota was estimated to be near the national median with respect to imbedded water, with 59 gal/gal, of which 31 gal/gal were attributed to ground water and 28 gal/gal were attributed to surface water. One aspect of water use in all of the renewable fuels industries, then, is the consideration of non rain-supplied water supplies required for production of feedstock.

Process water used for the dry milling process is used for slurring, boiling, fermentation, distilling, system reject water and water released from evaporators outside of the system (Chiu and others 2009). Some aspects of water use in an efficient ethanol production facility can be summarized using Blue Flint Ethanol (Underwood, ND) as an example.[4] Process water is used for cook water in the slurry blender for the initial enzymatic breakdown of starch. Water is also injected as steam to raise the temperature of the slurry mash and later to sterilize and cook the slurry in the hydroheater. Water is used to wash carbon dioxide vapor of alcohol before venting. Water conservation is employed through several recycling mechanisms. These include: After distillation, alcohol-free water from the side stripper is recycled to the cook water stream and reused. Similarly, in the sequential processing of whole stillage pumped from the bottom of the beer column, heat from water evaporated from the initial stages of wet stillage is used in evaporators to evaporate the water from other batches of wet stillage, and the water vapor from those evaporators is used, finally, as low-pressure steam to heat the beer column. Condensed water from the evaporators is reused as process water. Water use may be expected to vary somewhat in different plants.

The largest use of water is for cooling. Cooling may be accomplished using *once-through*, *wet-recirculating*, or *dry-recirculating* processes. The distinction of water *withdrawal* and *consumption* discussed for thermoelectric power applies for ethanol production as well, with largest *withdrawal* and lowest *consumption* for once-through cooling systems, and largest consumption and lowest withdrawal for *wet-recirculating* systems.

---

[4] Based on information provided by: Zueger, Jeff. (Blue Flint Ethanol). July 27, 2009. E-mail communication.

### *Unit Water Use in Corn-Based Ethanol*

Estimates of process water-use efficiency have varied widely in the literature, and generally range from about 3 to 7 gal/gal (Pate and others 2007, National Research Council 2008, King and Webber 2008, Keeney and Muller 2006). They have generally decreased over time as the industry has improved in its water use. Keeney and Muller (2006) have estimated a requirement of about 10 gpm for each million gallons of yearly ethanol production, which would require about 5.25 gal/gal for year-round pumping. They reported that average water use in Minnesota ethanol plants had decreased from 5.8 gal/gal in 1998 to about 4.2 gal/gal, with minimum reported use of about 3.5 gal/gal. The National Corn Growers Association,[5] and the Michigan Corn Growers Association,[6] and the Renewable Fuels Association[7] have estimated that water-use efficiencies of about 3 gal/gal may be achievable for corn-based ethanol.

### *Potential Unit Water Use in Cellulosic Ethanol*

The Renewable Fuels Standard (RFS) established by the Energy Policy Act of 2005 has called for a minimum of 250 million gallons of ethanol derived from lignocellulosic biomass beginning in 2013 (Pate and others 2007). According to the National Research Council (2008) total water requirements for ethanol from cellulose are thought to be large initially, about 9.5 gal/gal. However this is projected to decline as efficiency increases with experience, and eventual consumptive use is projected to be about 2 to 6 gal/gal (Pate and others 2007). The 2 to 6 gal/gal estimate is “lumped” from several different production methods. The National Research Council (2008) has reported that a thermochemical conversion process for cellulosic ethanol may hold promise for unit water use of 2 gal/gal, less than corn ethanol plants. The thermochemical conversion technology was available only at a demonstration scale, and would likely require some modifications of auto manufacturing and fuel delivery.

### *Estimated Unit Water Use for Ethanol Production in North Dakota*

In North Dakota there are, or have been, six ethanol-producing plants in operation. The time of operation varies from more than 20 years to a few months. Unit water use was estimated for each facility by dividing total water use by total ethanol production as denatured product for the available period of record.

#### Alchem Ltd (LLLP)

Alchem Ltd (LLLP) Ethanol of Grafton, North Dakota, is the longest-established ethanol-producing plant in North Dakota, and has a permitted capacity of 10 million gallons of ethanol per year. Alchem began operation in 1983, producing about 4 million gallons per year of product, and increased to about 9.5 million gallons per year in 1987.

---

[5] NCGA. Corn and Water: Facts in Perspective. PowerPoint presentation.

[6] http://www.micorn.org/myths/index.html

[7] Renewable Fuels Association. Ethanol Facts: Environment. http://www.ethanolrfa.org/resource/facts/environment

The plant operated until October of 2007, when production ceased. Water was supplied by the city of Grafton. Unit water use for 2001 through 2007, estimated by dividing total annual production by the total water supplied by the city ofGrafton, had a median value of 6.6 gal/gal, with a minimum of 5.1 gal/gal in 2007.[8] Additional water-use efficiencies are difficult to ascertain because plant operational personnel are no longer available for consultation. At the present (2009-2010) Alchem is upgrading plant efficiencies, and future operation is anticipated, depending on economic conditions.

### ADM Corn Processing

ADM Corn Processing, at Walhalla, ND, is owned by Archer Daniels Midland of Decatur, Illinois. ADM has been in operation since 1985, and has been producing ethanol since 1998. The plant is permitted to produce about 34 million gallons of ethanol per year. The plant employs a dry milling process. ADM holds a conditionally approved water permit (#3662) for 900 acre-feet per year from the Icelandic and Pembina River aquifers, with an approved withdrawal rate of 750 gpm, from four points of diversion combined. In addition, about 40 to 200 acre-feet of untreated well water is obtained from the city of Walhalla, and a relatively small amount (less than 2 acre-feet) of water is purchased from North Valley Rural Water for sanitary use. Raw water is used for cooling. Boiler water is treated using reverse osmosis, microfiltration and softening. Return waters from the distillation process are used for slurrying, with some supplementation from raw water. About 25 to 50 acre-feet of discharge is reused for irrigation. Calculations of unit water use included the annual sum of all water sources, with irrigation wastewater subtracted in years in which irrigation was practiced. Operational years 1998 through 2003 had a median unit water use of 5 gal/gal. During the most recent five years (2004 through the 2008), unit water use ranged from 2.8 to 4.8, with a median of 3.7 gal/gal.

### Blue Flint Ethanol

Blue Flint Ethanol LLC (BFE) is a joint venture between Headwaters Incorporated, headquartered in Salt Lake City, Utah, and Great River Energy, headquartered in Maple Grove, Minnesota. The Blue Flint facility is designed to produce 50 million gallons of ethanol per year. Blue Flint has been designed to operate in conjunction with the Great River Energy (GRE) Coal Creek Power Plant at Underwood, ND, and to share water and water-use facilities to maximize the water-use efficiency of both operations. Blue Flint shares the Coal Creek water intake from the Missouri River, and draws its process water from the river water storage basin used by Coal Creek. The fire-water system for BFE is treated and housed at Coal Creek. Potable water treated by Coal Creek is delivered to the Blue Flint Ethanol. Low-pressure steam from the Coal Creek Station is also used by Blue Flint to heat mash prior to fermentation, to operate the distillation process, and to provide heat for drying wet stillage. The process water is used

---

[8] Based on statistics supplied by Chris Rathgen. Dec. 15, 2009. E-mail communication.

for slurrying and for cooling, using a *wet-recirculating* cooling system. Process water treated only by settling is used as replacement water for evaporative loss and blowdown. Blowdown water is returned to the Coal Creek facility for use in cooling. Water evaporated from the wet stillage is recovered and reused for slurrying. Most of water consumption is from cooling tower blowdown and evaporative loss, with lesser consumption from evaporation during the drying of the wet stillage.

Blue Flint Ethanol has been authorized for the use of 742 acre-feet per year from the Missouri River under Perfected Water Permit #5802. Plant operation began in 2007, and water use has been reported at 461.4 acre-feet in 2007 and 567.5 acre-feet in 2008. The design unit water use for Blue Flint is estimated at 366 gallons per minute. The design total water-use efficiency for the plant was 3.82 gal/gal. Calculations of actual unit water consumption using 2007, 2008 and 2009 production and total water-use data result in unit water use estimates of 3.04, 3.05, and 3.17 gal/gal respectively.[9] The 2009 data were only available through October, and were thus skewed upward slightly because of additional cooling demands during the warmer seasons. Some additional items of efficiency not reflected in the calculated unit water use are: (1) the filtrate (46%) from the demineralization process for boiler water is counted as consumed in the calculations, but is returned to and used by Coal Creek; and (2) cooling tower blowdown from BFE is used by Coal Creek in its cooling towers. A decrease in denaturant added from 5% in 2007 to 2% in 2008 would tend to slightly increase the ratio of water use to final denatured product, although the effect is not apparent in the calculations.

### Hankinson Renewable Energy

The Hankinson Renewable Energy (HRE) ethanol plant, owned and operated by Murphy Oil Corporation of El Dorado, Arkansas, began operation in October of 2009. The plant was originally planned and built by U.S. Bioenergy, but was purchased in 2008 by VeraSun Energy Corporation of Brookings, SD. The plant was designed to have an annual production capacity of 110 million gallons per year. The Hankinson ethanol facility receives water from the city of Hankinson under two state water permits: Conditional Water Permit #5899 for 871 acre-feet, and a maximum pumping rate of 1,500 gpm from the Milnor Channel aquifer; and Conditional Water Permit #5900 for 871 acre-feet, and a maximum pumping rate of 930 gpm from the Hankinson aquifer; for a total of 1,742 acre-feet per year. Pipelines for water conveyance to the plant were funded through bonds issued by the city, but are paid in monthly installments by HRE. Water from the two aquifers is mixed in approximate half portions to enhance water quality, as the Milnor Channel has higher dissolved solids. Raw water is supplied to the plant where it is treated in a multilayered sand filter to remove metals (including arsenic, iron and manganese). The filtered water is used for process water (slurrying) and for cooling. Water for steam is further treated by reverse osmosis and softening. Blowdown from the cooling towers and reverse osmosis is discharged, after settling, to the Wild Rice

---

[9] Based on statistics supplied by Adam Dunlop. Dec. 2, 2009. E-mail communication.

River. Blowdown waters are replaced by waters from the multilayered filter. The design water-use efficiency is expected to be approximately 2.8 to 2.9 gal/gal. Calculations for a one-month production sample (Dec. 2009) based on total water use and total denatured product indicated a unit water use of 2.5 gal/lgal.

Red Trail Energy

Red Trail Energy, located at Richardton, North Dakota, is owned and operated by a private North Dakota based investment group, governed by a local seven-member board of directors. The plant has been designed to produce up to 50 million gallons of ethanol per year using corn as a feedstock. Initially water was planned for supply from the Fox Hills aquifer. However, aquifer capabilities were found to be inadequate. Red Trail Energy is currently supplied with water from the Missouri River by the Southwest Pipeline Project (SWPP) under Conditional Water Permit #5754. Conditional Water Permit #5754 is held by the State Water Commission on behalf of the SWPP, and authorizes up to 1,130 acre-feet per year at a 700 gpm pumping rate for industrial use. The Red Trail plant receives raw Missouri River water from the SWPP, which is untreated, except for chlorination. Water uses are: process water, steam and cooling water. Raw water is used for slurrying and for cooling. Water for steam is passed through a multilayered sand filter, a series of finer filters, and finally a reverse osmosis filter. The steam source water is deoxygenated using sulfide, the pH is adjusted using caustic soda, and softened. Raw water is used for cooling in a wet-recirculating cooling system. Blowdown and evaporative losses from cooling are replaced using raw water. For operational years 2007 and 2008, unit water use calculated from water use and production statistics was 2.87 and 3 gal/gal respectively. In 2009 (through October) unit water use was 3.06 gal/gal.[10] The 2009 data were only available through October, and were thus skewed upward somewhat because of additional cooling requirements during the warmer seasons. Almost all (>99.9%) of total water use was process water.

Tharaldson Ethanol

Tharaldson Ethanol, located in Casselton, ND, is a corn-fed ethanol plant employing a continuous fermentation process. The plant is designed to produce ethanol at a rate of about 100 million gal/year, and is permitted for up to 124 million gal/year. It first commenced operation on December 31, 2008, and has been operated intermittently in a “shakedown” phase during 2009. The plant has been designed for a unit water use of 3.2 gal/gal when fully operational. An additional water conservation feature is the reuse of discharge water from the city of Fargo. Tharaldson Ethanol and the city of Fargo have collaborated in an upgrade of Fargo’s water treatment facilities to deliver water that has been treated through ultrafiltration and reverse osmosis. The treated water is then supplied by Fargo to the Cass Rural Water District, which conveys the water to the Tharaldson plant. Conditional Water Permit # 5897 allocates a maximum of 4,480 acre-

---

[10] Based on statistics supplied by: Butterfield, Jean. Dec. 7, 2009. E-mail communication.

feet at a maximum pumping rate of 2,782.6 gpm of water from Fargo's waste stream. The received water is further treated by passing through a reverse osmosis unit, decarbonation and softening before being used as steam and boiler water. A wet-recirculating system is used for cooling. Wastewater from ethanol production is treated by anaerobic digestion and aerobic clarification. The treated wastewater is then used for cooling tower replacement water. Blowdown from the cooling tower is returned to Fargo for retreatment and reuse. Depending on production rates, about 1.5 million gal/day of water is expected be received at Tharaldson Ethanol from Fargo, of which about 470,000 gal/day are expected to be returned to Fargo for retreatment. Ethanol production and water use statistics for the "shakedown year" (2009) indicate a unit water use of about 3.4 gal/gal.[11] Plant water-use efficiencies are expected to approach design specifications as the plant approaches full production goals.

### *Potential Water Use for a Cellulosic Ethanol Plant: Dakota Spirit AgEnergy*

A cellulosic ethanol-producing facility, called Dakota Spirit AgEnergy, is currently in the feasibility evaluation phase for possible future construction in the Jamestown, ND, Energy Spiritwood Industrial Park. If determined to be feasible, construction may be completed and start-up commenced as early as 2014. Dakota Spirit AgEnergy plans to use wheat straw and/or a variety of other agricultural and waste byproducts as feedstock to produce ethanol, molasses and lignin. The current plan is to use an enzymatic-hydrolysis cellulose digestion process employed by Dong Energy and Inbicon in a demonstration scale plant in Kalundborg, Denmark. The feasibility planning group includes Great River Energy, Blue Flint Ethanol, the North Dakota Department of Commerce, and the Jamestown-Stutsman Development Corporation, and will likely be expanded to include other members, including financial and contracting entities. At the current state of planning (April 2010), details of water use are not yet defined. However, Dakota Spirit AgEnergy plans to use steam from the Spiritwood Energy Station, currently in construction, for its fermentation process. Because the water stream for steam produced at the Spiritwood Energy Station is drawn from treated wastewater from the city of Jamestown, Dakota Spirit AgEnergy, with Cargill Malt and other potential future energy-producing enterprises in the Jamestown Energy Park are expected to serve as prototypes for a very high level of water-use efficiency.

### *Current and Projected Water Use for Ethanol in North Dakota*

From general industry trends and specific unit water use data for North Dakota ethanol production facilities, it may be reasonably estimated that future unit water use for corn-based ethanol will be in the range of 3 to 3.5 gal/gal. Using published design capacities for currently operating facilities, a total of 335,000,000 gal/year of ethanol production is projected for the state. From this production estimate, **current total water use at full capacity would be expected to range from about 3,100 acre-feet to 3,600 acre-feet per year.** The addition of four proposed facilities (Buffalo Creek Energy,

---

[11] Based on statistics supplied by Ken Bennett. Dec. 3, 2009. E-mail communication.

Lakota Biofuels, Dakota AgEnergy, and Yellowstone Ethanol) would increase capacity by about 270,000,000 gal/year. **Additional water use would be expected to range from 2,500 to 2,900 acre-feet per year.** Total water use from full current and future combined production would be between 5,600 and 6,500 acre-feet per year.

## Water Use for Biodiesel Fuel Production

According to Pate and others (2007), domestic biodiesel fuel production lags behind ethanol, but is also experiencing rapid growth. Production increased from about 25 million gallons in 2004 to 75 million gallons in 2005, and then tripled again to about 225 million gallons in 2006. Common ranges of unit process water consumption for biodiesel fuel production are shown on Table 2. Generally, overall consumption use is between 1 and 3 gal/gal. But Pate and others have stated that new future technologies, which include the possibility of using recycled wastewater with various degrees of treatment, may increase water-use efficiency.

### *Unit Water Use in Biodiesel Fuel*

In North Dakota there are or have been only two biodiesel fuel producing plants in operation, and the operational periods of record are short, less than two years. Unit water use was estimated by dividing total water use by total biodiesel fuel production for the available period of record.

#### ADM Biodiesel

The ADM processing plant located at Velva, ND, is owned and operated by Archer-Daniels Midland Company of Decatur, Illinois. It has a permitted capacity for 85 million gallons of biodiesel fuel per year. Water is supplied under Perfected Water Permit #3182 that allocates 276.2 acre-feet per year from the Voltaire aquifer for beneficial use at a maximum withdrawal rate of 450 gpm. The water is used for two operations: for the canola crushing plant, and the biodiesel production plant. Both use steam and cooling towers for various heat and cooling operations. For steam, the water is first flocculated and settled, then acidified, and then treated with reverse osmosis. For cooling water, the water is flocculated and acidified. About 60% of the water is used for steam, and the balance is used mostly for cooling tower make-up water. Water is used at a steady rate of about 200 gpm. About 2,000 metric tons of seed per day are crushed. Plant canola crushing operations were in progress for several years before biodiesel production began in 2007. The amount of water used per unit of biodiesel fuel production is relatively small and does not differ appreciably from pre-2007 estimates. The water used for biodiesel fuel production is not separated in reporting from water used for crushing. The combined bulk water use (gal), per unit (gal) of biodiesel fuel produced for a single full production year (2008), as calculated using reported water use and total biodiesel fuel production, was about 1.5 gal/gal.[12] Water use in this calculation includes

---

[12] Based on statistics supplied by Michelle Bublitz. Dec. 15, 2009. E-mail communication.

both feedstock crushing and biodiesel fuel processing combined. The calculated unit water use is within the lower range of national use estimates (Pate and others 2007).

### Northwood Agri-Biodiesel

A second biodiesel facility was piloted as a joint venture (Northwood Agri-Biodiesel LLP) by Northwood Mills (LLP) and Baseview Petroleum of Northwood, North Dakota, as an expansion of the Northwood Mills soybean oil plant. The plant was originally permitted for 3 million gallons of biodiesel fuel per year, and was planning to produce up to 7 million gallons of biodiesel fuel per year. Production was terminated after eight months, and according to Jeff Bengtson, the current plant general manager, there are no current plans for future operation. There is an insufficient basis for estimation of unit water use in this facility.

## ***Current and Projected Water Use for Biodiesel Fuel in North Dakota***

Annual water use for biodiesel fuel production in North Dakota is currently less than 300 acre-feet. A reasonable estimate for unit water use would be about 1 to 1.5 gal/gal for future production. However, there are no current plans for additional biodiesel plants in North Dakota (Appendix A, Commerce Table).

# Water Use for Natural Gas Production in North Dakota

The Oil and Gas Division of the Industrial Commission has listed 29 natural gas processing plants in North Dakota. Of these, 16 are listed as inactive and 13 are listed as operational. These are summarized on Table 3. Locations of North Dakota natural gas wells and processing plants are shown on Figure 5.

Table 3. List of current operational natural gas plants and inactive natural gas plants in North Dakota.[13]

| Operational Natural Gas Plants | Operator | Capacity (1999) MMCF/day* | | Inactive Natural Gas Plants | Last Reported Production |
|---|---|---|---|---|---|
| Ambrose | Sterling Energy | 0.5 | | Alexander | 7/1993 |
| Badlands | Hiland Partners | 40 | | Alpar-Peterson | 12/1980 |
| Lignite | Bear Paw | 6 | | Boxcar Butte | 7/1987 |
| Little Knife | Petro Hunt | 32 | | Coyote Creek | 12/1992 |
| Marmarth | Bear Paw | 7.5 | | Killdeer | 1/1995 |
| Grasslands | Bear Paw | 100 | | Little Beaver | 7/2006 |
| Nesson | Nesson | 10 | | Medicine Pole Hills | 2/1999 |
| Norse | Hiland Partners | 10 | | Missouri Ridge | 12/1985 |
| Ray | Whiting Oil & Gas | 10 | | Mon-Dak | 10/1983 |
| Red Wing Creek | True Oil | 4 | | North Tioga | 3/1995 |
| Robinson Lake | Whiting Oil & Gas | 30 | | South Horse Creek | 12/1987 |
| Stanley | Pecan Pipeline | 80 | | Stateline | 3/1992 |
| Tioga | Hess | 120 | | T.R. | 7/1993 |
| | | | | Temple | 5/1996 |
| | | | | Trenton | 5/1987 |
| | | | | Williston | 12/1985 |

- million cubic feet per day

For the most part, little water is used by the natural gas industry. Uses and supplies vary between individual facilities. Water is used for boiler water and for wet sulfur scrubbers at some plants. At others it is used only for office, personnel and cleaning purposes. Industrial water permits for two plants authorize 25 and 29 acre-feet per year, a relatively small amount. Other plants are supplied as domestic users through community or rural water supply associations. Some are metered, others not. Some facilities truck their water from other locations. Most plants have residual produced water from the wet gas that is disposed of, in most cases, by trucking it to centralized injection-well sites, where it is injected into the Dakota Formation. One plant evaporates the produced water.

---

[13] Oil and Gas Division, North Dakota Industrial Commission. Accessed May 1, 2010. https://www.dmr.nd.gov/oilgas/feeservices/gasplants.asp

The median unit water use for measured plants is around 0.4 gal/MCF.[14] Because of the relatively small amount of water used, natural gas plants should be serviceable with little difficulty by local ground-water wells, surface-water sources, water user associations, municipalities, or water depot.

**Ambrose Natural Gas Processing (Ambrose)**

The Ambrose gas processing plant, near Ambrose, ND, is owned and operated by Ambrose Gas Processing (LLC) and has reported production since 1984. Since 2008 Ambrose Gas Processing has been a wholly owned subsidiary of Sterling Energy Co. of Denver, CO. The plant had a rated production capacity of 0.5 million cubic feet per day in 2009, but as of November, 2009 Sterling has announced plans to increase capacity to 3 million cubic feet per day, with a possible future increase to as much as 50 million cubic feet per day.[15] Production has varied from as little as 21,000 MCF/year to as much as 141,000 MCF/year over the plant history, with a recent production of about 70,000 MCF/year. The Ambrose plant produces methane, ethane, propane, butane and natural gasoline. There are no water dispensing facilities, including bathrooms, on the Ambrose site. Site personnel bring their own bottled water (personal size) when needed, and "jugs" of water are sometimes brought in for cleaning. Unit water use is, therefore, negligible. Produced water is stored and trucked to a well-injection site. Very little water is produced.

**Badlands Natural Gas Processing (Rhame)**

The Badlands natural gas plant, located south of Rhame, North Dakota, is owned and operated by Hiland Partners (LLP), headquartered in Enid, Oklahoma. The plant has reported production since August 1997. In 2006 the Badlands plant had a reported capacity of 4 million cubic feet per day wet gas from the wells. In 2007 the plant was upgraded, and as of 2008 it had a capacity of 40 million cubic feet per day. Production (wet gas at the well) before the upgrade averaged a little more than a million MCF per year, but has increased to near 8 million MCF per year since the upgrade. The Badlands plant produces methane, propane, mixed butane and natural gasoline. Water is used for facility operation (bathrooms, cleaning, drinking water, etc.) and for boiler water, after suitable filtration and reverse osmosis filtration. Sulfur is removed using a dry process. Since the plant upgrade, water has been supplied to the Badlands plant by the Southwest Pipeline Project. The post-upgrade unit water use has been about 0.14 gal/MCF. Produced water is mostly removed at a central reservoir, and is trucked to a central location for reinjection.

---

[14] MCF = 1,000 cubic feet.

[15] Smith, Nick. Nov. 5, 2009. Williston Herald.

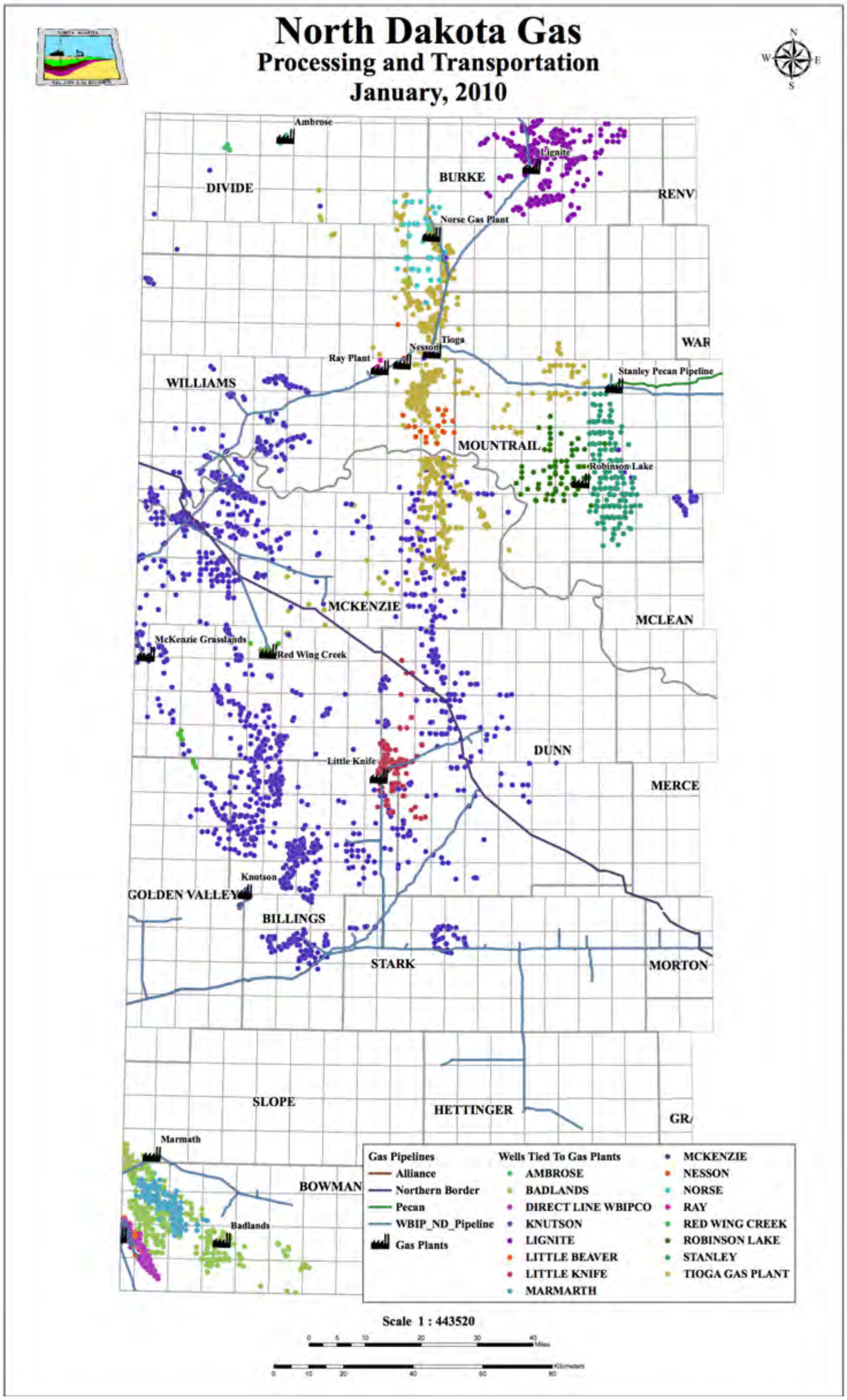


Figure 5. Location of natural gas production wells and processing plants in North Dakota.[16]

---

[16] ND Pipeline Authority. Provided by Rory Nelson, Manager of Hess, Tioga Gas Plant. March 26, 2010.

## Grasslands Natural Gas Processing (McKenzie) and Marmarth Natural Gas Processing (Marmarth)

The Grasslands and Marmarth plants are discussed together because they share the same water supply - water is trucked from the Grasslands plant to the Marmarth Plant. Both the Grasslands plant (located in McKenzie County near Sidney, Montana) and the Marmarth plant (located near Marmarth, North Dakota) are owned and operated by Bear Paw Energy (LLC) of Sidney, Montana. Grasslands first reported production in December 1980. The Marmarth plant first reported production in November 1996. Product outputs from the Grasslands plant include methane, propane, butane, isobutane, and natural gasoline. The Grasslands plant capacity in 2006 was 63 million cubic feet per day, but was increased to 100 million cubic per day by 2008. Average production since 1996 has been about 13 million MCF per year, but is currently around 25 million MCF per year.

The Marmarth plant production capacity is listed at 7.5 million cubic feet per day. Since 2004 production has averaged about 2 million MCF per year. Product output from the Marmarth plant includes condensate and a natural gas liquids mix (or Y-grade) product which is trucked to the Baker Gas Plant at Baker, Montana, for further processing. Water is used for mixing with treating chemicals, for sweetening and dehydration of the gas, as well as steam boilers for assisting the process. A minor amount is used for the usual utilities such as restroom facilities. Water for both plants is supplied from wells located at the Grasslands plant which are screened in the Fox Hills aquifer, and which are authorized for 25 acre-feet per year under state Perfected Water Permit #4794. Water is trucked from the Grasslands wells to the Marmarth plant. Because of the combined supply, unit water use is calculated for both facilities by dividing annual water use by combined wet gas processed. The unit water for 1996 through 2008 varied from 0.18 gal/MCF to 0.57 gal/MCF, with a median of 0.38 gal/MCF. Produced water, separated at the wells and at the plant, is trucked to a centralized location for injection into the Dakota Formation.

## Hess Natural Gas Processing (Tioga)

Hess Corporation, headquartered in New York City, New York, and Woodbridge, New Jersey, operates a natural gas processing plant at Tioga, North Dakota. The plant has been in operation since 1954, and has a capacity of up to 120 million cubic feet per day. In recent years the Tioga plant has processed about 37 million MCF of natural gas per year received from the wells. Output products for sale are methane, liquid propane, butane, pentane and sulfur. The plant uses about 115 gpm, mostly for cooling, with a small amount used for facilities (bathrooms, etc.). Water was previously supplied by local wells, but the plant now purchases treated water (up to a maximum of 200 gpm) from the Ray-Tioga Water Supply system. Total annual water use for 2003 through 2009 averaged about 185 acre-feet (60 million gallons) per year. The unit water use, based on raw product delivered from the wells ranged from 1.55 gal/MCF to 1.74 gal/MCF. Produced water is removed and vented as steam.

**Lignite Natural Gas Processing (Lignite)**

The Lignite natural gas processing plant, located near Lignite, North Dakota, is owned and operated by Bear Paw Energy (LLC) of Sidney, Montana. Lignite first reported production in 1960. The Lignite production capacity is about 6 million cubic feet per day, and actual production has been about 2 million MCF per year. the Lignite plant produces methane, ethane, propane, butane and natural gasoline. Water is mixed with chemicals to aid in the sweetening and dehydration of the gas. It is also used for the domestic utilities. Water is supplied by the city of Lignite, but it is unmetered, so unit water use cannot be calculated. Produced water is trucked to a central site for reinjection into the Dakota Formation.

**Little Knife Natural Gas Processing (Killdeer)**

Petro-Hunt (LLC), headquartered in Dallas, Texas, and its predecessors, have operated the Little Knife natural gas plant near Killdeer in Billings County, North Dakota. The Little Knife plant has reported production since January 1979. The plant has a capacity of about 24 million cubic feet per day, and in recent years has processed about 2.8 million MCF per year. The Little Knife plant produces methane, propane, mixed butane and natural gasoline. Water is used for facility operation (bathrooms, cleaning, drinking water, etc.), for boiler water, and for stripping sulfur ($H_2S$). The Little Knife plant obtains water from its own Fox Hills well under Perfected Water Permit #3270. The plant is approved for 29 acre-feet per year at a pumping rate of 60 gpm. Actual water use since 1990 has averaged 9.6 acre-feet per year. Reported natural gas production has averaged about 3.5 million MCF per year since 1995. Unit water use since 1995 has ranged from 0.4 to 1.8 gal/MCF, with a median of 0.95 gal/MCF. Recently the Little Knife plant has contracted with the Southwest Pipeline Project for its facility water. Produced water is separated from the wet gas stream both at the wells and at the plant. The produced water is generally trucked to a centralized injection well.

**Nesson Natural Gas Processing (Ray)**

The Nesson natural gas plant, located near Ray, North Dakota, is owned and operated by Nesson Gathering Systems (LLC) of Fort Worth, Texas. The Nesson plant first reported production for April 2008, and has a capacity for 10 million cubic feet per day. The plant produces methane, ethane, propane, butane and natural gasoline. Water is supplied by the Ray and Tioga Water Supply Association. Water is used mainly for facilities (bathrooms, kitchen, office, cleaning). Unit water use for 2009 was 0.02 gal/MCF. About 10,500 gallons of produced water was disposed through trucking to centralized injection wells.

**Norse Natural Gas Processing (McGregor)**

The Norse-McGregor natural gas plant, located about five miles north of McGregor, North Dakota, is owned and operated by Hiland Partners (LLP), headquartered in Enid, Oklahoma. The plant has reported production since April 2009. The Norse plant has a capacity for 14 million cubic feet per day. The plant produces Y-grade product, which includes gaseous methane and ethane, and a non-fractionated liquid product consisting of compounds having three carbons or more, with some dissolved ethane. Water is used only for a single bathroom. No water is used in process. Water has been supplied by a water hauler, who purchases the water from the city of Noonan. Total water use for eight months in 2009 was about 6,000 gallons. Unit water use for 2009 was 0.007 gal/MCF. A shallow (about 80 feet deep) well has been drilled at the plant, which may be capable of producing a few gallons per minute of water. Plant operators plan to use the well to supply water for the bathroom in the future. No water treatment is planned. Produced water is separated at the plant, and is disposed of by hauling to centralized injection wells.

### *Ray Natural Gas Processing Plant (Ray)*

The natural gas processing plant located near Ray, North Dakota, is owned and operated by the Whiting Oil and Gas Corporation, headquartered in Denver, Colorado. The plant first reported production March 2008. It has a listed capacity of 10 million cubic feet per day. The Ray plant operation was terminated at the end of December 2008 after less than a year of operation. There is insufficient operational record to calculate or estimate a unit water use.

### *Robinson Lake Natural Gas Processing Plant (New Town)*

The natural gas processing plant located at New Town, North Dakota, is owned and operated by the Whiting Oil and Gas Corporation, headquartered in Denver, Colorado. The plant has reported production since April 2008. It has a listed capacity of 30 million cubic feet per day, and its early production has been about 3 million MCF per year. The Robinson Lake plant produces methane, ethane, propane, butane and natural gasoline. Water is used only for personnel (office, bathrooms, cleaning, etc.). The water is supplied by a private well, and is not metered, so unit water use cannot be determined.

### *Stanley Natural Gas Processing Plant (Stanley)*

The Stanley natural gas processing plant is owned and operated by Pecan Pipeline Corporation of Houston, Texas, which is a subsidiary of E.O.G. Natural Resources Corp., also of Houston, Texas. An initial facility, rated for 20 million cubic feet per day in 2008, was replaced by a second plant rated for 80 million cubic feet per day of gas from the wells in 2009. Combined operational output has been reported since April of 2008. The rate of production has increased steadily, but most recent reported production rates (August through November, 2009) have averaged about 5.3 million MCF per year. The output product includes a light carbon product (4 carbon or less) which is piped to Chicago for fractionation, and a condensed product (5 carbon or more) which is shipped as a liquid. Water is used only for facility and personnel purposes (bathrooms, cleaning etc.). The water is trucked to the facility from a supply depot. An example of water use would be 25,000 gallons obtained from January 1 through December 31, 2009. From this, estimated unit water use would be about 0.08 gal/MCF. Produced water is transported by truck to a centralized injection-well site.

## Water Use for the Bakken – Three Forks - Sanish Play

The recent increase in oil-field development in western North Dakota brings with it a demand for more water use. At the end of 2009 about 4,606 pumping wells were in operation in the North Dakota portion of the Williston Basin, with an additional 500 wells capable of producing but not currently in operation for various reasons.[17] Estimates of future oil-field activity are highly dynamic. As recently as December 2009 North Dakota Department of Mineral Resources[18] and industry sources estimated that up to 1,500 new wells per year may be drilled over the next 15 years. However, as of February, 2010 estimates were increased to 1,800 wells per year.[19] Adequate water supplies are essential for drilling operations and for ongoing pumping for extraction of oil.

Williston Basin oil production in western and north-central North Dakota requires water during the construction and completion of oil wells, occasionally as oil is produced, and as part of secondary recovery operations in older oil fields. In the October 2007, issue of North Dakota Water, Alan Wanek published a short article titled "Water demand for the Oil Industry in Western North Dakota."[20] Wanek described oil-field water uses as: *(1) drilling fluid, (2) mixing concrete grout for surface casing, (3) formation fracturing (or fracing), (4) waterflooding, and (5) operation.*

### Drilling Fluid and Casing

Freshwater is used in making up the circulating fluid used when drilling the hole for an oil well's surface casing and when mixing cement slurry to seal the annular space between the casing of the well and the drill hole. The purpose of the casing is to protect ground water from the infusion of low-quality water from other formations and from other contaminants, such as petroleum, drilling fluids, and recovery additives. Oil well surface casing is set from land surface to a few hundred feet below the deepest fresh-water aquifer. In much of the Williston Basin this would require casing to about 2,000 to 2,500 feet below land surface. Earlier estimates indicated up to about 10,000 gallons of freshwater would be required for circulating fluid, and another 2,000 gallons for mixing cement grout.[21] **More recent estimates[22] indicate that the quantity of fresh make-up water for drilling an oil well and mixing cement is about 3,160 barrels (132,720 gallons), about an order of magnitude higher than previous estimates.**

---

[17] Hvinden, David. Jan. 8, 2010. Oil and Division, NDIC. E-mail communication.

[18] Helms, Lynn. Dec. 10, 2009. PowerPoint Presentation. Ramkota Inn.

[19] Helms, Lynn. Feb. 3, 2010. PowerPoint Presentation. Red River Room, North Dakota State Capital.

[20] Wanek, Alan. Oct. 2007. Water demand for the oil industry in western North Dakota. North Dakota Water. p. 18.

[21] Ibid.

[22] Kovacevich, Terry (Marathon Oil) – E-mail communication to Lynn Helms, June 30, 2010. Forwarded by Dave Hvinden to W.M. Schuh, June 2, 2010.

The required water quality of drilling fluid used to the final cased depth would be determined by the quality of ground water protected. High sodium may, in some cases, cause a problem for drilling additives. Saltwater, commonly from the deeper Dakota Formation, is used for drilling fluid below the cased depth.

### Water for Hydraulic Fracturing (Fracing)

Wanek[23] described the hydraulic fracturing process as follows:

> "the completion and development of some oil wells includes formation fracturing to increase, or stimulate the permeability of the well. Oil can be recovered from low-permeability, oil-bearing rocks, such as the mostly shale and siltstone Bakken Formation, by drilling and casing a hole down to the formation of interest, then drilling one or two miles laterally following a relatively permeable interval within the formation, then pumping water and sand into the drilled (cased and perforated) hole under enough pressure to fracture the oil-bearing formation. Grains of sand, suspended in the gelled and pressurized water, move out into the fractures, holding them open after the water pressure is released. The open fractures allow oil to move to the well bore as the well is pumped."

Viscosity and strength of the fluid for carrying *proppant* sand grains (usually 20/40 or 40/70 sand)[24] and fracturing are maintained by crosslinking polymers, which are normally propriatory and specific to individual fracing contractors; and which are fitted specifically to the chemical characteristics of the water carrier. The polymers typically degrade quickly (within a few hours) of use, leaving the sand grains in place.

The process of fracing typically consists of segments 300 to 1,000 feet long, and about 10 to 30 or more segments per well. Fracing may take two or three days, or seven to ten days, depending on the methods used. Wanek reported estimated frac-water use at about 800,000 gallons per well.[25] However, more recent estimates[26] indicate that staged hydraulic facturing now uses about 50% to 100% more water than previously. Figure 6 illustrates the increasing frequency of high frac-water usage in April through July 2009. Reported frac-water use per well for 2009 ranged from 0.004 to 9.82 acre-feet per well, with median and mean both of 2 acre-feet per well.[27] The North Dakota Industrial Commission has estimated average current frac-water use at about 1.5 to 4 million gallons per well.[28]

Critical water quality factors for fracing fluid include water components that can impair polymer crosslinking and biological agents that can deteriorate the geochemical environment of the formation, particularly in the formation of $H_2S$ gas. Scaling is also a

---

[23] Op Cit, Wanek.

[24] Klapperich, Ryan. July 23, 2009. EERC. E-mail communication to W.M. Schuh.

[25] Op Cit. Wanek, 2009.

[26] Op Cit. Kovacedich.

[27] North Dakota Industrial Commission, Oil and Gas Division.

[28] Op Cit. Helms, Feb. 3, 2010.

potential problem. According to Pat Tsacher of Marathon Oil[29] each oil company has its own gel system and its own water quality standard and preferences. One major concern is high sulfates (>200 mg/L), which can act as a crosslink breaker and destabilize gel (depending on temperature). Tsacher states that high bicarbonate (>200 mg/L) can also affect cross-linked gel (affected by pH). Doug McCrady of XTO Energy[30] stated that freshwater can work to dissolve salt crystals, enhancing secondary permeability. He further stated that sodium concentrations are not as critical in affecting frac gelling polymers, as they are for bentonite gelling properties, and that concentrations of concern are more in the range of chloride, i.e. less than a few thousand mg/L. Other "bad actors" cited include calcium, magnesium, barium, strontium and iron.[31] [32] In addition, high bacterial content is undesirable. Sulfur reducing bacteria are particularly problematic, and can cause *souring* of the crude oil within the formation by forming hydrogen sulfide through reduction of sulfate added in frac water (Hubert and Voordouw 2007).

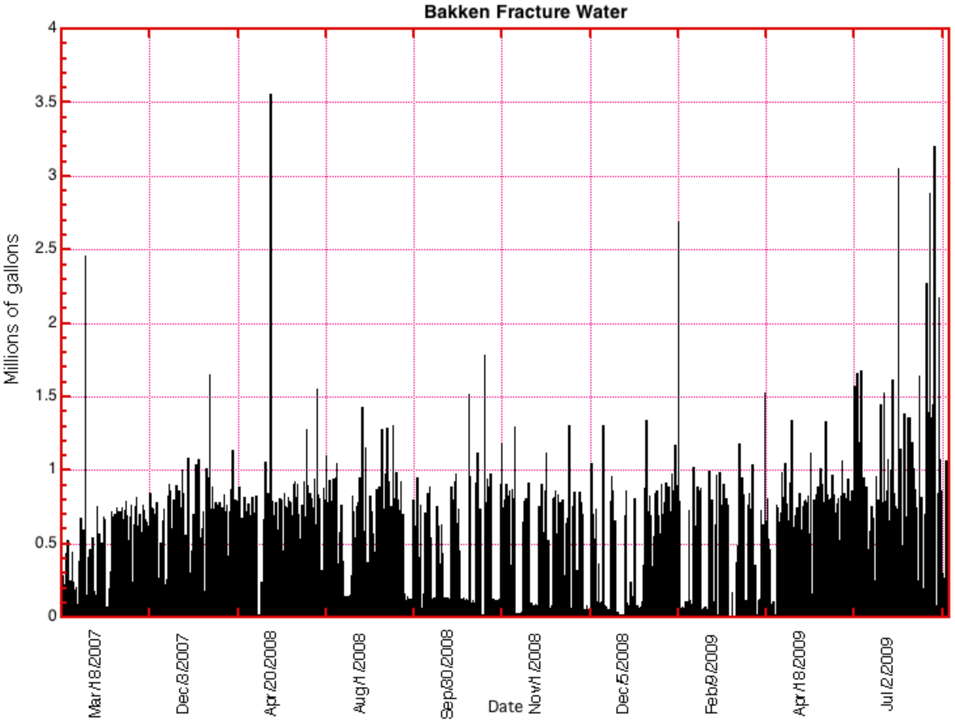


Figure 6. Water use for hydraulic fracturing in the Bakken Formation (2007-2009).

Water quality guidelines on Tables 4 and 5 were provided Mike Eberhard of Halliburton.[33] Other contractors may use other guidelines. Eberhard described typical

---

[29] Tsacher, Pat. Nov. 21, 2009. Marathon Oil. E-mail communication to Bob Shaver.

[30] McCrady, Doug (XTO Energy). Nov. 23, 2009. Phone communication with Robert Shaver.

[31] Eberhard, Mike (Halliburton). Dec. 10, 2009. Fracturing Water Quality. Water for Oil-Field Use. PowerPoint presentation. Ramkota Inn. Bismarck, ND.

[32] Atkins, Russ. Nov. 20, 2009. Continental Resources. Phone communication with Robert Shaver.

[33] Op Cit. Eberhard.

frac fluid treatments as consisting of base water, temporary clay control, biocide, scale inhibitor, gelling agent, pH buffer, crosslinker (polymer), surfactant, and breaker.[34] Chemicals are usually added as the water is pumped into the formation. Generally, the higher the level of treatment the less augmentation that will be needed at the site.

Table 4. Water quality guidelines for frac water (From Halliburton).[35]

|  | Limit* | Comments |
|---|---|---|
| pH | 6-8.5 | Interferes w/hydration of polymer, affects scaling |
| Ca | < 2,000 mg/L | Scales, interferes w/ breakers |
| Mg | <2,000 mg/L | Scales, interferes w/ breakers |
| Fe | <10 mg/L | Catalyst for polymer oxidation, affects scaling |
| Ba | <5 mg/L | Reducing agent, interferes w/breakers |
| Sr | <5 mg/L | Reducing agent, interferes w/breakers |
| Cl | <40,000 mg/L | Interferes with hydration of polymers and breakers |
| HCO3 | <300 mg/L | Will scale with Ca and Mg when heated, delay crosslink |
| PO4 | < 5 ppm | Interferes w/metal crosslinker |
| SO4 | < 500 mg/L | Scales, crosslinker precipitation |

Table 5. Effects of bacterial counts in frac water (From Halliburton).[36]

| Bacterial Level (Count/ml) | Days to gel degradation |
|---|---|
| $<10^4$ | 3 |
| $<10^5$ | 2 |
| $<10^6$ | <1 |

**Alternative Frac-Water Supply Initiatives**

The Energy and Environmental Research Center (EERC) of the University of North Dakota is currently working with the North Dakota Oil and Gas Research Council and petroleum industry cooperators to investigate the physical and economic feasibility of various water treatment technologies for supplying or supplementing freshwater for oil-field use. Two potential water supplies identified for investigation are: (1) treated and recycled frac water, and (2) treated water from the Dakota aquifer.

Preliminary investigations by the EERC (Stepan and others 2010) have indicated that opportunities for treating and reusing frac water are limited by relatively low

---

[34] Op Cit. Eberhard.

[35] Op Cit. Eberhard.

[36] Op Cit. Eberhard.

recoveries (17 to 47% of frac water within a "reasonable time") during the early phases of oil extraction; and by high dissolved solids in the flowback water which reach levels "as high as 220,000 mg/L." In addition, the cost-effectiveness of treatment methods is weighed against estimated current water handling costs of about $2.00/bbl to $16.00/bbl for frac water from natural sources. The estimated costs include acquisition, transportation and disposal of frac water. The EERC research group specified that treatment of Bakken flowback water would require "extremely robust technologies built on highly mobile platforms."

The EERC research group explored several thermal treatment technologies using gas at the well as a power source, and several membrane technologies. Generally, the thermal treatments were identified as best suited for removing high dissolved solids in flowback waters, but treated-water yields were found to be too low for routine use in the Bakken play. They concluded that "while there will certainly be niche opportunities using certain technologies to recycle frac flowback water, widespread recycling will not likely be economically viable."[37]

The EERC research group remains optimistic about possible treatment and use of "moderately saline groundwater from the Dakota Formation" using pretreatment and membrane technologies. Dakota aquifer water in western North Dakota is brackish, with dissolved solids concentrations commonly in the range of 5,000 to 18,000 mg/L, but with some samples as high as 31,000 mg/L.[38] Stepan and others (2010) have observed that reverse osmosis is capable of treating water with dissolved solids of up to 40,000 mg/L, while electrodialysis methods may be feasible for dissolved solids up to 10,000 mg/L. The EERC is currently teaming with an oil industry partner to conduct a pilot-scale demonstration of Dakota water treatment for use in fracturing.

### Water for Operation (Produced-Water Dilution)

During the ongoing operation of some oil wells, water is normally entrained with produced oil. Once produced, the water and oil are separated and the water is either injected into the Dakota aquifer using saltwater disposal wells, or is injected back into the oil-producing zone. Water produced with oil typically is characterized by elevated concentrations of dissolved ions, primarily sodium and chloride. Occasionally, in areas where oil occurs near bedded rock salt, the water produced with oil is a salt-saturated brine. Because Bakken oil is pumped from about a two-mile depth in western North Dakota, the water entrained with produced oil is hot. The salt-saturated water cools as it travels up the oil well production tubing, losing energy and precipitating salt onto the tubing. To prevent the oil well tubing from being plugged by precipitating salt, a small amount of freshwater is pumped down the oil well casing where it mixes with and dilutes the saltwater sufficiently to prevent salt from precipitating as the water cools. Oil wells using freshwater for dilution of saltwater will normally require the water for as long as oil

---

[37] Stepan and others. p. 24. See Citations.

[38] Tom Schumacher. Oil and Gas Division, ND Industrial Commission. E-mail communication. June 16, 2010.

is being produced from the saltwater-saturated zone. Although variable, depending on the amount of produced saltwater, the quantity of water used in an oil well for saltwater dilution is typically on the order of one gallon per minute (526,000 gallons, or 1.6 acre-feet per year). Freshwater for brine dilution is needed on about 10% of producing wells in North Dakota.[39] Oil wells in the Bakken Formation can operate for years or tens of years (we will assume an average of 35 to 40 years).[40] The water quality required for brine dilution can vary, and need be only sufficiently low in dissolved solids to prevent precipitation and scaling as the brine cools. Generally, the fresher the water, the less needed to dilute the brine.

### Waterflooding for Enhanced Recovery

A secondary recovery technique called *waterflooding* is used to maintain fluid pressure in oil-bearing zones. In a waterflood, an oil field is operated as a unit, with some of the oil wells in the unit being converted to water injection wells. The injected water increases the formation's fluid pressure, causing oil to move to the remaining oil wells. Waterflood operations typically require some tens or hundreds of gallons of water per minute and may last for years. Because of the large quantity of water used in waterflooding, the source of water for pressure maintenance operations is restricted to the Dakota aquifer or underlying zones, that are characterized by high dissolved solids concentrations, thus rendering the water unfit for human and livestock consumption. Water used for waterflooding is separated from the oil and can be reused.

### Total Projected Freshwater Needs for Oil-Field Development

High dissolved solids Dakota aquifer water and process-recovery water are used for drilling fluid below the casing depth, and for enhanced oil recovery. High dissolved solids water is plentiful, and does not compete with other beneficial uses. Dakota aquifer water is further described in the section: *POTENTIAL USE OF GROUND WATER FOR THE ENERGY INDUSTRY IN NORTH DAKOTA / Bedrock Aquifers / Dakota Aquifer (*p. 116).

Figure 7 shows a projected 15-year estimate of freshwater use for oil-field production in western North Dakota. All estimates include a baseline of 720 acre-feet for operation (brine dilution) water in 10% of about 4,606 existing operational wells at an annual rate of 526,000 gallons (1.6 acre-feet) per well. For each year, operation water is added at a rate of 10% of new wells, at projected drilling rates of 1,500 wells per year, and 1,800 wells per year. For each additional well, 1 acre-foot of water is assumed for drilling fluid and cement grout for the cased interval. Frac water uses a conservative average of about 2 million gallons (6 acre-feet) per well, based on projected averages of 1.75 million gallons per well from the North Dakota Oil and Gas Division. The results for 2 million gallons of frac water per well indicate initial freshwater needs of 11,000 to 13,000 acre-feet per year, increasing at rates of 242 to 290 acre-feet per year for 1,500

---

[39] Op Cit. Helms.

[40] Op Cit. Helms.

and 1,800 well per year scenarios to about 14,000 to 17,000 acre-feet per year at the end of 15 years, and more beyond that. For 4 million gallons of frac water per well, results indicate initial freshwater needs of 20,000 to 24,000 acre-feet per year, increasing at rates of 242 to 290 acre-feet per year for 1,500 and 1,800 well per year scenarios to about 23,000 to 28,000 acre-feet per year at the end of 15 years, and more beyond that.

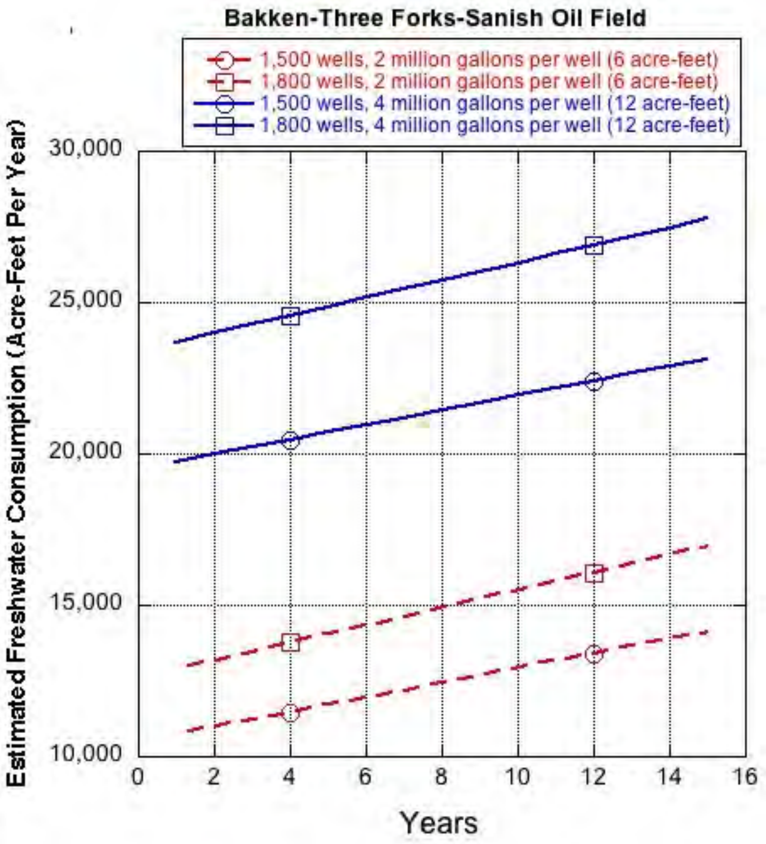


Figure 7. Estimated annual freshwater consumption for petroleum production in western North Dakota, beginning 2010.

## Water Sources for Oil-Field Development

Potential water sources for different phases of petroleum production in western North Dakota include, in lower to upper stratigraphic order: (1) the Dakota Group; (2) the Fox Hills Group (FH);, (3) the Hell Creek Group(HC): (4) Tertiary deposits; (5) and quaternary deposits including the Coleharbor Group (Pleistocene) and modern surface waters, particularly the Missouri River and Lake Sakakawea. Of these the Dakota aquifer is deep (2,000 to 6,000 feet below land surface, depending on location) and characterized by poor quality water. Dakota water and production water are commonly used for drilling fluid below the casing depth, and for water flooding. Because they are poor-quality waters their use should not impair other beneficial uses.

Freshwater for drilling and grouting to the casing depth, for fracing and for operation has usually been drawn from the Fox Hills and Lower Hell Creek aquifers, or from overlying Tertiary deposits, including glacial materials of the Coleharbor Group. Because the Fox Hills-Hell Creek (FH-HC) aquifer system is the only large-scale dependable local water supply for much of the western part of the state, its conservation for long-term use is an important priority. Issues concerning the FH-HC aquifer system and its use for energy development are discussed in the section on Bedrock Aquifers. Large-scale use of the FH-HC aquifer system for industrial use is discouraged.

Shallow aquifers in western North Dakota have been discussed by Wanek[41] as consisting of Tertiary deposits of lenticular coarse materials of later age overlying the FH-HC aquifer system, and of Quaternary glacial and post-glacial deposits, referred to as "Pleistocene" deposits, or as the Coleharbor Group. The Tertiary deposits are often low yielding, and sufficiently coarse lenses are not always present at any given location. They have frequently proven to be sufficient for production-water (brine dilution) use. The general policy has been to allow use of FH-HC brine dilution water only when shallower depths have not been adequate. Tertiary deposits have been adequate, in some cases, for operation water. They will not, however, supply a dependable large-scale supply of freshwater in quantities required for drilling and fracing.

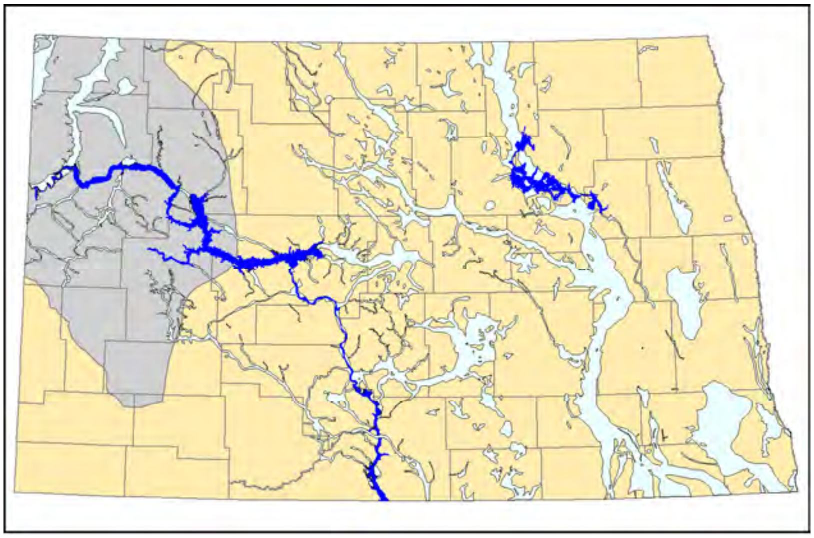


Figure 8. General map of glacial aquifers (light blue) within the Bakken play in North Dakota (from Robert Shaver[42]).

Pleistocene deposits are sparse in western North Dakota, and are often small enough that long-term dependable water supplies cannot be obtained without harm to other water users. A general map of glacial aquifers in the area of the Bakken play is provided on Figure 8. More detailed discussions of glacial aquifers within the Bakken

---

[41] Wanek, Alan. 2007. Recommended Decision. Zenergy Water Permit Applications. Water Permit File No. 5758.

[42] Shaver, Robert, Director Water Appropriations Division, SWC. Dec. 10, 2009. PowerPoint presentation. Ramkota Inn.

play, their water quality and water availability are provided in the section on shallow glaciofluvial aquifers (Study Areas 1, 2, 6 and 7). Aside from their lack of abundance and limits imposed by prior appropriators, many of the glacial aquifers are valley deposits which are narrow and have limited areal extent. These aquifers do not receive large amounts of recharge and storage is also limited. As a result, large-scale ground-water withdrawals are not sustainable. In addition, large-scale pumping from narrow, deep aquifers can draw water as underflow from flanking bedrock units characterized by large dissolved solids concentrations (Figure 9). This results in degradation of the aquifer water quality. Both quantitative and qualitative limitations imposed by boundaries in valley aquifers can place severe limitations on industrial use capabilities, and on other water users.

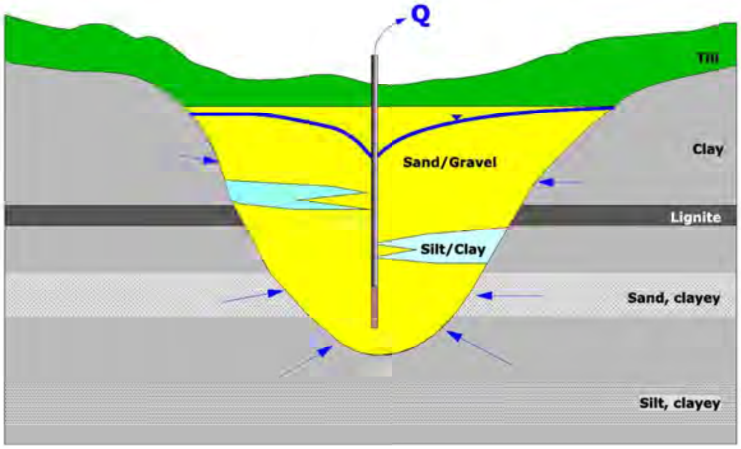


Figure 9. Boundary-imposed limitations on well extraction and saline water encroachment (blue arrows). From Robert Shaver.[43]

Since the 1980s, the SWC has understood that ground-water sources for oil-field development are limited, and has adopted the policy of authorizing use of FH-HC water only when other ground-water sources are inadequate. The rationale for this policy was presented in a memorandum by Milton Lindvig[44] and is discussed in detail in the section: *POTENTIAL USE OF GROUND WATER FOR THE ENERGY INDUSTRY IN NORTH DAKOTA / Bedrock Aquifers / Fox Hills - Hell Creek Aquifer / Industrial Use of Fox Hills - Hell Creek Water* (p. 124). However, the limited use policy was adopted under conditions of much more limited development than that envisioned for the early 21st century. At the time of the 1984 Lindvig memorandum, only 321.4 acre-feet of water had been appropriated from Tertiary aquifers, of which 203 acre-feet were permitted from the lower FH-HC aquifer system. As of December, 2009 there were 28 water

---

[43] Ibid

[44] Lindvig, Milton. 1984.

depots, for a total of 2,340 acre-feet per year serving the oil industry in western North Dakota. Thirty more water permits for water depots are pending, for a total of 5,534 additional acre-feet per year. Approved and pending water depot locations (as of June 7, 10) are shown on Figure 10. A list of active water depots is provided in Appendix C.

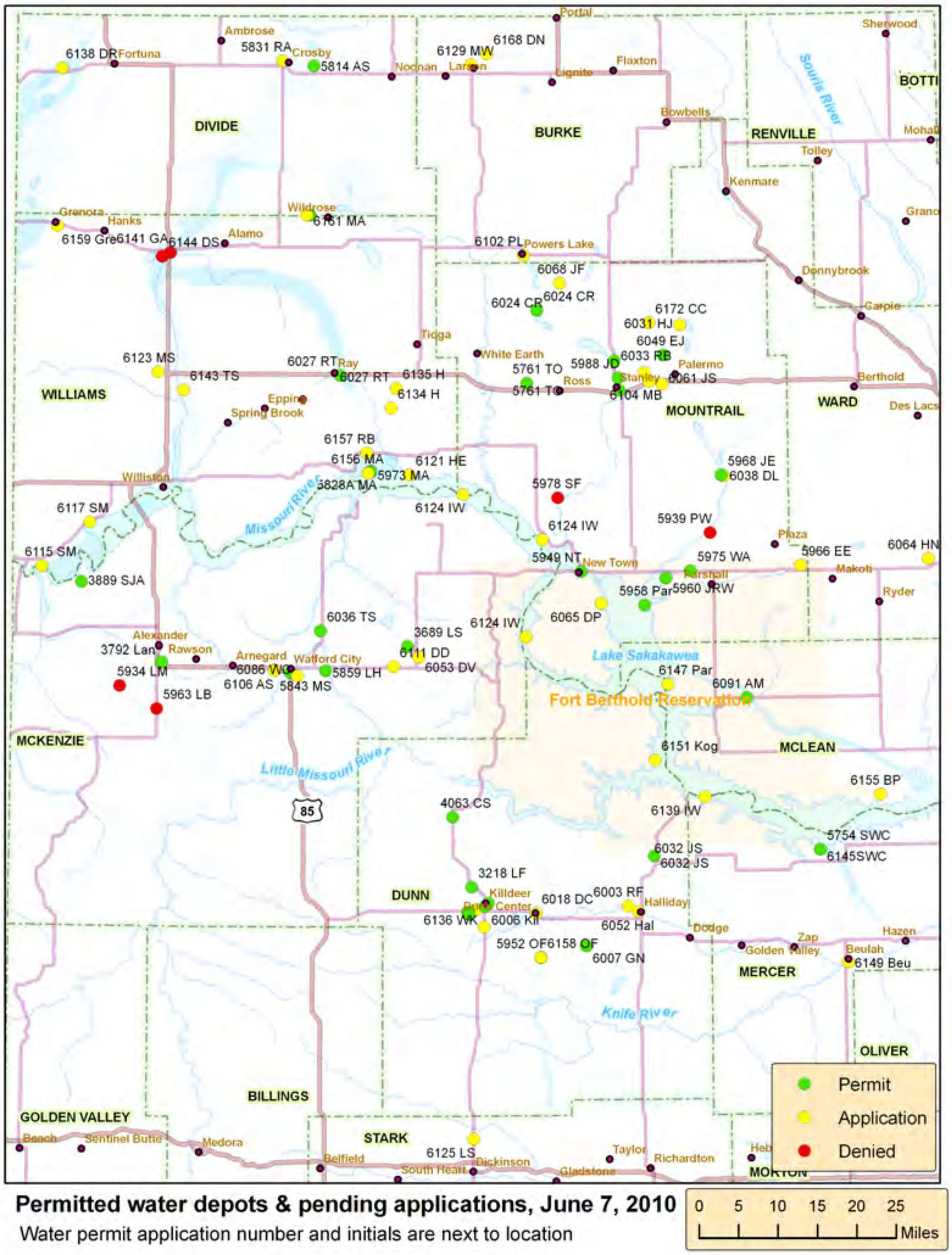


Figure 10. Locations of approved and pending water permits for water depots in western North Dakota as of June 7, 2010.[45]

---

[45] Wanek, Alan. June 7, 2010. E-mail communication.

Of the new applications, some may be granted water permits and others not. But it seems clear that projected withdrawals of 20,000 to 23,000 acre-feet per year, as currently envisioned, would cause problems with short-term mining of pressure head in the FH-HC aquifer system, and long-term problems affecting the water supplies of prior appropriators and water quality of both bedrock and surficial aquifers. **It is concluded that the only plentiful and dependable supply of water for the oil industry in western North Dakota, at projected rates of extraction, is the Missouri River system.**

## Water Supplies for North Dakota Oil Field Development (2010-2025)

On December 10, 2009, a public meeting was hosted by Governor Hoeven and the North Dakota Petroleum Council, concerning water supplies for oil-field development in western North Dakota.[46] The panel included topical discussions on water requirements for oil-field development, water quality for fracturing, potential water supplies from treated Dakota water, water accessibility, and opportunities presented by some current water sellers in western North Dakota. The agenda is appended (Appendix D). The purpose of the meeting was to achieve direction and consensus for an approach to providing the water needed for expanded oil-field development during the coming decade. Several key points were brought forward:

- Robert Shaver, director of the Water Appropriations Division of the North Dakota State Water Commission, stated that the Missouri River system, including Lake Sakakawea, is the only viable source for large-scale freshwater supplies.
- Lynn Helms, Director of the Oil and Gas Division of the Industrial Commission met with the 12 most active Bakken/Three Forks operators concerning drilling plans for post-2009 development. Helms presented a template for a system of centralized water depots to serve six oil-development areas using water from Lake Sakakawea.[47] The proposed development areas are shown on Figure 11.
- The Southwest Water Authority, the McKenzie County Water Resource District, and RT Water Users discussed their capabilities as potential water suppliers.

  While observers must be careful in interpreting the "consensus" of a meeting, it seemed that both government and industry representatives had decided to move in the direction of developing Lake Sakakawea as a primary water source. Several directions were discussed, including expanded use of existing water sellers, and the employment of a privately-funded water service industry.

At the time of writing the situation is dynamic and clear directions have not yet materialized. One option being explored is use of Southwest Pipeline Project (SWPP) water. In a meeting conducted at the State Water Commission on Jan. 8, 10 it was

---

[46] Western North Dakota Water Resource Opportunities. Dec. 10, 2009. Ramkota Hotel, Bismarck, ND. See Appendix D.

[47] Op Cit. Helms. Dec. 10, 2009.

determined that it may be feasible to supply raw water pumped from Lake Sakakawea at the location of the Dodge pumping plant (Figure 12). While water contracts for the SWPP are fully committed, managers have estimated that there is usually unused water, if off peak consumption and full pumping capabilities are considered. Two, 2-million gallon reservoirs at Zap would usually be sufficient to allow for consistent access at Dodge. It is estimated that oil industry needs could be supplied at a rate of 1,000 gpm for 11 of 12 months in most years.

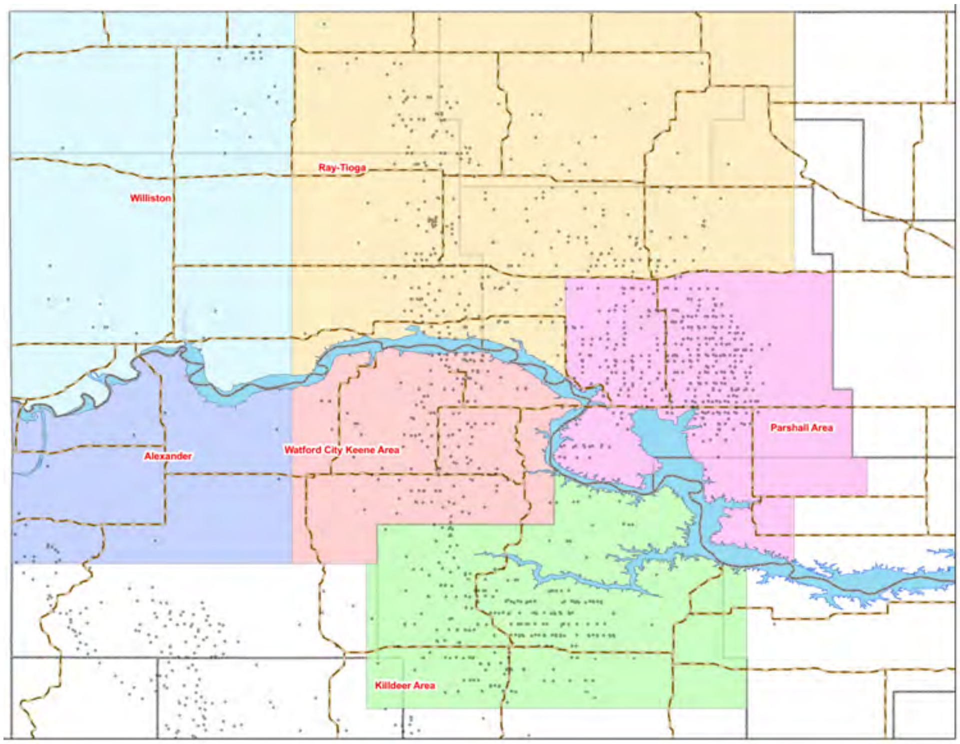


Figure 11. Water-depot development areas (colored map units) proposed by Helms.[48] Grey dots are Bakken oil-well sites. (The map was provided by Dave Hvinden of the North Dakota Industrial Commission, Oil and Gas Division.)

There may be some limitations during summer months of dry years when demand is highest. Water supplies of up to 1,300 acre-feet per year may be accessible at Dodge, based on 11 months of pumping 80% of the time. Modifications required to supply water to the oil and gas industry at Dodge are relatively minor and could likely be accomplished within a couple of weeks. Water could be available as early as the summer of 2010, if contracted by users. As of this writing (2/15/2010) discussions between SWPP project managers, landowners and prospective water users are in progress. Completion of the required works is expected during the summer of 2010.[49]

---

[48] Op Cit. Helms. Dec. 10, 2009.

[49] Freije, Tim. SWPP Project Manager. Feb. 9, 2009. Phone conversation with William Schuh.

Applicants for water permits to supply water depots from Lake Sakakawea are summarized on Table 6. All of the locations are shown on Figure 10. Of the six recent applicants, the city of Parshall has been approved to supply water at an annual rate of up to 370 acre-feet per year. Steve Mortenson has been supplying water under two temporary water permits (#ND2009-4010 and #ND2009-4011) for 500 acre-feet and 200 acre-feet, respectively. Permitted pumping rates for Mortenson are 1,000 gpm for each permit. The temporary permits expire in October 2010. Mortenson has also applied for two conditional water permits, which are under consideration (Table 6). The largest current applicant is the International Western Company, which has applied for 28,900 acre-feet per year, to be supplied at five different points of diversion. Penningtons have applied to service up to four different points of diversion. Enquiries have been made by other potential suppliers, but none have applied for water permits with the SWC. The SWPP and Parshall options have the advantage of established points of diversion, which means that regulatory processes and time limitations imposed by the Corps of Engineers permitting process can be avoided, and water supplies can be obtained within a relatively short time (45 to 90 days). Other potential sources must obtain authorization for access to the Missouri River or to Lake Sakakawea. This will require permitting through the Corps of Engineers (Lake Sakakawea or the Oahe Reservoir), and a sovereign lands permit (through the Water Commission) for the free-flowing Missouri River. Access through tribal lands will also require permission through the appropriate tribal authorities. Additional potential water suppliers for oil-field use are discussed in the section titled: *POTENTIAL SURFACE-WATER SOURCES FOR USE BY THE ENERGY INDUSTRY IN NORTH DAKOTA* (p. 78).

Table 6. Water permits and applications for water supply depots with points of diversion on Lake Sakakawea as of May 2010.

| Permit_ Number | POD | Name | City | State | Priority_Date | Req_ AcFt | Req_ Rate gpm | App_ AcFt | App_ Rate |
|---|---|---|---|---|---|---|---|---|---|
| 5958A | 15109110B | PARSHALL, CITY OF | PARSHALL | ND | 10/23/07 | 370 | 375 | 370 | 375 |
| 6065 | 15109203C | PENNINGTON, DONALD, STEVEN & JACK | NEWTOWN | ND | 12/5/08 | 800 | 1,000 | - | - |
| 6065 | 15109203D | PENNINGTON, DONALD, STEVEN & JACK | NEWTOWN | ND | 12/5/08 | | | | |
| 6065 | 15109210A | PENNINGTON, DONALD, STEVEN & JACK | NEWTOWN | ND | 12/5/08 | | | | |
| 6065 | 15109210B | PENNINGTON, DONALD, STEVEN & JACK | NEWTOWN | ND | 12/5/08 | | | | |
| 6121 | 15409613D | HEXOM EARTH CONSTRUCTION, INC. | WILLISTON | ND | 11/16/09 | 2,000 | 1,400 | - | - |
| 6124 | 15109331B | INTERNATIONAL WESTERN COMPANY | FORT WORTH | TX | 12/15/09 | 18,000 | 12,600 | - | - |
| 6124 | 15109436A | INTERNATIONAL WESTERN COMPANY | FORT WORTH | TX | 12/15/09 | | | | |
| 6124 | 15309326D | INTERNATIONAL WESTERN COMPANY | FORT WORTH | TX | 12/15/09 | | | | |
| 6124 | 15309335A | INTERNATIONAL WESTERN COMPANY | FORT WORTH | TX | 12/15/09 | | | | |
| 6124 | 15409431A | INTERNATIONAL WESTERN COMPANY | FORT WORTH | TX | 12/15/09 | | | | |
| 6139 | 14709009C | INTERNATIONAL WESTERN COMPANY | FORT WORTH | TX | 2/24/10 | 6,000 | 4,200 | - | - |
| NA | 15409724B | INTERNATIONAL WESTERN COMPANY | FORT WORTH | TX | 5/26/10 | 4,900 | 3,000 | | |
| 6115 | 15210414B | MORTENSON, STEVE M. | WILLISTON | ND | 1/7/10 | 5,000 | 3,600 | - | - |
| 6117 | 15310217CD | MORTENSON, STEVE M. | WILLISTON | ND | 1/7/10 | 370 | 375 | - | - |
| 6155 | 14708607D | PEASE, BERNARD | LAMBERT | MT | 4/20/10 | 1,000 | 2.000 | - | - |

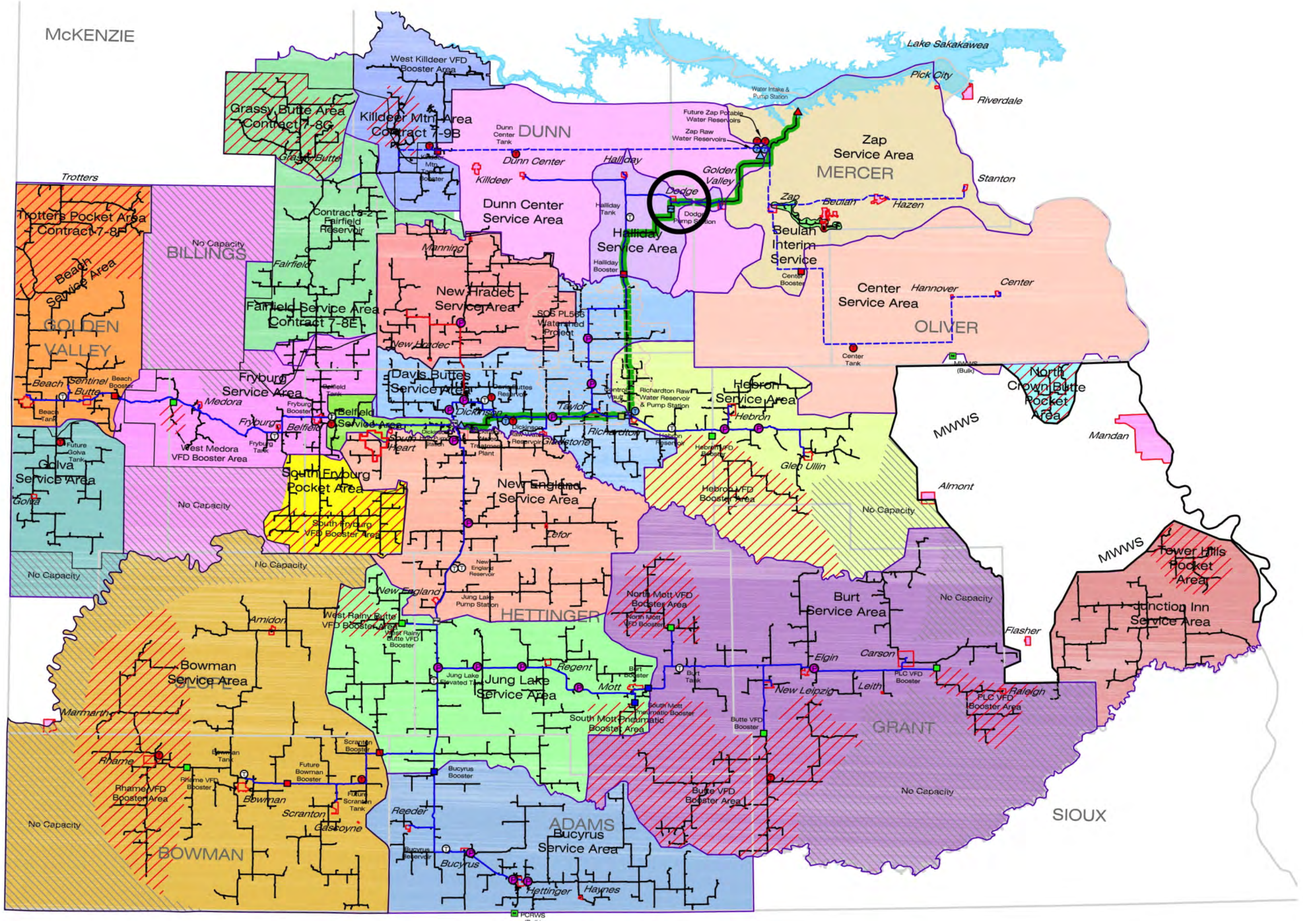


Figure 12. Map of the Southwest Pipeline Project service plan (Provided by Tim Freije, SWC). The circle on the town of Dodge (added by the author) indicates a possible location for a water depot to access off-peak SWPP water for oil-field use.

## A Preliminary Proposal for Use of Devils Lake for the Bakken-Three Forks-Sanish Play

In the introduction to the section, *POTENTIAL SURFACE-WATER SOURCES FOR USE BY THE ENERGY INDUSTRY IN NORTH DAKOTA (*p.78)*,* we state that water sources from closed basins, like many of the lakes in the Prairie Pothole Region, including Devils Lake, should not be considered as reliable long-term water supplies due to large variations in available water in response to climate variation. Because of large water supplies needed in the oil fields, limited ground-water supplies, and uncertainties of access to Lake Sakakawea (see the section: *Potential Water Supplies From The Missouri River System*) some have proposed piping water from Devils Lake for use in oil well development. The water volume in Devils Lake at June 2010 elevations (near 1,472 feet amsl) is about 3.2 million acre-feet.[50] If one were to consider water volume above a certain base elevation (say arbitrarily 1,430 feet amsl) available for beneficial use, almost 2.2 million acre-feet would be available in the short term. There are, however, several important considerations with the export of Devils Lake water to western North Dakota. If the the Bakken-Three Forks-Sanish play is projected for about 20 years, using about 20,000 acre-feet of freshwater per year, total use would be about 400,000 acre-feet. If ALL of the oil-field water were drawn exclusively from Devils Lake, it would correspond to a drop in lake surface elevation of only 2.5 feet from the 1,452 feet elevation. The water supply would not likely be limiting. However, important considerations would include the following:

- Pumping energy costs would be very large due to a pumping lift of about 1,000 feet from the surface of Devils Lake to the area of Mountrail and Burke Counties, which have a general land surface elevation of about 2,500 feet amsl.

- Pumping and construction costs would be affected by a distance of about 130 miles.

- Suitability of water quality and potential treatment will need to be considered. For example, high-water sulfate concentrations in Devils Lake from sampling locations at Round Lake and West Bay are in the range of about 550 mg/L to 600 mg/L.

- Cross-basin transport (Red River basin to Missouri River basin) may be objectionable to some and may pose some legal challenges.

- Other supply efforts, including the Southwest Pipeline Project, the McKenzie County Rural Water District pipeline project, potential expansion of Williston's supply capabilities, and independent water supply enterprises, such as

---

[50] U.S. Geological Survey. Devils Lake – Stump Lake elevation and area capacity table. Available at: http://nd.water.usgs.gov/devilslake/pdf/elevation-area-volume.pdf

International Western, which has applied for 28,900 acre-feet from Lake Sakakawea, could, if successful, undercut the demand for piped Devils Lake water before its completion.

- Potential pipeline completion times would need to be considered in relation to oil-field demands.
- Short-term and long-term uncertainties of the petroleum price and market could affect oil-field demand for water, and affect investment returns on the pipeline.
- Marginal elevation changes for Devils Lake would be small, amounting to a only a fraction of a foot per year at maximum rates of use.
- The use-life for the pipeline would be limited by natural variations in Devils Lake elevation, remembering that prior to 1993 the greatest concerns were for sustaining lake water levels.

## Summary of Water Use for Refining Petroleum in North Dakota

U.S. Department of Energy sources have estimated water use for petroleum refining at about 1.5 gal/gal (Pate and others 2007; U.S. Department of Energy 2006). There is currently only one oil refinery in North Dakota, the Tesoro Refinery at Mandan. In addition, there is a proposed expansion of the Tesoro Refinery to produce low-sulfur diesel fuel from coal; and there are three proposed refineries for future construction. These include: Northwest Refining at Williston, planned for 100,000 bpd, Dakota Oil Processing at Trenton, planned for 20,000 bpd, and the Three Affiliated Tribes Refinery at Makoti planned for 15,000 bpd. None of the planned facilities are currently in construction.

### Mandan Refinery (Tesoro Corp.)

The Mandan Refinery is owned and operated by the Tesoro corporation, with headquarters in San Antonio, Texas, and has been in operation since 1954 under various owners. The Tesoro refinery processes about 60,000 barrels of crude oil per day, and uses about 1.5 million gallons per day of water pumped from the Missouri River. About a half million gallons of water per day are treated and returned to the stream. About a million gallons of water are consumed, mainly through evaporation. The approximate distribution of use is:

(1) Boiler feed water (10-15%)
(2) Desalting crude oil (30-40%)
(3) Cooling water (approx. 35%).

#### *Water Quality Requirements*

Water is pumped from the Missouri River to a wet sump through three intake lines. All of the water is flocculated, clarified and softened from about 240 pm to 100-120 ppm hardness in a cold lime softener. Specifications for raw water include:

| | |
|---|---|
| Conductivity | <3,300 ppm |
| Alkalinity | 60-200 ppm |
| Phosphate | 4-8 ppm |
| Chlorine | 0.25 ppm |
| Microbial | 0 - 1 million organisms per ml for both cooling towers |

The raw water product is used for three cooling towers, fire-control water, oil movement, and the wet-gas scrubber.

Raw water is further treated to avoid mineral and biological scale formation in boiler feed water used for power generation and steam generation. Raw water is passed through a sand "rapid filter" to trap turbidity and suspended solids, followed by micron (0.5-1 micron) filtration, and then reverse osmosis (RO) to reduce the mineral load by approximately 99%. The water is treated with sulfuric acid to lower the pH, antiscalant to impede scale formation, and sodium bisulfite to inhibit microbial growth. The water is then degasified to remove carbon dioxide and oxygen (which cause corrosion), and softened.

RO-treated water is also used for “desalting.” Petroleum and treated water form an emulsion in which salts precipitate. Salt removal is necessary to prevent formation of hydrochloric acid, which would corrode the process piping.

Cooling tower water may be relatively high in dissolved solids as long as it is soft. However, the cost of filtering water for use in boilers can be high, and the refinery likely would not be interested in water having much higher than 1,000 ppm.

### *Water Use by the Mandan Tesoro Refinery*

The Tesoro refinery is permitted to divert up to 9,521 acre-feet per year, at an authorized withdrawal rate of 10,417 gpm from the Missouri River under Water Permit # 0483, with a priority date of January 17, 1953. Since Tesoro replaced British Petroleum as the owner and operator of the refinery in 2003, the median water withdrawal (through 2008) has been 2,100 acre-feet per year, and median water consumption has been 1,275 acre-feet per year. Consumptive water use has ranged narrowly from 0.46 to 0.53 gal/gal liquid product, with a median of 0.48 gal/gal. Total water withdrawal has ranged narrowly from 0.78 to 0.85 gal/gal liquid product, with a median of 0.8 gal/gal.

## Projected Future Water Use for Petroleum Refining in North Dakota

Current water use for refining at Tesoro has averaged about 1,300 acre-feet per year over the last nine years (2000 through 2008) consumed in refining petroleum. If an additional 137,000 barrels were to be refined, at a range of 1 to 2 gallons of water per gallon of refined product, additional water use of 6,900 to 13,800 acre-feet of water would be required – for a total of 8,200 to 15,100 acre-feet per year.

# Water Use for Coal-Based Syngas and Liquid Fuel Synthesis

The extraction of synthesis gas (syngas) from coal or methane can be used to produce several different energy fuels, from hydrogen to natural gas and diesel fuel. Syngas is a mixture of hydrogen gas and carbon monoxide produced by oxidizing coal or natural gas in the presence of steam. To enhance hydrogen production the carbon monoxide is usually converted to carbon dioxide using additional steam treatment. The hydrogen of the product can be used directly as a power source. Alternately, the syngas product can be further processed to form alkanes of various length using the Fischer-Tropsch process:

$$(2n+1)H_2 + nCO \rightarrow C_nH_{(2n+2)} + nH_2O \qquad (1)$$

If the number n is 1, the product is methane – larger n values produce larger molecular liquid fuels, such as diesel fuel. There are few Fischer-Tropsch production plants in the world at the present time.

Syngas production, or planned production in North Dakota, uses lignite exclusively as a carbon and hydrogen feedstock. The Dakota Gasification plant at Beulah uses lignite to produce methane. The proposed synfuels plant at South Heart plans to produce hydrogen gas to directly fuel thermoelectric power generation. A joint venture between Tesoro and an area utility has been proposed to use coal from the Falkirk mine, with steam from the Tesoro refinery, to produce aircraft fuel or diesel fuel using the Fischer-Tropsch process. The later process should provide an additional water conservation measure for both the Tesoro refinery and the proposed synfuel plant. American Lignite Energy is planning another coal-to-liquid facility for future construction.

The U.S. Department of Energy (USDOE 2006) has estimated unit water use at 4.6 to 6.9 gal/gal of liquid Fischer-Tropsch product, depending on the coal used. Nowakowski (2007) has presented a range of 1.5 gal/gal for a zero-discharge air-cooled plant, to 5 to 7 gal/gal for a plant with water cooling and less recycled use of waste heat. King and Webber (2008) have estimated that water use for production of hydrogen gas from methane is about 4.5 gal/kg hydrogen produced. The energy in one kg of hydrogen is about the same as in a gallon of gasoline.

## Dakota Gasification Plant (Beulah)

The Great Plains Synfuels Plant, located at Beulah, North Dakota, is owned and operated by Dakota Gasification Company, a subsidiary of Basin Electric Power Cooperative, with home offices in Bismarck, ND. The Synfuels Plant is designed to produce about 175 million standard cubic feet of natural gas per day (MMSCFD). Lignite coal is reacted with steam and oxygen to produce syngas and other byproducts. The syngas is then reacted over a catalyst to produce methane as the main plant product.

Dakota Gasification is authorized under Perfected Water Permit # 1901A to use up to 11,410 acre-feet of water per year from Lake Sakakawea, at a withdrawal rate of up to 9,000 gpm. Water is pumped from Lake Sakakawea using an intake shared with the Antelope Valley Station power plant (and also shared with the Southwest Pipeline Project). Since 1985, water use has varied from about 5,300 to 8,500 acre-feet per year, with a pumping rate that is generally between 4,000 and 5,000 gpm. The median water use is 7,429 acre-feet per year.

All water (except for fire response water) is treated using filtration, water softening, and anti-scalants. Half of the water is additionally treated with reverse osmosis and ion exchange resins for use in the high pressure steam system. Most of the water is used to generate steam. The steam is then used: (1) to power compressors, pumps and other equipment on one of two parallel process paths (trains) – the other is powered by electricity; and (2) as a feedstock and energy source for the coal gasification process. The inherent moisture in the coal, along with the steam not consumed in the gasification process is condensed, and various organic byproducts are separated from the condensate. The residual water, which remains relatively high in dissolved organic residues, is then used for cooling water makeup in an open-loop (cooling tower) system. Cooling water is reused. Replacement water for evaporation losses and blowdown are usually adequately supplied by the recovered process water after gasification. In addition to process water, a small amount of water is used for sanitation and human consumption.

Unit water consumption over an eight-year sample (2000 through 2008) had both median and mean values of 0.049 gallons per standard (60°F, 14.7 PSIA) cubic foot (SCF) of methane gas, with very little variation (range 0.045 to 0.053 gal/SCF). Efficiencies in water use are enhanced by the production of additional products, including anhydrous ammonia, ammonium sulfate, and various organic compounds.

## South Heart Energy Facility (Proposed)

The proposed South Heart Energy Facility was initiated by Great Northern Power Development Corporation (GNPDC), headquartered at Houston, Texas, and Allied Syngas Corporation, headquartered at Wayne, Pennsylvania.[51] The project was then transitioned to the South Heart Energy Development Corporation. The purpose of the planned facility is to use 1.8 million tons of coal per year as feedstock to produce hydrogen fuel for an Integrated Gasification Combined Cycle (IGCC) power plant.

The proposed facility will operate in three stages:

(1) Coal beneficiation, the purpose of which is to dehydrate coal from about 40% water content to about 15%, and form the coal into briquettes, which is the feedstock for the gasifiers that produce syngas. The beneficiation technology used will be that of GTLE Inc. The GTLE technology is best fitted to GNPDC needs because it uses low-pressure steam rather than high-pressure steam required by other technologies, thereby reducing required energy input.

---

[51] Industrial Commission of North Dakota. Nov. 20, 2007. Great Northern Power Development and Industrial Commission announce coal gasification project at South Heart. Press Release.

(2) The coal briquettes will be gasified to produce syngas, which is a combination of CO + $H_2$. The CO will then be further treated with low-pressure steam to convert the CO to $CO_2$ and create additional $H_2$. The $CO_2$ will be removed yielding a high-hydrogen stream.

(3) The $CO_2$ byproduct will be sold for use in production enhancement in the Williston Basin oil fields. $H_2$ will be used as fuel for an IGCC power plant. The $H_2$ will be combusted in a gas turbine that will drive a generator. The heat from $H_2$ combustion will then be used to produce high-pressure steam in boilers to drive a steam turbine that will also drive a generator. The combined turbines will produce about 285 MW, of which about 118 MW are parasitic, leaving about 167 MW net power produced for sale. The original plan was to use 4.8 million tons of coal per year and use the syngas to produce methane, but this was modified to direct combustion of hydrogen gas.

### *Project Status*

The zoning change (from Agricultural to Industrial) required for the project was approved in December 2008, but was subsequently overturned. The zoning change was successfully challenged in court on the basis that the county failed to follow prescribed procedures. The court remanded the case back to the county to resolve. The county has addressed the procedural issues and, in October 2009 reconsidered an application for re-zoning for a separate beneficiation demonstration facility operated by GTLE (not a part of the SHED project). A new application for the re-zoning necessary to allow the SHED project to proceed is expected to follow shortly thereafter. Current plans are for the SHED project to be in operation by 2014-15.

### *Water Use at the Proposed South Heart Facility*

Water requirements for beneficiation are negligible. Water requirements for the IGCC facility will include: boiler water, cooling water, other process water needs, and water for human use and sanitation. For the syngas process, 250 gpm, 500 gpm and 750 gpm water-supply options were examined.

The planned use is an average of 650 gpm, raw water supplied by the Southwest Pipeline Project (SWPP), via an interconnect just upstream of the Dickinson Water Treatment Plant. Differential needs will be regulated with an onsite reservoir. Raw water will be treated at the facility as needed. Boiler water will be RO treated; cooling water as needed. Cost of water from the SWPP will include the capital cost of the upstream-system improvements necessary to get the additional volume to the Dickinson interconnect point, the pipeline between the interconnect point in Dickinson to the project site and the prescribed fee for raw water set by the Southwest Water Authority (SWA).

Some of the steam on the low-pressure end of the boiler system (after use as high-pressure steam in the turbine) will be used for the beneficiation of coal, which will enhance overall water-use efficiency. Power plant cooling will be a combined air- and water-cooled system. Water supplementation will be needed mainly in the summer. The water-cooling system will be a closed-loop system. One option being considered is a possible zero net use of water enabled by the capture of water from the beneficiation of coal – a net of about 25% water recovery (40%-15% water content). Economic and environmental (more energy input to condense water from coal) impacts of that option are being evaluated. There would be an imbalance between summer (deficit) and winter (excess) water supplies with this process.

Another option considered was use of mine waters. GNPD has filed for a water permit for 724 acre-feet of water per year to dewater the coal vein. Water will be used for dust suppression, and otherwise will be evaporated from retention ponds. South Heart Energy Development has considered using water from dewatering of the coal as a part of their water supply, but a well field would be required which could adversely affect local wells. Without a well field, harvesting water from the mine would require constant adjustment of the pipeline and supplies could be uneven, depending on local characteristics of the coal and its water content.

Another optional water supply currently being considered is the use of treated wastewater from the Dickinson Wastewater Treatment Plant. The amount wastewater available would be insufficient to meet all demands, but could be supplemental. GNPD is considering putting two pipelines in the same trench, for both SWPP and Dickinson wastewater.

### American Lignite Energy Coal Liquefaction (Proposed)

A coal liquefaction plant, to be constructed at an unnamed site in North Dakota, has been proposed by American Lignite Energy (LLC), which is jointly owned by North American Coal (of Dallas, TX) and Headwaters Inc. (South Jordan, UT). The goal of the proposed coal-to-liquid (CTL) facility is to produce 38,000 bpd of liquid fuel, using about 11.5 million tons of North Dakota lignite annually. According to the U.S. Chamber of Commerce[52], as of January 2009 further plan development was put on hold pending clarification of national energy policy.

The three major uses of water in a CTL facility are: process water, boiler feed water, and cooling water. An additional small use component would be facility water (drinking and sanitation water). In general, the planned coal liquefaction plant will use lignite to produce syngas ($H_2$ + CO), which will then be used to produce either diesel fuel using the Fischer-Tropsch process, or gasoline using a patented MTG (methane to gas) process. Steam will be used in the production of syngas and in adjustment of the $H_2$/CO ratio prior to production of methanol, which will then be converted to gasoline. The methanol-to-gasoline step is exothermic, and preliminary plans are to use the heat released to produce steam to run steam turbines. In addition, a portion of the syngas will be used to fuel gas turbines in an integrated gasification combined cycle (IGCC) power plant.

---

[52] U.S. Chamber of Commerce. http://pnp.uschamber.com/2009/03/american-lignite-energy-llc-coal-to-liquids-project.html

Because plans for the proposed CTL plant are incomplete, evaluation of unit water use and total potential water use is somewhat speculative. A major factor will be the design of the cooling system for the electrical generation component.

# Summary of Water Requirements for Coal-fired Thermoelectric Power Generation in North Dakota

Thermoelectric power accounts for about 39% of all surface-water withdrawals, about 3% of all water consumption, and about 53% of all water returns to surface waters in the United States (Torcellini 2003). Saline water is used for about 30% of thermoelectric power generation, while about 70% of the water used in fossil-fuel based thermoelectric power generation is freshwater (Hoffman and others 2002).

Aside from water used in the mining and beneficiation of coal for power generation, water is used for flue gas desulfurization (FGD), cooling, boiler water, and facility water (bathrooms, drinking water, etc.). Of these, most of the water consumption is used for cooling. In evaluating and comparing water use, an important distinction cited by most sources is between *withdrawn* water and *consumed* water (Hoffman and others 2002, Torcellini 2003, Feeley and others 2006, Pate and others 2007). *Withdrawn* water is returned to the source stream after it is used and has little effect on the source waters. *Consumed* water is not returned to the source stream after it is used.

The main uses for water in thermoelectric power generation are for *boiler feedwater, FGD* and *cooling water*. *Boiler feedwater*, which is heated to steam and drives the turbines, recirculates with negligible consumption. *Boiler feedwater* is treated to a very high level of purity through sedimentation, softening, multiple filtration steps, reverse osmosis (RO), and ultrafiltration, to avoid scaling and corrosion of the components within the steam cycle. *Cooling water* is used to condense the steam as it recirculates after driving the turbines. According to the DOE/NETL (2008, p. 9) the steam condensation "typically occurs in a shell-and-tube heat exchanger known as a condenser. The steam is condensed on the shell side by the flow of cooling water through tube bundles located within the condenser. Cooling water mass flow rates of greater than 50 times the steam mass flow rate are typically necessary depending on the allowable temperature rise of the cooling water - typically 15-25$^{o}$F." The amount and temperature of cooling water limits the temperature of the steam condensate, and strongly affects the efficiency of the turbines. The higher the temperature of the steam condensate, the higher the backpressure on the turbines and the lower the power generation efficiency.

Cooling water systems in electric power generation are of three basic types: (1) *once-through*, (2) *wet-recirculating*, and (3) *dry-recirculating* cooling (Hoffman, Forbes and Feeley 2002, p. 2). A *once-through* system *withdraws* significantly more water, but a *wet-recirculating* system can *consume* ten times more water than a *once-through* system. W*et-recirculating* systems use large cooling towers, or in some cases, ponds and canals, to recycle the cooling water. *Dry-recirculating* systems have low water requirements, but have parasitic power needs and high capital costs (Hoffman, Forbes and Feeley 2002, p. 3). Dry cooling is most efficient in cool and wet climates because recirculating cooling water temperatures are limited to the temperatures of ambient air. High air temperatures therefore indirectly limit the efficiency of the turbines through temperature-induced backpressure (DOE/SANDIA 2006, p. 34). Dry-cooled systems impose a cost penalty ranging from 2 to 16 percent for the cost of energy compared to evaporative closed-loop cooling, depending on the local value of energy not produced when air temperatures are high (DOE/SANDIA 2006, p. 40). An alternative is the use of parallel *dry-recirculating* and *wet-recirculating* systems, with the wet systems used to supplement cooling in warm weather. These have generally been applied only on small power plants (DOE/SANDIA 2006, p. 37).

A comparison of *once-through* and *wet-recirculating* cooling system water use was provided by Feeley and others (2006), and is reproduced on Table 7.

Table 7. Comparison of water withdrawal and consumption for *Once-through* and Wet-recirculating cooling systems. Reproduced from Table 3 of Feeley and others (2006).

| Type of Cooling System | Water Withdrawal gal/kWh | Water Consumption gal/kWh |
|---|---|---|
| *Once-through* | 37.7 | 0.1 |
| *Wet-recirculating* | 1.2 | 1.1 |

Larger consumption for *wet-recirculating* cooling systems results mainly from evaporative losses in the cooling towers, and make-up water to replace water drained during *blowdown*. *Blowdown* consists of water drained and replaced to dilute cooling water that has been concentrated through evaporative loss to prevent the precipitation and buildup of minerals in the cooling towers. A schematic representation of water circulation in a wet-recirculating cooling system is provided on Figure 13.

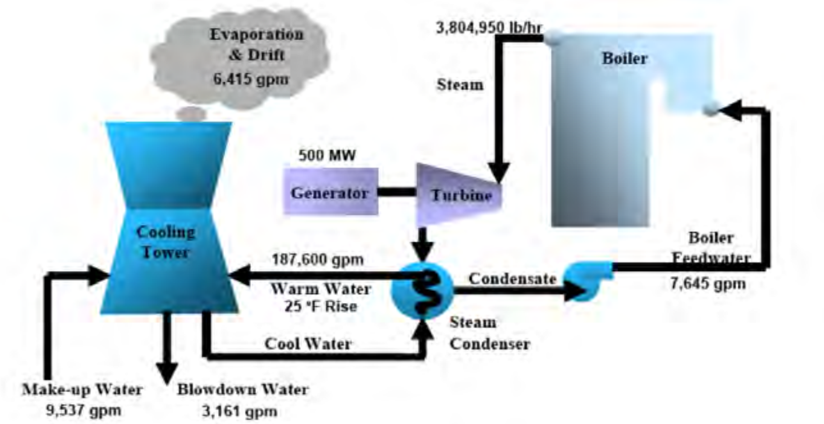


Figure 13. Process flow schematic for a *wet-recirculating* cooling system (from Figure 3 of Feeley and others, 2006).[53]

---

[53] Numbers shown are generic and do not represent any of North Dakota's power plants. For example, *blowdown* for the Coyote Station is only 300 gpm, 1/10 of that represented on the figure.

While consumption of water in *once-through* cooling systems is lower, based on return flows to the source near the point of intake, at least two sources (Feeley and others 2006, and DOE/NETL 2008) have suggested that actual total losses of *once-through* systems may, in some cases, be similar to *closed-circulation systems* when the effects of additional heat on downstream evapotranspiration (ET) are considered. The effect of discharged cooling water on increased temperature in, and evaporation from the receiving water body would be expected to be greatest where changes in water temperature are substantial, and where climate-based cooling does not dominate the evaporative process. Evaporative effects would be mitigated in a northern climate, like North Dakota, where a large water body, like the Missouri River, is frozen for a substantial portion of the year, and where the amount of discharge is small in relation to the receiving water body, therefore minimizing relative temperature changes.[54]

The National Environmental Technology Laboratory (NETL) of the U.S Department of Energy (DOE) has speculated that most future plants will likely have to employ closed system cooling systems due to the environmental impact of heat in discharge waters (DOE /NETL 2008). As of 2004, only about ten steam-electric plants had been built with open-loop cooling since 1980 (Feeley and others 2006). However, many of the open loop systems can be expected to be in service for many years, and open loop systems may remain a practical option for northern climates.

### Additional Water-Use Factors (Sulfur Scrubbers and $CO_2$ Capture)

Two factors adding to water requirements are requirements for *flue-gas desulfurization* (FGD) and potential future requirements for carbon capture and sequestration.

#### *Water Loss Caused by Flue-Gas Desulfurization*

One example provided by Feeley and others (2006) estimate water use from a wet FGD system at about 10% of the evaporative loss - 500 gpm for FGD compared with 5,000 to 6,000 gpm for evaporation in a 500 MW power plant (Feeley and others 2006). A dry FGD system is expected to use less water than a wet system. According to Feeley and others (2006, p. 22) the installation of "regenerative reheat" on FGD systems is expected to reduce water consumption by one-half, compared with conventional FGD technology. However, the capital and operating costs associated with regenerative reheat are large.

#### *Water Loss Caused by Carbon Capture*

It is generally accepted that requirements for carbon capture and sequestration will signicantly increase water withdrawal and use. However $CO_2$ capture technologies are still emerging.

---

[54] Observations of the climate and water-body size relationships were offered by Chris Miller of Basin Electric Power Cooperative. Dec. 17, 2009. E-mail communication.

Pulverized Coal and Natural Gas Water Loss

There are no full-scale fully-integrated carbon capture systems in operation. Thermoelectric power generation using pulverized coal (PC) as a feedstock requires a "post-combustion" $CO_2$ capture process. Problems with existing processes are:

- Low pressures and low $CO_2$ concentrations in the flue gas mean that large volumes of gas must be treated;
- Trace impurities in the gas reduce efficiency of $CO_2$ adsorption; and
- Compressing captured $CO_2$ to pipeline pressures requires a large parasitic load. [55]

Additional water use is required due to both reduced plant efficiency, partially caused by parasitic power load from energy required to compress the gas, and cooling water and process water requirements required by the capture process itself (DiPietro and others 2009). The main post-combustion process is a chemical process called the Fluor Econamine FG Plus technology, which uses a monoethanolamine (MEA) recovery unit. According to DiPietro and others,

> *"A polishing scrubber simultaneously cools the flue gas and reduces the* $SO_2$ *concentration to less than 10 ppmv. The gas then contacts the MEA, which absorbs the* $CO_2$*. The* $CO_2$*-laden MEA is then steam-heated to release the* $CO_2$*. The MEA is recovered and reused, and the carbon dioxide is cooled and compressed for shipment. Overall, the CDR facility involves a number of subprocesses which collectively require a significant amount of cooling water. This includes flue gas cooling, water wash cooling, absorber intercooling, reflux condenser duty, reclaimer cooling, the lean solvent cooler, and* $CO_2$ *compression interstage cooling."*

The DOE/NETL (2008, p. 26) has stated that "current carbon capture technologies under development for coal-based power generation require large amounts of water." The DOE/NETL estimates a minor (1.5 to 2.5%) overall increase in water withdrawals, but a large (greater than 103%) increase in water consumption. Much of the projected increase has been attributed to the parasitic power load required by the capture process. Di Pietro and others (2009) estimated a total increased water consumption of 87 and 90% for $CO_2$ capture in supercritical and subcritical pulverized coal power plants, respectively. Of this, 44% and 48% increases in water use were attributed to lost efficiency, including parasitic power load; and a 43% increase in water use was attributed to the carbon capture process itself. An additional parasitic power loss of about 79.3 GW has been estimated for carbon capture retrofits. Loss of power efficiency due to retrofits is not included in the 87 to 103% decrease in water-consumption efficiency discussed above, and will represent a increase in water use. Increased water use for natural-gas

---

[55] DOE/NETL. Accessed April 8, 2010.
http://www.netl.doe.gov/technologies/carbon_seq/core_rd/co2capture.html

combined-cycle (NGCC) power plants is slightly less than pulverized coal, at about 76%. A smaller percent of water loss for NGCC plants is due to lost efficiency (16%) compared with PC plants, while a larger percent (60%) is attributed to carbon-dioxide recovery equipment.

Integrated-Gas Combined-Cycle Water Loss

Water losses for carbon capture in integrated-gas combined-cycle (IGCC) plants are somewhat less than for PC and NGCC plants. DiPietro and others (2008) have estimated increased water use at about 46 to 61%. Because IGCC plants burn hydrogen gas produced from coal or methane, $CO_2$ can be removed in a more concentrated stream before combustion, using a physical process called the Selexol process, which uses a glycol-based solvent. A substantial portion of the increased water use in the Selexol process is due to what is called the *water-gas shift*, in which carbon-monoxide is converted to $CO_2$ before capture.

Summary: Carbon Capture Effects on Water Use

The impact of carbon capture and sequestration on the use of water for any form of fossil-fuel based thermoelectric power generation is very large, ranging from about 50% to 100% additional water use. Current goals of the DOE National Energy Technology Laboratory (NETL) are to develop carbon capture technologies "that offer significant cost reductions" by 2014, and to initiate large-scale field testing by 2018.[56] **Effects of prospective new technologies on water use are ill-defined at this time, but by any current indications, impacts of $CO_2$ capture technology on water consumption by fossil-fuel fed thermoelectric power generation are likely to be large.**

## Additional Efficiencies of Water Use

Two potential practices that may increase water-use efficiency are: (1) use of more efficient boilers (super-critical or ultra-supercritical boilers), and (2) use of natural gas simple cycle (NGSC), combined cycle (NGCC), or syngas combined cycle (IGCC) production facilities. NGCC and IGCC plants produce about 2/3 of their power using gas turbines, and about 1/3 using steam turbines powered by the steam heated in the gas combustion phase (DOE/NETL 2008, p.9). A water-use efficiency enhancement of about 2/3 would be expected. However, water use in the production of natural gas or syngas would have to be factored into the water budget for a true comparison of water-use efficiency.

Another efficiency factor would be the use of supercritical or ultra-supercritical boilers, which operate at higher efficiency and therefore require less water per unit of electrical power produced. The U.S. Department of Energy estimates that about 75% of

---

[56] NETL. Accessed April 12, 2010. Carbon Sequestration/ Carbon Capture. http://www.netl.doe.gov/technologies/carbon_seq/core_rd/co2capture.html

future coal-fired power plants will be equipped with supercritical boilers (DOE/NETL 2008, p. 21).

## Water Quality Requirements

The main uses for water in coal-fired electrical power generation are: (1) boiler feed water, used for steam to drive the turbine/generators in all facilities, and (2) cooling water and FGD. Water used in boilers must be purified and treated to inhibit scale formation, corrosion, and impurity contamination of steam. Two general approaches are used to optimize boiler water chemistry. First, impurities in the water are minimized by purification of make-up water, condensate polishing, deaeration and blowdown. Second, chemicals are added to control pH, electrochemical potential, and oxygen concentration. Chemicals may also be added to otherwise inhibit scale formation and corrosion. Proper water chemistry controls boiler efficiency and reduces maintenance and component replacement costs. It also improves performance and life of the plant components.

The primary goals of boiler chemistry treatment and control are acceptable steam purity and acceptably low corrosion deposition rates. General water chemistry control limits and guidelines have been developed and issued by various groups of boiler owners and operators, water treatment specialists, utilities and industries. Also, manufacturers provide chemistry control limits for each boiler and for other major cycle components. For each boiler system, specific water chemistry limits and treatment practices must be developed and tailored to specific operating environments.

A wide range of water chemistries has been used for cooling. But the main concerns for cooling water are *scaling*, *corrosion* and *biological fouling* of cooling towers in *wet-recirculating* cooling systems (Mortenson 2003). Scale can be prevented or controlled by reducing calcium by water softening, or by pH adjustment. Further modifications may consist of using sequestering agents. Corrosion consists of metal dissolution by oxidation. It is limited by using biological agents and controlling oxidants. Biological fouling is avoided by limiting air-wash, by filtration and, in some cases, by the use of biocides (Mortenson 2003).

Variation in treatment of cooling water would be expected between facilities. All power plants currently in operation are receiving raw water from the Missouri River system. In some cases, particularly for *once-through* cooling systems, untreated water is considered sufficient. In others employing cooling towers, specifications for raw water used for cooling towers water is often flocculated, clarified and softened to avoid mineral scaling. Microbiological inhibitors are sometimes added to prevent biological scaling. The quality of boiler water is particularly critical. While treatment processes may vary, some of the following treatment steps are common. Raw water is passed through a sand "rapid filter" to trap turbidity and suspended solids, followed by micron (0.5-1 micron) filtration, and then reverse osmosis (RO). The filtered water is also frequently treated with sulfuric acid to lower the pH, with anti-scalant to impede scale formation, and sodium bisulfite to inhibit microbial growth; and degasified to remove carbon dioxide and oxygen (which cause corrosion). Each treatment process is fitted to the requirements of the individual plant, the characteristics of its source waters, and cost and benefits obtained with more advanced treatments in relation to operational function.

## Current Water Use for Coal-Fired Thermoelectric Power in North Dakota

There are seven coal-fired thermoelectric power plants in North Dakota. Their water use and water-use efficiency are summarized on Table 8 in the order of water permit number and priority data. Four of the power plants (Heskett, Leland-Olds, Stanton, and Milton R. Young) employ *once-through* cooling systems, while three (Coal Creek, Antelope and Coyote) employ *wet-recirculating* cooling systems. All boilers used are *subcritical*.

All of the power plants draw water from the Missouri River system, including Lake Sakakawea, with the exception of the Milton R. Young Station which draws its main supply from Square Butte Creek, with a supplemental supply from the Missouri River. Annual permitted water use for each station is summarized in Table 8, Column 5. The total water permitted for coal-fired electricity generation is about 1.8 million acre-feet. This includes both withdrawn water (non-consumed) and consumed water. The mean annual long-term water use for each station is summarized in Columns 12 (consumptive use) and 13 (non-consumptive use). The mean long-term consumptive use is about 28,500 acre-feet, while non-consumptive use is about a million acre-feet, for a combined total of almost 1.1 million acre-feet, or about 60% of the permitted use.

The large differences in water permit allocations reflect the type of cooling system (Column 4), with largest allocations generally corresponding to the *once-through* cooling systems which do not reuse the water and return it to the source. But the differences also reflect changes in water-permitting policy over time, with larger surplus allocations generally allowed for earlier times. In addition, the Milton R. Young Station represents a special case. Compared with other *once-through* plants, the water permit allocation is small. While the Milton R. Young employs a *once-through* cooling, strictly speaking with respect to the plant, it is, in a broader sense, a *wet-recirculating* system employing the impoundment of Nelson Lake as an exterior recirculating cooling element in the place of a cooling tower.

For the Milton R. Young plant, allocations for Perfected Water Permits #1324 and #1963 are supplied by withdrawals from Square Butte Creek. No pumping rate is specified for Perfected Water Permit #1964, because the allocation is supplemental to Perfected Water Permit #1324. The pumping rate effectively captures almost all flow in Square Butte Creek, with the condition that 8% of the flow must be passed for "upstream development," and a minimum total of 350 acre-feet per year must be passed downstream. The water diverted from Square Butte Creek, however, is impounded in Nelson Lake and continuously recycled through the Milton R. Young plant's cooling system. Perfected Water Permit #1964 provides supplemental water for treatment and use as boiler replacement water, and for restoring lake levels in Nelson Lake during periods of drought to maintain the required head at the intake.

Table 8. Summary of water use and unit water use for coal-driven thermoelectric power generation in North Dakota.

| 1 Water Permit # | 2 Station | 3 Operator | 4 Cooling | 5 WP Allocation AF/year | 6 Pumping Rate cfs | 7 FGD | 8 Water Source | 9 Consumption gal/kWh | 10 Withdrawal gal/kWh | 11 Years Of Record | 12 Mean Annual Consumptive Use Acre-Feet | 13 Mean Annual Non-Consumptive Use Acre-Feet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 463 | Heskett Station | MDU | OT[¶] | 88,709.60 | 55,000 | ** | Missouri River | 0.03 | 32.35 | 30 | 52 | 50,431 |
| 1039 | Leland Olds Station | Basin | OT | 970,000 | 23,832 | Wet | Missouri River | 0.03 | 26.95 | 27 | 299 | 269,074 |
| 1161 | Stanton Station | Great River | OT | 733,000 | 499,918 | Dry* | Missouri River | 0.05 | 37.97 | 27 | 163 | 154,355 |
| 1324 | Milton R Young | MINNKOTA | OT | 1,700 | 93,680 | | Square Butte Creek | - | - | 33 | 1,138 | 255,991 |
| 1963 | Milton R Young | MINNKOTA | OT | 2,480 | * | | Square Butte Creek | - | - | 33 | 653 | 325,881 |
| 1964 | Milton R Young | MINNKOTA | OT | 7,500 | 24,750 | Wet* | Sake Sakakawea | 0.04 | 22.42 | 22 | 3,529 | 0 |
| 1977 | Coal Creek Station | Great River | R[¶¶] | 15,000 | 15,500 | Wet | Missouri River | 0.50 | 0.50 | 5 | 11,057 | 0 |
| 2179 | Antelope Valley Station | Basin | R | 15,000 | 14,800 | Dry | Lake Sakakawea | 0.52 | 0.52 | 21 | 7,672 | 0 |
| 2292 | Coyote Station | Ottertail | R | 20,197.40 | 11,000 | Dry | Missouri River | 0.55 | 0.57 | 22 | 3,921 | 242 |
| Total | | | | 1,853,587.00 | | | | | | | 28,484 | 1,055,974 |

* FGD in place for one unit, under construction or in planning (Stanton) for the second unit.

** No FGD - Unit 2 employs an Atmospheric Fluiding Bed Combustor, which reduces sulfur emissions.

[¶] Once-through cooling system.

[¶¶] Recirculating cooling system.

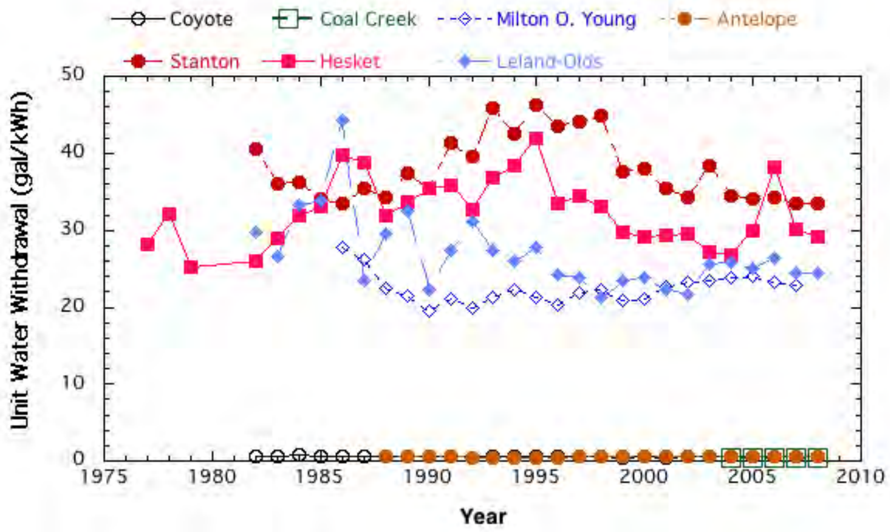


Figure 14. Estimated unit water withdrawal per kWh by North Dakota coal-fired thermoelectric power plants.

The water use per unit power production (gal/kWh) was estimated by dividing the reported annual water use in the SWC database by reported net annual energy production data as supplied by each of the producers. Annual water withdrawal was estimated as the sum of consumptive and non-consumptive use, as reported to the SWC in annual water use reports. Unit water withdrawal summaries are shown on Figure 14. The mean unit withdrawal for each station over the period of record (Table 8, Col. 10) was calculated using only the non-zero reported years, since zero withdrawal rates would indicate non-operation, and must be in error. Long-term mean unit water withdrawal for power stations employing *once-through* cooling systems (Table 8, Col. 10) ranged from 22 to 38 gal/kWh, compared with 37.7 gal/kWh cited by Feeley and others (2006), shown on Table 7. As expected, unit water withdrawal for stations employing *wet-recirculating* cooling systems were negligible.

Unit water consumptive use summaries for North Dakota power plants are shown on Figure 15. Long-term mean unit water consumption values for power stations employing *once-through* cooling systems (Table 8, Col. 9) are negligible. Unit water consumption for stations employing *wet-recirculating* cooling systems (Antelope Valley, Coal Creek and Coyote Stations) all about 0.5 gal/kWh, compared with 1.1 gal/kWh cited by Feeley and others (2006) and shown on Table 7.

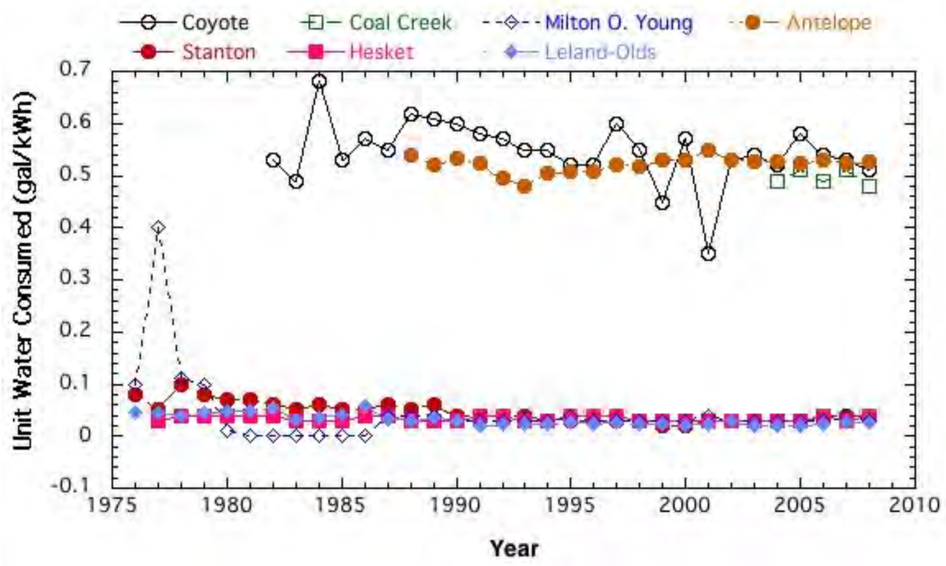


Figure 15. Estimated unit water consumption per kWh by North Dakota coal-fired thermoelectric power plants.

## Water Use by New Thermoelectric Power Plants- Spiritwood Energy Station

The only new coal-fired thermoelectric electric generation plant currently planned in North Dakota is the Spiritwood Station, which is under construction near Jamestown by Great River Energy. The Spiritwood Station is designed to generate 64 annual MWh of baseload electricity and 35 annual MWh of peaking electricity for the regional energy market. Dryfined coal is to be supplied by Great American Energy, with the raw coal supply coming from the Falkirk Mine. The Spiritwood Station was originally planned to operate in conjunction with a new ethanol plant, and with the existing Cargill Malting Plant located at Spiritwood, which would purchase low-pressure steam from the Station. A net of 49 MWh would be available annually for sale to regional customers. The ethanol plant has been put on hold (feasibility is being evaluated), but construction of the Spiritwood Station is proceeding and the partnership with Cargill is still in place. The Station is intended for operation in 2010.

The Spiritwood Station will employ an innovative water-use plan, similar to Tharaldson Ethanol, by using waters from the municipal waste stream from the city ofJamestown. Reuse of wastewater greatly enhances water-use efficiency, and minimizes competition for natural waters. Spiritwood Energy further enhances water-use and energy efficiencies by cycling its low-pressure steam for use by the Cargill Malting Plant. Water-use efficiencies in terms of units of energy produced per gallon of water may be further enhanced by providing steam for a future ethanol plant.

Water requirements for power-plant operation are 325 gpm for the full 64 MWh power production capacity. With continuous operation, this would be equivalent to 524 acre-feet per year. The water supply is *grey water*, purchased from the city of Jamestown and from the Cargill lagoons. The *grey water* used for boilers is to be clarified, demineralized, processed through a reverse osmosis filter and through microfiltration, and then adjusted for pH and softened. Boiler water will be used first to power the turbines. Residual low-pressure steam will then be sent to the Cargill plant, which will use the steam for the malting process. The condensate of the used steam will be returned to the Spiritwood Station for reuse. The Cargill use and condensation of the steam serves to decrease cooling requirements in the Spiritwood process. However, the Spiritwood Station operates using *wet-recirculating* cooling system and still requires a cooling tower to dissipate residual heat from the steam turbine boiler waters. Water for cooling, and cooling replacement water to replace *blowdown*, is treated by passing through a mesh filter to remove particulate matter.

Desulfurication occurs on two levels: (1) a fluid-bed boiler; and (2) a dry FGD scrubber. Carbon sequestration is not currently required, but if a future retrofit is required station loads of less than 10% may possibly increase to as much as 20 to 40%, depending on the technology developed for carbon removal. Because cooling water requirements would remain the same, the reduction in water-use efficiency would be at least proportional to the decrease in salable power.

## Projected Future Water Use for Coal-Fired Thermoelectric Power Generation in North Dakota

Except for the Spiritwood power and steam generation facility currently under construction near Jamestown, there are no pending coal-fired thermoelectric power generation plants that have been issued construction permits or are currently under agency review. Because of the wide variety of factors affecting unit water use, it is difficult to estimate future water requirements with precision. Perhaps the best method is to use a range of values, depending on system designs. Table 9 below summarizes national average withdrawal and consumption factors for coal plants, which were used as input by the U.S. Department of Energy to model future national water needs (Appendix D, DOE/NETL, 2008). Because of pending U.S. EPA limitations on temperatures of discharge waters, the most applicable would likely be the *Freshwater Recirculating* plants. All of the options, supercritical and subcritical, and with wet or dry FGD, are indicated to have unit water consumptions within the narrow range of 0.4 to 0.7 gal/kWh. The effect of future carbon sequestration requirements on water use is unknown, as adequate or standardized carbon sequestration processes have not yet been fully developed. Current estimates predict about an 80 to 100% increase in unit water use. The use of dry cooling or integrated dry and wet cooling processes would decrease unit water use, as would the use of NGSC, NGCC, or IGCC facilities. Future implementation of these technologies is speculative at this time. A range of unit values less than a maximum of about 0.75 gal/kWh may be a safe estimate for current use. If carbon capture is required, a future unit water use of up to about 1.5 gal/kWh may be a reasonable estimate.

Table 9. National average withdrawal and consumption factors used by the U.S. Department of Energy (2008) to model future water requirements for coal-fired thermoelectric power plants (from Appendix D of DOE/NETL 2008).

| Model Plant | Withdrawal Factor (gal/kWh) | Consumption Factor (gal/kWh) |
|---|---|---|
| Freshwater, Once-Through, Subcritical, Wet FGD | 27.113 | 0.138 |
| Freshwater, Once-Through, Subcritical, Dry FGD | 27.088 | 0.113 |
| Freshwater, Once-Through, Subcritical, No FGD | 27.046 | 0.071 |
| Freshwater, Once-Through, Supercritical, Wet FGD | 22.611 | 0.124 |
| Freshwater, Once-Through, Supercritical, Dry FGD | 22.590 | 0.103 |
| Freshwater, Once-Through, Supercritical, No FGD | 22.551 | 0.064 |
| Freshwater, Recirculating, Subcritical, Wet FGD | 0.531 | 0.462 |
| Freshwater, Recirculating, Subcritical, Dry FGD | 0.506 | 0.437 |
| Freshwater, Recirculating, Subcritical, No FGD | 0.463 | 0.394 |
| Freshwater, Recirculating, Supercritical, Wet FGD | 0.669 | 0.518 |
| Freshwater, Recirculating, Supercritical, Dry FGD | 0.648 | 0.496 |
| Freshwater, Recirculating, Supercritical, No FGD | 0.609 | 0.458 |
| Freshwater, Cooling Pond, Subcritical, Wet FGD | 17.927 | 0.804 |
| Freshwater, Cooling Pond, Subcritical, Dry FGD | 17.902 | 0.779 |
| Freshwater, Cooling Pond, Subcritical, No FGD | 17.859 | 0.737 |
| Freshwater, Cooling Pond, Supercritical, Wet FGD | 15.057 | 0.064 |
| Freshwater, Cooling Pond, Supercritical, Dry FGD | 15.035 | 0.042 |
| Freshwater, Cooling Pond, Supercritical, No FGD | 14.996 | 0.004 |

## Water Use for Wind Energy in North Dakota

There are currently 17 completed wind energy projects in North Dakota (Appendix A, Commerce). One additional project (Rugby Wind Farm, PPM Energy, 149.1 MW) is in construction. Fifteen more have filed letters of intent (to develop) with the North Dakota Public Service Commission, and six have announced their intentions, but have not yet filed a letter of intent with the PSC.

With respect to water, Torcellini (2003), the U.S. Department of Energy (2006), and Pate and others (2007) have stated that wind energy consumes very little water. From Pate and others (2007, p. 6):

*"Solar photovoltaic, solar dish-engine, wind, and air-cooled geothermal hot water (binary) power systems offer a single significant advantage over the other electricity generation technologies -- they consume almost no water while producing electricity…"*

Discussions with representatives of Nextera, a subsidiary of Florida Power and Light which has managed the construction and operation of several North Dakota wind-power projects, and with representatives of Ottertail Power Co. have indicated that after construction the wind turbines themselves use virtually no water. During construction water is used for dust suppression on roads and for concrete, but this is a temporary use. After construction water is used solely for consumption, sanitation and cleaning in a maintenance shop. One example is that of a 200 MW project having 133 towers near Langdon, ND. A centrally-located shop of about 5,000 square feet is used by 14 maintenance employees. About 28,000 gallons per year of potable water from a local rural water system is used to provide potable water and sanitary water. With energy generated at half of full capacity on an annual basis, this would be less than $4x10^{-5}$ gal/KWh, This quantity is insignificant, and is within the supply capability of most municipal and rural water systems.

## Estimated Total Water Use for Energy Industries

Statewide estimates of total water use for energy are difficult to derive for many reasons. Water permits poorly reflect use because of differences in policy over many years of water appropriation – some earlier water permits granted large appropriations in excess of common actual use. There are differences between consumed and non-consumed water use. In some cases, where uses are small, as in natural gas processing, there is no record of water use. In other cases, as commonly occurs with ethanol facilities, production capacity currently exceeds actual production, pending removal of operating constraints or appropriate economic conditions. In the case of the Bakken play, water use requirements are highly dynamic as plans for the numbers of new wells change, or as technologies for extracting oil advance. The following "ballpark" estimate of total water use is somewhat speculative, and based on eight general observations.

- Based on median unit water use for existing plants, ethanol production at full production capacity would use about 3,100 to 3,600 acre-feet per year. With four additional plants operating at full permitted production, about 2,500 to 2,900 acre-feet per year would be used additionally – for a total of about 5,600 to 6,500 acre-feet per year.

- All currently operating natural gas plants combined use less than 200 acre-feet of water per year. Addition of a few extra plants would not change this substantially.

- Biodiesel production (one facility) uses about 276 acre-feet per year. No additional biodiesel plants are currently planned.

- Total water used for the Bakken play would be about 12,000 to 24,000 acre-feet per year, depending on several factors. Oil-field water use will be about 11,000 to 23,000 acre-feet per year for drilling and fracing, and will increase annually at a rate of about 242 to 290 acre-feet per year, depending on the number of wells drilled (1,500 or 1,800 wells per year) and the average amount of water used for fracing (2 million gallons per frac – to about 4 million gallons per frac). Maintenance water for about 10% of about 5,000 pumping wells at about 1.6 acre-feet per well would require about 800 acre-feet of water per year. Computations for explaining increased annual water use are provided in the section titled *Total Projected Freshwater Needs for Oil-Field Development.*

- Petroleum refining at a single plant, the Mandan Tesoro refinery, uses about 1,275 acre-feet per year.

- Dakota Gasification uses about 7,500 acre-feet of water per year.

- Coal-fired thermoelectric power generation consumes about 28,500 acre-feet per year.

- Plans for additional oil refineries and additional coal gasification plants are not fully formulated, and their water needs are indefinite.

Based on these approximate figures, total water use for the energy industry in North Dakota, with full capacity ethanol production in existing facilities, would be expected to be about 53,000 to 65,000 acre-feet per year. If four additional ethanol plants were added, total water use would be about 55,000 to 68,000 acre-feet per year. With carbon capture, total water use would likely expand to as much as 85,000 to 93,000 acre-feet per year, mainly due to increased water use for coal gasification and coal-fired thermoelectric power generation. With four additional ethanol plants, the total would be about 88,000 to 96,000 acre-feet per year.

## Citations

American Lignite Energy LLC, Coal-to-Liquids project. (http://pnp.uschamber.com/2009/03/american-lignite-energy-llc-coal-to-liquids-project.html).

Chiu, Yi-Wen, Brian Walseth, and Sangwon Suh. 2009. Water embodied in bioethanol in the United States. Environ. Sci. Technol. 43:2688-2692.

DiPietro, Phil, Kristin Gerdes and Cristopher Nichols. April 2009 revision. Water requirements for existing and emerging thermoelectric plant technologies. DOE/NETL-402/080108. 17 pp.

USDOE/NETL. 2008. Estimating freshwater needs to meet future thermoelectric generation requirements. DOE/NETL-400/2008/1339.

Feeley, Thomas J. III, Lindsay Green, Andrea McNemar, Barbara A. Carney, and Sara Pletcher. Department of Energy/Office of Fossil Energy's Water-Energy Interface Research Program. DOE/FE's Power Plant Water Management R&D Program Summary, April 2006 Update.

Hoffman, Jeffrey, Sarah Forbes, and Thomas Feeley. 2002. Estimating freshwater needs to meet 2025 electricity generating capacity forecasts. U.S. Department of Energy/National Energy Technology Laboratory. 12 pp.

Hubert, Casey, and Gerrit Voordouw. 2007. Oil field souring control by nitrate-reducing Sulfurospirillum *spp*. that outcompete sulfate-reducing bacteria for organic electron donors. Appl. and Environ. Micro. : 73:8:2644-2652.

Keeney, Dennis, and Mark Muller. 2006. Water use for ethanol plants: potential challenges. The Institute for Agriculture and Trade Policy. 2105 First Ave. S. , Mpls, MN. 7 pp.

King, C.W., and Michael E. Webber. 12/27/2008. Water Intensity of Transportation. Environ. Sci. Technol. 43:21:7866-7872. U.S. Chamber of Commerce.

Mortenson, Ken. 2003. How to manage cooling water quality. RSES Journal. 4 pp.

National Research Council. 2008. Water implications of biofuels production in the United States. National Academies Press. Washington, D.C. 76 pp.

Nelson, John A. 1986. Cooling towers and slat water. The Marley Cooking Tower Company. 3 pp.

Nowakowski, Sonja. November 8, 2007. Coal to Liquids Water Usage. *Report to the Telecommunications and Energy Interim Committee of the Montana Legislature*. http://leg.mt.gov/css/Committees/Interim/2007_2008/energy_telecom/assigned_studies/coal2liquidpage/coal2liquid.asp

Pate, Ron, Mike Hightower, Chris Cameron, and Wayne Einfeld. 2007. Overview of energy-water interdependencies and the emerging energy demands on water resources. Sandia National Laboratories. SAND 2007-1349C. 20 pp.

Stepan, Daniel J., Richard E. Shockey, Bethany A. Kurz, Nicholas S. Kalenze, Robert M. Cowan, Joshua J. Ziman, and John A. Harju. April, 2010. Bakken Water Opportunities Assessment – Phase I. Report 2010-EERC-04-03, Energy and Environmental Research Center. Grand Forks, ND. 27 pp.

Torcellini, P., N. Long, and R. Judkoff. 2003. Consumptive water use for U.S. Power Production. NREL/TP-550-33905.

U.S. Department of Energy. Dec. 2006. Energy demands on water resources: Report to congress on the interdependency of energy and water. 80 pp. http://www.sandia.gov/energy-water/congress_report.htm.

U.S. Department of Energy. 2006. The wind/water nexus. Wind Powering America Fact Sheet Series. 4 pp. http://www.nrel.gov/wind/pdfs/37790.pdf

# WATER AND ENERGY RESEARCH INITIATIVES

Water use practices by the energy industries are dynamic and constantly changing to improve cost and use efficiencies. Improved efficiencies are based on new technologies and practices derived from research. Research is usually initiated and funded through partnerships of research institutions, industries and government entities like the U.S. Department of Energy. In North Dakota several research initiatives related to water use in state energy industries are being conducted by the Energy and Environmental Research Center of the University of North Dakota (EERC) under what is titled the "EERC Energy-Water Nexus Program Area."

The EERC's Northern Great Plains Water Consortium (NGPWC)**,** a partnership between the U.S. Department of Energy (DOE) and key energy-producing and water-using entities in the northern Great Plains, is addressing issues related to water availability, reducing freshwater use, and minimizing the impacts of facility operations on water quality. The NGPWC expands the breadth and activities of one of the EERC's Water Management Center cornerstone programs, the Red River Water Management Consortium. The expanded program includes the involvement and participation of a growing and more diverse group of regional stakeholders and is a national model for water management.

The overall goal of this stakeholder-driven effort is to assess, develop, and demonstrate technologies and methodologies that minimize water use and reduce the discharges of wastewater from a range of energy technologies, including coal combustion, coal gasification, coalbed methane, and oil and natural gas production. Maintaining an awareness of competing water use issues, including agriculture, industry, and municipalities, is critical in effectively achieving project goals and to identifying water management synergies that exist between the competing uses.

Current activities of the NGPWC include the following:

## Bakken Water Opportunities Assessment

A project was implemented to study the potential to economically recover and reuse water that is used in the oil field to pressurize and fracture oil-bearing formations to increase permeability and enhance the flow and recovery of oil. As much as 3 million gallons of freshwater can be used to fracture an oil well in the Bakken Formation. This water is typically hauled to the well site in 7500- to 8000-gallon tanker trucks. Once the formation fracturing is completed, the water flows back (frac flowback) as the well is pumped. Frac flowback is typically disposed of via deep well injection. Transportation costs, particularly for long haul distances, can be large for both freshwater and flowback water. Treatment and reuse of frac flowback water may be an attractive economic alternative to disposal via deep well injection.

Phase 1 research on this project determined that there would be significant challenges for recycling frac flowback water. The flowback water recovery rates observed in the field were typically only 15% to 50% of the original volume of water used in the fracturing process after ten days of pumping, and the recovery rate further diminishes after that time. Additionally, the dissolved salt content (salinity) of the flowback water was extremely high, which makes treatment of the flowback water very challenging, even with the most robust of technologies. As a result, recycling will likely not be cost-effective in most cases.

The demand for freshwater, however, continues to increase, and access to conventional sources of freshwater continues to be a challenge. As with many areas with limited freshwater supplies, there is an abundant supply of marginal-quality ground water that is not a potential underground source of drinking water. In certain cases, treatment of non-potable ground water may provide an economical alternative resource. A Phase 2 effort to demonstrate the treatment and use of non-potable water supply is being conducted. The project will be cofunded by the North Dakota Industrial Commission's Oil and Gas Research Council and an industrial project sponsor.

## Recovery of Water from Drying of North Dakota Lignite

The drying of lignite produces a lower-moisture fuel that can significantly improve coal-fired power generation efficiency as well as reduce emissions. Great River Energy's (GRE) Lignite Fuel Enhancement System (LFES) uses waste heat to drive a bubbling fluidized-bed coal dryer that reduces the moisture of the lignite from 38% to 28%. Processing 20,000 tpd lignite would result in the generation of 2,800 tpd water (667,000 gpd). Recovery of 30% of that moisture would produce as much as 200,000 gpd of water that may be suitable for use in a utility boiler or cooling water make-up. Recovery of this water would ultimately reduce the freshwater demand for power generation.

The EERC obtained dryer operating information from GRE and conducted a preliminary assessment of water recovery potential, including projections of warm, moist air discharges based on available information, estimates of energy required to condense the water vapor, an evaluation of applicable water recovery technologies, and a preliminary economic assessment. Economics of moisture recovery could be extremely favorable, particularly in applications where hybrid cooling systems can avoid derating generation during peak demand periods. A commercially available moisture recovery technique was identified for this application, and the EERC is working with SPX Cooling Technologies to develop a proposal to demonstrate the moisture recovery potential of SPX's Air2Air™ heat exchanger technology from a LFES dryer at GRE's Coal Creek Station near Underwood, North Dakota.

## NGPWC Water Resource Decision Support System

The EERC has developed an interactive, Web-based decision support system (DSS) to provide power generation utilities and other users with an assessment tool for addressing water supply issues when planning new or modifying existing facilities. The Web-based DSS integrates water and wastewater treatment technology and water law information with a geographic information system-based interactive map that links to state and federal surface water and ground water quality and quantity databases. The DSS also includes interactive maps and data sections that provide information on nontraditional water resources, including municipal and industrial wastewater treatment plant discharges, oil and natural gas produced waters, and deep saline aquifers. The entire DSS links to other web sites that provide additional in-depth information. This allows users to leverage and integrate knowledge of water and wastewater treatment technologies with the physical and spatial relationships of available water sources, competing uses, and current water demands.

## Energy-Water Nexus Documentary

This project is developing a half-hour documentary in high-definition format on the energy-water nexus and documenting the key issues related to the interdependence of water and energy in the NGPWC region. The video will be developed in partnership with Prairie Public Broadcasting of Fargo, North Dakota, to be broadcast on Prairie Public Television (North Dakota, eastern Montana, western Minnesota, and southern Manitoba), uplinked for national distribution on the public television network, and made available on DVD.

The documentary is intended to introduce the general public to the broad issues of water use and future demands, especially with respect to energy production—past, present, and future. The primary focus will be the northern Great Plains; however, as background information, issues related to the energy –water nexus across the nation will be included.

## Regional Carbon Sequestration Partnership Water Working Group

The EERC leads and facilitates the National Energy Technology Laboratory's (NETL) Regional Carbon Sequestration Partnership Program's Water Working Group (WWG). The WWG comprises individuals from all seven RCSPs as well as several NETL individuals. The WWG's mission is to identify issues and opportunities associated with the nexus of water and carbon capture and sequestration and to act as a sounding board so that these issues and opportunities can be addressed, either directly through the work of the WWG or through suggesting research funding ideas to the U.S. Department of Energy, NETL.

# POTENTIAL SURFACE-WATER SOURCES FOR USE BY THE ENERGY INDUSTRY IN NORTH DAKOTA

Surface-water sources in North Dakota consist of rivers, lakes, potholes and wetlands. Of these, wetlands, potholes and freestanding lakes (not maintained as reservoirs of streams) do not provide viable sources for large-scale dependable water supplies. A large expanding lake, like Devils Lake, might appear to be a viable source for energy development. However, Devils Lake and associated lakes and potholes should not be considered as viable long-term water supplies. Enclosed lakes and potholes, however large they may appear, are subject to large variations in size and generally follow cycles of flooding and depletion. Before the recent expansion of Devils Lake following large rains in 1993, there were concerns over its depletion following the drought of 1988, and proposals for enhancing its volume using Missouri River water. Hydrologists have, since that time, come to understand that Devils Lake, and other North Dakota enclosed water bodies, undergo larger repeating flood/depletion cycles of between 150 and 200 years, and that these have occurred for several thousand years. Such variable water sources do not provide good prospects for sustainable water supplies, and are poor prospects for industrial-use planning. For this reason, the discussion of this report will be confined to rivers and reservoirs within river systems.

North Dakota has eight major rivers. They are: the Missouri River, the Red River, the Sheyenne River, the Little Missouri River, and the Cannonball, Heart, Knife and James Rivers. Of these, the Missouri River and the Red River and their tributaries carry 98.4% of the surface water leaving the state (Ripley 1990). Most of the state's surface waters are heavily appropriated for their normal (year-round) flows, so there is little water available for additional appropriation and use. In fact, the main concern in many areas is the long-term sustainability of current municipal, domestic and industrial uses during a severe drought scenario, as indicated by the recommendations of the Red River Water Supply Project.[57] An exception is the Missouri River system (including the Lake Sakakawea and Lake Oahe reservoirs), which has an average annual outflow from the state of about 16.9 million acre-feet. Because of these limitations, this report will focus mainly on potential surface-water applications from the Missouri River system, the only abundant current source of unallocated water. We will also consider briefly the potential for storing seasonal waters from other surface-water sources for use in the energy industry.

## Potential Water Supplies From The Missouri River System

The Missouri River system, including free flowing reaches and reservoirs, comprises one of the few water sources with plentiful supply in North Dakota. The use of Missouri River water requires: (1) a water right for the beneficial use of the water, (2)

---

[57] U.S. Bureau of Reclamation. Dec. 2007. Executive summary: final environmental impact statement Red River Valley Water Supply Project. 52 pp.

access to the river or reservoirs to establish a point of diversion and the right to construct the necessary works to obtain the water, and (3) conveyance infrastructure to the point of distribution or use. Water rights are under the jurisdiction of the state. Procedures for appropriation of water have been discussed in another section *(Obtaining Water Rights for Energy Development in North Dakota*). In this section we will first discuss regulatory requirements for access to Missouri River water. We will then consider possible conveyance options for diverting and using Missouri River water.

**Missouri River Access**

Several state, federal, local and tribal entities are involved with access to the Missouri River and its reservoirs and will need to be involved with proposed water-use projects. Ownership or lease agreements will be needed for properties required for conveyance works. *Appropriate local governments should be consulted, including local county and city planning and zoning commissions, and tribal authorities if access and construction are to be undertaken on tribal lands.* Planners for projects involving pumping water from Lake Sakakawea that require access through lands of the Three Affiliated Tribes should contact:

Tribal Energy Department
Three Affiliated Tribes – Fort Berthold Reservation
404 Frontage Road
New Town, ND 58763
Office (701) 627-5154
Fax (701) 627-5105[58]

For issues concerning access to Lake Oahe from adjoining lands of the Standing Rock Sioux Tribe, contact:

Reservation Resources
Standing Rock Sioux Tribe
PO Box D
Fort Yates, ND 58538
(701) 854-8598[59]

In addition, provisions of state and federal law will need to be satisfied. ***In general, for free flowing reaches of the Missouri River a sovereign lands permit will be required. If any alteration of the channel (dredging, excavation, construction of works) is required, a regulatory permit will be required from the U.S. Army Corps of***

---

[58] http://www.mhanation.com/main/energy.html#

[59] Provided by Joe Smith, Director of Reservation Resources. Feb. 11, 2010. E-mail communication.

***Engineers (Corps). For reservoir reaches, including Lake Sakakawea and Lake Oahe, and for free flowing reaches of the Missouri Rivers with federally owned shorelines, access would require both real estate and regulatory permits from the Corps. If the planned works for an intake intend to access the main channel of the Missouri River within the reservoir, a sovereign lands permit will also be required from the state.***

### *Sovereign Lands*

Under North Dakota Century Code (Chapter 61-33-01.3) sovereign lands are defined as *"those areas, including beds and islands, lying within the ordinary high watermark of navigable lakes and streams. Lands established to be riparian accretion or reliction lands pursuant to section 47-06-05 are considered to be above the ordinary high watermark and are not sovereign lands."* From this, all lands underlying navigable rivers and streams from high watermark to high watermark are deemed sovereign lands of the state. Sovereign Lands include lands that would constitute the main channel of the Missouri River underlying the Oahe Reservoir and Lake Sakakawea. If a structure or intake is planned for placement within the channel flowing through what would have been the original bed of the river, a Sovereign Lands Permit will be required, regardless of ownership of lands adjoining the water body.

To summarize requirements under North Dakota Administrative Code (Chapter 89-10-01), authorization for a permit, easement, lease, or management agreement must be obtained from the State Engineer prior to construction or operation. Applications must be on forms prescribed by the State Engineer and contain information required by the State Engineer. After receipt of an application, the State Engineer must request review comments concerning public impact from: the State Game and Fish department, the State Department of Health, the State Historical Society, the State Land Department, the State Parks and Recreation Department, the United States Fish and Wildlife service, the park district and planning commission of any city or county, if the project is within the boundaries of that city or county, any water resource district in which the proposed project will be wholly or partially located, and other agencies, private entities and landowner associations deemed to be appropriate or required by law. Each reviewing entity must comment within 30 days of the written request for comment. The State Engineer may grant, deny or condition the application. The general permit standards are: the State Engineer shall consider the potential effects of the proposed project on riparian owner's rights, recreation, navigation, aesthetics, environment, erosion, maintenance of existing water flows, fish and wildlife, water quality, cultural artifacts, and alternative uses. An application form can be obtained from the North Dakota State Water Commission, or downloaded from the North Dakota State Water Commission web site at: http://www.swc.state.nd.us/4dlink9/4dcgi/GetSubCategoryRecord/Permits/Sovereign%20Lands%20Permits. Applicants should plan on at least 90 days from the time of received application to the decision of the State Engineer.

### *Federal Regulatory and Real Estate Permit Requirements and Conditions*

Any action potentially affecting navigable waters is subject to federal laws and regulations including, but not limited to: Section 10 of the Rivers and Harbors Act, provisions (including Sections 401, 402 and 404) of the Clean Water Act, the National Environmental Protection Act (NEPA), the National Historical Preservation Act (NHPA), the Endangered Species Act (ESA), and several other laws, regulations and policies. The Missouri River system is a navigable water, and any party intending to divert water from, and any action in or affecting (over or under) the Missouri River within the State of North Dakota, whether free flowing or impounded, must obtain a regulatory permit from the U.S. Army Corps of Engineers (Corps). The application form and information pertaining to the regulatory permit can be viewed on the web at:
https://www.nwo.usace.army.mil/html/od-rnd/ndhome.htm
or can be located by querying under "North Dakota Regulatory Office" on Google. For guidance concerning the requirements of the application process, applicants are advised to contact the Corps Regulatory Office at:

North Dakota Regulatory Office
U.S. Army Corps of Engineers
1513 South 12th Street
Bismarck, ND 58504
Phone (701)-255-0015

In addition, if access to waters of the Missouri River system is desired through Corps lands, a real estate authorization is required. Real estate permits are administered by appropriate Project Office, Lake Sakakawea at Riverdale or Lake Oahe at Bismarck, which serve as the land managers and evaluate impacts of proposed projects on lands under their management. Under current Corps policy, the land managers serve as the first evaluators of proposed projects on the lands they manage. Once the location is initially approved, the Project Office initiates consultation, if necessary, with other appropriate parties and agencies concerning potential impacts on cultural, historical and wildlife resources on Corps lands. They may also determine whether coordination is required under a Programmatic Agreement with Indian Tribes.[60]

For Corps lands, the application is first sent, for Lake Sakakawea, to:

Garrison Project Office
U.S. Army Corps of Engineers
PO Box 527
Riverdale, ND 58545
Phone (701) 654-7411

---

[60] Erhardt, Toni. U.S. Army Corps of Engineers Regulatory Office. Bismarck, ND. E-mail communication. Jan. 22, 2010.

A "handout" provided by the Garrison Project Lake Sakakawea Office describing information and materials required needed for the permit process is appended (Appendix E).[61] For Lake Oahe, the application is sent to:

Lake Oahe Project Office
U.S. Army Corps of Engineers
1513 South 12th Street
Bismarck, ND 58504
Phone (701)-255-0015

Applicants are advised to contact the appropriate Project Office for guidance, and to receive an "applicant package" to be filed with the Project Office. Once the area has been cleared with the Project Office, applications are forwarded to Real Estate and Regulatory Offices along with any recommendations and/or permit conditions the Project Office would like to see incorporated into the authorizations, if granted. At this point, real estate and regulatory authorizations are evaluated concurrently. Upon completion, both regulatory permit and real estate authorization are returned to the Project Office for distribution. The process time normally varies from 30 days to 120 days. However, if the requested action has location or design concerns it may require more formal consultation with federal, state or tribal agencies, or more NEPA documentation may be required. Complications can extend the permitting period considerably. The regulatory office notifies the applicant after completion of the permit.

The following examples of permit conditions are provided to give the reader a sense of some of the limitations that are commonly required of applicants on the Missouri River system. These examples are neither exhaustive nor universally required. Conditions will be placed according to the conditions of the individual case. Some examples of typical intake conditions include, but are not limited to:[62]

*(1) In that portion of the Missouri River above river mile 1519 in Williams and McKenzie Counties, the following conditions are applicable:*

- *Only floating intakes are authorized*
- *The intakes will be located over water with a minimum depth of 20 feet.*
- *If the 20-foot depth is not attainable, the intake will be located over the deepest water available at the start of the pumping season.*
- *If the water depth beneath screen falls below 6 feet, the intake will be moved to deeper water or the maximum intake velocity limited to ¼-foot per second, with intake placed over the maximum practicable attainable depth.*

---

[61] Brown, Phil. U.S. Army Corps of Engineers Garrison Project Office. Riverdale, ND. E-mail communication. Dec. 17, 2009.

[62] Op Cit. Erhardt.

*(2) Intakes located in Lake Sakakawea below river mile 1519, and in the Missouri River below Garrison Dam are subject to the following conditions:*

- *The intakes will be submerged.*
- *At the beginning of the pumping season, the intake will be placed at least 20 vertical feet below the existing water level.*
- *The intake will be elevated 2 to 4 feet off the bottom of the river or reservoir bed.*
- *If the 20-foot depth is not attainable, then the intake velocity will be limited to n-foot per second with the intake placed at the maximum practicable attainable depth.*

*(3) That pumping plant sound levels will not exceed 75 dB at 50 feet.*

*(4) If the activity includes any dredging or placement of fill material, the installation will not occur below the water surface from April 25 to June 1.*

*(5) If the intake lines are to be buried beneath the riverbed, the trench shall be backfilled to the original contours of the riverbed.*

*(6) Pumps placed on government-owned land will be located so as to minimize mechanical and electrical hazards to the public, as well as minimize visual impacts. This may be accomplished by locating pumps underground (minimally below surface) in concrete or wooden structures with lockable manhole type covers. If an underground location is impracticable, some type of natural landscaping or other tamper-proof structure will be considered.*

*(7) Electrical services to submerged motors will be controlled from a panel located on land. Submersible pumps located in less than four feet of water must be marked by a buoy with an orange diamond.*

*(8) Energy support structures carrying electrical lines ranging from 1kV to 69kV will be designed in a raptor friendly manner. Information and recommendations can be found in the Edison Electric Institute's current guidelines for preventing raptor electrocutions; "Suggested Practices for Raptor Protection on Power Lines: The State of the Art in 1996."*

*(9) Permanent non-residential intake structures will be located above or flood proofed to above the 100-year floodwater surface elevation.*

Prospective applicants are encouraged to contact the Corps Regulatory Office, or the appropriate Project Office (listed above) for more detailed information concerning their applications.

### *Missouri River Access Map*

The length of time required to obtain a Corps regulatory or real estate permit, or a state sovereign lands permit, depends to a substantial degree on potential damage to other resources, including historical, cultural, and fish and wildlife resources. Existing resources at any proposed site also affect the conditions required by the permits, including specifications on placement of intakes, limitations on construction time, and limitations on pumping. After consultation with several state and federal agencies, a map was constructed showing which areas along the Missouri River and its reservoirs in North Dakota are least likely to have difficulty and delays in obtaining permits. Agencies consulted for map development and review included the Corps of Engineers (both Lake Sakakawea and Lake Oahe Project Offices), the North Dakota State Water Commission, the North Dakota Department of Game and Fish, the North Dakota Historical Society, the U.S. Fish and Wildlife Service, and the North Dakota Department of Parks and Recreation. Both the Standing Rock Sioux and the Three Affiliated Tribes cultural offices were invited to participate, but they declined.

The end product is a map of the Missouri River system in five segments (Map sheets one through five) provided on the following pages. To avoid misinterpretation it is important to understand how the map was derived, what it represents, and what it does not represent. The map key content consists of three general groupings. These are:

(1) River system reaches, shorelines and near-shore areas where critical resources are most likely to cause prolonged or difficult delays in permitting (red);

(2) River reaches, shorelines and near-shore areas where critical resources are somewhat likely to cause delays in permitting (orange);

(3) River reaches, shorelines and near-shore areas where critical resources are least likely to cause prolonged or difficult delays in permitting (no color).

The sole purpose of the map is to provide a "first cut" level of guidance for potential water users who are considering locations for an intake. Cultural, historical, park and recreation, and fish and wildlife resources are not differentiated on the map. Some resources, particularly fish and wildlife, are mobile and areas of concern may change. The U.S. Fish and Wildlife Service, in particular, consider that the locations of critical habitat for some endangered species may change with lake elevations. They consider the entire Missouri River system to be "sensitive." Further exploration, or in some cases, further shore development, or changes in water levels may cause changes in our understanding of historical and cultural or park and recreational resources. Other agencies or entities, such as the Tribes, may have areas of concern not indicated on these maps. <u>The map is intended as an initial screening tool only.</u> In ALL cases, regulatory agencies are charged with due diligence and must carefully examine proposed points of diversion and their impact. Designation as an area of least concern does <u>not</u> <u>guarantee</u> that a given location will be acceptable or that permits will be processed quickly – only that the chances are better. Designation as an area of highest concern does not guarantee that placement of an intake will be prohibited or excessively delayed – only that the chances of refusal or delay are higher.

### *New Corps Restrictions – the Closure of Lake Sakakawea to All Water Use*

As of January, 2010, the Corps placed a new requirement on information required for the real estate permit process (Appendix E). New applicants are required to provide, essentially, a market analysis identifying current and future needs for water.

As of May 14, 2010, the Corps informed the Governor and the State Engineer that it was placing a moratorium on all access to water in Lake Sakakawea, pending a three-to seven-year study. Suggestions that current water intakes for other purposes, including irrigation, be converted to water depot use for the oil fields were not received positively by the Corps. Their position as of May 19 appeared to be inflexible. After discussions with the Governor and the congressional delegation, Corps Assistant Secretary of the Army Jo-Ellen Darcy indicated that permitting for access would not be put on hiatus during the study. The effect of these proceedings on the actual speed of permit acquisition is uncertain at the time of writing (May 28, 2010).

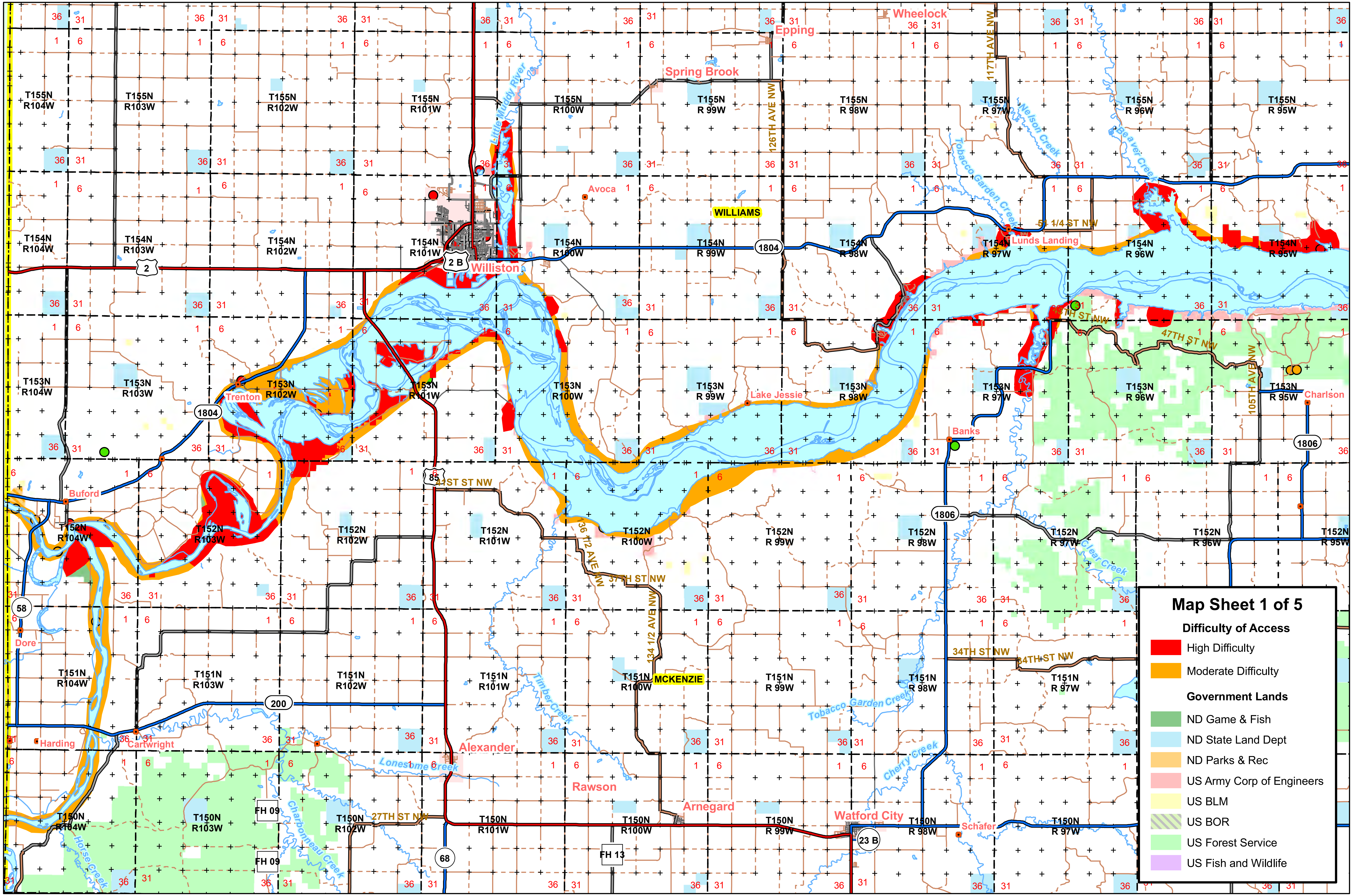
## Potential Use of Northwest Area Water Supply (NAWS) and Other Water Supply Systems for The Energy Industry in Northwestern and North-Central North Dakota

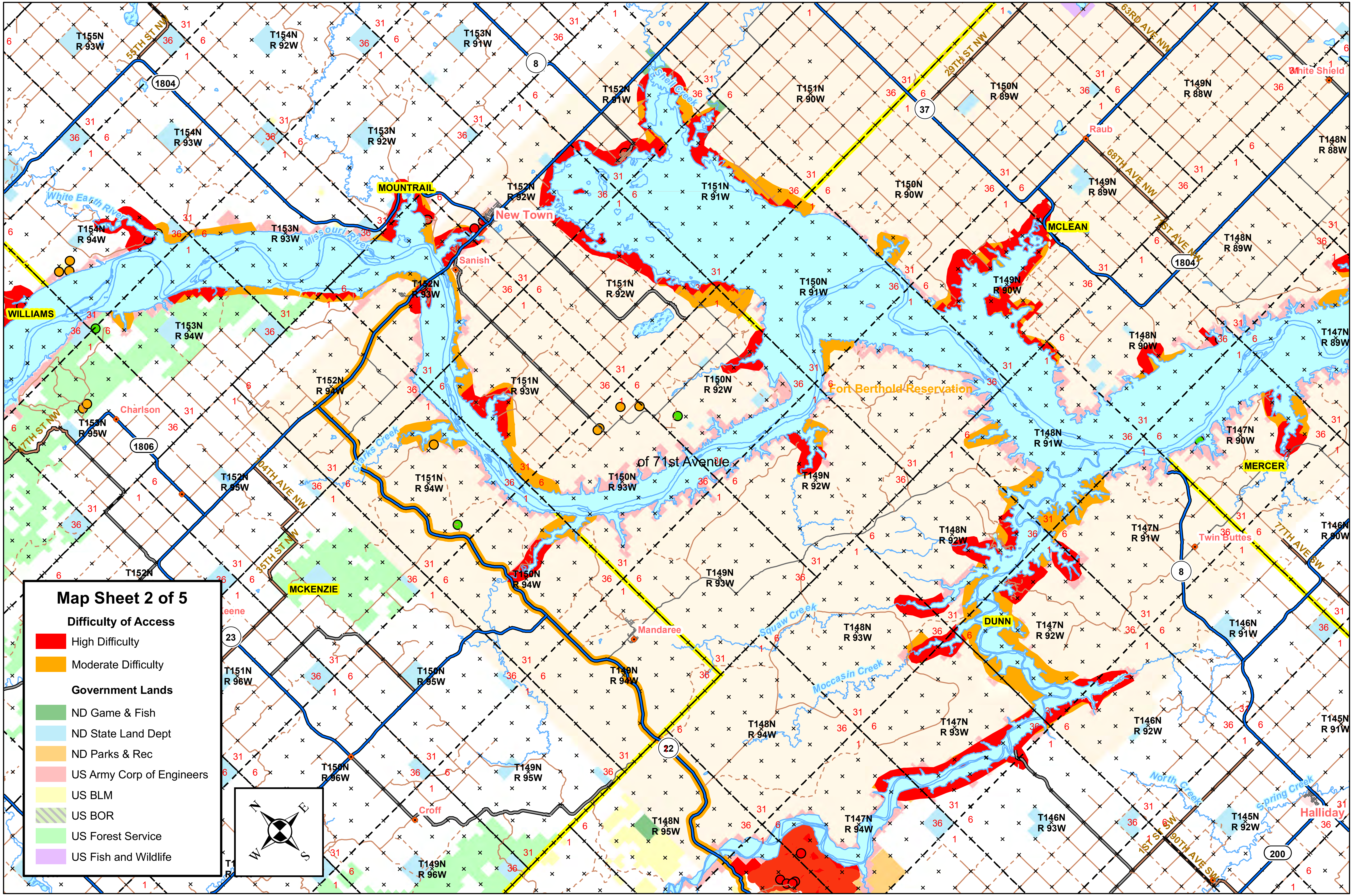
The development of water supplies for northwestern North Dakota and the expansion of conveyance facilities using waters from Lake Sakakawea have been implemented mainly under the planning, guidance and funding of the North Dakota State Water Commission and the Garrison Diversion Conservancy District under what has been called the Northwest Area Water Supply Project (NAWS). The planning process has been and continues to be highly dynamic, with ongoing changes and modifications, so a simple, clear description is not possible. For the objectives of this study, we will try to focus on aspects of planning and NAWS implementation most likely to provide substantial water supplies for development of energy industry use in northwestern North Dakota. The main focus will be, therefore, on potential capacity of NAWS and related projects to serve water from Lake Sakakawea, the only locally plentiful and sustainable source, to outlying areas.

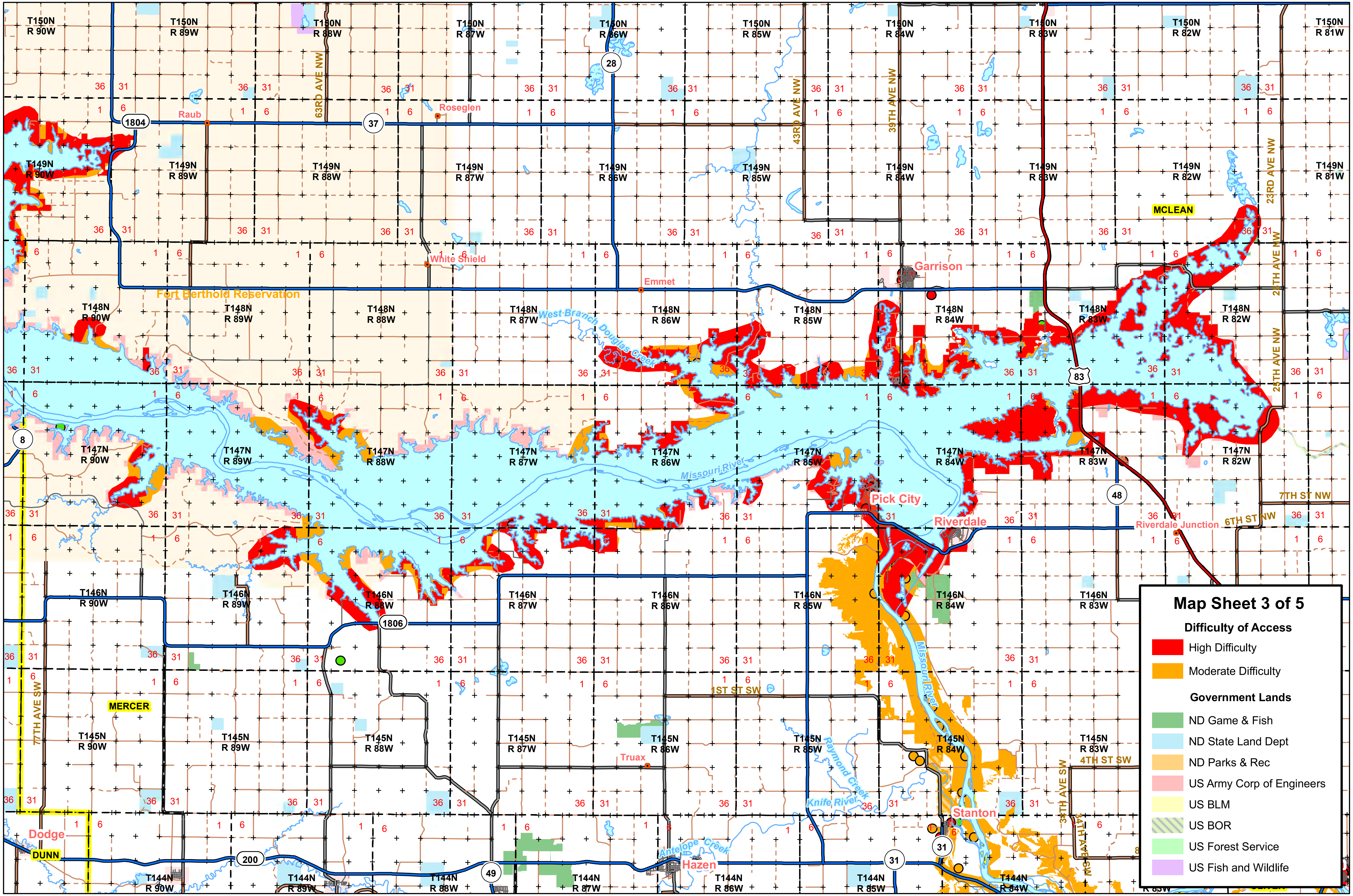
As described by Houston Engineering and others[63], the "Garrison Diversion Reformulation Act of 1986 authorized the appropriation of $200 million in federal funds for planning and construction of water supply facilities throughout North Dakota. This authorization was implemented through the Garrison Diversion Municipal, Rural and Industrial Water Supply (MR&I) program. An agreement between the North Dakota State Water Commission and the Garrison Diversion Conservancy District, entitled 'Agreement for Joint Exercise of Governmental Powers,' dated July 18, 1986, [provided]

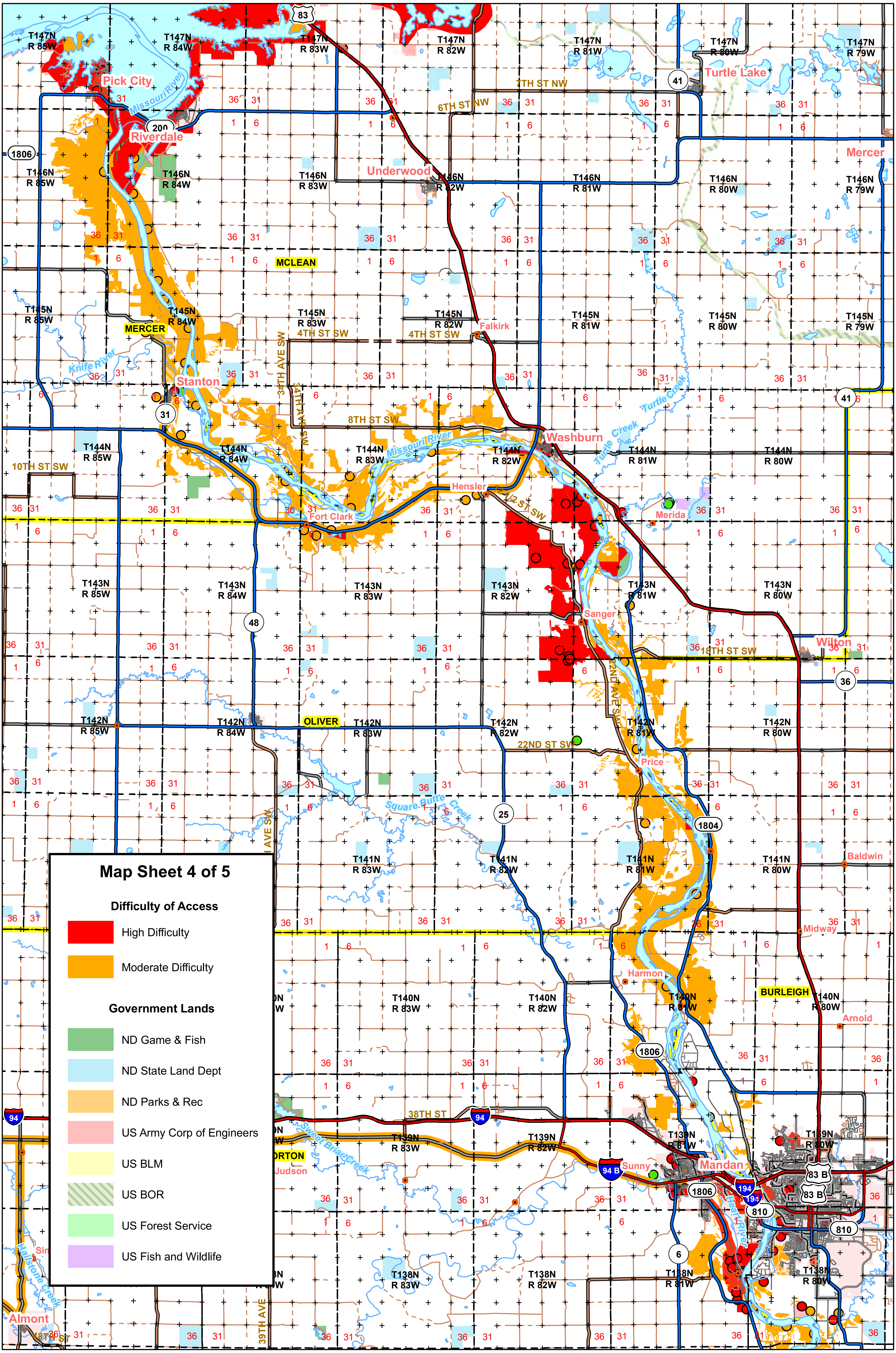
---

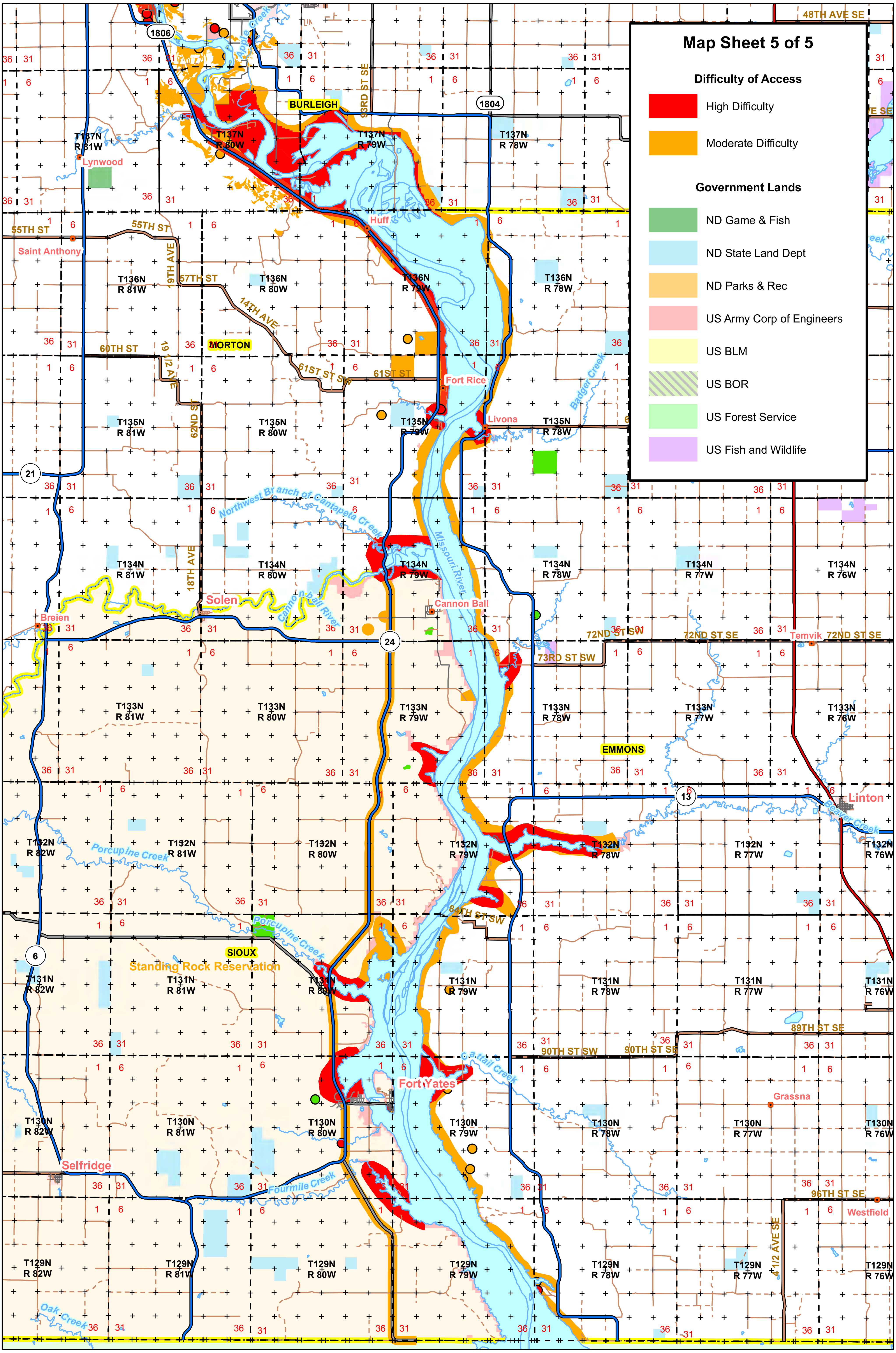
[63] Houston Engr., American Engr., and James M. Montgomery Engr. Nov. 30, 1988. Final Report: Northwest Area Water Supply Study. p 2-1.

Map Sheet 1 of 5
Difficulty of Access
High Difficulty
Moderate Difficulty
Government Lands
ND Game & Fish
ND State Land Dept
ND Parks & Rec
US Army Corp of Engineers
US BLM
US BOR
US Forest Service
US Fish and Wildlife
Wheelock
Epping
Spring Brook
Avoca
WILLIAMS
Williston
Lunds Landing
Trenton
Lake Jessie
Banks
Charlson
Buford
Dore
Harding
Cartwright
Alexander
Rawson
Arnegard
Watford City
Schafer
MCKENZIE
Little Muddy River
Nelson Creek
Beaver Creek
Tobacco Garden Creek
Clear Creek
Timber Creek
Lonesome Creek
Charbonneau Creek
Horse Creek
Cherry Creek
117TH AVE NW
126TH AVE NW
51 1/4 ST NW
47TH ST NW
105TH AVE NW
41ST ST NW
136 1/2 AVE NW
37TH ST NW
134 1/2 AVE NW
34TH ST NW
27TH ST NW
2
2 B
85
1804
1806
58
200
68
23 B
FH 09
FH 13
T155N R104W
T155N R103W
T155N R102W
T155N R101W
T155N R100W
T155N R 99W
T155N R 98W
T155N R 97W
T155N R 96W
T155N R 95W
T154N R104W
T154N R103W
T154N R102W
T154N R101W
T154N R100W
T154N R 99W
T154N R 98W
T154N R 97W
T154N R 96W
T154N R 95W
T153N R104W
T153N R103W
T153N R102W
T153N R101W
T153N R100W
T153N R 99W
T153N R 98W
T153N R 97W
T153N R 96W
T153N R 95W
T152N R104W
T152N R103W
T152N R102W
T152N R101W
T152N R100W
T152N R 99W
T152N R 98W
T152N R 97W
T152N R 96W
T152N R 95W
T151N R104W
T151N R103W
T151N R102W
T151N R101W
T151N R100W
T151N R 99W
T151N R 98W
T151N R 97W
T150N R104W
T150N R103W
T150N R102W
T150N R101W
T150N R100W
T150N R 99W
T150N R 98W
T150N R 97W


Map Sheet 2 of 5
Difficulty of Access
🟥 High Difficulty
🟧 Moderate Difficulty
Government Lands
ND Game & Fish
ND State Land Dept
ND Parks & Rec
US Army Corp of Engineers
US BLM
US BOR
US Forest Service
US Fish and Wildlife
N
E
S
W
MOUNTRAIL
WILLIAMS
MCKENZIE
MCLEAN
DUNN
MERCER
New Town
Sanish
Charlson
Keene
Mandaree
Croff
Raub
White Shield
Twin Buttes
Halliday
Fort Berthold Reservation
of 71st Avenue
Missouri River
White Earth River
Shell Creek
Clarks Creek
Squaw Creek
Moccasin Creek
North Creek
Spring Creek
55TH ST NW
29TH ST NW
63RD AVE NW
68TH AVE NW
71ST AVE NW
77TH ST NW
104TH AVE NW
35TH ST NW
77TH AVE SW
1ST ST SW
90TH AVE SW
1804
1806
8
37
23
22
200
T155N R 93W
T154N R 92W
T153N R 91W
T154N R 93W
T153N R 92W
T154N R 94W
T153N R 93W
T152N R 92W
T152N R 91W
T151N R 91W
T151N R 90W
T150N R 89W
T149N R 88W
T148N R 88W
T150N R 90W
T149N R 89W
T148N R 89W
T152N R 93W
T151N R 92W
T150N R 91W
T149N R 90W
T148N R 90W
T147N R 89W
T153N R 94W
T153N R 95W
T152N R 94W
T151N R 93W
T150N R 92W
T148N R 91W
T147N R 90W
T152N R 95W
T151N R 94W
T150N R 93W
T149N R 92W
T148N R 92W
T147N R 91W
T146N R 90W
T152N
T150N R 94W
T149N R 93W
T148N R 93W
T147N R 92W
T146N R 91W
T151N R 96W
T150N R 95W
T149N R 94W
T148N R 94W
T147N R 93W
T146N R 92W
T145N R 91W
T150N R 96W
T149N R 95W
T148N R 95W
T147N R 94W
T146N R 93W
T145N R 92W
T149N R 96W


Map Sheet 3 of 5
Difficulty of Access
High Difficulty
Moderate Difficulty
Government Lands
ND Game & Fish
ND State Land Dept
ND Parks & Rec
US Army Corp of Engineers
US BLM
US BOR
US Forest Service
US Fish and Wildlife
T150N R 90W
T150N R 89W
T150N R 88W
T150N R 87W
T150N R 86W
T150N R 85W
T150N R 84W
T150N R 83W
T150N R 82W
T150N R 81W
T149N R 90W
T149N R 89W
T149N R 88W
T149N R 87W
T149N R 86W
T149N R 85W
T149N R 84W
T149N R 83W
T149N R 82W
T149N R 81W
T148N R 90W
T148N R 89W
T148N R 88W
T148N R 87W
T148N R 86W
T148N R 85W
T148N R 84W
T148N R 83W
T148N R 82W
T147N R 90W
T147N R 89W
T147N R 88W
T147N R 87W
T147N R 86W
T147N R 85W
T147N R 84W
T147N R 83W
T147N R 82W
T146N R 90W
T146N R 89W
T146N R 88W
T146N R 87W
T146N R 86W
T146N R 85W
T146N R 84W
T146N R 83W
T145N R 90W
T145N R 89W
T145N R 88W
T145N R 87W
T145N R 86W
T145N R 85W
T145N R 84W
T145N R 83W
T144N R 90W
T144N R 89W
T144N R 88W
T144N R 87W
T144N R 86W
T144N R 85W
T144N R 84W
Raub
Roseglen
White Shield
Emmet
Garrison
Fort Berthold Reservation
West Branch Douglas Creek
Missouri River
Pick City
Riverdale
Riverdale Junction
Truax
Stanton
Hazen
Dodge
Knife River
Raymond Creek
Antelope Creek
MCLEAN
MERCER
DUNN
1804
37
28
8
83
48
1806
200
49
31
63RD AVE NW
43RD AVE NW
39TH AVE NW
23RD AVE NW
24TH AVE NW
25TH AVE NW
7TH ST NW
6TH ST NW
1ST ST SW
4TH ST SW
77TH AVE SW
33RD AVE SW
34TH AVE SW


Map Sheet 4 of 5
Difficulty of Access
🟥 High Difficulty
🟧 Moderate Difficulty
Government Lands
🟩 ND Game & Fish
ND State Land Dept
ND Parks & Rec
US Army Corp of Engineers
US BLM
▨ US BOR
US Forest Service
US Fish and Wildlife
MCLEAN
MERCER
OLIVER
BURLEIGH
MORTON
Pick City
Riverdale
Underwood
Falkirk
Turtle Lake
Mercer
Stanton
Washburn
Hensler
Fort Clark
Merida
Sanger
Wilton
Price
Baldwin
Midway
Harmon
Arnold
Sunny
Mandan
Judson
Almont
Missouri River
Knife River
Turtle Creek
Square Butte Creek
Sweet Briar Creek
Heart River
Hailstone Creek
7TH ST NW
6TH ST NW
4TH ST SW
8TH ST SW
10TH ST SW
12 ST SW
18TH ST SW
22ND ST SW
22ND AVE SW
34TH AVE SW
39TH AVE
38TH ST
T147N R 85W
T147N R 84W
T147N R 83W
T147N R 82W
T147N R 81W
T147N R 80W
T147N R 79W
T146N R 85W
T146N R 84W
T146N R 83W
T146N R 82W
T146N R 81W
T146N R 80W
T146N R 79W
T145N R 85W
T145N R 84W
T145N R 83W
T145N R 82W
T145N R 81W
T145N R 80W
T145N R 79W
T144N R 85W
T144N R 84W
T144N R 83W
T144N R 82W
T144N R 81W
T144N R 80W
T143N R 85W
T143N R 84W
T143N R 83W
T143N R 82W
T143N R 81W
T143N R 80W
T142N R 85W
T142N R 84W
T142N R 83W
T142N R 82W
T142N R 81W
T142N R 80W
T141N R 83W
T141N R 82W
T141N R 81W
T141N R 80W
T140N R 83W
T140N R 82W
T140N R 81W
T140N R 80W
T139N R 83W
T139N R 82W
T139N R 81W
T139N R 80W
T138N R 83W
T138N R 82W
T138N R 81W
T138N R 80W
83
200
1806
41
31
48
25
36
1804
6
94
94 B
194
810
83 B


Map Sheet 5 of 5
Difficulty of Access
High Difficulty
Moderate Difficulty
Government Lands
ND Game & Fish
ND State Land Dept
ND Parks & Rec
US Army Corp of Engineers
US BLM
US BOR
US Forest Service
US Fish and Wildlife
BURLEIGH
MORTON
EMMONS
SIOUX
Standing Rock Reservation
Lynwood
Saint Anthony
Huff
Fort Rice
Livona
Solen
Breien
Cannon Ball
Temvik
Linton
Fort Yates
Selfridge
Grassna
Westfield
Missouri River
Apple Creek
Badger Creek
Northwest Branch of Cantapeta Creek
Cannonball River
Porcupine Creek
Beaver Creek
Cattail Creek
Fourmile Creek
Oak Creek
1806
1804
21
24
13
6
48TH AVE SE
93RD ST SE
55TH ST
57TH ST
19TH AVE
14TH AVE
60TH ST
19 1/2 AVE
61ST ST SW
61ST ST
62ND ST
18TH AVE
72ND ST SW
72ND ST SE
73RD ST SW
84TH ST SW
89TH ST SE
90TH ST SW
90TH ST SE
96TH ST SE
4 1/2 AVE SE
T137N R 81W
T137N R 80W
T137N R 79W
T137N R 78W
T136N R 81W
T136N R 80W
T136N R 79W
T136N R 78W
T135N R 81W
T135N R 80W
T135N R 79W
T135N R 78W
T134N R 81W
T134N R 80W
T134N R 79W
T134N R 78W
T134N R 77W
T134N R 76W
T133N R 81W
T133N R 80W
T133N R 79W
T133N R 78W
T133N R 77W
T133N R 76W
T132N R 82W
T132N R 81W
T132N R 80W
T132N R 79W
T132N R 78W
T132N R 77W
T132N R 76W
T131N R 82W
T131N R 81W
T131N R 80W
T131N R 79W
T131N R 78W
T131N R 77W
T131N R 76W
T130N R 82W
T130N R 81W
T130N R 80W
T130N R 79W
T130N R 78W
T130N R 77W
T130N R 76W
T129N R 82W
T129N R 81W
T129N R 80W
T129N R 79W
T129N R 78W
T129N R 77W
T129N R 76W

a basis for cooperative work between the two agencies in developing and submitting proposals to the Secretary of Interior for project funding." Through this process, a study for providing water to the northwest area of the state, called the Northwest Area Water Supply study, was initiated in 1987. In the resulting study[64] several regional water supply system options were explored. An example, Regional System No. 1, is shown on Figure 16. Generally, four sub-regional project areas were considered, including: (1) an East Water Supply system, (2) a Parshall system, (3) a New-Town Stanley system, and (4) a West Water Supply system. Almost all project options have been modified considerably.

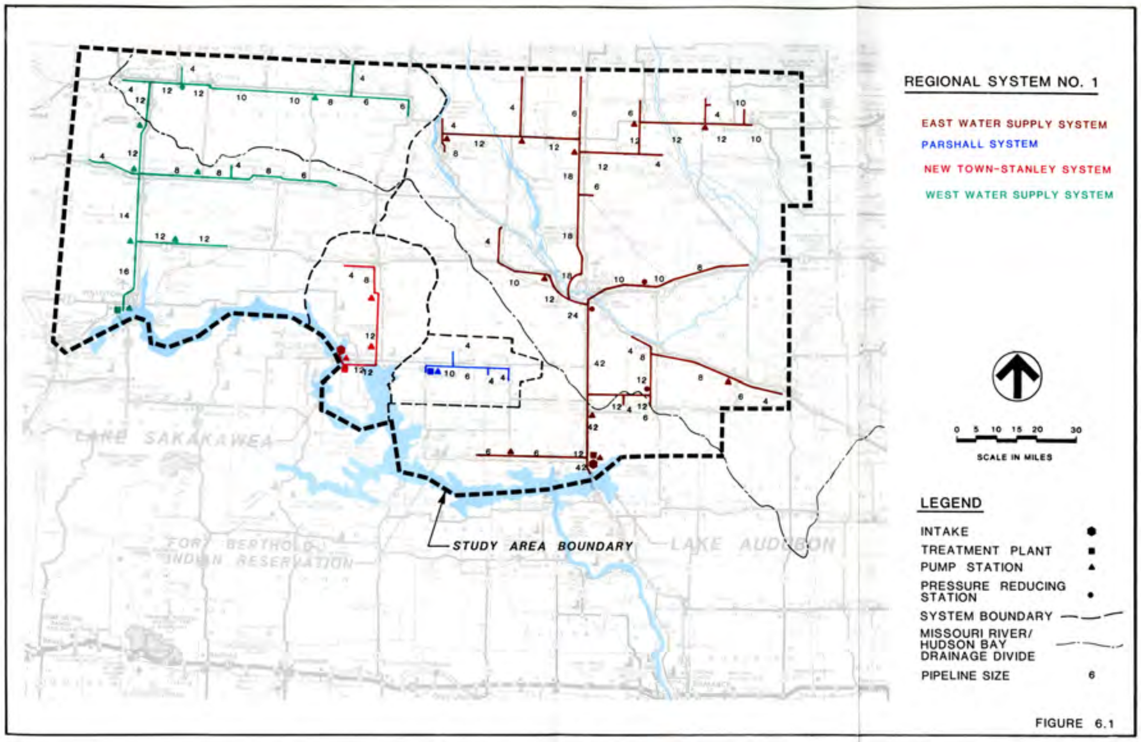


Figure 16. Water system subcomponents of the proposed 1988 NAWS Regional Water System 1.[65]

### *The East Water Supply System (NAWS)*

The East Water Supply System (Figure 17) was selected for development as the preferred option, and is now identified as NAWS. The development of the East Water Supply System project was spurred by the needs of the city of Minot, and the deterioration of its ground-water source in the Sundre aquifer. A community water needs assessment was conducted in 1993, and a design report was completed in 1995. The service base of NAWS consists of the communities and rural water systems that signed onto the project in 1995 with the Community Needs Assessment. NAWS funding is 65%

---

[64] Ibid.

[65] Ibid.

federal from U.S. Bureau of Reclamation MR&I funding, and 35% from a 1% sales tax in Minot. The State of North Dakota has also provided some funding.

Water is to be pumped from Lake Sakakawea at the Snake Creek Pumping Plant, treated for biota at Max, ND, and then piped to Minot where it will be treated to a potable level before distribution. The treatment, conveyance and distribution plan is shown on Figure 17.

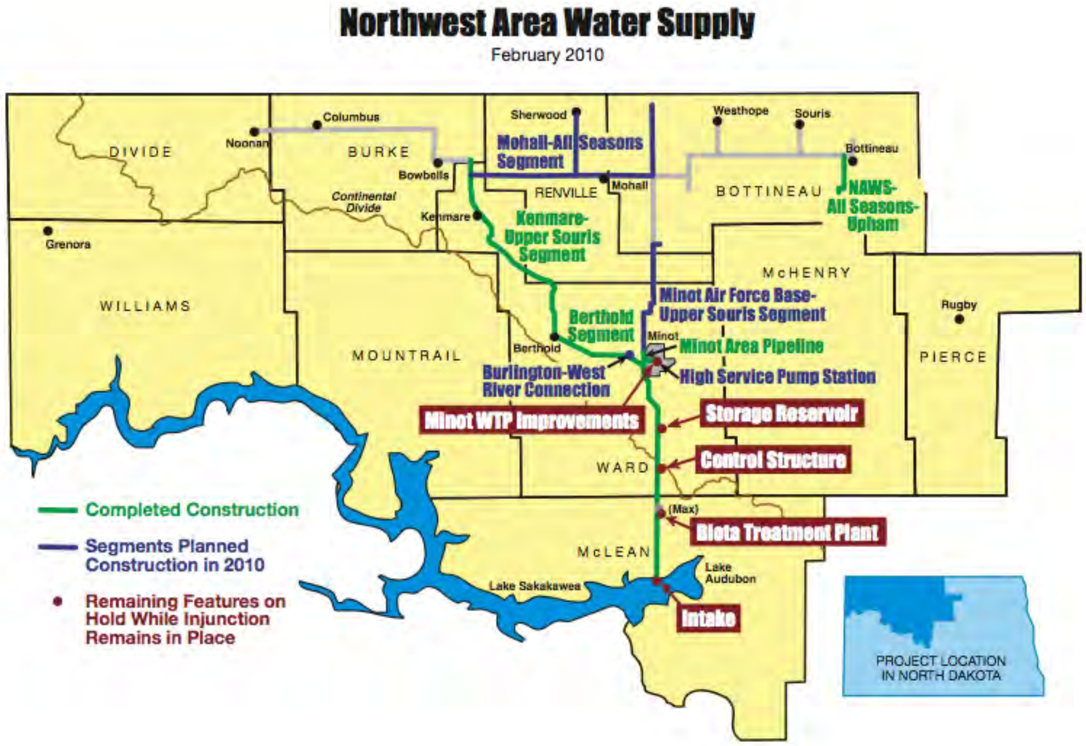


Figure 17. Conveyance, treatment and distribution plan for the Northwest Area Pipeline (NAWS) project as approved under the federal Environmental Assessment (February 2010 status). [66]

The planned design conveyance capacity, and the upper limit of beneficial use are 15,000 acre-feet per year, which was the basis for the Environmental Assessment. An Environmental Impact Statement (EIS) was completed for biota treatment at the Max treatment facility.[67] The planned average water use is for 10 million gallons per day (11,193 acre-feet per year), with a maximum capacity for peak use of about 26 million gallons per day. Water systems to be served are listed on Table 10.

---

[66] Figure provided by Michelle Klose, NAWS Project Manager.

[67] U.S. Bureau of Reclamation. Jan. 15, 2009. Record of Decision for the Northwest Area Water Supply Project Final Environmental Impact Statement on Water Treatment. 19 pp.

The NAWS project design includes community and rural water system contracts and allowances for reasonable expansion of water use (2 to 3 million gpd) within the existing design capacity. Industrial use of NAWS water is allowed under the water permit, which is for multiple uses. **However, the project design does not include large-scale industrial use. There may be some potential for off-peak use for industrial applications, like oil-field development, that can utilize NAWS water at various outlet points at limited hours of the day, or during off-peak use seasons.** Annual off-peak use would be limited to the difference between overall (average) use and permitted use (about 3,807 acre-feet). Daily off-peak use would be limited by maximum capacity (26 million gpd) and the actual pumping use by contract users. Where and when off-peak water would be available would also depend on the distribution of capacity and use within the NAWS system.

Table 10. List of municipalities and water-supply districts that have agreed to purchase NAWS water (Feb. 9, 2010).

| | |
|---|---|
| All Seasons Water Users District | Mohall |
| Berthold | Noonan |
| Bottineau | North Prairie Water District (through their contract with Minot) |
| Bowbells | Souris |
| Burlington | Sherwood |
| Columbus | Upper Souris Water District |
| Kenmare | Westhope |
| Minot | West River Water and Sewer District |

**An indirect effect of NAWS on potential industrial water use would be possible use of ground-water sources previously used by municipalities, but vacated by the use of NAWS water.** For example, some community or rural water system wells could be reemployed for oil-field use, or for some bio-energy applications. A change of water use would require an application for an industrial water permit, as municipal water use or domestic water use (rural water systems) cannot be transferred to a lower priority application (industrial use).

NAWS water, or water uses vacated by NAWS water for industrial use will not be available in the short term. As of February 2010, the NAWS project is under a court injunction to prevent construction of facilities (locations shown on Figure 17) needed to deliver the water to the system, pending the outcome of a lawsuit filed by the Province of Manitoba and the State of Missouri. While pipeline construction may proceed, improvement of the intake at Lake Sakakawea, construction of the biota treatment plant (Max), construction of the control structure at the continental divide, construction of the storage reservoir, and improvements of the Minot water treatment plant must wait for the court decision. If a favorable court decision were received in mid-to late 2010, another five years would be required for construction and commencement of operation. Furthermore, design modification involving larger amounts of water or new service areas would require additional environmental review, and would likely involve further delays. **The earliest potential date for use of NAWS water would likely be 2015.**

***City of Parshall and Fort Berthold Rural Water***

Water service to the Parshall area was one of the options included in the Northwest Water Supply study (blue on Figure 16). It was not included as a part of the NAWS project. Instead, the city of Parshall is expanding its water-supply capacity. Current capacity is 0.5 million gpd diverted from Lake Sakakawea at the Van Hook Arm. A new intake and treatment plant are being constructed about 17 miles south of Parshall near the intersection of HWY 37 and HWY 1804. The new intake will be capable of about 5 million gpd (possibly as much as 10 million gpd depending on the lake elevation). The treatment plant will be capable of treating 2.5 million gpd, expandable to 5 million gpd with additional filters. The pipeline capacity, as planned, is limited to 5 million gpd. The intake and water treatment plant will be owned by the city of Parshall. Fort Berthold Rural Water will own the conveyance lines. In addition, 0.5 million gpd of supplemental raw (untreated) water will be available for beneficial use from the original intake. **The city of Parshall is currently operating a water-supply depot for the oil industry under Water Permit 5958A, which is authorized to provide up to 370 acre-feet per year and a rate of 375 gpm. A portion of the expanded water supply may be available for use in the energy industry.** [68]

***West Water Supply System***

The 1988 NAWS study[69] included a proposed West Water Supply System, consisting of areas of Williams, Divide and Burke Counties north of Lake Sakakawea, and serviced by treated water from the Williston municipal water system (aqua features on Figure 16). The West Water Supply System was dropped from the NAWS project during the environmental assessment. The Garrison Diversion Conservancy District later contracted with EES Consulting to examine the cost-effectiveness of water supply options in the West Water Supply system area. For service north of Lake Sakakawea, EES considered supply options for: (1) the Ray and Tioga (R&T) Water Supply Association, (2) the Burke, Divide, Williams (BDW)/Crosby water supply area (in turquoise, the northern pipeline along HWY 1, from Fortuna east through Bowbells on Figure 16), and (3) the Williams Rural Water system (not shown). The EES study concluded that north of Lake Sakakawea "implementing a regional transmission system to access surplus water from the city ofWilliston is preferred to building local options for all the utilities considered except BDW/Crosby."[70] Under current plan, The BDW/Crosby

---

[68] As of July 15, 2010, Parshall and Fort Berthold Rural Water has applied for an industrial water permit (#1647) for 1,000 acre-feet per year from the new intake. The application is in processing.

[69] Op Cit. Houston Engr., American Engr., and James M. Montgomery Engr.

[70] EES Consulting. June, 2009. Upper Missouri Water Supply Options. p. 1.

service area will be served locally using ground-water sources. **Because of limited ground-water supplies the BDW/Crosby area would, therefore, provide a poor prospect for substantial industrial use, including the energy industry.**

Plans for enhanced service for the western portion of the original West Water Supply System service area include expansion of diversion, treatment and distribution of additional water by the city of Williston. Williston has expanded its treatment facility to 10 million gpd. Further expansion to 14 million gpd could be accomplished at moderate additional cost (approx. $4 million).[71] Average total combined water use by Williston and Williams County Rural water is about 3 million gpd, with a peak use of about 6 million gpd. This leaves up to 4 million gpd of available capacity (system capacity – peak use) for other water users under current peak capacity. The available margin could be increased to up to 8 million gpd with expansion of system capacity to 14 million gpd. In addition to potential expansion of stable water supplies, additional off-peak water may be available for some uses. For example, on an average use day, 7 million gpd of unused water would be available with the 10 million gpd capacities; 11 million gpd would be available with the 14 million gpd capacities. The amount of off-peak water would vary with time of year and time of day. If appropriately permitted for industrial use, a portion of this water may be available for use by the energy industry. The Garrison Diversion Conservancy retained EES Consulting Inc. and AE2S to perform a cost-benefit analysis, comparing local water supply options to regions options for the Upper Missouri region.[72] The regional options included: (1) a North Segment (north of the Missouri River), including the Ray and Tioga Water Supply Association, Williams County Rural Water, and BDW/Crosby; and (2) a South Segment (south of Lake Sakakawea) supplying the McKenzie County Regional Water System service area.

### *Ray and Tioga (R&T) Regional Water*

In place of the proposed New Town-Stanley system (Figure 16), current expansion is planned for the Ray and Tioga (R&T) Regional Water System supply to the city of Stanley. The R&T system withdraws and treats water from the Ray aquifer. R&T is currently expanding its service capacity from about 1 million gpd to 2.5 million gpd, and will be expanding its service to include Wildrose. Optional plans for withdrawal of water from Lake Sakakawea (about 14 miles of pipeline) include a 3 million gpd option ($30 to $40 million estimated cost) and a 5 million gpd ($40 to $50 million estimated cost) option.[73] The R&T Regional Water Supply has elected not to purchase water from Williston, as suggested in the Northwest Area Water Supply Study. **The Ray aquifer source is not a good option for development of industrial water use. The lake source**

---

[71] Chorne, Cory, AE2S Engineering. Phone conversation with W.M. Schuh. Jan. 25, 2010, 2:30 P.M.

[72] Op. Cit. EES Consulting.

[73] Op Cit. Chorne, Cory.

**option would provide a good prospect for industrial (energy) water use development, but is not planned.**[74]

### *McKenzie Rural Water Expansion*

Several optional water-service expansions using Williston water for McKenzie County municipalities, residents and industries have been outlined by $AE_2S$ Engineering.[75] Pertaining to the energy industry, it was stated that:

> "The expanding energy industry has strained existing water system's ability to keep up with the growing industrial and residential needs. Furthermore, the ever-increasing water demands of the energy industry are also negatively impacting regional groundwater resources many of our long-time residents have utilized for their water needs. Declining flow rates and pressures are being experienced by numerous residents in our region… the need for rural water service in the area has become apparent to and a top priority of the County Commission and McKenzie Water Resource District (MCWRD)." [76]

The Regional Water Service option, currently in negotiation between the city of Williston and MCWRD, would provide about 4 million gpd to Watford City, and to many rural water users. **The proposed service would include four water depots for oil-field use, including three along the pipeline (one south of Alexander) and one at Watford City.** The proposed service areas are shown on Figure 18.

The proposed cost estimate is $29,875,000.[77] If authorized, water conveyance from Williston to a reservoir nine miles south of Williston could be completed by the fall of 2010 and in service by spring of 2011. The entire service project could be completed and in operation by the spring of 2012.

---

[74] As of June 30, 2010, Ray&Tioga has signed a letter of support for a regional water system "centered on the Missouri River and the Williston Regional Water Treatment Facility as a source for the regional water demands," addressed to Governor Hoeven, and requesting cost share for an estimated $127 million water supply project.

[75] AE2S. Dec. 23, 2009. *Fact sheet*: McKenzie County Water Development Projects Summary, System I, System IV, and Regional Water Supply Improvement Projects. 1 p.

[76] Ibid.

[77] Ibid.

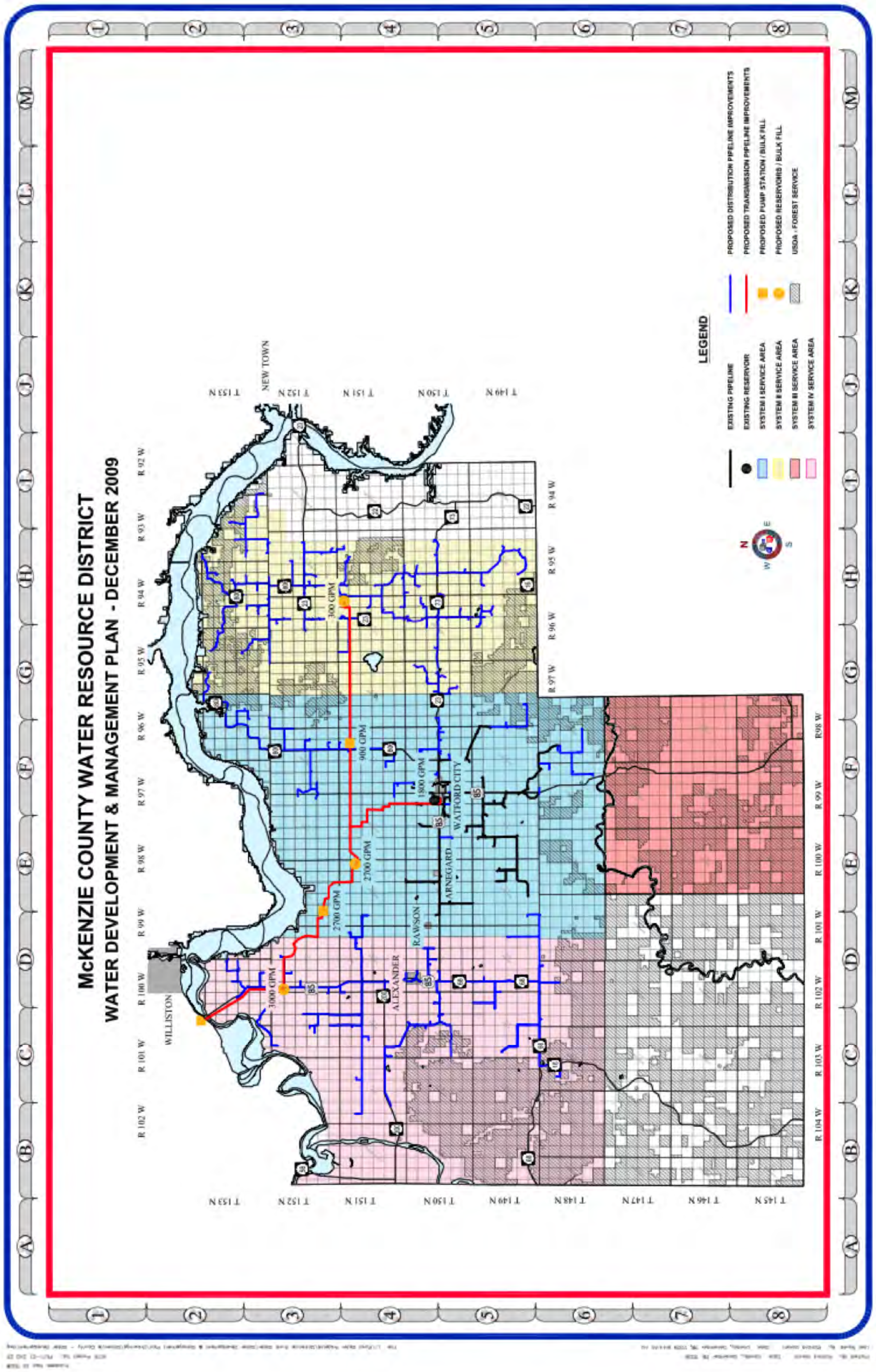


Figure 18. Proposed Regional Water Service for McKenzie County.[78]

---

[78] Map provided by Cory Chorne, AE2S. E-mail communication. Jan. 26, 2010.

## *Summary of Potential Water Supplies for North Central and Northwest North Dakota*

- The NAWS East Water Supply pipeline project, as currently designed and planned, does not have strong potential for substantial industrial use expansion. Temporary water supplies are from ground water, and are limited. Delivery of Lake Sakakawea water is presently delayed by litigation, and with a timely resolution of legal concerns would still be unavailable until about 2015, pending completion of construction. In addition, demands of prospective water users that have agreed to use NAWS water will require most of the planned water-supply capability. There may be some potential for "off-peak" use. Use of NAWS water in the East Water Supply System may additionally free some ground water currently in use for other beneficial uses.

- The area served by the Parshall-Fort Berthold Water Supply may have capacity to provide as much as about 2.5 million gpd (2,800 acre-feet per year) additional water for energy industrial use, through expanding treatment capability to the conveyance capacity, and through use of the previous 0.5 million gpd capacity of the previous intake as salable raw water.

- The Ray and Tioga Regional Water System uses a ground-water source and has poor prospects as a future source for substantial energy-industrial use. Implementation of plan options for drawing 3 million gpd or 5 million gpd from Lake Sakakawa would allow for substantial industrial use, perhaps as much as 2.5 million gpd (2,800 acre-feet per year). There are no current plans for using the lake source. A further source of funding for expansion and use would be needed to encourage implementation of the lake options.

- The city of Williston has expanded its water supply capacity, and is capable of supplying up to 4-million gpd (4,500 acre-feet per year) above current demand with current capacity, and as much as 8 million gpd (9,000 acre-feet per year) with further expansion of its water treatment plant capacity to 14-million gpd. Additional "off-peak" water supplies of as much as 7-million gpd (7,800 acre-feet per year) to 11-million gpd (12,300 acre-feet per year) may be available for use by energy industries.

- The McKenzie County Rural Water District is currently planning to provide up to about 4-million gpd to municipalities, industries and residents in its service area, including pipelines to Watford City and outlying areas using Williston water. The plans would include at least four water depots for use by the oil industry, including one south of Alexander and one at Watford City. Water may be available at a reservoir nine miles south of Williston as early as the spring of 2011. With funding, the full project could be completed by the spring of 2012.

- The McKenzie County Rural Water District would likely use the 4 million gpd additional water supply capacity achieved by Williston. An additional 4 million gpd could be made available with expansion of treatment capacity. There are currently no firm plans for service of lake water to the northern Burke-Williams/Divide county areas (Fortuna, Crosby, Bowbells – along HWY 5). These communities will be supplied using ground water, and have limited potential for substantial industrial water use expansion. Similarly, there are no current plans to service the Grenora through Powers Lake areas – along HWY 50) using Williston water. These areas also have limited potential for industrial water use. New sources of financing, or other independent suppliers would be necessary to supply substantial amounts of lake water for use in the energy industry in these areas.

## Potential Use of Southwest Pipeline Project Water for Energy Industries in Southwestern North Dakota

One potential distribution system for Missouri River water is the Southwest Pipeline Project (SWPP). The SWPP "is a state-owned project administered by the North Dakota State Water Commission and is operated and maintained by the Southwest Water Authority (SWA). The pipeline transports raw water from Lake Sakakawea to Dickinson where it is treated and delivered to the project's customers in southwest North Dakota."[79] A new water treatment plant is being constructed near Zap to service the northeast portion of the service area. There are two pipelines, one "raw water" pipeline passing through the Zap Reservoir to Golden Valley, Dodge and Richardton to Dickinson, and the "treated water" distribution system which distributes water after treatment at Dickinson. Water can be supplied by both systems, although the treated water is more extensively distributed. The distribution of treated water is, or will soon be extended into the "Trotter's Pocket," Fairfield, Grassy Butte, and West Killdeer Mountain areas (Figure 12, p. 49).[80]

### *Industrial Use of SWPP Water*

The legislature's statement of purpose for the SWPP included industrial use:

> "the legislative assembly finds that adequate water supplies for municipal, domestic, livestock, rural, irrigation, industrial, and other uses are essential for social stability and economic security of the people of the state of North Dakota."[81]

The statement of authorization for the SWPP, however, referred only to "supplementation of the water resources of a portion or the area of North Dakota south and west of the Missouri River…for multiple purposes, including domestic, rural, and municipal uses."[82] While the SWPP mission did not exclude industrial use, it was not a part of the initial planned customer base. The initial water permit (#3688) for the SWPP was for 17,100 acre-feet of water at a maximum pumping rate of 10,590 gpm for municipal use and rural domestic use. No water was permitted for industrial use. Under state law, water permitted for domestic, municipal, livestock, or irrigation use cannot be transferred to industrial use, which is a lower priority. Thus, while energy industries could be supplied by the SWPP infrastructure, a separate water permit would be required.

### *Red Trail Energy*

In 2004 Red Trail Energy applied to the SWC for a water permit to use 968 acre-feet per year at a pumping rate of 600 gpm from the Fox Hills aquifer as a supply for an

---

[79] Massad, Mary. 2008. Annual Operating Report, Southwest Water Authority. pp. 10-13.

[80] Ibid.

[81] N.D.C.C. 61-24.3

[82] Ibid.

ethanol plant at Richardton. The aquifer capabilities were found to be inadequate to meet their needs. Red Trail Energy then requested that their water be supplied by SWPP. To supply Red Trail, and other current and potential industrial water users, the Water Commission obtained, on behalf of the SWPP, a second water permit (#5754), requesting authorization to appropriate 1,130 acre-feet of water annually from Lake Sakakawea, at a 700 gpm rate of withdrawal, for industrial use.

In 2008 total reported industrial use by the SWPP was 516.9 acre-feet, of which 505.8 acre-feet was supplied from the raw water source to Red Trail Energy, and another 11.1 acre-feet was supplied to two other small industrial users. This leaves a potential margin of 613 acre-feet for further industrial allocation by SWPP. While other industries, energy-based and other, may apply for the use of this water, Red Trail Energy is currently operating at only partial capacity. Additional water will likely be needed from the SWPP, or from other sources, to enable full operation of Red Trail's ethanol plant.

### *Potential Use of SWPP Water for Oil Field Applications*

High quality water is needed for brine dilution and "fracing" fluid during the drilling and development of oil wells. As indicated on Figure 12 (p. 49), the SWPP distribution system is extensive and has breakout points in relatively close proximity to some petroleum exploration and production locations south of Lake Sakakawea. The potential use of SWPP water for oil-field development would be affected, from a practical standpoint, by four factors: (1) the quantity of uncommitted water available for use; (2) the actual use of committed water by individual contractors; (3) limitations imposed by the industrial water permit (#5754); and (4) potential expansion of water supply capabilities.

Local capacity varies widely, with some areas having residual delivery capacity, while others are fully saturated. Additional capacity based on physical capacity and current agreements has been estimated at about 200 gpm. This water could be available and contracted for oil-field use at some locations, provided that the physical capacity to deliver the additional water is available at a given distribution point.

Even if all of the water is contracted, however, at any given time there may be a difference between contracted water and actual use at a specified distribution point. Some contractors may be using less water than they have contracted. Examples of under use by some service areas are shown on Table 11. Because oil-field use of raw or treated water is temporary with respect to each new well, it may be feasible to access unused SWPP water under contract for municipal or domestic use, at some times in some locations. For example, a contractor may "sell" unused contracted SWPP water for oil-field use. In addition, the unused margins on Table 11 are annual summaries. There may be short-term periods of low use within the year that would allow for larger rates of pumping for short periods of time. Arrangements for sale terms would have to be made between the SWA, the Water Commission, and the contractor for the desired outlet.

Table 11. Actual 2007 use and 2008 allocated use of SWPP water for five service areas in southwestern North Dakota (from Table 5A of BAW/B).[83]

| Service Area | 2007 total use gpm | 2008 allocated use gpm | Unused Water gpm |
|---|---|---|---|
| Beach | 289 | 377 | 88 |
| Belfield | 120 | 132 | 12 |
| Fairfield | 4 | 176 | 172 |
| Fryburg | 416 | 464 | 48 |
| Halliday | 84 | 125 | 41 |
| Bowman | 180 | 195 | 15 |

A sale by subcontract, or other arrangement, of SWPP water for oil-field use would not be allowed under an existing contract for municipal or domestic use under water permit #3688. It would be necessary for the contractor to negotiate another agreement with the SWPP to temporarily transfer some of their use allocation to the industrial use "pool" authorized under water permit #5754. This would be feasible only if total water allocated for industrial use is less than 1,130 acre-feet. Otherwise, a new water permit for expanded industrial use would be required. The industrial-use pool is not being fully utilized as of August 2009 (about 600 acre-feet per year are unused), but these conditions could change, depending on other requests.

As an example of this type of arrangement, the Southwest Water Authority was approached by Power Fuels (of Watford City) in early 2008 about the availability of raw water from the SWPP. Power Fuels proposed a truck filling station along the project raw water transmission facilities which would provide water to be used for fracturing oil-bearing strata at remote oil drilling sites. A hydraulic analysis was completed which indicated that Power Fuels could receive some water without unduly impacting other users. The SWA subsequently offered Power Fuels a water use contract allowed them a temporary allocation of 200 gpm. As of this date this contract has not been executed by Power Fuels. Higher flow rates than 200 gpm could be available through the use of storage facilities which could be filled during off-peak times and would then allow higher pumping rates to fill trucks. A similar concept for water supply could be employed for unallocated, or allocated but unused water at other withdrawal points along the raw, or treated water lines. Because water use varies, this possibility would need to be examined on a case-by-case basis.

Finally, an important consideration is the delivery capability at a given distribution point. End-line taps; such as field taps for livestock or homes would likely be able to deliver low flows of about seven gallons per minute.

---

[83] Bartlett and West, Inc./Boyle Engineering corporation. July 2008. System Improvement Study for Raw Water Main Transmission Line Facilities of the Southwest Pipeline Project. W.O. No. 3033.01. North Dakota State Water Commission Project 1736. 3456 East Century Ave., Bismarck, ND, 58501.

### *The Proposed Great Northern Power Development Coal Gasification Plant*

Great Northern Power Development (GNPD), LP, announced in December of 2008, that it would construct a new coal gasification plant at South Heart, ND, west of Dickinson. Additional needed water capacity was initially estimated at flow rates of 250, 500, and 750 gpm, for a combined air-cooled and water-cooled facility. Great Northern later requested 1,000, 1,500 and 2,000 gpm for a fully water-cooled facility. The proposed lower rates may be feasible under the limitations of water permit # 5754. The higher rates would not. In addition, delivery capacity for SWPP water would be surely limiting in the upper range, and would likely be limiting in the lower range of flow rates requested as well. Under the current industrial water permit and pipeline constraints, Great Northern water use may also constrict eventual full use of the existing Red Trail Energy ethanol plant.

### *Potential Expanded SWPP Capacity for Industrial Use*

The request of the prospective GNPD coal gasification enterprise, possible additional water use rates of up to 1,042 gpm for anticipated growth of the city of Dickinson, and a potential additional need for between 233 gpm and 2,233 gpm for new users, including rural customers, commercial, industrial, and livestock use, have initiated an evaluation of the possible expansion of current SWPP capabilities. Considering these needs the SWC authorized Bartlett and West Inc./Boyle Engineering Corp (BAW/B) to study the capability for existing raw water facilities to provide additional flows.

The BAW/B report concluded that at least 12,725 gpm at the intake (an increase of 1,725 gpm) and 9,850 gpm (an increase of 700 gpm) south of the Zap Reservoir can be realized without the need for parallel piping, except for 385 feet of parallel piping required at the Dickinson Water Treatment Plant.[84] In addition, it was estimated that capacity at the intake could be increased to 13,475 gpm (an increase of 1,975 gpm), and 10,600 gpm (an increase of 1,450 gpm) downstream of the Zap Reservoirs by adding only 1.13 miles of parallel pipe.

Graduated additional flow and cost options provided by BAW/B are shown on Table 12. A slight (50 gpm) difference from BAW/B's reported table[85] is due to a correction from 9,100 gpm base flows south of Zap, to 9,150 gpm provided as a footnote by BAW/B. Results generally indicated that beyond the Zap Reservoir, increased flows of up to 700 gpm can be obtained with relatively small additional modification and cost (about $5.5 million). Above 700 gpm, incremental costs increase. A maximum additional flow of about 4,000 gpm (3,975 gpm on Table 12) could be obtained for about $42 million. Above 4,000 gpm, substantial additional infrastructure is needed and costs would be much higher. In their report, BAW/B that: "It is our opinion that any flow rate in excess of QMB+4,025[86] would likely involve complete separate pumping stations, as

---

[84] Ibid.

[85] Ibid, p. 1.

[86] QMB [Modified Base Flow (Q)] indicates the current carrying capacity of the SWPP pipeline.

well as a separate, large size, intake structure and significant lengths of parallel piping."[87] They further suggested that "significant up-front costs could be deferred into later years, as the system grows, by investing capital in the pumping infrastructure and phasing in the parallel piping segments as the demand for additional capacity increases." Any further expansion of the raw water supply would require an additional water permit appropriately defined for the prospective new use, and a new agreement with Basin Electric Cooperative for increased use of their inlet.

If physical capabilities are limiting, up to 700 gpm of additional water could be transported to the Dickinson treatment plant with relatively minor additional infrastructure costs. Larger-scale modifications in SWPP infrastructure to accommodate major energy production facilities, like the proposed GNPD facility in South Heart, could also be used to enhance water supplies for oil-field use at some locations.

Table 12. Estimated capability and cost for an additional raw water supply for the Southwest Pipeline Project. (Adapted from a table in the executive summary prepared by BAW/B.)[88]

| Intake to Zap Reservoir gpm | Zap Reservoir To Dickinson gpm | Additional Transmission gpm | Additional Annual Flow* Acre-feet | Additional Cost $(millions) |
|---|---|---|---|---|
| 11,600 | 9,150 | 0 | 0 | 0 |
| 11,975 | 9,150 | 0 | 0 | 0 |
| 12,225 | 9,350 | 200 | 323 | 3.9 |
| 12,475 | 9,600 | 450 | 726 | 5.3 |
| 12,725 | 9,850 | 700 | 1,129 | 5.5 |
| 13,475 | 10,600 | 1,450 | 2,339 | 12.8 |
| 14,000 | 11,125 | 1,975 | 3,186 | 19.8 |
| 15,000 | 12,125 | 2,975 | 4,799 | 31.2 |
| 16,000 | 13,125 | 3,975 | 6,412 | 42.1 |

## Missouri River Water: A Proposed McClusky - New Rockford Canal Water Supply Corridor

The original plan of the Garrison Diversion Project was to supply water for one million acres of irrigation. The initial supply system, which was to include the Snake Creek Pumping Plant, Lake Audubon, the McClusky Canal and the New Rockford Canal was designed for a quarter of that project total (250,000 acres of irrigation). The New Rockford Canal is empty and disconnected from a water supply through the McClusky Canal, but the McClusky Canal is capable of carrying water. The design capacity of the McClusky Canal is 1,950 cfs, which under constant flow could supply 1.4 million acre-feet per year, or about 350,000 acre-feet in a three-month period, with a planned water

---

[87] Op cit. Massad.

[88] Op cit. Bartlett and West, Inc./Boyle Engineering Corporation.

level in Lake Audubon at the inlet of 1,850 feet above mean sea level (amsl). Due to erosion impacts on the islands in Lake Audubon, the water-level elevation has been reduced to 1,847 feet amsl. The lower inlet elevation would reduce somewhat the carrying capacity of the McClusky Canal.

The Secretary of the Interior is authorized to develop irrigation in the following project service areas: Turtle Lake service area (13,700 acres); the McClusky Canal service area (10,000 acres); with stipulations, the New Rockford Canal service area (1,200 acres); and up to 28,000 acres of irrigation in other areas of North Dakota that are not located in the Hudson Bay/Devils Lake drainage basin or James River drainage basin.

Using a maximum allocation of 1.5 acre-feet per acre irrigation (the Bureau of Reclamation does not place this limit on its allocations, but it is a reasonable assumption), the 250,000-acre supply capacity might be estimated at 375,000 acre-feet, close to the estimated three-month seasonal carrying capacity of 350,000 acre-feet. Of this, a typical large project would be designed to supply around 2/3 of the irrigated acres at one time,[89] so a reasonable adjusted estimate would be about 250,000 acre-feet. Of this amount, 23,700 acres of irrigation have been allocated along the McClusky Canal. At an allowance of 1.5 acre-feet per acre, the equivalent maximum "call" on water would be about 41,000 x 2/3 = 27,300 acre-feet. The U.S. Bureau of Reclamation (Bureau) is currently authorized to supply water for 28,000 additional acres of irrigation (assume an additional 42,000 x 2/3 = 28,000 acre-feet per year), which may or may not be supplied through the Snake Creek Pumping Plant.

After considering several options for a Red River Valley Water Supply Project (RRVWSP), the "preferred alternative" proposed by the Bureau is to transfer up to about 82,345 acre-feet of water per year, at a rate of 120 cfs, to the Red River Valley. The simulated average future conveyance for use in the Red River Valley is about 30,000 acre-feet, based on 70 years of past climate data.[90] The proposal includes removing and treating the water at Hoffer Lake mile, mile marker #57 on the McClusky Canal, about 2¾ miles northwest of the town of McClusky, and piping it to the Sheyenne River for transport to the Valley. The "preferred alternative" has not been accepted or authorized at this time. However, for the sake of a general water capacity budget, if we assume a maximum supply capacity of about 350,000 acre-feet of water per year, and account for 82,000 acre-feet for the Red River Valley, 27,300 currently allocated for irrigation, and a possible maximum additional 28,000 acre-feet allocated for future irrigation, a maximum of about 212,700 acre-feet of water may be available for other use from the McClusky Canal. More would be available if the projected average use (30,000 acre-feet) is used to estimate the Red River Water Supply requirements, rather than maximum transfer. However, actual available water may be substantially less after accounting for seepage and evaporation losses. **While the exact quantity of water is difficult to determine, it seems reasonable to conclude that a substantial amount of water would be available for beneficial use along the McClusky-New Rockford Canal corridor.**

---

[89] Weigel, Jim. Sept. 15 2009. Written review comments.

[90] Hiemenz, Greg. 15 2009. Written review comments.

**Although industrial use is not a part of the current Bureau plans, it is not unreasonable to consider that the McClusky Canal might provide a "corridor" for industrial use, and specifically for energy industries within a reasonable distance of the Canal itself between its inlet at Lake Audubon and the town of McClusky**.

In addition, four other possible options for extended corridors of McClusky Canal waters might be suggested as extended corridors for water use in energy development. These include:

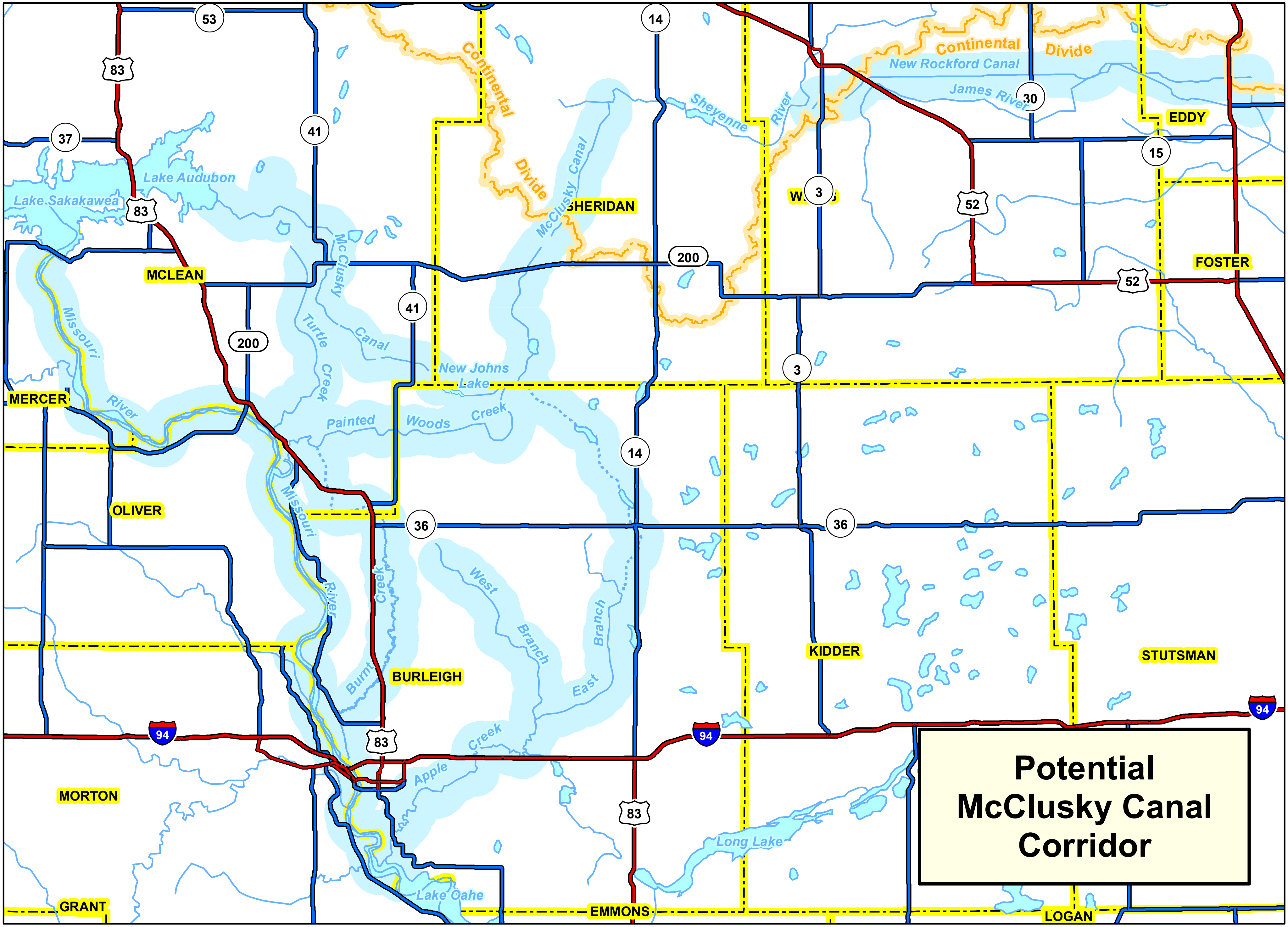
(1) Supplying water from the McClusky Canal at mile marker 7 of the Canal, through Turtle Creek, which drains to the Missouri River.

(2) Supplying water from the McClusky Canal at approximately mile marker 36 on New Johns Lake, through Painted Woods Creek, which drains to the Missouri River through Burleigh County.

(3) Supplying water from the McClusky Canal at mile marker 38-42 of the Canal, east of New Johns Lake, through Apple Creek, which drains to the Missouri River through Kidder and Burleigh Counties. This proposal would require pumping.

(4) Most of the dry New Rockford Canal lies within Wells County, which is within the Missouri River watershed. The New Rockford Canal may not, therefore, be problematic as a distribution system, from the standpoint of inter-basin transport to the Hudson Bay Basin. However, U.S. Public Law 89-108 authorizing the Garrison Diversion Project specified that "any water systems authorized under this Act to deliver Missouri Water to the Hudson Bay basin…..must determine that adequate treatment can be provided to meet the requirements of the Treaty between the United States and Great Britain relating to Boundary Waters …" Compliance measures would need to be worked out through legal analysis and negotiation by appropriate parties. Transport of water from the McClusky Canal to the New Rockford Canal, however, would have to transverse the Divide between the Missouri River and Red River Basins, and may require special measures, such as water treatment at the McClusky Canal outlet and enclosed conveyance. As an additional consideration, under the Dakota Water Resources Act of 2000, the Secretary of the Interior is authorized to construct "industrial water systems to serve areas throughout the State of North Dakota" but may not authorize irrigation water use in the James River Basin in excess of water required for the Oakes

# Potential McClusky Canal Corridor



> Test Area (5,000 acres). Some clarification of limitations for water use in the James River Basin using the New Rockford Canal may be needed.[91]

*It is important to point out that the proposed McClusky Canal and related "corridors" are presented as possibilities. While most of the options above have been considered in the past, we are unaware of any current plans by the Bureau of Reclamation, the Garrison Diversion Conservancy District, or any other entity to implement any of the options presented.*

One caveat on the delivery capacity of the McClusky Canal is that landslides from mile markers 20 to 22 have damaged the Canal. Repair options being considered by the Bureau include: (1) a 1,000 cfs option (about half the design capacity of 1,950 cfs), and (2) a 500 cfs option. Of the authorized irrigation water use, 13,700 acres is located upstream of the slide area, and would therefore not be affected by it. The location of the 10,000 acres authorized for irrigation development adjacent to the Canal has not been identified and may be above and/or below the slide. It may be presumed, but not necessarily assumed, that the repair would include sufficient capacity to meet the Red River Water Supply Project needs. Sufficiency to meet current demand would cause a bottleneck in the Canal for future development. However, a two-to three-mile segment of canal could be repaired and extended at a later date.

**In conclusion, a substantial amount of Missouri River water, tens of thousand of acre-feet or more,may be available for beneficial use along a corridor defined by the McClusky and New Rockford Canals. Further clarification of federal and state laws and policies related to use of the canals would be needed if this option were pursued.**

## Potential Water Supplies from the Heart River System

Flows of western rivers are highly variable and subject to drought, and normally cannot provide dependable water supplies for industry without substantial reservoir storage capacity. Of these, the Heart River system contains two reservoirs that provide long-term storage, Patterson Lake near Dickinson, and Lake Tschida near Glen Ulen. While some water is available for development from Lake Tschida, it is locked in an irrigation permit and cannot be used for energy development.

The original Conditional Water Permit (#250) for Patterson Lake and Lake Tschida, which was filed by the U.S. Bureau of Reclamation, has a priority date of March 13, 1946. The application requested 7,000 acre-feet for storage in Patterson Lake, and 162,000 acre-feet of storage for Lake Tschida. The application requested water for

---

[91] Dakota Water Resources Act of 2000, Pub. L. No. 106-554, Appendix. D, Title VI, 114 Stat. 2763A-281, §§ 602, 605, 607.

irrigation of 800 acres from Patterson Lake, and 13,538 acres from Lake Tschida.[92] The Certificate of Completion of Works[93] specifies that works on Patterson Lake are also sufficient to provide 1,100 acre-feet for municipal use by Dickinson, and 800 acre-feet of expanded use by Dickinson, with a reserve of 4,200 acre-feet for ultimate use.

### Potential Water Development from Lake Tschida

In 1979, Perfected Water Permit #250 was split into two separate permits: #250A for Patterson Lake, and #250B for Lake Tschida. The Perfected Water Permit for Lake Tschida,[94] dated July 3, 1979, authorized 75,785 acre-feet of water for storage and 13,538 acres of irrigation. Through a series of extensions of the time required for completing beneficial use of the water, the Water Commission and the Bureau of Reclamation have agreed upon the eventual development of 13,100 acres of irrigation out of the 13,538 acres requested under Perfected Water Permit #250B.[95] As of February 12, 1991, the Bureau of Reclamation had developed 6,294 acres for irrigation, and an environmental assessment (EA) resulted in a Finding of No Significant Impact (FONSI) for the 10,000-acre development option. The 10,000 acres was and is not intended by Reclamation to be the upper limit of development of irrigation below Lake Tschida. It has been proposed that additional environmental surveys and studies will be completed as development approaches 10,000 acres and prior to proceeding with irrigation development up to the original authorized level of 13,100 acres. As of 2007, 7,269 acres were reported to be under irrigation. **This leaves a current margin of water equivalent to the irrigation of 5,800 acres, and at least 5,800 acre-feet of water by a conservative (1 foot per acre) estimate, available for beneficial use from Lake Tschida.** The beneficial use, however, is currently locked in Perfected Water Permit (#250B) for irrigation, a higher use than industrial use under state law, with a priority date in 1946. It cannot, therefore, be transferred for use by the energy industry unless an undeveloped portion of Water Permit #250B is canceled, a new permit application is filed for the unused portion, and an agreement for access to the water is arranged with the Bureau of Reclamation. **Although the FONSI (1991) has indicated that withdrawal of sufficient water to affect development of 10,000 acres (an additional 2,731 acres) of irrigation would not adversely affect the reservoir, and although the current intent is still to fully develop 13,100 irrigation acres (an additional 5,831 acres), opposition of recreational users to application of the remaining water for industrial use would likely be strong.**

---

[92] Comstock, H.D. June 29, 1947. Application for a permit to divert and appropriate water of the state of North Dakota. Water Permit File #250A, or Water Permit File #250B. North Dakota State Water Commission, Bismarck, ND.

[93] Certificate of the Completion of Works. November 30, 1957. Water Permit File #250A or #250B. North Dakota State Water Commission, Bismarck, ND.

[94] Perfected Water Permit No. #250B. July 3, 1979. North Dakota State Water Commission, Bismarck, ND.

[95] Odenbach, Craig. March 26, 1991. Memorandum to David A. Sprynczynatyk, State Engineer. RE: Permit # 250B – Extension request. Water Permit File #250B. North Dakota State Water Commission, Bismarck, ND.

## Potential Water Development from Patterson Lake

Potential use of water from Paterson Lake for energy development is mainly tied to the city of Dickinson's change of source from Patterson Lake to the Southwest Pipeline. The application for Water Permit #250 requested 7,000 acre-feet of storage, of which 800 acre-feet was to be used for irrigation.[96] The Certificate of Completion of Works[97] cited capacity for 900 acres of irrigation, 1,100 acre-feet for the city of Dickinson, and 800 acre-feet of reserve water for Dickinson (assuming one acre-foot per acre of irrigation, a total of about 2,800 acre-feet), with a 4,200 acre-foot reserve for "ultimate use." It would appear that the intended use was 2,800 acre-feet for the Dickinson water supply and irrigation, with the rest held in reserve. The Perfected Water Permit #250A (July 3, 1979) granted a total of 7,000 acre-feet for "storage in the Dickinson reservoir," and specified only that "380 acres to be irrigated out of the Dickinson reservoir with the remaining to be used for the city of Dickinson."[98] The intended total use is not specified, and would appear to be, from the permit alone, the entire 7,000 acre-feet of storage. However, the previous Certificate of Completion of Works indicates a more probable intention to use about 3,000 acre-feet. This seems to be confirmed by a 1995 review of actual Bureau allocations which indicated that the "water is allocated in the order: (1) city of Dickinson – 1,100 acre-feet; (2) Mutual Aid Corp. – 900 acre-feet; (3) city of Dickinson – 900 acre-feet from Perfected Water Permit #250 A, a total of 2,900 acre-feet."[99]

An additional Conditional Water Permit (#3216) having a priority date of February 11, 1980, was granted for additional storage of 3,493 acre-feet of water from Patterson Lake for "municipal, industrial, recreation, fish and wildlife purposes."[100] The context of the permit would indicate that the intention was to use up to the full 3,493 acre-feet, employing the same initial reserve specified on Perfected Water Permit #250A. The 1995 review cited above indicates that as of January 26, 1995, 900 acre-feet of the 3,493 acre-feet permitted had been allocated to the city of Dickinson. Dickinson's total allocation was thus 2,900 acre-feet.

The water use reports from the Bureau of Reclamation do not separate irrigation and municipal use, but from 1977 through 1991 they range consistently between a minimum of 1,858 acre-feet to a maximum of 3,105 acre-feet, with a median value of 2,470 acre-feet. In 1991, Dickinson transferred its water supply from Patterson Lake to the Southwest Water Authority. From 1992 through 2007, with the exception of two years (1993 and 1994), all reported water use for Perfected Water Permits #250A and #3216 combined are within a range common to irrigation alone (0 to 414 acre-feet, with a median of 91.5 acre-feet). From 2000 through 2007 median acreage irrigated was 238,

---

[96] Op Cit. Comstock.

[97] Op Cit. Certificate of the Completion of Works. Water Permit File #250A or #250B.

[98] Perfected Water Permit No. 250A. July 3, 1979. Water Permit File #250B. North Dakota State Water Commission, Bismarck, ND.

[99] SWC Water Permit File #250A.

[100] SWC Water Permit File #3216.

with range of 231 to 243 acres. Following 1995, water use by the city of Dickinson was negligible.

**It would appear that as much as 3,493 acre-feet, the amount of the additional storage granted under Conditional Water Permit #3216, could be applied for industrial, as well as municipal, recreation, and fish and wildlife use, and was intended for use under the permit. It also appears that long-term median annual use of 2,470 acre-feet, with a maximum of 3,105 acre-feet, has been mostly vacated by Dickinson's shift to the SWPP as its primary water source. Because Conditional Water Permit #3216 is a general use permit, this amount could be available for other beneficial uses, including industrial use, if agreed upon and allocated by the Bureau of Reclamation.** Considerable opposition to redevelopment of this water might be expected from recreational interests.

Elsewhere on the Heart River, water is heavily appropriated for irrigation and livestock use. While some additional appropriation may be available for irrigation at some locations, and under limited circumstances, the Heart River waters not regulated by the reservoirs would be undependable for uses in the energy industries which require a steady, dependable supply.

## Surface-Water Storage and Use

Except for the Missouri River system, most of the state's surface waters are heavily appropriated and are not good prospects for large-scale long-term sustainable water supplies. For many of the state's rivers, however, there are seasonal flows that are not being captured and used. With appropriate capture and storage these waters could be retained and used. Possible storage techniques would include surface storage and aquifer recharge and recovery.

The use of aquifer recharge and recovery technology (ARR) has been investigated as a means of storing excess spring flows for use throughout the year. ARR can be implemented where an aquifer is near a surface-water source. For unconfined aquifers, water is pumped from the river and infiltrated into the aquifer through an infiltration basin, and later recovered through wells. For confined aquifers, water is pumped into the aquifer using injection wells. Pretreatment of water to avoid sediment clogging and biological and chemical fouling is particularly critical for injection wells. Raw water, pumped directly from the surface-water source, can usually be used for surface infiltration basins. ARR has been used by the cities of Valley City and Minot at various times to augment their water supplies. From 1993 to the present, the Forest River Hutterite Community has used seasonal spring flows from the Forest River to place as much as 1,000 acre-feet per year in the aquifer for later irrigation use (Schuh and others 2009A).

Figure 19. Aquifer recharge and recovery basin operated by the Forest River Hutterite Community to store and use high flows from the Forest River.

Feasibility and methods for ARR have been investigated thoroughly in North Dakota (Schuh and Shaver 1988, Schuh 1990, Schuh 1991, Shaver and Schuh 1988, Shaver 1989, Shaver and Schuh 1989a, Shaver 1990, Cline and others 1993, Shaver and Wucetich 1994, Schuh and others 2009a, Schuh and others 2009b). In general, ARR methods can be used to store water for one to three years, depending on local conditions. In most cases, longer retention results in losses through natural discharge areas. Although ARR has been shown to be an effective method for storing and recovering water, potential applicants must consider the probability distribution for availability of usable waters in the surface-water source, particularly the dry years. They should also consider the chemical compatibility of recharge waters and those of the receiving aquifer, the potential time retention of recoverable storage in the aquifer, and the recoverability of the water. These issues are all treated in the above cited sources, which are available through public libraries, and most of which are available through the North Dakota Water Commission web site "Reports and Publications" section.[101]

---

[101] http://intranet.swc.nd.gov/4dlink9/4dcgi/GetCategoryRecord/Reports%20and%20Publications

# Citations

Cline, R.C., C. Odenbach, P. Schutt, and W.M. Schuh. 1993. Feasibility of stabilization and expansion of water use from the Englevale aquifer using water conservation, well field modification, and artificial recharge. Water Resources Investigation No. 23. North Dakota State Water Commission. Bismarck, ND. 151 pp.

Ripley, David. March 20-21, 1990. An overview of North Dakota's water resources. Proceedings of the North Dakota Water Quality Symposium. NDSU Extension Service. Fargo, ND. pp. 1-15.

Schuh, W.M. and R.B. Shaver. 1988. Feasibility of artificial recharge to the Oakes aquifer, southeastern North Dakota: evaluation of experimental recharge basins. Water Resources Investigation No. 7. North Dakota State Water Commission. Bismarck, ND. 248 pp.

Schuh, W.M. 1990. Seasonal variation in clogging of an artificial recharge basin in a northern climate. J. Hydrol. 121:193-205.

Schuh, W.M. 1991. Effects of an organic mat filter on artificial recharge with turbid water. Water Resour. Res. 27:6:1335-1344.

Schuh, W.M., D.L. Klinkebiel, J.C. Gardner, and R.F. Meyer. 1993. Tracer and nitrate movement to groundwater in the Northern Great Plains. J. Environ. Qual. 26:1335-1347.

Schuh, W.M., J. Patch and Ben Maendel. 2009a. The planning, construction and operation of an aquifer recharge and recovery infiltration basin in Grand Forks County, North Dakota. Water Resources Investigation No. 47. North Dakota State Water Commission. Bismarck, ND. 80 pp.

Schuh, W.M., and J. Patch. 2009b. Retention of aquifer recharge and recovery water in a shallow unconfined aquifer: simulations of a basin recharge and recovery facility in Grand Forks County, North Dakota. Water Resources Investigation No. 48. North Dakota State Water Commission. Bismarck, ND. 109 pp.

Shaver, Robert B. 1989. Feasibility of artificial recharge to the Oakes aquifer, southeastern North Dakota: preliminary cost analysis of a project-scale and pilot-scale well field and artificial recharge facilities. Water Resources Investigation No. 8. North Dakota State Water Commission. Bismarck, ND. 113 pp.

Shaver, Robert B. 1990. An interim water supply for the Oakes aquifer test area of the Garrison Diversion Unit: evaluation and selection of well-field sites and well-field design. Water Resources Investigation No. 15. North Dakota State Water Commission. Bismarck, ND. 539 pp.

Shaver, R.B., and W.M. Schuh. 1988. Feasibility of artificial recharge to the Oakes aquifer, southeastern North Dakota. *In (Ed.) A.I. Johnson and Donald J. Finlayson, Artificial Recharge of Ground Water.* Proceedings of the International Symposium on the Artificial Recharge of Ground Water. ASCE. New York. pp. 74-84.

Shaver, R.B., and W.M. Schuh. 1989a. Feasibility of artificial recharge to the Oakes aquifer, southeastern North Dakota: hydrogeology of the Oakes aquifer. Water Resources Investigation No. 5. North Dakota State Water Commission. Bismarck, ND. 121 pp.

Shaver, R.B., and W.M. Schuh. 1989b. Feasibility of artificial recharge to the Oakes aquifer, southeastern North Dakota: Executive summary. Water Resources Investigation No. 8. North Dakota State Water Commission. Bismarck, ND. 79 pp.

Shaver, R.B. and Joe Wucetich. 1994. An evaluation of injection well plugging from a ground-water heat pump system in southeastern North Dakota. *In (Ed.) Johnson, A.I., and David G. Pyne, Artificial Recharge of Ground Water, II.* Proceedings of the Second International Symposium on the Artificial Recharge of Ground Water. ASCE. New York. pp. 720-731.

## POTENTIAL USE OF WASTEWATER FOR ENERGY INDUSTRY DEVELOPMENT IN NORTH DAKOTA

One possible water source, where other primary water supply sources are scarce, would be treated municipal wastewater. As explained under the section titled *Obtaining Water Rights for Energy Development in North Dakota (p. 9),* this means that water, once used and treated, need not be returned to the natural stream. The water may be reused and recycled indefinitely as long as it does not reenter a natural waterway. Once the wastewater has entered a natural waterway, it cannot be recovered for reuse without applying for a new conditional water permit.

Table 13. Total reported annual municipal wastewater (acre-feet per year) for major cities in North Dakota from 2004 through 2008.[102] (from data provided by Gary Haberstroh of the North Dakota Department of Health).

| Year | Beulah | Bismarck | Devils Lake | Dickinson | Fargo | Grafton |
|---|---|---|---|---|---|---|
| 2004 | 107 | 7,128 | 2,315 | 694 | 11,953 | 643 |
| 2005 | 125 | 6,855 | 1,360 | 461 | 12,821 | 579 |
| 2006 | 203 | 6,622 | 1,376 | 384 | 11,964 | 406 |
| 2007 | 114 | 6,713 | 788 | 267 | 12,699 | 524 |
| 2008 | 119 | 6,513 | 830 | 366 | 12,510 | 420 |

| Year | Grand Forks | Jamestown | Langdon | Mandan | Minot | USAF GFKS |
|---|---|---|---|---|---|---|
| 2004 | 6,916 | 2,574 | 509 | 1,694 | 2,139 | 483 |
| 2005 | 8,839 | 2,997 | 607 | 1,651 | 3,496 | 551 |
| 2006 | 5,299 | 2,113 | 426 | 1,636 | 4,458 | 158 |
| 2007 | 6,810 | 2,432 | 319 | 1,739 | 3,157 | 157 |
| 2008 | 6,435 | 2,090 | 319 | 1,699 | 2,738 | 212 |

| Year | USAF Minot | Valley City | Wahpeton | West Fargo | Williston |
|---|---|---|---|---|---|
| 2004 | 374 | 612 | 1,338 | 1,621 | 1,103 |
| 2005 | 602 | 377 | 1,482 | 1,728 | 1,146 |
| 2006 | 307 | 344 | 1,171 | 1,816 | 1,076 |
| 2007 | 201 | 472 | 1,287 | 1,927 | 1,295 |
| 2008 | 132 | 502 | 1,590 | 1,892 | 1,083 |

An example of municipal water reuse would be the Tharaldson ethanol plant at Casselton, which has been allocated a maximum of 4,489 acre-feet to be pumped at a

---

[102] Calculated from data provided by Gary Haberstroh. N.D. Department of Health. E-mail communication. Jan. 29, 2010.

maximum range of 2,782 gpm from Fargo's wastewater stream. On an average year (Table 13) a little more than 12,000 acre-feet of wastewater is released at Fargo. After the Tharaldson sale is completed, as much as 7,500 acre-feet of wastewater may be available annually for further sale and beneficial use. If Fargo's wastewater stream increases (Fargo has a considerable volume of unused water on its current perfected water permit) proportionately more water could be sold for reuse. A five-year record of total effluent wastewater for 15 North Dakota Municipalities and two air force bases is shown on Table 13. The minimum annual total wastewater supply from North Dakota's municipalities for 2004 through 2008 was 36,000 acre-feet. The median was 41,000 acre-feet. Much of this water may be available for beneficial use.

Table 14 shows wastewater from six North Dakota industries, including American Crystal Sugar at Drayton and Hillsboro, Cargill (Pro-Gold, Wahpeton), Minn Dak Farmer's Cooperative, Minnkota Power Cooperative, and the Tesoro Refinery at Mandan.

Table 14. Total reported annual wastewater (acre-feet per year) for six North Dakota industries.[103]

| Year | ACS* Drayton | ACS* Hillsboro | Cargill Wahpeton | Minn Dak** | Minnkota[#] | Tesoro |
|---|---|---|---|---|---|---|
| 2004 | 856 | 268 | 1,699 | 991 | 21 | - |
| 2005 | 729 | 254 | 1,117 | 1,176 | 77 | - |
| 2006 | 325 | 312 | 1,547 | 1,359 | 47 | - |
| 2007 | 512 | 358 | 1,251 | 1,000 | 13 | 598 |
| 2008 | 498 | 450 | 1,413 | 1,574 |  | 812 |

| | |
|---|---|
| * | American Crystal Sugar |
| ** | Minn Dak Farmers Cooperative |
| # | Minnkota Power Cooperative |

One concern in using wastewater is the distribution of the water supply. Wastewater discharge varies considerably within the year, and differs with each municipality. The intra-annual distribution of wastewater discharge for 14 North Dakota municipalities and two air force bases from 2004 through 2008 is summarized on Tables 15A through 15D. Where seasonal shortfalls in wastewater occur, conjunctive use of wastewater with other water sources may prove to be practical. For example, for some surface waters, non-appropriated flows may be available in winter to offset winter gaps in discharge. Similarly, sufficient ground water may be available for short-term winter use where ground-water supplies would be insufficient for year-round use.

---

[103] Ibid.

Table 15A. Monthly distribution of wastewater discharge (acre-feet) from 2004 through 2008 for North Dakota municipalities.[104]

| Municipality | Month | Sample Years | Mean | Median | Min | Max |
|---|---|---|---|---|---|---|
| Beulah | 4 | 2 | 60 | 60 | 48 | 72 |
| | 5 | 3 | 82 | 72 | 54 | 119 |
| | 6 | 1 | 83 | 83 | 83 | 83 |
| | 7 | 1 | 66 | 66 | 66 | 66 |
| | 11 | 3 | 38 | 48 | 12 | 54 |
| | 12 | 1 | 42 | 42 | 42 | 42 |
| Bismarck | 1 | 5 | 547 | 549 | 518 | 572 |
| | 2 | 5 | 500 | 505 | 477 | 515 |
| | 3 | 4 | 562 | 562 | 557 | 568 |
| | 4 | 5 | 639 | 537 | 522 | 1,049 |
| | 5 | 5 | 554 | 551 | 544 | 568 |
| | 6 | 5 | 576 | 555 | 551 | 644 |
| | 7 | 5 | 588 | 574 | 561 | 630 |
| | 8 | 5 | 597 | 590 | 560 | 636 |
| | 9 | 5 | 563 | 558 | 541 | 593 |
| | 10 | 5 | 570 | 567 | 555 | 597 |
| | 11 | 5 | 528 | 523 | 503 | 546 |
| | 12 | 5 | 655 | 551 | 518 | 1,082 |
| Dickinson | 1 | 4 | 10 | 11 | 8 | 12 |
| | 3 | 1 | 244 | 244 | 244 | 244 |
| | 4 | 6 | 31 | 14 | 10 | 116 |
| | 5 | 2 | 80 | 80 | 65 | 95 |
| | 7 | 6 | 91 | 19 | 8 | 294 |
| | 8 | 2 | 197 | 197 | 25 | 369 |
| | 9 | 1 | 347 | 347 | 347 | 347 |
| | 10 | 7 | 90 | 12 | 3 | 310 |
| | 11 | 2 | 96 | 96 | 7 | 185 |
| Fargo | 1 | 5 | 927 | 961 | 694 | 1,035 |
| | 2 | 5 | 872 | 862 | 806 | 922 |
| | 3 | 4 | 1,020 | 1,024 | 945 | 1,089 |
| | 4 | 5 | 886 | 1,008 | 533 | 1,099 |
| | 5 | 5 | 1,169 | 1,171 | 1,118 | 1,230 |
| | 6 | 5 | 942 | 1,027 | 372 | 1,348 |
| | 7 | 5 | 1,068 | 1,064 | 931 | 1,205 |
| | 8 | 5 | 1,198 | 1,073 | 969 | 1,778 |
| | 9 | 6 | 1,235 | 1,108 | 929 | 2,057 |
| | 10 | 6 | 860 | 1,037 | 190 | 1,096 |
| | 11 | 5 | 999 | 979 | 839 | 1,177 |
| | 12 | 5 | 999 | 1,021 | 959 | 1,028 |

---

[104] Ibid.

Table 15B. Monthly distribution of wastewater discharge (acre-feet) from 2004 through 2008 for North Dakota municipalities.[105]

| Municipality | Month | Sample Years | Mean | Median | Min | Max |
|---|---|---|---|---|---|---|
| Grafton | 5 | 3 | 211 | 236 | 144 | 255 |
| | 6 | 3 | 227 | 251 | 177 | 255 |
| | 11 | 5 | 251 | 270 | 155 | 324 |
| Grand Forks | 4 | 5 | 1,508 | 1,472 | 284 | 2,754 |
| | 5 | 4 | 1,213 | 1,138 | 419 | 2,159 |
| | 6 | 5 | 1,016 | 865 | 332 | 2,013 |
| | 7 | 3 | 443 | 490 | 20 | 817 |
| | 8 | 2 | 777 | 777 | 412 | 1,142 |
| | 9 | 4 | 650 | 529 | 379 | 1,165 |
| | 10 | 3 | 672 | 723 | 207 | 1,086 |
| | 11 | 5 | 1,080 | 1,027 | 526 | 2,101 |
| | 12 | 3 | 1,308 | 1,170 | 1,077 | 1,677 |
| Jamestown | 1 | 5 | 136 | 125 | 97 | 193 |
| | 2 | 5 | 121 | 114 | 71 | 170 |
| | 3 | 5 | 145 | 153 | 95 | 183 |
| | 4 | 4 | 204 | 205 | 157 | 249 |
| | 5 | 5 | 328 | 227 | 181 | 765 |
| | 6 | 5 | 178 | 174 | 123 | 249 |
| | 7 | 5 | 308 | 208 | 167 | 605 |
| | 8 | 5 | 189 | 217 | 96 | 227 |
| | 9 | 5 | 271 | 220 | 134 | 566 |
| | 10 | 5 | 283 | 241 | 162 | 475 |
| | 11 | 5 | 156 | 179 | 104 | 200 |
| | 12 | 5 | 125 | 126 | 100 | 163 |
| Langdon | 4 | 1 | 126 | 126 | 126 | 126 |
| | 5 | 4 | 96 | 104 | 57 | 117 |
| | 6 | 4 | 126 | 120 | 80 | 184 |
| | 7 | 2 | 106 | 106 | 95 | 117 |
| | 8 | 2 | 110 | 110 | 110 | 110 |
| | 10 | 3 | 100 | 110 | 80 | 110 |
| | 11 | 3 | 94 | 107 | 64 | 110 |
| | 12 | 2 | 77 | 77 | 61 | 92 |

---

[105] Ibid.

Table 15C. Monthly distribution of wastewater discharge (acre-feet) from 2004 through 2008 for North Dakota municipalities.[106]

| Municipality | Month | Sample Years | Mean | Median | Min | Max |
|---|---|---|---|---|---|---|
| Mandan | 1 | 4 | 145 | 147 | 122 | 164 |
| | 2 | 5 | 160 | 134 | 126 | 279 |
| | 3 | 5 | 141 | 139 | 136 | 147 |
| | 4 | 5 | 133 | 130 | 120 | 150 |
| | 5 | 5 | 141 | 142 | 136 | 147 |
| | 6 | 5 | 148 | 143 | 132 | 177 |
| | 7 | 5 | 148 | 150 | 139 | 154 |
| | 8 | 5 | 147 | 147 | 142 | 155 |
| | 9 | 5 | 139 | 140 | 134 | 143 |
| | 10 | 5 | 142 | 143 | 135 | 146 |
| | 11 | 5 | 136 | 136 | 131 | 142 |
| | 12 | 5 | 133 | 142 | 116 | 146 |
| Minot | 4 | 5 | 180 | 158 | 119 | 281 |
| | 5 | 5 | 392 | 315 | 211 | 866 |
| | 6 | 5 | 426 | 408 | 351 | 543 |
| | 7 | 5 | 453 | 490 | 271 | 618 |
| | 8 | 4 | 349 | 322 | 251 | 500 |
| | 9 | 4 | 354 | 311 | 266 | 527 |
| | 10 | 4 | 695 | 338 | 172 | 1,932 |
| | 11 | 4 | 391 | 382 | 351 | 451 |
| | 12 | 5 | 316 | 254 | 222 | 519 |
| USAF Grand Forks | 5 | 3 | 86 | 82 | 75 | 102 |
| | 6 | 4 | 90 | 82 | 82 | 117 |
| | 7 | 3 | 136 | 156 | 75 | 176 |
| | 8 | 2 | 78 | 78 | 75 | 82 |
| | 9 | 1 | 82 | 82 | 82 | 82 |
| | 10 | 2 | 99 | 99 | 82 | 117 |
| | 11 | 2 | 48 | 48 | 41 | 56 |
| USAF Minot | 1 | 0 | - | - | - | - |
| | 4 | 3 | 41 | 0 | 0 | 123 |
| | 5 | 4 | 46 | 0 | 0 | 183 |
| | 6 | 7 | 94 | 109 | 0 | 222 |
| | 7 | 3 | 45 | 0 | 0 | 134 |
| | 8 | 3 | 0 | 0 | 0 | 0 |
| | 9 | 3 | 0 | 0 | 0 | 0 |
| | 10 | 5 | 92 | 0 | 0 | 306 |
| | 11 | 1 | 52 | 52 | 52 | 52 |

---

[106] Ibid.

Table 15D. Monthly distribution of wastewater discharge (acre-feet) from 2004 through 2008 for North Dakota municipalities.[107]

| Municipality | Month | Sample Years | Mean | Median | Min | Max |
|---|---|---|---|---|---|---|
| Valley City | 5 | 2 | 176 | 176 | 165 | 187 |
| | 6 | 4 | 230 | 196 | 147 | 381 |
| | 8 | 1 | 109 | 109 | 109 | 109 |
| | 10 | 4 | 164 | 158 | 135 | 205 |
| | 11 | 1 | 123 | 123 | 123 | 123 |
| Wahpeton | 4 | 1 | 227 | 227 | 227 | 227 |
| | 5 | 5 | 274 | 276 | 107 | 455 |
| | 6 | 4 | 356 | 358 | 95 | 613 |
| | 7 | 1 | 255 | 255 | 255 | 255 |
| | 8 | 4 | 226 | 195 | 165 | 347 |
| | 9 | 1 | 207 | 207 | 207 | 207 |
| | 10 | 4 | 299 | 291 | 216 | 399 |
| | 11 | 3 | 281 | 274 | 224 | 345 |
| | 12 | 2 | 221 | 221 | 216 | 227 |
| West Fargo | 6 | 2 | 373 | 373 | 295 | 452 |
| | 7 | 5 | 493 | 478 | 183 | 934 |
| | 8 | 3 | 299 | 265 | 256 | 376 |
| | 9 | 4 | 399 | 403 | 139 | 652 |
| | 10 | 5 | 448 | 447 | 98 | 754 |
| | 11 | 4 | 260 | 282 | 147 | 330 |
| Williston | 5 | 3 | 371 | 368 | 356 | 389 |
| | 6 | 2 | 365 | 365 | 350 | 381 |
| | 7 | 1 | 224 | 224 | 224 | 224 |
| | 9 | 1 | 313 | 313 | 313 | 313 |
| | 10 | 5 | 371 | 383 | 343 | 389 |
| | 11 | 5 | 293 | 339 | 133 | 353 |

---

[107] Ibid.

# POTENTIAL USE OF GROUND WATER FOR THE ENERGY INDUSTRY IN NORTH DAKOTA

Ground water supplies about 18% of municipal, 6% of rural, and about 8% of industrial water use in the state of North Dakota.[108] Ground water is stored in two major types of reservoirs (aquifers): (1) bedrock aquifers, which are extensive consolidated or semi-consolidated fine to coarse sand deposits, mostly of ancient (Cretaceous) origin and underlie large portions of the state; and (2) glaciofluvial and fluvial aquifers, which are local to regional in areal extent, are comprised of unconsolidated sands and gravels, and which were formed as more recent (Pleistocene) glacial meltwater deposits or post-glacial river deposits. The bedrock aquifers are more extensive. The glaciofluvial aquifers generally have better quality water.

As discussed previously in the section titled: *Water Availability for Energy Use in North Dakota* (p. 7), much of North Dakota's ground water is fully appropriated, or nearly fully appropriated. The purpose of this section is to examine the issues involving availability of ground water for use in development of the energy industry in North Dakota, to help identify areas where ground water is most likely to be obtained with least difficulty, and to identify the characteristics of available waters that may influence their usability.

## Bedrock Aquifers

Ripley (1990) estimated that about 346 million acre-feet of water is stored in the Fox Hills - Hell Creek aquifer system and in the overlying Fort Union aquifer system, which occur in western North Dakota. Lenticular consolidated sediments in the Fort Union Group can produce sufficient water for rural stock and domestic use, but not much more. The Fox Hills -Hell Creek aquifer provides water for many farms and ranches in western North Dakota and for a few communities. The deeper Dakota aquifer, which underlies most of the state, has additional water (not included in Ripley's estimate), but the quality of water is poor enough under most of the state that it is seldom used, except for secondary recovery of oil in depleted oil-producing zones. In the western portion of the state the Dakota aquifer is also used as a storage reservoir for injection of brines produced with oil and recovered frac water in the oil field. Dakota water near the Red River Valley is fresher and is used for domestic and livestock consumption.

While bedrock aquifers have large amounts of water, the main recharge areas are distant (in eastern Montana and Wyoming or eastern North Dakota and South Dakota) with long distances (and travel times) to North Dakota extraction points. Some of the recharge to the aquifers occurred during wetter climates in the distant past, or is drawn from the overlying and underlying shales which have poor water quality. Because of their large spatial extent, bedrock aquifers provide a base water supply that can be used to maintain a minimal economy in times of severe drought. While water from bedrock

---

[108] North Dakota State Water Commission. 2009. State Water Management Plan. p. 20.

aquifers can be used, care is needed to prevent overuse and depletion. Bedrock waters of the Dakota aquifer and the Fox Hills - Hell Creek (FH-HC) aquifer system will be examined in this section.

## Dakota Aquifer

The Dakota aquifer is a regional bedrock aquifer that underlies most of the Great Plains, and almost the entire state of North Dakota. The Dakota aquifer underlies the FH-HC aquifer in the west and central portions of the state.

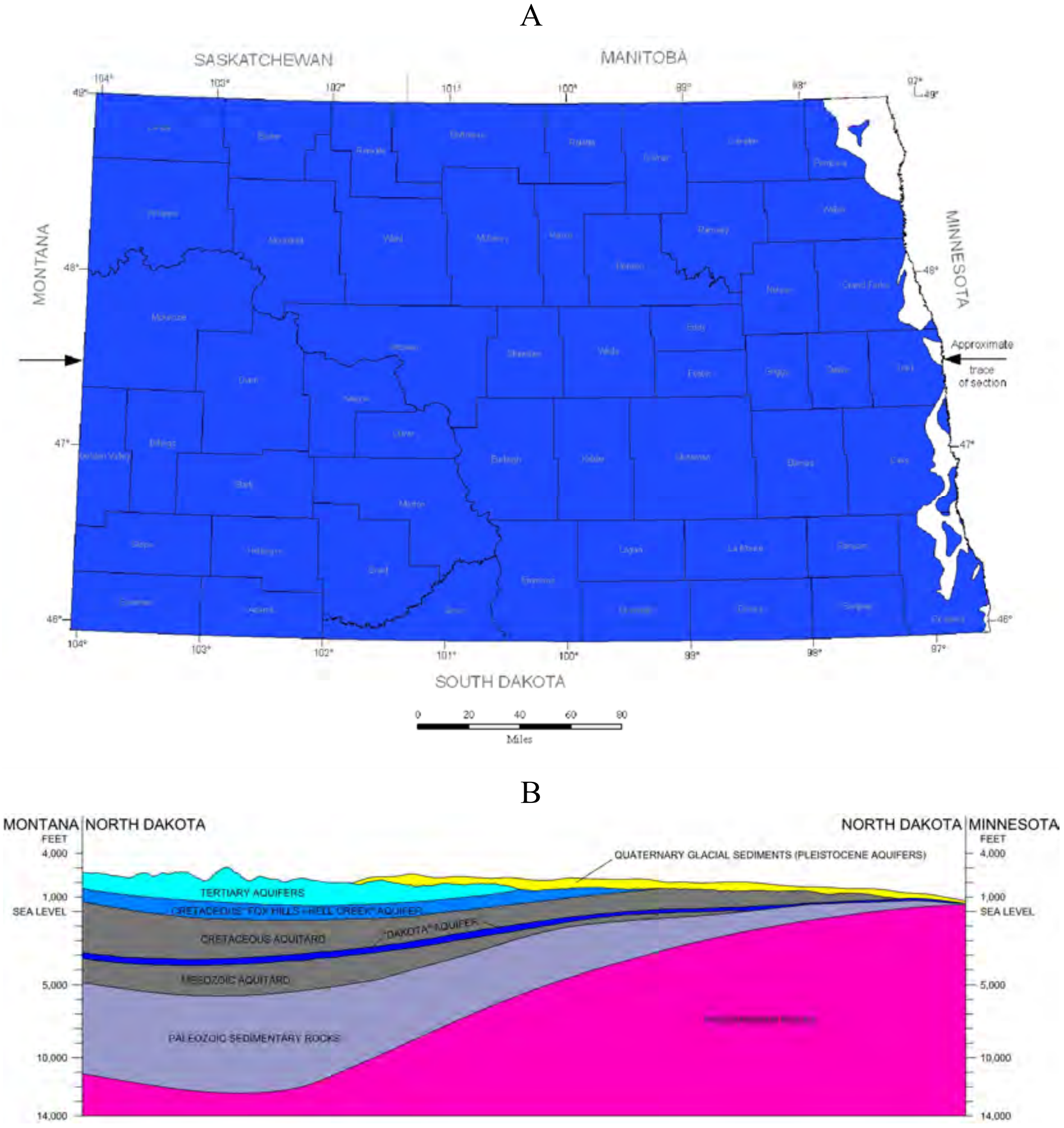


Figure 20. (A) State area underlain by the Dakota aquifer, and (B) cross-sectional map of North Dakota sedimentary deposits. (Figure provided by the Fred Anderson of the North Dakota Geological Survey.)

The FH-HC and Dakota aquifers are separated by Cretaceous shales of the Pierre, Niobrara, Carlile and Greenhorn Formations that vary in combined thickness from about 2,000 feet in east-central North Dakota where the Fox Hills subcrops below drift to about 3,500 feet in the central part of the Williston basin in western North Dakota. Like other sedimentary deposits in the Williston Basin, including the Fox Hills aquifer, the Dakota aquifer is bowl-shaped in cross section, with surficial recharge exposures along the eastern slope of the Rocky Mountains in Montana and Wyoming, and the Black Hills in South Dakota, sloping eastward to as deep as 4,000 to 6,000 feet below land surface (bls) in the Williston Basin in western North Dakota, then sloping upward in a relatively steady incline, ending in subcrops beneath the drift near the Red River in North Dakota and Minnesota (Figure 20B). The Dakota aquifer lies about 2,000 to 3,000 feet bls in north-central North Dakota. The distribution of SWC data for the Dakota aquifer is heavily skewed toward the eastern portion of the state where wells were installed in the early 1900s to take advantage of flowing pressure head (Figure 21). Dakota wells used for injection by the oil industry are regulated by the North Dakota Industrial Commission. Depth trends for the 128 Dakota wells shown on Figure 22 are highly consistent and linear from west to east (r=0.94). Depths to the aquifer decrease by about 600 feet per degree longitude, beginning at about 3,300 feet bls in west-central North Dakota in the deepest part of the Williston Basin (longitude approx. 103), and ending near land surface, overlain only by glacial and lacustrine overburden the Red River Valley in eastern North Dakota (longitude approx. 96.5).

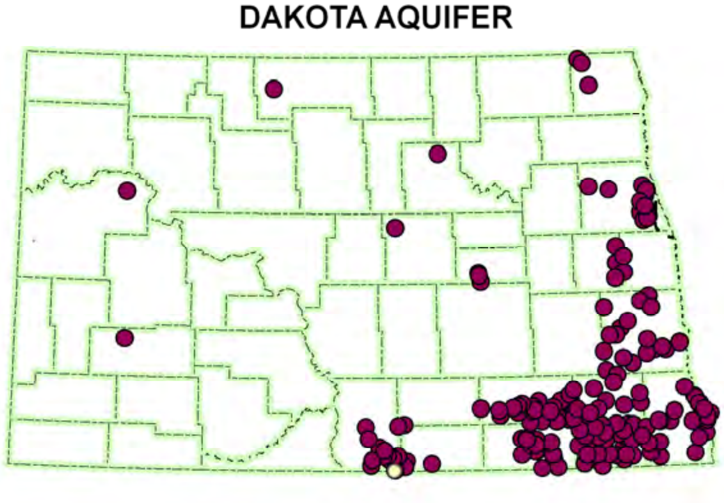


Figure 21. Locations of Dakota aquifer wells (SWC database).

### *Aquifer Composition*

The Dakota aquifer in northwestern North Dakota has been described by Armstrong (1969) as consisting of fine to very-fine sandstones interbedded with clay and silt. Kelly and Paulson (1970) described the Dakota aquifer composition similarly, but included a fine to coarse range of sand textures. Sand lenses, primarily in the Newcastle and Inyan Kara Formations have been indicated to occupy 25 to 45% of the Dakota Group, comprising the Dakota aquifer. The aquifer thickness varies from 280 to 460 feet in the west (Armstrong 1969, 1971) but decreases eastward to about 150 feet in Foster and Eddy Counties (Trapp. 1968) and 0 to 200 feet near its eastern boundaries in the Red River Valley (Hutchinson 1977) where it pinches out.

### *Well Yields*

Well yields of 156 to 290 gpm have been described for Burke and Mountrail Counties in the west (Armstrong 1971) and 300 to 500 gpm for Cavalier and Pembina Counties in the east (Hutchinson 1977). Specific capacities for Burke and Mountrail Counties have been described as 0.4 to 3 gpm per foot of drawdown. Flowing wells at 10 to 17 gpm have been described in Foster and Eddy Counties (Trapp. 1968). Dakota wells in the Red River Valley often flow, but the aquifer's pressure head has been declining for more than a century.

### *Water Quality*

Water quality for the Dakota aquifer varies widely and, untreated, is often poor for human and livestock use. Water composition ranges from moderately saline to saline. Generally, water is freshest in the southeastern part of the state, and increases in salinity moving northwestward. Dissolved solids trends for wells in the SWC database are illustrated on Figure 22. The data is heavily skewed toward the southeastern part of the state, and an additional characterization provided by the USGS (1996, Figure 59) is shown on Figure 22, using dashed lines.

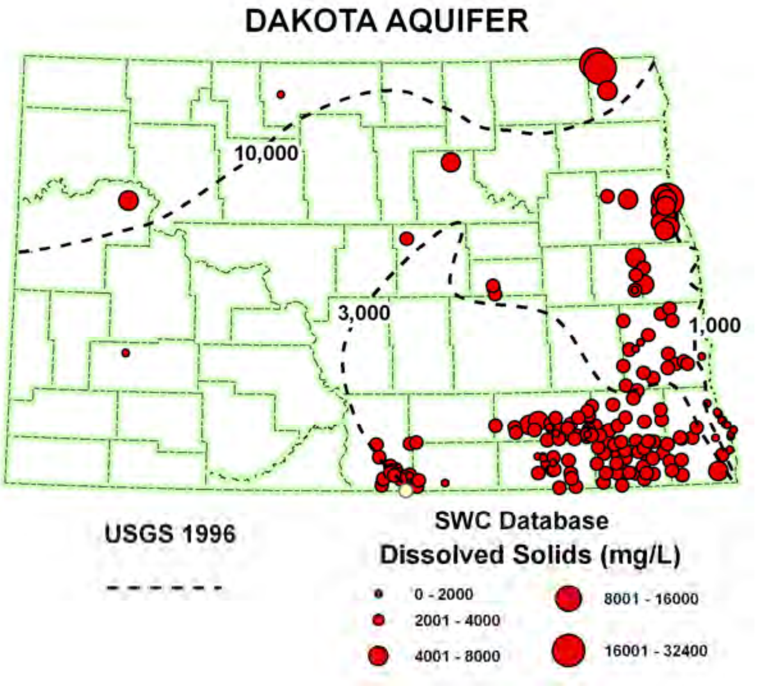


Figure 22. Dissolved solids in Dakota aquifer wells.

The Dakota aquifer water is primarily a sodium-sulfate and chloride type, but can be of a sodium bicarbonate type (Figure 23). Generally, Dakota water with lower concentrations of dissolved solids have more bicarbonate. Sulfate increases with increasing dissolved solids (above 2,000 mg/L), and chloride is predominant in waters with the highest dissolved solids (above 4,000 mg/L) in western North Dakota. Statewide water chemistry data for the Dakota aquifer from the SWC database are summarized on Tables 16 and 17. Dissolved solids range from as little as 500 mg/L to as high as 32,000 mg/L, and the anion and cation composition also varies widely. Dakota water is relatively high in iron. Median dissolved solids are about 2,600 mg/L; however, the SWC data is highly skewed toward the southeast. Water from the Dakota aquifer in western North Dakota and from underlying zones is unsuitable for human or livestock consumption or for irrigation use because of the high concentration of dissolved solids, particularly sodium and chloride. Dissolved solids concentrations in water samples from three wells in Bottineau (161-082-14), McKenzie (152-095-08CB) and Stark (140-097-25DDD) Counties range from about 7,000 to 12,000 mg/L, and are a sodium chloride-bicarbonate type, sodium chloride-sulfate type, and a sodium chloride type respectively. Dissolved solids for four water samples from the Oil and Gas Division[109] were 10,700 mg/L (no location), 14,500 mg/L (Burke County), 17,000 mg/L (Williams County) and 31,000 mg/L (Renville County), all of the sodium bicarbonate type.

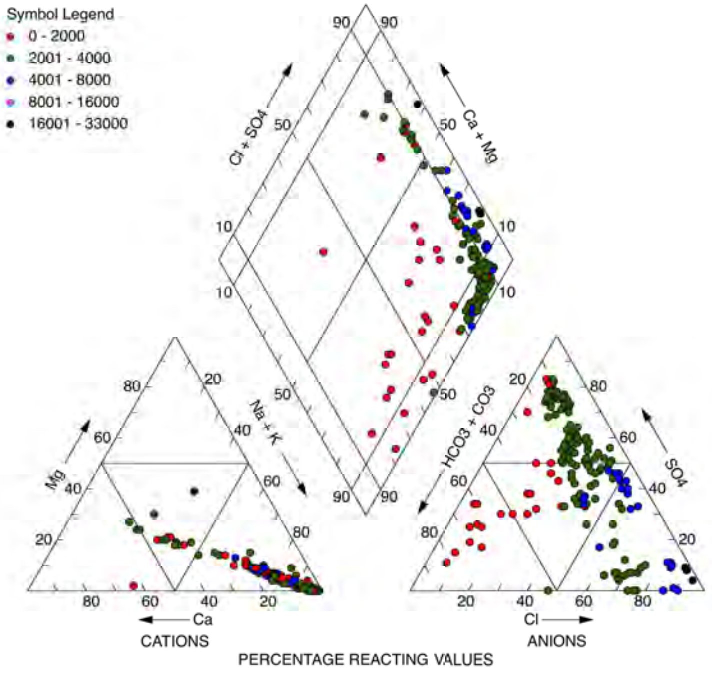


Figure 23. Piper plot showing relative anion and cation distribution of water samples collected from Dakota aquifer wells. *The symbol legend units are dissolved solids (mg/L).*

---

[109] Schumacher, Tom. North Dakota Industrial Commission: Oil and Gas Division. E-mail communication. June 16, 2010.

Table 16.  Summary of Chemical Properties of the Dakota aquifer in North Dakota: general chemistry.

| | $S_C$-f µS/cm | $S_C$-l µS/cm | TDS-d mg/L | TDS-c mg/L | pH-f | pH-l | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 491 | 527 | 541 | 340 | 7.2 | 6.8 | 6 | 2.3 | 0 | 0 | 2.7 | 35.9 | 0 | 77 | 0 | 1.6 | 9.75 | 0 |
| **Maximum** | 58,000 | 48,700 | 35,300 | 32,400 | 10.75 | 10.5 | 30 | 52 | 2,740 | 2,910 | 260 | 9,200 | 26 | 2,060 | 600 | 2,300 | 20,000 | 190 |
| **Points** | 128 | 205 | 198 | 201 | 70 | 205 | 132 | 182 | 202 | 202 | 196 | 202 | 198 | 207 | 203 | 208 | 208 | 205 |
| **Mean** | 4,271.4 | 5,079.4 | 3,406.8 | 3,306 | 8.02 | 7.96 | 13.74 | 9.97 | 101.28 | 45 | 24.04 | 1,025.6 | 3.2 | 382.45 | 4.95 | 967.26 | 971.13 | 4.38 |
| **Median** | 3,900 | 3,970 | 2,655 | 2,650 | 8 | 8 | 12.65 | 7.91 | 33 | 10 | 18 | 880 | 2.7 | 323 | 0 | 1,185 | 435.5 | 1 |
| **Std Deviation** | 5,095.7 | 5,665.4 | 4,013.9 | 3,751 | 0.45 | 0.39 | 5.44 | 7 | 240.38 | 209.93 | 24.66 | 1,064.7 | 2.54 | 214.08 | 42.31 | 479.83 | 2,252.1 | 17.36 |
| **Std Error** | 450.4 | 395.69 | 285.25 | 264.57 | 0.05 | 0.03 | 0.47 | 0.52 | 16.91 | 14.77 | 1.76 | 74.91 | 0.18 | 14.88 | 2.97 | 33.27 | 156.15 | 1.21 |

Table 17. Summary of Chemical Properties of the Dakota aquifer in North Dakota: use parameters, and trace elements

| **Hardness** | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | SAR | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L |
|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0 | 0 | 63 | 1.23 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Maximum** | 18,800 | 18,500 | 673 | 200 | 6.6 | 10 | 1.1 | 29.3 | 0.1 | 7.03 |
| **Points** | 206 | 193 | 9 | 196 | 178 | 207 | 150 | 5 | 3 | 5 |
| **Mean** | 437.6 | 316.72 | 327.22 | 34.77 | 2.46 | 1.35 | 0.09 | 6.68 | 0.03 | 2.41 |
| **Median** | 128.5 | 0 | 263 | 36 | 2.25 | 0.65 | 0.06 | 1 | 0 | 1 |
| **Std Deviation** | 1,417.9 | 1,440.2 | 189.18 | 23.6 | 1.57 | 1.83 | 0.15 | 12.67 | 0.06 | 3.06 |
| **Std Error** | 98.79 | 103.66 | 63.06 | 1.69 | 0.12 | 0.13 | 0.01 | 5.66 | 0.03 | 1.37 |

### *Use of Dakota Water for Energy Development*

Because of its poor quality and depth, the Dakota aquifer in western North Dakota is not suitable for human, livestock, irrigation and most industrial purposes. There is little competition for the use of Dakota water in western North Dakota. The oil industry uses Dakota water for water flooding and as make-up water for drilling fluid below the cased (freshwater) zone. Conversely, the Dakota Formation is used as an injection reservoir for highly saline water produced with crude oil. The Energy and Environmental Research Center of the University of North Dakota (EERC) has reviewed the potential use of thermal and membrane technologies for retreating frac flowback waters and also water from the Dakota Formation for fracturing (Stepan and others 2010). Their work is discussed in a previous section (Alternative Frac-Water Supply Initiatives, p 39). The EERC research group is currently working with an industry partner to examine the feasibility of treating and using Dakota water for fracturing and other uses.

The Dakota aquifer may be worth considering for some use in the energy industry in eastern North Dakota. Because of shallower depths and less saline Dakota water in the east, it has been proposed that the Dakota aquifer be considered for reverse osmosis treatment and municipal use (Kurz, Shockey and Stepan 2009). Based on preliminary estimates derived from a literature search, the EERC speculated that pumping rates as high as 500 to 1,000 gpm might be possible from the Dakota aquifer in some areas. These pumping rates, if sustainable, would allow for water withdrawal in the range of 800 to 1,600 acre-feet per year. Kurz and others (2009) stated, however, "whether or not these pumping rates can be sustained for extended periods of time (multiple years) depends on the site-specific aquifer properties." There are several considerations for potential use of Dakota water in the energy industry. These considerations include:

(1) Large-scale pumping of the Dakota aquifer will lead to an accelerated decline of the pressure head and reduce the remaining time flowing wells will flow.

(2) The lenticular nature of sand comprising the Dakota aquifer and the resulting variability in horizontal transmissivity may reduce the overall sustainable large-scale pumping. The long-term pumping test of Doering and Benz (1972) used to estimate the 500 to 1,000 gpm potential pumping rates also showed indications of boundary interference that would later limit pumping.

(3) There are some indications, cited by the authors, that fresher Dakota water in eastern North Dakota may have been influenced by an influx of fresh glacial meltwater during the Pleistocene. If this were the case, the freshwater component of the Dakota aquifer in eastern North Dakota would not be replaceable under modern conditions and could not be sustained indefinitely. Western outcrop recharge areas are several hundred miles distant, with transit times in thousands of years or more. Bredehoeft and others (1983) determined that most of the water released from storage must have come from confining layers. Because confining layers frequently have low quality water, replacement water for large scale pumping may result in a water quality decline, which may affect the sustainability of Dakota water for some uses.

(4) The Dakota aquifer is the only extensive bedrock aquifer in eastern North Dakota, and under the most extreme drought scenarios, in which surface waters and shallow aquifers are depleted, the Dakota aquifer may provide the only viable backup water supply. Unnecessary large-scale mining of the aquifer is therefore undesirable.

There is some capability for additional development and use of Dakota water in eastern North Dakota. The extent to which Dakota water can be extracted without excessive overdraft is unknown at the present time. Within a reasonable conservation framework it is likely that some situational beneficial use of Dakota water may be feasible for the energy industry. It would seem best to use other water sources that are renewable within a more immediate time scale whenever possible. Further investigation of water treatment options and aquifer sustainability for the Dakota aquifer would be useful.

## Fox Hills - Hell Creek Aquifer

The horizontally continuous shoreline sand left by a retreating Cretaceous mid-continent sea has been called lower Hell Creek-upper Fox Hills aquifer, the Hell Creek-Fox Hills aquifer, the FH-HC aquifer (used here and abbreviated FH-HC aquifer), and sometimes, informally, the Fox Hills aquifer (as ‘Fox Hills water’ or ‘Fox Hills well’). The aquifer underlies the western two-thirds of North Dakota at depths of up to 2,000 feet in the central part of the Williston Basin. Generally speaking, the aquifer occurs between 1,000 and 2,000 feet below land surface (bls) in the western two tiers of North Dakota counties, except where it outcrops along the Cedar Creek anticline in western Bowman County (Figure 24). The FH-HC aquifer is underlain by between 2,000 and 3,500 feet of the Pierre and other Cretaceous shales. Like the underlying Dakota aquifer, the FH-HC aquifer is approximately “bowl-shaped,” surfacing along the margins of the Williston and Powder River Basins, and at its deepest in the center of the basins. The FH-HC aquifer was described by Wanek (2009) in a recommended decision memo to the State Engineer.[110]

### *Fox Hills-Hell Creek Aquifer Composition*

The FH-HC aquifer consists of the upper Colgate Member of the Fox Hills Formation, composed principally of moderately well sorted fine to medium sand, grading finer with depth, and occasional lenticular sand deposits in the overlying Hell Creek Formation. The thickness of the FH-HC aquifer is about 100 feet, plus or minus, underlain by 150 to 200 feet of finer sediments of the lower Fox Hills Formation, grading to clay or shale of the Pierre Formation.

### *Fox Hills-Hell Creek Aquifer Hydraulic Properties*

Based primarily on single well response tests, the FH-HC aquifer transmissivity is about 100 to 500 ft.$^2$/day. With a thickness of about 100 feet (plus or minus 50 feet), the

---

[110] Wanek, Alan. June 24, 2009. Recommended Decision, city ofAlexander Water Permit Application No. 5990. SWC Water Permit File #5990.

hydraulic conductivity is between one and five feet per day. The FH-HC aquifer storativity in confined areas has been estimated at about 0.0001 to 0.0005. Common well yields for 2-inch wells (below the pump setting) are 50 to 100 gpm, with 200 gpm or slightly more possible for efficiently constructed larger diameter wells at suitable locations.

The upper Fox Hills sands extend horizontally to higher elevation recharge areas in Montana, Wyoming, and South Dakota. Over the millennia the hydraulic connection to higher areas has caused the FH-HC aquifer to establish an artesian pressure head in western North Dakota and far eastern Montana that is higher than the head of the overlying, lenticular sediments. In low-lying areas along the Yellowstone, Little Missouri, and Missouri River valleys, and the lower parts of their tributaries, the FH-HC aquifer has a flowing artesian pressure head. The pressure head of the FH-HC aquifer is, in places, as much as 200 feet above land surface.

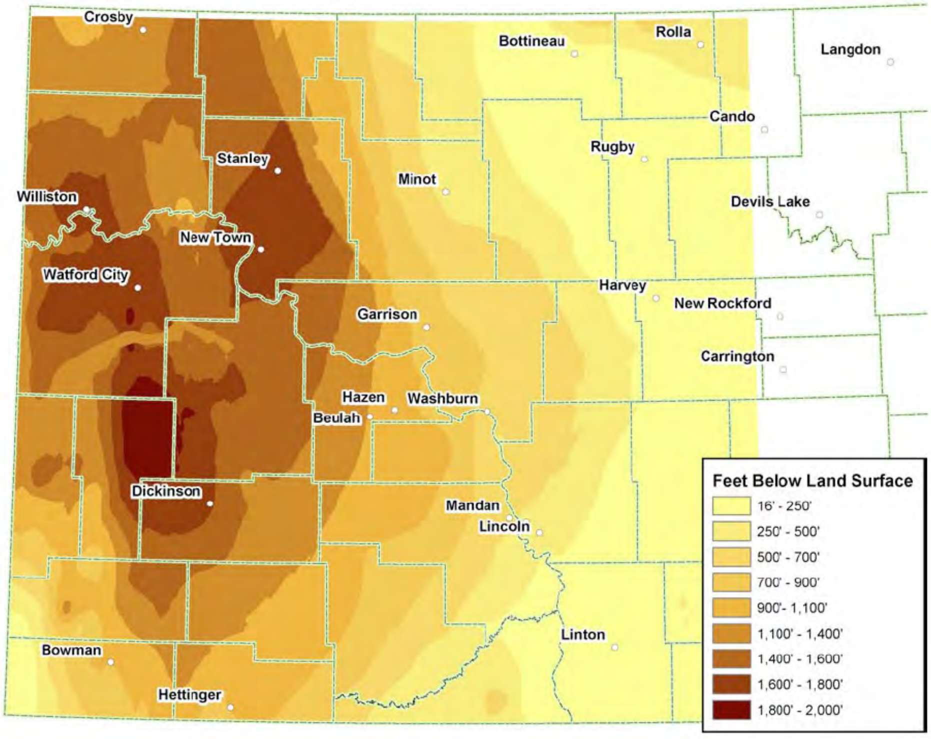


Figure 24. Extent and depth of the FH-HC aquifer in North Dakota.

### *Fox Hills Water Quality*

The quality of FH-HC water away from surficial recharge areas is soft, of a sodium-bicarbonate type, and slightly saline, having dissolved solids concentrations over 1,000 mg/L. A Piper plot showing the relative anion and cation distribution for 15 western North Dakota FH-HC wells is shown on Figure 25. The general chemistry, hardness, alkalinity, iron and manganese concentrations for 14 of the wells are shown on Tables 18 and 19. Dissolved solids range from 1,000 to 3,000 mg/L, with concentrations increasing with distance from recharge areas, and a median of about 1,600 mg/L. The maximum calcium and magnesium concentrations are only 11 and 5 mg/L, respectively. Far from recharge areas, north and east of the Missouri River in North Dakota, FH-HC waters have increasing concentrations of chloride (as well as total dissolved solids). The pH ranges from 8.78 to 12.2, with most of the samples being slightly (rather than highly) alkaline. Iron concentrations range from 0.02 mg/L to 3.95 mg/L, with a median of 0.18 mg/L; the higher iron concentrations probably being due to dissolution of the iron well casing.

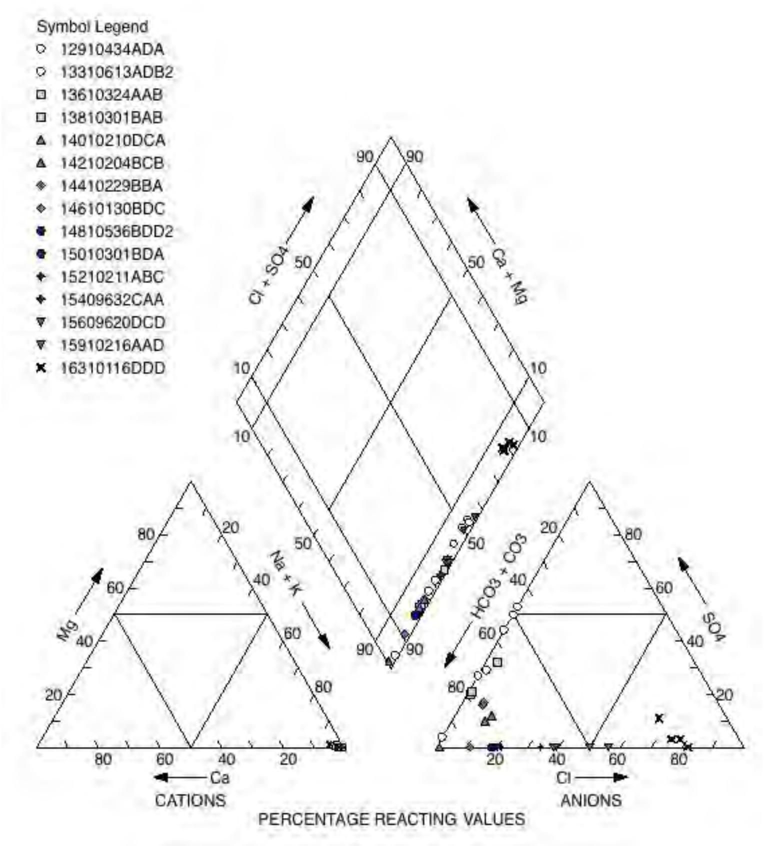


Figure 25. Piper Plot for 15 western North Dakota FH-HC wells. *Symbol legend is well location, U.S. Bureau of Land Management System.*

### *Use of Fox Hills – Hell Creek Water*

There are concerns with ongoing, and potential increased future use of FH-HC water, particularly near where the flowing pressure head of the aquifer is used by ranchers. Ranchers with remote pastures distant from electrical power sources found it economical to drill to the deeper FH-HC aquifer, if the well would flow and therefore not require an electric pump. Since the installation of water supply wells in the FH-HC aquifer beginning about a century ago in western North Dakota, and flowing-head wells largely about a half-century ago, the extraction of water has resulted in the aquifer's pressure head declining. Recharge to the FH-HC aquifer is distant, in eastern Montana and northwestern South Dakota. The travel time for aquifer replenishment by recharge from the basin margin is very large when considered on a human time scale.

Table 18.  Summary of Chemical Properties of the FH-HC aquifer in western North Dakota: general chemistry.

| | $S_C$-f □S/cm | $S_C$-l □S/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 1,495 | 1,660 | 8.78 | - | 1,230 | 1,030 | 10 | 3.04 | 1.6 | 0.4 | 1 | 369 | 0.16 | 607 | 1 | 0.3 | 0 | 0.09 |
| **Maximum** | 6,660 | 6,810 | 12.2 | - | 1,230 | 4,220 | 17.9 | 13.6 | 11 | 5 | 4.93 | 1,540 | 5.56 | 1,430 | 117 | 636 | 1,860 | 2.3 |
| **Points** | 13 | 14 | 6 | - | 1 | 14 | 9 | 4 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| **Mean** | 2,584.7 | 2,606.4 | 10.28 | - | 1,230 | 1,599.3 | 14.36 | 9.41 | 3.07 | 1.29 | 2.06 | 609 | 3.19 | 904.86 | 42.57 | 117.75 | 293.43 | 0.25 |
| **Median** | 2,050 | 2,175 | 10.21 | - | 1,230 | 1,300 | 13.8 | 10.5 | 2 | 1 | 1.63 | 506 | 3.27 | 822.5 | 36.5 | 5 | 79.2 | 0.09 |
| **Std Deviation** | 1,436.4 | 1,379.3 | 1.15 | - | 0 | 845.06 | 2.41 | 4.81 | 2.42 | 1.1 | 1.16 | 312.38 | 1.86 | 251.07 | 26.52 | 182.61 | 503.47 | 0.59 |
| **Std Error** | 398.38 | 368.65 | 0.47 | - | 0 | 225.85 | 0.8 | 2.4 | 0.65 | 0.29 | 0.31 | 83.49 | 0.5 | 67.1 | 7.09 | 48.81 | 134.56 | 0.16 |

Table 19. Summary of Chemical Properties of the FH-HC
aquifer in western North Dakota: use parameters, and iron and manganese.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Iron mg/L | Manganese mg/L |
|---|---|---|---|---|---|---|---|
| **Minimum** | 6 | 0 | 557 | - | 52.2 | 0.02 | 0.01 |
| **Maximum** | 48 | 0 | 1,200 | - | 114 | 3.95 | 0.29 |
| **Points** | 14 | 14 | 13 | - | 14 | 14 | 14 |
| **Mean** | 12.93 | 0 | 815.46 | - | 75.39 | 0.43 | 0.03 |
| **Median** | 9 | 0 | 812 | - | 70.9 | 0.18 | 0.01 |
| **Std Deviation** | 10.45 | 0 | 212.4 | - | 20.67 | 1.02 | 0.08 |
| **Std Error** | 2.79 | 0 | 58.91 | - | 5.52 | 0.27 | 0.02 |

Table 20. Summary of chemical properties of the FH-HC aquifer in North Dakota: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium mg/L | Mercury mg/L | Arsenic mg/L | Lithium mg/L | Molybdenum mg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0.02 | 0.02 | - | - | - | - | - |
| Maximum | 2.3 | 9.3 | 2.3 | - | - | - | - | - |
| Points | 42 | 65 | 65 | - | - | - | - | - |
| Mean | 0.61 | 1.07 | 0.39 | - | - | - | - | - |
| Median | 0.44 | 0.46 | 0.24 | - | - | - | - | - |
| Std Deviation | 0.58 | 1.53 | 0.44 | - | - | - | - | - |
| Std Error | 0.09 | 0.19 | 0.05 | - | - | - | - | - |

A partial inventory of FH-HC flowing wells in the North Dakota portion of the Williston Basin was undertaken by the SWC in 2008, based on well completion reports filed by water well contractors and other well information sources. The locations of FH-HC wells inventoried are shown on Figure 26. In three selected ‘study areas’ (Figure 26) a more thorough field investigation was made of existing FH-HC wells. Based on the fieldwork and conversations with residents, it was estimated that about half again as many FH-HC wells exist in the field as are included in the well inventory, most of the previously unknown wells having been installed prior to 1972 when well drillers were first required to file reports. The distribution of inventoried FH-HC wells is shown on Table 21. The distribution of FH-HC wells by county is shown on Table 22.

Because a pump is not needed, most flowing head FH-HC wells are constructed using casing two inches or less in diameter. When the aquifer pressure head declines below land surface, a small diameter FH-HC well will no longer function as a water source. It may be possible to airlift water for a few years after a well has stopped flowing. A few previously flowing wells have been over-drilled to 100 or 200 feet depth, with larger diameter casing, capable of holding a pump, replacing the small diameter casing. At some locations, a replacement well may not have to be completed in the FH-HC aquifer. However, a shallower well completed in a sand lens or lignite bed, will require a source of power, which may be cost-prohibitive.

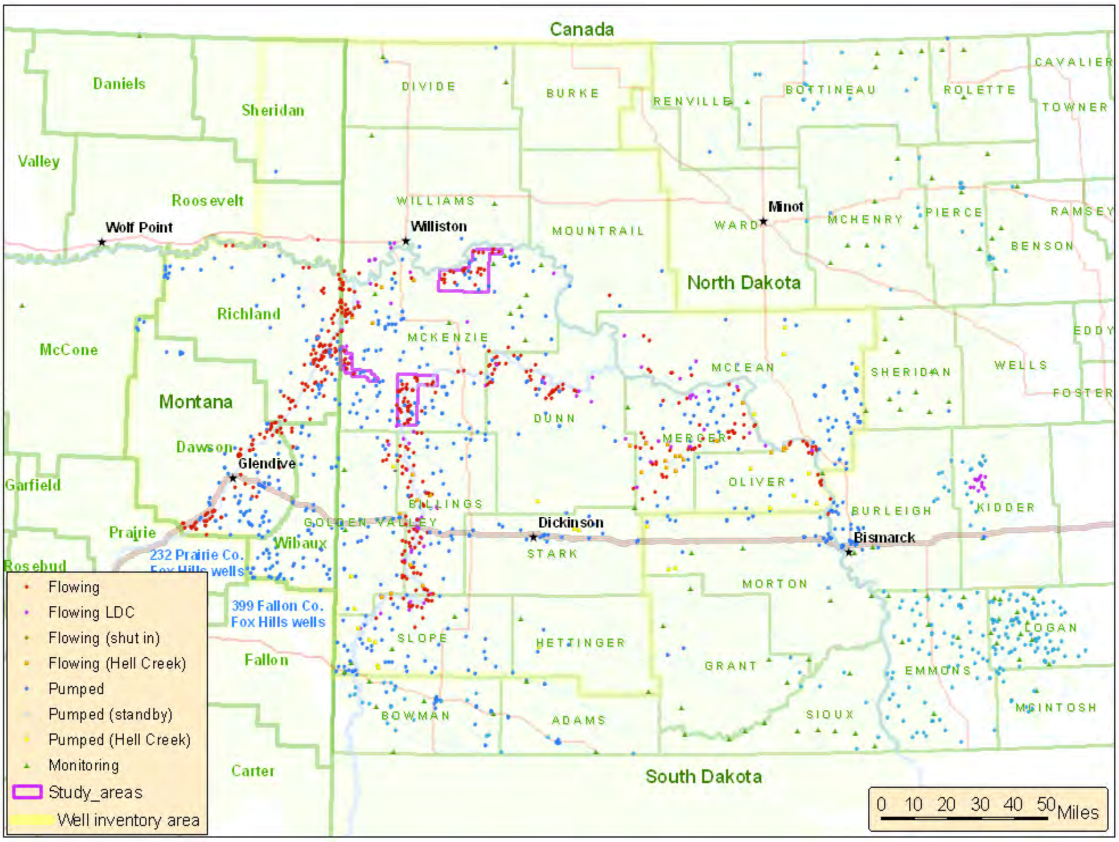


Figure 26. Locations of FH-HC wells.[111] 'LDC' indicates casing larger than two inches in diameter.

---

[111] Op Cit. Wanek. June 24, 2009.

Table 21. Use distribution of the listed FH-HC wells (From Table 3 of Wanek[112]).

| Well type | ND wells | MT wells | Total |
|---|---|---|---|
| Flowing domestic/stock | 47 | 2 | 49 |
| Flowing domestic/stock LDC | 13 | - | 13 |
| Flowing domestic | 38 | 74 | 112 |
| Flowing domestic LDC | 20 | - | 20 |
| Flowing stock | 194 | 60 | 254 |
| Flowing stock LDC | 42 | - | 42 |
| Flowing municipal LDC | 8 | 1 | 9 |
| Flowing rural water LDC | 3 | - | 3 |
| Flowing industrial | 2 | 6 | 8 |
| Flowing industrial LDC | 3 | - | 3 |
| Flowing shut-in | 12 | 4 1 | 6 |
| Flowing shut-in LDC | 3 | - | 3 |
| Flowing unknown | - | 6 | 6 |
| Flowing Hell Creek | 31 | - | 31 |
| Pumped Hell Creek | 24 | - | 24 |
| Pumped domestic/stock | 64 | 0 | 64 |
| Pumped domestic | 264 | 69 | 333 |
| Pumped stock (+1 'wildlife' well) | 239 | 87 | 326 |
| Pumped municipal | 30 | 3 | 33 |
| Pumped rural water | 1 | 0 | 1 |
| Pumped industrial | 35 | 16 | 51 |
| Pumped standby | 53 | 3 | 56 |
| Pumped unknown | - | 7 | 7 |
| Pumped irrigation* | 1 | 1 | 2 |
| Monitoring | 88 | 3 | 91 |
| Monitoring – plugged | 22 | 0 | 22 |
| Total | 237 | 342 | 1,579 |

---

[112] Op Cit. Wanek. June 24, 2009.

Table 22. Distribution of 1,579 identified FH-HC wells, by county (Table 4 from Wanek[113]).

| County | Wells | | County | Wells |
|---|---|---|---|---|
| Adams | 15 | | Morton | 30 |
| Benson | 12 | | Mountrail * | 5 |
| Billings * | 113 | | Oliver * | 38 |
| Bottineau | 20 | | Pierce | 14 |
| Bowman | 42 | | Renville | 2 |
| Burke * | 0 | | Rolette | 4 |
| Burleigh | 43 | | Sheridan | 12 |
| Divide * | 4 | | Sioux | 14 |
| Dunn * | 68 | | Slope * | 80 |
| Emmons | 77 | | Stark * | 22 |
| Golden Valley * | 48 | | Williams * | 13 |
| Grant | 13 | | Custer, MT | 1 |
| Hettinger * | 7 | | Daniels, MT | 1 |
| Kidder | 30 | | Dawson, MT * | 171 |
| Logan | 91 | | McCone MT | 1 |
| McHenry | 14 | | Prairie, MT | 1 |
| McIntosh | 11 | | Richland, MT * | 90 |
| McKenzie * | 236 | | E. Roosevelt MT | 1 |
| McLean * | 62 | | E. Sheridan MT | 1 |
| Mercer * | 98 | | Wibaux, MT * | 74 |

* = Counties in which well driller's reports (or the Montana's GWIC web site) were reviewed for FH-HC wells.

Rates of pressure-head decline of the FH-HC aquifer have been estimated to vary from negligible to about 3 feet per year under current usage. The highest rates of pressure head decline take place along the Little Missouri and Yellowstone River valleys where there is a greater concentration of flowing head wells, and in McKenzie County where there is generally more permitted water use from the FH-HC aquifer (Figure 26). A reduction in water flowing or pumped from FH-HC wells due to conservation, a switch to alternative water sources, or from wells losing their flowing pressure head, will slow the rate of aquifer head decline.

---

[113] Op Cit. Wanek. June 24, 2009.

Alternatively, increased pumping of FH-HC water will increase the rate of pressure head decline. Some of the permit applicants proposing to supply water for oil-field use intend to use FH-HC wells. As an exercise to examine the effect added FH-HC water use would have on existing flowing-head wells, Wanek [114]compared the number of years 16 FH-HC wells in western McKenzie County would continue to flow at the current rate of aquifer head decline with the projected number of years the wells will flow if an additional 76.4 gpm (123 acre-feet/year) of water is continually pumped from the aquifer. The 16 selected wells are now expected to flow for between about 7 and 95 years. Pumping an additional 76.4 gpm constantly at a distance of between 10 and 32 miles from the 16 selected wells, the wells were projected to stop flowing between 1 to 7 years sooner. For 13 of the 16 wells the projected pumping reduced the remaining flow time by between 4 and 7 percent.

### *Industrial Use of Fox Hills – Hell Creek Water*

From time to time industrial projects are proposed for southwestern North Dakota requiring large quantities of freshwater for which the FH-HC aquifer has been proposed as a water source. The Red Trail ethanol plant at Richardton originally considered obtaining its industrial water supply from the FH-HC aquifer. However, the largest current industrial user of FH-HC water in western North Dakota is the oil industry.

Freshwater is needed by the oil industry for drilling fluids, aquifer stimulation by hydraulic fracturing ('fracing') and in oil well operation, primarily diluting brine. The issue of FH-HC aquifer water depletion and potential adverse impact from large-scale oil-field water use was addressed as early as 1984 in a memorandum from Milton Lindvig, then Director of the State Water Commission Water Appropriation Division, to the State Engineer.[115] In presenting the need for water conservation, Lindvig writes that, "the water needs of industry are in conflict with the farmers' and ranchers' need to conserve the aquifer pressure head. There is a need to develop a policy which will balance these needs." Lindvig recognized that for practical purposes the pressure head of the FH-HC aquifer is a one-time resource, requiring decades or centuries recharge, and that as the aquifer's pressure head declines, "some appropriators will need to make an added effort to capture their water, and for some appropriators, the economic impact of the "added effort" may preclude further utilization of some of the well locations."

Lindvig considered assigning economic value to agriculture (livestock) and the oil industry as a method of comparing competing needs. Lindvig stated that, while "it would be difficult to assign a high economic value to a unit quantity of water" for agriculture (livestock watering), "it can be assumed that agriculture will be a viable industry in the area long after the oil is depleted." Alternatively, for water use by the oil industry "a relatively high value could be assigned to a unit quantity of water for a shorter period of time." The issue, then, was articulated as, "the emphasis should be placed on preserving

---

[114] Op Cit. Wanek. June 24, 2009. p 65.

[115] Lindvig, Milton O. To: Vern Fahy, State Engineer. 4/5/1984. Considerations in appropriating water for industry from the Hell Creek-Fox Hills Aquifer System – SWC #1400.

the flow from the largest number of wells for a reasonable period of time." The policy proposed in the memorandum is one of "limited use." In 1984, when the memorandum was written, oil wells were being installed in northeastern McKenzie County requiring freshwater for diluting the saturated brine produced with oil. Lindvig recommended that water use applications, "require all industrial water permit applicants in northeast McKenzie County to develop their water supplies from the shallower Tertiary aquifers, and approve access to the FH-HC aquifer only when the shallower aquifers prove inadequate." This general policy has been followed to the present time.

The issue of water supplies for the oil industry is discussed further in the section "*Total Projected Freshwater Needs for Oil-Field Development*," on p. 41. In general, any large-scale use of FH-HC water for industrial development in western North Dakota is problematic and alternatives should be considered in plans for facility locations. Alternative renewable water supply sources should be encouraged whenever possible.

## Shallow Glaciofluvial Aquifers

Ripley (1990) estimated that about 60 million acre-feet of water is stored in glacial aquifers. In general, water in glacial aquifers is fresher than bedrock water, although water near discharge areas can be highly saline. Glacial aquifers in eastern North Dakota also tend to be marginally high (just over the EPA-MCL of 10 μg/L) in arsenic, and often require treatment for municipal use.

Shallow glaciofluvial aquifers provide excellent water supplies for many farms, homes, municipalities and industries, and provide the main water supply for irrigation (about 68% of all irrigation water.)[116] They are, however, subject to drought, and the water appropriation policy must consider the level of appropriation that can be sustained under a wide range of climatic conditions. Ground-water use in North Dakota has increased substantially over the last half century, and many of the state's shallow aquifers are fully appropriated or nearly fully appropriated. It is very important that planners for future development of the energy industry consider the local availability of water in the siting of their facilities.

### Aquifer Water-Use Maps

To assist potential water users in their initial screening of future sites, this report will present an inventory of shallow glaciofluvial aquifers with a brief description of their potential future development for beneficial use. The inventory is divided into 15 study areas, shown on the study area key map following p. 139. Within each study area, managing SWC hydrologists were asked to evaluate the availability of water for each aquifer within their management areas. The results are shown in detail on individual maps for each study area. Aquifer boundaries shown are based on limited test drilling, and may be thought of as delineating an area within which one or more smaller and/or narrower aquifers may be located. The maps should be interpreted as follows: (1) The

---

[116] Ibid.

areas classified as "poor" (colored pink) are highly appropriated, so that obtaining a water permit is likely to require extensive and time-consuming analysis, and/or objections and extended hearing processes are likely to be involved. In some "poor" areas a moratorium on additional allocation may be in effect, requiring many years of data collection and study before additional allocations would be authorized. *The "poor" classification does not mean that obtaining a water permit is impossible. It means that obtaining a water permit is likely to be more time-consuming, that areas available for use within the aquifer will be limited, and that the possibility of denial is high.* (2) The aquifer areas classified as "good" (colored green) are those for which managing hydrologists consider that a substantial amount of water may be available for future beneficial use. These areas should be considered to have the best potential in an initial screening for future water supplies. *The "good" classification does not mean that obtaining a water permit is certain. Due diligence still must be applied in examining the local circumstances of the application in relation to other water users and the local hydrology of the aquifer. It means that the likelihood of obtaining a water permit is relatively good, and that the amount of time required for future field investigations will likely be more limited.* (3) Aquifer areas mapped as "conditional" (yellow) are considered by managing hydrologists to have potential for substantial additional beneficial use but may incur some impediments. These may include potential water quality problems, unknown factors that need further investigation, or, in some cases, concentrations of present use that will likely restrict locations for future pumping from the aquifer. **Planners and potential applicants should understand that the aquifer potential maps were compiled using information current in the last half of 2009, and that water availability changes with ongoing applications and investigations. In all cases, planners and potential applicants are advised to contact the Water Appropriation Division of the North Dakota State Water Commission at: 701-328-2754, and consult with the managing hydrologist for the most recent information concerning the area of interest.**

### Aquifer Narrative and Table Information for Water Chemistry

A brief description of each aquifer is provided based on existing published information, or the professional judgment of current managing hydrologists. The description includes: a description of the aquifer composition; a description of hydrologic properties or well properties affecting potential well yields; a general description of aquifer water quality and characteristics of dissolved constituents; a brief evaluation of its availability for water permit acquisition; and a rough estimate of the amount of water that may be available for future beneficial use.

For water chemistry, each aquifer description includes three tables: (1) general chemistry, including dissolved solids, specific conductance, pH, and common cations and anions; (2) use parameters, mostly related to scaling or dispersive properties, including alkalinity, sodium adsorption ratio, and Langelier Index (where sufficient information was available for computation); and (3) trace metals (where available). Interpretive standards for the trace metals are shown on Table 23.

Table 23. Use standards for minor and trace elements included (when available) in aquifer chemistry tables.

| Solute | Conc. | Units | Standard |
|---|---|---|---|
| Boron | 4/0.9 | mg/L | 1 day / long-term child toxicity* |
| Iron | 0.3 | mg/L | Rust color, metallic taste, red stain, sediment – Secondary EPA-MCL** |
| Manganese | 0.05 | mg/L | Black/brown stain, bitter metallic taste – Secondary EPA-MCL ** |
| Selenium | 50 | μg/L | Toxicity, EPA-MCL† |
| Mercury | 2 | μg/L | Toxicity, EPA-MCL |
| Arsenic | 10 | μg/L | Toxicity, EPA-MCL |
| Molybdenum | 20/10 | μg/L | 1 day / long-term child toxicity* |

*[117] **[118] †[119]

## Estimates of Water Available for Future Development

The distribution of water permits for aquifers having "good" or "conditional" potential for further water-use development is shown on Figure 27. The number and status (abeyance, conditional, perfected) of water permits is listed in Appendix Table F. A summary of the amounts of water allocated in water permits for each aquifer having "good" or '"conditional" potential for future development are also listed in Appendix Table F. Estimates of water available for future development are provided in the text narrative and are summarized on Table 24. These estimates were made based solely on current permitted use, and on what the author and managing hydrologists consider to be conservative estimates of annual recharge for the specific aquifer. For several reasons, such estimates are simplistic. First, actual locations within an aquifer where water may be available depend on locations of present development. Second, all water in shallow ground-water systems is currently being discharged through other sinks, such as rivers through seepage, springs, wetlands, or other wells. The value and function of the existing discharges must be considered in evaluating future use. For example, if the water in a given location is currently discharging to a stream, a new appropriation for ground water may conflict with current surface-water uses. It may be necessary to withdraw water at distance from the river. In addition, the locations of a proposed new diversion with respect to existing uses and recharge and discharge zones may be important. For example, if a proposed new well intervenes between an existing well and a recharge area, and if aquifer depth is constricted at the existing well, drawdown from

---

[117] EPA. 1996. Drinking Water Regulations and Health Advisories. EPA-822-R-96-001.

[118] EPA. Accessed April 4, 2010. Secondary Drinking Water Regulations: Guidance for Nuisance Chemicals. Secondary Drinking Water Regulations http://www.epa.gov/safewater/consumer/2ndstandards.html

[119] EPA. Accessed April 4, 2010. Drinking Water Contaminants. http://www.epa.gov/safewater/contaminants/index.html

the new use may interfere with the existing well. Conversely, a new well placed near an evaporative discharge area may have minimal interference with existing wells, but may draw in saline water to the new well. In addition, recharge estimates are somewhat speculative. **After selecting a potential ground-water source based on an initial screening of the potential availability numbers provided, potential users must understand that substantial further work must be done in locating and confirming an appropriate point of diversion. The managing area hydrologist at the Water Commission should be consulted for further advice.**

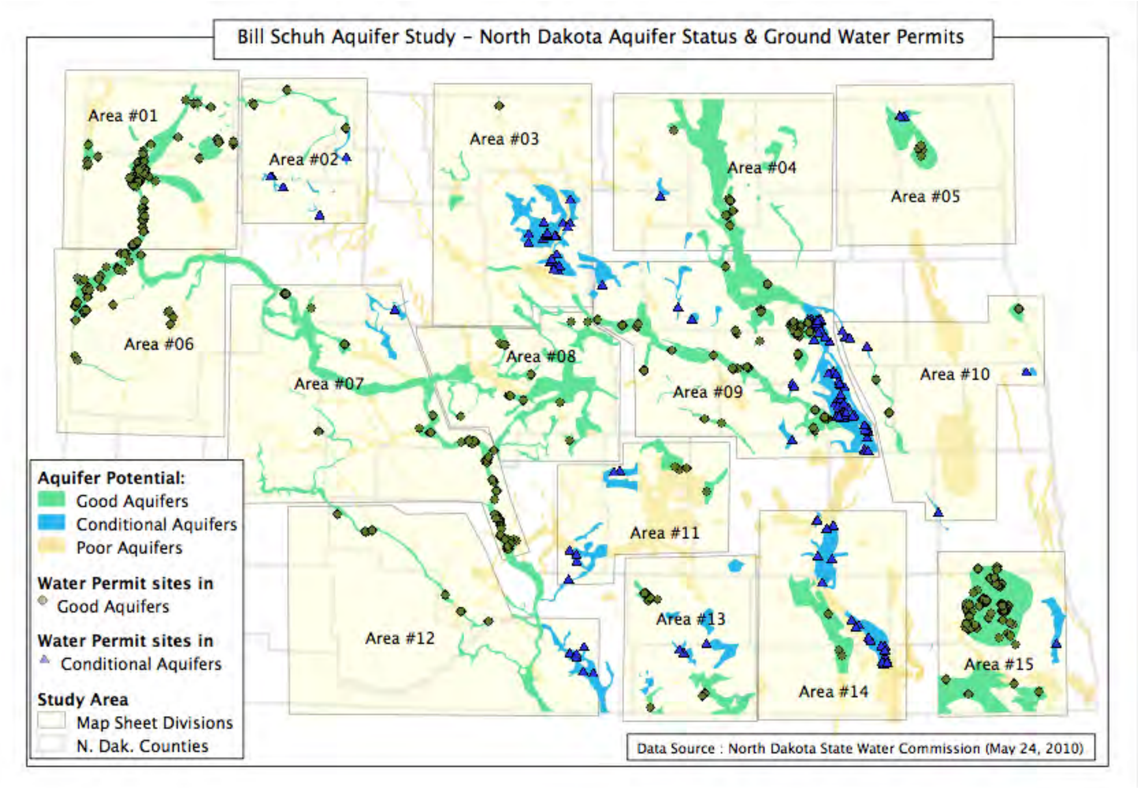
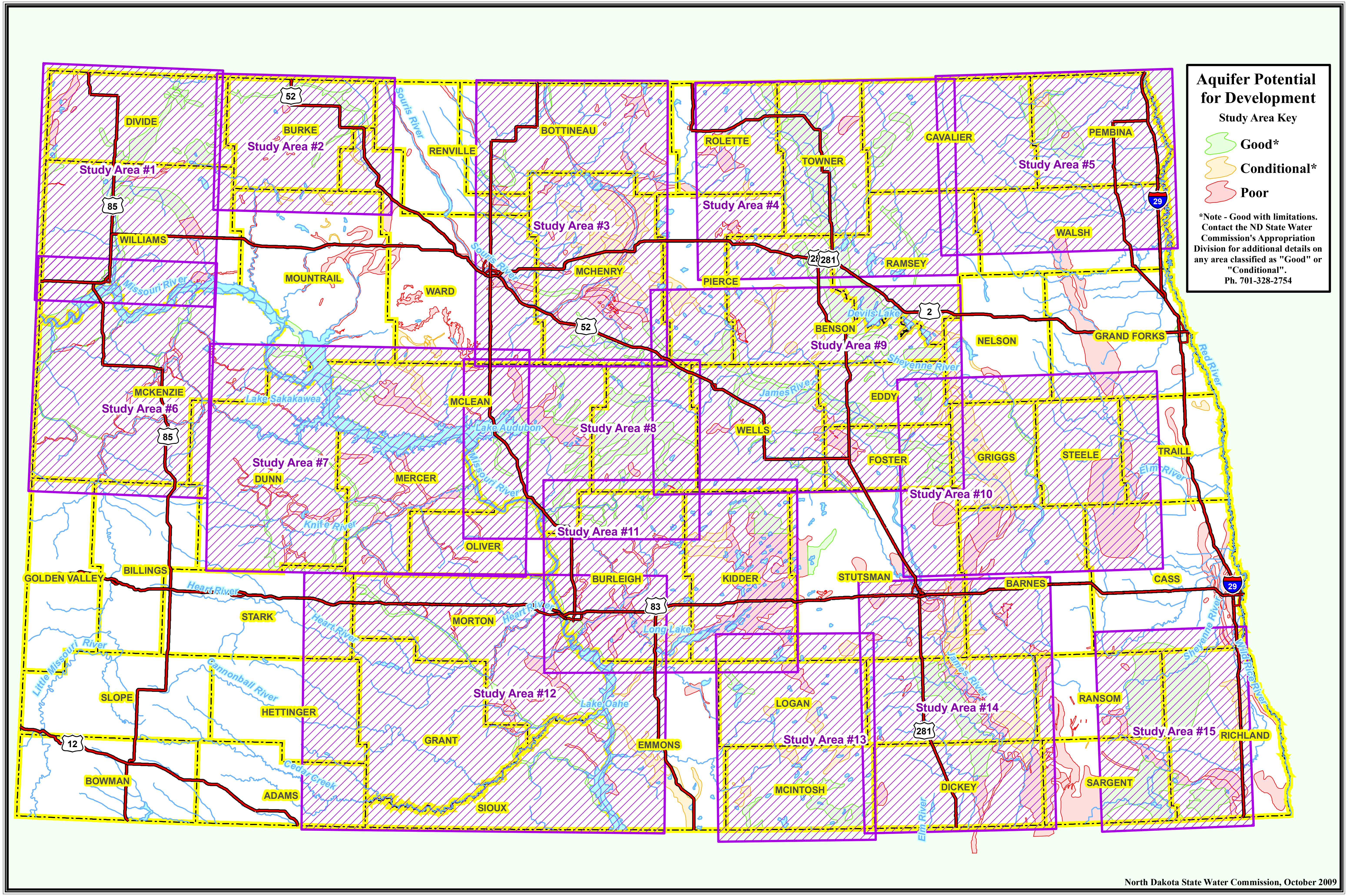


Figure 27. The distribution of existing water permits and applications. A summary of the number and status of water permits and the amount of water allocated for each aquifer in each of the study areas is provided in Appendix F.

Table 24. Summary of potential ground-water development in shallow glacial and fluvial aquifers.

| Study Area | Aquifer | Potential Acre-feet | Total Low Acre-feet | Total High Acre-feet |
|---|---|---|---|---|
| 1 | Grenora | 200-300 | | |
| | Little Muddy | 500-600 | | |
| | Ray | 1,000-2,000 | | |
| | Wildrose | 500 | | |
| | Yellowstone BV, | 1,500-2000 | | |
| | Crosby, Estevan, Smoky Butte & Little Muddy | 300-500 | | |
| | **AREA TOTAL** | | 4,000 | 5,900 |
| 2 | Columbus | 600-1,200 | | |
| | Kenmare | ~100-200 | | |
| | Shell Creek | 200-900 | | |
| | **AREA TOTAL** | | 900 | 2,300 |
| 3 | Denbigh | ~300 | | |
| | Glenburn | 400-800 | | |
| | Lake Souris | 400-600 | | |
| | New Rockford (McHenry City) | 400-1,000 | | |
| | Voltaire | 1,000-1,900 | | |
| | **AREA TOTAL** | | 2,500 | 4,600 |
| 4 | Munich | 1,000-2,000 | | |
| | Rolla | 900 | | |
| | Spiritwood (N. Ramsey and Towner) | 4,500 | | |
| | Starkweather | ~200 | | |
| | **AREA TOTAL** | | 6,600 | 76600 |
| 5 | Icelandic | 2,500-3,500 | | |
| | Pembina Delta/River | 1,500-2,000 | | |
| | **AEA TOTAL** | | 4,000 | 5,500 |
| 6 | Bennie Peer | 500-1,000 | | |
| | Charbonneau | ~100-200 | | |
| | Tobacco Garden | ~ 400 | | |
| | Yellowstone-Missouri-Trenton (Williams and McKenzie Counties) | ~1,000-5,000 | | |
| | **AREA TOTAL** | | 2,000 | 6,600 |
| 7 | Goodman Creek | 500 | | |
| | Kildeer | 500-1,500 | | |
| | Knife River (Dunn and Mercer Counties) | ~300 | | |
| | Missouri River (Burleigh, McLean, Mercer, Morton and Oliver Counties) | 8,000 -16,000 | | |
| | White Shield | 2,000-5,000 | | |
| | **AREA TOTAL** | | 2,000 | 5,000 |
| 8 | | | | |
| | Lake Nettie | 8,000-16,000 | | |
| | Lost Lake and Painted Woods Creek | 800-1,600 | | |
| | Martin & Butte | 2,000-6,000 | | |
| | North Burleigh | ? | | |
| | Strawberry Lake | 700-1500 | | |
| | Turtle Lake/Weller Slough/Wolf Creek | 1,000-2,000 | | |
| | **AREA TOTAL** | | 12,800 | 27,100 |



Aquifer Potential for Development

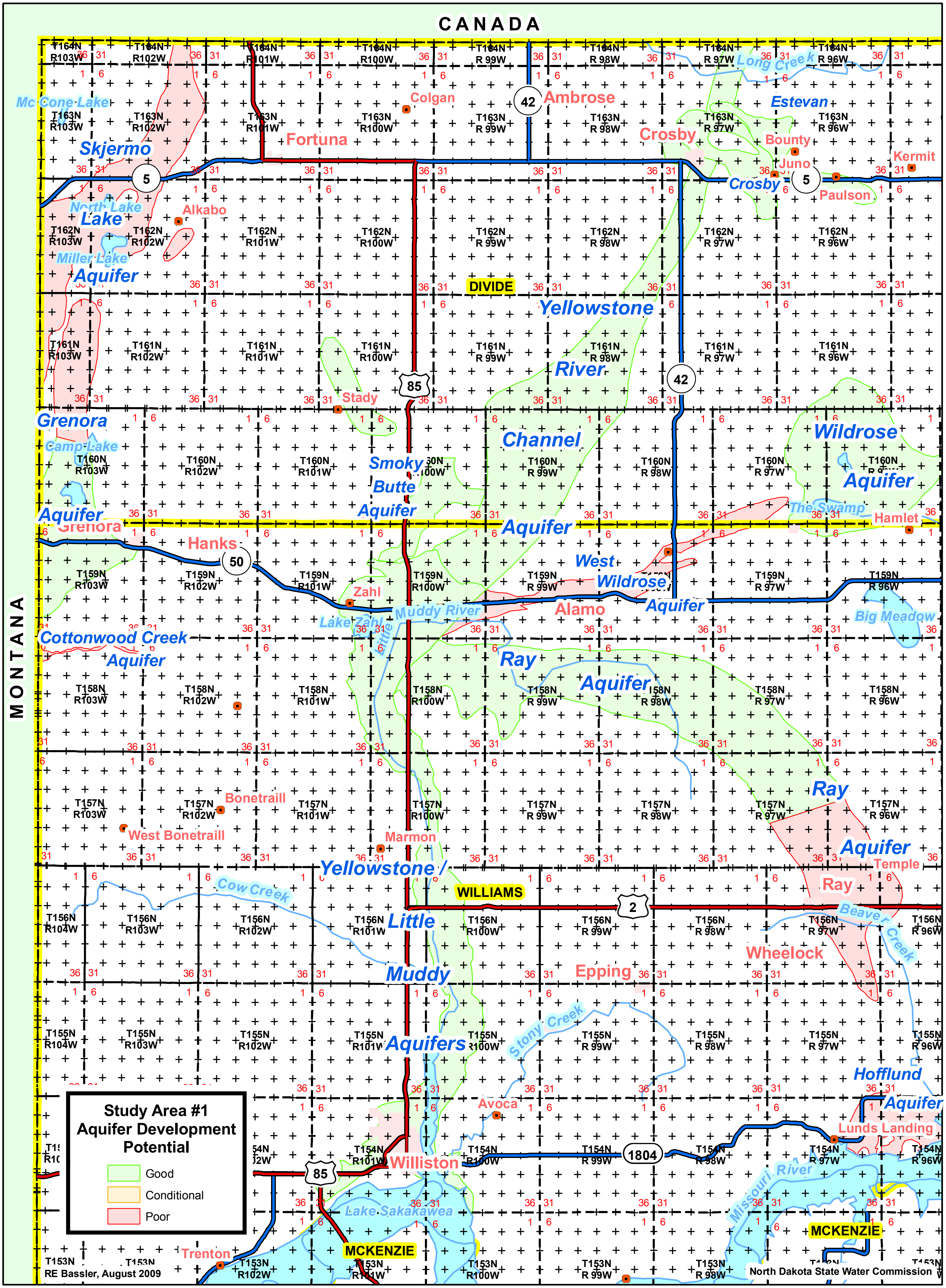
Study Area Key

*Note - Good with limitations. Contact the ND State Water Commission's Appropriation Division for additional details on any area classified as "Good" or "Conditional". Ph. 701-328-2754

North Dakota State Water Commission, October 2009

Table 24. Summary of potential ground-water development in shallow glacial and fluvial aquifers.

| Study Area | Aquifer | Potential<br>Acre-feet | Total Low<br>Acre-feet | Total High<br>Acre-feet |
|---|---|---|---|---|
| 9 | **Cherry Lake** | 500-1,000 | | |
| | **Eastman** | 600 | | |
| | **Manfred** | ~300 | | |
| | **New Rockford** | 0-4,000 | | |
| | **Pipestem Creek** | 600 | | |
| | **Spiritwood (Ramsey, Benson, Nelson, NE Griggs)** | 600-1,200 | | |
| | **Tokio** | 1,500-4,000 | | |
| | **Warwick** | 1,000-5,000 | | |
| | **AREA TOTAL** | | **5,100** | **16,700** |
| 10 | **Spiritwood (See Study Area 9.6)** | | | |
| | **McVille** | 200 | | |
| | **AREA TOTAL** | | **200** | **200** |
| 11 | **Missouri River (See Study Area #8)** | | | |
| | **North Burleigh (See Study Area #8)** | | | |
| | **Central Dakota (Kidder and Stutsman)** | 2,500-5,100 | | |
| | **AREA TOTAL** | | **3,300** | **6,600** |
| 12 | **Elm Creek** | 2,000 | | |
| | **Little Heart** | 500 | | |
| | **Shields (Morton and Sioux)** | 1,000-2100 | | |
| | **St. James** | 500 | | |
| | **AREA TOTAL** | | **4,000** | **5,100** |
| 13 | **Beaver Creek** | 200-300 | | |
| | **Beaver Lake** | 400 | | |
| | **Hillsburg** | 500-600 | | |
| | **McIntosh** | 500-600 | | |
| | **Napoleon** | 500-1000 | | |
| | **Spring Creek** | 2,000-2,500 | | |
| | **Wishek** | 200 | | |
| | **Zeeland** | 400-500 | | |
| | **AREA TOTAL** | | **4,700** | **6,100** |
| 14 | **Ellendale** | 1,500-3,500 | | |
| | **Spiritwood (S. Stutsman, LaMoure, N. Dickey)** | ? | | |
| | **AREA TOTAL** | | **1,500** | **1,500** |
| 15 | **Brightwood** | 1,000-2,000 | | |
| | **Colfax** | 1,000-2,000 | | |
| | **Sheyenne Delta** | ? | | |
| | **Spiritwood (Sargent)** | 2,200-5,000 | | |
| | **AREA TOTAL** | | **4,200** | **9,000** |
| | **TOTAL** | | **57,800** | **109.800** |


CANADA
MONTANA
Study Area #1
Aquifer Development Potential
🟩 Good
🟨 Conditional
🟥 Poor
DIVIDE
WILLIAMS
MCKENZIE
Skjermo Lake Aquifer
North Lake
Miller Lake
Mc Cone Lake
Grenora Aquifer
Camp Lake
Grenora
Yellowstone River Channel Aquifer
Smoky Butte Aquifer
Wildrose Aquifer
The Swamp
West Wildrose Aquifer
Cottonwood Creek Aquifer
Ray Aquifer
Yellowstone / Little Muddy Aquifers
Hofflund Aquifer
Big Meadow
Lake Zahl
Little Muddy River
Long Creek
Cow Creek
Stony Creek
Beaver Creek
Missouri River
Lake Sakakawea
Fortuna
Colgan
Ambrose
Crosby
Estevan
Bounty
Juno
Kermit
Paulson
Alkabo
Stady
Hamlet
Hanks
Zahl
Alamo
Bonetraill
West Bonetraill
Marmon
Temple
Ray
Wheelock
Epping
Avoca
Lunds Landing
Williston
Trenton
5
42
85
50
2
1804
T164N R103W
T164N R102W
T164N R101W
T164N R100W
T164N R 99W
T164N R 98W
T164N R 97W
T164N R 96W
RE Bassler, August 2009
North Dakota State Water Commission

## Study Area 1: Northwest North Dakota / Divide and Williams Counties

### *1.1 Grenora Aquifer (Divide and Williams Counties)*

The Grenora aquifer underlies about 25 to 30 square miles in northwestern Divide and Williams Counties (Study Area #1 map).

Aquifer Composition: The Grenora aquifer, as described by Nygren[120] is composed of fluvial sand and gravel in one to three layers. The extent and geometry of the deeper units is unknown. The surficial unit (up to 60 feet thick), when present, is unconfined and composed of fine to medium sand. The second deeper unit (approx. 100 to 130 feet bls), when present, is composed of sand and gravel. The third unit (approx. 300 to 320 feet bls), when present, is composed of sand and gravel. The deeper two units are separated from the surficial unit, and from each other, by clay and till. Examples of the Grenora aquifer lithology are shown on Appendix Figures B.1.1.1, B.1.1.2 and B.1.1.3.

Aquifer Yield: Sand and gravel have an estimated hydraulic conductivity of 100 to 150 feet per day in the upper unit, and about 260 feet per day in the lower unit. Storativity of the lower unit (S) is estimated at about 0.0003.[121] Expected well yields would vary with local conditions, but may be as high as 500 gpm in some of the thicker units.

Aquifer Chemistry: Grenora aquifer chemistry ranges from a calcium-bicarbonate type, to a calcium magnesium sodium-bicarbonate type, and a sodium-bicarbonate type (Figure 1.1.1). Dissolved solids concentrations range from about 400 to 2,500 mg/L (Table 1.1.1). The water is characteristically hard. The proportion of sodium increases with dissolved solids (Figure 1.1.1). Sulfate increases slightly with dissolved solids. Dissolved solids increase linearly with depth, and depth alone can account for about 80% of the variability in dissolved solids. Dissolved iron is high (>0.3 mg/L) in some samples, but the median value is low. Dissolved manganese is usually high (>0.05 mg/L) (Table 1.1.3).

Permit Acquisition Status Grenora: There are currently four water permits in the southern portion of the Grenora aquifer, two perfected and two conditional for a total of 315.5 acre-feet. Additional beneficial use of 200 to 300 acre-feet may be feasible from the Grenora aquifer, depending on recharge characteristics.

Additional Considerations: Applicants should avoid the proximity to points of diversion from existing permits or applications. Local exploratory drilling may be necessary. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

---

[120] Nygren, Andrew. Sept. 9, 2009. Written communication to W.M. Schuh.

[121] Ibid.

Table 1.1.1. Summary of chemical properties of the Grenora aquifer in Divide and Williams Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 650 | 625 | 8.0 | 7.5 | 411 | 407 | 6.7 | 20 | 57.1 | 30 | 3.2 | 11 | 0.1 | 273 | 0 | 54 | 2 | 0 |
| **Maximum** | 2,320 | 2,930 | 8.3 | 8.3 | 2,530 | 2,510 | 13 | 33.3 | 272 | 204 | 18 | 515 | 0.61 | 1,150 | 1 | 1,410 | 58 | 108 |
| **Points** | 12 | 16 | 2.00 | 16.00 | 9 | 16 | 10 | 16 | 16 | 16 | 16 | 16 | 15 | 16 | 16 | 16 | 16 | 16 |
| **Mean** | 1,311.5 | 1,428.9 | 8.2 | 7.8 | 805.56 | 967.87 | 8.38 | 25.39 | 101.18 | 51.61 | 8.22 | 166.39 | 0.29 | 606.69 | 0.44 | 304.38 | 15.2 | 7.3 |
| **Median** | 1,190 | 1,335 | 8.2 | 7.9 | 499 | 881.5 | 7.6 | 24.5 | 85.35 | 38.5 | 6.1 | 142 | 0.2 | 541.5 | 0 | 245 | 7.29 | 0.29 |
| **Std Deviation** | 579.08 | 731.18 | 0.2 | 0.3 | 676.38 | 583.21 | 2.18 | 4.07 | 50.74 | 42.52 | 4.35 | 155.77 | 0.19 | 270.1 | 0.51 | 327.19 | 17.75 | 26.86 |
| **Std Error** | 167.17 | 182.8 | 0.1 | 0.1 | 225.46 | 145.8 | 0.69 | 1.02 | 12.68 | 10.63 | 1.09 | 38.94 | 0.05 | 67.52 | 0.13 | 81.8 | 4.44 | 6.72 |

Table 1.1.2. Summary of chemical properties of the Grenora aquifer in Divide and Williams Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 308 | 0 | 283 | 0 | 0.3 | - | 0.61 | - | 1.61 |
| **Maximum** | 1,520 | 1,170 | 940 | 571 | 12.7 | - | 0.98 | - | 1.98 |
| **Points** | 16 | 16 | 7 | 16 | 16 | - | 9 | - | 9 |
| **Mean** | 465.06 | 104.5 | 669.14 | 204.38 | 3.56 | - | 0.79 | - | 1.79 |
| **Median** | 409 | 16 | 696 | 231.5 | 2.5 | - | 0.83 | - | 1.83 |
| **Std Deviation** | 290.28 | 287 | 209.02 | 203.48 | 3.61 | - | 0.11 | - | 0.11 |
| **Std Error** | 72.57 | 71.75 | 79 | 50.87 | 0.9 | - | 0.04 | - | 0.04 |

Table 1.1.3. Summary of chemical properties of the Grenora aquifer in Divide and Williams Counties: selected trace elements.

|  | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0 | 0.04 | 0.01 | - | - | - | - | - |
| **Maximum** | 0.3 | 2.5 | 1.1 | - | - | - | - | - |
| **Points** | 9 | 16 | 10 | - | - | - | - | - |
| **Mean** | 0.11 | 0.6 | 0.27 | - | - | - | - | - |
| **Median** | 0.04 | 0.16 | 0.11 | - | - | - | - | - |
| **Std Deviation** | 0.12 | 0.8 | 0.4 | - | - | - | - | - |
| **Std Error** | 0.04 | 0.2 | 0.13 | - | - | - | - | - |

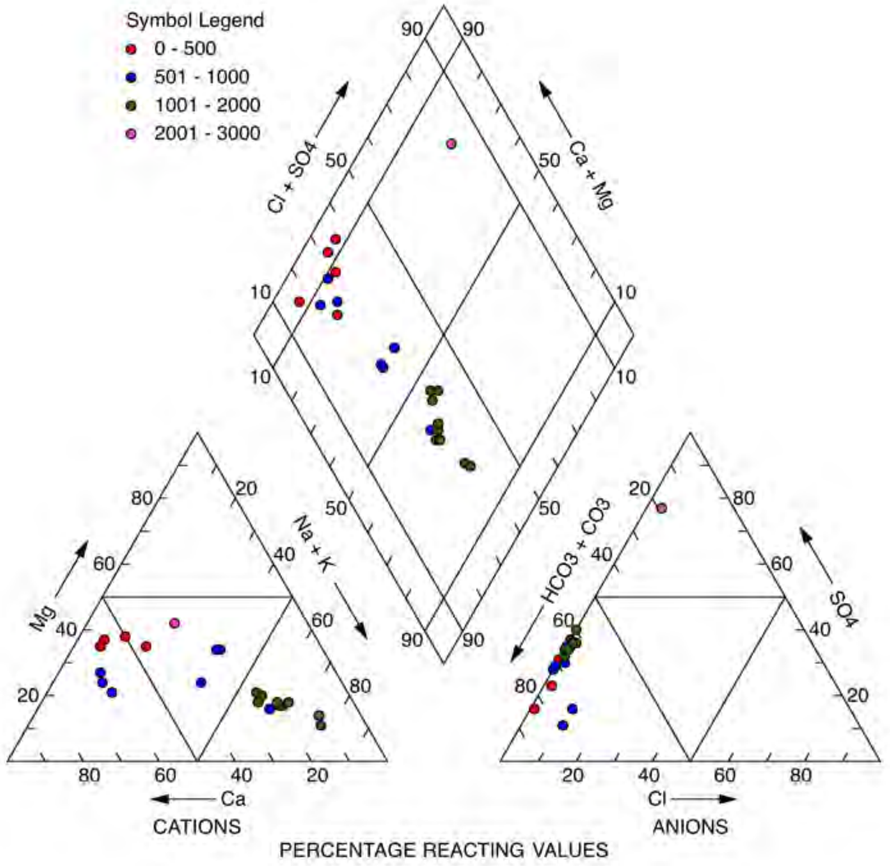


Figure 1.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Grenora aquifer in Divide and Williams Counties.

### *1.2 Little Muddy Aquifer (Williams County)*

The Little Muddy aquifer was described by Armstrong (1967) as a buried valley aquifer underlying the Little Muddy River valley in southern Williams County (Study Area #1 map).

Aquifer Composition: According to Armstrong (1967), the aquifer consists of two zones. An upper zone consists of less than one foot to 116 feet of mixed sand and gravel, with an average thickness of about 43 feet. However, from recent drilling, the northern portion is thicker, averaging about 76 feet thick. A deeper zone, usually more than 130 feet below land surface, consists of a narrow sand and gravel deposit having a thickness of up to 110 feet, and an average thickness of about 28 feet. Three examples of aquifer lithology are provided on Appendix Figures B.1.3.1, B.1.3.2 and B.1.3.3.

Aquifer Yield: Based on one aquifer test, Armstrong (1967) reported a transmissivity of 17,000 $ft.^2/d$ and a storativity of 0.0004. He estimated that sustained 3-day pumping rates of up to 1,200 gpm may be possible.

Aquifer Chemistry: Dissolved solids concentrations range between about 400 and 4,000 mg/L (Table 1.2.1). The anion and cation distribution for water samples ranges from a calcium-bicarbonate type to a sodium-sulfate type. Water having higher dissolved solids tends to be more sodic and more sulfatic. Iron and manganese tend to be high. No determinations of selenium or arsenic are available (Table 1.2.3). Potential users should test for these trace elements. The deeper unit tends to have higher dissolved solids.

Permit Acquisition Status: There are currently 53 water permits, 33 perfected, 11 conditional, seven applied for (deferred status) and two held in abeyance, for a total of 12,187 acre-feet from the Little Muddy aquifer. The shallow aquifer unit is heavily appropriated. However, the deeper unit has two water permits for a total of 734 acre-feet. Depending on the length of the lower zone (estimating about 33 square miles for a one-mile wide deposit), and assuming an average recharge rate of about 0.25 to 0.5 inches per year with some isolated areas of connection with the upper unit, there may be as much as 500 to 1,500 acre-feet available for future development.

Additional Considerations: Most of the water available for future appropriation would be from the lower zone. Exploratory work will likely be required. Prospective water users should contact the managing hydrologist at the State Water Commission for further guidance. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Armstrong, C.A. 1967. Geology and ground-water resources of Divide County, North Dakota. County Ground-water Studies 6. North Dakota State Water Commission. Bismarck, ND. 37 pp.

Table 1.2.1. Summary of chemical properties of the Little Muddy aquifer in Williams County: general chemistry.

| | $S_C$-f µS/cm | $S_C$-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 448 | 448 | 7.44 | 6.3 | 365 | 259 | 7.8 | 11 | 14 | 8.5 | 2.2 | 7.9 | 0.08 | 228 | 0 | 4.69 | 0 | 0 |
| **Maximum** | 14,002 | 4,400 | 8.21 | 8.29 | 2,360 | 3,420 | 13.1 | 41 | 280 | 244 | 18 | 953 | 1.76 | 1,623 | 94 | 1,580 | 50.3 | 91.2 |
| **Points** | 126 | 161 | 5 | 145 | 45 | 158 | 10 | 93 | 144 | 144 | 143 | 144 | 142 | 147 | 147 | 146 | 146 | 142 |
| **Mean** | 1,831.2 | 1,778.8 | 7.9 | 7.73 | 1,247.7 | 1,204.3 | 9.57 | 25.17 | 109.58 | 56.63 | 7.21 | 239.75 | 0.34 | 693.2 | 1.4 | 464.38 | 9.97 | 4.89 |
| **Median** | 1,727 | 1,800 | 7.98 | 7.74 | 1,230 | 1,170 | 8.95 | 25.6 | 101 | 50.9 | 7.37 | 218.5 | 0.29 | 675 | 1 | 448 | 8.21 | 0.13 |
| **Std Deviation** | 1,249.3 | 648.92 | 0.29 | 0.27 | 405.22 | 486.55 | 1.85 | 3.96 | 45.71 | 27.63 | 2.31 | 151.45 | 0.23 | 273.54 | 7.73 | 272.89 | 7.88 | 14.97 |
| **Std Error** | 111.3 | 51.14 | 0.13 | 0.02 | 60.41 | 38.71 | 0.58 | 0.41 | 3.81 | 2.3 | 0.19 | 12.62 | 0.02 | 22.56 | 0.64 | 22.59 | 0.65 | 1.26 |

Table 1.2.2. Summary of chemical properties of the Little Muddy aquifer in Williams County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 70 | 0 | 187 | 0 | 0.23 | 0.53 | -0.76 | 1.53 | 0.24 |
| **Maximum** | 1,630 | 1,160 | 1,340 | 1,340 | 24.3 | 0.53 | 1.4 | 1.53 | 2.4 |
| **Points** | 162 | 142 | 101 | 163 | 146 | 1 | 41 | 1 | 41 |
| **Mean** | 493.41 | 83.94 | 572.24 | 167.17 | 4.94 | 0.53 | 0.75 | 1.53 | 1.75 |
| **Median** | 459 | 0 | 553 | 0 | 4.05 | 0.53 | 0.76 | 1.53 | 1.76 |
| **Std Deviation** | 224.61 | 143.47 | 235.73 | 290.97 | 3.73 | 0 | 0.36 | 0 | 0.36 |
| **Std Error** | 17.65 | 12.04 | 23.46 | 22.79 | 0.31 | 0 | 0.06 | 0 | 0.06 |

Table 1.2.3. Summary of chemical properties of the Little Muddy aquifer in Williams County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0.02 | 0 | 0 | 0 | 3 | 60 | 0 |
| Maximum | 1.35 | 9.71 | 2.6 | 3.76 | 0.2 | 33 | 140 | 6 |
| Points | 28 | 146 | 127 | 6 | 6 | 6 | 6 | 6 |
| Mean | 0.21 | 2.28 | 0.39 | 0.63 | 0.05 | 18.38 | 88.65 | 2.74 |
| Median | 0.14 | 2.07 | 0.25 | 0 | 0 | 20.5 | 85 | 3 |
| Std Deviation | 0.29 | 1.92 | 0.39 | 1.54 | 0.08 | 11.31 | 27.9 | 2.48 |
| Std Error | 0.05 | 0.16 | 0.03 | 0.63 | 0.03 | 4.62 | 11.39 | 1.01 |

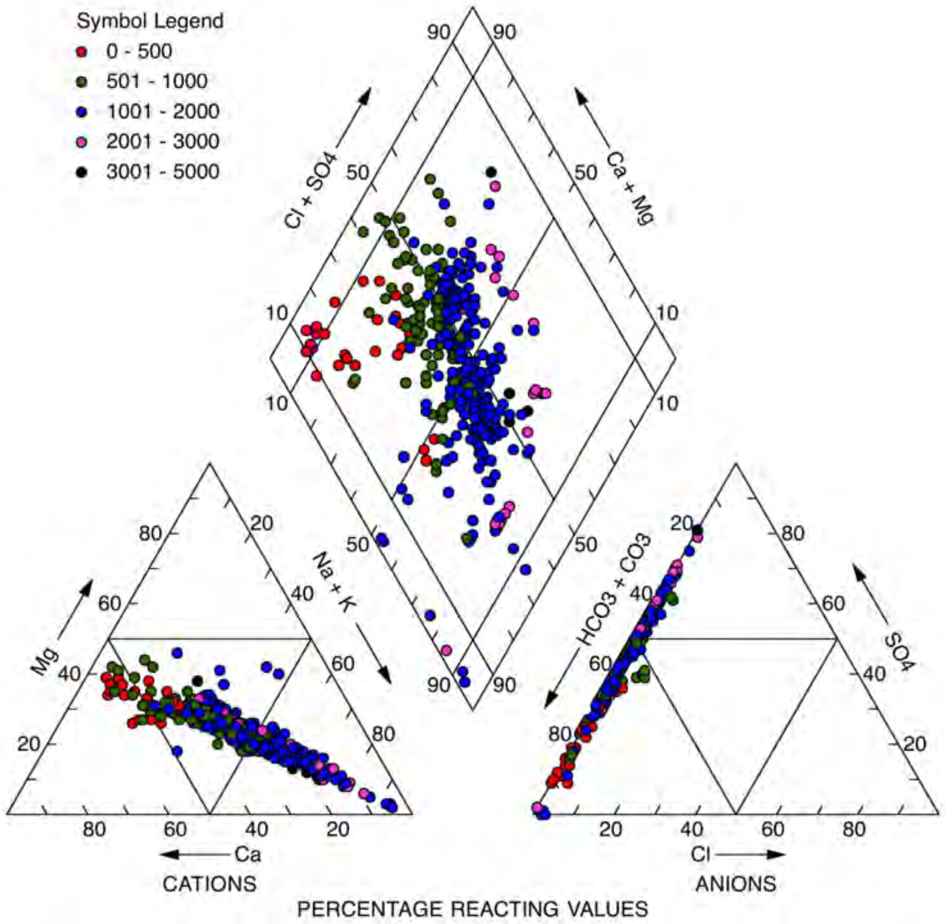


Figure 1.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Little Muddy aquifer in Williams County.

## *1.3 Ray Aquifer (Williams County)*

The northern portion of the Ray aquifer underlies about 75 square miles in northeastern and central Williams County (Study Area #1 map).

<u>Aquifer Composition:</u> The Ray aquifer, as described by Andrew Nygren,[122] is composed of fluvial sand and gravels. Although overlain by about 150 feet of till, it is leaky-confined in the northern area, and unconfined in its southern extent. The Ray aquifer has a saturated thickness as great as 90 feet in some areas. Three examples of aquifer lithology are provided on Appendix Figures B.1.3.1, B.1.3.2 and B.1.3.3.

<u>Aquifer Yield:</u> Sand and gravel have an estimated transmissivity of as much as 20,400 square feet per day, and a storage coefficient of 0.05. Expected yields would vary with local conditions, but may be as high as 500 gpm in some of the thicker areas.

<u>Aquifer Chemistry:</u> Ray aquifer chemistry is mainly of the calcium sodium-sulfate and bicarbonate type (Piper Plot, Figure 1.3.1). Dissolved solids concentrations vary from about 450 to 3,000 mg/L. Median dissolved solids are relatively high, about 1,500 mg/L (Table 1.3.1). According to Nygren[123], there seems to be a tendency toward saltier water in the more northwestern portions of the aquifer, which is more confined. Ray aquifer water is hard (Table 1.3.2). Iron and manganese concentrations are both high (> 0.32 mg/L and >0.05 mg/L, respectively – Table 1.3.3). Arsenic is marginally high, with a median below the EPA MCL (10 µg/L), and mean above the EPA MCL.

<u>Permit Acquisition Status:</u> There are currently seven perfected water permits, for a total allocation of 1,737 acre-feet in the portion of the Ray aquifer indicated to be available for further development (Study Area #1 map). There are no pending permit applications that would slow the time of water permit acquisition.

<u>Additional Considerations:</u> If we assume an average recharge rate of about 0.5 inches per year, which would be reasonably conservative for leaky confined conditions, additional development of 1,000 to 2,000 acre-feet of water for beneficial use may be possible in the designated portion of the Ray aquifer. Potential applicants should consult the managing hydrologist (SWC) for further information concerning a prospective site for beneficial use. They should also consider that pumping the leaky confined aquifers could increase recharge and may possibly cause degradation of water quality through an increased influx of till water. Applicants should consider the water quality for their respective applications. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

---

[122] Ibid.

[123] Ibid.

Table 1.3.1. Summary of chemical properties of the Ray aquifer in Williams County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 780 | 740 | 0 | 7.2 | 465 | 438 | 6.1 | 1.6 | 26 | 12 | 2.8 | 43 | 0.1 | 111 | 0 | 123 | 0.5 | 0 |
| **Maximum** | 2,730 | 4,640 | 0 | 8.65 | 3,110 | 2,290 | 12.8 | 32 | 354 | 167 | 22 | 499 | 1.2 | 1,000 | 6 | 1,160 | 220 | 26 |
| **Points** | 22 | 34 | 0 | 33 | 26 | 33 | 21 | 25 | 33 | 33 | 33 | 33 | 33 | 33 | 32 | 33 | 33 | 33 |
| **Mean** | 1,793.3 | 2,092.8 | 0 | 7.74 | 1,493.5 | 1,430.5 | 8.77 | 19.55 | 160.76 | 99.56 | 9.59 | 189.27 | 0.25 | 670.36 | 0.44 | 648.18 | 14.53 | 2.15 |
| **Median** | 1,980 | 2,115 | 0 | 7.8 | 1,565 | 1,530 | 8 | 19 | 164 | 104 | 9.8 | 202 | 0.2 | 730 | 0 | 640 | 6 | 0.44 |
| **Std Deviation** | 558.92 | 755.39 | 0 | 0.3 | 648.24 | 494.6 | 1.81 | 6.08 | 62.28 | 34.69 | 3.6 | 100.03 | 0.2 | 175.89 | 1.11 | 306.89 | 37.67 | 5.08 |
| **Std Error** | 119.16 | 129.55 | 0 | 0.05 | 127.13 | 86.1 | 0.4 | 1.22 | 10.84 | 6.04 | 0.63 | 17.41 | 0.03 | 30.62 | 0.2 | 53.42 | 6.56 | 0.88 |

Table 1.3.2. Summary of chemical properties of the Ray aquifer in Williams County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 110 | 0 | 599 | 0 | 0.8 | 0 | 0.36 | 0 | 1.36 |
| **Maximum** | 1,800 | 959 | 697 | 820 | 7.4 | 0 | 1.61 | 0 | 2.61 |
| **Points** | 34 | 33 | 8 | 34 | 33 | 0 | 25 | 0 | 25 |
| **Mean** | 838.94 | 273.91 | 644.75 | 381.85 | 2.98 | 0 | 0.96 | 0 | 1.96 |
| **Median** | 870 | 252 | 643 | 449 | 3.05 | 0 | 0.99 | 0 | 1.99 |
| **Std Deviation** | 329.66 | 224.22 | 35.46 | 266.09 | 1.56 | 0 | 0.32 | 0 | 0.32 |
| **Std Error** | 56.54 | 39.03 | 12.54 | 45.64 | 0.27 | 0 | 0.06 | 0 | 0.06 |

Table 1.3.3. Summary of chemical properties of the Ray aquifer in Williams County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | nd | nd | 0.01 | - | - | 1 | 50 | 0 |
| Maximum | 1.1 | 21 | 1.11 | - | - | 31 | 80 | 7 |
| Points | 23 | 33 | 23 | - | - | 6 | 6 | 6 |
| Mean | 0.36 | 2.94 | 0.4 | - | - | 11 | 65 | 2.67 |
| Median | 0.28 | 1.1 | 0.36 | - | - | 6.5 | 60 | 2.5 |
| Std Deviation | 0.28 | 4.23 | 0.34 | - | - | 11.44 | 12.25 | 2.42 |
| Std Error | 0.06 | 0.74 | 0.07 | - | - | 4.67 | 5 | 0.99 |

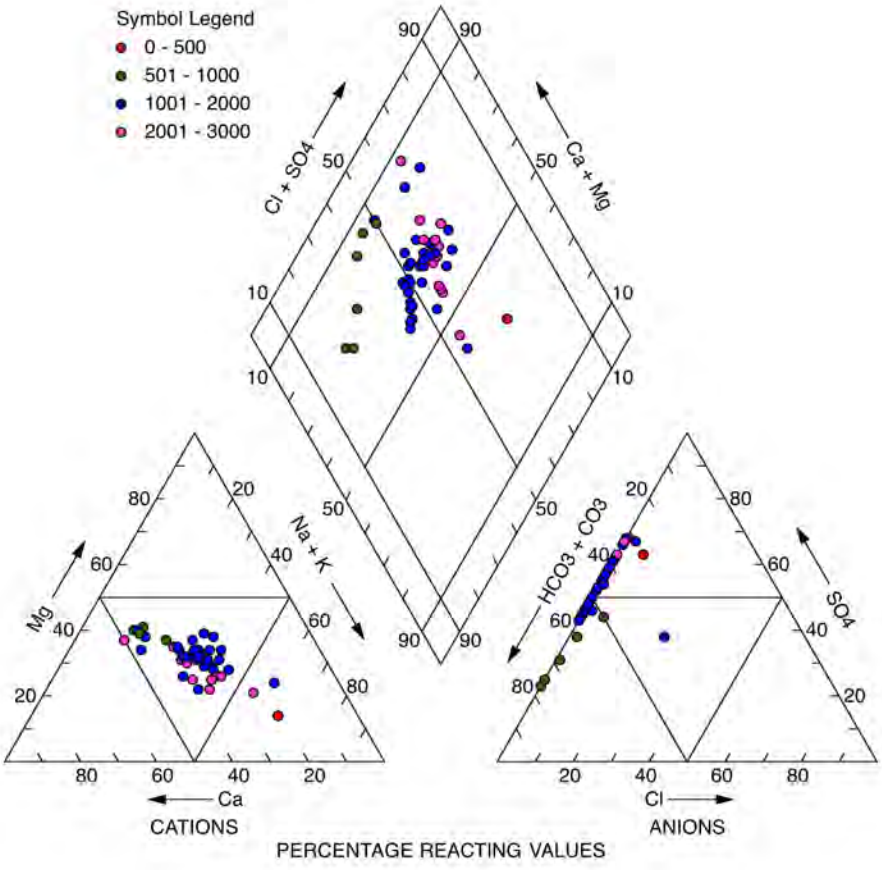


Figure 1.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Ray aquifer in Williams County.

### *1.4 Wildrose Aquifer (Divide County)*

The Wildrose aquifer underlies about 40 square miles in southeastern Divide County (Study Area #1 map).

Aquifer Composition: According to Armstrong (1967) the Wildrose aquifer consists of "poorly sorted fine sand to medium gravel in beds that are 1 to 29 feet thick." The aquifer consists of interlocking meltwater channels converging in the west into the West Wildrose Channel aquifer. The aquifer is structured as one to three coarse deposits, separated by silt, clay and till layers (Appendix Figures B.1.4.1 and B.1.4.2), similar to other area aquifers.

Aquifer Yield: Armstrong (1967) has stated that production wells are capable of 5 to 10 gpm per foot drawdown. Based on characteristic thicknesses of less than 50 feet, expected well yields would be less than 500 gpm, except in the deepest areas. The municipal well of Wildrose was reported to yield about 85 gpm.

Aquifer Chemistry: Wildrose aquifer chemistry is highly variable, consisting of calcium and sodium-bicarbonate type water at some sites, and calcium sodium-sulfate type water at others (Figure 1.4.1). Based on five water samples, dissolved solids concentrations range from about 300 to 3,000 mg/L (Table 1.4.1). Higher sulfate concentrations correspond to sites of high dissolved solids (Figure 1.4.1, Table 1.4.1). The water is predominantly hard (Table 1.4.2). Dissolved iron is high (>0.3 mg/L - Table 1.4.3), dissolved manganese is high (>0.05 mg/L), and the single arsenic sample is above the EPA-MCL (>10 μg/L - Table 1.4.3).

Permit Acquisition Status: There is currently one perfected water permit, for 120 acre-feet from the Wildrose aquifer. If average overall recharge is 0.5 inches per year, with 40 square miles of surface, an additional beneficial use of up to 800 acre-feet of water may be feasible. While there is further development potential for beneficial use of water, the aquifer has been little explored and the recharge rates of deeper deposits are unknown.

Additional Considerations: Further local investigation and exploration should be undertaken before assuming a dependable and sustainable long-term water supply for industrial use. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Armstrong, C.A. 1967. Geology and ground-water resources of Divide County, North Dakota. County Ground-water Studies 6. North Dakota State Water Commission. Bismarck, ND. 37 pp.

Table 1.4.1. Summary of chemical properties of the Wildrose aquifer in Divide County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 3,990 | 570 | 9.24 | 7.2 | 291 | 316 | 6.1 | 20 | 60 | 25 | 4.4 | 9.6 | 0.2 | 277 | 0 | 43 | 3.9 | nd |
| **Maximum** | 3,990 | 3,610 | 9.24 | 8.3 | 1,587 | 2,800 | 8.9 | 25 | 189 | 86 | 14 | 573 | 0.6 | 802 | 1 | 1,530 | 48 | 3 |
| **Points** | 1 | 6 | 1 | 5 | 5 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Mean** | 3,990 | 1,740 | 9.24 | 7.77 | 896.8 | 1,132.2 | 7.4 | 22.46 | 108.4 | 50.3 | 8.7 | 186.72 | 0.33 | 470.2 | 0.2 | 503.4 | 24.92 | 0.66 |
| **Median** | 3,990 | 1,688 | 9.24 | 7.65 | 899 | 909 | 7.2 | 22 | 102 | 34 | 10 | 143 | 0.3 | 437 | 0 | 350 | 22 | 0.09 |
| **Std Deviation** | 0 | 1,153.5 | 0 | 0.44 | 564.57 | 1,009.8 | 1.41 | 2.13 | 49.07 | 29.9 | 4.1 | 230.62 | 0.16 | 213.68 | 0.45 | 607.98 | 15.89 | 1.31 |
| **Std Error** | 0 | 1.3305e+06 | 0 | 0.19 | 3.1873e+05 | 1.0197e+06 | 1.99 | 4.56 | 2,408.3 | 893.95 | 16.79 | 53,186 | 0.03 | 45,659 | 0.2 | 3.6964e+05 | 252.52 | 1.72 |

Table 1.4.2. Summary of chemical properties of the Wildrose aquifer in Divide County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 60 | 15 | 658 | 0 | 0.3 | 0 | 0.25 | 0 | 1.25 |
| **Maximum** | 800 | 170 | 658 | 440 | 8.81 | 0 | 0.93 | 0 | 1.93 |
| **Points** | 6 | 5 | 1 | 6 | 5 | 0 | 4 | 0 | 4 |
| **Mean** | 408.17 | 92.2 | 658 | 211.5 | 3.2 | 0 | 0.65 | 0 | 1.65 |
| **Median** | 359.5 | 77 | 658 | 235.5 | 3 | 0 | 0.71 | 0 | 1.71 |
| **Std Deviation** | 263.95 | 63.17 | 0 | 181.35 | 3.46 | 0 | 0.3 | 0 | 0.3 |
| **Std Error** | 69,668 | 3,990.7 | 0 | 32,887 | 11.96 | 0 | 0.09 | 0 | 0.09 |

Table 1.4.3. Summary of chemical properties of the Wildrose aquifer in Divide County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0.07 | 0.52 | - | - | 17.1 | - | - |
| Maximum | 0.38 | 3.52 | 0.52 | - | - | 17.1 | - | - |
| Points | 5 | 5 | 1 | - | - | 1 | - | - |
| Mean | 0.14 | 0.93 | 0.52 | - | - | 17.1 | - | - |
| Median | 0 | 0.28 | 0.52 | - | - | 17.1 | - | - |
| Std Deviation | 0.19 | 1.47 | 0 | - | - | na | - | - |
| Std Error | 0.03 | 2.15 | 0 | - | - | na | - | - |

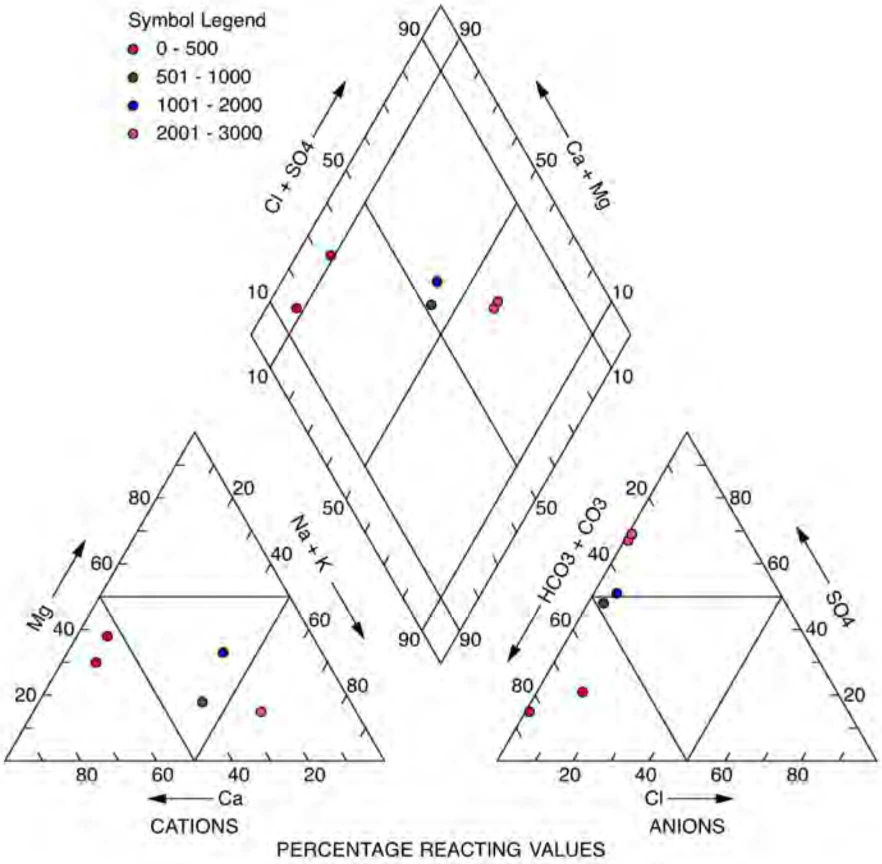


Figure 1.4.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Wildrose aquifer in Divide County.

### *1.5 Yellowstone Buried Valley (YBV), Crosby, Estevan, Smoky Butte and Little Muddy Aquifer System (Divide and Williams Counties)*

The four aquifers listed are treated together as a continuum of a system of buried valleys occupying the preglacial valley of the Yellowstone River and its nearby tributaries, or occupying channels eroded into the landscape by glacial diversions of the Yellowstone River (Study Area #1 map). As described by Wanek[124] the preglacial buried-valley aquifer system associated with the preglacial Yellowstone River begins near the confluence of the modern Yellowstone and Missouri Rivers, where the underlying aquifer is known as the Yellowstone-Missouri aquifer (see Study Area #6 map), and extends through about 20 miles of the current Missouri River valley, where the name of the underlying valley in Williams County is changed to the Trenton aquifer (see Study Area #6 map). Then, beginning at Williston, the buried-valley aquifer system extends northward through Williams County under the Little Muddy River, where it is known as the Little Muddy aquifer. From about the Williams-Divide county line to the U.S.-Canada border the aquifer is known as the Yellowstone Buried Valley aquifer (YBV). Under the Little Muddy near-surface outwash aquifer a deep buried channel is considered as a continuation of the southern extension of the YBV aquifer (the narrower YBV is within the boundaries of shallower deposits shown on the Study Area #1 map). The Smoky Butte aquifer (west of the main channel near the Williams-Divide county line), and the Crosby and Estevan aquifer near Crosby in northern Divide County were likely formed by tributaries of the preglacial Yellowstone River, but are separated because of evidence of hydraulic discontinuities. Water-level data have indicated a variance of heads between the Yellowstone Buried Valley aquifer and the Crosby aquifer. Water levels for the Estevan aquifer have shown indications of connections to aquifer system subunits north of the Canadian border.

<u>Aquifer Composition:</u> The aquifers are confined and are similar in lithology and composition, consisting of lenticular sand and gravel deposits, intermixed with silt and clay lenses, buried under till. Two examples of the Crosby aquifer lithology (Appendix Figures B.1.5.1 and B.1.5.2), and three examples of the YBV aquifer lithology (Appendix Figures B.1.5.3, B.1.5.4 and B.1.5.5) show a similar range of local stratigraphies, consisting of one to several silt, sand and gravel subunits, varying from 5 to 60 feet in thickness.

The southern extension of the YBV aquifer (between the dotted lines north of Williston on Study Area Map #2) is composed of fluvial sand and gravel. The southern extension is likely only about a mile wide. It lies about 100 to 200 feet below the Little Muddy aquifer (which is fully appropriated) and can range in thickness from a few feet to 100 feet. An example of the south extension of the YBV aquifer is shown as the bottom sand interval on Appendix Figure B.1.5.5. It has an upper boundary at 239 feet, and a saturated thickness of about 27 feet.

---

[124] Wanek, Alan. Sept. 2, 2009. Written communication.

The Estevan aquifer consists of varying layers of sand, gravel and cobbles between about 230 and 450 feet bls. The combined saturated thickness varies from about 52 to 86 feet, with an average (based on four locations) of about 74 feet. The bottom of the aquifer is coarsest, consisting of very coarse to coarse cobbles. Aquifer materials are finer at shallower depths in stratigraphic column.[125]

Aquifer Yield: According to Wanek[126] hydraulic characteristics are highly variable. The city of Crosby reports pumping rates of 150 to 250 gpm in its municipal wells. According to Nygren[127] pumping rates of up to 500 gpm may be attainable in some of the thicker portions of the south extension of the YBV aquifer.

Aquifer Chemistry: Concentrations of dissolved solids range between about 100 and 2,700 mg/L in the YBV aquifer (Table 1.5.1) and between about 800 and about 2,100 mg/L in the Crosby aquifer (Table 1.5.2). Median dissolved solids are similar, at 1,425 mg/L for the YBV aquifer, and 1,100 for the Crosby aquifer. Chemical composition is similar for the two aquifers, consisting of calcium-sulfate type water in some aquifer subunits, and sodium-bicarbonate type water in others (Figure 1.5.1).

A single water sample from the south extension of the YBV aquifer is of the sodium-bicarbonate type, hard, and has a TDS of about 2,000 mg/L (Tables 1.5.3 and 1.5.4).

Dissolved iron and manganese concentrations are high in both aquifers. Trace element samples are sparse, but one of three arsenic measurements was above the EPA-MCL of 10 μ/L (Tables 1.5.5 and 1.5.6).

Water samples from the Estevan aquifer are of a sodium-bicarbonate type, and dissolved solids vary from about 1,000 to 2,000 mg/L.[128]

Permit Acquisition Status: There are currently three water permits, including one perfected, one in process, and one held in abeyance in the YBV aquifer, for a total of 767 acre-feet of allocated water. The Crosby aquifer has two water permits, one conditional and one perfected, for a total of 433 acre-feet. There are no pending water-permit applications in any of the aquifers considered.

If we assume about a half inch of recharge per year (this assumes that the aquifers are connected to the surface through somewhat permeable materials and are not fully confined beneath low permeability unoxidized till), a possible maximum of about 1,500 to 2,000 additional acre-feet may be available for beneficial use from the YBV aquifer system, and about 300 to 500 additional acre-feet may be available for beneficial use from the combined associated deposits in the Crosby, Estevan, and Smoky Butte aquifers.

Additional Considerations

---

[125] Nygren, Andrew. May 4, 2009. Written communication to W.M. Schuh.

[126] Op Cit, Wanek, Alan.

[127] Op Cit, Nygren, Andrew.

[128] Ibid, Nygen, Andrew.

There is potential for limited increased use of the deep southern extension of the YBV aquifer in Williams County, but the extent of the aquifer is limited, its geometry is presently poorly-defined, and recharge is likely to be limited.

For the greatest probability of successful application in the least time, applicants would be advised to avoid proximity to the existing points of diversion, such as the Crosby city wells, or to the area of water permits held in abeyance, which would need to be considered and granted before consideration of new applicants.

**Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Table 1.5.1. Summary of chemical properties of the Yellowstone Buried Valley aquifer in Divide County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 233 | 227 | 7.44 | 6.76 | 119 | 134 | 8 | 4.2 | 10.8 | 5.1 | 5 | 7 | 0.1 | 124 | 0 | 15 | 4 | 0.09 |
| **Maximum** | 2,620 | 3,030 | 7.44 | 8.43 | 1,650 | 2,700 | 9 | 28 | 423 | 170 | 25 | 522 | 0.9 | 1,030 | 20 | 1,790 | 254 | 6 |
| **Points** | 6 | 6 | 1 | 6 | 3 | 6 | 2 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **Mean** | 1,767.2 | 1,852.8 | 7.44 | 7.84 | 881 | 1,363.2 | 8.5 | 18.22 | 116.3 | 76.88 | 10.33 | 223.83 | 0.35 | 595.67 | 5.17 | 559.73 | 56.35 | 1.67 |
| **Median** | 2,070 | 2,140 | 7.44 | 7.98 | 874 | 1,425 | 8.5 | 22.9 | 59.5 | 67.1 | 7.15 | 187 | 0.24 | 620.5 | 1 | 390 | 18.65 | 0.54 |
| **Std Deviation** | 869.27 | 987.57 | 0 | 0.63 | 765.52 | 856.46 | 0.71 | 11.13 | 158.21 | 68.68 | 7.7 | 186.13 | 0.31 | 311.87 | 8.04 | 656.44 | 97.17 | 2.34 |
| **Std Error** | 354.88 | 403.17 | 0 | 0.26 | 441.98 | 349.65 | 0.5 | 4.54 | 64.59 | 28.04 | 3.14 | 75.99 | 0.13 | 127.32 | 3.28 | 267.99 | 39.67 | 0.96 |
| **15910029DCD (South)** | | 2930 | | 8.51 | 2020 | 2050 | | 29 | 70 | 39 | 14 | 640 | 0.7 | 1220 | 23 | 590 | 39 | 1 |

Table 1.5.2. Summary of chemical properties of the Crosby aquifer in Divide County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 1,250 | 1,300 | 8.1 | 6.93 | 831 | 795 | 7 | 13 | 28.4 | 14 | 5.1 | 100 | 0.1 | 344 | 0 | 0.3 | 10.8 | 0.09 |
| **Maximum** | 3,200 | 3,480 | 8.1 | 8.5 | 1,780 | 2,160 | 17 | 30 | 328 | 93.8 | 13 | 724 | 1.5 | 1,470 | 48 | 1,460 | 69.6 | 7.3 |
| **Points** | 15 | 19 | 1 | 19 | 10 | 19 | 5 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 19 | 18 |
| **Mean** | 1,827.5 | 1,874.6 | 8.1 | 7.89 | 1,085 | 1,189.4 | 10.4 | 24.02 | 100.65 | 42.51 | 8.22 | 313.42 | 0.67 | 899.47 | 4.58 | 248.62 | 45.98 | 1.03 |
| **Median** | 1,696 | 1,710 | 8.1 | 7.85 | 911 | 1,100 | 9 | 25.7 | 70 | 31.3 | 7.8 | 227 | 0.62 | 847 | 1 | 90 | 47.5 | 0.95 |
| **Std Deviation** | 497.91 | 562.31 | 0 | 0.37 | 328.4 | 371.24 | 3.97 | 4.42 | 76.61 | 22.81 | 2.19 | 185.69 | 0.34 | 299.55 | 11.78 | 397.26 | 15.16 | 1.65 |
| **Std Error** | 128.56 | 129 | 0 | 0.08 | 103.85 | 85.17 | 1.78 | 1.01 | 17.58 | 5.23 | 0.5 | 42.6 | 0.08 | 68.72 | 2.7 | 91.14 | 3.48 | 0.39 |

Table 1.5.3. Summary of chemical properties of the Yellowstone Buried Valley aquifer in Divide County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 48 | 0 | 329 | 0 | 0.3 | 0.53 | -1.45 | 1.53 | -0.45 |
| **Maximum** | 1,650 | 1,330 | 652 | 878 | 32.8 | 0.53 | 1.13 | 1.53 | 2.13 |
| **Points** | 6 | 6 | 3 | 6 | 6 | 1 | 3 | 1 | 3 |
| **Mean** | 607.17 | 239.5 | 506.67 | 351.83 | 7.72 | 0.53 | 0.21 | 1.53 | 1.21 |
| **Median** | 564 | 19.5 | 539 | 290 | 3.34 | 0.53 | 0.96 | 1.53 | 1.96 |
| **Std Deviation** | 583.61 | 534.95 | 163.91 | 372.41 | 12.44 | 0 | 1.45 | 0 | 1.44 |
| **Std Error** | 238.26 | 218.39 | 94.63 | 152.04 | 5.08 | 0 | 0.84 | 0 | 0.83 |
| **15910029DCD (South)** | 340 | 0 |  | 1038 | 15 |  | 1.74884 |  | 2.75 |

Table 1.5.4. Summary of chemical properties of the Crosby aquifer in Divide County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 831 | 795 | 129 | 0 | 282 | 0 | 1.5 | 0 | 0.08 |
| **Maximum** | 1,780 | 2,160 | 1,210 | 769 | 1,100 | 1,205 | 16.9 | 0 | 1.23 |
| **Points** | 10 | 19 | 19 | 19 | 9 | 19 | 19 | 0 | 10 |
| **Mean** | 1,085 | 1,189.4 | 426.63 | 83 | 796.33 | 474.05 | 8.06 | 0 | 0.94 |
| **Median** | 911 | 1,100 | 316 | 0 | 863 | 657 | 6 | 0 | 1.1 |
| **Std Deviation** | 328.4 | 371.24 | 277.59 | 207.09 | 277.43 | 415.21 | 5.7 | 0 | 0.36 |
| **Std Error** | 103.85 | 85.17 | 63.68 | 47.51 | 92.48 | 95.26 | 1.31 | 0 | 0.11 |

Table 1.5.5. Summary of chemical properties of the Yellowstone Buried Valley aquifer in Divide County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0.04 | 0.02 | 0.02 | nd | 0.1 | nd | 7 | 0 |
| **Maximum** | 0.59 | 10 | 2.6 | nd | 0.1 | 3 | 340 | 4 |
| **Points** | 3 | 6 | 6 | 3 | 3 | 3 | 3 | 3 |
| **Mean** | 0.32 | 2.8 | 0.8 | nd | 0.1 | 1 | 145.67 | 1.33 |
| **Median** | 0.33 | 1.24 | 0.29 | nd | 0.1 | 0 | 90 | 0 |
| **Std Deviation** | 0.28 | 3.9 | 1.05 | - | 0 | 1.73 | 173.34 | 2.31 |
| **Std Error** | 0.16 | 1.59 | 0.43 | - | 0 | 1 | 100.08 | 1.33 |
| **15910029DCD (South)** | 0.17 | 0.07 | 0.1 | - | - | - | - | - |

Table 1.5.6. Summary of chemical properties of the Crosby aquifer in Divide County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0.1 | 0 | 0 | 0 | 2 | 120 | 4 |
| Maximum | 0.49 | 40 | 1.8 | 5.02 | 0 | 24.9 | 120 | 4 |
| Points | 11 | 19 | 18 | 2 | 1 | 2 | 1 | 1 |
| Mean | 0.27 | 3.93 | 0.23 | 2.51 | 0 | 13.45 | 120 | 4 |
| Median | 0.26 | 1.79 | 0.1 | 2.51 | 0 | 13.45 | 120 | 4 |
| Std Deviation | 0.18 | 8.84 | 0.41 | 3.55 | 0 | 16.19 | 0 | 0 |
| Std Error | 0.05 | 2.03 | 0.1 | 2.51 | 0 | 11.45 | 0 | 0 |

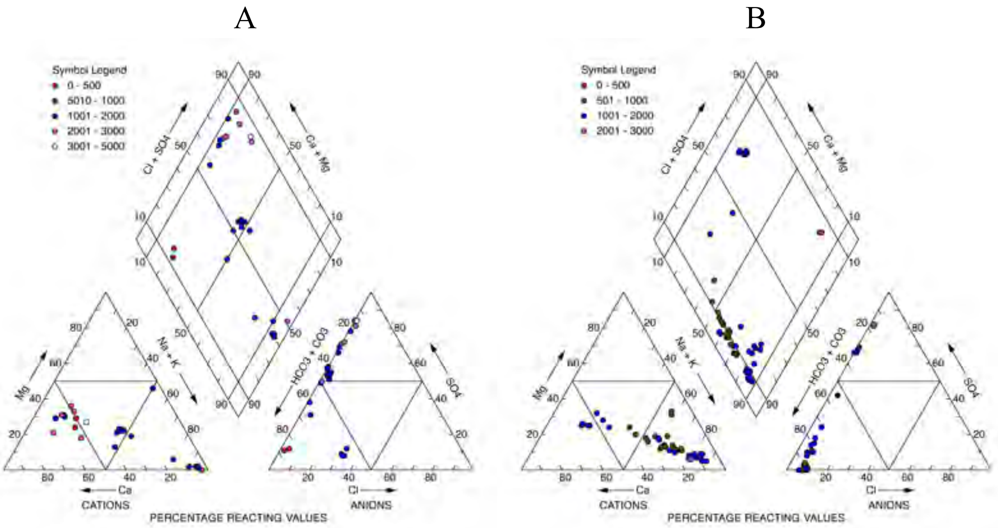
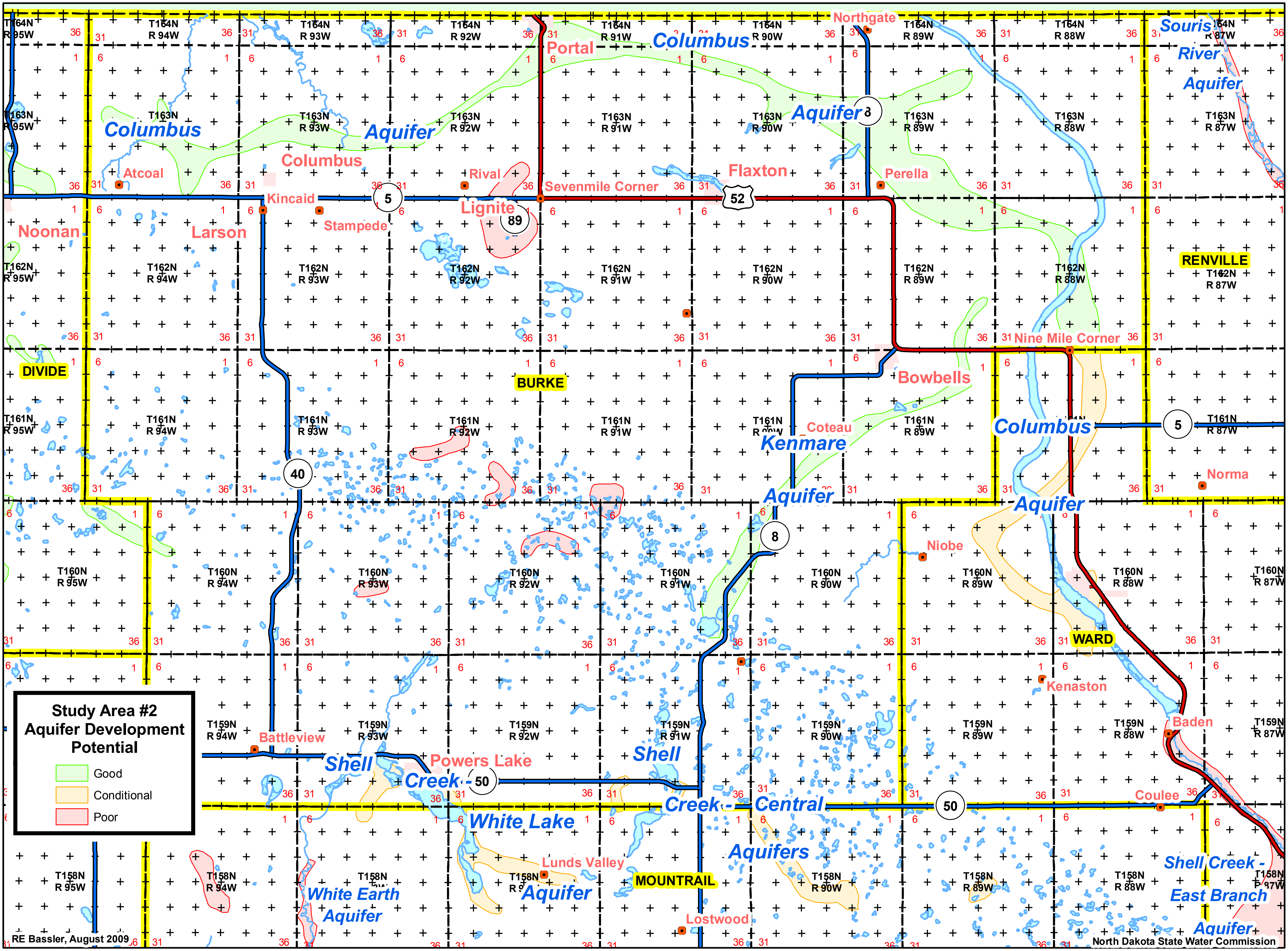


Figure 1.5.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Yellowstone Buried Valley aquifer (A) and the Crosby aquifer (B) in Divide County, North Dakota.


Study Area #2
Aquifer Development Potential
🟩 Good
🟨 Conditional
🟥 Poor
RE Bassler, August 2009
North Dakota State Water Commission
RENVILLE
DIVIDE
BURKE
WARD
MOUNTRAIL
Northgate
Portal
Atcoal
Kincaid
Stampede
Rival
Lignite
Sevenmile Corner
Flaxton
Perella
Nine Mile Corner
Bowbells
Coteau
Norma
Noonan
Larson
Niobe
Kenaston
Baden
Coulee
Battleview
Powers Lake
Lunds Valley
Lostwood
Columbus Aquifer
Souris River Aquifer
Kenmare Aquifer
Shell Creek - Central Aquifers
White Lake Aquifer
White Earth Aquifer
Shell Creek - East Branch Aquifer
Shell Creek - 50
5
8
52
89
40
50
T164N R 95W
T164N R 94W
T164N R 93W
T164N R 92W
T164N R 91W
T164N R 90W
T164N R 89W
T164N R 88W
T164N R 87W
T163N R 95W
T163N R 94W
T163N R 93W
T163N R 92W
T163N R 91W
T163N R 90W
T163N R 89W
T163N R 88W
T163N R 87W
T162N R 95W
T162N R 94W
T162N R 93W
T162N R 92W
T162N R 91W
T162N R 90W
T162N R 89W
T162N R 88W
T162N R 87W
T161N R 95W
T161N R 94W
T161N R 93W
T161N R 92W
T161N R 91W
T161N R 89W
T161N R 87W
T160N R 95W
T160N R 94W
T160N R 93W
T160N R 92W
T160N R 91W
T160N R 90W
T160N R 89W
T160N R 88W
T160N R 87W
T159N R 94W
T159N R 93W
T159N R 92W
T159N R 91W
T159N R 90W
T159N R 89W
T159N R 88W
T159N R 87W
T158N R 95W
T158N R 94W
T158N R 93W
T158N
T158N R 90W
T158N R 89W
T158N R 88W
T158N R 87W

## Study Area 2: Northwest North Dakota / Burke, Mountrail and Ward Counties

### *2.1. Columbus Aquifer (Burke and Northwest Ward Counties)*

The Columbus aquifer is a buried valley aquifer, ranging in width from less than a mile up to three miles, extending from northwestern Burke County to northwestern Ward County (Study Area #2 map). The aquifer underlies about 60 square miles.

Aquifer Composition: According to Armstrong (1971) the Columbus aquifer consists of two deposits of lenticular sand and gravel, divided by till or silt. The lower zone is generally more than 225 feet bls and ranges from 1 to 100 feet in thickness with a maximum of 146 feet. The shallower zone is thinner. An example of lithology is provided in Appendix Figures B.2.1.1 and B.2.1.2.

Aquifer Yield: An aquifer test in the lower unit has indicated a specific capacity of about 19.5 gpm/foot (Armstrong 1971). Armstrong stated that pumping rates above 500 gpm are possible. However, he indicated that narrow boundary conditions would likely prevent long-term pumping at that rate, and a sustained pumping capacity of about 200 gpm would be a more reasonable estimate.

Aquifer Chemistry: The Columbus aquifer has mostly sodium-bicarbonate type water with some of the sodium-sulfate and some of the calcium-bicarbonate type (Figure 2.1.1). Dissolved solids concentrations are moderately high, ranging from about 1,200 mg/L to about 2,800 mg/L (Table 2.1.1). Armstrong has identified the sodium-bicarbonate type with the lower zone, the sodium-sulfate type with the upper part of the lower zone, and the calcium-sulfate type with the upper zone. The mean and median dissolved solids are about 1,800 mg/L. The water is relatively high in iron and manganese. A single water sample tested slightly above the EPA-MCL (10 μg/L) in arsenic (Table 2.1.3).

Permit Acquisition Status: There is one perfected water permit for 448 acre-feet per year in the southern portion of the aquifer. In the northern area, shown as good for future development, there are five water permits, three perfected, one conditional and one application in process, for a total of 872 acre-feet. Assuming an average recharge rate of about 0.5 inches per year, there may be 300 to 500 acre-feet per year available for future development from the Columbus aquifer.

Additional Considerations: Boundary conditions for the narrow valley deposits may limit pumping rates. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Armstrong, C.A. 1971. Ground-water Resources of Burke and Mountrail Counties. County Ground Water Studies 14 - Part III. North Dakota State Water Commission. Bismarck, ND. pp. 30-41.

Table 2.1.1. Summary of chemical properties of the Columbus aquifer in Burke and Ward Counties:  general chemistry.

| | $S_C$-f µS/cm | $S_C$-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 1,700 | 1,880 | 7.6 | 7.8 | 1,240 | 1,170 | 6.8 | 6.6 | 8 | 7.9 | 4.7 | 246 | 0.1 | 380 | 0 | 0.63 | 10 | 0 |
| **Maximum** | 3,623 | 3,740 | 8.6 | 8.9 | 2,800 | 2,730 | 18 | 29.9 | 529 | 226 | 16.7 | 729 | 2.2 | 1,630 | 63 | 2,230 | 490 | 3.3 |
| **Points** | 14 | 22 | 2 | 22 | 19 | 22 | 15 | 22 | 22 | 22 | 22 | 22 | 21 | 22 | 22 | 22 | 22 | 21 |
| **Mean** | 2,373.9 | 2,673.6 | 8.1 | 8.2 | 1,828.9 | 1,807.7 | 10.65 | 20.41 | 101.34 | 39.19 | 8.68 | 510.68 | 0.88 | 934.36 | 7 | 612.84 | 101.37 | 0.54 |
| **Median** | 2,450 | 2,610 | 8.1 | 8.1 | 1,770 | 1,750 | 8.9 | 24 | 78.5 | 27.5 | 8.55 | 510 | 0.9 | 984 | 0 | 582.5 | 83 | 0 |
| **Std Deviation** | 530.53 | 442.34 | 0.7 | 0.3 | 340.99 | 345.42 | 4.03 | 8.56 | 106.94 | 45.04 | 2.34 | 116.39 | 0.59 | 298.51 | 15.31 | 523.98 | 97.94 | 0.82 |
| **Std Error** | 141.79 | 94.31 | 3.4e+38 | 0.1 | 78.23 | 73.64 | 1.04 | 1.83 | 22.8 | 9.6 | 0.5 | 24.81 | 0.13 | 63.64 | 3.26 | 111.71 | 20.88 | 0.18 |

Table 2.1.2. Summary of chemical properties of the Columbus aquifer in Burke and Ward Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 100 | 0 | 402 | 0 | 2.25 | 0.95 | 0.97 | 1.95 | 1.97 |
| **Maximum** | 2,250 | 1,850 | 899 | 1,336 | 23 | 0.95 | 1.75 | 1.95 | 2.75 |
| **Points** | 22 | 22 | 3 | 22 | 22 | 1 | 19 | 1 | 19 |
| **Mean** | 414.5 | 109 | 729.33 | 718.82 | 13.63 | 0.95 | 1.27 | 1.95 | 2.27 |
| **Median** | 300 | 0 | 887 | 754.5 | 13 | 0.95 | 1.23 | 1.95 | 2.23 |
| **Std Deviation** | 444.15 | 401.95 | 283.54 | 328.05 | 5.45 | 0 | 0.23 | 0 | 0.23 |
| **Std Error** | 94.69 | 85.7 | 163.7 | 69.94 | 1.16 | 0 | 0.05 | 0 | 0.05 |

Table 2.1.3. Summary of chemical properties of the Columbus aquifer in Burke and Ward Counties: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.14 | 0 | 0 | - | 0 | 11 | 10 | 0 |
| Maximum | 0.59 | 3.1 | 3.92 | - | 0 | 11 | 170 | 7.5 |
| Points | 20 | 22 | 16 | - | 0 | 1 | 3 | 28 |
| Mean | 0.36 | 0.83 | 0.33 | - | 0 | 11 | 66.67 | 2.74 |
| Median | 0.38 | 0.3 | 0.07 | - | 0 | 11 | 20 | 3.05 |
| Std Deviation | 0.14 | 1.08 | 0.96 | - | 0 | 0 | 89.63 | 2.09 |
| Std Error | 0.03 | 0.23 | 0.24 | - | 0 | 0 | 51.75 | 0.39 |

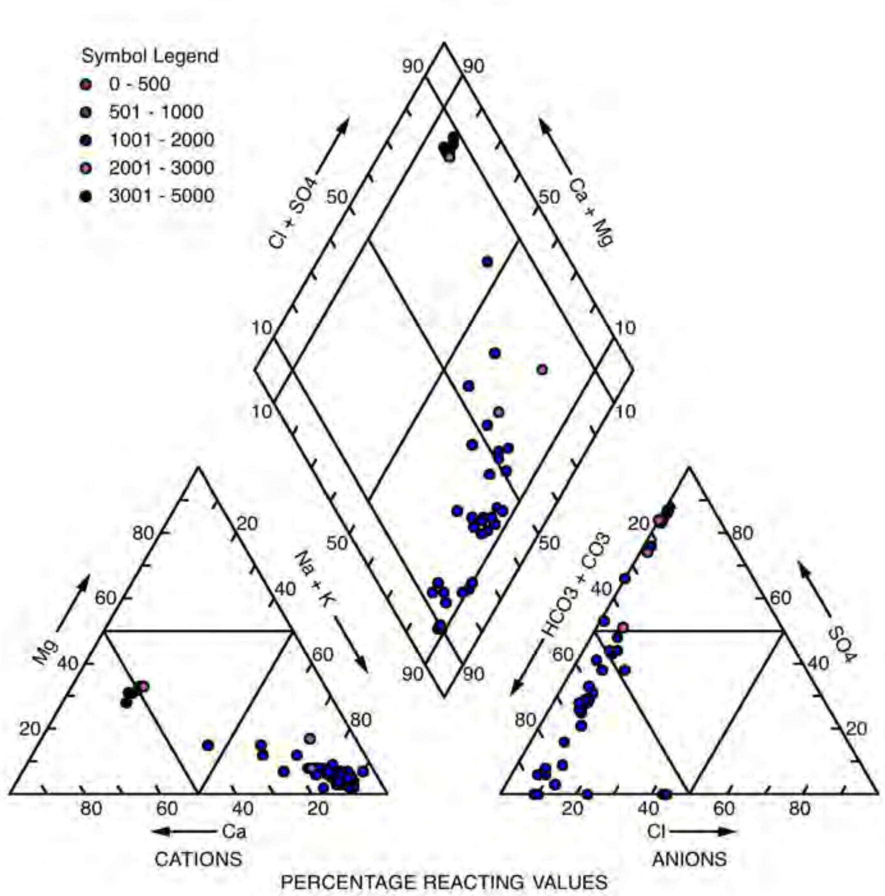


Figure 2.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Columbus aquifer.

## *2.2 Kenmare Aquifer (Burke County)*

The Kenmare aquifer consists of buried sand and gravel deposits underlying about ten square miles of Burke County, North Dakota (Armstrong 1971). It extends southwestward about 18 miles, with its northeastern boundary near Bowbells (Study Area #2 map).

Aquifer Composition: The Kenmare aquifer consists of multiple layers of buried sand and gravel deposits (Armstrong 1971). Three monitoring wells completed in the Kenmare aquifer are screened in the mid-300s of feet below land surface. An example of its lithology is shown on Appendix Figure B.2.2.1.

Aquifer Yield: Armstrong (1971) estimated potential yields of 200 to 500 gpm, but indicated that sustained yields in excess of 100 gpm would likely have excessive drawdown due to the narrowness of the aquifer. Armstrong observed that water levels of the aquifer tended to vary with climate.

Aquifer Chemistry: Kenmare aquifer water is of the sodium-bicarbonate and calcium-bicarbonate type, with some elevated sulfate (Figure 2.1.1). Dissolved solids concentrations are moderately high, with median and mean values near 1,200 mg/L (Table 2.2.1).

Permit Acquisition Status: There are no water permits for the Kenmare aquifer. Assuming a half inch of recharge per year, about 266 acre-feet or recharge would be expected. About 300 acre-feet may be available for further development, depending on specific local conditions.

Additional Considerations: Large pumping rates would likely cause excessive drawdown. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Armstrong, C.A. 1971. Ground-water Resources of Burke and Mountrail Counties. County Ground Water Studies 14 - Part III. North Dakota State Water Commission. Bismarck, ND. pp. 30-41.

Table 2.2.1. Summary of chemical properties of the Kenmare aquifer in Burke County: general chemistry.

| | $S_C$-f µS/cm | $S_C$-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 900 | 971 | 7.8 | 7.4 | 666 | 654 | 7 | 11 | 28 | 9.7 | 5.2 | 21 | 0 | 460 | 0 | 66 | 2.7 | 0.7 |
| **Maximum** | 2,270 | 2,250 | 7.8 | 8.1 | 1,470 | 1,410 | 12.2 | 27 | 184 | 64 | 17 | 516 | 1.4 | 1,270 | 0 | 510 | 140 | 8.5 |
| **Points** | 3 | 7 | 1 | 7 | 7 | 7 | 5 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **Mean** | 1,430 | 1,825.9 | 7.8 | 7.8 | 1,193.7 | 1,209.1 | 9.76 | 23.29 | 92.57 | 32.1 | 8 | 318.14 | 0.76 | 885.29 | 0 | 217.14 | 76.84 | 2.3 |
| **Median** | 1,120 | 2,140 | 7.8 | 7.9 | 1,290 | 1,390 | 10 | 25 | 65 | 26 | 6.2 | 450 | 0.9 | 1,130 | 0 | 117 | 120 | 1 |
| **Std Deviation** | 735.73 | 497.81 | 0 | 0.3 | 267.2 | 283.68 | 1.93 | 5.71 | 63.35 | 21.22 | 4.3 | 221.1 | 0.61 | 371.32 | 0 | 184.4 | 66.73 | 2.81 |
| **Std Error** | 424.77 | 188.15 | 0 | 0.1 | 100.99 | 107.22 | 0.86 | 2.16 | 23.94 | 8.02 | 1.63 | 83.57 | 0.23 | 140.35 | 0 | 69.7 | 25.22 | 1.06 |

Table 2.2.2. Summary of chemical properties of the Kenmare aquifer in Burke County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 120 | 0 | 0 | 377 | 0.4 | 1.02 | 0.62 | 2.02 | 1.62 |
| **Maximum** | 665 | 234 | 0 | 1,041 | 20 | 1.02 | 1.25 | 2.02 | 2.25 |
| **Points** | 7 | 7 | 0 | 7 | 7 | 1 | 7 | 1 | 7 |
| **Mean** | 363 | 89.71 | 0 | 725.71 | 10.21 | 1.02 | 0.93 | 2.02 | 1.93 |
| **Median** | 270 | 0 | 0 | 926 | 12 | 1.02 | 1.02 | 2.02 | 2.02 |
| **Std Deviation** | 239.68 | 113 | 0 | 304.32 | 8.56 | 0 | 0.24 | 0 | 0.24 |
| **Std Error** | 90.59 | 42.71 | 0 | 115.02 | 3.23 | 0 | 0.09 | 0 | 0.09 |

Table 2.2.3. Summary of chemical properties of the Kenmare aquifer in Burke County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0 | 0.2 | 0.01 | 0 | 0 | 0 | 0 | 0 |
| **Maximum** | 0.44 | 3.3 | 1 | 0 | 0 | 0 | 0 | 0 |
| **Points** | 7 | 7 | 4 | 0 | 0 | 0 | 0 | 0 |
| **Mean** | 0.22 | 0.98 | 0.54 | 0 | 0 | 0 | 0 | 0 |
| **Median** | 0.23 | 0.4 | 0.57 | 0 | 0 | 0 | 0 | 0 |
| **Std Deviation** | 0.14 | 1.17 | 0.47 | 0 | 0 | 0 | 0 | 0 |
| **Std Error** | 0.05 | 0.44 | 0.23 | 0 | 0 | 0 | 0 | 0 |

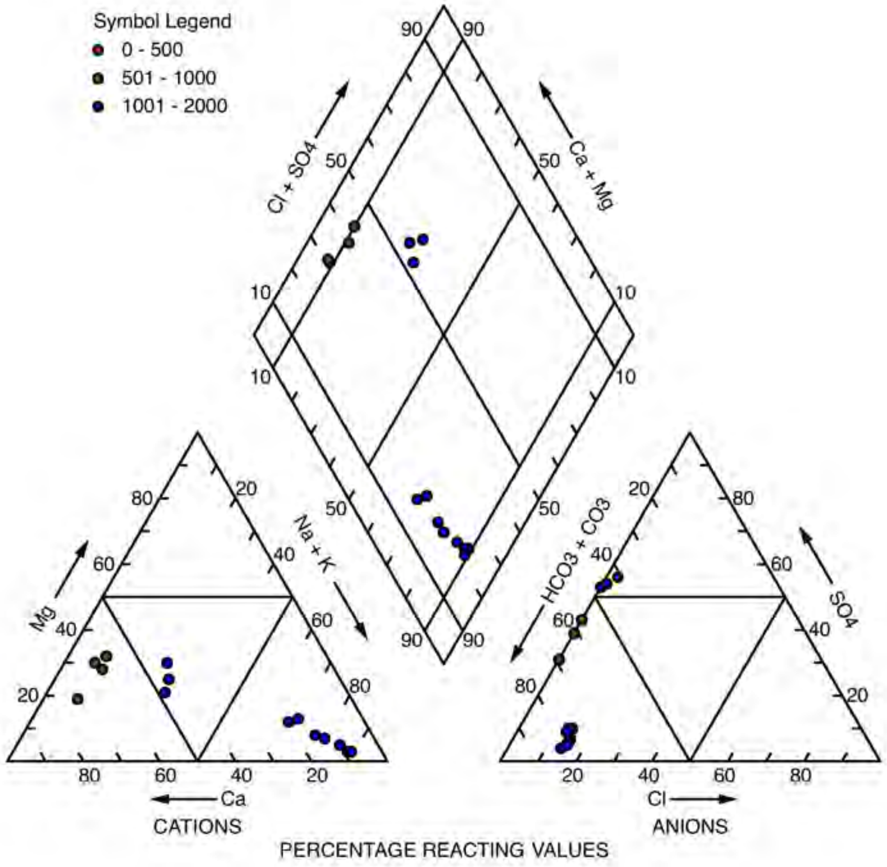


Figure 2.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Kenmare aquifer.

## *2.3 Shell Creek Aquifer (Burke and Mountrail Counties)*

The Shell Creek aquifer consists of sand and gravel deposits in three locations: the **White Lake** sub aquifer located in southwest Burke County and northwest Mountrail County; the **Central** sub aquifer located in south-central Burke County and north-central Mountrail County; and the **East Branch** sub aquifer in western Ward County. We here treat only the White Lake and Central sub aquifers, which underlie about nine square miles (Study Area #2 map).

<u>Aquifer Composition:</u> According to Armstrong (1971), the White Lake sub aquifer consists of sand and gravel deposits, often poorly-connected, and about 12 to 37 feet thick. The Central sub aquifer consists of sand and gravel deposits that appear to have "considerable continuity," and can have thicknesses of up to 128 feet. An example of the aquifer lithology is provided on Appendix Figure B.2.3.1.

<u>Aquifer Yield:</u> Armstrong (1971) suggests that pumping rates of more than 100 gpm would likely cause excessive drawdown, due to the narrowness of the aquifer.

<u>Aquifer Chemistry:</u> There are five water chemistry samples in the SWC database. These few indicated that water is predominantly of the calcium sodium-bicarbonate type (Figure 2.3.1). Dissolved solids concentrations vary from about 300 mg/L to 2,000 mg/L, with mean and median values between 600 and 800 mg/L (Table 2.3.1).

<u>Permit Acquisition Status:</u> There is one perfected water permit for 219.8 acre-feet, from the White Lake portion of the Shell Creek aquifer, and one water-permit application in processing for 300 acre-feet from the Central portion of the Shell Creek aquifer, for a total of about 520 acre-feet. The White Lake sub aquifer may have as little as 40 acre-feet or as much as 600 acre-feet available for beneficial use. The Central sub aquifer may have as little as 200 acre-feet, or as much as 900 acre-feet available for additional beneficial use. There are other unmapped sand and gravel deposits in the area that may or may not be part of the Shell Creek aquifer, and which may be available for further beneficial use. Further exploration is needed to determine the extent of these deposits.

<u>Additional Considerations:</u> Actual availability would depend on further analysis by the managing hydrologist. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

<u>Citations:</u>

Armstrong, C.A. 1971. Ground-water Resources of Burke and Mountrail Counties. County Ground Water Studies 14 - Part III. North Dakota State Water Commission. Bismarck, ND. pp. 30-41.

Table 2.3.1. Summary of chemical properties of the Shell Creek aquifer in Burke and Mountrail Counties: general chemistry.

| | $S_C$-f µS/cm | $S_C$-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | - | 510 | 0 | 7.8 | 366 | 316 | 6.1 | 3.9 | 35.8 | 18 | 4.67 | 2.3 | 0.1 | 205 | 0 | 27 | 3.5 | 0 |
| **Maximum** | - | 3,420 | 0 | 8.3 | 802 | 2,120 | 9.4 | 26 | 81 | 35 | 9.1 | 728 | 0.45 | 975 | 1 | 1,040 | 11.9 | 53 |
| **Points** | - | 5 | 0 | 5 | 4 | 5 | 2 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Mean** | - | 1,397.6 | 0 | 8.1 | 601 | 897.6 | 7.75 | 18.73 | 61.56 | 25.2 | 6.85 | 216.86 | 0.21 | 446.8 | 0.2 | 371.2 | 6.62 | 12.83 |
| **Median** | - | 976 | 0 | 8 | 618 | 641 | 7.75 | 22.5 | 71 | 20 | 6.6 | 85 | 0.2 | 343 | 0 | 200 | 5.1 | 3.1 |
| **Std Deviation** | - | 1,160.7 | 0 | 0.2 | 186.54 | 708.77 | 2.33 | 10.1 | 20.7 | 8.11 | 1.96 | 295.04 | 0.14 | 304.14 | 0.45 | 404.53 | 3.44 | 22.69 |
| **Std Error** | - | 519.1 | 0 | 0.1 | 93.27 | 316.97 | 3.4e+38 | 5.05 | 9.26 | 3.62 | 0.88 | 131.95 | 0.06 | 136.02 | 0.2 | 180.91 | 1.54 | 10.15 |

Table 2.3.2. Summary of chemical properties of the Shell Creek aquifer in Burke and Mountrail Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 164 | 0 | 800 | 0 | 0.1 | - | 0.18 | - | 1.18 |
| **Maximum** | 340 | 39 | 800 | 333 | 24.7 | - | 1.03 | - | 2.03 |
| **Points** | 5 | 5 | 1 | 5 | 5 | - | 4 | - | 4 |
| **Mean** | 257.2 | 18 | 800 | 206.4 | 6.98 | - | 0.65 | - | 1.65 |
| **Median** | 274 | 20 | 800 | 250 | 2 | - | 0.7 | - | 1.7 |
| **Std Deviation** | 78.35 | 15.22 | 0 | 129.97 | 10.19 | - | 0.38 | - | 0.37 |
| **Std Error** | 35.04 | 6.8 | 0 | 58.13 | 4.56 | - | 0.19 | - | 0.19 |

Table 2.3.3. Summary of chemical properties of the Shell Creek aquifer in Burke and Mountrail Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0 | 0 | 0.01 | - | - | - | - | - |
| **Maximum** | 0.24 | 4.9 | 0.3 | - | - | - | - | - |
| **Points** | 4 | 5 | 4 | - | - | - | - | - |
| **Mean** | 0.11 | 1.2 | 0.11 | - | - | - | - | - |
| **Median** | 0.1 | 0.03 | 0.07 | - | - | - | - | - |
| **Std Deviation** | 0.11 | 2.12 | 0.14 | - | - | - | - | - |
| **Std Error** | 0.05 | 0.95 | 0.07 | - | - | - | - | - |

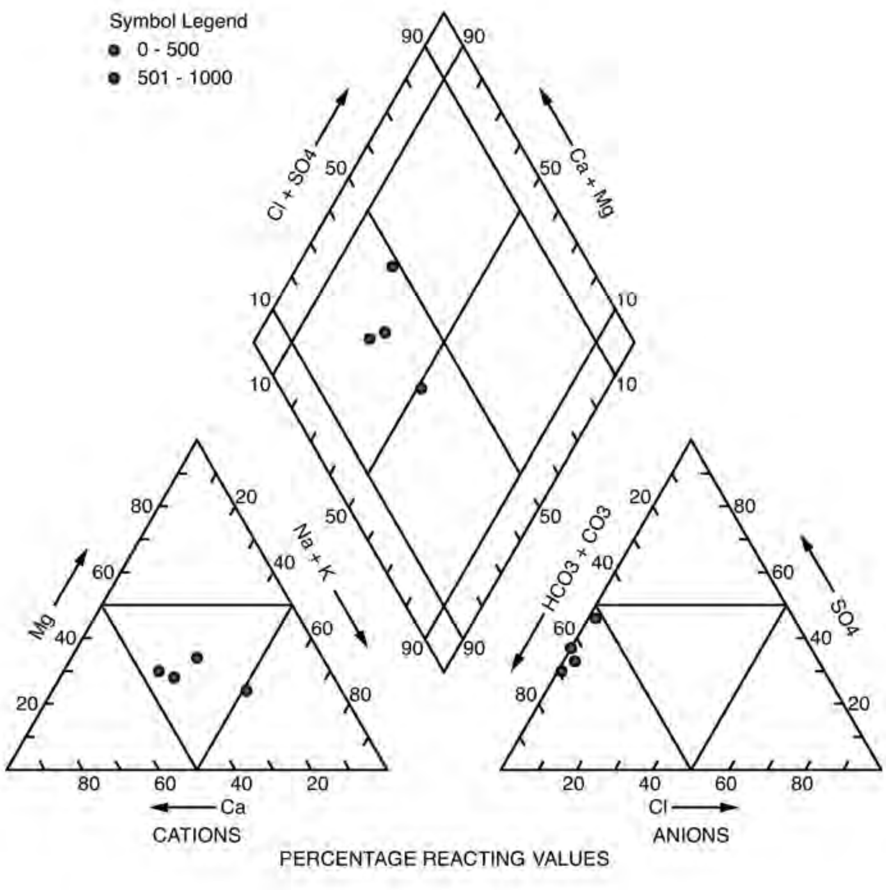
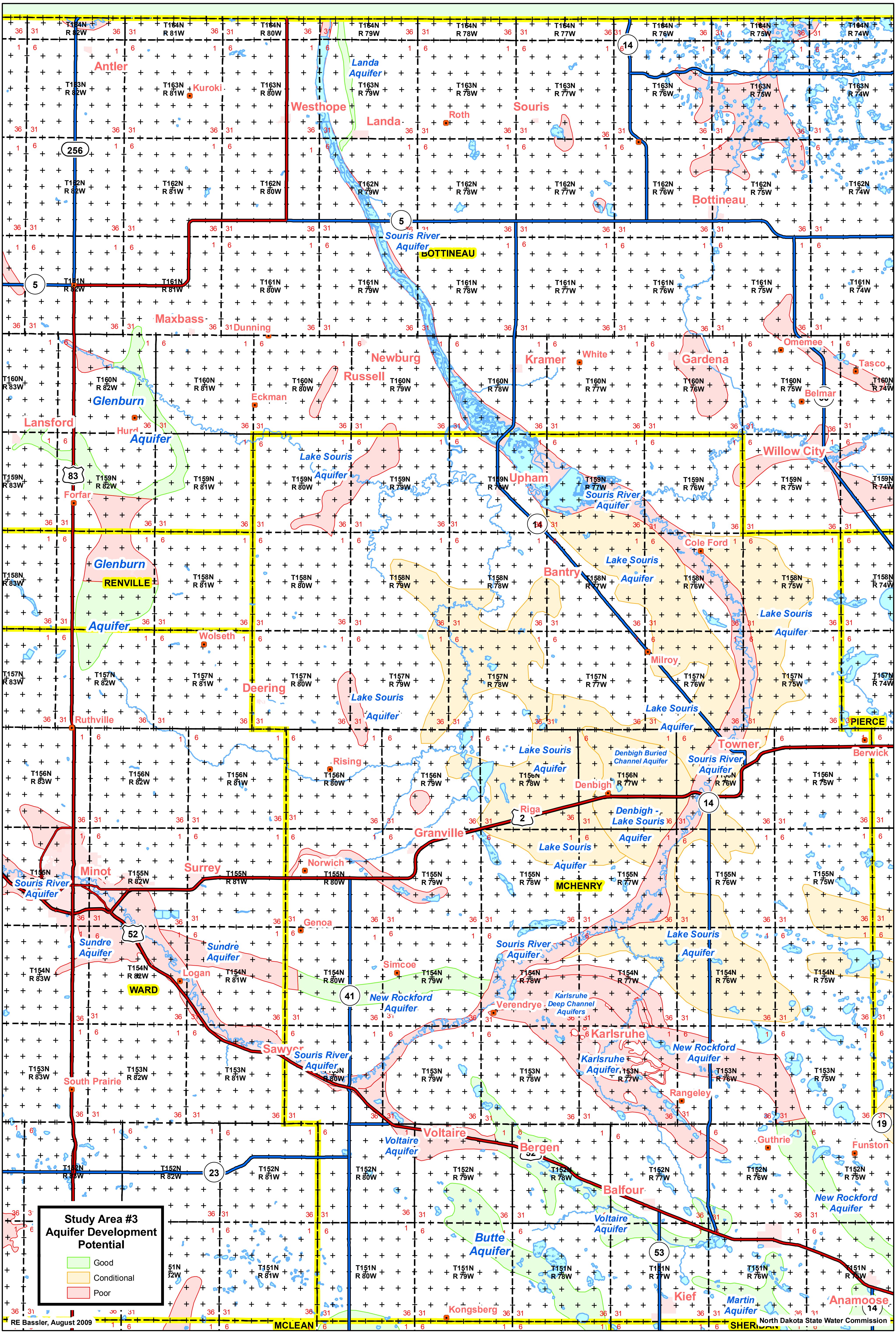


Figure 2.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Shell Creek aquifer.


Study Area #3
Aquifer Development Potential
Good
Conditional
Poor
RE Bassler, August 2009
North Dakota State Water Commission
BOTTINEAU
RENVILLE
MCHENRY
WARD
PIERCE
MCLEAN
SHERIDAN
Antler
Kuroki
Westhope
Landa
Roth
Souris
Bottineau
Maxbass
Dunning
Newburg
Russell
Eckman
Kramer
White
Gardena
Omemee
Tasco
Belmar
Willow City
Lansford
Glenburn
Hurd
Forfar
Upham
Cole Ford
Bantry
Milroy
Wolseth
Deering
Ruthville
Towner
Berwick
Rising
Denbigh
Riga
Granville
Norwich
Minot
Surrey
Genoa
Simcoe
Logan
Verendrye
Karlsruhe
Rangeley
Sawyer
South Prairie
Voltaire
Bergen
Balfour
Guthrie
Funston
Kief
Anamoose
Kongsberg
Landa Aquifer
Souris River Aquifer
Glenburn Aquifer
Lake Souris Aquifer
Denbigh Buried Channel Aquifer
Denbigh - Lake Souris Aquifer
Sundre Aquifer
New Rockford Aquifer
Karlsruhe Deep Channel Aquifers
Karlsruhe Aquifer
Voltaire Aquifer
Butte Aquifer
Martin Aquifer
5
14
256
83
2
52
41
23
53
19
T164N R 82W
T164N R 81W
T164N R 80W
T164N R 79W
T164N R 78W
T164N R 77W
T164N R 76W
T164N R 75W
T164N R 74W
T163N R 82W
T163N R 81W
T163N R 80W
T163N R 79W
T163N R 78W
T163N R 77W
T163N R 76W
T163N R 75W
T163N R 74W
T162N R 82W
T162N R 81W
T162N R 80W
T162N R 79W
T162N R 78W
T162N R 77W
T162N R 76W
T162N R 75W
T162N R 74W
T161N R 82W
T161N R 81W
T161N R 80W
T161N R 79W
T161N R 78W
T161N R 77W
T161N R 76W
T161N R 75W
T161N R 74W
T160N R 83W
T160N R 82W
T160N R 81W
T160N R 80W
T160N R 79W
T160N R 78W
T160N R 77W
T160N R 76W
T160N R 75W
T160N R 74W
T159N R 83W
T159N R 82W
T159N R 81W
T159N R 80W
T159N R 79W
T159N R 78W
T159N R 77W
T159N R 76W
T159N R 75W
T159N R 74W
T158N R 83W
T158N R 81W
T158N R 80W
T158N R 79W
T158N R 78W
T158N R 77W
T158N R 76W
T158N R 75W
T158N R 74W
T157N R 83W
T157N R 82W
T157N R 81W
T157N R 80W
T157N R 79W
T157N R 78W
T157N R 77W
T157N R 76W
T157N R 75W
T157N R 74W
T156N R 83W
T156N R 82W
T156N R 81W
T156N R 80W
T156N R 79W
T156N R 78W
T156N R 77W
T156N R 76W
T156N R 75W
T155N R 83W
T155N R 82W
T155N R 81W
T155N R 80W
T155N R 79W
T155N R 78W
T155N R 77W
T155N R 76W
T155N R 75W
T154N R 83W
T154N R 82W
T154N R 81W
T154N R 80W
T154N R 79W
T154N R 78W
T154N R 77W
T154N R 76W
T154N R 75W
T153N R 83W
T153N R 82W
T153N R 81W
T153N R 80W
T153N R 79W
T153N R 78W
T153N R 77W
T153N R 76W
T153N R 75W
T152N R 83W
T152N R 82W
T152N R 81W
T152N R 80W
T152N R 79W
T152N R 78W
T152N R 77W
T152N R 76W
T152N R 75W
T151N R 82W
T151N R 81W
T151N R 80W
T151N R 79W
T151N R 78W
T151N R 77W
T151N R 76W
T151N R 75W

## Study Area 3: North-Central North Dakota / Bottineau, McHenry, Renville and Ward Counties

### *3.1 Denbigh Aquifer (McHenry County)*

The Denbigh aquifer underlies about 25 square miles in central McHenry County (Study Area #3 map). It consists of the Denbigh Buried Channel aquifer and the Denbigh-Lake Souris aquifer.

Aquifer Composition: According to Randich (1981) the Denbigh aquifer consists of surficial sand and gravel on the Souris Lake Plain, part of which is underlain by buried (confined) sand and gravel beds ranging in thickness from about 14 feet to 81 feet, with an average thickness of about 40 feet. An example of the aquifer lithology is shown on Figure B.3.1.1.

Aquifer Yield: Randich (1981) estimated that properly-constructed wells could yield from 50 to 1,000 gpm.

Aquifer Chemistry: The anion and cation distribution is primarily of the calcium bicarbonate type, with some of the sodium bicarbonate type (Figure 3.1.1). The water is predominantly fresh, with median dissolved solids concentrations near 350 mg/L, and a range from about 250 mg/L to 1,700 mg/L (Table 3.1.1). Increasing dissolved solids correspond to higher sodium content. Iron and manganese are both high (Table 3.1.3).

Permit Acquisition Status***:*** There are currently seven water permits, five perfected and two conditional, for a total of 1,834 acre-feet per year from the Denbigh aquifer. There are no applications pending.

Additional Considerations: The aquifer is listed as "conditional" for further development, because the shallower (unconfined) portions have been heavily appropriated. There may, however, be some water available in the deeper channels that might be developed for a few hundred acre-feet. Further exploration would be needed. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Randich, P.G. 1981. Ground-water Resources of McHenry County, North Dakota. County Ground-Water Studies 33-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 28-29.

Table 3.1.1. Summary of chemical properties of the Denbigh aquifer in McHenry County: general chemistry.

| | $S_C$-f µS/cm | $S_C$-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 460 | 442 | 7.4 | 7.6 | 263 | 272 | 7.5 | 10 | 11.3 | 3.7 | 1.4 | 6.4 | 0.1 | 275 | NA | 0.54 | 0.6 | 0.09 |
| **Maximum** | 2,600 | 2,760 | 8.5 | 8.5 | 649 | 1,710 | 14 | 29.4 | 154 | 37.8 | 6.02 | 682 | 0.62 | 753 | NA | 225 | 529 | 2 |
| **Points** | 24 | 24 | 10 | 24 | 9 | 24 | 11 | 21 | 24 | 24 | 24 | 24 | 24 | 24 | NA | 24 | 24 | 22 |
| **Mean** | 835.5 | 864.54 | 7.7 | 8 | 384.33 | 525.13 | 9.23 | 22.33 | 72.66 | 21.6 | 2.78 | 94.76 | 0.24 | 419.46 | NA | 32.91 | 61.67 | 0.55 |
| **Median** | 595.5 | 598 | 7.6 | 7.9 | 350 | 367.5 | 8.5 | 22.7 | 74.05 | 21.7 | 2.35 | 26.65 | 0.19 | 381 | NA | 19.1 | 2.75 | 0.25 |
| **Std Deviation** | 580.67 | 614.12 | 0.35 | 0.22 | 114.77 | 382.71 | 1.95 | 5.29 | 29.01 | 8.65 | 1.17 | 177.83 | 0.15 | 117.56 | NA | 48.28 | 149.15 | 0.53 |
| **Std Error** | 118.53 | 125.36 | 0.11 | 0.05 | 38.26 | 78.12 | 0.59 | 1.15 | 5.92 | 1.76 | 0.24 | 36.3 | 0.03 | 24 | NA | 9.86 | 30.45 | 0.11 |

Table 3.1.2. Summary of chemical properties of the Denbigh aquifer in McHenry County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 43 | 0 | 247 | - | 0.18 | -0.06 | 0.44 | 0.94 | 1.44 |
| **Maximum** | 527 | 214 | 627 | - | 45 | 0.94 | 0.94 | 1.94 | 1.94 |
| **Points** | 24 | 24 | 15 | - | 24 | 8 | 9 | 8 | 9 |
| **Mean** | 270.33 | 11.04 | 363 | - | 4.62 | 0.42 | 0.63 | 1.42 | 1.63 |
| **Median** | 279.5 | 0 | 314 | - | 0.64 | 0.37 | 0.59 | 1.38 | 1.59 |
| **Std Deviation** | 103.62 | 43.71 | 116.57 | - | 10.97 | 0.29 | 0.17 | 0.29 | 0.17 |
| **Std Error** | 21.15 | 8.92 | 30.1 | - | 2.24 | 0.1 | 0.06 | 0.1 | 0.06 |

Table 3.1.3. Summary of chemical properties of the Denbigh aquifer in McHenry County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0.06 | 0.02 | - | - | - | - | - |
| Maximum | 1.59 | 3.5 | 0.8 | - | - | - | - | - |
| Points | 11 | 24 | 24 | - | - | - | - | - |
| Mean | 0.18 | 1.53 | 0.26 | - | - | - | - | - |
| Median | 0 | 1.77 | 0.24 | - | - | - | - | - |
| Std Deviation | 0.47 | 1.02 | 0.16 | - | - | - | - | - |
| Std Error | 0.14 | 0.21 | 0.03 | - | - | - | - | - |

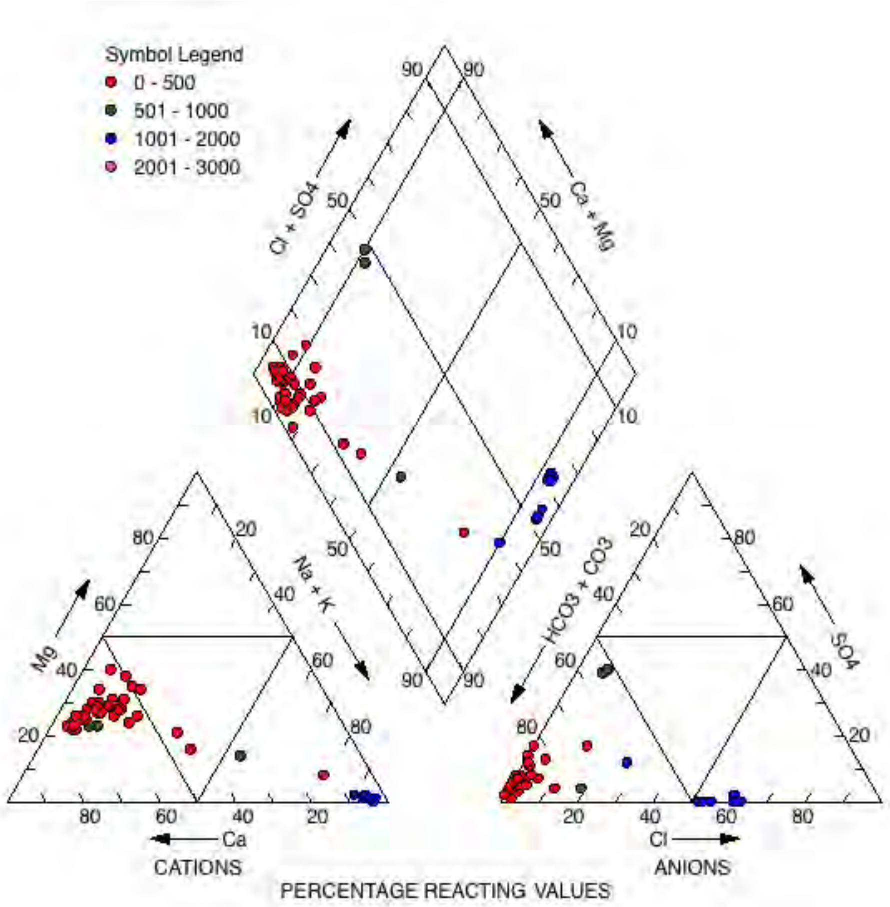


Figure 3.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Denbigh aquifer in McHenry County.

### *3.2 Glenburn Aquifer (Bottineau, Renville and Ward Counties)*

The Glenburn aquifer underlies about 46 square miles in Bottineau, Renville and Ward Counties, of which about 33 square miles have potential for further water development (Study Area #3 map).

Aquifer Composition Glenburn aquifer: According to Randich and Kuzniar (1984) the aquifer consists of sand, gravel and silt deposits ranging from 5 to 155 feet thick, and having an average saturated thickness of about 40 feet. An example of the aquifer lithology is provided on Appendix Figure B.3.2.1.

Aquifer Yield: Based on transmissivities calculated from lithology logs, Randich and Kuzniar estimated potential well yields as ranging from 10 to 1,000 gpm. Stock wells currently in use range from 5 to 120 gpm.

Aquifer Chemistry: The anion and cation distribution is primarily of the sodium-carbonate type, with some water samples of the calcium-sulfate type (Figure 3.2.1). Dissolved solids concentrations range from about 700 to 2,000 mg/L (Table 3.2.1). Ninety-five percent of the water samples had more than 1,000 mg/L dissolved solids. Iron and manganese are both high. Arsenic for all of three water samples is below the EPA-MCL (Table 3.2.3).

Permit Acquisition Status: There are currently two water permits, both perfected, held by the city of Kenmare for water from the central part of the Glenburn aquifer mapped as "poor" for additional development, but there are no water permits or applications pending within the area classified as "good" for further water-use development.

Additional Considerations: Using an estimated recharge of about 0.25 to 0.5 inches for a buried-valley aquifer, as much as 400 to 800 acre-feet of water may be available for development from the Glenburn aquifer. Narrowness of the aquifer in the north may limit pumping rates. The quality of water from the aquifer has limited its development. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Randich, P.G. and R.L. Kuzniar. 1984. Ground-water Resources of Bottineau and Rolette Counties, North Dakota. County Ground-Water Studies 35-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 25-26.

Table 3.2.1. Summary of chemical properties of the Glenburn aquifer in Bottineau, Renville and Ward Counties: general chemistry.

| | $S_C$-f µS/cm | $S_C$-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 1,015 | 1,190 | 7.1 | 7.7 | 773 | 710 | 2 | 17 | 14 | 2 | 5.4 | 190 | 0.2 | 310 | 0 | 0 | 25 | 0 |
| **Maximum** | 2,900 | 3,910 | 8.2 | 8.5 | 2,050 | 2,060 | 13 | 30 | 210 | 61 | 13 | 590 | 0.7 | 993 | 14 | 1,100 | 680 | 7 |
| **Points** | 18 | 18 | 15 | 18 | 16 | 18 | 15 | 17 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 17 |
| **Mean** | 1,904.8 | 2,332.8 | 7.8 | 8 | 1,431.4 | 1,395 | 7.97 | 24.73 | 83.67 | 26.1 | 8.97 | 405.67 | 0.41 | 772.56 | 0.89 | 178.04 | 282 | 1.42 |
| **Median** | 2,051.5 | 2,275 | 7.8 | 8 | 1,405 | 1,370 | 8 | 25 | 66.5 | 23 | 8.9 | 410 | 0.4 | 813.5 | 0 | 19.5 | 290 | 1 |
| **Std Deviation** | 527.67 | 559.82 | 0.35 | 0.2 | 289.05 | 297.25 | 2.31 | 3.44 | 44.59 | 14.29 | 1.66 | 95.82 | 0.18 | 172.99 | 3.29 | 334.81 | 175.28 | 1.77 |
| **Std Error** | 124.37 | 131.95 | 0.09 | 0.05 | 72.26 | 70.06 | 0.6 | 0.83 | 10.51 | 3.37 | 0.39 | 22.58 | 0.04 | 40.77 | 0.77 | 78.92 | 41.31 | 0.43 |

Table 3.2.2. Summary of chemical properties of the Glenburn aquifer in Bottineau, Renville and Ward Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 62 | 0 | 679 | 0 | 4.8 | 0.25 | 0.81 | 1.25 | 1.81 |
| **Maximum** | 750 | 400 | 716 | 814 | 33 | 1.16 | 1.35 | 2.16 | 2.35 |
| **Points** | 18 | 18 | 2 | 18 | 18 | 14 | 16 | 14 | 16 |
| **Mean** | 316.28 | 41.67 | 697.5 | 557.06 | 11.37 | 0.85 | 1 | 1.85 | 2 |
| **Median** | 275 | 0 | 697.5 | 630 | 10.5 | 0.98 | 0.99 | 1.98 | 1.99 |
| **Std Deviation** | 162.68 | 121.57 | 26.16 | 246.39 | 6.39 | 0.31 | 0.15 | 0.31 | 0.15 |
| **Std Error** | 38.34 | 28.65 | 18.5 | 58.07 | 1.51 | 0.08 | 0.04 | 0.08 | 0.04 |

Table 3.2.3. Summary of chemical properties of the Glenburn aquifer in Bottineau, Renville and Ward Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.03 | 0.02 | 0.07 | 0 | 0 | 6 | 50 | 3 |
| Maximum | 1.3 | 11 | 0.84 | 5.58 | 0.4 | 12 | 180 | 17 |
| Points | 16 | 18 | 18 | 3 | 2 | 3 | 2 | 2 |
| Mean | 0.34 | 1.64 | 0.28 | 2.19 | 0.2 | 8.33 | 115 | 10 |
| Median | 0.25 | 0.69 | 0.27 | 1 | 0.2 | 7 | 115 | 10 |
| Std Deviation | 0.31 | 2.72 | 0.2 | 2.98 | 0.28 | 3.21 | 91.92 | 9.9 |
| Std Error | 0.08 | 0.64 | 0.05 | 1.72 | 0.2 | 1.86 | 65 | 0 |

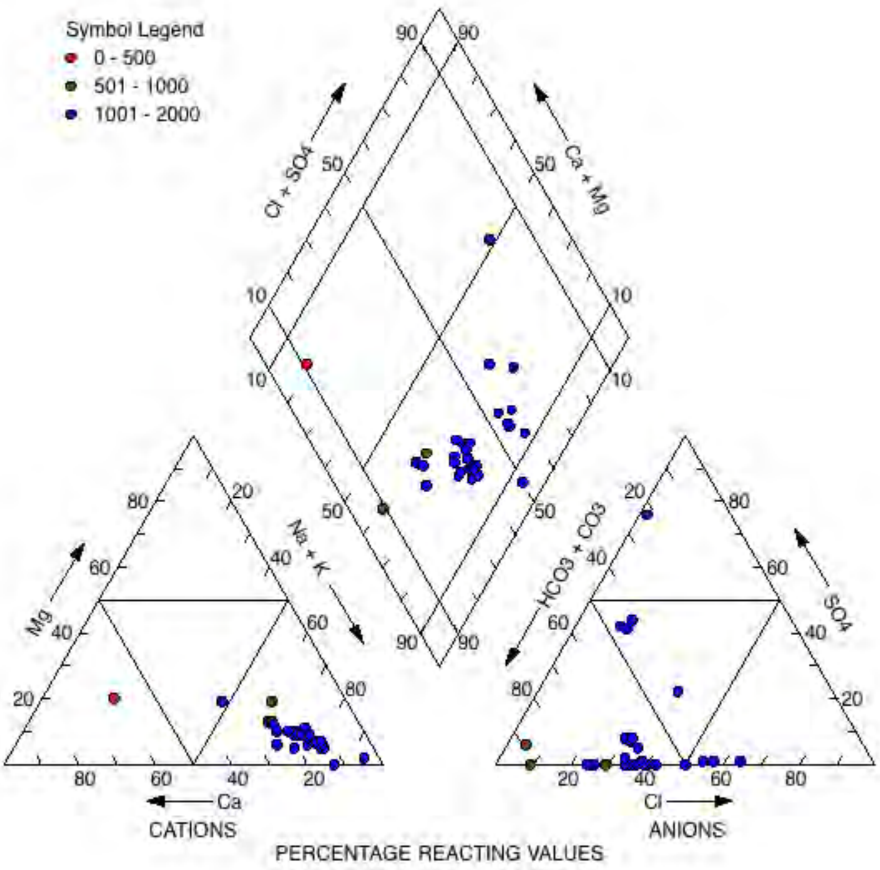


Figure 3.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Glenburn aquifer in Bottineau, Renville and Ward Counties.

### *3.3 Lake Souris Aquifer (McHenry County)*

The Lake Souris aquifer underlies about 219 square miles in central McHenry County (Study Area #3 map).

Aquifer Composition: The Lake Souris aquifer was described by Randich (1981) as consisting of a system of isolated areas of surficial windblown sand. Aquifer thicknesses were described as varying from 5 to 57 feet, with an average thickness of about 22 feet. Two examples of local lithologies are provided on Appendix Figures B.3.3.1 and B.3.3.2.

Aquifer Yield: Randich (1981) estimated potential well yields of 5 to 50 gpm, depending on local aquifer textures and aquifer thickness. Many areas of the aquifer are thin.

Aquifer Chemistry: The Lake Souris aquifer water is predominantly fresh, having dissolved solids concentrations ranging from about 200 to 1,200 mg/L, and a median dissolved solids near 400 mg/L (Table 3.3.1). The anion and cation distribution is predominantly of the calcium-bicarbonate type, but includes some water of the calcium magnesium sodium-bicarbonate type, and the sodium-bicarbonate type (Figure 3.3.1). A few of the water samples having higher dissolved solids are sulfatic. Iron concentrations are generally high. The manganese concentration for a single water sample was high (Table 3.3.3).

Permit Acquisition Status: There are currently 19 water permits, 11 perfected, five conditional, and two applications in process for the Lake Souris aquifer system. Total permtted allocation is 5,382 acre-feet. Based on a conservative estimate of a half inch to one inch of annual recharge for a surficial aquifer, as much as 400 to 600 acre-feet of water may be available for development.

Additional Considerations: The aquifer is mapped as "conditional" for development because of its thinness and limited areal extent. Multiple wells will likely be needed for many uses. Local exploration and aquifer tests would be advised. Arsenic for a single sample was below the EPA-MCL. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Randich, P.G. 1981. Ground-water Resources of McHenry County, North Dakota. County Ground-Water Studies 33-Part III. North Dakota State Water Commission. Bismarck, ND. p. 33.

Table 3.3.1. Summary of chemical properties of the Lake Souris aquifer in McHenry County: general chemistry.

| | $S_C$-f µS/cm | $S_C$-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 230 | 380 | 9 | 7.1 | 529 | 200 | 6 | 14.1 | 33.3 | 10.9 | 1 | 3 | 0.05 | 213 | - | 0.3 | 0 | 0.09 |
| **Maximum** | 1,860 | 1,930 | 9 | 8.1 | 529 | 1,200 | 9.6 | 28.9 | 205 | 75 | 13.9 | 299 | 0.22 | 1,360 | - | 440 | 104 | 170 |
| **Points** | 99 | 61 | 1 | 61 | 1 | 61 | 52 | 21 | 61 | 61 | 61 | 61 | 61 | 61 | - | 61 | 61 | 50 |
| **Mean** | 628.36 | 704.08 | 9 | 7.7 | 529 | 425.75 | 7.89 | 22.92 | 79.21 | 27.83 | 2.85 | 28.48 | 0.12 | 382.93 | - | 50.39 | 12.64 | 11.6 |
| **Median** | 568 | 673 | 9 | 7.8 | 529 | 406 | 7.95 | 23.9 | 78.5 | 26.3 | 2.35 | 12.1 | 0.11 | 324 | - | 30.3 | 5.37 | 0.38 |
| **Std Deviation** | 253.12 | 300.19 | 0 | 0.27 | 0 | 191.74 | 0.89 | 4.3 | 25.31 | 12.91 | 2.46 | 48.51 | 0.04 | 189.2 | - | 80.65 | 18.47 | 33.13 |
| **Std Error** | 25.44 | 38.44 | 0 | 0.04 | 0 | 24.55 | 0.12 | 0.94 | 3.24 | 1.65 | 0.31 | 6.21 | 0 | 24.22 | - | 10.33 | 2.36 | 4.69 |

Table 3.3.2. Summary of chemical properties of the Lake Souris aquifer in McHenry County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 181 | 0 | 174 | - | 0.07 | - | 0.56 | - | 1.56 |
| **Maximum** | 754 | 370 | 1,120 | - | 5.98 | - | 0.56 | - | 1.56 |
| **Points** | 61 | 61 | 60 | - | 61 | - | 1 | - | 1 |
| **Mean** | 312.38 | 37.44 | 314.47 | - | 0.66 | - | 0.56 | - | 1.56 |
| **Median** | 306 | 0 | 264.5 | - | 0.31 | - | 0.56 | - | 1.56 |
| **Std Deviation** | 97.6 | 68.87 | 156.56 | - | 1 | - | 0 | - | 0 |
| **Std Error** | 12.5 | 8.82 | 20.21 | - | 0.13 | - | 0 | - | 0 |

Table 3.3.3. Summary of chemical properties of the Lake Souris aquifer in McHenry County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.01 | 0.01 | 2.45 | - | 1.84 | 7.13 | 1.12 | 0.01 |
| Maximum | 29.9 | 1.15 | 2.45 | - | 1.84 | 7.13 | 1.12 | 29.9 |
| Points | 61 | 61 | 1 | - | 1 | 1 | 1 | 61 |
| Mean | 1.89 | 0.26 | 2.45 | - | 1.84 | 7.13 | 1.12 | 1.89 |
| Median | 1.04 | 0.24 | 2.45 | - | 1.84 | 7.13 | 1.12 | 1.04 |
| Std Deviation | 3.91 | 0.22 | - | - | - | - | - | 3.91 |
| Std Error | 0.5 | 0.03 | - | - | - | - | - | 0.5 |

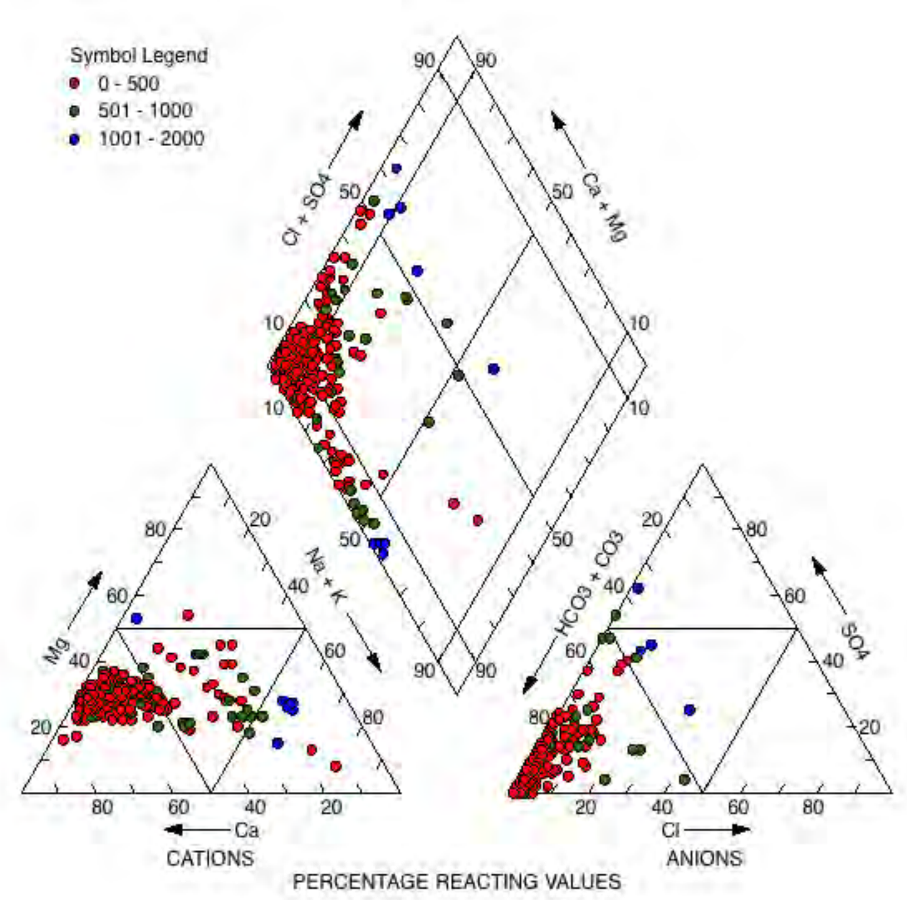


Figure 3.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Lake Souris aquifer in McHenry County.

## 3.4 *New Rockford Aquifer (McHenry County)*

Areas of the New Rockford aquifer in Study Area #3 having potential for further water-use development underlie about 25 square miles in McHenry County (Study Area # 3 map).

Aquifer Composition: Randich (1981) described the New Rockford aquifer in McHenry County as consisting of "several sand and gravel deposits," which range in thickness from 4 to 226 feet, with an average thickness of about 90 feet. Depending on depth, deposits can be confined or unconfined. An example of the local lithology is provided in Appendix Figure B.3.4.1.

Aquifer Yield: Randich (1981) reported a transmissivity of 39,000 $ft^2$/day, and a storage coefficient of 0.0005 from an aquifer test of the New Rockford aquifer. Randich estimated potential well yields of 50 to 2,000 gpm, depending on location.

Aquifer Chemistry: Anion and cation distributions for water samples from 34 wells at 32 locations range from the calcium and sodium-sulfate type, to a sodium-sulfate type (Figure 3.4.1). Dissolved solids range from about 300 to 2,000 mg/L, with a median near 700 mg/L (Table 3.4.1). The sodium-sulfate type corresponds to the higher dissolved solids (Figure 3.4.1). Iron and manganese are both high (Table 3.4.3).

Permit Acquisition Status: There is one perfected water permit for 188 acre-feet in the area designated as having potential for further water-use development. Using an estimate of 0.5 to 1 inch of annual recharge (based on variable depth of sand and gravel deposits to the surface), as much as 400 to 1,000 acre-feet of water may be available for beneficial use from the areas of the New Rockford aquifer designated as having potential for further development in Study Area #3.

Additional Considerations: The aquifer is narrow (about 1.5 miles wide), so pumping may be limited by aquifer geometry, depending on location. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Randich, P.G. 1981. Ground-water Resources of McHenry County, North Dakota. County Ground-Water Studies 33-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 21-27.

Table 3.4.1. Summary of chemical properties of the New Rockford aquifer in McHenry County: general chemistry.

| | $S_C$-f µS/cm | $S_C$-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 453 | 542 | 7.6 | 6.9 | - | 304 | 7.9 | 10.5 | 14.3 | 4.3 | 3.5 | 12.2 | 0.08 | 176 | NA | 8.67 | 1.55 | 0.09 |
| **Maximum** | 2,710 | 2,890 | 8.2 | 8.4 | - | 2,130 | 9.7 | 30.9 | 235 | 80 | 20.3 | 470 | 0.49 | 865 | NA | 1,100 | 194 | 0.35 |
| **Points** | 32 | 33 | 5 | 33 | - | 33 | 17 | 23 | 33 | 33 | 33 | 33 | 33 | 33 | NA | 33 | 33 | 10 |
| **Mean** | 1,354.2 | 1,448.1 | 7.9 | 7.8 | - | 964.82 | 8.62 | 25.95 | 102.65 | 34.13 | 8.07 | 177.88 | 0.21 | 548.24 | NA | 336.9 | 27.39 | 0.14 |
| **Median** | 1,194.5 | 1,220 | 7.8 | 7.9 | - | 741 | 8.5 | 26.4 | 77.5 | 22.1 | 7.4 | 169 | 0.18 | 534 | NA | 128 | 15.8 | 0.13 |
| **Std Deviation** | 680.87 | 773.67 | 0.28 | 0.33 | - | 587.75 | 0.58 | 4.02 | 66.35 | 22.53 | 3.32 | 117.35 | 0.09 | 182.16 | NA | 365.53 | 39.52 | 0.08 |
| **Std Error** | 120.36 | 134.68 | 0.13 | 0.06 | - | 102.31 | 0.14 | 0.84 | 11.55 | 3.92 | 0.58 | 20.43 | 0.02 | 31.71 | NA | 63.63 | 6.88 | 0.02 |

Table 3.4.2. Summary of chemical properties of the New Rockford aquifer in McHenry County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 57 | 0 | 144 | - | 0.33 | - | - | - | - |
| **Maximum** | 917 | 367 | 709 | - | 16.4 | - | - | - | - |
| **Points** | 33 | 33 | 33 | - | 33 | - | - | - | - |
| **Mean** | 397.09 | 68.61 | 449.76 | - | 4.53 | - | - | - | - |
| **Median** | 297 | 0 | 438 | - | 3.35 | - | - | - | - |
| **Std Deviation** | 255.69 | 113.78 | 149.8 | - | 3.96 | - | - | - | - |
| **Std Error** | 44.51 | 19.81 | 26.08 | - | 0.69 | - | - | - | - |

Table 3.4.3. Summary of chemical properties of the New Rockford aquifer in McHenry County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | - | 0.08 | 0.01 | 1 | - | 3.15 | 24.3 | 1.62 |
| Maximum | - | 32.2 | 0.82 | 13.6 | - | 21.3 | 135 | 9.17 |
| Points | - | 31 | 33 | 7 | - | 7 | 7 | 7 |
| Mean | - | 2.81 | 0.25 | 9.22 | - | 9.86 | 64.33 | 4.73 |
| Median | - | 1.03 | 0.19 | 12 | - | 7.31 | 53.6 | 4.03 |
| Std Deviation | - | 5.8 | 0.19 | 5.74 | - | 6.32 | 36.94 | 2.65 |
| Std Error | - | 1.04 | 0.03 | 2.17 | - | 2.39 | 13.96 | 1 |

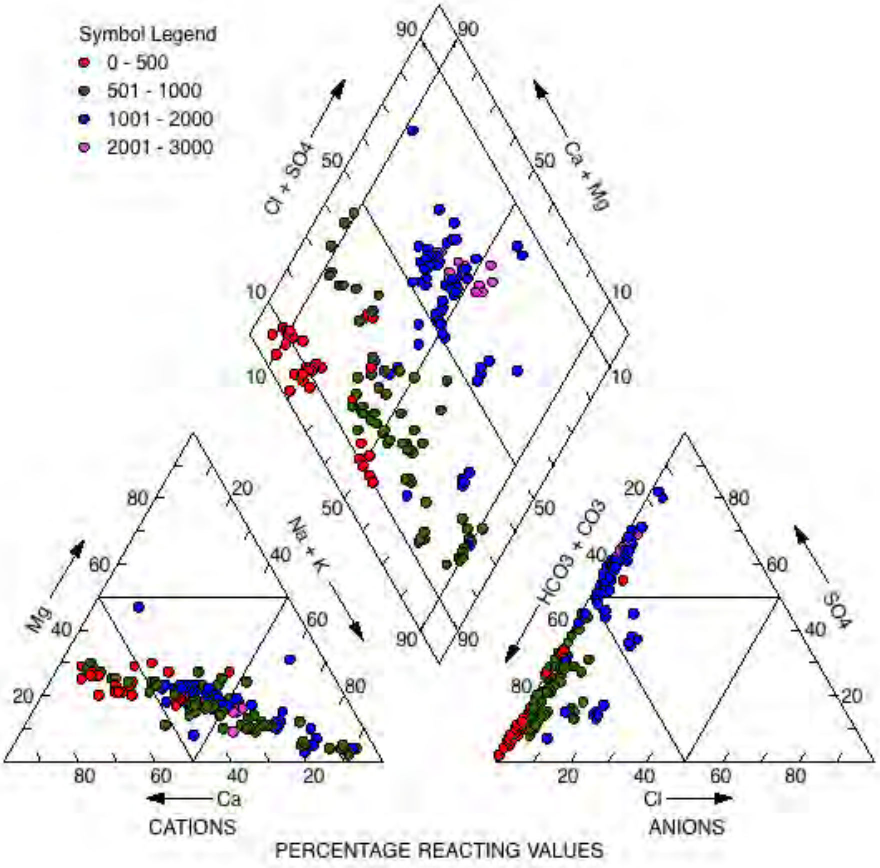


Figure 3.4.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the New Rockford aquifer in McHenry County.

### *3.5 Voltaire Aquifer (McHenry County)*

The portion of the Voltaire aquifer indicated to have potential for further water-use development underlies about 35 square miles in southeastern McHenry County (Study Area #3 map), mostly between Velva and Balfour along HWY 52. The area of the aquifer having potential for further water-use development lies between Bergen and Balfour.

Aquifer Composition: According to Randich (1981) the Voltaire aquifer consists of "sand and gravel beds" with a thickness range of 4 to 71 feet, and an average thickness of about 25 feet. The most productive areas are near Voltaire and Velva. An example of the aquifer lithology is shown on Appendix Figure B.3.5.1.

Aquifer Yield: Randich (1981) reported aquifer tests indicating transmissivities from 6,500 to 18,000 $ft^2$/day, and storage coefficients of 0.1 to 0.15, indicative of predominantly unconfined conditions. He estimated that potential well yields of 50 to 500 gpm would be possible, depending on location.

Aquifer Chemistry: The anion and cation distributions from seven well sites indicate that the aquifer waters are primarily of the sodium-bicarbonate and sodium-sulfate type (Figure 3.5.1). Dissolved solids concentrations range from about 500 to 2,000 mg/L, with a median value near 850 mg/L (Table 3.5.1). Higher dissolved solids generally correspond with higher sodium and sulfate (Figure 3.5.1). Iron and manganese concentrations are both high (Table 3.5.3).

Permit Acquisition Status: There are currently four perfected water permits for a total of 1,072 acre-feet per year, and one application for 654 acre-feet from the Voltaire aquifer. There are, however, no water permits or new applications within the aquifer area mapped as having good potential for further water-use development. However, the point-of-diversion for the water permit nearest the area designated as having potential for future development is more than six miles from that area. Using an estimated annual recharge of about 0.5 to 1 inch per year (based on the unconfined status of the aquifer), as much as 1,000 to 1,900 acre-feet of water may be available for beneficial use from the undeveloped portion of the Voltaire aquifer.

Additional Considerations: **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Randich, P.G. 1981. Ground-water Resources of McHenry County, North Dakota. County Ground-Water Studies 33-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 28-29.

Table 3.5.1. Summary of chemical properties of the Voltaire aquifer in McHenry County: general chemistry.

| | $S_C$-f µS/cm | $S_C$-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 610 | 755 | 7.4 | 7.5 | 481 | 472 | 7 | 15 | 58 | 21 | 5.2 | 79 | 0.1 | 316 | NA | 110 | 3.9 | - |
| **Maximum** | 2,045 | 2,790 | 7.7 | 8.1 | 1,450 | 1,910 | 9.5 | 36.4 | 150 | 55 | 14 | 552 | 0.32 | 1,170 | NA | 730 | 37.4 | - |
| **Points** | 6 | 7 | 4 | 7 | 5 | 7 | 4 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | NA | 7 | 7 | - |
| **Mean** | 1,269.7 | 1,420.3 | 7.5 | 7.7 | 822.4 | 982.29 | 8 | 20.89 | 88.09 | 33.76 | 7.16 | 202 | 0.14 | 482.43 | NA | 383.57 | 13.95 | - |
| **Median** | 1,186.5 | 1,220 | 7.5 | 7.7 | 754 | 858 | 7.75 | 16 | 89 | 30.3 | 5.6 | 150 | 0.1 | 375 | NA | 370 | 6.2 | - |
| **Std Deviation** | 500.49 | 714.84 | 0.13 | 0.2 | 387.67 | 511.47 | 1.08 | 7.75 | 30.62 | 11.5 | 3.19 | 163.54 | 0.08 | 304.82 | NA | 217.12 | 14.06 | - |
| **Std Error** | 204.32 | 270.19 | 0.06 | 0.08 | 173.37 | 193.32 | 0.54 | 2.93 | 11.57 | 4.35 | 1.2 | 61.81 | 0.03 | 115.21 | NA | 82.06 | 5.31 | - |

Table 3.5.2. Summary of chemical properties of the Voltaire aquifer in McHenry County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 230 | 0 | 323 | NA | 2.3 | 0.17 | 0.25 | 1.17 | 1.25 |
| **Maximum** | 600 | 260 | 960 | NA | 12 | 0.57 | 0.67 | 1.57 | 1.67 |
| **Points** | 7 | 7 | 2 | NA | 7 | 4 | 5 | 4 | 5 |
| **Mean** | 358.71 | 53.71 | 641.5 | NA | 4.54 | 0.39 | 0.46 | 1.39 | 1.46 |
| **Median** | 350 | 4 | 641.5 | NA | 3.4 | 0.42 | 0.43 | 1.42 | 1.43 |
| **Std Deviation** | 121.31 | 94.63 | 450.43 | NA | 3.41 | 0.18 | 0.17 | 0.18 | 0.17 |
| **Std Error** | 45.85 | 35.77 | 318.5 | NA | 1.29 | 0.09 | 0.08 | 0.09 | 0.08 |

Table 3.5.3. Summary of chemical properties of the Voltaire aquifer in McHenry County: selected trace elements.

|  | **Boron** mg/L | **Iron** mg/L | **Manganese** mg/L | **Selenium** µg/L | **Mercury** µg/L | **Arsenic** µg/L | **Lithium** µg/L | **Molybdenum** µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.2 | 0.54 | 0.2 | - | - | - | - | - |
| Maximum | 0.55 | 5.7 | 0.76 | - | - | - | - | - |
| Points | 5 | 7 | 7 | - | - | - | - | - |
| Mean | 0.32 | 2.93 | 0.51 | - | - | - | - | - |
| Median | 0.31 | 3 | 0.58 | - | - | - | - | - |
| Std Deviation | 0.14 | 1.67 | 0.2 | - | - | - | - | - |
| Std Error | 0.06 | 0.63 | 0.07 | - | - | - | - | - |

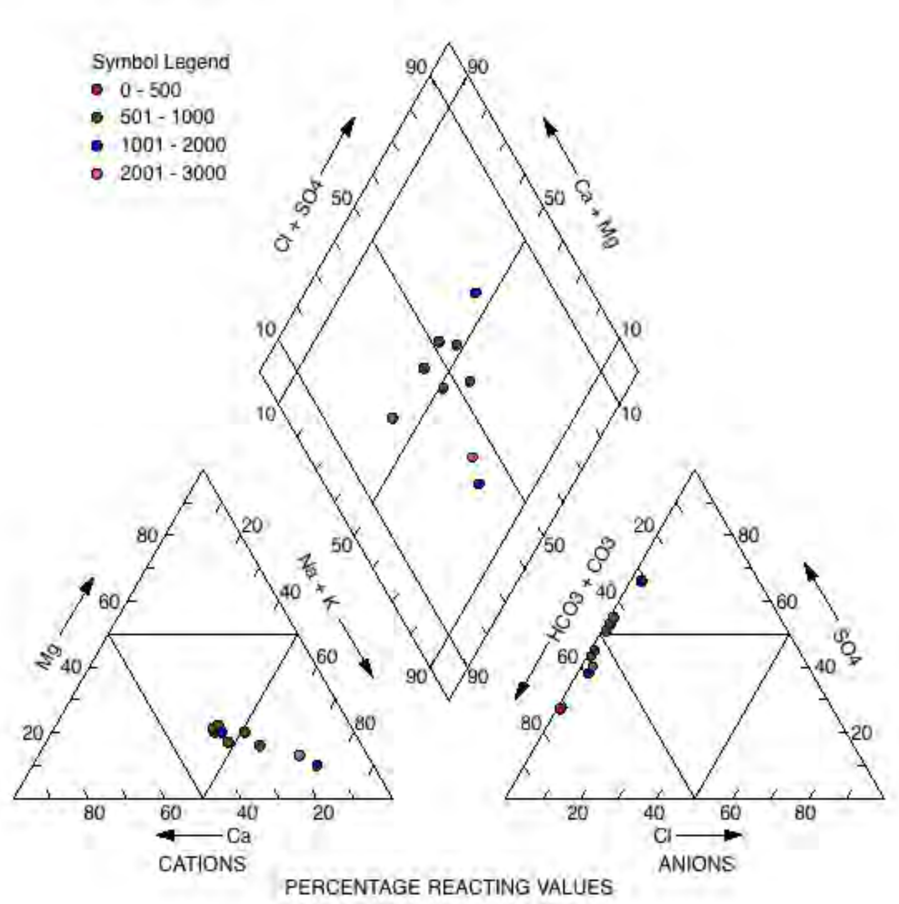
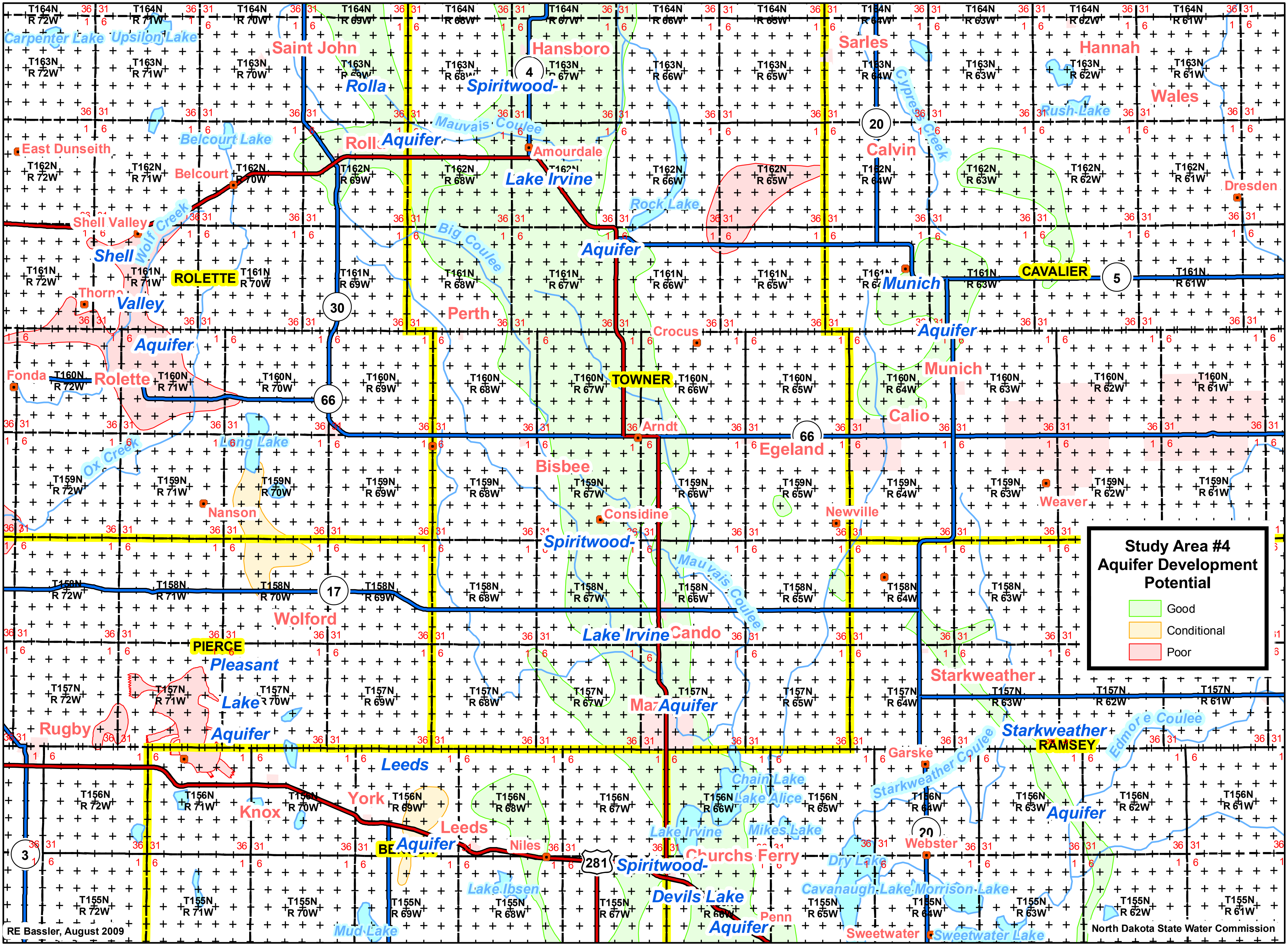


Figure 3.5.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Voltaire aquifer in McHenry County.



**Study Area #4 Aquifer Development Potential**

- 🟩 Good
- 🟨 Conditional
- 🟥 Poor

RE Bassler, August 2009

North Dakota State Water Commission

## Study Area 4: North-Central North Dakota / Bottineau, McHenry, Renville and Ward Counties

### *4.1. Munich Aquifer (Cavalier County)*

The Munich aquifer was indicated by Hutchinson (1977) to underlie about 30 square miles in Cavalier County. In this discussion, we have included an additional sand and gravel deposit underlying about 14 square miles, a few miles northeast of the labeled deposit on the Study Area #4 map.

Aquifer Composition: According to Hutchinson (1977), the Munich aquifer consists of shaly sand and gravel, interbedded with clay and silt. The thickness ranges from 0 to about 200 feet, with an average of about 40 feet. Two examples of lithology are provided in Appendix Figures B.4.1.1 and B.4.1.2.

Aquifer Yield: Hutchinson (1977) cited an aquifer test that measured a transmissivity of 4,200 $ft.^2$/day and a storage coefficient of 0.0004. He estimated that properly-constructed wells might yield as much as 500 gpm, depending on location.

Aquifer Chemistry: The water of the Munich aquifer is primarily of the sodium-sulfate type, with some of the calcium-bicarbonate type (Figure 4.1.1). Dissolved solids concentrations range from about 500 mg/L to as high as 5,000 mg/L, and have a median near 1,600 mg/L. Iron and manganese concentrations are high (Table 4.1.3). The maximum arsenic concentration exceeds three times the EPA-MCL .

Permit Acquisition Status: There are no current water permits or permit applications pending from the Munich aquifer. Considering the relatively shallow depth to the surface of sand and gravel deposits, and using a potential recharge range of about 0.5 to 1 inch per year, as much as 1,000 to 2,000 acre-feet of water may be available for development in aggregate from the Munich aquifer and the ancillary coarse deposit northeast of the Munich aquifer.

Additional Considerations: Salinity is generally high. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Hutchinson, R.D. 1977. Ground-water Resources of Cavalier and Pembina Counties, North Dakota. County Ground-Water Studies 20-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 33-36.

Table 4.1.1. Summary of chemical properties of the Munich aquifer in Cavalier County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 800 | 774 | 7.3 | - | 509 | 535 | 5 | 23 | 41 | 9.8 | 5.7 | 57 | 0.1 | 315 | 0 | 130 | 1.6 | 0 |
| **Maximum** | 2,475 | 8,300 | 8.3 | - | 5,130 | 5,130 | 10.5 | 31 | 268 | 69 | 18 | 1,770 | 0.9 | 720 | 1 | 1,050 | 1,870 | 11 |
| **Points** | 7 | 28 | 5 | - | 27 | 27 | 16 | 24 | 27 | 27 | 27 | 28 | 27 | 28 | 28 | 28 | 28 | 27 |
| **Mean** | 1,733.4 | 2,343.3 | 7.9 | - | 1,653.8 | 1,627.6 | 6.28 | 27.92 | 159.93 | 49.24 | 13.59 | 334.25 | 0.41 | 548.46 | 0.04 | 638.29 | 147.29 | 2.92 |
| **Median** | 1,934 | 2,200 | 8 | - | 1,600 | 1,580 | 6 | 28 | 152 | 54 | 14 | 278.5 | 0.4 | 578.5 | 0 | 720 | 70 | 2.5 |
| **Std Deviation** | 621.03 | 1,348.4 | 0.36 | - | 850.37 | 841.09 | 1.32 | 1.59 | 55.94 | 17.44 | 3.41 | 324.06 | 0.19 | 114.89 | 0.19 | 219.84 | 351.6 | 2.82 |
| **Std Error** | 234.73 | 254.82 | 0.16 | - | 163.65 | 161.87 | 0.33 | 0.32 | 10.77 | 3.36 | 0.66 | 61.24 | 0.04 | 21.71 | 0.04 | 41.55 | 66.45 | 0.54 |

Table 4.1.2. Summary of chemical properties of the Munich aquifer in Cavalier County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 10 | 143 | 0 | 557 | 1.2 | - | - | - | - |
| **Maximum** | 170 | 918 | 405 | 557 | 45 | - | - | - | - |
| **Points** | 3 | 28 | 26 | 1 | 27 | - | - | - | - |
| **Mean** | 66.67 | 592.89 | 190.62 | 557 | 6.76 | - | - | - | - |
| **Median** | 20 | 569 | 214.5 | 557 | 4.1 | - | - | - | - |
| **Std Deviation** | 89.63 | 204.32 | 144.85 | 0 | 9.38 | - | - | - | - |
| **Std Error** | 51.75 | 38.61 | 28.41 | 0 | 1.81 | - | - | - | - |

Table 4.1.3. Summary of chemical properties of the Munich aquifer in Cavalier County: selected trace elements.

| | **Boron**<br>**mg/L** | **Iron**<br>**mg/L** | **Manganese**<br>**mg/L** | **Selenium**<br>**µg/L** | **Mercury**<br>**µg/L** | **Arsenic**<br>**µg/L** | **Lithium**<br>**µg/L** | **Molybdenum**<br>**µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | - | 0 | 0.01 | 0 | 0 | 0 | 10 | 0 |
| Maximum | - | 7.5 | 1.8 | 3 | 0.4 | 36.4 | 170 | 7.5 |
| Points | - | 28 | 27 | 4 | 3 | 4 | 3 | 28 |
| Mean | - | 2.74 | 0.51 | 1 | 0.27 | 23.1 | 66.67 | 2.74 |
| Median | - | 3.05 | 0.33 | 0.5 | 0.4 | 28 | 20 | 3.05 |
| Std Deviation | - | 2.09 | 0.56 | 1.41 | 0.23 | 16.09 | 89.63 | 2.09 |
| Std Error | - | 0.39 | 0.11 | 0.71 | 0.13 | 8.04 | 51.75 | 0.39 |

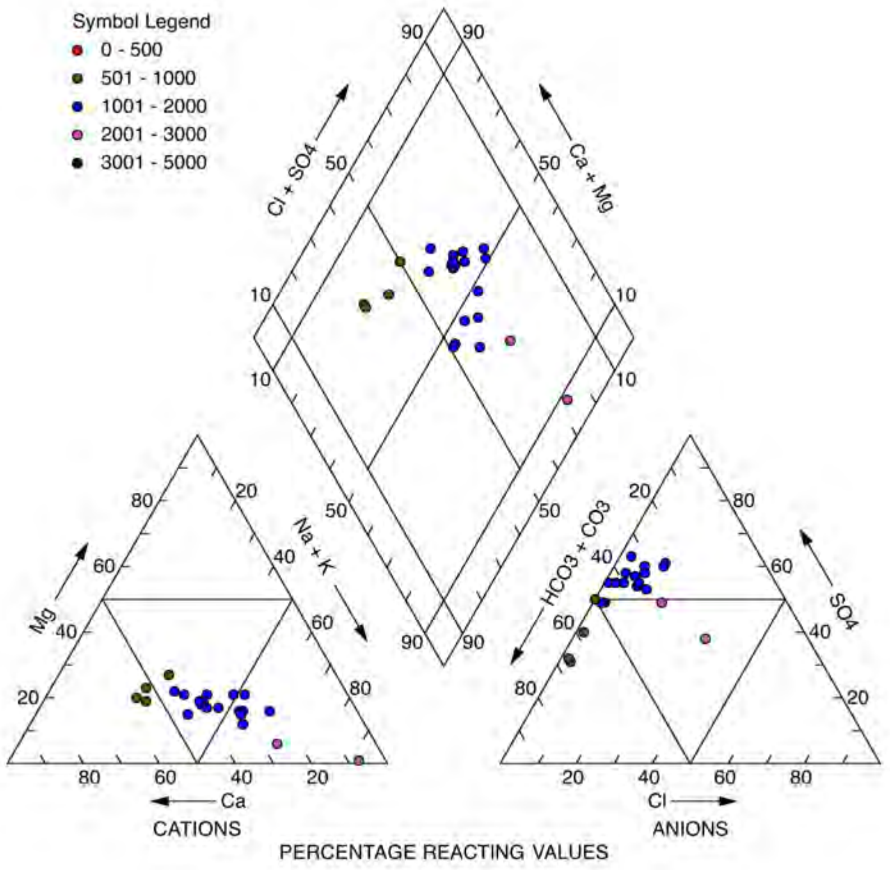


Figure 4.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Munich aquifer.

### *4.2. Rolla Aquifer (Rolette and Towner Counties)*

The Rolla aquifer consists of a system of unconfined and confined coarse deposits underlying about 48 square miles in northeastern Rolette County and northwestern Towner County (Study Area #4 map).

Aquifer Composition: Randich and Kuzniar (1984) described the aquifer as consisting of sand and gravel layers, interbedded with silt, clay and till. The aquifer thickness ranges from 5 to 86 feet, with an average thickness of about 30 feet. Water tables vary from 2 to 35 feet bls. An example of the Rolla aquifer lithology is shown on Appendix Figure B.4.2.1.

Aquifer Yield: Randich and Kuzniar (1984) estimated potential aquifer yield at 5 to 250 gpm.

Aquifer Chemistry: The anion and cation distribution of the Rolla aquifer is primarily of the calcium-sulfate type, with some of the calcium sodium-sulfate type, and some of the calcium-carbonate type (Figure 4.2.1). Dissolved solids concentrations are somewhat high, ranging from about 600 mg/L to 2,200 mg/L, and with a median close to 1,600 mg/L (Table 4.2.1). The dissolved sulfate proportion generally increases with increasing dissolved solids. Iron and manganese concentrations are both high (Table 4.2.3).

Permit Acquisition Status: There is currently one water perfected water permit for 560 acre-feet from the Rolla aquifer. Using an estimated annual recharge rate of about 0.5 inches for a variably confined aquifer, with some sand and gravel deposits above 50 feet, others deeper, there may be as much as 900 acre-feet of water available for development and beneficial use.

Additional Considerations: **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Randich, P.G. and R.L. Kuzniar. 1984. Ground-water Resources of Bottineau and Rolette, North Dakota. County Ground-Water Studies 35-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 22-25.

Table 4.2.1. Summary of chemical properties of the Rolla aquifer in Rollette and Towner Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 925 | 460 | 6.9 | 7.2 | 589 | 599 | 5 | 15 | 38 | 40 | 5.3 | 19 | 0.2 | 329 | 0 | 125 | 9.1 | 0 |
| **Maximum** | 2,250 | 3,010 | 8.2 | 8.1 | 2,262 | 2,086 | 7 | 30 | 360 | 197 | 16 | 260 | 0.7 | 598 | 24 | 1,172 | 80 | 50 |
| **Points** | 9 | 19 | 6 | 17 | 19 | 15 | 9 | 15 | 19 | 19 | 15 | 19 | 17 | 19 | 19 | 19 | 19 | 18 |
| **Mean** | 1,721.7 | 1,755.1 | 7.6 | 7.7 | 1,487.8 | 1,425.6 | 5.78 | 23.2 | 197.68 | 88.26 | 10.6 | 134.47 | 0.38 | 461.47 | 1.26 | 689.74 | 29.16 | 8.7 |
| **Median** | 2,000 | 1,967 | 7.4 | 7.8 | 1,594 | 1,570 | 6 | 23 | 204 | 89 | 12 | 133 | 0.3 | 463 | 0 | 750 | 24 | 1 |
| **Std Deviation** | 491.24 | 760.68 | 0.53 | 0.29 | 485.18 | 476.32 | 0.71 | 4.66 | 75.54 | 35.19 | 4.03 | 71.02 | 0.17 | 83.82 | 5.51 | 293.67 | 16.46 | 16.05 |
| **Std Error** | 163.75 | 174.51 | 0.22 | 0.07 | 111.31 | 122.98 | 0.24 | 1.2 | 17.33 | 8.07 | 1.04 | 16.29 | 0.04 | 19.23 | 1.26 | 67.37 | 3.78 | 3.78 |

Table 4.2.2. Summary of chemical properties of the Rolla aquifer in Rollette and Towner Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 440 | 140 | 340 | 270 | 0.4 | 0.31 | -0.23 | 1.31 | 0.77 |
| **Maximum** | 1,300 | 920 | 490 | 490 | 4.6 | 1.71 | 1.34 | 2.71 | 2.34 |
| **Points** | 19 | 15 | 4 | 19 | 15 | 6 | 17 | 6 | 17 |
| **Mean** | 862.47 | 490.8 | 422.5 | 380.42 | 1.99 | 0.83 | 0.86 | 1.83 | 1.86 |
| **Median** | 890 | 480 | 430 | 380 | 1.7 | 0.51 | 0.99 | 1.51 | 1.99 |
| **Std Deviation** | 231.17 | 231.75 | 68.13 | 66.74 | 1.23 | 0.65 | 0.43 | 0.65 | 0.43 |
| **Std Error** | 53.03 | 59.84 | 34.07 | 15.31 | 0.32 | 0.26 | 0.1 | 0.26 | 0.1 |

Table 4.2.3. Summary of chemical properties of the Rolla aquifer in Rolette and Towner Counties: selected trace elements.

| | **Boron** mg/L | **Iron** mg/L | **Manganese** mg/L | **Selenium** µg/L | **Mercury** µg/L | **Arsenic** µg/L | **Lithium** µg/L | **Molybdenum** µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0.04 | 0.22 | - | - | - | - | - |
| Maximum | 2.1 | 19 | 2.7 | - | - | - | - | - |
| Points | 15 | 19 | 13 | - | - | - | - | - |
| Mean | 0.35 | 2.13 | 1.34 | - | - | - | - | - |
| Median | 0.2 | 0.71 | 1.35 | - | - | - | - | - |
| Std Deviation | 0.53 | 4.3 | 0.89 | - | - | - | - | - |
| Std Error | 0.14 | 0.99 | 0.25 | - | - | - | - | - |

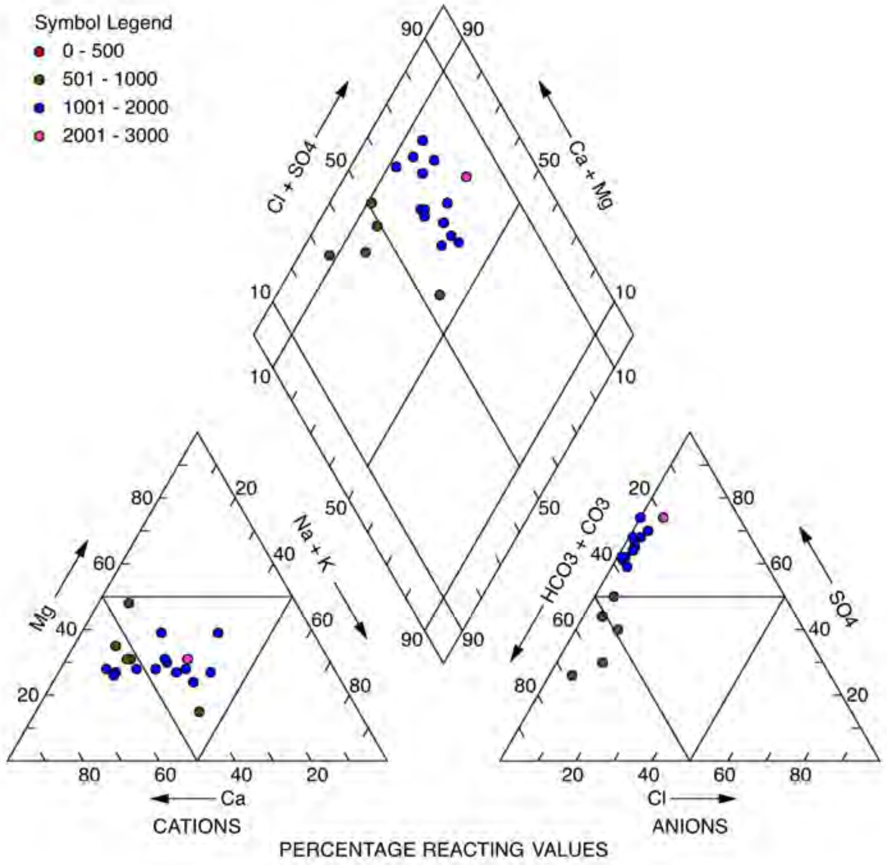


Figure 4.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Rolla aquifer.

### *4.3. Spiritwood Aquifer (Northern Ramsey and Towner Counties)*

The Spiritwood aquifer system underlies about 370 square miles in Towner County, and is the northern portion of an extensive aquifer system that extends from South Dakota in the south to Manitoba in the north (Study Area #4 map).

Aquifer Composition: Randich and Kuzniar described the local Spiritwood aquifer as consisting of sand and gravel beds interbedded with lenses of silt, clay and till. The aquifer system thickness ranges from 4 to 287 feet, with an average aggregate thickness of 67 feet. Two examples of the aquifer lithology are shown in Appendix Figures B.4.3.1 and B.4.3.2. The main sand and gravel deposits are located as shallow as 63 feet (Appendix Figure B.4.3.1) or as deep as 178 feet (Appendix Figure B.4.3.2).

Aquifer Yield: Randich and Kuzniar (1984) estimated that aquifer yields of 50 to 1,500 gpm may be feasible, depending on location, for properly-constructed wells.

Aquifer Chemistry: The local Spiritwood aquifer water is primarily of the sodium-sufate type, with some of the sodium-sulfate and sodium-bicarbonate type (Figure 4.3.1). Dissolved solids concentrations range from about 900 mg/L to 2,600 mg/L, with a median near 1,200 mg/L (Table 4.3.1). Iron and manganese concentrations are both high. A single arsenic sample is below the EPA-MCL of 10 mg/L (Table 4.3.3).

Permit Acquisition Status: There are currently six water permits, two perfected, three conditional, and one held in abeyance, for a total of 2,148 acre-feet from the Spiritwood aquifer in Study Area #4. Based on an estimated annual recharge rate of 0.25 inches per year an initial estimate for as much as 4,500 acre-feet may be available for development and beneficial use.

Additional Considerations: Caution expansion of use beyond this amount may be feasible, depending on the local discontinuities in the aquifer. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Randich, P.G. and R.L. Kuzniar. 1984. Ground-water Resources of Towner County, North Dakota. County Ground-Water Studies 36-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 13-14.

Table 4.3.1. Summary of chemical properties of the Spiritwood aquifer in northern Ramsey and Towner Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 1,530 | 1,360 | 0 | 7.6 | 852 | 887 | 6.5 | 11 | 39 | 15 | 7.3 | 84 | 0.18 | 363 | 0 | 130 | 13 | 0.4 |
| **Maximum** | 5,000 | 4,400 | 0 | 8.2 | 2,480 | 2,430 | 14 | 33 | 220 | 71 | 48 | 860 | 0.5 | 650 | 1 | 861 | 1,000 | 17 |
| **Points** | 6 | 11 | 0 | 11 | 10 | 11 | 8 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 10 |
| **Mean** | 2,298.3 | 2,174.5 | 0 | 7.8 | 1,361.2 | 1,407.9 | 9.44 | 25.78 | 95.46 | 36.78 | 15.8 | 343.27 | 0.29 | 517.45 | 0.09 | 425 | 205.73 | 4.82 |
| **Median** | 1,760 | 1,740 | 0 | 7.8 | 1,190 | 1,220 | 8.5 | 28 | 84 | 33 | 14 | 250 | 0.3 | 520 | 0 | 372 | 51 | 3.85 |
| **Std Deviation** | 1,342.4 | 940.87 | 0 | 0.19 | 476.19 | 475.57 | 2.73 | 6.3 | 53.19 | 16.77 | 11.07 | 227.38 | 0.11 | 78.67 | 0.3 | 204.71 | 333.83 | 5.05 |
| **Std Error** | 548.04 | 283.68 | 0 | 0.06 | 150.59 | 143.39 | 0.97 | 1.9 | 16.04 | 5.06 | 3.34 | 68.56 | 0.03 | 23.72 | 0.09 | 61.72 | 100.65 | 1.6 |

Table 4.3.2. Summary of chemical properties of the Spiritwood aquifer in northern Ramsey and Towner Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 174 | 0 | 473 | 0 | 1.3 | 0 | 0.4 | - | - |
| **Maximum** | 840 | 470 | 473 | 533 | 25 | 0 | 1.05 | - | - |
| **Points** | 11 | 11 | 1 | 11 | 11 | 0 | 10 | - | - |
| **Mean** | 389.91 | 67.27 | 473 | 381.09 | 8.88 | 0 | 0.78 | - | - |
| **Median** | 330 | 0 | 473 | 405 | 6 | 0 | 0.8 | - | - |
| **Std Deviation** | 200.39 | 145.76 | 0 | 140.89 | 7.22 | 0 | 0.22 | - | - |
| **Std Error** | 60.42 | 43.95 | 0 | 42.48 | 2.18 | 0 | 0.07 | - | - |

Table 4.3.3. Summary of chemical properties of the Spiritwood aquifer in northern Ramsey and Towner Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.13 | 0.12 | 0.04 | 4.82 | - | 5.36 | 240 | 2.21 |
| Maximum | 2 | 5.2 | 0.49 | 4.82 | - | 5.36 | 240 | 2.21 |
| Points | 10 | 11 | 11 | 1 | - | 1 | 1 | 1 |
| Mean | 0.62 | 1.78 | 0.18 | 4.82 | - | 5.36 | 240 | 2.21 |
| Median | 0.42 | 1.55 | 0.14 | 4.82 | - | 5.36 | 240 | 2.21 |
| Std Deviation | 0.55 | 1.4 | 0.15 | - | - | - | - | - |
| Std Error | 0.17 | 0.42 | 0.05 | - | - | - | - | - |

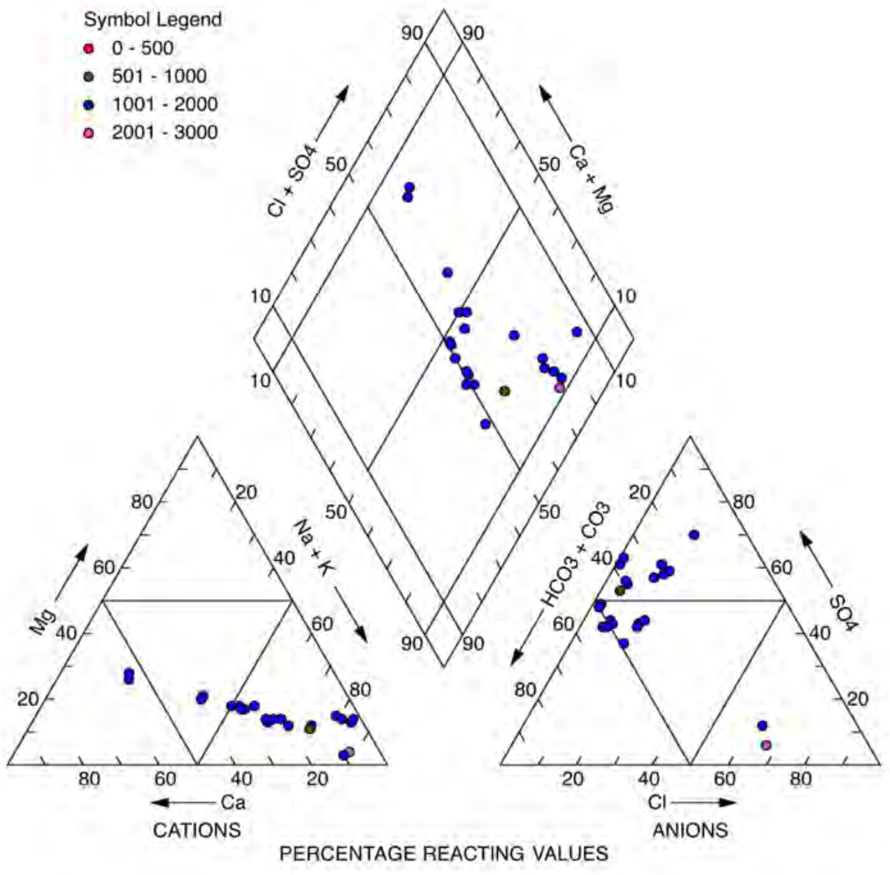


Figure 4.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Spiritwood aquifer in northern Ramsey and Towner Counties.

## *4.4 Starkweather Aquifer (Ramsey County)*

The Starkweather aquifer in the portion of Ramsey County in Study Area #3 is about 20 miles long, and a half mile to a mile wide (Study Area #4 map). It is estimated to underlie about 13 square miles (Hutchinson and Klausing 1980).

Aquifer Composition: The Starkweather aquifer has been described as consisting of sand and gravel lenses and beds ranging in total thickness from 3 feet to as much as 319 feet, with a mean aggregate thickness of 184 feet (Hutchinson and Klausing 1980). The main sand and gravel deposits are near or below 200 feet bls, and sometimes nearly 500 feet bls. One example of the local lithology is in Appendix Figure B.4.4.1.

Aquifer Yield: Hutchinson and Klausing (1980) estimated potential aquifer yields of 50 to 250 gpm from properly-constructed individual wells.

Aquifer Chemistry: Water samples are only available for three locations, so a statistical description is unnecessary. Water from all three is of the sodium-sulfate type (Figure 4.4.1). The general chemistry data are shown on Table 4.4.1. Dissolved solids are high, ranging from near 1,200 to about 2,500 mg/L. Iron and manganese are both high (Table 4.4.3).

Permit Acquisition Status: There are no current water permits or pending applications for the Starkweather aquifer. The Starkweather aquifer is likely to bear only limited further development, due to the depth of burial and limited lateral extent.

Additional Considerations: Appropriation of a couple hundred acre-feet per year may be possible. A long-term aquifer test should be conducted and plausible recharge rates should be considered. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Hutchinson, R.D. and Robert L. Klausing. 1980. Ground-water Resources of Ramsey County, North Dakota. County Ground-Water Studies 26-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 24-28.

Table 4.4.1. Summary of chemical properties of the Starkweather aquifer in Ramsey County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **15506206DDD** | 4,050 | 4,130 | | 7.4 | 2,940 | 2,490 | 8 | 22 | 160 | 49 | 20 | 660 | 0.2 | 398 | 0 | 370 | 1,000 | 12 |
| **15506218AAA2** | 1,830 | 1,860 | | 7.9 | 1,240 | 1,240 | 6.5 | 18 | 66 | 18 | 9.9 | 340 | 0.2 | 620 | 0 | 450 | 30 | 1 |
| **15506325AAA** | 3,500 | 4,090 | | 7.72 | 2,500 | 2,300 | 12 | 24 | 210 | 60 | 21 | 540 | 0.1 | 331 | 0 | 280 | 1,000 | 0 |

Table 4.4.2. Summary of chemical properties of the Starkweather aquifer in Ramsey County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **15506206DDD** | 600 | 270 | | 326 | 12 | | 0.48 | | 1.48 |
| **15506218AAA2** | 240 | 0 | | 508 | 9.6 | | 0.82 | | 1.82 |
| **15506325AAA** | 770 | 500 | | 271 | 8.5 | | 0.84 | | 1.84 |

Table 4.4.3. Summary of chemical properties of the Starkweather aquifer in Ramsey County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| **15506206DDD** | 0.6 | 0.1 | 0.89 | - | - | - | - | - |
| **15506218AAA2** | 0.87 | 0.08 | 0.24 | - | - | - | - | - |
| **15506325AAA** | 0.75 | 2.7 | 1.3 | - | - | - | - | - |
| **15506325AAA** | 0.75 | 2.7 | 1.3 | - | - | - | - | - |

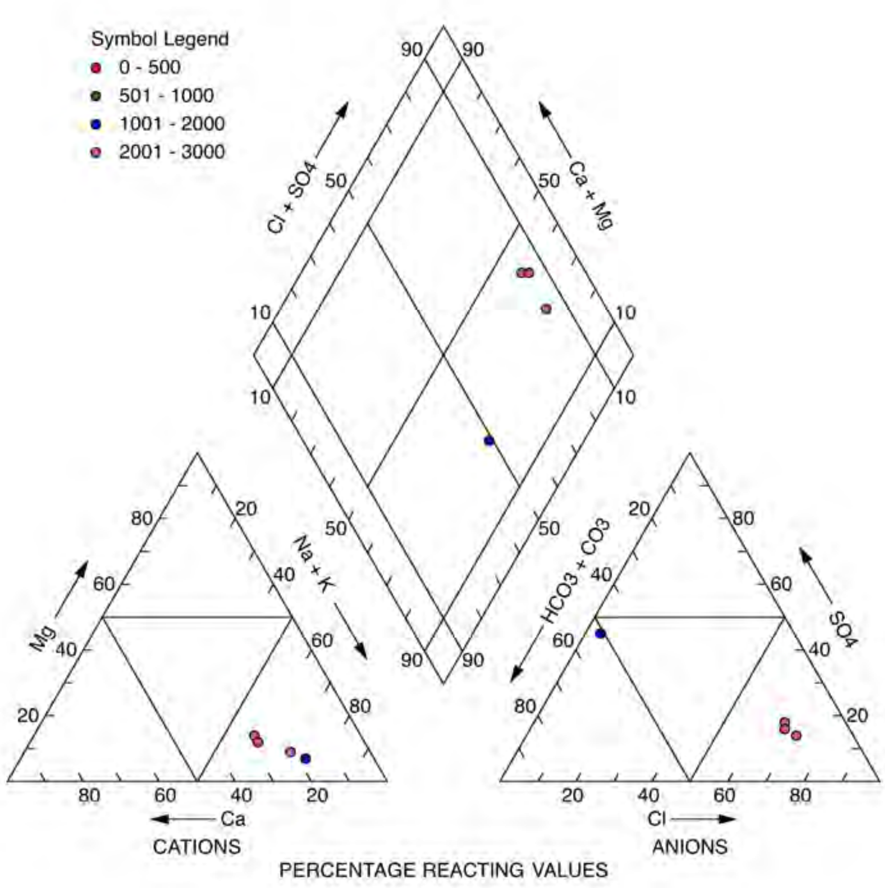
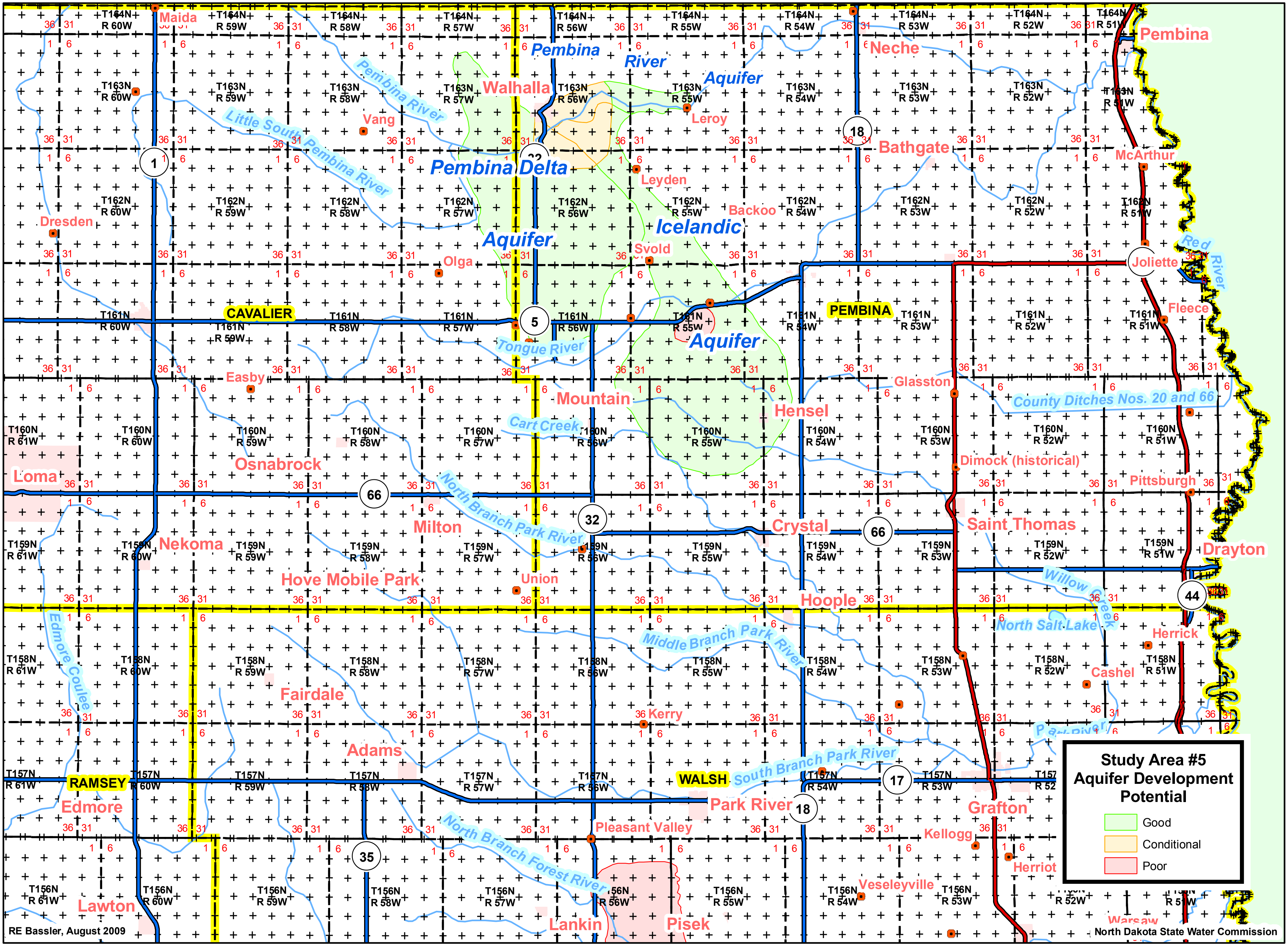


Figure 4.4.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Starkweather aquifer.



RE Bassler, August 2009

North Dakota State Water Commission

## Study Area 5: Northeastern North Dakota / Cavalier, Pembina and Walsh Counties

### *5.1. Icelandic Aquifer (Pembina County)*

The Icelandic aquifer underlies about 82 square miles in northern Pembina County (Study Area #5 map).

Aquifer Composition: The aquifer is predominantly unconfined and consists of very fine to medium sand interbedded with silt and clay. The maximum saturated thickness is about 70 feet (Hutchinson 1977). An example of Icelandic aquifer lithology is provided on Appendix Figure B.5.1.1.

Aquifer Yield: Hutchinson (1977) has estimated potential well yields of up to 50 gpm in properly-constructed and fully-penetrating wells.

Aquifer Chemistry: Icelandic aquifer water is very fresh, having a range of dissolved solids between about 100 and 400 mg/L (Table 5.1.1), and a median dissolved solids near 220 mg/L. The anion and cation distribution is almost entirely of the calcium bicarbonate type (Figure 5.1.1). Iron concentrations are low, but manganese concentrations are relatively high (Table 5.1.3).

Permit Acquisition Status: There are currently five water permits, one perfected, two conditional and one held in abeyance for a total of 2,125 acre-feet from the Icelandic aquifer. Of these, one permit is perfected, three are conditionally approved, and one is held in abeyance. One water permit for 900 acre-feet, held by ADM Corn Processing and the city of Walhalla, is within the area mapped conditional for development in the north. Four water permits for a total of 1,250 acre-feet have been granted (or held in abeyance) within the area mapped as good for further development. Except for the permit held in abeyance, there are no pending applications.

Using an estimated recharge rate of one inch per year, and accounting for currently allocated waters, there may be as much as 2,500 to 3,500 acre-feet of water available for development.

Additional Considerations: **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Hutchinson, R.D.. 1977. Ground-water Resources of Cavalier and Pembina Counties, North Dakota. County Ground-Water Studies 20-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 37-51.

Table 5.1.1. Summary of chemical properties of the Icelandic aquifer in Pembina County: general chemistry.

| | SC-f µS/cm | $S_C$-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 210 | 246 | 7.6 | 7 | 137 | 143 | 4 | 5.8 | 2 | 1 | 0.4 | 1.5 | 0 | 131 | 0 | 0 | 0 | 0.09 |
| **Maximum** | 967 | 1,460 | 9.2 | 8.6 | 394 | 900 | 10.2 | 42.1 | 162 | 35.6 | 7.1 | 360 | 0.88 | 701 | 17 | 247 | 30.2 | 4.6 |
| **Points** | 104 | 111 | 28 | 111 | 69 | 111 | 52 | 52 | 111 | 111 | 111 | 111 | 111 | 111 | 111 | 111 | 111 | 111 |
| **Mean** | 383.56 | 405.95 | 8 | 7.6 | 221.62 | 225.57 | 8.72 | 26.84 | 58.04 | 13.5 | 1.4 | 6.89 | 0.14 | 233.37 | 0.52 | 24.59 | 1.6 | 0.35 |
| **Median** | 365.5 | 384 | 7.8 | 7.6 | 214 | 210 | 8.8 | 27.5 | 56.4 | 13 | 1.1 | 3 | 0.1 | 221 | 0 | 22.1 | 0.51 | 0.1 |
| **Std Deviation** | 96.62 | 127.17 | 0.56 | 0.26 | 38.35 | 81.59 | 1.17 | 4.29 | 13.7 | 3.06 | 0.98 | 34.02 | 0.09 | 60.95 | 1.65 | 27.43 | 3.67 | 0.6 |
| **Std Error** | 9.47 | 12.07 | 0.11 | 0.02 | 4.62 | 7.74 | 0.16 | 0.59 | 1.3 | 0.29 | 0.09 | 3.23 | 0.01 | 5.79 | 0.16 | 2.6 | 0.35 | 0.06 |

Table 5.1.2. Summary of chemical properties of the Icelandic aquifer in Pembina County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 9 | 0 | 148 | 0 | 0 | - | -0.94 | - | 0.06 |
| **Maximum** | 551 | 229 | 604 | 603 | 51.8 | - | 0.82 | - | 1.82 |
| **Points** | 111 | 111 | 42 | 113 | 110 | - | 69 | - | 69 |
| **Mean** | 200.5 | 17.37 | 204.93 | 117.33 | 0.59 | - | 0.16 | - | 1.16 |
| **Median** | 200 | 12 | 186.5 | 161 | 0.1 | - | 0.23 | - | 1.23 |
| **Std Deviation** | 45.55 | 24.86 | 72.77 | 103.41 | 4.93 | - | 0.3 | - | 0.3 |
| **Std Error** | 4.32 | 2.36 | 11.23 | 9.73 | 0.47 | - | 0.04 | - | 0.04 |

Table 5.1.3. Summary of chemical properties of the Icelandic aquifer in Pembina County: selected trace elements.

|  | **Boron** mg/L | **Iron** mg/L | **Manganese** mg/L | **Selenium** µg/L | **Mercury** µg/L | **Arsenic** µg/L | **Lithium** µg/L | **Molybdenum** µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.03 | 0 | 0.01 | 0 | 0 | 1.37 | 7 | 0 |
| Maximum | 0.28 | 9.45 | 0.78 | 1.05 | 0.2 | 25 | 92 | 11.1 |
| Points | 10 | 110 | 111 | 9 | 9 | 9 | 9 | 9 |
| Mean | 0.09 | 1.13 | 0.43 | 0.12 | 0.09 | 11.71 | 18.76 | 1.23 |
| Median | 0.06 | 1 | 0.45 | 0 | 0.1 | 11 | 10 | 0 |
| Std Deviation | 0.08 | 0.99 | 0.13 | 0.35 | 0.06 | 6.95 | 27.56 | 3.7 |
| Std Error | 0.03 | 0.09 | 0.01 | 0.12 | 0.02 | 2.32 | 9.19 | 1.23 |

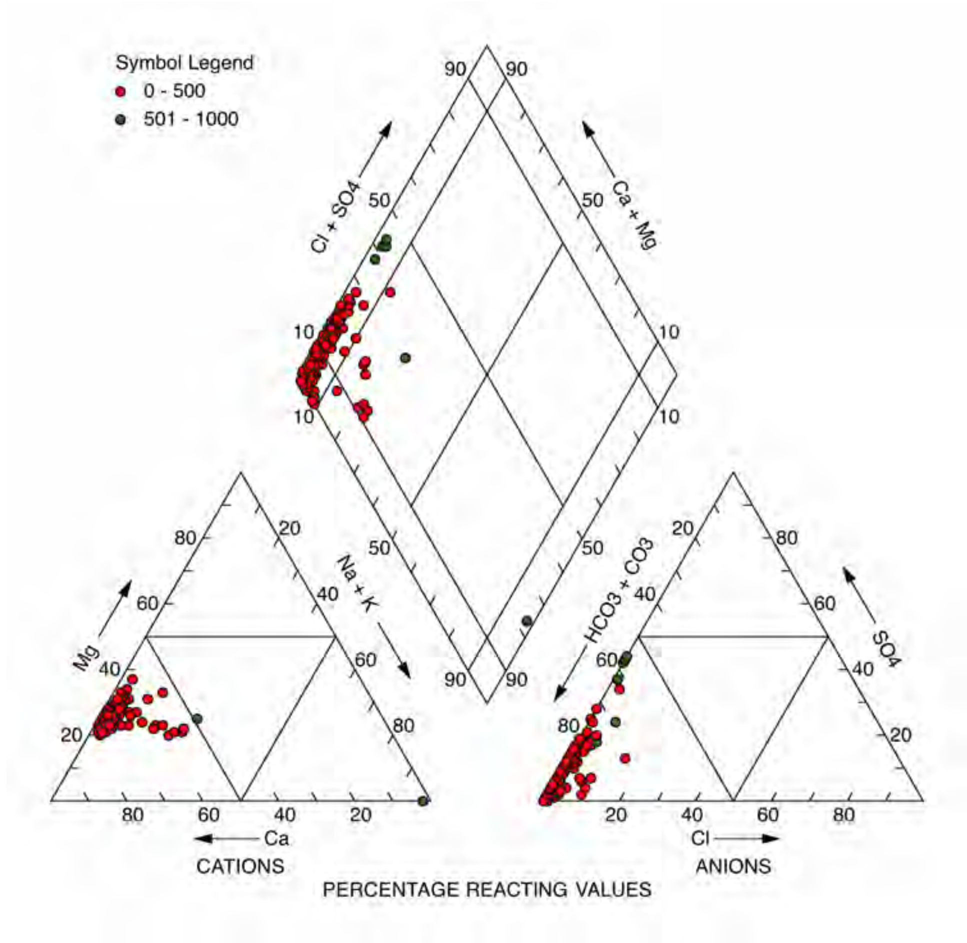


Figure 5.1.1. Piper plot illustrating the relative distribution of anions and cations for water samples collected from the Icelandic aquifer in Pembina County.

### *5.2. Pembina Delta and Pembina River Aquifers (Cavalier and Pembina Counties)*

The Pembina River aquifer underlies about 19 square miles in Pembina County. The Pembina Delta aquifer underlies about 71 square miles in Cavalier and Pembina Counties (Study Area #5 map). The aquifers are contiguous and connected.

<u>Aquifer Composition:</u> According to Hutchinson (1977) the Pembina River aquifer consists predominantly of sand and gravel, interbedded with silt and clay lenses. The saturated thickness is usually less than 35 feet, with an average saturated thickness of about 20 feet. An example of the Pembina River aquifer lithology is shown on Appendix Figure B.5.2.1. The Pembina Delta aquifer consists of very fine to very coarse sand and gravel, interbedded with silt and clay lenses. The depth to the water table varies from about 10 to 150 feet, and the average saturated thickness is about 50 feet. An example of Pembina Delta aquifer lithology is on Appendix Figure B.5.2.1.

<u>Aquifer Yield:</u> Hutchinson (1977) has estimated potential yields from the Pembina River aquifer of up to 250 gpm in properly-constructed fully-penetrating wells, depending on location. Potential yields of up to 50 gpm were estimated for the Pembina Delta aquifer.

<u>Aquifer Chemistry:</u> Water samples from the Pembina River aquifer are fresh, having a range of dissolved solids concentrations ranging from about 300 to as 636 mg/L. Measured and calculated median dissolved solids are 466 and 571 mg/L, respectively (Table 5.2.1) The single water sample for the Pembina Delta aquifer has a dissolved solids concentration similar to the Pembina River aquifer, at about 450 mg/L (Table 5.2.1). The anion and cation distribution is dominantly of the calcium-bicarbonate type, with a few samples having slightly elevated magnesium and/or sulfate (Figure 5.2.1). Iron and manganese concentrations are both high (Table 5.2.3).

<u>Permit Acquisition Status:</u> There are currently two perfected water permits for a total of 561 acre-feet from the Pembina River aquifer, and none for the Pembina Delta aquifer. Two water permits for a total of 561 acre-feet are held by the city of Walhalla. Estimating a conservative one-inch per year recharge rate, and depending on the status of the ADM project, as much as 1,500 to 2,000 acre-feet of water may be available for future development and use.

<u>Additional Considerations:</u> The area of the ADM Corn Processing Permit is mapped as conditional because the proposed beneficial use is on hold. ADM waters may be available in the future for other uses, depending on the ongoing status of the ADM project. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

<u>Citations:</u>

Hutchinson, R.D. 1977. Ground-water Resources of Cavalier and Pembina Counties, North Dakota. County Ground-Water Studies 20-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 37-51.

Table 5.2.1. Summary of chemical properties of the Pembina Delta and Pembina River aquifers in Cavalier and Pembina Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 844 | 417 | - | 7.3 | 302 | 285 | 5.6 | 22 | 46 | 18 | 2.63 | 3.1 | 0 | 207 | 0 | 30 | 2.02 | 0 |
| **Maximum** | 1,439 | 1,550 | - | 8.3 | 636 | 961 | 7.2 | 26 | 199 | 42.4 | 7.4 | 43.4 | 0.5 | 469 | 1 | 264 | 244 | 1.28 |
| **Points** | 12 | 17 | - | 17 | 6 | 17 | 4 | 5 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 16 |
| **Mean** | 981.33 | 936.18 | - | 7.8 | 466.17 | 570.65 | 6.63 | 23.8 | 131.12 | 32.88 | 5.02 | 20.88 | 0.25 | 379.94 | 0.65 | 150.19 | 25.65 | 0.5 |
| **Median** | 920 | 938 | - | 7.8 | 424 | 579 | 6.85 | 24 | 130 | 34 | 5.1 | 21.9 | 0.22 | 399 | 1 | 170 | 10.2 | 0.29 |
| **Std Deviation** | 163.13 | 235.96 | - | 0.23 | 136.17 | 151.81 | 0.71 | 1.79 | 39.99 | 7.55 | 1.48 | 11.69 | 0.11 | 69.06 | 0.49 | 71.5 | 56.69 | 0.44 |
| **Std Error** | 47.09 | 57.23 | - | 0.05 | 55.59 | 36.82 | 0.36 | 0.8 | 9.7 | 1.83 | 0.36 | 2.84 | 0.03 | 16.75 | 0.12 | 17.34 | 13.75 | 0.11 |
| **Pemb-Delta** | - | 682 | - | 7.9 | 457 | 423 | 7.2 | 26 | 115 | 22 | 2.8 | 5.5 | 0 | 408 | 0 | 45 | 3.3 | 1 |

Table 5.2.2. Summary of chemical properties of the Pembina Delta and Pembina River aquifers in Cavalier and Pembina Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 229 | 32 | 281 | 0 | 0.1 | - | 0.23 | - | 1.23 |
| **Maximum** | 672 | 344 | 384 | 364 | 0.93 | - | 0.93 | - | 1.93 |
| **Points** | 17 | 17 | 11 | 17 | 17 | - | 6 | - | 6 |
| **Mean** | 463 | 150.88 | 327.64 | 99.41 | 0.41 | - | 0.68 | - | 1.68 |
| **Median** | 470 | 130 | 327 | 0 | 0.42 | - | 0.71 | - | 1.71 |
| **Std Deviation** | 118.42 | 92.02 | 27.39 | 146.49 | 0.24 | - | 0.25 | - | 0.25 |
| **Std Error** | 28.72 | 22.32 | 8.26 | 35.53 | 0.06 | - | 0.1 | - | 0.1 |
| **Pemb-Delta** | 379 | 44 | | 334 | 0.1 | - | 0.93 | - | 1.93 |

Table 5.2.3. Summary of chemical properties of the Pembina Delta and Pembina River aquifers aquifer in Cavalier and Pembina Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.2 | 2.8 | 4.7 | - | - | - | - | - |
| Maximum | 5 | 16 | 17 | - | - | - | - | - |
| Points | 0.07 | 0.63 | 1.36 | - | - | - | - | - |
| Mean | 0.03 | 0.29 | 0.89 | - | - | - | - | - |
| Median | 0.09 | 0.85 | 1.18 | - | - | - | - | - |
| Std Deviation | 0.04 | 0.21 | 0.29 | - | - | - | - | - |
| Std Error | 0.14 | 0.1 | 0.8 | - | - | - | - | - |

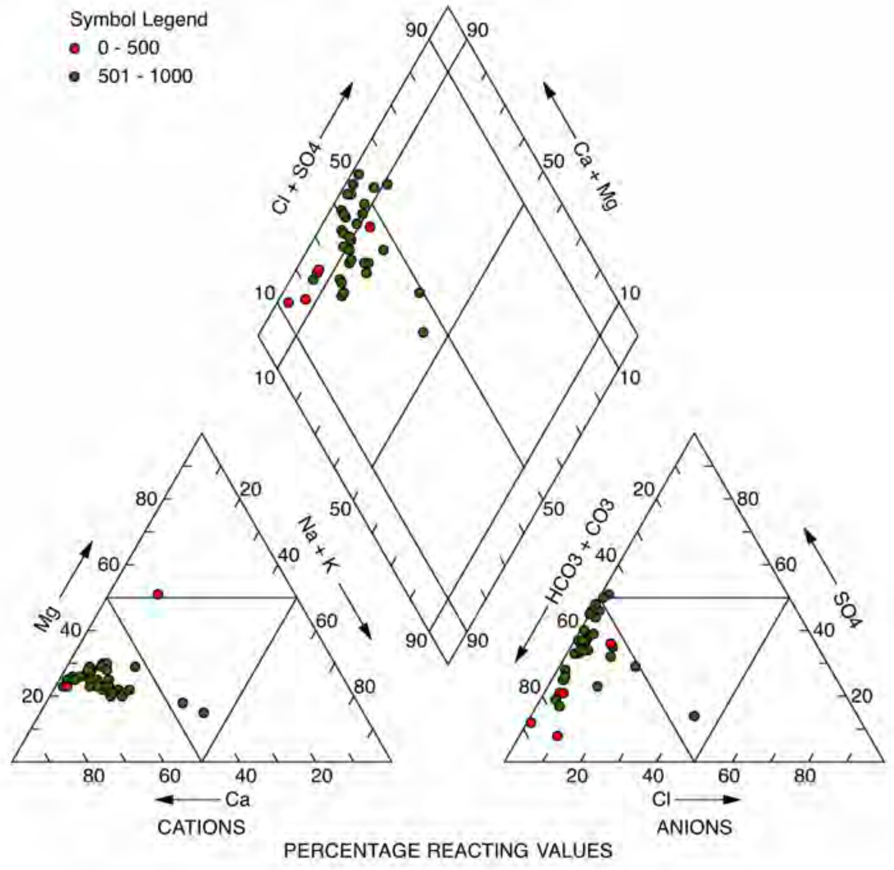
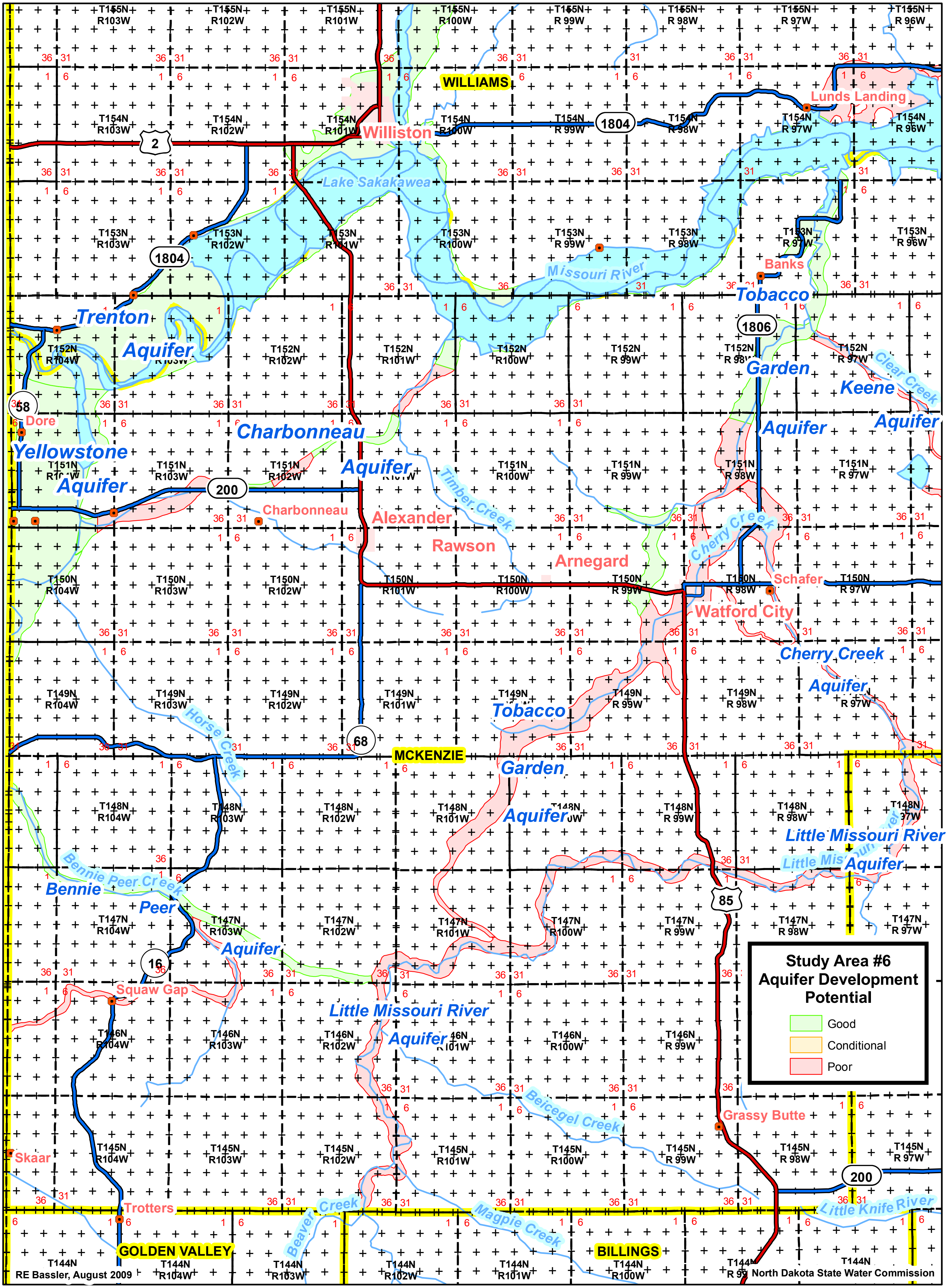


Figure 5.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Pembina Delta and Pembina River aquifers in Cavalier and Pembina Counties.


Study Area #6
Aquifer Development Potential
🟩 Good
🟨 Conditional
🟥 Poor
WILLIAMS
MCKENZIE
GOLDEN VALLEY
BILLINGS
Williston
Lunds Landing
Banks
Tobacco
Lake Sakakawea
Missouri River
Trenton Aquifer
Yellowstone Aquifer
Charbonneau Aquifer
Tobacco Garden Aquifer
Keene Aquifer
Cherry Creek Aquifer
Little Missouri River Aquifer
Bennie Peer Aquifer
Dore
Charbonneau
Alexander
Rawson
Arnegard
Schafer
Watford City
Squaw Gap
Grassy Butte
Skaar
Trotters
Clear Creek
Timber Creek
Cherry Creek
Horse Creek
Bennie Peer Creek
Little Missouri River
Beicegel Creek
Beaver Creek
Magpie Creek
Little Knife River
2
1804
1806
58
200
68
16
85
T155N R103W
T155N R102W
T155N R101W
T155N R100W
T155N R 99W
T155N R 98W
T155N R 97W
T155N R 96W
T144N R104W
T144N R103W
T144N R102W
T144N R101W
T144N R100W
T144N R 99
T144N
RE Bassler, August 2009
North Dakota State Water Commission

## Study Area 6: Northwestern North Dakota / McKenzie and Southern Williams Counties

### *6.1. Bennie Peer Aquifer (McKenzie County), North Dakota*

The Bennie Peer aquifer is a long narrow glaciofluvial deposit in the valleys of Bennie Peer and West and East Hay Draw Creeks from the Montana state line near Sidney to the Little Missouri River (Croft, 1985). Their location is shown on the Study Area #6 map. The aquifer is about 22 miles long and less than a mile wide.

Aquifer Composition: The aquifer consists of up to 70 feet of sand and gravel, mixed with finer sediments. One example of lithology is shown on Appendix Figure B.6.1.1.

Aquifer Yield: Croft (1985) estimated transmissivities ranging from 3,000 to 13,000 ft.$^2$/day, and potential well yields greater than 100 gpm in the central part of the aquifer.

Aquifer Chemistry: Water in the Bennie Peer aquifer has relatively high dissolved solids, ranging from about 2,600 to 5,000 mg/L, with a median of about 3,000 mg/L (Table 6.1.1). The water is mainly of the sodium-sulfate type (Figure 6.1.1). Mean sulfate is about 1,500 mg/L, with a maximum of 2,500 mg/L.

Permit Acquisition Status: There are currently no water permits or pending applications from the Bennie Creek aquifer. Assuming 0.5 to 1 inch annual recharge, about 500 to 1,000 acre-feet of withdrawals may possibly be sustained from this aquifer.

Additional Considerations: Water quality is marginal. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Croft, M.G. 1985. Ground-water Resources of McKenzie County, North Dakota. County Ground-Water Studies 37-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 35-36.

Table 6.1.1. Summary of chemical properties of the Bennie Peer aquifer in McKenzie County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 3,400 | 3,720 | 7.6 | 7.9 | 2,640 | 2,740 | 8.5 | 12 | 44 | 22 | 7.3 | 820 | 0.7 | 955 | 0 | 910 | 6.5 | 1 |
| **Maximum** | 6,300 | 6,060 | 8.75 | 8.4 | 4,970 | 4,880 | 13 | 38 | 150 | 89 | 16 | 1,400 | 4.6 | 1,570 | 14 | 2,400 | 18 | 8.1 |
| **Points** | 6 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **Mean** | 4,400 | 4,403.3 | 7.99 | 8.13 | 3,350 | 3,346.7 | 10 | 23.17 | 94 | 50.33 | 11.25 | 1,011.7 | 1.63 | 1,327.5 | 2.33 | 1,485 | 10.2 | 2.18 |
| **Median** | 3,950 | 4,130 | 8 | 8.1 | 3,050 | 3,030 | 9 | 22 | 86 | 50.5 | 11.5 | 955 | 1.1 | 1,430 | 0 | 1,450 | 9.25 | 1 |
| **Std Deviation** | 1,071.4 | 848.17 | 0.47 | 0.2 | 837.62 | 778.17 | 1.82 | 11.81 | 42.86 | 24.2 | 3.32 | 199.84 | 1.5 | 244.37 | 5.72 | 501.35 | 4.29 | 2.9 |
| **Std Error** | 437.42 | 346.26 | 0.21 | 0.08 | 341.96 | 317.69 | 0.74 | 4.82 | 17.5 | 9.88 | 1.36 | 81.59 | 0.61 | 99.76 | 2.33 | 204.67 | 1.75 | 1.18 |

Table 6.1.2. Summary of chemical properties of the Bennie Peer aquifer in McKenzie County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 200 | 0 | 0 | 783 | 15 | 0.95 | 1.35 | 1.95 | 2.35 |
| **Maximum** | 740 | 0 | 0 | 1,287 | 29 | 1.85 | 1.52 | 2.85 | 2.52 |
| **Points** | 6 | 6 | 0 | 6 | 6 | 5 | 6 | 5 | 6 |
| **Mean** | 441.67 | 0 | 0 | 1,092 | 22 | 1.25 | 1.45 | 2.25 | 2.45 |
| **Median** | 390 | 0 | 0 | 1,172 | 22 | 1.21 | 1.47 | 2.21 | 2.47 |
| **Std Deviation** | 198.74 | 0 | 0 | 203.23 | 4.47 | 0.36 | 0.07 | 0.36 | 0.07 |
| **Std Error** | 81.13 | 0 | 0 | 82.97 | 1.83 | 0.16 | 0.03 | 0.16 | 0.03 |

Table 6.1.3. Summary of chemical properties of the Bennie Peer aquifer in McKenzie County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0.11 | 0.02 | - | - | - | - | - |
| Maximum | 0.29 | 2.6 | 0.24 | - | - | - | - | - |
| Points | 6 | 6 | 6 | - | - | - | - | - |
| Mean | 0.15 | 0.77 | 0.1 | - | - | - | - | - |
| Median | 0.16 | 0.5 | 0.07 | - | - | - | - | - |
| Std Deviation | 0.1 | 0.91 | 0.08 | - | - | - | - | - |
| Std Error | 0.04 | 0.37 | 0.03 | - | - | - | - | - |

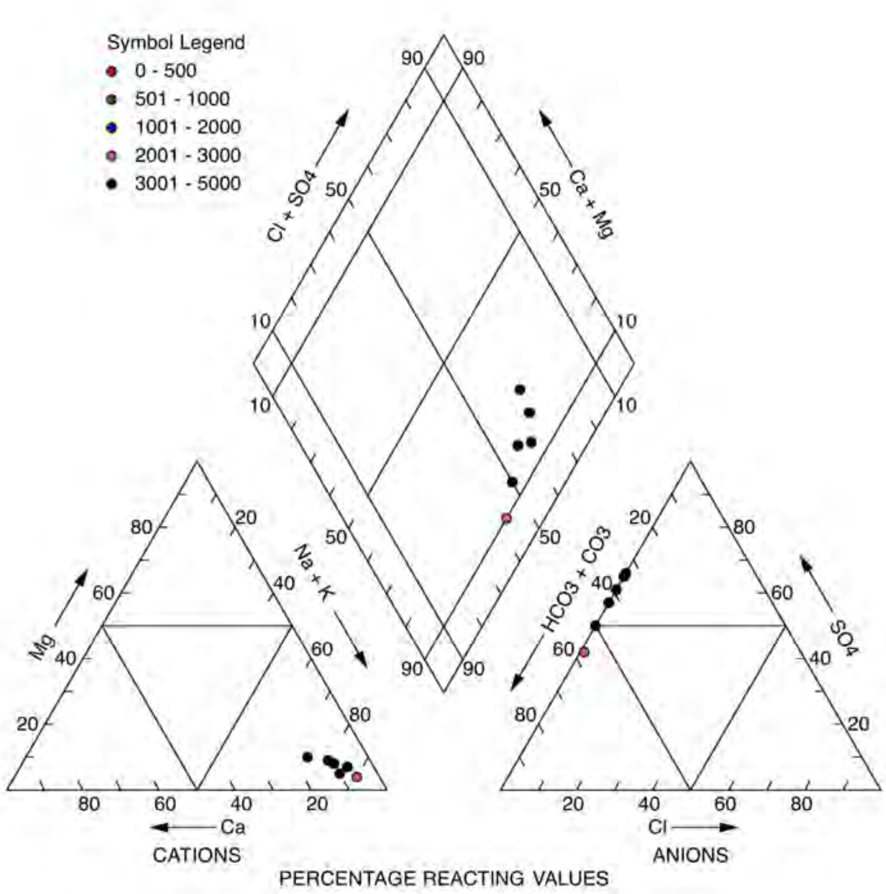


Figure 6.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Bennie Peer aquifer, McKenzie County.

## *6.2. Charbonneau Aquifer (McKenzie County)*

The Charbonneau aquifer is a long, thin aquifer underlying parts of Charbonneau and Timber Creeks from the Yellowstone River bottom near Cartwright to Lake Sakakawea northeast of Alexander (Study Area #6 map). Three segments of the aquifer are indicated to have additional development potential.

Aquifer Composition: The aquifer consists of sand and gravel deposits interbedded with fine materials. One example of the aquifer lithology is shown on Appendix Figure B.6.2.1.

Aquifer Yield: Croft (1985) estimated that well yields in excess of 100 gpm are possible. Several irrigators are pumping at rates greater than 500 gpm.

Aquifer Chemistry: The Charbonneau aquifer is mainly of the calcium and sodium-sulfate, and sodium-sulfate type (Figure 6.2.1). Dissolved solids range from about 900 mg/L to 2,900 mg/L, with a median of 1,300 mg/L (Figure 6.2.1). Iron and manganese are both high (Table 6.2.3).

Permit Acquisition Status: There are currently two conditional and one perfected water permit for 1,230 acre-feet from the area of the Charbonneau aquifer mapped as having good potential for future water-use development. Amounts would likely be limited to a few hundred acre-feet.

Additional Considerations: Water would potentially be available for further development only within the limited areas indicated on the Study Area #6 map. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Croft, M.G. 1985. Ground-water Resources of McKenzie County, North Dakota. County Ground-Water Studies 37-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 36-42.

Table 6.2.1. Summary of chemical properties of the Charbonneau aquifer in McKenzie County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 1,450 | 1,320 | 7.3 | 7.6 | 1,140 | 860 | 9 | 9.5 | 8 | 0 | 5.7 | 196 | 0.18 | 669 | 0 | 48 | 2.55 | 0.09 |
| **Maximum** | 3,300 | 3,720 | 7.3 | 8.6 | 2,860 | 2,720 | 14.4 | 39.7 | 190 | 120 | 10.5 | 697 | 0.94 | 1,777 | 26 | 1,200 | 120 | 110 |
| **Points** | 9 | 10 | 1 | 11 | 3 | 10 | 4 | 9 | 11 | 11 | 10 | 11 | 10 | 11 | 11 | 11 | 11 | 10 |
| **Mean** | 1,964.1 | 2,091 | 7.3 | 8 | 2,181 | 1,447 | 11.88 | 25.24 | 95.35 | 51.98 | 7.85 | 378.09 | 0.54 | 962.18 | 3 | 422.82 | 17.18 | 11.25 |
| **Median** | 1,742 | 1,905 | 7.3 | 8 | 2,543 | 1,300 | 12.05 | 24.6 | 86 | 39.3 | 7.7 | 322 | 0.47 | 878 | 1 | 325 | 4.4 | 0.18 |
| **Std Deviation** | 616.66 | 714.93 | 0 | 0.28 | 915.36 | 571.67 | 2.21 | 9.93 | 62.91 | 36.63 | 1.53 | 178.01 | 0.27 | 294.68 | 7.64 | 341.06 | 34.64 | 34.7 |
| **Std Error** | 205.55 | 226.08 | 0 | 0.08 | 528.48 | 180.78 | 1.11 | 3.31 | 18.97 | 11.05 | 0.48 | 53.67 | 0.09 | 88.85 | 2.3 | 102.83 | 10.45 | 10.97 |

Table 6.2.2. Summary of chemical properties of the Charbonneau aquifer in McKenzie County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 12 | 0 | 592 | 0 | 3.07 | 0.76 | 0.13 | 1.76 | 1.13 |
| **Maximum** | 970 | 310 | 1,458 | 1,457 | 17 | 0.76 | 1.06 | 1.76 | 2.06 |
| **Points** | 11 | 10 | 9 | 11 | 10 | 1 | 3 | 1 | 3 |
| **Mean** | 452 | 31 | 805.33 | 320.18 | 7.89 | 0.76 | 0.66 | 1.76 | 1.66 |
| **Median** | 372 | 0 | 719 | 0 | 6.72 | 0.76 | 0.79 | 1.76 | 1.79 |
| **Std Deviation** | 305.13 | 98.03 | 261.43 | 494.16 | 4.76 | 0 | 0.48 | 0 | 0.48 |
| **Std Error** | 92 | 31 | 87.14 | 148.99 | 1.5 | 0 | 0.28 | 0 | 0.28 |

Table 6.2.3. Summary of chemical properties of the Charbonneau aquifer in McKenzie County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.03 | 0 | 0.01 | - | - | - | - | - |
| Maximum | 0.05 | 3.93 | 0.53 | - | - | - | - | - |
| Points | 2 | 10 | 10 | - | - | - | - | - |
| Mean | 0.04 | 1.03 | 0.2 | - | - | - | - | - |
| Median | 0.04 | 0.21 | 0.15 | - | - | - | - | - |
| Std Deviation | 0.01 | 1.37 | 0.16 | - | - | - | - | - |
| Std Error | 0.01 | 0.43 | 0.05 | - | - | - | - | - |

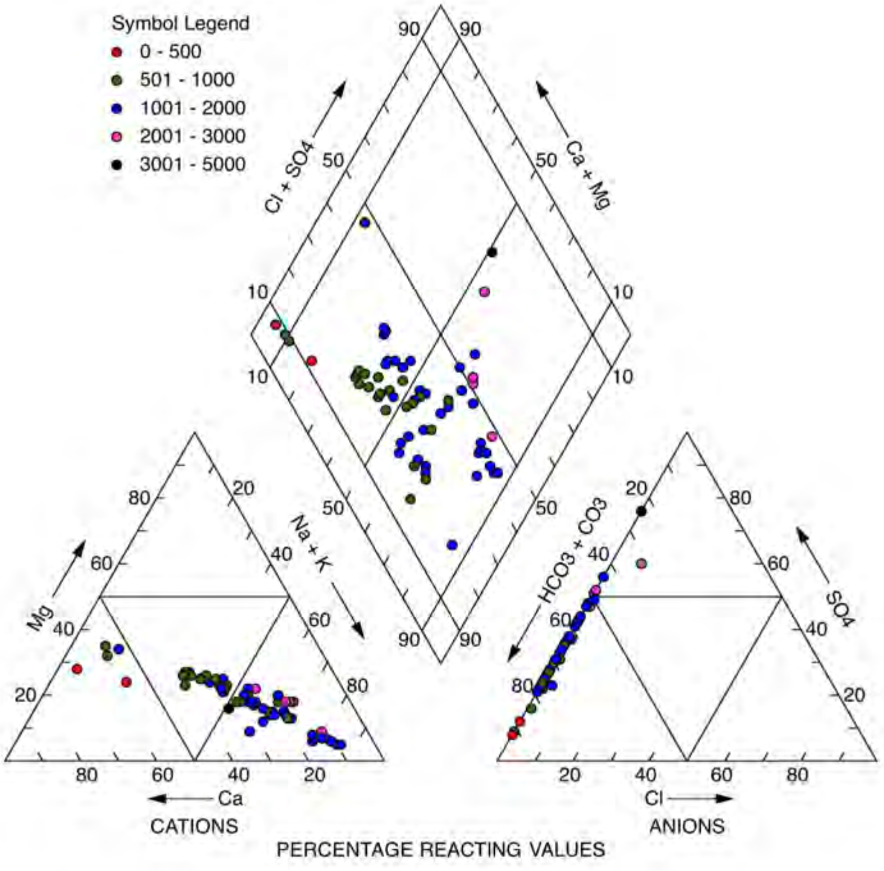


Figure 6.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Charbonneau aquifer in McKenzie County.

### *6.3. Tobacco Garden Aquifer (McKenzie County)*

The Tobacco Garden aquifer is a long narrow aquifer extending from the Little Missouri River northeast of Bennie Peer Creek to Lake Sakakawea south of Lunds Landing. Two segments of the aquifer, including a segment of about 15 miles extending southward from Lake Sakakawea and an arm of the aquifer northwest of Watford City are indicated to have additional development potential (Study Area #6 map).

Aquifer Composition Tobacco Garden Aquifer: The aquifer consists of up to 90 feet of sand and gravel interbedded with clay beds. Two examples of the aquifer lithology are shown on Appendix Figures B.6.3.1 and B.6.3.2.

Aquifer Yield: Croft (1985) reported transmissivities ranging from 7,000 to 19,900 $\text{ft.}^2$/day and a hydraulic conductivity exceeding 500 ft./day of one site. Well yields in excess of 500 gpm are possible in some areas.

Aquifer Chemistry: Water samples from the Tobacco Garden aquifer in areas of potential development are mainly of the sodium-bicarbonate type. Dissolved solids concentrations range from about 850 to 2,900 mg/L, with a median of 1,300 mg/L (Table 6.3.1). Iron and manganese are both high.

Permit Acquisition Status: There are currently four water permits, two perfected, one conditional and one application in processing, for a total of 472 acre-feet in the areas of the Tobacco Garden and Tobacco Garden Creek aquifers that are designated as having good potential for water-use development. An estimated several hundred acre-feet per year of water would potentially be available for further development only within the limited areas indicated suitable for further development in Study Area #6.

Additional Considerations: **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Croft, M.G. 1985. Ground-water Resources of McKenzie County, North Dakota. County Ground-Water Studies 37-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 36-42.

Table 6.3.1. Summary of chemical properties of the Tobacco Garden aquifer in McKenzie County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 700 | 787 | 7.4 | 7.3 | 467 | 490 | 8 | 11 | 3 | 1 | 2 | 110 | 0.2 | 424 | | 71 | 0 | |
| **Maximum** | 3,320 | 3,760 | 8.65 | 8.69 | 3,530 | 3,330 | 11.9 | 24 | 610 | 190 | 20 | 755 | 1.1 | 1,220 | | 2,100 | 42 | |
| **Points** | 28 | 28 | 9 | 28 | 17 | 28 | 13 | 13 | 28 | 28 | 28 | 28 | 28 | 28 | | 28 | 28 | |
| **Mean** | 1,904.3 | 2,092.6 | 7.94 | 8.03 | 1,362.1 | 1,389.2 | 9.72 | 18.83 | 72.62 | 35.49 | 7.78 | 386.57 | 0.53 | 808.46 | | 515.5 | 5.68 | |
| **Median** | 1,938 | 1,975 | 7.93 | 8.03 | 1,190 | 1,255 | 9 | 20.5 | 46.8 | 30.6 | 7.28 | 388 | 0.49 | 825.5 | | 414.5 | 4.26 | |
| **Std Deviation** | 719.7 | 863.5 | 0.4 | 0.26 | 744.59 | 662.08 | 1.4 | 5.3 | 108.9 | 33.17 | 3.61 | 189.67 | 0.24 | 244.98 | | 442.39 | 7.82 | |
| **Std Error** | 5.1797e+05 | 7.4562e+05 | 0.16 | 0.07 | 5.5441e+05 | 4.3836e+05 | 1.97 | 28.05 | 11,859 | 1,100.1 | 13.01 | 35,974 | 0.06 | 60,017 | | 1.9571e+05 | 61.08 | |

Table 6.3.2. Summary of chemical properties of the Tobacco Garden aquifer in McKenzie County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 12 | 0 | 405 | | 1 | 0 | 0.2 | 1 | 1.2 |
| **Maximum** | 2,300 | 1,800 | 1,000 | | 49 | 1.67 | 1.52 | 2.67 | 2.52 |
| **Points** | 28 | 28 | 11 | | 28 | 5 | 17 | 5 | 17 |
| **Mean** | 326.96 | 64.29 | 702.82 | | 11.95 | 0.77 | 0.87 | 1.77 | 1.87 |
| **Median** | 241.5 | 0 | 733 | | 10.45 | 0.92 | 0.89 | 1.92 | 1.89 |
| **Std Deviation** | 403.45 | 340.17 | 201.34 | | 8.94 | 0.73 | 0.4 | 0.73 | 0.4 |
| **Std Error** | 1.6277e+05 | 1.1571e+05 | 40,539 | | 79.89 | 0.53 | 0.16 | 0.53 | 0.16 |

Table 6.3.3. Summary of chemical properties of the Tobacco Garden aquifer in McKenzie County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.03 | 0.02 | 0.01 | - | - | - | - | - |
| Maximum | 0.4 | 3.78 | 0.89 | - | - | - | - | - |
| Points | 9 | 28 | 28 | - | - | - | - | - |
| Mean | 0.22 | 0.65 | 0.32 | - | - | - | - | - |
| Median | 0.23 | 0.4 | 0.28 | - | - | - | - | - |
| Std Deviation | 0.13 | 0.89 | 0.21 | - | - | - | - | - |
| Std Error | 0.02 | 0.8 | 0.05 | - | - | - | - | - |

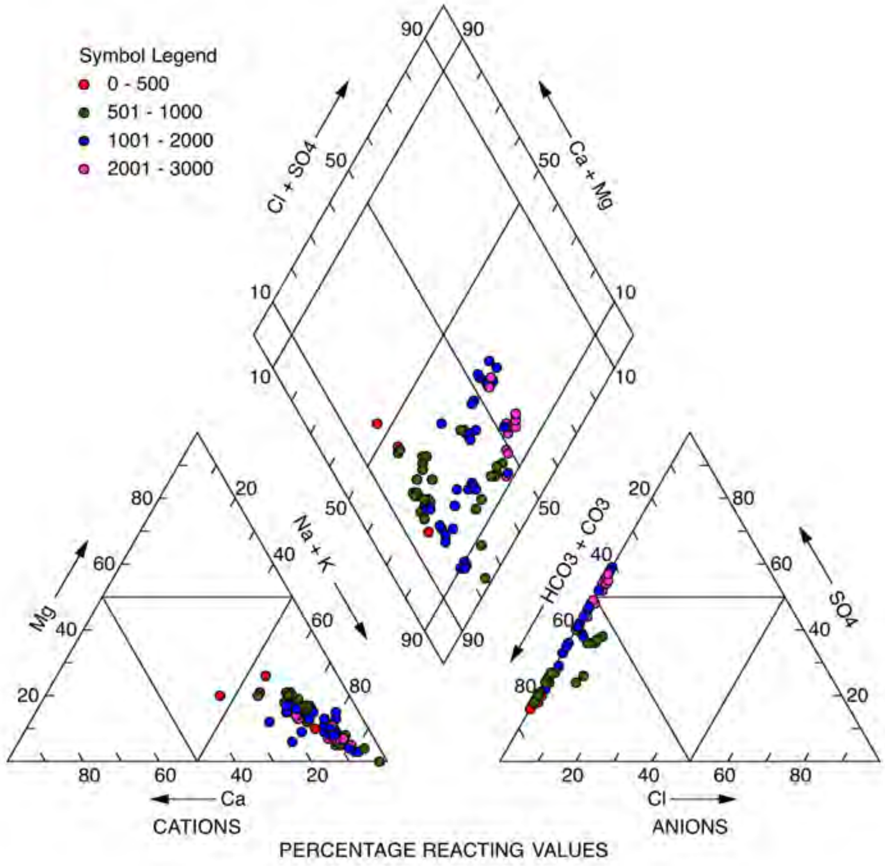


Figure 6.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Tobacco Garden aquifer in McKenzie County.

### *6.4. Yellowstone-Missouri-Trenton River Valley (YMT) Aquifer System (McKenzie and Williams Counties)*

The combined Yellowstone-Missouri-Trenton aquifer (YMT) occupies the Yellowstone River valley in North Dakota and the Missouri River valley between the North Dakota-Montana border and Williston. The valley aquifer underlying the south, or McKenzie County side of the Missouri River between the Montana border and Williston is called the Yellowstone-Missouri aquifer, while essentially the same aquifer north of the Missouri River is called the Trenton aquifer (Study Area #6 map).

Aquifer Composition: Components of the combined aquifer system have a similar depositional history and a similar composition. They consist of alluvial and glaciofluvial sand or sand and gravel. The stratigraphy consists of a mixture of alluvium and coarser outwash. Generally alluvium in the uppermost 20 feet or so consists of silt, clay and fine sand. Underlying material is coarser, but is interbedded with silt and clay lenses. Two examples of local lithology are shown in Appendix Figures B.6.4.1 and B.6.4.2.

Aquifer Yield: According to Wanek,[129] hydraulic characteristics were measured for an 80 feet thick deposit in the southern portion of the North Dakota segment of the aquifer system. The transmissivity was about 15,000 ft.$^2$/day, with a hydraulic conductivity of slightly less than 200 ft./day. Storativity values indicated leaky confined conditions. According to Croft (1985) well yields of more than 500 gpm might be expected in some areas.

Aquifer Chemistry**:** A comparison of dissolved ion distributions in the Trenton and Yellowstone-Missouri segments of the aquifer system indicated no substantial difference in solute composition (Figure 6.4.1), so the data were combined for statistical analysis. Dissolved solids concentrations in the YMT aquifer system range between about 400 to 5,000 mg/L, with a median of about 1,000 mg/L (Table 6.4.1). Anion and cation distributions vary from a calcium and sodium-bicarbonate type and sodium-bicarbonate type, to a sodium-sulfate type (Figure 6.4.1). Higher TDS water tends to be more sulfatic. Sulfate and TDS are strongly correlated, and sulfate accounts for about half of all increased TDS mass as TDS increases. Iron and manganese content are both high (Table 6.4.3). There is no relationship between dissolved solids and depth. The strongest relationship with lower concentrations of dissolved solids is proximity to the Missouri or Yellowstone Rivers.

Permit Acquisition Status: There are currently 21 water permits, including 13 perfected permits, seven conditional permits, and one with 111 acre-feet held in abeyance, for a total of 5,391 acre-feet from the area mapped as having good potential for future water-use development. Other than the permit held in abeyance, there are no pending

---

[129] Wanek, Alan. Sept. 2, 2009. Written communication.

applicants. The best opportunities for additional beneficial use will be near the Yellowstone or Missouri Rivers, where recharge is most abundant. Potential applicants should consult with the managing hydrologist for the area for further guidance. Near the Yellowstone and Missouri Rivers, water levels follow the river stages, indicating a recharge source. In these areas, the potential for additional ground-water appropriation is substantial.

Additional Considerations: Both the quality and quantity of water available will be best nearest the rivers, where recharge from the rivers can be induced by pumping. Siting of supply wells near the rivers may be difficult in some areas, because of encroachment from Lake Sakakwea when the reservoir fills. Several thousand acre-feet of water may be available for recharge near the Missouri River, depending on the location and proximity of connections with the Missouri River. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Croft, M.G. 1985. Ground-water Resources of McKenzie County, North Dakota. County Ground-Water Studies 37-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 46-48.

Table 6.4.1. Summary of chemical properties of the Yellowstone-Missouri-Trenton aquifer system in Williams County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 650 | 671 | 7.5 | 7.08 | 394 | 416 | 6.1 | 5.9 | 2.5 | 0.5 | 0.5 | 7.7 | 0 | 193 | 0 | 2.5 | 1.6 | 0 |
| **Maximum** | 4,350 | 5,800 | 8.35 | 8.7 | 4,730 | 4,620 | 15.8 | 44.1 | 320 | 130 | 28.1 | 1,290 | 3.7 | 1,670 | 120 | 2,500 | 150 | 120 |
| **Points** | 117 | 140 | 15 | 138 | 99 | 135 | 49 | 78 | 140 | 140 | 133 | 146 | 133 | 142 | 142 | 142 | 142 | 142 |
| **Mean** | 1,574.6 | 1,723.3 | 7.84 | 7.69 | 1,334.9 | 1,182.7 | 8.82 | 22.34 | 130.37 | 50.22 | 8.19 | 212.56 | 0.48 | 637.26 | 1.32 | 447.98 | 17.61 | 3.65 |
| **Median** | 1,416 | 1,510 | 7.8 | 7.7 | 1,130 | 992 | 8.5 | 22 | 118 | 47.5 | 7.9 | 157.5 | 0.36 | 634 | 0 | 332 | 13.7 | 0.21 |
| **Std Deviation** | 686.93 | 878.98 | 0.3 | 0.27 | 828.11 | 730.96 | 1.73 | 6.31 | 65.61 | 23.87 | 3.75 | 201.94 | 0.41 | 234.68 | 10.21 | 417.07 | 17.53 | 12.31 |
| **Std Error** | 63.51 | 74.29 | 0.08 | 0.02 | 83.23 | 62.91 | 0.25 | 0.71 | 5.55 | 2.02 | 0.32 | 16.71 | 0.04 | 19.69 | 0.86 | 35 | 1.47 | 1.03 |

Table 6.4.2. Summary of chemical properties of the Yellowstone-Missouri-Trenton aquifer system in Williams County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 8 | 0 | 192 | 0 | 0.12 | 0.35 | -0.9 | 1.35 | 0.1 |
| **Maximum** | 1,300 | 1,000 | 1,260 | 1,369 | 51 | 1.37 | 1.8 | 2.37 | 2.8 |
| **Points** | 146 | 133 | 53 | 104 | 137 | 13 | 87 | 13 | 87 |
| **Mean** | 527.84 | 86.65 | 496.58 | 505.63 | 4.52 | 1 | 0.89 | 2 | 1.88 |
| **Median** | 498.5 | 26 | 465 | 525.5 | 2.7 | 1.13 | 0.92 | 2.13 | 1.92 |
| **Std Deviation** | 250.34 | 144.61 | 195.39 | 243.77 | 6.05 | 0.33 | 0.38 | 0.33 | 0.38 |
| **Std Error** | 20.72 | 12.54 | 26.84 | 23.9 | 0.52 | 0.09 | 0.04 | 0.09 | 0.04 |

Table 6.4.3. Summary of chemical properties of the Yellowstone-Missouri-Trenton aquifer system in McKenzie and Williams Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 0.01 | 3 | 0.1 | 5 | 100 | 3 |
| Maximum | 0.52 | 24 | 3 | 3 | 0.1 | 5 | 100 | 3 |
| Points | 67 | 135 | 121 | 1 | 1 | 1 | 1 | 1 |
| Mean | 0.17 | 3.32 | 0.76 | 3 | 0.1 | 5 | 100 | 3 |
| Median | 0.15 | 2.2 | 0.65 | 3 | 0.1 | 5 | 100 | 3 |
| Std Deviation | 0.14 | 3.81 | 0.63 | 0 | 0 | 0 | 0 | 0 |
| Std Error | 0.02 | 0.33 | 0.06 | 0 | 0 | 0 | 0 | 0 |

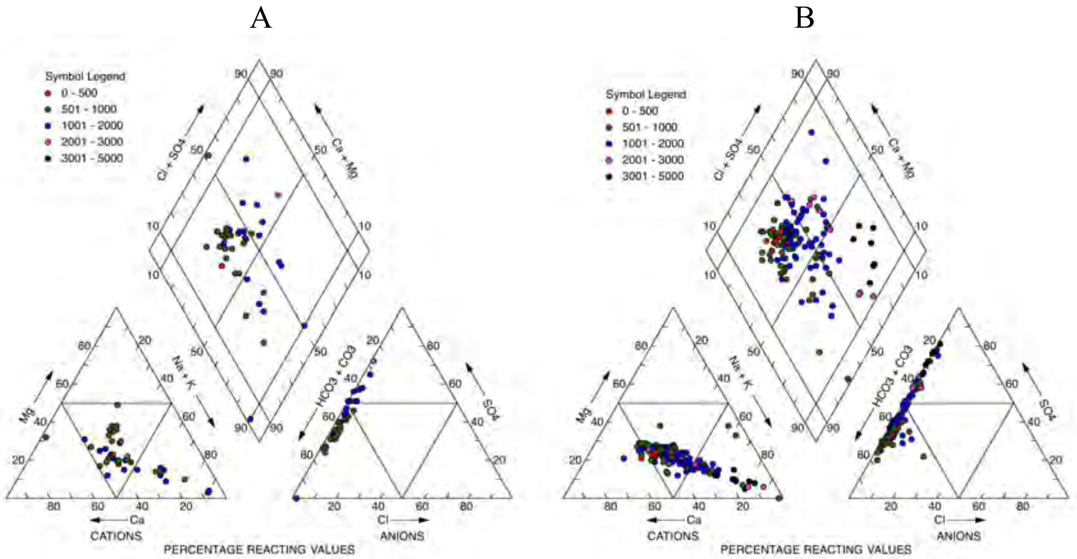
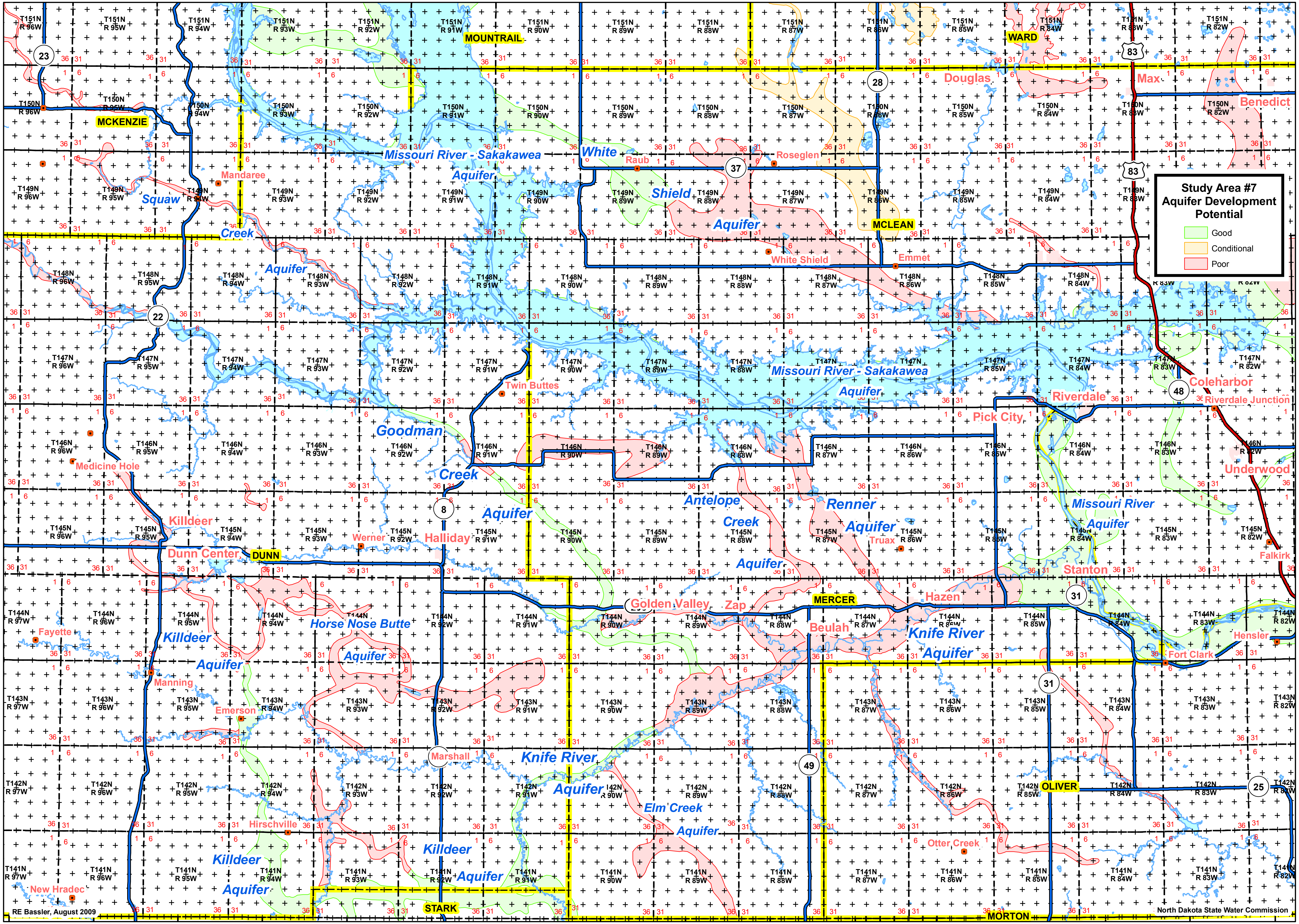


Figure 6.4.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Yellowstone-Missouri River aquifer system (A) and the Trenton aquifer (B) in McKenzie and Williams Counties, North Dakota.



RE Bassler, August 2009

North Dakota State Water Commission

## Study Area 7: West Central North Dakota / Dunn, McKenzie, McLean, Mercer and Oliver Counties

### *7.1 Goodman Creek Aquifer (Dunn and Mercer Counties)*

The Goodman Creek aquifer is a long narrow glaciofluvial deposit, about one-half to one mile wide, extending from Wolf Chief Bay near the confluence of the Little Missouri River and Lake Sakakawea in Dunn County, southeastward along Hans Creek and Goodman Creek to the Knife River near the city of Golden Valley in Mercer County (Study Area #7 map).

Aquifer Composition: The aquifer consists of up to 200 feet of sand and gravel interbedded with alluvial silt and clay. The aquifer is overlain by as much as 40 feet of alluvium. Lithologic descriptions are very similar to other nearby aquifers, including the Knife River, Killdeer, Missouri River, and White Shield aquifers. A sample lithology is shown on Appendix Figure B.7.1.1. Conditions are both confined and unconfined.

Aquifer Yield: Croft (1973) estimated potential well yields at 100 to 500 gpm. Transmissivities and storage coefficients have not been measured but may be compared to those of the Knife River aquifer (described below in Section 7.3).

Aquifer Chemistry: Water samples from the Goodman Creek aquifer are mainly of the calcium and sodium-bicarbonate type and sodium-bicarbonate type, with some samples of the sodium-sulfate type (Figure 7.1.1). Dissolved solids concentrations range from about 400 to 2,300 mg/L, with a median of 1,114 mg/L (Table 7.1.1). Increasing dissolved solids are highly correlated with and consist mainly (74%) of increasing sodium (36% of increase) and sulfate (38% of increase). There is no correlation with depth. Concentrations of both iron and manganese are high. Water quality is very similar to that of the Knife River aquifer, the Missouri River aquifer and the White Shield aquifer in the same study area.

Permit Acquisition Status: There is currently only one water permit for the Goodman Creek aquifer, for which 250 acre-feet have been requested, 100 acre-feet have been granted, and 150 acre-feet are held in abeyance. There are no water permits or applications in the good development potential areas on Study Area #7 map. Assuming a conservative half-inch per year of recharge, small amounts of water, up to about 500 acre-feet per year may be available for beneficial use from the Goodman Creek aquifer.

Additional Considerations: **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Croft, M.G. 1973. Ground-water Resources of Mercer and Oliver Counties, North Dakota. County Ground-Water Studies 15-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 42-48.

Table 7.1.1. Summary of chemical properties of the Goodman Creek aquifer in Dunn and Mercer Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 140 | 110 | 7 | 6.5 | 514 | 68 | 6 | 11 | 4.72 | 2.9 | 1 | 13.7 | 0.1 | 62 | 0 | 0.49 | 0.4 | 0 |
| **Maximum** | 2,530 | 2,640 | 7 | 8.4 | 2,100 | 2,250 | 15 | 31 | 180 | 126 | 8.4 | 489 | 1.1 | 717 | 9 | 1,190 | 78 | 2.5 |
| **Points** | 21 | 22 | 1 | 22 | 21 | 22 | 21 | 21 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 22 | 21 |
| **Mean** | 1,341.2 | 1,405.5 | 7 | 7.9 | 1,006 | 978.41 | 8.81 | 21.81 | 79.53 | 39.59 | 6.22 | 207.44 | 0.54 | 555.73 | 0.45 | 340.52 | 8.97 | 0.77 |
| **Median** | 1,220 | 1,300 | 7 | 8 | 869 | 861.5 | 7.7 | 22 | 73 | 33 | 6.4 | 205 | 0.5 | 596.5 | 0 | 245 | 2.55 | 1 |
| **Std Deviation** | 542.32 | 567.17 | 0 | 0.39 | 422.13 | 481.31 | 2.4 | 4.64 | 37.37 | 24.85 | 1.84 | 110.6 | 0.24 | 141.18 | 1.92 | 295.83 | 17.97 | 0.7 |
| **Std Error** | 294,110 | 321,680 | 0 | 0.15 | 1.7819e+05 | 2.3166e+05 | 5.78 | 21.56 | 1,396.3 | 617.46 | 3.37 | 12,232 | 0.06 | 19,931 | 3.69 | 87,516 | 322.96 | 0.49 |

Table 7.1.2. Summary of chemical properties of the Goodman Creek aquifer in Dunn and Mercer Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 24 | 0 | 51 | 0 | 1 | - | 0.44 | - | 1.44 |
| **Maximum** | 968 | 491 | 51 | 603 | 8.6 | - | 1.36 | - | 2.36 |
| **Points** | 22 | 22 | 1 | 22 | 22 | - | 21 | - | 21 |
| **Mean** | 362.23 | 34.36 | 51 | 453.86 | 4.72 | - | 0.96 | - | 1.96 |
| **Median** | 325 | 0 | 51 | 489 | 5.15 | - | 0.97 | - | 1.97 |
| **Std Deviation** | 187.35 | 111.53 | 0 | 125.14 | 2.12 | - | 0.24 | - | 0.24 |
| **Std Error** | 35,098 | 12,439 | 0 | 15,660 | 4.47 | - | 0.06 | - | 0.06 |

Table 7.1.3. Summary of chemical properties of the Goodman Creek aquifer in Dunn and Mercer Counties: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 0.01 | - | - | - | - | - |
| Maximum | 0.62 | 9.6 | 1.2 | - | - | - | - | - |
| Points | 22 | 22 | 22 | - | - | - | - | - |
| Mean | 0.23 | 0.93 | 0.3 | - | - | - | - | - |
| Median | 0.23 | 0.24 | 0.17 | - | - | - | - | - |
| Std Deviation | 0.15 | 2.03 | 0.31 | - | - | - | - | - |
| Std Error | 0.02 | 4.11 | 0.09 | - | - | - | - | - |

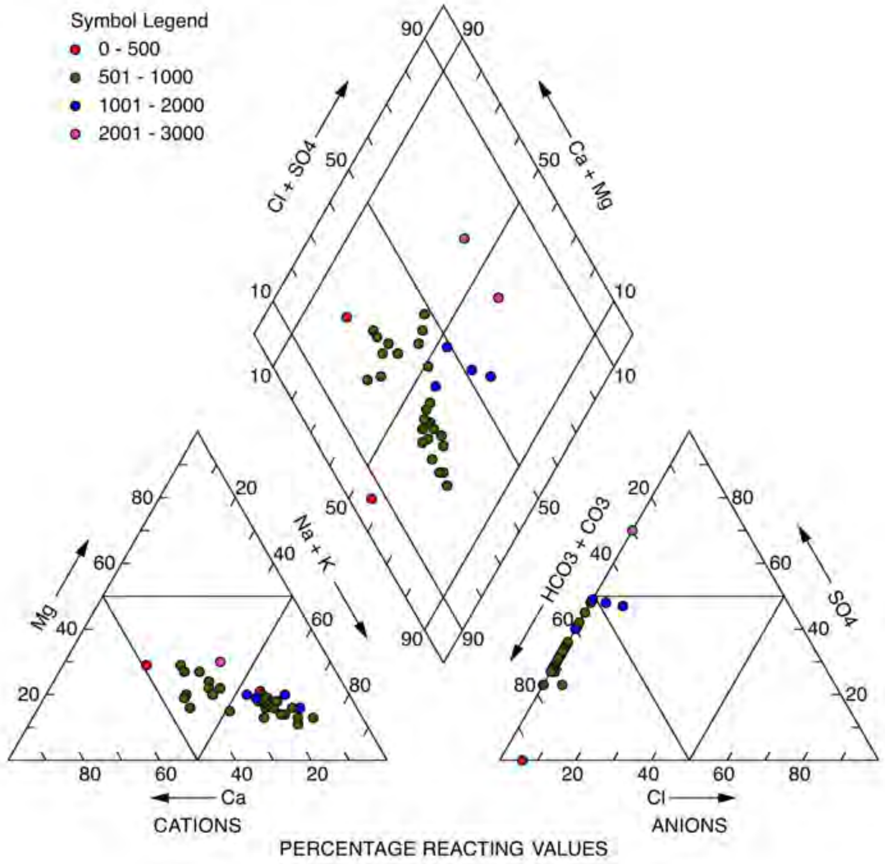


Figure 7.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Goodman Creek aquifer in Dunn and Mercer Counties.

### *7.2 Killdeer Aquifer (Dunn, Morton and Stark Counties)*

The Killdeer aquifer is the south-westernmost glaciofluvial aquifer in North Dakota, extending from a few miles north of he city of Killdeer into northwestern Morton County where it joins with the Elm Creek aquifer (Study Area #7 map). The area mapped as having potential for further water-use development underlies about 70 square miles.

Aquifer Composition: The aquifer, as described for Morton County (Klausing 1979, Wanek 2009), consists of up to 233 feet of fine and medium sand, with some gravel interbedded with silt and clay. The mean thickness is about 80 feet (Klausing 1979). Two examples of the aquifer lithology are shown on Appendix Figures B.7.2.1, B.7.2.2, and B.7.2.3.

Aquifer Yield: An aquifer test two miles west of the city of Killdeer indicated a transmissivity of 10,000 $ft.^2$/day and a storativity of 0.02, in a channel estimated at 2,000 feet wide. The aquifer is overlain by about 20 feet of finer alluvial material, and pumping would therefore transition to unconfined conditions near a well. Pumping rates of about 300 gpm are achieved in the Killdeer area. Outside of the Killdeer area information on the aquifer is sparse (Wanek 2009). Klausing (1979) estimated potential aquifer yields ranging from 50 gpm to as much as 1,000 gpm, depending on location.

Aquifer Chemistry: Water in the Killdeer aquifer in areas of potential development is mainly of the sodium-bicarbonate and sodium-sulfate type (Figure 7.2.1). There is no correlation between sulfate and depth. Dissolved solids concentrations vary from about 450 mg/L to 2,300 mg/L, with a median of 2,550 mg/L (Table 7.2.1). Increasing dissolved solids are strongly related to increased sulfate (60%) and sodium (23%). These account for about 83% of increased dissolved solids. Dissolved solids concentrations generally increase in a southerly direction along the course of the aquifer. Iron and manganese concentrations are high (Table 7.2.3). Killdeer aquifer waters have higher dissolved solids and are more sulfatic in some areas than those of other nearby aquifers (Goodman Creek aquifer, Knife River aquifer).

Permit Acquisition Status: There are currently ten water permits, for a total of 952 acre-feet from the Killdeer aquifer. Three are perfected, four are conditionally approved, three have been partially granted, with 735 acre-feet held in abeyance, and there are two applications in process for 484 acre-feet. However, the only permitted water use from the "good potential" area of the Killdeer aquifer is near the southeast end of the aquifer, two miles east of Glen Ullin, where there is an industrial water permit for 20 acre-feet. An estimated several hundred acre-feet per year, perhaps as much as 1,500 acre-feet per year of water (using a half inch per year recharge rate) may potentially be available for further development.

Additional Considerations: The water quality is described as poorer (higher in dissolved solids), south of Manning. The cities of Hebron and Glen Ullin, before switching to the Southwest Water Authority for their municipal water supply, opted for water from Fox Hills-Hell Creek aquifer rather than from the Killdeer aquifer.

**Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Klausing, Robert L. 1979. Ground-water Resources of Dunn County, North Dakota. County Ground-Water Studies 25-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 30-31.

Wanek, Alan. Sept. 1, 2009. Ground water availability in western North Dakota. North Dakota State Water Commission Office Memorandum. pp. 8-10.

Table 7.2.1. Summary of chemical properties of the Killdeer aquifer in Dunn, Morton and Stark Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 670 | 717 | 0 | 7.7 | 421 | 456 | 6.7 | 16 | 22 | 7.8 | 4.2 | 50 | 0.3 | 343 | 0 | 110 | 0 | 0 |
| **Maximum** | 5,275 | 5,900 | 0 | 8.5 | 5,030 | 5,060 | 13 | 25 | 570 | 160 | 17 | 1,200 | 2.7 | 1,490 | 23 | 3,000 | 17 | 2.5 |
| **Points** | 18 | 21 | 0 | 19 | 21 | 21 | 21 | 15 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| **Mean** | 3,064.3 | 3,088 | 0 | 8.1 | 2,350.1 | 2,324.5 | 8.91 | 21.4 | 115.67 | 56.9 | 9.5 | 601.33 | 0.86 | 902.14 | 3.1 | 1,070.4 | 4.75 | 1.1 |
| **Median** | 3,350 | 3,540 | 0 | 8.1 | 2,550 | 2,560 | 8.7 | 22 | 72 | 44 | 8.7 | 650 | 0.7 | 892 | 0 | 1,100 | 4.2 | 1 |
| **Std Deviation** | 1,234.6 | 1,262.7 | 0 | 0.23 | 1,110 | 1,090.9 | 1.62 | 2.72 | 121.4 | 42.08 | 3.78 | 306.28 | 0.53 | 300.42 | 6.28 | 678.42 | 4.22 | 0.6 |
| **Std Error** | 291 | 275.54 | 0 | 0.05 | 242.23 | 238.06 | 0.35 | 0.7 | 26.49 | 9.18 | 0.82 | 66.84 | 0.12 | 65.56 | 1.37 | 148.04 | 0.92 | 0.13 |

Table 7.2.2. Summary of chemical properties of the Killdeer aquifer in Dunn, Morton and Stark Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 87 | 0 | - | 281 | 1.3 | - | 0.68 | - | 1.68 |
| **Maximum** | 2,100 | 1,600 | - | 1,240 | 43 | - | 1.76 | - | 2.76 |
| **Points** | 21 | 21 | - | 21 | 21 | - | 19 | - | 19 |
| **Mean** | 523.71 | 119 | - | 744.52 | 13.81 | - | 1.27 | - | 2.27 |
| **Median** | 335 | 0 | - | 731 | 12 | - | 1.25 | - | 2.25 |
| **Std Deviation** | 464.96 | 359.32 | - | 250.17 | 9.48 | - | 0.31 | - | 0.31 |
| **Std Error** | 101.46 | 78.41 | - | 54.59 | 2.07 | - | 0.07 | - | 0.07 |

Table 7.2.3. Summary of chemical properties of the Killdeer aquifer in Dunn, Morton and Stark Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 0.02 | - | - | - | - | - |
| Maximum | 1 | 5.5 | 3.7 | - | - | - | - | - |
| Points | 15 | 21 | 21 | - | - | - | - | - |
| Mean | 0.41 | 0.7 | 0.42 | - | - | - | - | - |
| Median | 0.43 | 0.31 | 0.08 | - | - | - | - | - |
| Std Deviation | 0.3 | 1.24 | 0.82 | - | - | - | - | - |
| Std Error | 0.08 | 0.27 | 0.18 | - | - | - | - | - |

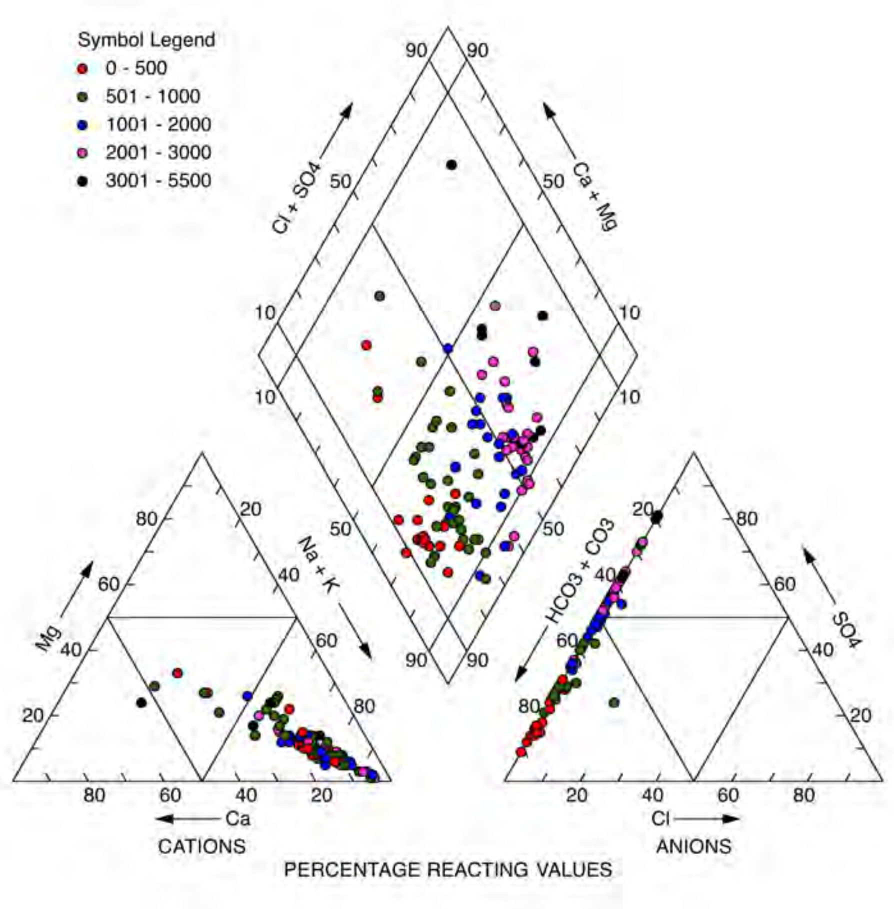


Figure 7.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Killdeer aquifer in Dunn, Morton and Stark Counties.

### *7.3. Knife River Aquifer (Dunn and Mercer Counties)*

The Knife River aquifer is a long narrow aquifer underlying the Knife River valley from southeastern Dunn County through southern Mercer County to the confluence of the Knife River with the Missouri River (Study Area #7 map). The area mapped as having good potential for development includes about 18 square miles.

Aquifer Composition: The aquifer consists of up to 140 feet of sand and gravel interbedded with clay beds. The mean thickness is about 60 feet Klausing (1979). One example of the aquifer lithology is shown on Appendix Figure B.7.3.1.

Aquifer Yield: Croft (1973) reported transmissivities ranging from 6,700 and 8,000 $ft.^2$/day from aquifer tests near Beulah, to 23,100 $ft.^2$/day from an aquifer test near Stanton. The latter test had a storage coefficient of 0.0003, characteristic of a confined system. Croft estimated that wells might yield from 100 to 500 gpm in Mercer County, while Klausing estimated potential well yields of 50 to 1,000 gpm in Dunn County.

Aquifer Chemistry: Aquifer chemistry for water in the Knife River aquifer is similar to that of the Goodman Creek aquifer, ranging from the calcium-bicarbonate type to a sodium-bicarbonate type (Figure 7.3.1). The range of dissolved solids concentrations is also similar, having a range of about 400 mg/L to 2,300 mg/L, and a median of 1,113 mg/L (Table 7.3.1). Higher dissolved solids concentrations are strongly correlated with increasing sodium and sulfate. Iron and magnesium are both high (Table 7.3.3).

Permit Acquisition Status: There are currently 14 water permits for a total of 5,333 acre-feet from the Knife River aquifer, of which 11 are perfected, two are conditional, and one is held partially in abeyance with 205 acre-feet remaining to be granted. Within the area designated as having good potential for further development, there are two water permits granted or pending for a total of 413.5 acre-feet. Assuming a conservative recharge value of about 0.5 inches per year, up to 300 acre-feet per year of water may be available for development in the southwestern reaches of the Knife River (see Study Area #7 map).

Additional Considerations: The recharge limitation is based on the assumption that drawing more recharge from the overlying Knife River is undesirable. A larger amount of water may be available for development near Stanton, where the Knife River aquifer may be augmented by recharge water from the Missouri River, or direct interaction with the Missouri River aquifer. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Croft, M.G. 1973. Ground-water Resources of Mercer and Oliver Counties, North Dakota. County Ground-Water Studies 15-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 50-58.

Klausing, Robert L. 1979. Ground-water Resources of Dunn County, North Dakota. County Ground-Water Studies 25-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 36-38.

Table 7.3.1. Summary of chemical properties of the Knife River aquifer system in Dunn and Mercer Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 601 | 607 | 0 | 6.9 | 431 | 376 | 7 | 10 | 21 | 8 | 1.04 | 12.6 | 0.08 | 316 | 0 | 20 | 0 | 0 |
| **Maximum** | 2,600 | 3,040 | 0 | 8.4 | 2,280 | 2,330 | 12 | 30 | 184 | 61 | 12 | 670 | 1.5 | 1,790 | 19 | 1,090 | 15 | 2.5 |
| **Points** | 28 | 32 | 0 | 32 | 15 | 32 | 11 | 9 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| **Mean** | 1,393 | 1,417.6 | 0 | 8 | 1,113.9 | 919.34 | 8.68 | 19.89 | 73.99 | 30.01 | 5.47 | 223.72 | 0.49 | 709.97 | 1.38 | 218.57 | 5.61 | 0.53 |
| **Median** | 1,300.5 | 1,305 | 0 | 8 | 1,090 | 809 | 8.8 | 17 | 69.65 | 29.05 | 5.19 | 181.5 | 0.41 | 656.5 | 1 | 147.5 | 4.5 | 0.25 |
| **Std Deviation** | 532.63 | 590.53 | 0 | 0.31 | 584.68 | 441.96 | 1.36 | 7.37 | 31.65 | 11.63 | 2.25 | 173.51 | 0.35 | 323.64 | 3.36 | 223.71 | 3.9 | 0.56 |
| **Std Error** | 100.66 | 104.39 | 0 | 0.05 | 150.96 | 78.13 | 0.41 | 2.46 | 5.59 | 2.06 | 0.4 | 30.67 | 0.06 | 57.21 | 0.59 | 39.55 | 0.69 | 0.1 |

Table 7.3.2. Summary of chemical properties of the Knife River aquifer system in Dunn and Mercer Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 86 | 0 | 265 | 0 | 0.29 | 0 | -0.21 | 0 | 0.79 |
| **Maximum** | 653 | 117 | 643 | 1,467 | 31 | 0 | 1.38 | 0 | 2.38 |
| **Points** | 32 | 32 | 17 | 32 | 32 | 0 | 15 | 0 | 15 |
| **Mean** | 308.03 | 6.16 | 511.12 | 337.28 | 6.45 | 0 | 0.92 | 0 | 1.92 |
| **Median** | 289.5 | 0 | 536 | 297 | 4.39 | 0 | 1.09 | 0 | 2.09 |
| **Std Deviation** | 119.33 | 22.56 | 100.28 | 411.54 | 6.8 | 0 | 0.45 | 0 | 0.45 |
| **Std Error** | 21.09 | 3.99 | 24.32 | 72.75 | 1.2 | 0 | 0.12 | 0 | 0.12 |

Table 7.3.3. Summary of chemical properties of the Knife River aquifer in Dunn and Mercer Counties: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 0.01 | - | - | - | - | - |
| Maximum | 0.44 | 12 | 0.91 | - | - | - | - | - |
| Points | 9 | 32 | 32 | - | - | - | - | - |
| Mean | 0.23 | 1.35 | 0.26 | - | - | - | - | - |
| Median | 0.21 | 0.68 | 0.21 | - | - | - | - | - |
| Std Deviation | 0.14 | 2.22 | 0.21 | - | - | - | - | - |
| Std Error | 0.05 | 0.39 | 0.04 | - | - | - | - | - |

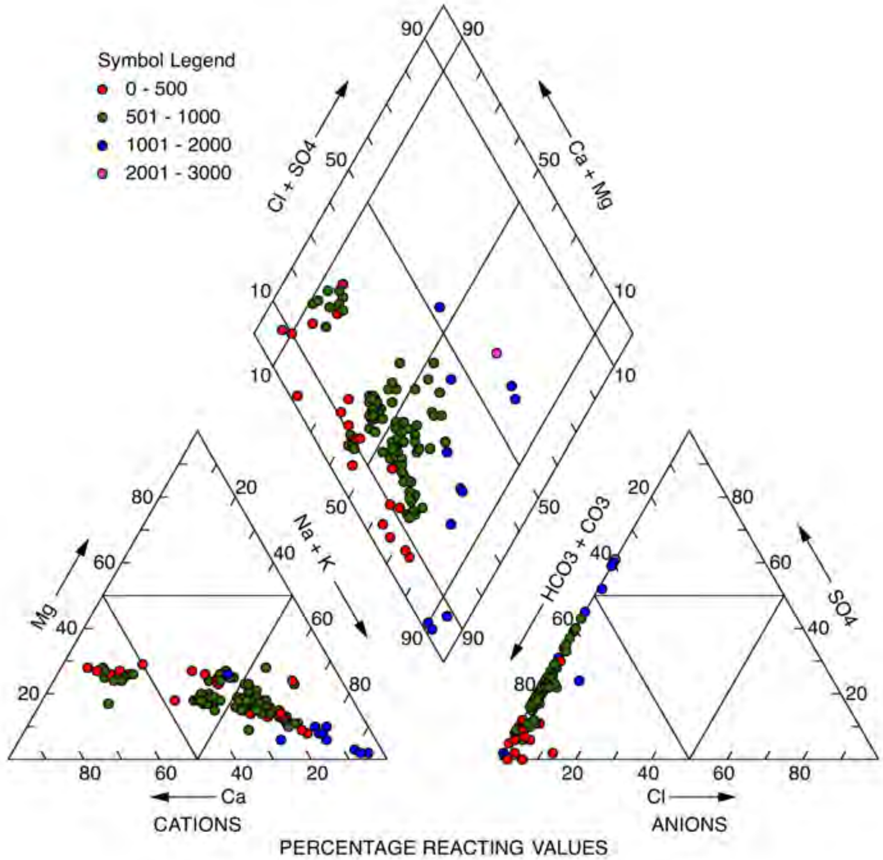


Figure 7.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Knife River aquifer in Dunn and Mercer Counties.

### *7.4. Missouri River Aquifer (Burleigh, McLean, Mercer, Morton and Oliver Counties)*

The entire Missouri River valley is underlain by glaciofluvial and alluvial sediments that could be considered as a single aquifer. About three-fourths of the valley, however, lie beneath Lake Sakakawea and Lake Oahe. What may be practically considered as the modern Missouri River aquifer in central North Dakota underlies about 75 linear miles of the Missouri Valley between the Garrison Dam and the north end of Lake Oahe (Study Area #7 and #11 maps). Of this, after removal of the area occupied by the Missouri River itself, the aquifer may be estimated to underlie about 110 square surface miles.

The Missouri River aquifer label here includes several subunits that have previously been given different labels. These have been summarized by Wanek (2009) as follows:

> "In Mercer and Oliver Counties the glacial aquifer in the Missouri River valley is called the Missouri River aquifer. However, in McLean, Burleigh, and Morton Counties the aquifer in the Missouri River valley is given a different name, generally each time the river meanders across the valley. In McLean County, segments of the aquifer in the Missouri River valley are known as the Riverdale aquifer, the Fort Mandan aquifer, the Buffalo Creek aquifer, and Painted Woods Creek aquifer. In Burleigh County the Glenview, Wagonsport, Burnt Creek, and (South) Bismarck aquifers occupy the Missouri River valley. In Morton County the aquifer in the Missouri River valley south of Mandan is included with the Heart River aquifer, and the aquifer in the Missouri River valley for a few miles downstream of where Square Butte Creek enters the Missouri River valley is included with the Square Butte Creek aquifer, which, like the Heart River aquifer, extends to the west."

<u>Aquifer Composition</u>: The aquifer consists of up to 100 feet of glaciofluvial sand and gravel overlain by finer aluvium. According to Wanek (2009) the aquifer skeleton tends to be finer near the surface and grades to coarser and more gravelly material with depth. Two examples of lithologies are provided on Appendix Figures B.7.4.1 and B.7.4.2.

<u>Aquifer Yield</u>: Wanek (2009) reported that a transmissivity of 12,500 ft.$^2$/day was measured from an aquifer test near Hensler, under initially confined conditions, which later progressed to unconfined or leaky confined conditions. A transmissivity of 26,000 ft.$^2$/day was measured from an aquifer test near Painted Woods Lake, initially under confined conditions (S = 0.00045). Croft (1973) estimated that well yields in excess of 500 gpm were expected from the aquifer north of Hensler.

<u>Aquifer Chemistry:</u> According to Wanek (2009), aquifer chemistry would be expected to resemble Missouri River water near the river, and water from surrounding bedrock and other boundary materials farther from the river. Water samples collected from 44 wells in the group of aquifers comprising the Missouri River aquifer varied from a calcium sodium-bicarbonate type to a sodium-bicarbonate type (Figure 7.4.1). Dissolved solids concentrations ranged from about 500 to 3,700 mg/L (Table 7.4.1) with a median of 1,210 mg/L. Increasing dissolved solids are strongly related to increasing sulfate and

sodium, which increases with distance from the river, and at depths near the base of the aquifer. Arsenic is low. Iron and manganese are high (Table 7.4.3).

Permit Acquisition Status: All aquifers named within the Missouri River Valley were combined under the Missouri River aquifer classification for evaluation of water permits (Appendix F). There are currently 40 water permits, 29 perfected and nine conditional, with one new pending application from the Missouri River aquifer, for a total of 12,936 acre-feet. These include water permits listed as the Bismarck aquifer (12 permits), the Burnt Creek aquifer (9 permits), the Heart River aquifer (within the Missouri River valley – 3 permits), and the Wagonsport aquifer (1 permit). Given the unique characteristic of this aquifer, being recharged by the Missouri River, there should be good potential for further water use and development from the Missouri River aquifer system, with best potential and the best quality water obtainable closer to the river. Development potential and water quality are likely to be less optimal with distance from the river. The applicant should consult the State Water Commission managing hydrologist for the area for further information on possible local interference with prior appropriators.

Additional Considerations: Land use and zoning along the Missouri River valley may restrict development of the valley aquifers. Cost, water quality, and access may be considerations when comparing accessing the Missouri River to accessing the aquifers in the river valley. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Croft, M.G. 1973. Ground-water Resources of Mercer and Oliver Counties, North Dakota. County Ground-Water Studies 15-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 58-67.

Wanek, Alan. Sept. 1, 2009. Ground water availability in western North Dakota. North Dakota State Water Commission Office Memorandum. pp. 15-16.

Table 7.4.1. Summary of chemical properties of the Missouri River aquifer system in Burleigh, McLean, Mercer, Morton and Oliver Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 810 | 728 | 7.5 | 7.3 | 456 | 474 | 7 | 14 | 1.1 | 2.4 | 3.4 | 7 | 0 | 242 | 0 | 3.3 | 0.1 | 0 |
| **Maximum** | 3,700 | 3,990 | 7.5 | 8.4 | 3,780 | 3,670 | 11.1 | 28.8 | 514 | 288 | 17 | 906 | 1.1 | 1,380 | 44 | 2,310 | 675 | 7.1 |
| **Points** | 17 | 44 | 1 | 39 | 37 | 41 | 19 | 37 | 38 | 38 | 38 | 41 | 36 | 39 | 39 | 39 | 39 | 39 |
| **Mean** | 1,578.9 | 1,733 | 7.5 | 7.9 | 1,209.3 | 1,187.9 | 8.82 | 22.74 | 117.6 | 48.45 | 7.33 | 249.06 | 0.43 | 784.72 | 1.41 | 297.83 | 51.67 | 1.24 |
| **Median** | 1,388 | 1,685 | 7.5 | 7.9 | 1,210 | 1,190 | 8.9 | 23 | 110 | 37.4 | 7.05 | 245 | 0.4 | 779 | 0 | 229 | 14 | 1 |
| **Std Deviation** | 749.08 | 660.62 | 0 | 0.25 | 572.46 | 540.75 | 1.19 | 4.19 | 91.29 | 46.99 | 3.18 | 187.56 | 0.26 | 272.17 | 7.07 | 356.01 | 120.62 | 1.63 |
| **Std Error** | 181.68 | 99.59 | 0 | 0.04 | 94.11 | 84.45 | 0.27 | 0.69 | 14.81 | 7.62 | 0.52 | 29.29 | 0.04 | 43.58 | 1.13 | 57.01 | 19.32 | 0.26 |

Table 7.4.2. Summary of chemical properties of the Missouri River aquifer system in Burleigh, McLean, Mercer, Morton and Oliver Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 17 | 0 | 478 | 0 | 1.4 | 0.85 | -0.75 | 1.85 | 0.25 |
| **Maximum** | 1,930 | 1,540 | 640 | 1,131 | 78 | 0.85 | 1.63 | 1.85 | 2.63 |
| **Points** | 44 | 37 | 5 | 44 | 42 | 1 | 33 | 1 | 33 |
| **Mean** | 456 | 51.81 | 566.2 | 507.73 | 8.77 | 0.85 | 1 | 1.85 | 2 |
| **Median** | 443.5 | 0 | 590 | 547.5 | 4.4 | 0.85 | 1.04 | 1.85 | 2.04 |
| **Std Deviation** | 282.69 | 253.27 | 79.91 | 347.77 | 15.52 | 0 | 0.42 | 0 | 0.42 |
| **Std Error** | 42.62 | 41.64 | 35.74 | 52.43 | 2.39 | 0 | 0.07 | 0 | 0.07 |

Table 7.4.3. Summary of chemical properties of the Missouri River aquifer in Burleigh, McLean, Mercer, Morton and Oliver Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | nd | nd | 0.03 | nd | nd | 6 | 50 | 4 |
| Maximum | 1.3 | 15 | 1.4 | nd | nd | 6 | 50 | 4 |
| Points | 36 | 39 | 28 | 1 | 1 | 1 | 1 | 1 |
| Mean | 0.39 | 3.62 | 0.31 | - | - | 6 | 50 | 4 |
| Median | 0.21 | 3.4 | 0.26 | - | - | 6 | 50 | 4 |
| Std Deviation | 0.4 | 3.18 | 0.31 | - | - | - | - | - |
| Std Error | 0.07 | 0.51 | 0.06 | - | - | - | - | - |

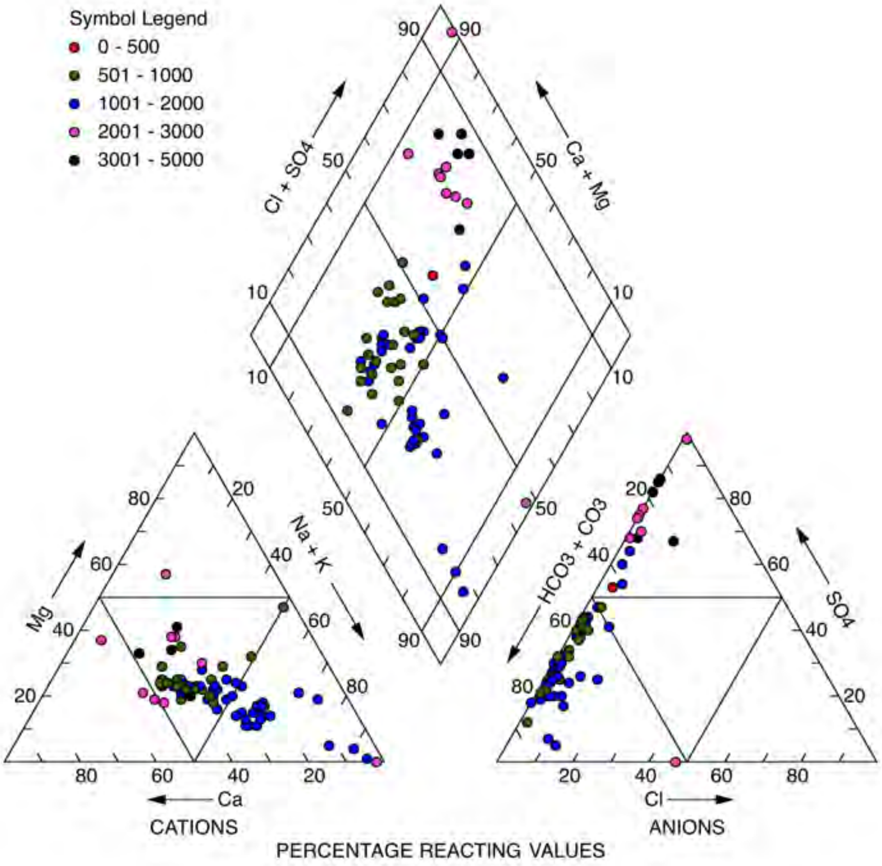


Figure 7.4.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Missouri River aquifer in Burleigh, McLean, Mercer, Morton and Oliver Counties.

### *7.5. White Shield Aquifer (McLean and Mountrail Counties)*

The White Shield aquifer occupies a bedrock valley formed by an interglacial diversion of the Missouri River (Klausing, 1974) and extends along a line from Lake Sakakawea Near Emmet, northwestward to Lake Sakakawea near Raub, then under the Lake and northwestward to the Missouri River on approximately the same line (Study Area #7 map). The portion of the aquifer having potential for further development includes about 60 square miles near and northwest of Raub.

<u>Aquifer Composition White Shield Aquifer:</u> According to Klausing (1974) the aquifer consists of about 18 to 226 feet of interbedded and intermixed sand, silt and gravel. The mean thickness is about 100 feet. The thickest coarse beds are usually near the bottom. Two examples of lithologies are shown on Appendix Figures B.7.5.1 and B.7.5.2.

<u>Aquifer Yield:</u> Klausing (1974) reported transmissivities ranging from 5,300 ft.$^2$/day in a thin-aquifer area near White Shield, to an estimated transmissivity of about 21,000 ft.$^2$/day in areas of maximum thickness. Well yields in excess of 500 gpm are possible in some areas. Wells should be capable of yielding up to 1,000 gpm in some areas of the aquifer.

<u>Aquifer Chemistry</u>: Water in samples from the White Shield aquifer in areas of potential further development are mainly of the sodium-bicarbonate type with some approximating a sodium-sulfate type (Figure 7.5.1). Dissolved solids concentrations for water samples from 23 wells range from about 350 to 3,900 mg/L, with a median of 1,040 mg/L (Table 7.5.1). Iron and manganese concentrations are both high (Table 7.5.3). The water chemistry is similar to the Missouri River aquifer.

<u>Permit Acquisition Status:</u> There are currently 13 water permits, all perfected, for about 3,800 acre-feet per year of water from the White Shield aquifer. Only one conditional water permit for 250 acre-feet is located in the area designated on the Study Area #7 map as having “good potential” for further development. There are no competing water permit applications. Because of proximity to, and interaction with Lake Sakakawea, there should be potential for substantial further water-use development, perhaps as much several thousand acre-feet, especially near the lake.

<u>Additional Considerations:</u> Issues of access on tribal lands of the Three Affiliated Tribes, and in some cases, Corps of Engineers lands and jurisdictions need to be considered. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

<u>Citations:</u>

Klausing, Robert L. 1974. Ground-water Resources of McLean County, North Dakota. County Ground-Water Studies 19-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 33-37.

Table 7.5.1. Summary of chemical properties of the White Shield aquifer in McLean and Mountrail Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 710 | 570 | 0 | 7.5 | 342 | 369 | 6.1 | 5.11 | 7.48 | 15 | 3.5 | 13 | 0 | 328 | NA | 37 | 0 | NA |
| **Maximum** | 4,000 | 4,450 | 0 | 9.1 | 3,810 | 3,880 | 12.2 | 31 | 246 | 191 | 9.5 | 731 | 1.26 | 928 | NA | 2,280 | 35 | NA |
| **Points** | 19 | 23 | 0 | 23 | 11 | 23 | 9 | 20 | 23 | 23 | 23 | 23 | 23 | 23 | NA | 23 | 23 | NA |
| **Mean** | 1,645.5 | 1,683.9 | 0 | 8.1 | 1,229.4 | 1,140.2 | 9.74 | 24.37 | 79.71 | 49.95 | 6.98 | 253.7 | 0.41 | 623.26 | NA | 440.7 | 6.19 | NA |
| **Median** | 1,491 | 1,530 | 0 | 8.1 | 1,040 | 1,010 | 11 | 26 | 79 | 48 | 6.98 | 211 | 0.4 | 637 | NA | 339 | 4.3 | NA |
| **Std Deviation** | 672.92 | 823.8 | 0 | 0.31 | 993.29 | 715.17 | 2.1 | 5.75 | 42.66 | 32.97 | 1.53 | 171.58 | 0.24 | 136.92 | NA | 457.17 | 7.2 | NA |
| **Std Error** | 154.38 | 171.77 | 0 | 0.06 | 299.49 | 149.12 | 0.7 | 1.28 | 8.9 | 6.87 | 0.32 | 35.78 | 0.05 | 28.55 | NA | 95.33 | 1.5 | NA |

Table 7.5.2. Summary of chemical properties of the White Shield aquifer in McLean and Mountrail Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 141 | 0 | 442 | NA | 0.3 | 0 | 0.62 | 0 | 1.62 |
| **Maximum** | 1,400 | 745 | 696 | NA | 18 | 0 | 1.56 | 0 | 2.56 |
| **Points** | 23 | 23 | 12 | NA | 23 | 0 | 11 | 0 | 11 |
| **Mean** | 404.26 | 35.3 | 529.25 | NA | 5.65 | 0 | 1 | 0 | 2 |
| **Median** | 390 | 0 | 518 | NA | 4.71 | 0 | 1.03 | 0 | 2.03 |
| **Std Deviation** | 233.42 | 155.07 | 65.72 | NA | 3.7 | 0 | 0.27 | 0 | 0.27 |
| **Std Error** | 48.67 | 32.33 | 18.97 | NA | 0.77 | 0 | 0.08 | 0 | 0.08 |

Table 7.5.3. Summary of chemical properties of the White Shield aquifer in McLean and Mountrail Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0.02 | 0.01 | - | - | - | - | - |
| Maximum | 0.55 | 8.6 | 0.84 | - | - | - | - | - |
| Points | 9 | 23 | 20 | - | - | - | - | - |
| Mean | 0.23 | 0.89 | 0.11 | - | - | - | - | - |
| Median | 0.18 | 0.28 | 0.07 | - | - | - | - | - |
| Std Deviation | 0.2 | 1.83 | 0.18 | - | - | - | - | - |
| Std Error | 0.07 | 0.38 | 0.04 | - | - | - | - | - |

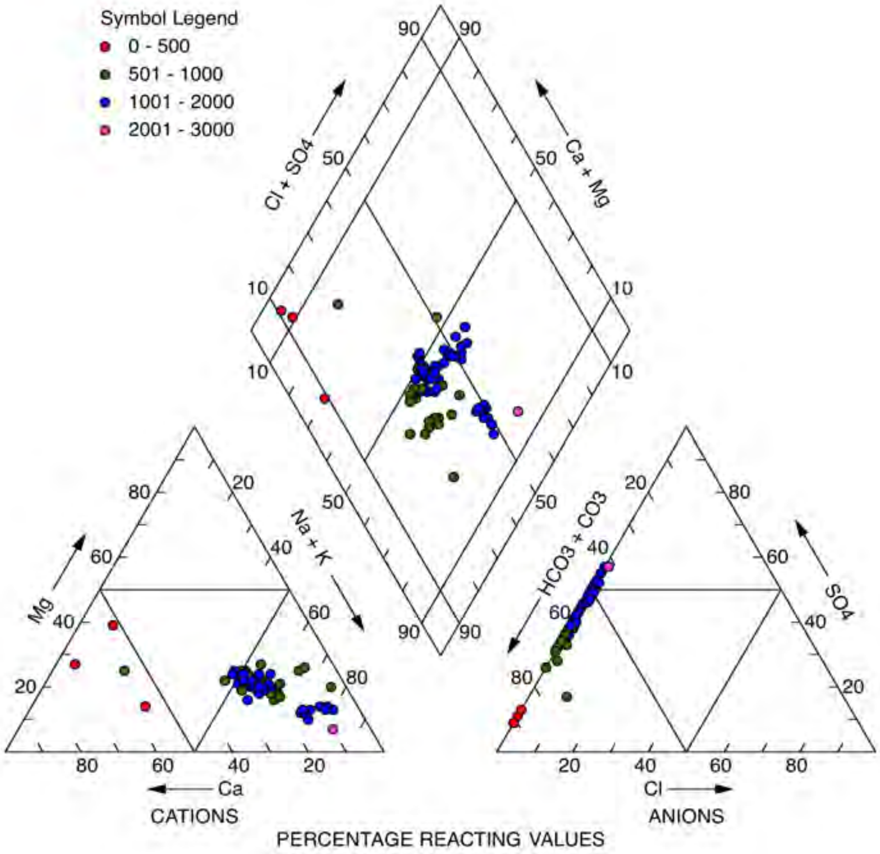
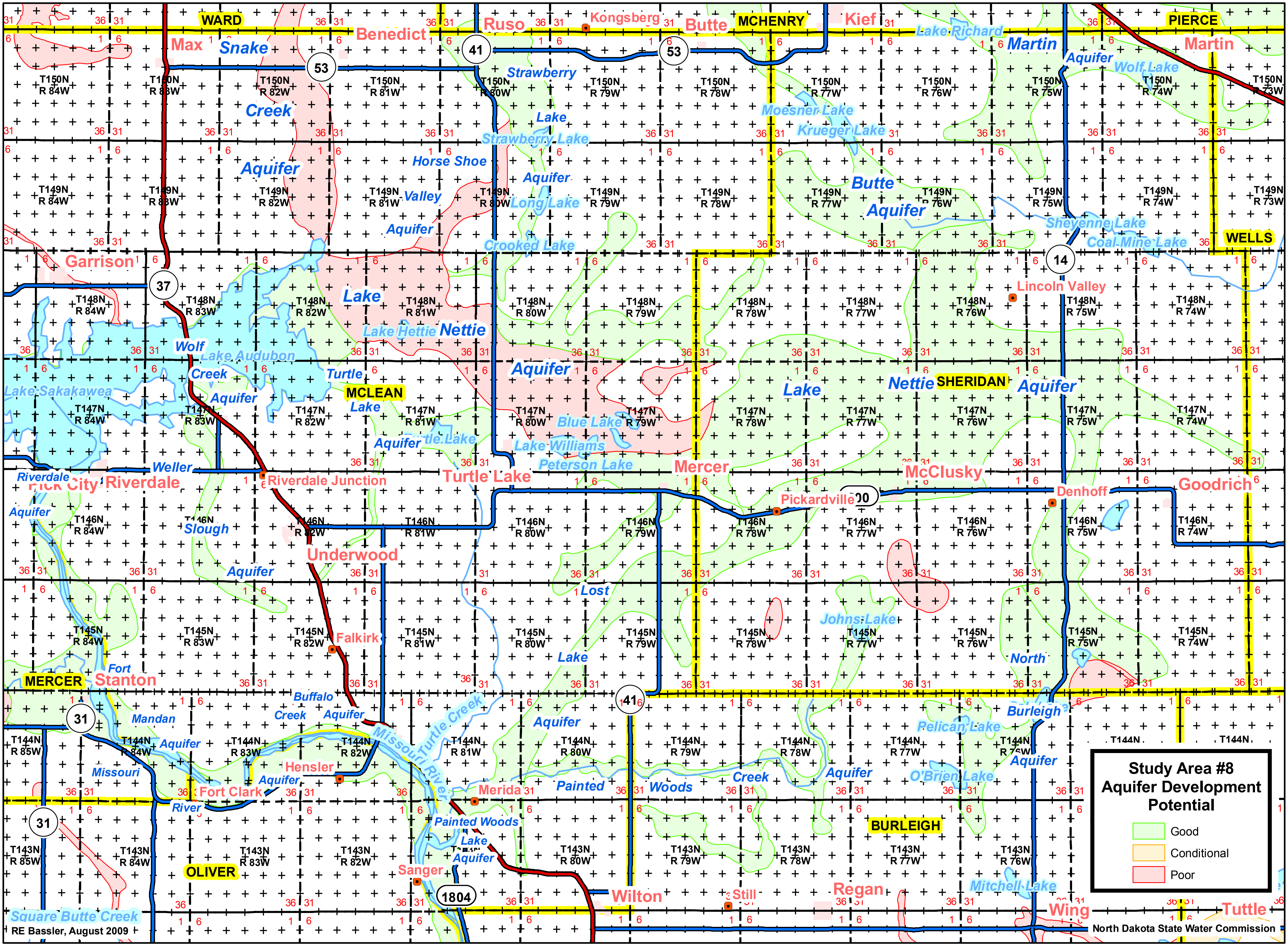


Figure 7.5.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the White Shield aquifer in McLean and Mountrail Counties.



Study Area #8 Aquifer Development Potential

🟩 Good

🟨 Conditional

🟥 Poor

RE Bassler, August 2009

North Dakota State Water Commission

## Study Area 8: Central North Dakota / Eastern McLean, Sheridan, and Northern Burleigh Counties

### *8.1. Lake Nettie Aquifer (McLean and Sheridan Counties)*

The Lake Nettie aquifer underlies about 270,000 acres in McLean and Sheridan Counties. It extends from Lake Audubon on the west to a few miles east of HWY 14, and from near HWY 200 on the south to an east-west line extending approximately through the northeast extent of Lake Audubon (Study Area #8 map).

Aquifer Composition: Klausing (1974) has described the aquifer as consisting of three units: (1) an upper layer consisting of 2 to 70 feet of sand and gravel, mainly unconfined but sometimes confined beneath as much as 80 feet of till; (2) a middle unit up to 97 feet thick separated from the upper unit by about 10 feet of till; and (3) a lower unit consisting of several sand and gravel beds, located about 162 to 190 feet bls. A composite thickness of up to 207 feet has been measured, with an average composite thickness of about 70 feet. Lithologies for two locations are shown on Appendix Figures B.8.1.1 and B.8.1.2. Site 148-080-34DCC (Appendix Figure B.8.1.2) has been cited by Klausing (1974) as a typical three-unit site.

Aquifer Yield: Two aquifer tests were described by Klausing (1974): (1) Site 148-080-34CBD, screened at 39-51 feet, had a measured transmissivity of 8,600 ft.$^2$/day and a storage coefficient of 0.14, indicating unconfined characteristics; while (2) Site 148-080-20CCD5, screened at 162-190 feet, had a measured transmissivity of 44,000 ft.$^2$/day, and a storage coefficient of 0.0002, indicative of confined conditions. Klausing estimated potential well yields at 50 to 1,500 gpm.

Aquifer Chemistry: The upper range of dissolved solids concentrations is nearly 4,000 mg/L, but the median is only 755 mg/L, and 95% of the all water samples have dissolved solids less than 2,000 mg/L (Table 8.1.1). Most of the high dissolved solids waters were from wells screened between 20 and 60 feet bls. The anion and cation distribution varies widely, ranging from predominantly a calcium bicarbonate type at low dissolved solids to a sodium sulfate type at the highest dissolved solids (Figure 8.1.1). A large intermediate range of calcium magnesium sodium-bicarbonate type and sodium-bicarbonate type is also found.

Permit Acquisition Status: There are currently 20 water permits and pending applications for a total of 3,091 acre-feet from the Lake Nettie aquifer, of which nine are perfected, two are conditional, and one has an additional 534 acre-feet held in abeyance, and six are pending applications with established priority dates. In the area mapped as having good potential for further development and beneficial use, however, there are no water permit permits or current applications. Using a conservative estimate of about 0.5 to 1 inches of recharge per year, additional development of 8,000 to 16,000 acre-feet of water for beneficial use may be possible from the Lake Nettie aquifer in the area mapped as having good potential for future development.

Additional Considerations**: Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Klausing, Robert. 1974. Ground-water Resources of McLean Counties, North Dakota. County Ground-Water Studies 19-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 16-24.

Table 8.1.1. Summary of chemical properties of the Lake Nettie aquifer in McLean and Sheridan Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 10.95 | 249 | 6.6 | 6.9 | 107 | 138 | 3 | 9.53 | 5 | 2.1 | 1.5 | 2.5 | 0 | 132 | 0 | 0.8 | 0 | 0 |
| **Maximum** | 6,500 | 6,090 | 8.5 | 8.8 | 3,950 | 3,780 | 1,320 | 41 | 610 | 268 | 210 | 920 | 1.05 | 2,080 | 400 | 3,430 | 144 | 440 |
| **Points** | 593 | 710 | 41 | 704 | 572 | 697 | 466 | 543 | 697 | 697 | 697 | 697 | 693 | 704 | 703 | 704 | 702 | 688 |
| **Mean** | 1,275.1 | 1,326.8 | 7.5 | 7.9 | 900.54 | 900.44 | 11.43 | 26.7 | 92.92 | 44.73 | 10.73 | 160.8 | 0.2 | 591.18 | 1.6 | 267.05 | 9.44 | 4.7 |
| **Median** | 1,115 | 1,150 | 7.4 | 8 | 755 | 752 | 8 | 27 | 82.4 | 36 | 7.1 | 109 | 0.2 | 532.5 | 0 | 190 | 5 | 1 |
| **Std Deviation** | 677.57 | 707.22 | 0.42 | 0.25 | 554.75 | 539.57 | 60.78 | 3.27 | 58.4 | 34.9 | 16.55 | 155.77 | 0.12 | 270.24 | 15.83 | 279.01 | 13.78 | 25.05 |
| **Std Error** | 27.82 | 26.54 | 0.07 | 0.01 | 23.2 | 20.44 | 2.82 | 0.14 | 2.21 | 1.32 | 0.63 | 5.9 | 0 | 10.19 | 0.6 | 10.52 | 0.52 | 0.95 |

Table 8.1.2. Summary of chemical properties of the Lake Nettie aquifer in McLean and Sheridan Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 24 | 0 | 223 | 0 | 0.08 | -0.28 | -0.12 | 0.72 | 0.88 |
| **Maximum** | 2,400 | 2,000 | 1,710 | 1,656 | 45.3 | 1.4 | 1.71 | 2.4 | 2.71 |
| **Points** | 711 | 695 | 132 | 711 | 705 | 8 | 565 | 8 | 565 |
| **Mean** | 414.32 | 66.93 | 485.1 | 398.38 | 3.96 | 0.38 | 0.91 | 1.38 | 1.91 |
| **Median** | 357 | 0 | 436 | 407 | 2.3 | 0.3 | 0.92 | 1.3 | 1.92 |
| **Std Deviation** | 249.48 | 186.92 | 209.09 | 284.31 | 4.48 | 0.51 | 0.27 | 0.51 | 0.27 |
| **Std Error** | 9.36 | 7.09 | 18.2 | 10.66 | 0.17 | 0.18 | 0.01 | 0.18 | 0.01 |

Table 8.1.3. Summary of chemical properties of the Lake Nettie aquifer in McLean and Sheridan Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 0.01 | 1.07 | - | - | - | - |
| Maximum | 4.4 | 12 | 3 | 6.23 | - | - | - | - |
| Points | 429 | 702 | 674 | 2 | - | - | - | - |
| Mean | 0.43 | 1.25 | 0.42 | 3.65 | - | - | - | - |
| Median | 0.3 | 0.65 | 0.33 | 3.65 | - | - | - | - |
| Std Deviation | 0.53 | 1.6 | 0.38 | 3.65 | - | - | - | - |
| Std Error | 0.03 | 0.06 | 0.01 | 2.58 | - | - | - | - |

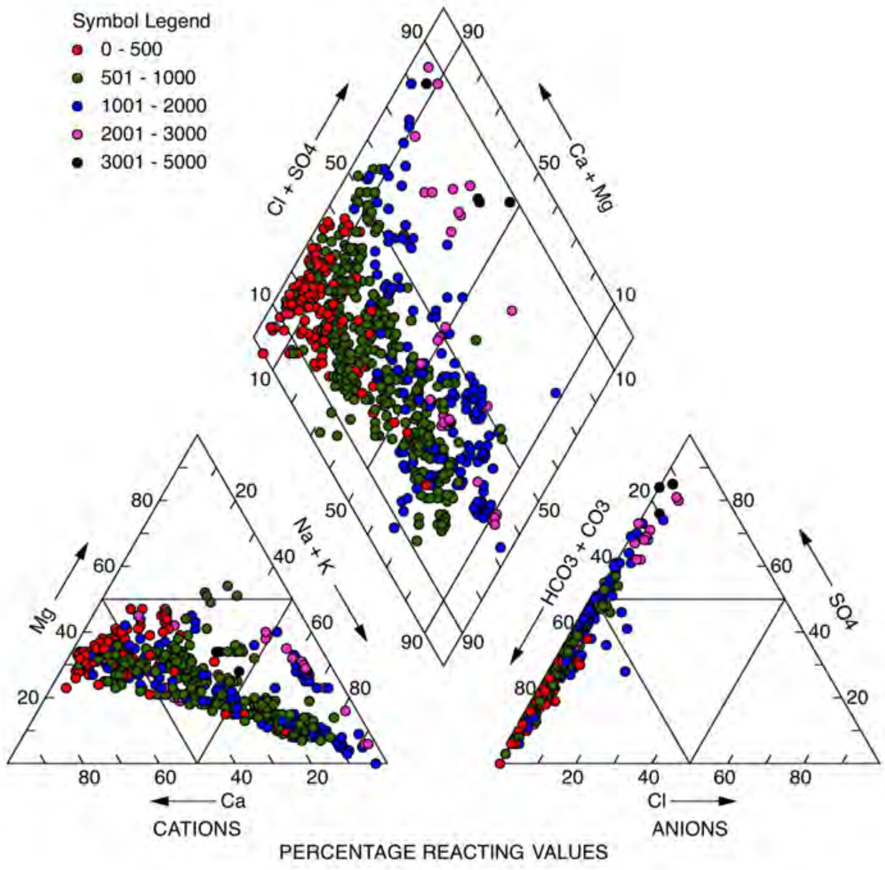


Figure 8.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Lake Nettie aquifer in McLean and Sheridan Counties.

### *8.2. Lost Lake Aquifer and Painted Woods Creek Aquifer (Burleigh and Sheridan Counties)*

The Lost Lake aquifer underlies about 25,900 acres in northern Burleigh and southwestern Sheridan Counties, extending diagonally from the southeast Lake Nettie aquifer though Pickardville to the confluence of Painted Woods Creek and the Missouri River. The Painted Woods Creek aquifer underlies about 21,000 acres in a thin band along Painted Woods Creek, and converges with the Lost Lake aquifer near the confluence with the Missouri River (Study Area #8 Map).

Aquifer Composition: Randich and Hatchett (1966) described the aquifer as consisting of 5 to 70 feet of interbedded sand, gravel and silt, generally coarser near the bottom. The aquifer was described as predominantly confined and under artesian pressure, usually about 90 to 150 feet bls. One sample of the aquifer lithology is provided on Appendix Figure B.8.2.1.

Aquifer Yield: The water permit for the city of Wilton has an approved pumping rate of 400 gpm, but three approved points of diversion indicate that pumping rates are likely substantially lower for individual wells.

Aquifer Chemistry: Water samples from the Lost Lake aquifer are predominantly of the sodium-bicarbonate type, with some of the calcium and calcium magnesium-bicarbonate type and a few of the calcium-sulfate type (Figure 8.2.1). The dissolved solids range approximately between 300 and 3,000 mg/L with a median value of 1,020 mg/L (Table 8.2.1). Increasing sodium and sulfate correspond with higher dissolved solids. Similarity of Lost Lake water sample chemistry to samples from the Lake Nettie aquifer system and other nearby aquifers suggests common source materials and a similar water product. There are no water samples from the Painted Woods Creek aquifer, but the assumption of similarity to the Long Lake aquifer is justified by uniformity of area aquifer characteristics. Iron and manganese concentrations are both high (Table 8.2.3).

Permit Acquisition Status: There is only one (perfected) water permit (the city of Wilton). There are no applications pending. Estimating recharge at about a half inch to one inch for the Lost Lake aquifer, as much as 800 to 1,600 acre-feet of annual use may be available for further development. The Painted Woods Creek aquifer is confined, and would likely be limited to less, perhaps 300 to 600 acre-feet of additional annual use.

Additional Considerations: Wells would likely have to be widely spaced and distributed to avoid interference, owing to the narrowness of the deposits. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Randich, P.G. and J.L. Hatchett. 1966. Geology and ground water resources of Burleigh County, North Dakota. County Ground Water Studies No. 42, Part III. North Dakota State Water Commission. Bismarck, ND. pp. 70-71.

Table 8.2.1. Summary of chemical properties of the Lost Lake aquifer in Burleigh and Sheridan Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 540 | 583 | 7.6 | 7.1 | 367 | 365 | 4 | 12 | 9 | 4 | 3.5 | 14 | 0 | 339 | 0 | 0.1 | 1.9 | 0 |
| **Maximum** | 2,450 | 2,520 | 8.9 | 9 | 1,950 | 1,870 | 15.6 | 33 | 410 | 92 | 15 | 520 | 1.8 | 1,180 | 36 | 1,100 | 220 | 5.7 |
| **Points** | 55 | 65 | 6 | 65 | 59 | 65 | 49 | 48 | 65 | 65 | 65 | 65 | 65 | 65 | 65 | 65 | 63 | 65 |
| **Mean** | 1,532 | 1,527 | 8.2 | 8.1 | 1,000.5 | 981.32 | 9.55 | 24.05 | 76.52 | 27.42 | 6.79 | 253.53 | 0.52 | 769.43 | 4.74 | 149.78 | 66.65 | 1.31 |
| **Median** | 1,531 | 1,570 | 8.1 | 8.1 | 1,020 | 1,040 | 9 | 25 | 66 | 24 | 6.9 | 240 | 0.3 | 809 | 0 | 104 | 33 | 1 |
| **Std Deviation** | 498.73 | 510.94 | 0.47 | 0.33 | 360.56 | 341.76 | 2.46 | 4.22 | 65.68 | 17.84 | 2.02 | 163.56 | 0.4 | 271.16 | 10.36 | 194.02 | 63.81 | 1.35 |
| **Std Error** | 67.25 | 63.37 | 0.19 | 0.04 | 46.94 | 42.39 | 0.35 | 0.61 | 8.15 | 2.21 | 0.25 | 20.29 | 0.05 | 33.63 | 1.29 | 24.07 | 8.04 | 0.17 |

Table 8.2.2. Summary of chemical properties of the Lost Lake aquifer in Burleigh and Sheridan Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 44 | 0 | 287 | 0 | 0.2 | 0 | 0.42 | 0 | 1.42 |
| **Maximum** | 1,610 | 1,000 | 875 | 1,019 | 33 | 0 | 1.55 | 0 | 2.55 |
| **Points** | 65 | 65 | 6 | 65 | 65 | 0 | 59 | 0 | 59 |
| **Mean** | 314 | 56.31 | 641.83 | 592.6 | 8.72 | 0 | 1.08 | 0 | 2.08 |
| **Median** | 280 | 0 | 691 | 583 | 5.8 | 0 | 1.14 | 0 | 2.14 |
| **Std Deviation** | 273.37 | 199.86 | 239.39 | 280.25 | 7.9 | 0 | 0.26 | 0 | 0.26 |
| **Std Error** | 33.91 | 24.79 | 97.73 | 34.76 | 0.98 | 0 | 0.03 | 0 | 0.03 |

Table 8.2.3. Summary of chemical properties of the Lost Lake aquifer in Burleigh and Sheridan Counties: selected trace elements.

|  | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0.02 | 0.02 | - | - | - | - | - |
| Maximum | 2.3 | 9.3 | 2.3 | - | - | - | - | - |
| Points | 42 | 65 | 65 | - | - | - | - | - |
| Mean | 0.61 | 1.07 | 0.39 | - | - | - | - | - |
| Median | 0.44 | 0.46 | 0.24 | - | - | - | - | - |
| Std Deviation | 0.58 | 1.53 | 0.44 | - | - | - | - | - |
| Std Error | 0.09 | 0.19 | 0.05 | - | - | - | - | - |

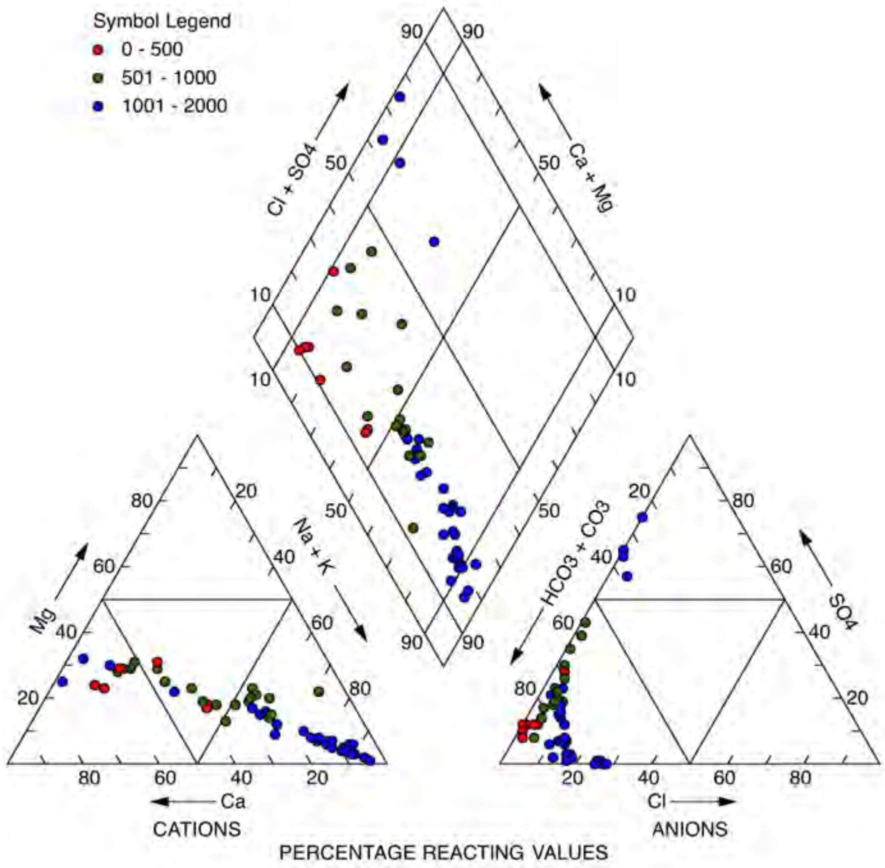


Figure 8.2.2. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Lost Lake aquifer in Burleigh and Sheridan Counties.

### *8.3. Martin Aquifer and Butte Aquifer (Sheridan, McHenry, Pierce and Wells Counties)*

The Butte aquifer is a northward extension of the Lake Nettie aquifer system underlying about 39,600 acres as currently mapped. The Martin aquifer underlies about 38,000 acres northeast of the Butte aquifer (Study Area #8 map). **Some of the aquifer area included in this study is mapped in Study Area #9.**

Aquifer Composition: Both aquifers consist of multiple layers of sand and gravel deposits. According to Burkart (1981) the Butte aquifer is predominantly confined, but has a surface varying from 3 to 197 feet bls. Combined aquifer thickness varies from 18 to 87 feet, with an average of about 54 feet. The Martin aquifer consists predominantly of two units: (1) a shallow predominantly unconfined unit having a maximum thickness of about 110 feet and an average thickness of about 50 feet; and (2) a deeper unit about 20 to 85 feet thick, having an average thickness of about 46 feet. The deeper zone occurs about 110 to 300 feet bls. Examples of lithologies for the Butte and Martin aquifers are provided on Appendix Figures B.8.3.1 and B.8.3.2, respectively.

Aquifer Yield: Burkart (1981) estimated Butte aquifer potential well yields of 50 to 250 gpm, and Martin aquifer potential well yields of 50 to 500 gpm.

Aquifer Chemistry: Water chemistry data for the Butte and Martin aquifers is sparse. The range of dissolved solids concentrations is similar (Table 8.3.1a and 8.3.1b) and median dissolved solids are similar, near 900 mg/L. Water samples for the Butte aquifer are mainly of the sodium-bicarbonate type, while those of the Martin aquifer are of the calcium to mixed cation-bicarbonate type (Figure 8.3.1). These data are within the range of characteristics of other area aquifers, and it is likely appropriate to consider the Butte and Martin aquifer water chemistries as reflecting the broader range of properties represented by the Lake Nettie aquifer and other nearby aquifers. Iron and manganese concentrations are high (Tables 8.3.3a and 8.3.3b).

Permit Acquisition Status: The Butte aquifer has no existing permits or applications. The Martin aquifer has two perfected permits for 150 acre-feet, and no applications pending. There should be little competition for new applications. Using a conservative recharge estimate of 0.5 to one inch per year, as much as 1,000 to 3,000 acre-feet of water annually may be available for further appropriation and beneficial use from each aquifer, or a total of 2,000 to 6,000 acre-feet.

Additional Considerations: **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Burkart, M.R. 1981. Ground-water Resources of Sheridan County, North Dakota. County Ground-Water Studies 75-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 20-21.

Table 8.3.1a.  Summary of chemical properties of the Butte aquifer in Sheridan and McHenry Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 850 | 1,010 | 7.6 | 7.8 | 655 | 605 | 7 | 15 | 18.4 | 4.9 | 3.6 | 210 | 0.2 | 461 | 0 | 109 | 10 | 0.09 |
| **Maximum** | 1,414 | 1,490 | 8 | 8.3 | 921 | 957 | 11 | 26.6 | 44.2 | 19 | 6.3 | 330 | 0.5 | 661 | 1 | 270 | 48 | 1.2 |
| **Points** | 8 | 8 | 5 | 8 | 5 | 8 | 5 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| **Mean** | 1,147.8 | 1,293.8 | 7.8 | 8 | 820.4 | 811.37 | 8.7 | 21.9 | 31.16 | 9.61 | 5.01 | 262.12 | 0.34 | 574.12 | 0.38 | 177.62 | 28.35 | 0.65 |
| **Median** | 1,250 | 1,340 | 7.7 | 8 | 847 | 852.5 | 9 | 23.5 | 27.5 | 6.85 | 4.9 | 260 | 0.33 | 600 | 0 | 175 | 30.1 | 0.85 |
| **Std Deviation** | 226 | 191.01 | 0.18 | 0.2 | 99.24 | 124.87 | 1.57 | 4 | 11.27 | 5.51 | 0.82 | 48.46 | 0.11 | 88.79 | 0.52 | 54 | 12.74 | 0.48 |
| **Std Error** | 79.9 | 67.53 | 0.08 | 0.07 | 44.38 | 44.15 | 0.7 | 1.41 | 3.98 | 1.95 | 0.29 | 17.13 | 0.04 | 31.39 | 0.18 | 19.09 | 4.5 | 0.17 |

Table 8.3.1b.  Summary of chemical properties of the Martin aquifer system in Sheridan, McHenry and Wells Counties: general chemistry.

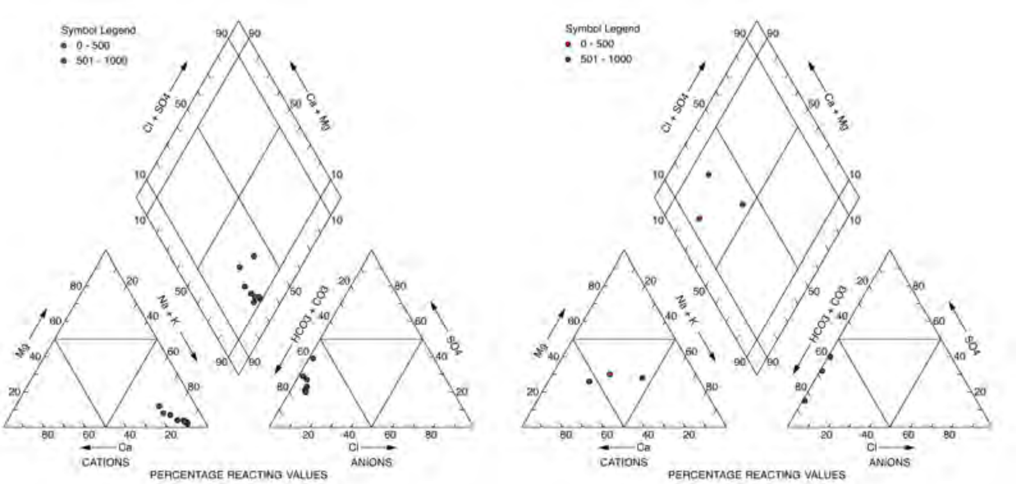
| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 880 | 657 | 7.4 | 7.4 | 400 | 420 | 5.6 | 15 | 18 | 9.2 | 4.1 | 20 | 0.2 | 339 | 0 | 48 | 5 | 0 |
| **Maximum** | 1,800 | 1,760 | 7.9 | 7.9 | 1,150 | 1,120 | 9.5 | 22 | 110 | 55 | 8.7 | 390 | 0.5 | 769 | 0 | 310 | 44 | 4.4 |
| **Points** | 3 | 8 | 3 | 7 | 7 | 5 | 4 | 4 | 5 | 5 | 4 | 7 | 5 | 7 | 6 | 5 | 5 | 7 |
| **Mean** | 1,260 | 1,023.8 | 7.6 | 7.7 | 653.29 | 794.2 | 7.4 | 18.5 | 67 | 30.84 | 6.3 | 109 | 0.28 | 458.43 | 0 | 164.8 | 13.6 | 2.74 |
| **Median** | 1,100 | 836.5 | 7.5 | 7.6 | 549 | 913 | 7.25 | 18.5 | 63 | 29 | 6.2 | 49 | 0.2 | 392 | 0 | 160 | 6.3 | 2.5 |
| **Std Deviation** | 480.42 | 427.93 | 0.26 | 0.2 | 274.78 | 283.39 | 1.61 | 2.89 | 33.6 | 16.34 | 2.12 | 131.82 | 0.13 | 153.76 | 0 | 116.02 | 17.02 | 1.78 |
| **Std Error** | 277.37 | 151.29 | 0.15 | 0.07 | 103.86 | 126.74 | 0.81 | 1.44 | 15.03 | 7.31 | 1.06 | 49.82 | 0.06 | 58.12 | 0 | 51.89 | 7.61 | 0.67 |

Table 8.3.3a. Summary of chemical properties of the Butte aquifer in Sheridan and McHenry Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.2 | 0 | 0.06 | - | - | - | - | - |
| Maximum | 0.67 | 1.2 | 0.22 | - | - | - | - | - |
| Points | 5 | 8 | 8 | - | - | - | - | - |
| Mean | 0.43 | 0.28 | 0.11 | - | - | - | - | - |
| Median | 0.42 | 0.08 | 0.1 | - | - | - | - | - |
| Std Deviation | 0.2 | 0.41 | 0.05 | - | - | - | - | - |
| Std Error | 0.09 | 0.15 | 0.02 | - | - | - | - | - |

Table 8.3.3b. Summary of chemical properties of the Martin aquifer in Sheridan, McHenry and Wells Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 1.8 | 1.2 | 0.6 | - | - | - | - | - |
| Maximum | 4 | 7 | 6 | - | - | - | - | - |
| Points | 0.65 | 0.63 | 0.24 | - | - | - | - | - |
| Mean | 0.32 | 0.5 | 0.18 | - | - | - | - | - |
| Median | 0.77 | 0.41 | 0.2 | - | - | - | - | - |
| Std Deviation | 0.39 | 0.16 | 0.08 | - | - | - | - | - |
| Std Error | 1.8 | 1.2 | 0.6 | - | - | - | - | - |



Butte aquifer

Martin aquifer

Figure 8.3.1. Piper plot illustrating the relative anion and cation compositions of water samples collected from the Butte aquifer in Sheridan and McHenry Counties and the Martin aquifer in Sheridan, McHenry and Wells Counties.

### *8.4 North Burleigh Aquifer (Burleigh and Sheridan Counties)*

The North Burleigh aquifer, as currently mapped, underlies about 25,700 acres along HWY 14 in northern Burleigh and southern McLean Counties. It appears to be a southern extension of the Lake Nettie aquifer near its eastern boundary (Study Area #8 map).

Aquifer Composition: Randich and Hatchett (1966) described the North Burleigh aquifer as an unconfined sand and gravel deposit having a thickness of 10 to 50 feet.

Aquifer Yield: Burkhardt (1981) estimated potential yields of 50 to 500 gpm in Sheridan County.

Aquifer Chemistry: Water chemistry is available for only one water sample collected from the North Burleigh aquifer. It has a determined dissolved solids content of 639 mg/L, and is of the magnesium-bicarbonate type. These values are within the range represented within the Lake Nettie aquifer, and the safest assumption is that the North Burleigh aquifer, which appears as a southeastern appendage to the Lake Nettie aquifer, has a similar distribution in its water chemistry.

Permit Acquisition Status: There are currently no water permits or pending applications.

Additional Considerations: Little is known of this aquifer. Local exploration is advised before planning for development and use.

Citations:

Randich, P.G. and J.L. Hatchett. 1966. Geology and ground water resources of Burleigh County, North Dakota. County Ground Water Studies No. 42, Part III. North Dakota State Water Commission. Bismarck, ND. pp. 70-71.

Burkart, M.R. 1981. Ground-water Resources of Sheridan County, North Dakota. County Ground-Water Studies 75-Part III. North Dakota State Water Commission. Bismarck, ND. p. 25.

## *8.5 Strawberry Lake Aquifer (McLean and Ward Counties)*

Strawberry Lake comprises a northwest extension of the northwest portion of the Lake Nettie aquifer, and underlies about 19,700 acres as currently mapped (Study Area #8 map).

<u>Aquifer Composition:</u> The aquifer consists of multiple layers of sand and gravel deposits, having a combined thickness ranging from about 2 to 169 feet, and an average combined thickness of about 65 feet (Klausing 1974). One example of the Strawberry Lake lithology is provided on Appendix Figure B.8.5.1.

<u>Aquifer Yield:</u> Klausing has estimated potential well yields of up to 1,000 gpm.

<u>Aquifer Chemistry:</u> The chemical composition is almost identical to the Lake Nettie aquifer, with dissolved solids ranging as high as 4,000 mg/L in a few samples, but with a median dissolved solids concentrations below 600 mg/L, and 95% of the samples below 2,000 mg/L (Table 8.5.1). Anion and cation composition is also very similar to the Lake Nettie aquifer, ranging from the calcium-bicarbonate type at lower dissolved solids to a sodium-bicarbonate type at higher dissolved solids, and a calcium-sulfate type at highest dissolved solids (Figure 8.5.1). Iron and Manganese concentrations are both high (Table 8.5.3).

<u>Permit Acquisition Status:</u> There are currently only two water permits (perfected) for 258 acre-feet from the Strawberry Lake aquifer. There should be little competition for water in most areas of the aquifer. As much as 700 to 1,500 acre-feet may be available for further development and beneficial use.

<u>Additional Considerations:</u> Klausing (1974) cautions that high-capacity wells should be spaced far apart to avoid well interference, owing to the narrowness of the aquifer. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

<u>Citations:</u>

Klausing, Robert. 1974. Ground-water Resources of McLean Counties, North Dakota. County Ground-Water Studies 19-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 16-24.

Table 8.5.1. Summary of chemical properties of the Strawberry Lake aquifer in McLean and Ward Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 295 | 308 | - | 6.9 | 154 | 172 | 6 | 9.7 | 15 | 15.9 | 1.1 | 2.5 | 0.08 | 201 | 0 | 1.2 | 0 | 0 |
| **Maximum** | 4,400 | 4,480 | - | 8.2 | 4,160 | 3,890 | 10 | 31.4 | 440 | 210 | 33 | 510 | 0.6 | 808 | 1 | 2,400 | 120 | 12 |
| **Points** | 88 | 115 | - | 115 | 98 | 115 | 58 | 87 | 115 | 114 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 114 |
| **Mean** | 1,154.5 | 1,174.2 | - | 7.8 | 851.93 | 845.47 | 8.1 | 24.47 | 127.89 | 50.5 | 6.98 | 87.22 | 0.15 | 441.71 | 0.15 | 331.24 | 6.32 | 1.04 |
| **Median** | 968 | 916 | - | 7.8 | 566.5 | 579 | 8 | 25 | 92.2 | 31.5 | 5.7 | 30 | 0.1 | 404 | 0 | 160 | 2.9 | 1 |
| **Std Deviation** | 848.93 | 945.92 | - | 0.32 | 874.35 | 833.85 | 1.1 | 4.09 | 90.13 | 43.08 | 5.63 | 137.65 | 0.07 | 142.46 | 0.36 | 542.42 | 15.02 | 1.69 |
| **Std Error** | 90.5 | 88.21 | - | 0.03 | 88.32 | 77.76 | 0.14 | 0.44 | 8.4 | 4.04 | 0.53 | 12.84 | 0.01 | 13.29 | 0.03 | 50.58 | 1.4 | 0.16 |

Table 8.5.2. Summary of chemical properties of the Strawberry Lake aquifer in McLean and Ward Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 100 | 0 | 199 | 0 | 0.1 | - | -0.89 | - | - |
| **Maximum** | 2,000 | 1,600 | 614 | 662 | 9.9 | - | 1.73 | - | - |
| **Points** | 114 | 115 | 17 | 115 | 115 | - | 98 | - | - |
| **Mean** | 529.68 | 193.47 | 378.12 | 306.14 | 1.61 | - | 0.76 | - | - |
| **Median** | 360 | 73 | 351 | 282 | 0.69 | - | 0.83 | - | - |
| **Std Deviation** | 395.29 | 328.36 | 125.86 | 166.61 | 2.38 | - | 0.45 | - | - |
| **Std Error** | 37.02 | 30.62 | 30.53 | 15.54 | 0.22 | - | 0.05 | - | - |

Table 8.5.3. Summary of chemical properties of the Strawberry Lake aquifer in McLean and Ward Counties: selected trace elements.

|  | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 0.01 | - | - | - | - | - |
| Maximum | 1 | 24 | 2.2 | - | - | - | - | - |
| Points | 72 | 115 | 115 | - | - | - | - | - |
| Mean | 0.23 | 1.22 | 0.56 | - | - | - | - | - |
| Median | 0.13 | 0.34 | 0.43 | - | - | - | - | - |
| Std Deviation | 0.25 | 2.67 | 0.46 | - | - | - | - | - |
| Std Error | 0.03 | 0.25 | 0.04 | - | - | - | - | - |

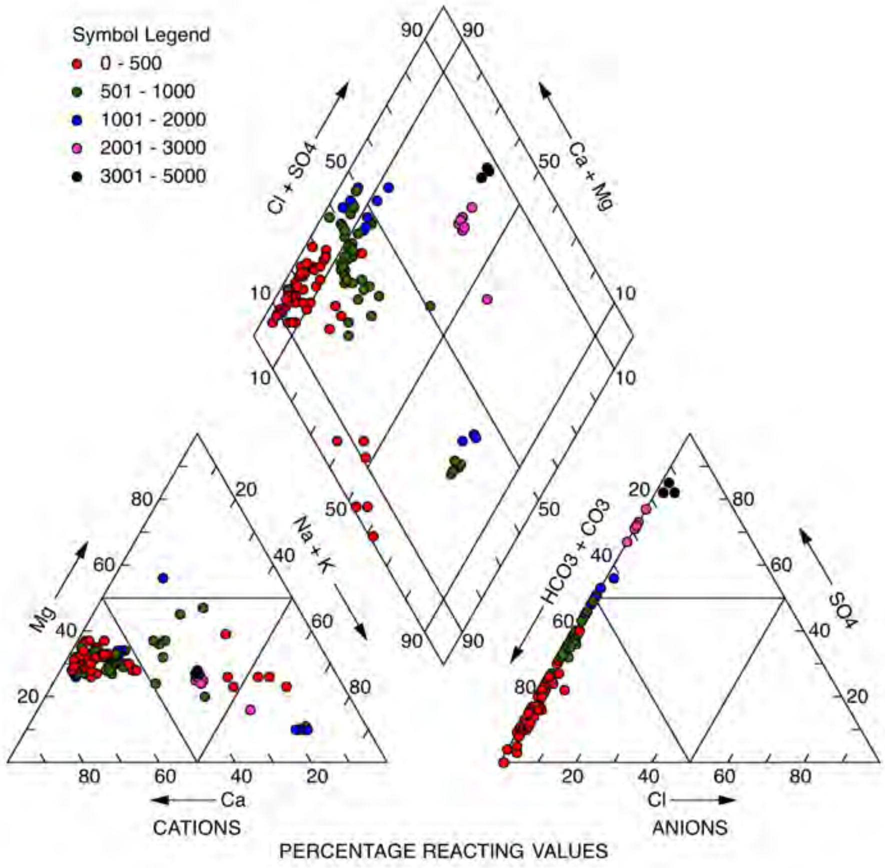


Figure 8.5.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Strawberry Lake aquifer in McLean and Ward Counties.

### *8.6 Turtle Lake, Weller Slough and Wolf Creek Aquifers (McLean County)*

These three aquifers underlie about 23,100 acres in an approximate loop extending from the southwestern border of Lake Audubon (Wolf Creek aquifer, approx. 3,200 acres), then southeastward (Weller Slough aquifer, approx. 7,500 acres), then extending northward and closing the loop on the southeast border of Lake Audubon (Turtle Lake aquifer, approx. 12,400 acres). Aquifer locations are shown on the Study Area #8 map.

Aquifer Composition: The three aquifers consist of interbedded sand and gravel, with thickest deposits in the deeper portions. Average aquifer thickness for the Turtle Lake and Weller Slough aquifers is about 40 feet, with maximum thickness of about 90 feet. The average thickness for the Wolf Creek aquifer is somewhat less. One example of lithology for each aquifer is shown on Appendix Figures B.8.6.1, B.8.6.2 and B.8.6.3.

Aquifer Yield: Klausing (1974) estimated potential well yields of 50 gpm to 1,000 gpm for the Turtle Lake and Weller Slough aquifers, and 50 to 500 gpm for the Wolf Creek aquifer.

Aquifer Chemistry: The chemical composition of the three aquifers is similar, primarily of the sodium-bicarbonate type, but with some water samples of the calcium and calcium-magnesium-bicarbonate type (Figure 8.6.1). Dissolved solids concentrations are generally similar, ranging from about 350 mg/L to 1,800 mg/L (Tables 8.6.1a, 8.6.1b and 8.6.1c). Higher sodium generally corresponds with the higher range of dissolved solids. Median dissolved solids are lowest for the Wolf Creek aquifer and highest for the Weller Slough, but the data are somewhat sparse for these two aquifers. Iron and manganese are high (Tables 8.6.3a, 8.6.3b and 8.6.3c). Substantial water supplies may be available. Considering varying depths of coarse beds and differing proximity the surface, and using an approximate but conservative recharge range of 0.5 to 1 inches per year, about 1,000 acre-feet (100 acre-feet Wolf Creek, 300 acre-feet Weller Slough, 600 acre-feet Turtle Lake) to 2,000 acre-feet (proportionally distributed as indicated above) may be available for beneficial use on an annual basis.

Permit Acquisition Status: There are no active water permits or applications.

Additional Considerations: **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Klausing, Robert. 1974. Ground-water Resources of McLean Counties, North Dakota. County Ground-Water Studies 19-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 29-44.

Table 8.6.1a. Summary of chemical properties of the Turtle Lake aquifer in McLean County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 530 | 494 | 0 | 7.2 | 277 | 314 | 6.7 | 12 | 16 | 6.4 | 2.2 | 20 | 0 | 237 | 0 | 37 | 0.9 | 0 |
| **Maximum** | 2,340 | 2,110 | 0 | 8.5 | 1,450 | 1,440 | 10 | 35 | 146 | 58 | 25 | 450 | 0.4 | 1,030 | 20 | 481 | 28 | 58 |
| **Points** | 45 | 61 | 0 | 61 | 53 | 61 | 45 | 51 | 61 | 61 | 61 | 61 | 60 | 61 | 61 | 61 | 60 | 61 |
| **Mean** | 1,353 | 1,399.9 | 0 | 7.9 | 941 | 938.38 | 8.15 | 25.11 | 72.32 | 27.91 | 6.95 | 229.63 | 0.2 | 662.56 | 1.05 | 244.07 | 5.79 | 5.09 |
| **Median** | 1,318 | 1,420 | 0 | 8 | 924 | 944 | 8 | 26 | 70 | 27.7 | 6.7 | 178 | 0.2 | 593 | 0 | 238 | 4.45 | 1 |
| **Std Deviation** | 483.94 | 502.99 | 0 | 0.25 | 350.79 | 346.8 | 0.9 | 4.69 | 29.1 | 12.42 | 3.29 | 156.64 | 0.09 | 242.03 | 3.62 | 117.15 | 5.03 | 11.74 |
| **Std Error** | 72.14 | 64.4 | 0 | 0.03 | 48.18 | 44.4 | 0.13 | 0.66 | 3.73 | 1.59 | 0.42 | 20.06 | 0.01 | 30.99 | 0.46 | 15 | 0.65 | 1.5 |

Table 8.6.1b. Summary of chemical properties of the Weller Slough aquifer in McLean County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 1,125 | 1,320 | 0 | 7.9 | 867 | 858 | 6.7 | 25 | 26.9 | 10 | 4.4 | 192 | 0.2 | 711 | 0 | 184 | 0 | 0.13 |
| **Maximum** | 2,200 | 2,620 | 0 | 8.6 | 1,730 | 1,790 | 8.9 | 31 | 77 | 42 | 8.3 | 641 | 0.6 | 1,230 | 44 | 561 | 17 | 19 |
| **Points** | 5 | 5 | 0 | 5 | 3 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Mean** | 1,764.8 | 2,034 | 0 | 8.2 | 1,392.3 | 1,382.4 | 7.6 | 28.46 | 52.36 | 28.58 | 6.74 | 424.4 | 0.37 | 940.4 | 10.22 | 368.8 | 5.79 | 4.71 |
| **Median** | 2,054 | 2,330 | 0 | 8.1 | 1,580 | 1,640 | 7.2 | 29 | 57 | 38 | 7.1 | 457 | 0.3 | 919 | 1 | 447 | 2.7 | 0.9 |
| **Std Deviation** | 534.32 | 661.2 | 0 | 0.25 | 461.09 | 470.05 | 1.15 | 2.22 | 21.76 | 16.09 | 1.64 | 219.58 | 0.18 | 237.21 | 19.05 | 172.45 | 6.72 | 8.07 |
| **Std Error** | 238.95 | 295.7 | 0 | 0.11 | 266.21 | 210.21 | 0.67 | 0.99 | 9.73 | 7.19 | 0.73 | 98.2 | 0.08 | 106.08 | 8.52 | 77.12 | 3.01 | 3.61 |

Table 8.6.1c. Summary of chemical properties of the Wolf Creek aquifer in McLean County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 774 | 664 | 0 | 7.3 | 378 | 382 | 8 | 4.6 | 40.8 | 23 | 4 | 12 | 0.1 | 318 | 0 | 11 | 0 | 0 |
| **Maximum** | 2,650 | 2,660 | 0 | 8.2 | 1,830 | 1,850 | 10 | 35 | 136 | 59 | 17 | 540 | 0.4 | 1,210 | 12 | 727 | 14 | 17 |
| **Points** | 12 | 22 | 0 | 22 | 18 | 21 | 8 | 18 | 22 | 22 | 21 | 22 | 22 | 22 | 20 | 22 | 22 | 21 |
| **Mean** | 1,754.8 | 1,504.3 | 0 | 7.9 | 910.61 | 1,030.2 | 8.94 | 24.29 | 89.67 | 36.65 | 7.57 | 219.77 | 0.23 | 675.09 | 0.8 | 304.31 | 6.04 | 3.06 |
| **Median** | 1,969 | 892 | 0 | 8 | 558.5 | 584 | 8.85 | 24.45 | 97 | 31 | 7.3 | 52.5 | 0.2 | 531 | 0 | 175.5 | 4.95 | 1 |
| **Std Deviation** | 767.5 | 850.03 | 0 | 0.21 | 567.4 | 607.99 | 0.74 | 6.33 | 30.14 | 11.69 | 2.77 | 219.32 | 0.1 | 312.91 | 2.67 | 258.32 | 4.14 | 4.89 |
| **Std Error** | 221.56 | 181.23 | 0 | 0.04 | 133.74 | 132.67 | 0.26 | 1.49 | 6.43 | 2.49 | 0.6 | 46.76 | 0.02 | 66.71 | 0.6 | 55.08 | 0.88 | 1.07 |

Table 8.6.2a. Summary of chemical properties of the Turtle Lake aquifer in McLean County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 82 | 0 | 226 | 0 | 0.5 | 0 | -0.22 | 0 | 0.78 |
| **Maximum** | 561 | 106 | 769 | 844 | 19.8 | 0 | 1.54 | 0 | 2.54 |
| **Points** | 61 | 61 | 8 | 61 | 61 | 0 | 53 | 0 | 53 |
| **Mean** | 295.33 | 10.1 | 535.63 | 474.33 | 6.96 | 0 | 0.89 | 0 | 1.89 |
| **Median** | 290 | 0 | 479.5 | 455 | 4.1 | 0 | 0.94 | 0 | 1.94 |
| **Std Deviation** | 118.92 | 23.92 | 193.84 | 264.61 | 5.99 | 0 | 0.29 | 0 | 0.29 |
| **Std Error** | 15.23 | 3.06 | 68.53 | 33.88 | 0.77 | 0 | 0.04 | 0 | 0.04 |

Table 8.6.2b. Summary of chemical properties of the Weller Slough aquifer in McLean County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 117 | 0 | 582 | 0 | 4.5 | - | 0.81 | - | 1.81 |
| **Maximum** | 350 | 0 | 1,000 | 1,008 | 25.8 | - | 1.33 | - | 2.33 |
| **Points** | 5 | 5 | 2 | 5 | 5 | - | 3 | - | 3 |
| **Mean** | 249 | 0 | 791 | 671 | 14.02 | - | 1.1 | - | 2.1 |
| **Median** | 315 | 0 | 791 | 763 | 11 | - | 1.17 | - | 2.17 |
| **Std Deviation** | 117.56 | 0 | 295.57 | 414.75 | 10.29 | - | 0.27 | - | 0.27 |
| **Std Error** | 52.57 | 0 | 3.4e+38 | 185.48 | 4.6 | - | 0.15 | - | 0.15 |

Table 8.6.2c. Summary of chemical properties of the Wolf Creek aquifer in McLean County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 240 | 0 | 280 | 0 | 0.3 | - | 0.2 | - | 1.2 |
| **Maximum** | 520 | 138 | 949 | 992 | 13 | - | 1.18 | - | 2.18 |
| **Points** | 22 | 20 | 5 | 22 | 21 | - | 18 | - | 18 |
| **Mean** | 374.95 | 18.1 | 591.4 | 432.59 | 5.22 | - | 0.96 | - | 1.96 |
| **Median** | 365 | 0 | 635 | 341.5 | 1.7 | - | 1.03 | - | 2.03 |
| **Std Deviation** | 64.5 | 36.73 | 253.48 | 315.01 | 5.07 | - | 0.24 | - | 0.24 |
| **Std Error** | 13.75 | 8.21 | 113.36 | 67.16 | 1.11 | - | 0.06 | - | 0.06 |

Table 8.6.3a. Summary of chemical properties of the Turtle Lake aquifer in McLean and Ward Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0 | 0 | 0 | - | - | - | - | - |
| **Maximum** | 1.3 | 5.04 | 0.56 | - | - | - | - | - |
| **Points** | 44 | 61 | 54 | - | - | - | - | - |
| **Mean** | 0.43 | 1.26 | 0.22 | - | - | - | - | - |
| **Median** | 0.31 | 0.9 | 0.15 | - | - | - | - | - |
| **Std Deviation** | 0.33 | 1.16 | 0.17 | - | - | - | - | - |
| **Std Error** | 0.05 | 0.15 | 0.02 | - | - | - | - | - |

Table 8.6.b. Summary of chemical properties of the Weller Slough aquifer in McLean County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0 | 0.08 | 0.03 | - | - | - | - | - |
| **Maximum** | 0.63 | 4.2 | 0.05 | - | - | - | - | - |
| **Points** | 3 | 5 | 5 | - | - | - | - | - |
| **Mean** | 0.31 | 1.18 | 0.04 | - | - | - | - | - |
| **Median** | 0.29 | 0.59 | 0.04 | - | - | - | - | - |
| **Std Deviation** | 0.32 | 1.73 | 0.01 | - | - | - | - | - |
| **Std Error** | 0.18 | 0.77 | 0 | - | - | - | - | - |

Table 8.5.3c. Summary of chemical properties of the Wolf Creek aquifer in McLean and Ward Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0.12 | 0 | 0.01 | - | - | - | - | - |
| **Maximum** | 0.88 | 6.2 | 1.1 | - | - | - | - | - |
| **Points** | 13 | 22 | 17 | - | - | - | - | - |
| **Mean** | 0.43 | 1.57 | 0.42 | - | - | - | - | - |
| **Median** | 0.33 | 0.93 | 0.42 | - | - | - | - | - |
| **Std Deviation** | 0.31 | 1.81 | 0.36 | - | - | - | - | - |
| **Std Error** | 0.09 | 0.39 | 0.09 | - | - | - | - | - |

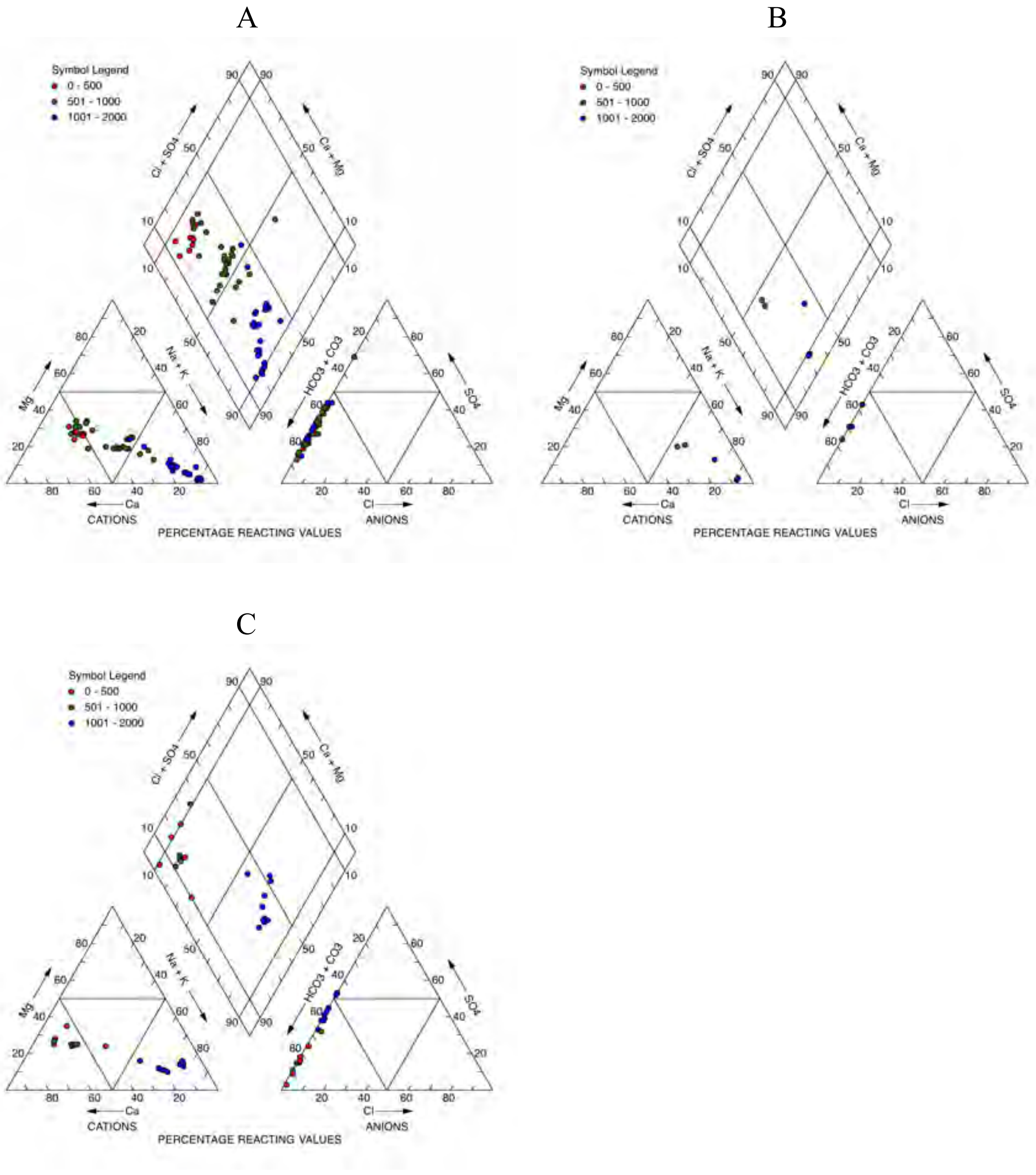
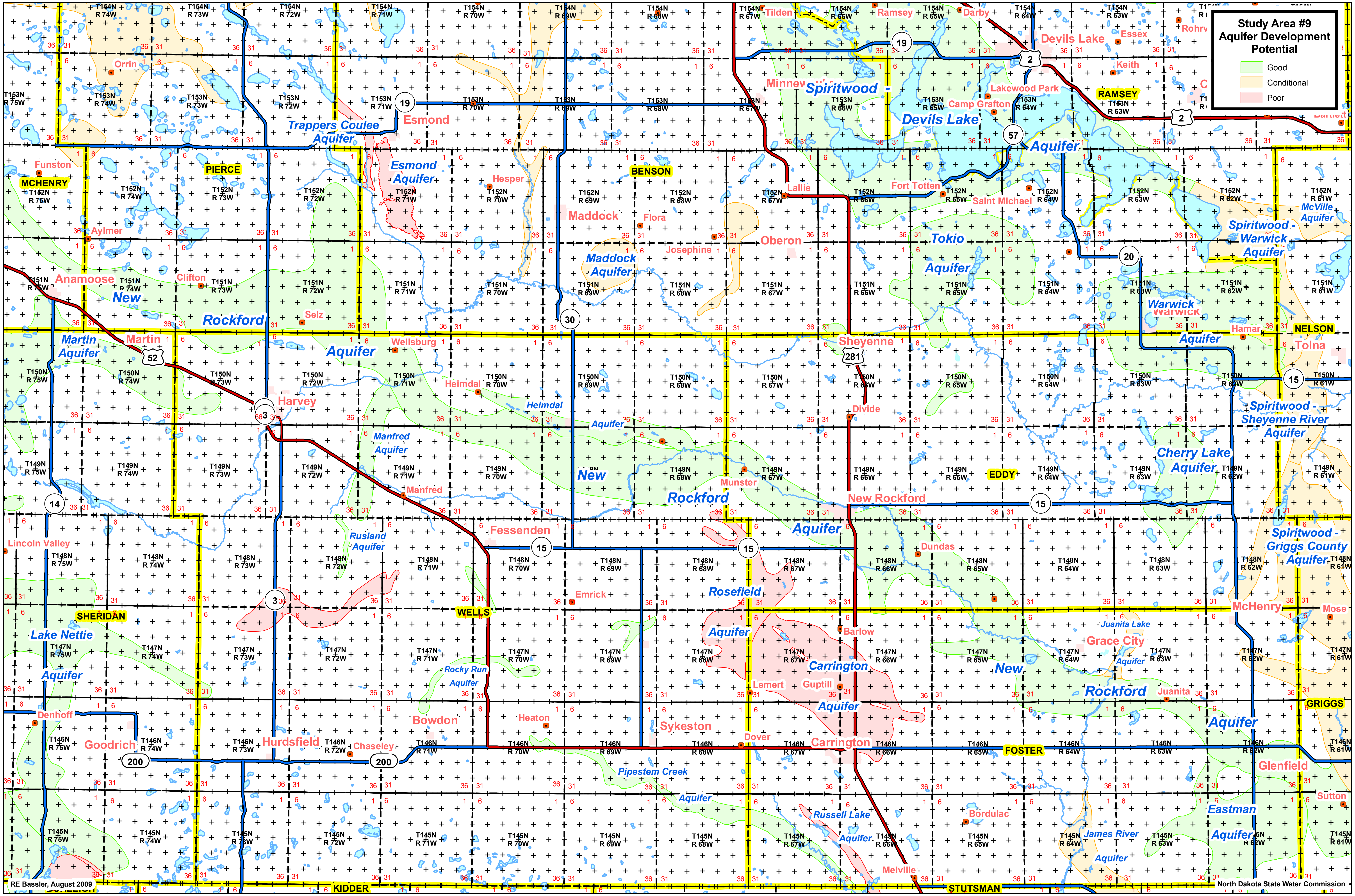


Figure 8.6.1. Piper plots illustrating the relative distribution of anions and cations in water samples collected from (A) Turtle Lake aquifer, (B) Weller Slough aquifer, and (C) Wolf Creek aquifer in McLean County.



## Study Area #9 Aquifer Development Potential

- 🟩 Good
- 🟨 Conditional
- 🟥 Poor

RE Bassler, August 2009

North Dakota State Water Commission

## Study Area 9: Central North Dakota / Benson, Eddy, Foster and Wells Counties

### *9.1 Cherry Lake Aquifer (Eddy County)*

The Cherry Lake aquifer underlies about 23 square miles in Eddy County (Study Area #9 map).

Aquifer Composition: Comesky (1989) described the Cherry Lake aquifer as consisting of three units: a surficial unit having a maximum thickness of about 29 feet, a shallow confined unit at 18 to 25 feet below land surface and having a maximum thickness of about 27 feet, and a deep confined unit about 126 to 182 feet bls having a maximum thickness of about 96 feet. The shallow unconfined unit defines the mapped boundaries (Study Area #9 map) and ranges in texture from silt to coarse pebble gravel. The shallow unconfined unit is less extensive (0.7 to 2 miles wide by 2.5 miles long, or about 3-4 square miles) and ranges in texture from fine sand to gravel. The deep confined unit is less extensive and ranges from fine sand to pebbles. An example of the lithology is provided on Appendix Figure B.9.1.1.

Aquifer Yield: There are no published well yields for this aquifer.

Aquifer Chemistry: Cherry Lake aquifer water is mostly fresh, with 95% of all water samples having dissolved solids concentrations below 1,000 mg/L, and 70% having dissolved solids below 500 mg/L. The median of dissolved solids is near 400 mg/L. The water varies from predominantly of the calcium-bicarbonate type, to some waters of the sodium-bicarbonate type (Figure 9.1.1). Higher sodium and higher sulfate concentrations correspond generally to higher dissolved solids, and correlate significantly but somewhat loosely with depth. Manganese concentrations are high. Arsenic concentrations vary widely, but exceed the EPA-MCL in some samples (Table 9.1.3).

Permit Acquisition Status: There are currently two perfected water permits, for less than one acre-foot per year. There are no pending applications. The Cherry Lake aquifer may have the capacity for about 500 to 1,000 acre-feet per year of additional development.

Additional Considerations: Most of the aquifer underlies lands of the Camp Grafton South Military Reservation, so the North Dakota National Guard should be consulted about any potential points of diversion. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Trapp, Henry Jr. 1968. Ground-water Resources of Eddy and Foster Counties, North Dakota. County Ground-Water Studies 5-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 93-94.

Comesky, A.E. 1989. Hydrogeology of Camp Grafton South, Eddy County, North Dakota. North Dakota Ground-Water Studies #8. North Dakota State Water Commission. Bismarck, ND. 81 pp.

Table 9.1.1. Summary of chemical properties of the Cherry Lake aquifer in Eddy County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 367 | 377 | 6.3 | 7.2 | 0 | 234 | - | - | 10 | 3.1 | 1.62 | 3 | 0.05 | 240 | 2 | 1.98 | 0.97 | 0.09 |
| **Maximum** | 4,260 | 4,560 | 9.7 | 8.3 | 0 | 2,830 | - | - | 117 | 52.1 | 21.8 | 974 | 0.66 | 761 | 2 | 331 | 1,070 | 73.9 |
| **Points** | 47 | 47 | 47 | 47 | 0 | 47 | - | - | 47 | 47 | 47 | 47 | 47 | 47 | 1 | 47 | 47 | 24 |
| **Mean** | 783.45 | 821.3 | 7.7 | 7.6 | 0 | 509.34 | - | - | 61.76 | 18.32 | 6.36 | 89.06 | 0.23 | 382.06 | 2 | 65.14 | 35 | 6.27 |
| **Median** | 613 | 632 | 7.6 | 7.5 | 0 | 392 | - | - | 64.1 | 18.3 | 5.94 | 22.2 | 0.2 | 353 | 2 | 41.5 | 4.44 | 0.71 |
| **Std Deviation** | 594.3 | 641.57 | 0.8 | 0.33 | 0 | 398.24 | - | - | 25.64 | 9.3 | 3.23 | 167.06 | 0.13 | 112.24 | 0 | 68.27 | 156.36 | 16 |
| **Std Error** | 86.69 | 93.58 | 0.12 | 0.05 | 0 | 58.09 | - | - | 3.74 | 1.36 | 0.47 | 24.37 | 0.02 | 16.37 | 0 | 9.96 | 22.81 | 3.27 |

Table 9.1.2. Summary of chemical properties of the Cherry Lake aquifer in Eddy County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 40 | 0 | 197 | - | 0.09 | - | - | - | - |
| **Maximum** | 442 | 118 | 624 | - | 37.3 | - | - | - | - |
| **Points** | 47 | 47 | 47 | - | 47 | - | - | - | - |
| **Mean** | 229.81 | 9.3 | 313.3 | - | 3.64 | - | - | - | - |
| **Median** | 248 | 0 | 289 | - | 0.58 | - | - | - | - |
| **Std Deviation** | 97.64 | 24.95 | 92.06 | - | 7.22 | - | - | - | - |
| **Std Error** | 14.24 | 3.64 | 13.43 | - | 1.05 | - | - | - | - |

Table 9.1.3. Summary of chemical properties of the Cherry Lake aquifer in Eddy County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | - | 0.01 | 0.01 | 1.02 | - | 1.24 | - | - |
| Maximum | 3.2 | 1.82 | 1.89 | 24.7 | - | 65.5 | - | - |
| Points | 47 | 38 | 46 | 13 | - | 42 | - | - |
| Mean | 0.36 | 0.33 | 0.46 | 3.98 | - | 14.3 | - | - |
| Median | 0.13 | 0.16 | 0.41 | 1.83 | - | 6.59 | - | - |
| Std Deviation | 0.6 | 0.42 | 0.35 | 6.32 | - | 16.89 | - | - |
| Std Error | 0.09 | 0.07 | 0.05 | 1.75 | - | 2.61 | - | - |

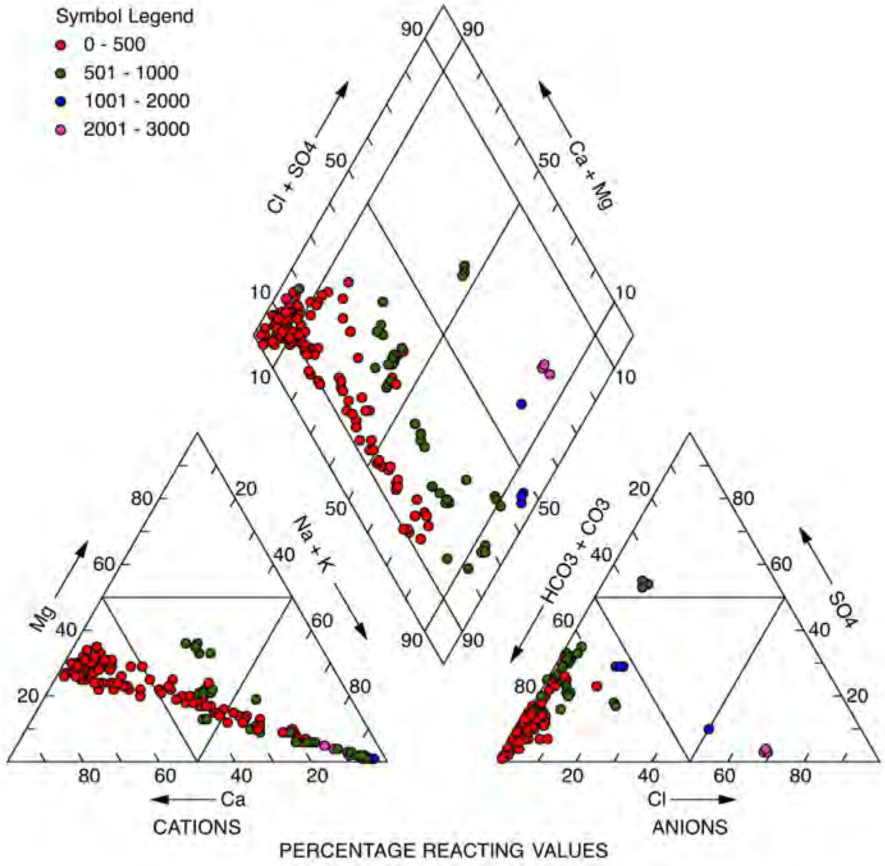


Figure 9.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Cherry Lake aquifer Eddy County.

### *9.2 Eastman (Foster County)*

The Eastman aquifer underlies about 45 square miles in Foster County (Study Area #9 map).

Aquifer Composition: The Eastman aquifer consists of layers of sand and gravel deposits interbedded with silt, clay and till. The saturated thickness, based on 20 sites, ranges from 17 to 130 feet, with an average thickness of about 60 feet. The depth to the aquifer varies from 29 to 173 feet with an average depth of about 96 feet. An example of the aquifer lithology is provided on Appendix Figure B.9.2.1.

Aquifer Yield: There are no published estimates of potential well yields. However, one water permit has specified three points of diversion for 1,800 gpm, or an average of about 600 gpm per site. Potential well yields of at least 500 gpm would not be unreasonable based on an average saturated thickness of 60 feet.

Aquifer Chemistry: The anion and cation distribution for water samples varies from a calcium-bicarbonate type to a sodium-bicarbonate type, with some water samples of the calcium and sodium-sulfate type (Figure 9.2.1). Dissolved solids concentrations range from about 700 to 2,000 mg/L, with mean and median values both near 1,400 mg/L (Table 9.2.1). Higher sulfate and sodium both correspond to higher dissolved solids (Figure 9.2.1).

Permit Acquisition Status: There are currently two water permits, one perfected and one conditional, for a total annual allocation of 608 acre-feet. There are no pending applications. If the recharge rate is as high as 0.5 inches per year, as much as 600 acre-feet per year may be available for further development from the Eastman aquifer.

Additional Considerations: **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Trapp, Henry Jr. 1968. Ground-water Resources of Eddy and Foster Counties, North Dakota. County Ground-Water Studies 5-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 67-68.

Table 9.2.1. Summary of chemical properties of the Eastman aquifer in Foster County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 1,015 | 1,190 | 7.1 | 7.7 | 773 | 710 | 2 | 17 | 14 | 2 | 5.4 | 190 | 0.2 | 310 | 0 | 0 | 25 | 0 |
| **Maximum** | 2,900 | 3,910 | 8.2 | 8.5 | 2,050 | 2,060 | 13 | 30 | 210 | 61 | 13 | 590 | 0.7 | 993 | 14 | 1,100 | 680 | 7 |
| **Points** | 18 | 18 | 15 | 18 | 16 | 18 | 15 | 17 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 17 |
| **Mean** | 1,904.8 | 2,332.8 | 7.8 | 8 | 1,431.4 | 1,395 | 7.97 | 24.73 | 83.67 | 26.1 | 8.97 | 405.67 | 0.41 | 772.56 | 0.89 | 178.04 | 282 | 1.42 |
| **Median** | 2,051.5 | 2,275 | 7.8 | 8 | 1,405 | 1,370 | 8 | 25 | 66.5 | 23 | 8.9 | 410 | 0.4 | 813.5 | 0 | 19.5 | 290 | 1 |
| **Std Deviation** | 527.67 | 559.82 | 0.35 | 0.2 | 289.05 | 297.25 | 2.31 | 3.44 | 44.59 | 14.29 | 1.66 | 95.82 | 0.18 | 172.99 | 3.29 | 334.81 | 175.28 | 1.77 |
| **Std Error** | 124.37 | 131.95 | 0.09 | 0.05 | 72.26 | 70.06 | 0.6 | 0.83 | 10.51 | 3.37 | 0.39 | 22.58 | 0.04 | 40.77 | 0.77 | 78.92 | 41.31 | 0.43 |

Table 9.2.2. Summary of chemical properties of the Eastman aquifer in Foster County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 62 | 0 | 679 | 0 | 4.8 | 0.25 | 0.81 | 1.25 | 1.81 |
| **Maximum** | 750 | 400 | 716 | 814 | 33 | 1.16 | 1.35 | 2.16 | 2.35 |
| **Points** | 18 | 18 | 2 | 18 | 18 | 14 | 16 | 14 | 16 |
| **Mean** | 316.28 | 41.67 | 697.5 | 557.06 | 11.37 | 0.85 | 1 | 1.85 | 2 |
| **Median** | 275 | 0 | 697.5 | 630 | 10.5 | 0.98 | 0.99 | 1.98 | 1.99 |
| **Std Deviation** | 162.68 | 121.57 | 26.16 | 246.39 | 6.39 | 0.31 | 0.15 | 0.31 | 0.15 |
| **Std Error** | 38.34 | 28.65 | 18.5 | 58.07 | 1.51 | 0.08 | 0.04 | 0.08 | 0.04 |

Table 9.2.3. Summary of chemical properties of the Eastman aquifer in Foster County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.03 | 0.02 | 0.07 | 0 | 0 | 6 | 50 | 3 |
| Maximum | 1.3 | 11 | 0.84 | 5.58 | 0.4 | 12 | 180 | 17 |
| Points | 16 | 18 | 18 | 3 | 2 | 3 | 2 | 2 |
| Mean | 0.34 | 1.64 | 0.28 | 2.19 | 0.2 | 8.33 | 115 | 10 |
| Median | 0.25 | 0.69 | 0.27 | 1 | 0.2 | 7 | 115 | 10 |
| Std Deviation | 0.31 | 2.72 | 0.2 | 2.98 | 0.28 | 3.21 | 91.92 | 9.9 |
| Std Error | 0.08 | 0.64 | 0.05 | 1.72 | 0.2 | 1.86 | 65 | 0 |

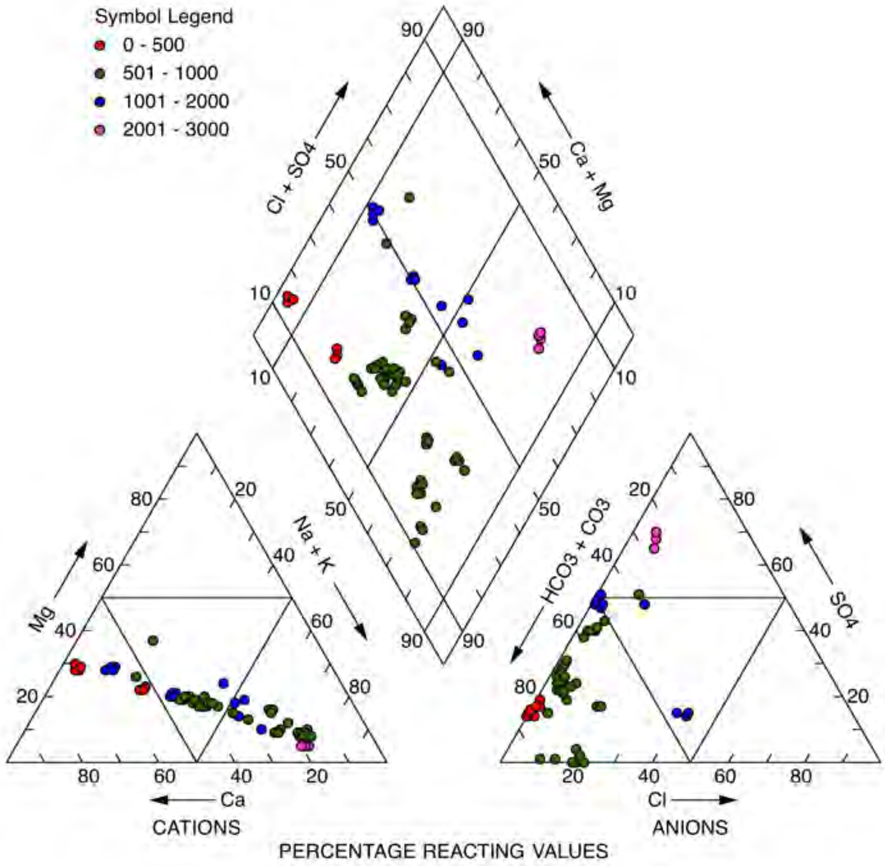


Figure 9.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Eastman aquifer in Foster County.

### *9.3 Manfred Aquifer (Wells County)*

The Manfred aquifer underlies about 12 square miles in Wells County (Study Area #9 map).

Aquifer Composition: The Manfred aquifer is a confined system of layered sand and gravel deposits interbedded with clay and silt. The range of saturated thicknesses for 20 sites was 121 to 129 feet, with a median saturated thickness of 45 feet, and buried at depths ranging from 30 to 221 feet, with a median depth of 68 feet bls. Buturla (1970) estimated the average thickness as about 70 feet, but with limited borings. An example of the lithology is provided on Appendix Figure B.9.3.1.

Aquifer Yield: Buturla (1970) estimated potential well yields as high as 500 gpm at some locations.

Aquifer Chemistry: Manfred aquifer water ranges from a calcium-bicarbonate type to a sodium-bicarbonate type, with some of the sodium-sulfate type (Figure 9.3.1). Dissolved solids concentrations range from about 200 to 3,000 mg/L, with a median of about 1,300 mg/L (Table 9.3.1). Higher sulfate concentrations correspond somewhat to higher dissolved solids. Iron and manganese concentrations are both high (Table 9.3.3).

Permit Acquisition Status: There are currently two perfected water permits for a total of 467 acre-feet per year. There are no applications pending.

Additional Considerations: Limited amounts of water, perhaps a few hundred acre-feet, may be available from this aquifer.

Citations:

Buturla, Frank Jr. 1970. Ground-water Resources of Wells County, North Dakota. County Ground-Water Studies 12-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 45-46.

Table 9.3.1. Summary of chemical properties of the Manfred aquifer in Wells County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 313 | 362 | 7.7 | 7.5 | 0 | 183 | 8.4 | 23.4 | 14.2 | 7.5 | 3.2 | 4 | 0.06 | 216 | NA | 7.91 | 1.07 | - |
| **Maximum** | 3,059 | 4,040 | 8.1 | 8.3 | 0 | 3,100 | 9.8 | 28.5 | 177 | 134 | 18.2 | 583 | 0.52 | 1,030 | NA | 1,750 | 240 | - |
| **Points** | 15 | 15 | 5 | 15 | 0 | 15 | 5 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | NA | 15 | 15 | - |
| **Mean** | 1,504 | 1,744.1 | 7.9 | 8 | 0 | 1,139 | 9.18 | 26.39 | 78.51 | 31.15 | 10.44 | 262.44 | 0.26 | 537.8 | NA | 425.94 | 65.07 | - |
| **Median** | 1,887 | 2,060 | 7.9 | 8 | 0 | 1,300 | 9 | 26.4 | 73.7 | 21.9 | 11.1 | 243 | 0.25 | 567 | NA | 336 | 49.8 | - |
| **Std Deviation** | 828.6 | 1,052.2 | 0.18 | 0.19 | 0 | 783.6 | 0.58 | 1.54 | 53.19 | 30.45 | 4.48 | 207.44 | 0.15 | 233.31 | NA | 448.49 | 66.44 | - |
| **Std Error** | 213.94 | 271.68 | 0.08 | 0.05 | 0 | 202.33 | 0.26 | 0.41 | 13.73 | 7.86 | 1.16 | 53.56 | 0.04 | 60.24 | NA | 115.8 | 17.16 | - |

Table 9.3.2. Summary of chemical properties of the Manfred aquifer in Wells County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 66 | 1 | 177 | - | 0.11 | - | - | - | - |
| **Maximum** | 994 | 530 | 843 | - | 25.3 | - | - | - | - |
| **Points** | 15 | 15 | 15 | - | 15 | - | - | - | - |
| **Mean** | 324.53 | 52.07 | 441.07 | - | 7.5 | - | - | - | - |
| **Median** | 257 | 0 | 465 | - | 5.94 | - | - | - | - |
| **Std Deviation** | 241.79 | 141.09 | 191.36 | - | 7.56 | - | - | - | - |
| **Std Error** | 62.43 | 36.43 | 49.41 | - | 1.95 | - | - | - | - |

Table 9.3.3. Summary of chemical properties of the Manfred aquifer in Wells County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | - | 0.13 | 0.04 | - | - | - | - | - |
| Maximum | - | 2.45 | 0.83 | - | - | - | - | - |
| Points | - | 15 | 15 | - | - | - | - | - |
| Mean | - | 0.76 | 0.28 | - | - | - | - | - |
| Median | - | 0.45 | 0.19 | - | - | - | - | - |
| Std Deviation | - | 0.67 | 0.24 | - | - | - | - | - |
| Std Error | - | 0.17 | 0.06 | - | - | - | - | - |

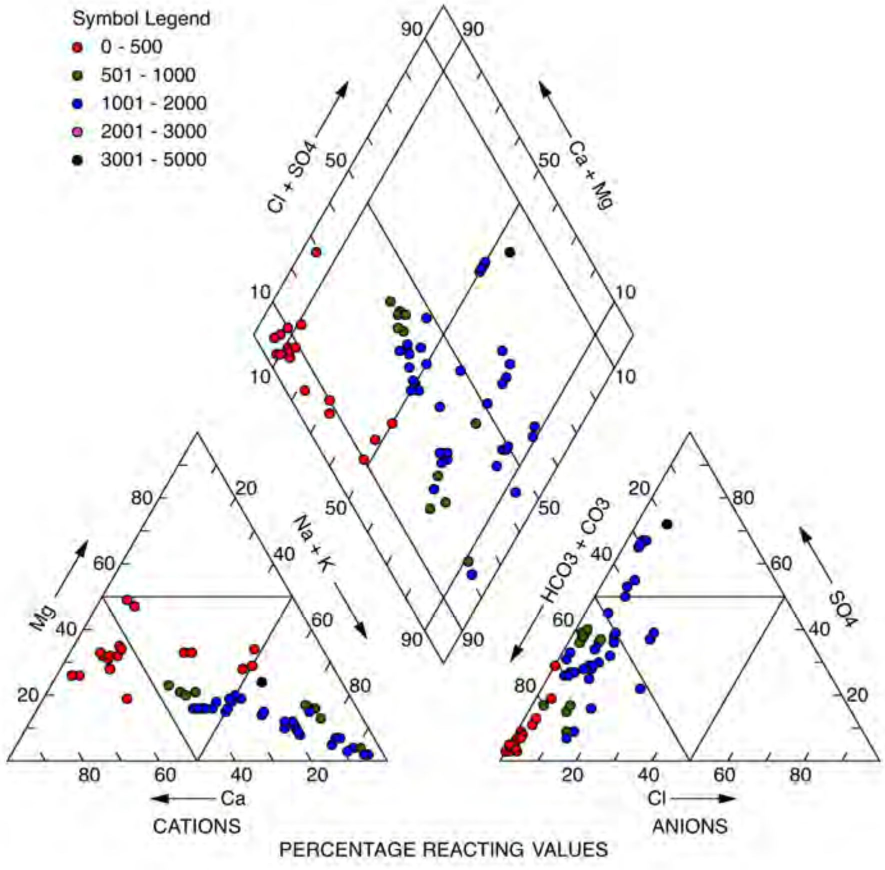


Figure 9.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Manfred aquifer in Wells County.

### *9.4 New Rockford Aquifer (McHenry, Pierce, Benson, Eddy, Foster, Griggs and Wells Counties)*

The New Rockford aquifer underlies about 328 square miles in McHenry, Pierce, Benson, Eddy, Foster, Griggs and Wells Counties (northwest to southeast) - see the Study Area #9 map.

Aquifer Composition: The New Rockford aquifer in the above listed counties has been described as consisting of medium and coarse sand to fine gravel. Buturla (1970) described the aquifer as having an average aquifer thickness of 120 feet, underlying about 134 feet of till. Randich (1977) described an average aquifer thickness of 147 feet underlying about 150 feet of till. Trapp (1968) reported a maximum thickness of about 161 feet underling 50 to 200 feet of till. Three examples of lithologies are provided on Appendix Figures B.9.4.1, B.9.4.2 and B.9.4.3.

Aquifer Yield: Two aquifer tests (near Selz and near New Rockford) have been reported to have transmissivities ranging from 34,760 ft.$^2$/day to 56,000 ft.$^2$/day and storage coefficients of ranging from 0.00043 to 0.0007 (Trapp. 1968, Randich 1971). Buturla (1970) has estimated that sustainable well yields of 250 to 500 gpm should be possible in many parts of the aquifer, and more may be sustainable where the aquifer is thickest. Randich (1977) suggested that sustained yields would likely be limited to 750 to 1,000 gpm.

Aquifer Chemistry: The aquifer chemistry varies widely from a calcium-bicarbonate, and sodium-bicarbonate type to a magnesium-sulfate type (Figure 9.4.1). Dissolved solids concentrations range from about 100 mg/L to as high as 7,400 mg/L, although 95% of the water samples are below 1,000 mg/L (Table 9.4.1). The median of dissolved solids is close to 1,000 mg/L. Higher sodium and higher sulfate generally correspond to higher dissolved solids. Highest dissolved solids also correspond to increased magnesium (Figure 9.4.1). Manganese concentrations are generally high. Arsenic also tends to be high, with a maximum measured concentration of 21.8 mg/L (double the EPA-MCL), and median and mean values for 17 wells both above the EPA-MCL. Selenium trends somewhat high, but is still less than the EPA-MCL (50 μg/L), (Table 9.4.3).

Permit Acquisition Status: There are currently 13 water permits, 11 perfected and two conditional for the New Rockford aquifer in Study Area #9. A total annual allocation of 4,454 acre-feet has been approved for beneficial use. There are no pending applications. Using an estimated recharge rate of 0.25 to 0.5 inches per year for a deep confined aquifer, up to 4,000 acre-feet of additional development may be possible.

Additional Considerations: Water use development will likely be incremental and monitored by the managing hydrologist. The SWC managing hydrologist should be consulted before planning development. Planning for disposal of filtrate from reverse osmosis should consider concentrations of both arsenic and selenium. **Important: read**

**pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Buturla, Frank Jr. 1970. Ground-Water Resources of Wells County, North Dakota. County Ground-Water Studies 12-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 36-42.

Patch, Jon C. and Gregory W. Knell. 1988. The Hydrogeology of the New Rockford aquifer system in Wells County, North Dakota. North Dakota Ground-Water Studies, No. 95. North Dakota State Water Commission. Bismarck, ND. 178 pp.

Randich, P.G. 1977. Ground-Water Resources of Benson and Pierce Counties, North Dakota. County Ground-Water Studies 18-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 21-30.

Trapp, Henry Jr. 1968. Ground-Water Resources of Eddy and Foster Counties, North Dakota. County Ground-Water Studies 5-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 41-57.

Table 9.4.1. Summary of chemical properties of the New Rockford aquifer in McHenry, Pierce, Benson, Eddy, Foster, Griggs and Wells Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 271 | 166 | 7.4 | 7.1 | 600 | 104 | 7.9 | 7.86 | 14.3 | 4.3 | 3.86 | 12.2 | 0.05 | 75 | - | 20.4 | 1.55 | - |
| **Maximum** | 8,250 | 9,090 | 8.8 | 8.4 | 1,610 | 7,440 | 16.5 | 30.9 | 288 | 155 | 23.1 | 2,160 | 0.49 | 1,340 | - | 4,120 | 444 | - |
| **Points** | 70 | 71 | 36 | 71 | 4 | 71 | 41 | 50 | 71 | 71 | 71 | 71 | 71 | 71 | - | 71 | 71 | - |
| **Mean** | 1,697.4 | 1,820.2 | 8.1 | 7.9 | 1,247.5 | 1,184.1 | 9.43 | 25.03 | 109.35 | 35.33 | 10.62 | 265.5 | 0.2 | 711.94 | - | 345.26 | 69.33 | - |
| **Median** | 1,585 | 1,660 | 8.2 | 7.9 | 1,390 | 998 | 9.2 | 25.85 | 90.6 | 27.8 | 10.4 | 229 | 0.19 | 710 | - | 162 | 42.9 | - |
| **Std Deviation** | 1,024.5 | 1,136.9 | 0.3 | 0.25 | 445.82 | 913 | 1.42 | 3.87 | 62.19 | 25.62 | 3.95 | 273.91 | 0.08 | 227.54 | - | 534.31 | 84.22 | - |
| **Std Error** | 122.45 | 134.93 | 0.05 | 0.03 | 222.91 | 108.35 | 0.22 | 0.55 | 7.38 | 3.04 | 0.47 | 32.51 | 0.01 | 27 | - | 63.41 | 9.99 | - |

Table 9.4.2. Summary of chemical properties of the New Rockford aquifer in McHenry, Pierce, Benson, Eddy, Foster, Griggs and Wells Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 57 | 0 | 61 | - | 0.33 | 1.17 | 0.67 | 2.17 | 1.67 |
| **Maximum** | 1,360 | 840 | 1,100 | - | 25.5 | 1.17 | 1.28 | 2.17 | 2.28 |
| **Points** | 71 | 71 | 67 | - | 71 | 1 | 4 | 1 | 4 |
| **Mean** | 418.65 | 53.34 | 579.54 | - | 6.11 | 1.17 | 1.04 | 2.17 | 2.04 |
| **Median** | 369 | 0 | 582 | - | 5.14 | 1.17 | 1.1 | 2.17 | 2.11 |
| **Std Deviation** | 251.38 | 146.95 | 189.17 | - | 4.81 | 0 | 0.26 | 0 | 0.26 |
| **Std Error** | 29.83 | 17.44 | 23.11 | - | 0.57 | 0 | 0.13 | 0 | 0.13 |

Table 9.4.3. Summary of chemical properties of the New Rockford aquifer in McHenry, Pierce, Benson, Eddy, Foster, Griggs and Wells Counties: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.18 | 0.05 | 0.01 | 0.00 | - | 3.49 | 24.3 | 1.62 |
| Maximum | 1.62 | 11.4 | 1.86 | 32.30 | - | 21.8 | 140 | 9.17 |
| Points | 11 | 71 | 71 | 17.00 | - | 17 | 8 | 8 |
| Mean | 0.46 | 1.42 | 0.47 | 10.10 | - | 11.72 | 77.44 | 5.07 |
| Median | 0.33 | 0.66 | 0.4 | 10.00 | - | 10.3 | 66.8 | 5.02 |
| Std Deviation | 0.4 | 2.18 | 0.33 | 7.86 | - | 5.33 | 41.56 | 2.69 |
| Std Error | 0.12 | 0.26 | 0.04 | 1.91 | - | 1.29 | 14.69 | 0.95 |

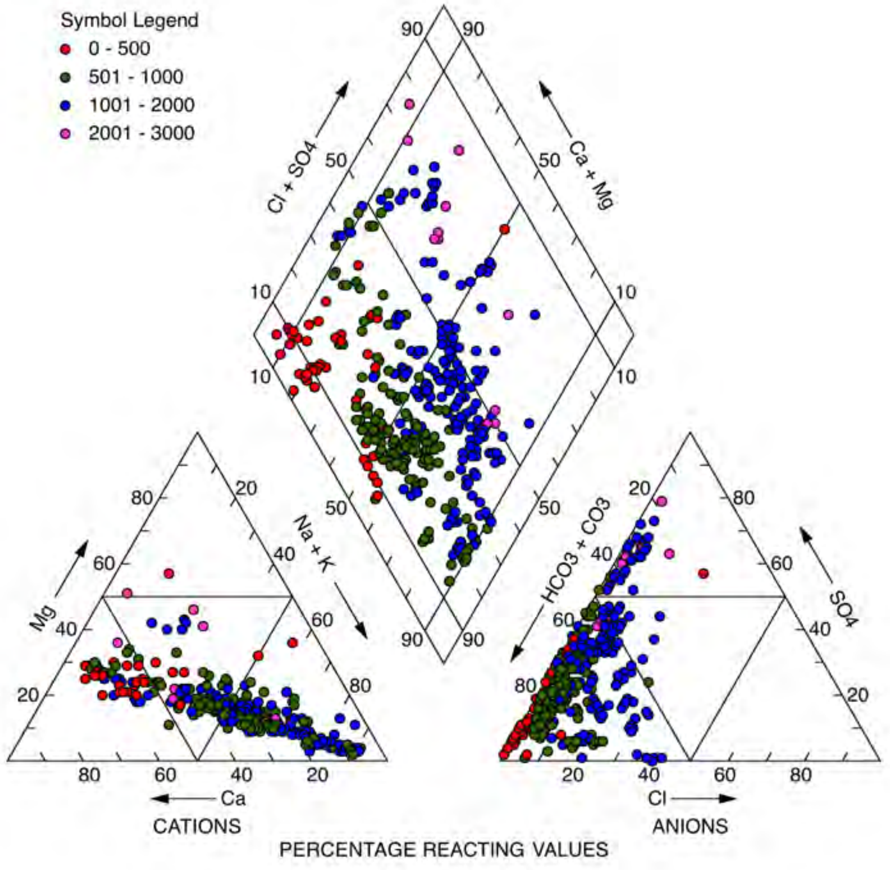


Figure 9.4.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the New Rockford aquifer in McHenry, Pierce, Benson, Eddy, Foster, Griggs and Wells Counties.

## *9.5 Pipestem Creek Aquifer (Foster and Wells Counties)*

The Pipestem Creek aquifer underlies about 24 square miles in Wells and Foster Counties (Study Area #9 map).

Aquifer Composition: Buturla (1970) described the aquifer as composed of medium to coarse sand and gravel, and having an average thickness of about 20 feet, with a water level 5 to 12 feet bls. An example of the aquifer lithology is provided on Appendix Figure B.9.5.1.

Aquifer Yield: No well yield estimates are provided by Burtula (1970). The Sykeston water permit is approved for 100 gpm between two points of diversion, and an irrigation permit is approved for 200 gpm between six points of diversion. These permits indicate that existing pumping rates may be low, near or less than 50 gpm. Relatively small saturated thickness will likely limit most local pumping rates to less than 200 gpm.

Aquifer Chemistry: Water is primarily of the calcium sodium-bicarbonate type, with some well samples of the sodium-sulfate type (Figure 9.5.1). Dissolved solids concentrations range from about 600 to 1,800 mg/L, with a median between 900 and 1,000 mg/L (Table 9.5.1). Iron and manganese concentrations are high (Table 9.5.3).

.

Permit Acquisition Status: There are currently two water permits, one conditional and one perfected, for a total of annual allocation of 614 acre-feet from the Pipestem Creek aquifer. Very little of the permitted water has been used in recent years. The city of Sykeston, one of the primary users, now obtains its municipal water from a rural water system. Using an estimated recharge of 1 to 2 inches per year for an unconfined aquifer, as much as 600 to 1,800 acre-feet per year may be available for future development.

Additional Considerations: Limited aquifer width, and limited saturated thickness may require multiple wells. Water supplies may not be sustainable during prolonged drought. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Buturla, Frank Jr. 1970. Ground-water Resources of Wells County, North Dakota. County Ground-Water Studies 12-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 45-46.

Table 9.5.1. Summary of chemical properties of the Pipestem Creek aquifer in Foster and Wells Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 975 | 958 | 8 | 7.8 | 641 | 648 | 8 | 25 | 80 | 36 | 4.6 | 62 | 0.1 | 327 | 0 | 205 | 15 | 0 |
| **Maximum** | 2,744 | 2,850 | 8.1 | 8 | 1,150 | 1,770 | 22 | 27 | 227 | 99.8 | 12 | 335 | 0.6 | 589 | 1 | 1,300 | 99 | 225 |
| **Points** | 4 | 6 | 3 | 6 | 5 | 6 | 4 | 3 | 4 | 4 | 4 | 6 | 4 | 6 | 6 | 6 | 6 | 5 |
| **Mean** | 1,571 | 1,611.3 | 8 | 7.9 | 945.6 | 1,049 | 12.38 | 26 | 131.5 | 58.7 | 8.9 | 154.83 | 0.27 | 434.33 | 0.17 | 490.33 | 43.18 | 65.98 |
| **Median** | 1,282.5 | 1,430 | 8 | 7.9 | 997 | 944 | 9.75 | 26 | 109.5 | 49.5 | 9.5 | 131.5 | 0.18 | 414 | 0 | 343.5 | 33.55 | 3.9 |
| **Std Deviation** | 795.35 | 648.52 | 0.08 | 0.1 | 188.14 | 380.42 | 6.63 | 1 | 65.84 | 29.18 | 3.47 | 100.56 | 0.23 | 102.35 | 0.41 | 419.65 | 31.42 | 98.58 |
| **Std Error** | 397.67 | 264.76 | 0.04 | 0.04 | 84.14 | 155.3 | 3.31 | 0.58 | 32.92 | 14.59 | 1.73 | 41.05 | 0.11 | 41.78 | 0.17 | 171.32 | 12.83 | 44.09 |

Table 9.5.2. Summary of chemical properties of the Pipestem Creek aquifer in Foster and Wells Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 350 | - | 330 | 0 | 1.1 | 0.78 | 0.68 | 1.78 | 1.68 |
| **Maximum** | 978 | 649 | 330 | 483 | 4.66 | 1.04 | 1.08 | 2.04 | 2.08 |
| **Points** | 6 | 6 | 1 | 6 | 6 | 2 | 3 | 2 | 3 |
| **Mean** | 610.33 | 266.67 | 330 | 300.83 | 2.66 | 0.91 | 0.89 | 1.91 | 1.89 |
| **Median** | 582 | 235 | 330 | 314 | 2.45 | 0.91 | 0.92 | 1.91 | 1.92 |
| **Std Deviation** | 232.37 | 237.85 | 0 | 169.17 | 1.28 | 0.18 | 0.2 | 0.18 | 0.2 |
| **Std Error** | 94.87 | 97.1 | 0 | 69.06 | 0.52 | 0.13 | 0.12 | 3.4e+38 | 0.12 |

Table 9.5.3. Summary of chemical properties of the Pipestem Creek aquifer in Foster and Wells Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | - | 0.1 | 0.01 | 13 | - | - | - | - |
| Maximum | 0.37 | 5.5 | 0.67 | 13 | - | - | - | - |
| Points | 4 | 6 | 4 | 1 | - | - | - | - |
| Mean | 0.26 | 1.63 | 0.25 | 13 | - | - | - | - |
| Median | 0.33 | 0.73 | 0.16 | 13 | - | - | - | - |
| Std Deviation | 0.17 | 2.11 | 0.29 | 0 | - | - | - | - |
| Std Error | 0.09 | 0.86 | 0.15 | 0 | - | - | - | - |

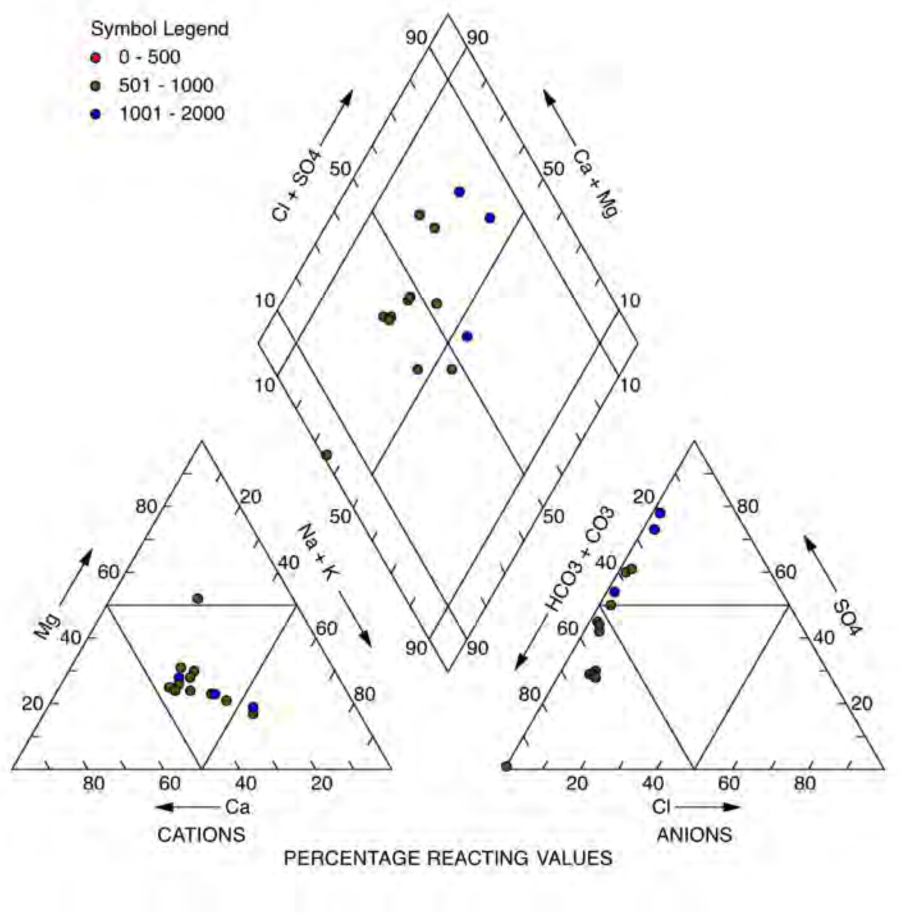


Figure 9.5.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Pipestem Creek aquifer in Foster and Wells Counties.

### *9.6 Spiritwood Aquifer (Benson, Eddy, Griggs, Nelson and Ramsey Counties / includes Griggs County portion from Study Area #10)*

The Spiritwood aquifer system in Study Area #9 is divided into four subunits, including the northernmost *Devils Lake(* 339 square miles) subunit, and proceeding southward a *Warwick* (60 square miles) subunit in northeastern Benson and northwestern Nelson Counties, a *Sheyenne River* (18 square miles) subunit in eastern Benson and southwestern Nelson Counties, and a *Griggs County* (290 square miles) subunit in southeastern Benson and northwestern Griggs Counties.

Aquifer Composition: All units are described as sand, gravel, and intermixed sand and gravel interbedded in many areas with clay. The Devils Lake subunit is described (Hutchinson and Klausing 1980) as having a maximum thickness of 336 feet and an average thickness of about 68 feet, except for the Minnewaukan area that is described as having a maximum thickness of about 159 feet and an average thickness of 50 feet. Randich (1977) described the *Warwick* subunit as having an average thickness of about 94 feet, with the aquifer surface between 79 and 180 feet bls. The *Sheyenne River* subunit was described by Downey (1973) as having a maximum thickness of 320 feet, and an average thickness of about 100 feet, buried about 148 feet bls. Downey and Armstrong (1977) described the *Griggs County* subunit as ranging from one to 550 feet in thickness, with an average of thickness of about 100 feet. Three examples of lithology are provided on Appendix Figures B.9.6.1 (*Griggs County* subunit), B.9.6.2 (*Warwick* subunit) and B.9.6.3 (*Devils Lake* subunit).

Aquifer Yield: All of the authors cited above have estimated potential well yields at between 500 and 1,500 gpm. Aquifer tests at Camp Grafton and seven miles west of the city of Devils Lake calculated transmissivities of 7,400 and 5,000 ft.$^2$/day, respectively. Storage coefficients were 0.0004 and 0.0002 (Hutchinson and Klausing 1980). An aquifer test in Griggs County was reported to have a transmissivity of 4,500 ft.$^2$/day and a storage coefficient of 0.02 (Downey and Armstrong 1977).

Aquifer Chemistry: The predominant anion and cation distribution ranges from the calcium-bicarbonate type to the sodium-bicarbonate type, with some of the calcium and sodium-sulfate type (Figure 9.6.1). Dissolved solids are highest in the *Devils Lak*e subunit, ranging from about 550 to 1,700 mg/L, with a median of 1,210 mg/L (Table 9.6.1a). They are somewhat similar in the *Sheyenne River* and *Griggs County* subunits, ranging from about 200 to 9,500 mg/L with a median of 462 mg/L (Table 9.6.1c). Although a few values are very high, 99% of all dissolved solids concentrations are below 2,300 mg/L. The aquifer is freshest in the *Warwick* subunit, possibly affected by the hydraulic connection with the overlying Warwick aquifer. Higher sulfate generally corresponds to higher dissolved solids. Sodium has a tendency to be higher with higher dissolved solids. Iron and manganese concentrations are high. Some water samples have arsenic concentrations above the EPA-MCL (Table 9.6.3).

Permit Acquisition Status: There are currently 64 water permits, 41 perfected, 12 conditional, five pending and six held in abeyance, for a total annual allocation of 20,842 acre-feet from the Spiritwood aquifer in Benson, Eddy, Griggs, Nelson and Ramsey Counties. Using potential annual recharge values of 0.25 to 0.5 inches, as much as 5,000 to 10,000 acre-feet may be available for beneficial use from the Spiritwood aquifer in the *Devils Lake* subunit area. There are no pending applications in this area. The *Warwick*, *Sheyenne River* and *Griggs County* subunits are mapped as conditional, indicating that some water may be available for beneficial use at some locations.

Additional Considerations: Availability will be dependent on individual permit locations and local recharge sources and conditions. Further use may pose some delays and impediments. Applicants should consult the managing SWC hydrologist before selecting points of diversion in this area. Water should be tested for arsenic, and consideration should be given to appropriate filtrate disposal if reverse osmosis water treatment is to be employed. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Downey, Joe S. 1973. Ground-Water Resources of Nelson and Walsh Counties, North Dakota. County Ground-Water Studies 17-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 27-31.

Downey, Joe S., and C.A. Armstrong 1977. Ground-Water Resources of Griggs County, North Dakota. County Ground-Water Studies 17-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 14-16.

Hutchinson, R.D. and Robert L. Klausing. 1980. Ground-water Resources of Ramsey County, North Dakota. County Ground-Water Studies 26-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 16-23.

Randich, P.G. 1977. Ground-Water Resources of Benson and Pierce Counties, North Dakota. County Ground-Water Studies 18-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 21-30.

Table 9.6.1a. Summary of chemical properties of the Spiritwood (*Devils Lake* - Townships 153 and 154) aquifer: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 843 | 878 | 6.8 | 6.7 | 1,070 | 544 | 12.5 | 29.5 | 61.7 | 25.4 | 4.65 | 17.5 | 0.1 | 285 | - | 219 | 9.34 | 0.4 |
| **Maximum** | 2,739 | 2,790 | 8.2 | 8.1 | 1,270 | 1,730 | 12.5 | 35.6 | 180 | 79 | 15 | 490 | 0.2 | 597 | - | 822 | 240 | 0.4 |
| **Points** | 7 | 7 | 3 | 7 | 2 | 7 | 1 | 4 | 7 | 7 | 7 | 7 | 7 | 7 | - | 7 | 7 | 1 |
| **Mean** | 1,602.4 | 1,756.9 | 7.6 | 7.7 | - | 1,145.7 | - | 33.15 | 123.76 | 49.77 | 10.82 | 227.21 | 0.14 | 475.14 | - | 460.43 | 84.79 | - |
| **Median** | 1,560 | 1,660 | 7.7 | 7.8 | - | 1,210 | - | 33.75 | 120 | 40.7 | 11.9 | 171 | 0.14 | 496 | - | 453 | 39.4 | - |
| **Std Deviation** | 738.41 | 680.37 | 0.71 | 0.47 | - | 412.17 | - | 2.62 | 42.66 | 20.87 | 3.68 | 170.11 | 0.04 | 108.79 | - | 206.83 | 93.8 | - |
| **Std Error** | 279.09 | 257.16 | 0.41 | 0.18 | - | 155.79 | - | 1.31 | 16.13 | 7.89 | 1.39 | 64.3 | 0.01 | 41.12 | - | 78.18 | 35.45 | - |

Table 9.6.1b. Summary of chemical properties of the Spiritwood (*Warwick* - T 151 and 152) aquifer: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 393 | 417 | 6.9 | 7.3 | 1,650 | 259 | 8.1 | 10.1 | 20.3 | 7.6 | 2.44 | 4.4 | 0.07 | 228 | - | 12.4 | 1.01 | 0.09 |
| **Maximum** | 2,460 | 2,600 | 8.1 | 8.2 | 1,650 | 1,690 | 11 | 41.9 | 205 | 83.3 | 18.1 | 495 | 0.46 | 687 | - | 706 | 239 | 2.04 |
| **Points** | 67 | 67 | 11 | 67 | 1 | 67 | 11 | 54 | 67 | 67 | 67 | 67 | 67 | 67 | - | 67 | 67 | 23 |
| **Mean** | 889.91 | 949.4 | 7.7 | 7.8 | 1,650 | 592.09 | 9.33 | 31.98 | 87.84 | 27.73 | 6.31 | 94.38 | 0.2 | 400.36 | - | 162.31 | 18.71 | 0.26 |
| **Median** | 675 | 745 | 7.7 | 7.8 | 1,650 | 462 | 9.3 | 32.4 | 71.7 | 23.1 | 5.63 | 56.1 | 0.17 | 378 | - | 78.2 | 5.9 | 0.18 |
| **Std Deviation** | 467.98 | 521.3 | 0.31 | 0.2 | 0 | 343.87 | 1.01 | 4.53 | 54.09 | 16.29 | 2.93 | 109.16 | 0.09 | 111.11 | - | 174.11 | 35.67 | 0.4 |
| **Std Error** | 57.17 | 63.69 | 0.09 | 0.02 | 0 | 42.01 | 0.3 | 0.62 | 6.61 | 1.99 | 0.36 | 13.34 | 0.01 | 13.57 | - | 21.27 | 4.36 | 0.08 |

Table 9.6.1c. Summary of chemical properties of the Spiritwood (*Sheyenne River - Griggs County* – T 146-150) aquifer: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 130 | 364 | 6.2 | 6.9 | 234 | 204 | 3 | 1 | 2 | 2 | 1.6 | 3 | 0.06 | 151 | 0 | 0 | 0 | 0 |
| **Maximum** | 6,500 | 10,000 | 8.3 | 10.1 | 9,800 | 9,480 | 16 | 39 | 719 | 917 | 50 | 1,040 | 4.8 | 802 | 100 | 5,660 | 649 | 526 |
| **Points** | 662 | 753 | 29 | 750 | 582 | 750 | 488 | 565 | 748 | 748 | 747 | 749 | 748 | 749 | 748 | 748 | 748 | 754 |
| **Mean** | 1,038.6 | 1,094.7 | 7.8 | 7.9 | 761.72 | 714.13 | 8.44 | 27.87 | 68.47 | 26.31 | 7.51 | 144.41 | 0.26 | 414 | 0.83 | 186.55 | 49.72 | 4.44 |
| **Median** | 932 | 964 | 7.7 | 7.9 | 652 | 622 | 8 | 28.8 | 55.7 | 20 | 7.4 | 140 | 0.2 | 400 | 0 | 123 | 24 | 0.95 |
| **Std Deviation** | 526.46 | 683.24 | 0.39 | 0.3 | 649.51 | 561.32 | 1.8 | 4.93 | 55.49 | 45.47 | 3.43 | 110.83 | 0.2 | 103.07 | 4.23 | 322.13 | 69.59 | 31.75 |
| **Std Error** | 20.46 | 24.9 | 0.07 | 0.01 | 26.92 | 20.5 | 0.08 | 0.21 | 2.03 | 1.66 | 0.13 | 4.05 | 0.01 | 3.77 | 0.15 | 11.78 | 2.54 | 1.16 |

Table 9.6.2a. Summary of chemical properties of the Spiritwood (*Devils Lake* - Townships 153 and 154) aquifer: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 259 | 0 | 233 | - | 0.34 | 1.01 | 1.15 | 2.01 | 2.15 |
| **Maximum** | 770 | 320 | 489 | - | 11.4 | 1.29 | 1.16 | 2.29 | 2.16 |
| **Points** | 7 | 7 | 5 | - | 7 | 2 | 2 | 2 | 2 |
| **Mean** | 514.14 | 145.43 | 373.8 | - | 4.75 | - | - | - | - |
| **Median** | 490 | 190 | 366 | - | 3.8 | - | - | - | - |
| **Std Deviation** | 182.31 | 134.22 | 103.15 | - | 3.95 | - | - | - | - |
| **Std Error** | 68.91 | 50.73 | 46.13 | - | 1.49 | - | - | - | - |

Table 9.6.2b. Summary of chemical properties of the Spiritwood (*Warwic*k - T 151 and 152): use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 82 | 0 | 187 | - | 0.13 | - | 1.13 | - | 2.13 |
| **Maximum** | 737 | 348 | 546 | - | 10.6 | - | 1.13 | - | 2.13 |
| **Points** | 67 | 67 | 66 | - | 67 | - | 1 | - | 1 |
| **Mean** | 333.69 | 67.75 | 324.55 | - | 2.59 | - | - | - | - |
| **Median** | 275 | 0 | 309 | - | 1.49 | - | - | - | - |
| **Std Deviation** | 194.71 | 104.81 | 86.98 | - | 2.78 | - | - | - | - |
| **Std Error** | 23.79 | 12.81 | 10.71 | - | 0.34 | - | - | - | - |

Table 9.6.2c. Summary of chemical properties of the Spiritwood (*Sheyenne River- Griggs County* - 146-150): use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 10 | - | - | - | 0.1 | 0.01 | -0.78 | 1.01 | 0.22 |
| **Maximum** | 5,030 | 4,490 | 640 | 673 | 36 | 0.43 | 1.51 | 1.43 | 2.51 |
| **Points** | 752 | 746 | 170 | 761 | 753 | 2 | 580 | 2 | 580 |
| **Mean** | 278.79 | 49.55 | 317.77 | 270.21 | 4.49 | 0.22 | 0.6 | 1.22 | 1.6 |
| **Median** | 228.5 | 0 | 288.5 | 311 | 4.06 | 0.22 | 0.64 | 1.22 | 1.64 |
| **Std Deviation** | 307 | 261.14 | 79.81 | 162.89 | 3.79 | 0.3 | 0.36 | 0.3 | 0.36 |
| **Std Error** | 11.2 | 9.56 | 6.12 | 5.9 | 0.14 | 0.21 | 0.01 | 0.21 | 0.01 |

Table 9.6.3a. Summary of chemical properties of the Spiritwood (*Devils Lake* - Townships 153 and 154) aquifer: selected trace elements.

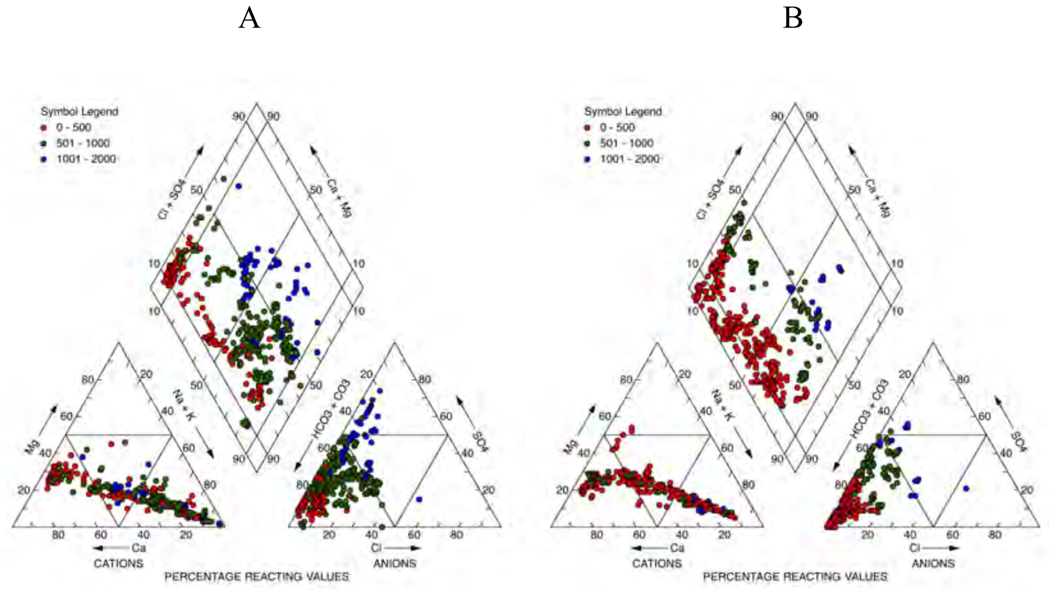
| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 1.42 | 0.05 | 0.15 | 0 | 0 | 2 | 160 | 1 |
| Maximum | 1.42 | 41.7 | 0.72 | 3.08 | 0.2 | 4 | 190 | 1 |
| Points | 1 | 7 | 7 | 3 | 2 | 3 | 2 | 2 |
| Mean | - | 7.65 | 0.41 | 1.03 | 0.1 | 3.28 | - | - |
| Median | - | 2.2 | 0.37 | 0 | 0.1 | 3.85 | - | - |
| Std Deviation | - | 15.09 | 0.19 | 1.78 | 0.14 | 1.11 | - | - |
| Std Error | - | 5.7 | 0.07 | 1.03 | 0.1 | 0.64 | - | - |

Table 9.6.3b. Summary of chemical properties of the Spiritwood (*Warwick* - Townships 151 and 152) aquifer: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | - | 0.02 | 0.05 | 2.15 | - | 1.14 | 29.6 | 1.2 |
| Maximum | - | 9.96 | 1.61 | 4.63 | - | 16.3 | 147 | 23.5 |
| Points | - | 67 | 67 | 2 | - | 15 | 15 | 15 |
| Mean | - | 1.77 | 0.4 | 3.39 | - | 6.09 | 68.75 | 7.92 |
| Median | - | 1.23 | 0.28 | 3.39 | - | 5.22 | 63.5 | 7.2 |
| Std Deviation | - | 1.76 | 0.36 | 1.75 | - | 4.07 | 25.87 | 6.63 |
| Std Error | - | 0.21 | 0.04 | 1.24 | - | 1.05 | 6.68 | 1.71 |

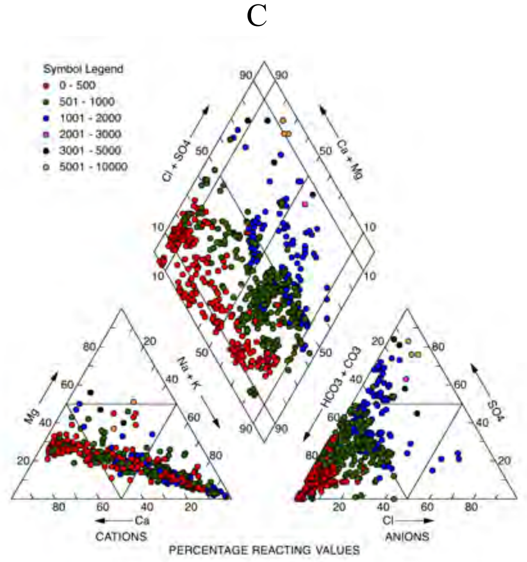
Table 9.6.3c. Summary of chemical properties of the Spiritwood (*Sheyenne River - Griggs County* – Townships 146-150) aquifer: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | - | - | - | - | - | - | 14.7 | - |
| Maximum | 8.11 | 13 | 3.9 | 7.62 | 0.4 | 64 | 155 | 19 |
| Points | 502 | 748 | 748 | 89 | 47 | 89 | 47 | 47 |
| Mean | 0.37 | 0.78 | 0.45 | 1.15 | 0.17 | 6.65 | 75.88 | 6.3 |
| Median | 0.34 | 0.47 | 0.21 | 1 | 0.2 | 6.03 | 62.3 | 5.76 |
| Std Deviation | 0.42 | 1.07 | 0.51 | 1.13 | 0.09 | 7.46 | 39.26 | 4.29 |
| Std Error | 0.02 | 0.04 | 0.02 | 0.12 | 0.01 | 0.79 | 5.73 | 0.63 |



Townships 146 through 150
(*Griggs County* and *Sheyenne River* subunits)

Townships 151 and 152
(*Warwick* subunit)



Townships 153 and 154
(*Devils Lake* subunit)

Figure 9.6.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Spiritwood aquifer in Benson, Eddy, Griggs, Nelson and Ramsey Counties.

### *9.7 Tokio Aquifer (Benson County)*

The Tokio aquifer underlies about 45 square miles in southestern Benson County (Study Area #9 map).

Aquifer Composition: The Tokio aquifer has been described as "collapsed outwash" consisting of sand and gravel, mixed with silt and clay (Randich 1977). The saturated thickness varies from 10 to 89 feet, with an average thickness of about 32 feet. An example of the aquifer lithology are shown on Appendix Figure B.9.7.1.

Aquifer Yield: Randich (1977) estimated potential well yields to be less than 100 gpm.

Aquifer Chemistry: Limited water samples (five wells) indicate that the water is very fresh, varying from about 200 to 400 mg/L, with a median near 350 mg/L (Table 9.7.1). The water is of the calcium-bicarbonate type (Figure 9.7.1). Manganese concentrations are high. Arsenic concentrations in one of only two water samples were very high, about five times the EPA-MCL of 10 µg/L (Table 9.7.3).

Permit Acquisition Status: There are currently two perfected water permits for an annual allocation of 712 acre-feet per year. There are no pending applications. Based on recharge estimates of 1 to 2 inches per year for an unconfined aquifer, as much as 1,500 to 4,000 acre-feet may be available for further development after accounting for current permitted use.

Additional Considerations: Much of the land overlying the Tokio aquifer is located on the Spirit Lake Sioux Reservation. The Tribal Council should be consulted concerning any major development. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Randich, P.G. 1977. Ground-water Resources of Benson and Pierce Counties, North Dakota. County Ground-Water Studies 18-Part III. North Dakota State Water Commission. Bismarck, ND. p. 60.

Table 9.7.1. Summary of chemical properties of the Tokio aquifer in Benson County: general chemistry.

| | **SC-f µS/cm** | **SC-l µS/cm** | **pH-f** | **pH-l** | **TDS-d mg/L** | **TDS-c mg/L** | **T °C** | **Si mg/L** | **Ca mg/L** | **Mg mg/L** | **K mg/L** | **Na mg/L** | **Fl mg/L** | **Bicarb mg/L** | **Carb mg/L** | **Sulfate mg/L** | **Cl mg/L** | **NO3 mg/L** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 500 | 414 | - | 7.9 | 244 | 263 | 6 | 26 | 55 | 11 | 5.3 | 13 | 0.1 | 250 | 0 | 11 | 2.3 | 0.1 |
| **Maximum** | 690 | 685 | - | 8.1 | 405 | 411 | 10 | 40 | 79 | 36 | 8.9 | 28 | 0.2 | 429 | 0 | 33 | 5.3 | 2.2 |
| **Points** | 4 | 5 | - | 5 | 5 | 5 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Mean** | 612.5 | 547.6 | - | 8 | 337.4 | 342 | 7.5 | 32.2 | 67.6 | 20.8 | 7.06 | 20.8 | 0.16 | 329.8 | 0 | 25.2 | 4.18 | 1.06 |
| **Median** | 630 | 560 | - | 8.1 | 353 | 358 | 7 | 32 | 68 | 18 | 6.7 | 20 | 0.2 | 324 | 0 | 26 | 4.5 | 1 |
| **Std Deviation** | 83.82 | 115.53 | - | 0.12 | 67.99 | 62.64 | 1.91 | 5.93 | 9.84 | 9.73 | 1.51 | 5.89 | 0.05 | 77.1 | 0 | 8.81 | 1.22 | 0.75 |
| **Std Error** | 41.91 | 51.67 | - | 0.05 | 30.41 | 28.01 | 0.96 | 2.65 | 4.4 | 4.35 | 0.67 | 2.63 | 0.02 | 34.48 | 0 | 3.94 | 0.55 | 0.33 |

Table 9.7.2. Summary of chemical properties of the Tokio aquifer in Benson County: use parameters.

| **Hardness** | **Hardness mg/L** | **NCH mg/L** | **ALK_ as_CaCO3 mg/L** | **ALK Calculated mg/L** | **SAR** | **Langelier, Field pH, 25°C** | **Langelier, Lab pH, 25°C** | **Langelier, Field pH, 82°C** | **Langelier, Lab pH, 82°C** |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 180 | - | - | 205 | 0.4 | - | 0.51 | - | 1.51 |
| **Maximum** | 320 | - | - | 352 | 0.7 | - | 0.96 | - | 1.96 |
| **Points** | 5 | - | - | 5 | 5 | - | 5 | - | 5 |
| **Mean** | 254 | - | - | 270.6 | 0.56 | - | 0.75 | - | 1.75 |
| **Median** | 260 | - | - | 266 | 0.6 | - | 0.74 | - | 1.74 |
| **Std Deviation** | 58.99 | - | - | 63.27 | 0.11 | - | 0.18 | - | 0.18 |
| **Std Error** | 26.38 | - | - | 28.3 | 0.05 | - | 0.08 | - | 0.08 |

Table 9.7.3. Summary of chemical properties of the Tokio aquifer in Benson County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.04 | 0.02 | 0.02 | - | 0.1 | 1 | 36 | 1 |
| Maximum | 0.09 | 0.59 | 0.72 | - | 0.1 | 50 | 47 | 5 |
| Points | 5 | 5 | 5 | - | 2 | 2 | 2 | 2 |
| Mean | 0.07 | 0.19 | 0.38 | - | 0.1 | 25.5 | 41.5 | 3 |
| Median | 0.07 | 0.13 | 0.4 | - | 0.1 | 25.5 | 41.5 | 3 |
| Std Deviation | 0.02 | 0.23 | 0.25 | - | 0 | 34.65 | 7.78 | 2.83 |
| Std Error | 0.01 | 0.1 | 0.11 | - | 0 | 24.5 | 3.4e+38 | 2 |

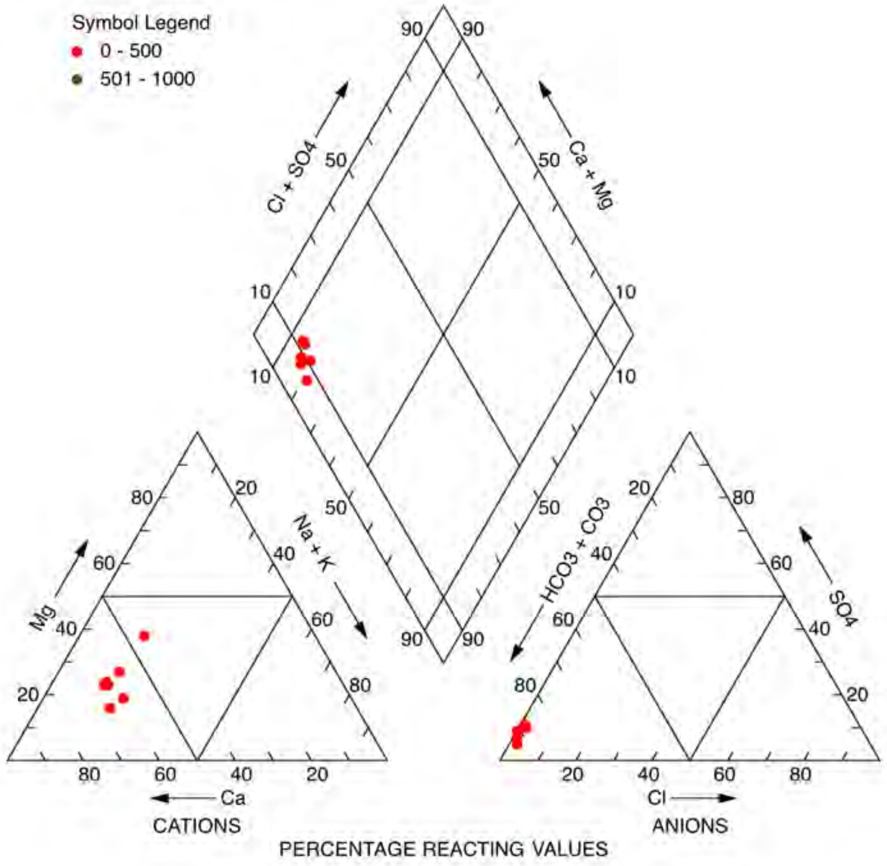


Figure 9.7.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Tokio aquifer in Benson County.

### *9.8 Warwick Aquifer (Benson, Eddy and Nelson Counties)*

The Warwick aquifer underlies about 74 square miles in Benson County, and small portions of northern Eddy and western Nelson Counties (Study Area #9 map).

Aquifer Composition Warwick aquifer: Randich (1977) described the Warwick aquifer as consisting of unconfined sand and gravel. The saturated thickness varies from 20 to 200 feet, with an average thickness of about 74 feet. Two examples of the aquifer lithology are provided on Appendix Figures B.9.8.1 and B.9.8.2.

Aquifer Yield: Randich (1977) reported transmissivities for nine aquifer tests, which ranged from 6,300 to 20,600 $ft^2$/day, with both mean and median near 10,500 $ft^2$/day. He estimated potential well yields ranging from 50 to 500 gpm for most of the aquifer, and some locations allowing for as much as 1,500 gpm.

Aquifer Chemistry: The water is some of the freshest ground water in the state, and is primarily of the calcium-bicarbonate type (Figure 9.8.1). Dissolved solids range from about 200 to 1,000 mg/L, with a median of 361 mg/L (Table 9.8.1). Iron concentrations are high. Arsenic concentrations vary, but can be as high as four times the EPA-MCL (Table 9.8.3). Use of reverse osmosis treatment will need to consider the necessity for proper filtrate disposal after concentration of trace elements.

Permit Acquisition Status: There are currently 15 perfected water permits for an annual allocation of 9,648 acre-feet from the Warwick aquifer. There are no current pending applications. However, 6,748 acre-feet belonging to the city of Devils Lake water permit are no longer in active use (the city of Devils Lake is now pumping from the Spiritwood aquifer) and may become available for other use in the near future. It may be more appropriate to estimate current annual appropriation at 2,928 acre-feet. Using estimated recharge rates of 1 to 2 inches per year for an unconfined aquifer, an increased allocation of 1,000 to 5,000 acre-feet may be possible from the Warwick aquifer after accounting for current use, and the change in status of the water permit for the city of Devils Lake.

Additional Considerations: Because much of the Warwick aquifer underlies lands of the Spirit Lake Sioux Reservation, and because Reservation water supplies are not accounted for in the water permits, consultation with the Spirit Lake Tribal Government is important for future water use planning. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Randich, P.G. 1977. Ground-water Resources of Benson and Pierce Counties, North Dakota. County Ground-Water Studies 18-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 44-51.

Table 9.8.1. Summary of chemical properties of the Warwick aquifer in Benson, Eddy and Nelson Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^oC$ | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 372 | 400 | 7.3 | 6.7 | 0 | 227 | 9.3 | 23.3 | 52.7 | 13.9 | 1 | 3.4 | 0.06 | 187 | - | 7.24 | 0.67 | 0.09 |
| **Maximum** | 1,538 | 1,690 | 7.3 | 8.2 | 0 | 1,050 | 9.3 | 34.2 | 158 | 150 | 7.14 | 79.9 | 0.5 | 1,200 | - | 139 | 31.1 | 171 |
| **Points** | 24 | 23 | 1 | 23 | 0 | 23 | 1 | 11 | 23 | 23 | 23 | 23 | 23 | 23 | - | 23 | 23 | 24 |
| **Mean** | 631.29 | 675.35 | 7.3 | 7.6 | 0 | 415.26 | 9.3 | 29.62 | 84.48 | 31.74 | 3.78 | 15.82 | 0.19 | 351.7 | - | 54.6 | 8.01 | 14.11 |
| **Median** | 557.5 | 583 | 7.3 | 7.7 | 0 | 361 | 9.3 | 29.5 | 77.4 | 22.2 | 3.17 | 6.4 | 0.15 | 302 | - | 40.4 | 2.88 | 0.11 |
| **Std Deviation** | 257.27 | 293.1 | 0 | 0.45 | 0 | 184.66 | 0 | 2.98 | 25.23 | 28.18 | 1.64 | 18.94 | 0.11 | 211.74 | - | 40.94 | 10.07 | 42.36 |
| **Std Error** | 52.52 | 61.12 | 0 | 0.09 | 0 | 38.51 | 0 | 0.9 | 5.26 | 5.88 | 0.34 | 3.95 | 0.02 | 44.15 | - | 8.54 | 2.1 | 8.65 |

Table 9.8.2. Summary of chemical properties of the Warwick aquifer in Benson, Eddy and Nelson Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^oC$ | Langelier, Lab pH, 25$^oC$ | Langelier, Field pH, 82$^oC$ | Langelier, Lab pH, 82$^oC$ |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 194 | 0 | 154 | - | 0.09 | - | - | - | - |
| **Maximum** | 860 | 256 | 982 | - | 1.86 | - | - | - | - |
| **Points** | 23 | 23 | 23 | - | 23 | - | - | - | - |
| **Mean** | 341.78 | 63.7 | 288.3 | - | 0.37 | - | - | - | - |
| **Median** | 306 | 27 | 248 | - | 0.17 | - | - | - | - |
| **Std Deviation** | 152.33 | 77.81 | 173.25 | - | 0.42 | - | - | - | - |
| **Std Error** | 31.76 | 16.22 | 36.13 | - | 0.09 | - | - | - | - |

Table 9.8.3. Summary of chemical properties of the Warwick aquifer in Benson, Eddy and Nelson Counties: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 4.55 | 3.74 | - | - | 23.8 | 30 | 4.72 | 4.55 |
| Maximum | 23 | 23 | - | - | 5 | 4 | 4 | 23 |
| Points | 0.71 | 0.78 | - | - | 9.35 | 24.13 | 3.82 | 0.71 |
| Mean | 0.14 | 0.6 | - | - | 4.37 | 23.9 | 3.61 | 0.14 |
| Median | 1.3 | 0.88 | - | - | 9.74 | 4.87 | 0.63 | 1.3 |
| Std Deviation | 0.27 | 0.18 | - | - | 4.36 | 2.44 | 0.31 | 0.27 |
| Std Error | 4.55 | 3.74 | - | - | 23.8 | 30 | 4.72 | 4.55 |

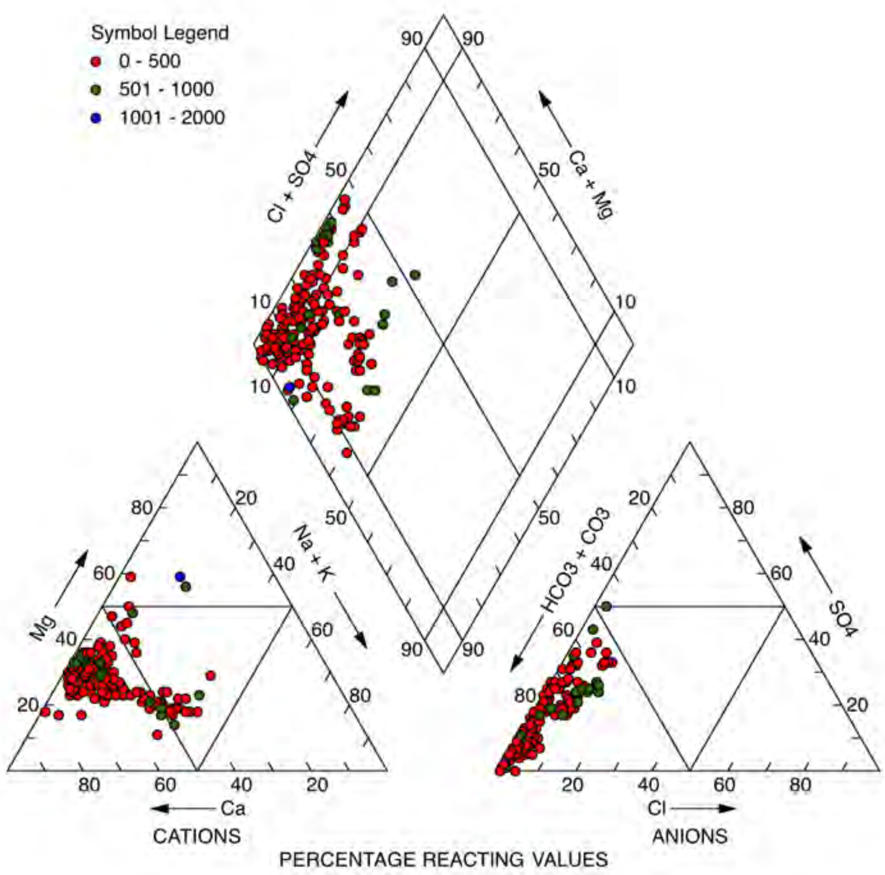
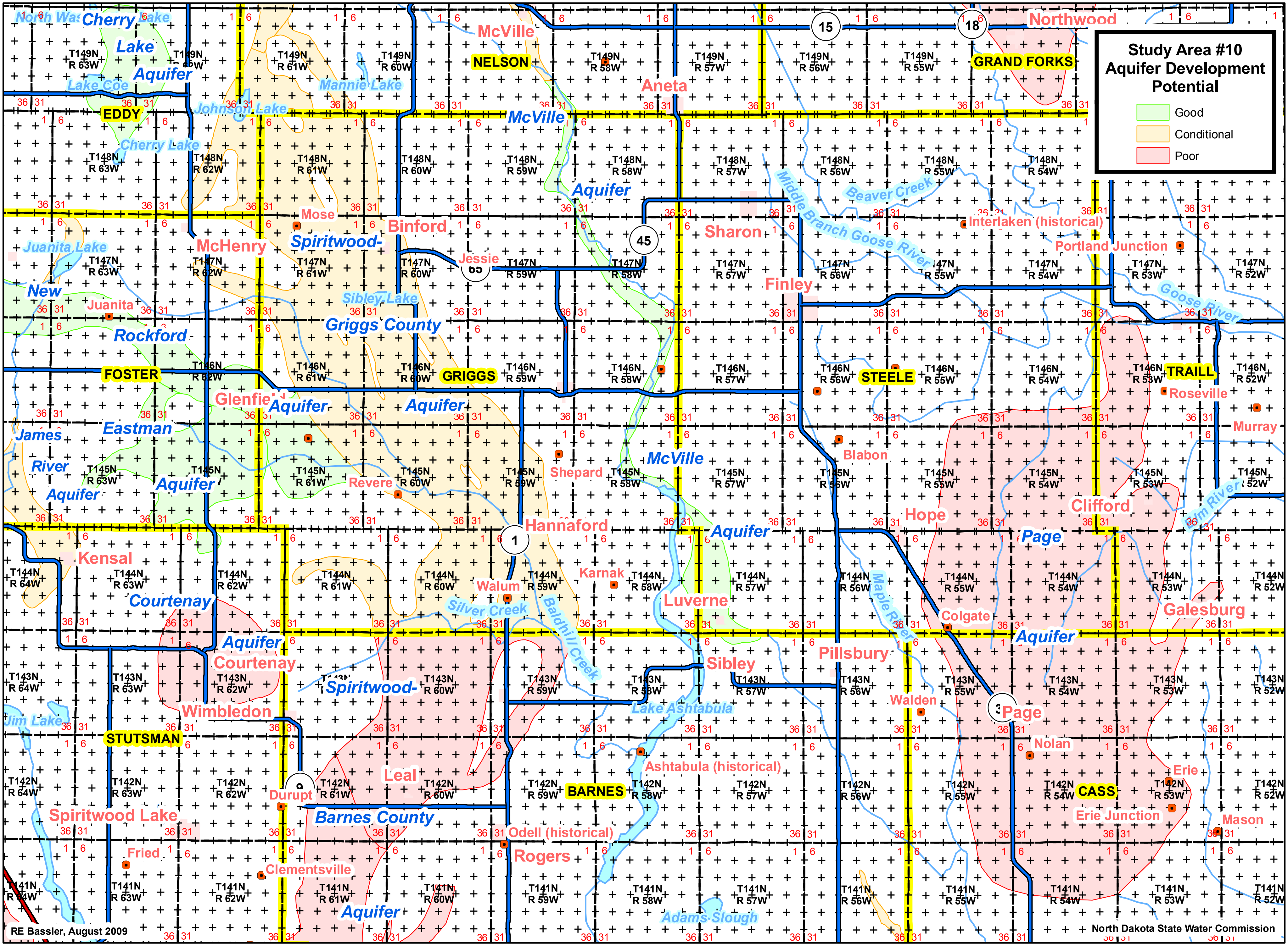


Figure 9.8.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Warwick aquifer in Benson, Eddy and Nelson Counties.


Study Area #10
Aquifer Development Potential
🟩 Good
🟨 Conditional
🟥 Poor
GRAND FORKS
NELSON
EDDY
FOSTER
GRIGGS
STEELE
TRAILL
STUTSMAN
BARNES
CASS
Northwood
McVille
Aneta
Mose
Binford
McHenry
Jessie
Sharon
Finley
Interlaken (historical)
Portland Junction
Roseville
Murray
Juanita
Rockford
Glenfield
Eastman
Revere
Shepard
Blabon
Hope
Clifford
Hannaford
Kensal
Walum
Karnak
Luverne
Colgate
Galesburg
Courtenay
Wimbledon
Sibley
Pillsbury
Walden
Page
Nolan
Leal
Durupt
Ashtabula (historical)
Erie
Erie Junction
Mason
Odell (historical)
Rogers
Spiritwood Lake
Fried
Clementsville
North Washington Lake
Cherry Lake
Lake Coe
Johnson Lake
Mannie Lake
Juanita Lake
Sibley Lake
Jim Lake
Lake Ashtabula
Adams Slough
Cherry Lake Aquifer
McVille Aquifer
Spiritwood-Griggs County Aquifer
Glenfield Aquifer
New Rockford Aquifer
James River Aquifer
Eastman Aquifer
Courtenay Aquifer
Spiritwood-Barnes County Aquifer
Page Aquifer
Middle Branch Goose River
Beaver Creek
Goose River
Elm River
Maple River
Silver Creek
Baldhill Creek
15
18
45
65
1
3
9
RE Bassler, August 2009
North Dakota State Water Commission

## Study Area 10: Central North Dakota / Barnes, Cass, Griggs and Steele Counties

### *10.1 Spiritwood Aquifer (Griggs County) - See Study Area 9.6.*

### *10.2 McVille Aquifer (Griggs and Steele Counties)*

The McVille aquifer underlies about nine square miles in Griggs and Steele Counties (Study Area #10 map).

Aquifer Composition: Downey and Armstrong (1977) have described the McVille aquifer as consisting of "fine sand, sandy gravel, and clayey silty sand interbedded with lenses of silty clay and glacial till." The aquifer saturated thickness varies from less than one foot near the edges to a maximum of more than 300 feet in its southern extreme, and averages about 80 feet. An example of the aquifer lithology is shown on Appendix Figure B.10.2.1.

Aquifer Yield: An aquifer test in Nelson County indicated a transmissivity between 2,000 and 9,000 ft.$^2$/day. Downey and Armstrong estimated potential maximum well yields as high as 500 gpm.

Aquifer Chemistry: The aquifer chemistry varies widely. It is predominantly of the calcium and sodium-bicarbonate type, but also yields some water of the calcium and sodium-sulfate type (Figure 10.2.1). Dissolved solids concentrations range from about 250 to 3,000 mg/L (Table 10.2.1), with a median value near 800 mg/L. Higher sodium and higher sulfate both correlate with higher dissolved solids. Manganese concentrations are high (Table 10.2.3).

Permit Acquisition Status: There are currently two perfected water permits for a total of 1,134.8 acre-feet from the McVille aquifer. No applications are pending. With an average recharge of about 2 inches per year, up to about 200 acre-feet additional beneficial use may be possible.

Additional Considerations: The top of the aquifer is relatively shallow, within 25 bls. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Downey, Joe S., and C.A. Armstrong 1977. Ground-Water Resources of Griggs County, North Dakota. County Ground-Water Studies 17-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 16-20.

Table 10.2.1. Summary of chemical properties of the McVille aquifer in Griggs and Steele Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 421 | 428 | 7.2 | 6.5 | 348 | 265 | 5.5 | 7.91 | 23.6 | 8 | 1.5 | 3.7 | 0.05 | 164 | 0 | 3.7 | 2.09 | 0 |
| **Maximum** | 2,280 | 3,670 | 7.7 | 8.2 | 2,850 | 2,850 | 15 | 35 | 438 | 96 | 21 | 607 | 1.1 | 581 | 1 | 1,570 | 354 | 253 |
| **Points** | 27 | 42 | 3 | 42 | 25 | 41 | 22 | 32 | 40 | 40 | 40 | 41 | 40 | 42 | 42 | 42 | 42 | 42 |
| **Mean** | 1,022.5 | 1,321.7 | 7.5 | 7.6 | 1,176.6 | 892.71 | 7.89 | 26.01 | 117.17 | 32.83 | 7.75 | 143.31 | 0.27 | 394.07 | 0.38 | 322.32 | 50.48 | 13.17 |
| **Median** | 1,005 | 1,235 | 7.5 | 7.6 | 982 | 765 | 7.05 | 27 | 87.45 | 24 | 7.68 | 90.2 | 0.2 | 399 | 0 | 215 | 24.4 | 0.99 |
| **Std Deviation** | 504.36 | 772.61 | 0.27 | 0.32 | 608.39 | 592.82 | 2.2 | 4.8 | 90.23 | 24.08 | 3.89 | 149.89 | 0.2 | 105.81 | 0.49 | 333.25 | 72.84 | 44.58 |
| **Std Error** | 97.06 | 119.22 | 0.15 | 0.05 | 121.68 | 92.58 | 0.47 | 0.85 | 14.27 | 3.81 | 0.62 | 23.41 | 0.03 | 16.33 | 0.08 | 51.42 | 11.24 | 6.88 |

Table 10.2.2. Summary of chemical properties of the McVille aquifer in Griggs and Steele Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 105 | 0 | 135 | 0 | 0.1 | -0.12 | 0.08 | 0.88 | 1.08 |
| **Maximum** | 1,490 | 1,080 | 388 | 476 | 16 | 0.51 | 1.13 | 1.51 | 2.13 |
| **Points** | 42 | 41 | 16 | 42 | 41 | 2 | 24 | 2 | 24 |
| **Mean** | 426.79 | 138.07 | 265.62 | 221.81 | 3.42 | 0.19 | 0.68 | 1.2 | 1.68 |
| **Median** | 330 | 30 | 281.5 | 297.5 | 2.19 | 0.19 | 0.68 | 1.2 | 1.68 |
| **Std Deviation** | 312.85 | 261.76 | 76.28 | 185.29 | 3.66 | 0.44 | 0.29 | 0.45 | 0.29 |
| **Std Error** | 48.27 | 40.88 | 19.07 | 28.59 | 0.57 | 0.31 | 0.06 | - | 0.06 |

Table 10.2.3. Summary of chemical properties of the McVille aquifer in Griggs and Steele Counties: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | - | - | - | - | - | 1.4 | - | - |
| Maximum | 2.5 | 14.5 | 2.01 | - | - | 8.64 | - | - |
| Points | 29 | 42 | 40 | - | - | 6 | - | - |
| Mean | 0.43 | 1.12 | 0.67 | - | - | 5.33 | - | - |
| Median | 0.28 | 0.32 | 0.63 | - | - | 5.29 | - | - |
| Std Deviation | 0.51 | 2.56 | 0.55 | - | - | 2.42 | - | - |
| Std Error | 0.09 | 0.4 | 0.09 | - | - | 0.99 | - | - |

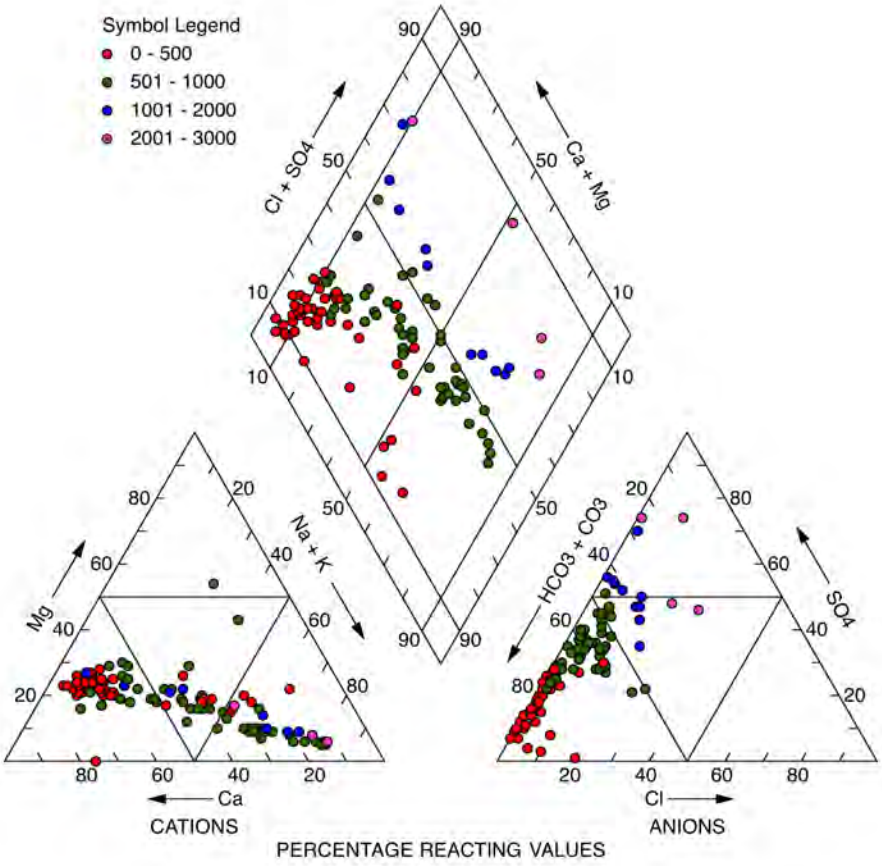
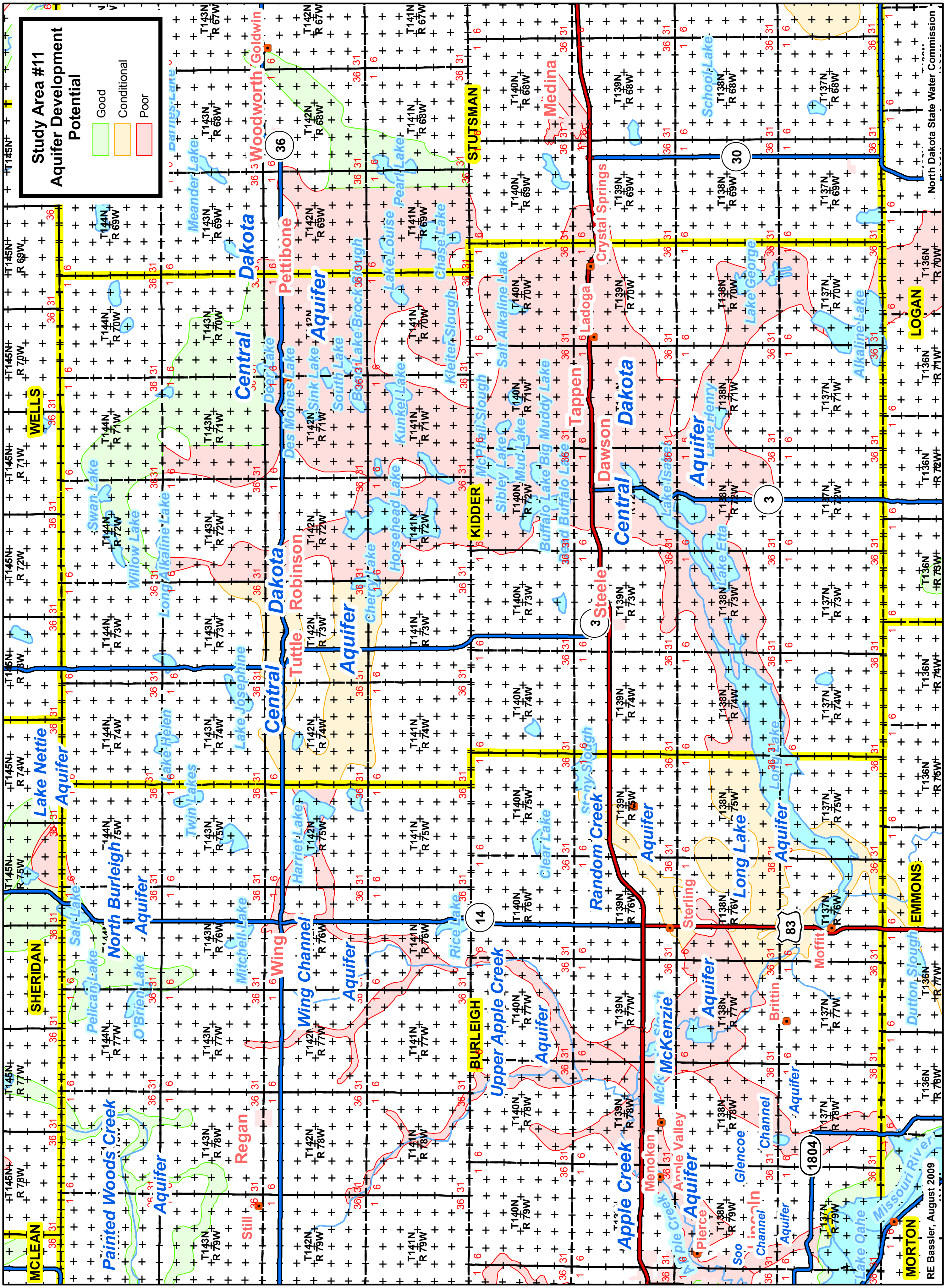


Figure 10.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the McVille aquifer in Griggs and Steele Counties.


Study Area #11
Aquifer Development Potential
Good
Conditional
Poor
MCLEAN
SHERIDAN
WELLS
BURLEIGH
KIDDER
STUTSMAN
EMMONS
LOGAN
MORTON
Painted Woods Creek Aquifer
Lake Nettie Aquifer
North Burleigh Aquifer
Central Dakota Aquifer
Wing Channel Aquifer
Upper Apple Creek Aquifer
Random Creek Aquifer
Long Lake Aquifer
McKenzie Aquifer
Apple Creek Aquifer
Glencoe Channel Aquifer
Lincoln Channel Aquifer
Missouri River
Lake Oahe
Still
Regan
Wing
Tuttle
Robinson
Pettibone
Woodworth
Goldwin
Steele
Dawson
Tappen
Ladoga
Crystal Springs
Medina
Sterling
Moffit
Brittin
Menoken
Apple Valley
Pierce
Soo
Salt Lake
Pelican Lake
O'Brien Lake
Mitchell Lake
Rice Lake
Harriet Lake
Twin Lakes
Lake Helen
Lake Josephine
Long Alkaline Lake
Willow Lake
Swan Lake
Cherry Lake
Horsehead Lake
Kunkel Lake
Sink Lake
South Lake
Des Moines Lake
Deer Lake
Lake Brock
Lake Louise
Pearl Lake
Chase Lake
Kleiter Slough
Meander Lake
Clear Lake
Stony Slough
Sibley Lake
Mud Lake
Big Muddy Lake
Buffalo Lake
Grand Buffalo Lake
McPhail Slough
Salt Alkaline Lake
Lake Isabel
Lake Etta
Lake Henry
Lake George
Alkaline Lake
School Lake
Dutton Slough
14
36
3
30
83
1804
RE Bassler, August 2009
North Dakota State Water Commission

## Study Area 11: Central North Dakota / Burleigh and Kidder Counties

### *11.1. Missouri River Aquifer (See Study Area #7.4).*

### *11.2 North Burleigh Aquifer (See Study Area #8.5).*

### *11.3 Central Dakota Aquifer (Kidder and Stutsman Counties)*

The Central Dakota aquifer system is located in central and eastern Kidder County and western Stutsman County (Study Area #11 map). Most of the aquifer is highly appropriated. Three areas may have potential for further development. These are located at: (1) the northwestern extension, (2) the northern extension, and (3) the northeastern extension of the aquifer.

<u>Aquifer Composition:</u> According to a general description provided by managing hydrologist Gordon Sturgeon,[130] the Central Dakota aquifer in northern Kidder and northwest Stutsman Counties is highly heterogeneous, and consists of two major subunits. The upper aquifer consists of coarse sand and bouldery gravel near the till highlands north of HWY 36. Grain size and aquifer thickness generally decrease southward with increasing distance from the highlands. The upper aquifer tends to be dominated by fine and medium sand and silt in its southern extent. The lower aquifer is heterogeneous, consisting of multiple layers of fine sand to coarse sand and gravel, interbedded with clay and muddy sand. Examples of lithologies are provided for the west (Appendix Figure B.11.3.2), north (Appendix Figure B.11.3.3) and eastern (Appendix Figure B.11.3.4) extents of the aquifer.

<u>Aquifer Yield:</u> A table of potential transmissivity ranges based on particle size was provided by Gordon Sturgeon[131].

Table 11.3.1. Estimated transmissivity (ft.$^2$/day) based on grain size and aquifer thickness.

| | | Minimum | Maximum | Mean | n |
|---|---|---|---|---|---|
| Western Area | Upper Aquifer | 1600 | 23400 | 11100 | 4 |
| | Lower Aquifer | 1200 | 9000 | 5200 | 4 |
| Northern Area | Upper Aquifer | 5800 | 70100 | 18700 | 16 |
| | Lower Aquifer | 1500 | 51100 | 12700 | 9 |
| Eastern Area | Upper Aquifer | 1900 | 52800 | 19500 | 7 |
| | Lower Aquifer | 5100 | 14000 | 9700 | 4 |

In the two aquifer tests conducted in Kidder County, the lower unit was estimated to have a storage coefficient of about 0.0005. Some layers of the lower aquifer unit may have storage coefficients as low as 0.0001, while unconfined areas of the upper unit may have

---

[130] Sturgeon, Gordon. September 4, 2009. Written communication.

[131] Ibid.

storage coefficients as high as 0.2. From Bradley and others (1963) well yields of up to 1,000 gpm may be possible, depending on location.

Aquifer Chemistry: Anion and cation distributions for the composite of Central Dakota water samples range from the calcium-carbonate type to a predominately sodium-carbonate type, with some samples trending toward a sulfatic type (Figure 11.3.1). Dissolved solids concentrations range from about 300 to 3,000 mg/L, with a median of 656 mg/L (Table 11.3.2). Higher sodium concentrations and higher sulfate generally correspond to higher dissolved. Dissolved solids, sodium and sulfate also tend to be higher at greater depths. Water samples for potential development areas (west, north and east) are sparse, but anions and cations fall within the characteristic range represented for the aquifer as a whole (West, North and East on Figure 11.3.1). For this reason, water chemistry summaries (Tables 11.3.2 through 11.3.4) are provided for all of the 289 observation wells in the aquifer. Iron and manganese concentrations are generally high. Arsenic concentrations tend to be high, with a median value slightly above the EPA-MCL of 10 μg/L, and a maximum value ten times the EPA-MCL (Table 11.3.4).

Permit Acquisition Status: There are currently four water permits with priority dates, one perfected, one conditionally approved and two pending applications, for a total of 757.5 acre-feet in areas of the Central Dakota aquifer system mapped as having potential for further development. Further applications should not be unduly delayed. Rough estimates of development potential based on areal extent (approx. 38 mi.$^2$ west, 30 mi.$^2$ north, 28 mi.$^2$ east) and recharge between 0.5 and 1 inches per year would indicate additional allocations of about 1,000 to 2,000 acre-feet/year (west), 700 to 1,500 acre-feet/year (north), and 800 to 1,600 acre-feet/year east. More may be possible, depending on connections of the lower units with the surface. Arsenic concentrations must be considered when treating water for use, particularly using reverse-osmosis treatment methods which concentrate dissolved arsenic in a brine that may require special disposal.

Additional Considerations: Designations of all three of the areas mapped as having potential for further development (Study Area #11 map) were based on limited exploration which has been considered as *inconclusive but promising* (Gordon Sturgeon, written communication September 4, 2009). The northern and eastern areas (mapped green-*good* on the Study Area #11 map) are considered as good prospective areas with further exploration advised. The western area (mapped yellow-*conditional* on the Study Area #11 map) may be productive, but further exploration is strongly advised to ascertain the saturated thickness and the continuity of the lower aquifer units. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Bradley, Edward, L.R. Petri, and D.G. Adolphson. 1963. Part III Ground Water and Chemical Quality of Water. North Dakota State Water Commission. Bismarck, ND. pp. 9-11.

Table 11.3.2. Summary of chemical properties of the Central Dakota aquifer in northern Kidder and Stutsman Counties: general chemistry.

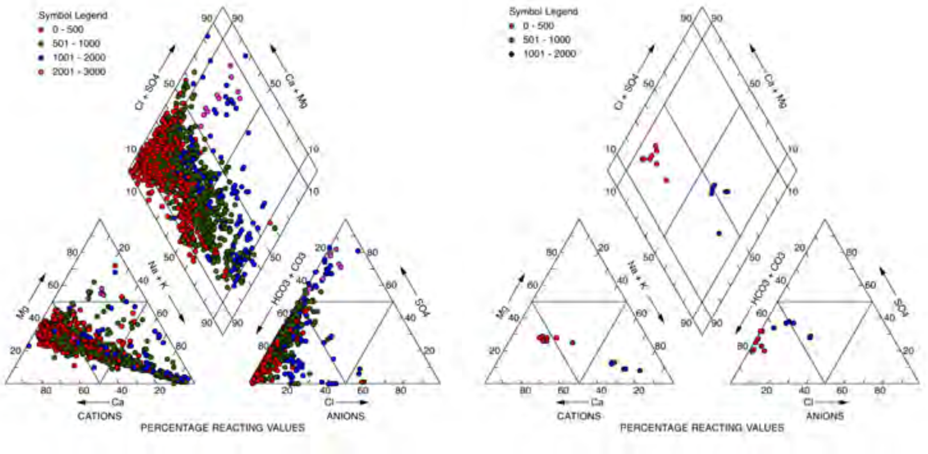
| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 315 | 337 | 5.9 | 6.7 | 312 | 209 | 7.8 | 4.9 | 6.55 | 4.6 | 1.5 | 2 | 0.05 | 154 | 0 | 0.37 | 0 | 0 |
| **Maximum** | 3,480 | 3,740 | 8.3 | 8.6 | 2,330 | 2,990 | 15.5 | 160 | 492 | 178 | 47.8 | 506 | 1.6 | 1,340 | 20 | 1,910 | 457 | 100 |
| **Points** | 272 | 289 | 32 | 286 | 75 | 285 | 104 | 79 | 284 | 282 | 282 | 284 | 282 | 288 | 287 | 286 | 288 | 287 |
| **Mean** | 1,058.1 | 1,113 | 7.5 | 7.8 | 655.99 | 700.99 | 10.26 | 30.4 | 105.79 | 36.77 | 7.97 | 95.41 | 0.21 | 505.85 | 0.94 | 180.1 | 23.21 | 3.03 |
| **Median** | 870 | 912 | 7.6 | 7.8 | 509 | 566 | 10.3 | 29 | 89.6 | 29.6 | 7.74 | 49.95 | 0.2 | 444.5 | 1 | 111 | 8.01 | 0.09 |
| **Std Deviation** | 539.61 | 578.5 | 0.45 | 0.31 | 367.13 | 387.83 | 1.42 | 15.27 | 60.91 | 24.13 | 5.1 | 109.66 | 0.12 | 210.85 | 1.7 | 222.01 | 51.56 | 12.36 |
| **Std Error** | 32.72 | 34.03 | 0.08 | 0.02 | 42.39 | 22.97 | 0.14 | 1.72 | 3.61 | 1.44 | 0.3 | 6.51 | 0.01 | 12.42 | 0.1 | 13.13 | 3.04 | 0.73 |

Table 11.3.3. Summary of chemical properties of the Central Dakota aquifer in northern Kidder and Stutsman Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 48 | 0 | 126 | 0 | 0 | - | -0.46 | - | 0.54 |
| **Maximum** | 1,960 | 1,660 | 1,100 | 812 | 20.5 | - | 1.4 | - | 2.4 |
| **Points** | 289 | 286 | 213 | 80 | 284 | - | 69 | - | 69 |
| **Mean** | 415.64 | 57.21 | 426.42 | 384.65 | 2.35 | - | 0.76 | - | 1.76 |
| **Median** | 357 | 15.5 | 368 | 326 | 1.04 | - | 0.75 | - | 1.75 |
| **Std Deviation** | 234.89 | 164.76 | 182.98 | 145.11 | 3.55 | - | 0.3 | - | 0.3 |
| **Std Error** | 13.82 | 9.74 | 12.54 | 16.22 | 0.21 | - | 0.04 | - | 0.04 |

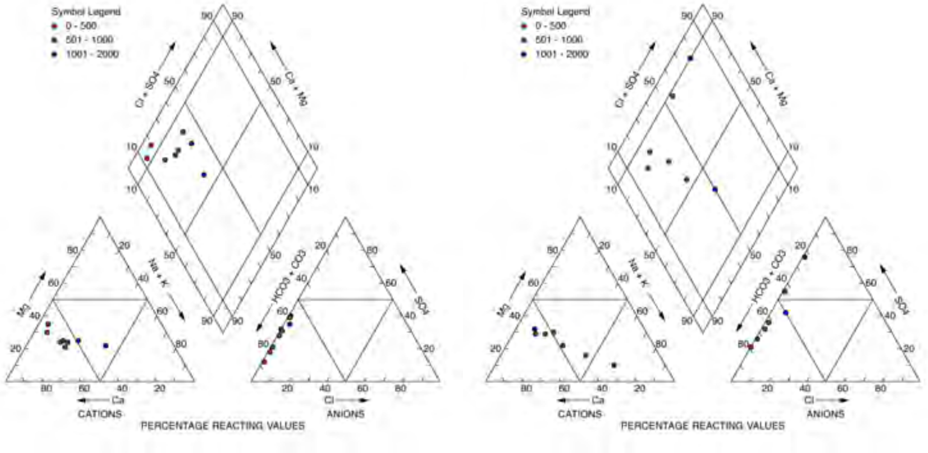
Table 11.3.4. Summary of chemical properties of the Central Dakota aquifer in northern Kidder and Stutsman Counties: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 0.02 | 0 | 0 | 1.14 | 20 | 2 |
| Maximum | 1.5 | 67.9 | 3.23 | 19.7 | 0.2 | 98.6 | 280 | 10 |
| Points | 49 | 286 | 279 | 48 | 17 | 48 | 17 | 17 |
| Mean | 0.35 | 2.04 | 0.81 | 3.2 | 0.07 | 17.61 | 117.4 | 4.96 |
| Median | 0.21 | 0.4 | 0.76 | 2.7 | 0 | 10.25 | 100 | 5 |
| Std Deviation | 0.35 | 6.03 | 0.48 | 3.22 | 0.1 | 19.67 | 68.65 | 2.3 |
| Std Error | 0.05 | 0.36 | 0.03 | 0.46 | 0.02 | 2.84 | 16.65 | 0.56 |



Composite

West



North

East

Figure 11.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Central Dakota aquifer in Kidder and Stutsman Counties.

## 11.4. Long Lake Aquifer (Burleigh County)

The Long Lake aquifer underlies about 32 square miles in southeastern Burleigh County.

Aquifer Composition: Randich and Hatchett (1966) described the Long Lake aquifer as confined. The aquifer consists of 5 to 70 feet of sand, gravel and silt, and is found about 90 to 120 feet bls. In general, the coarser (gravel) components are near the bottom, and materials grade to sand and silt near the surface, but there are sometimes abrupt transitions from gravel to silt or clay. The aquifer is more coarse in the northern portion, and more silty in the south. An example of aquifer lithology is provided on Appendix Figure B.11.4.1.

Aquifer Yield: No aquifer yield estimates are available. Randich and Hatchett (1966) reported that the aquifer was being used for a number of domestic and livestock wells.

Aquifer Chemistry: Aquifer water is predominantly of the sodium-bicarbonate type (Figure 11.4.1), some of which may be derived from recharge from the underlying Fox Hills aquifer. Dissolved solids range from about 500 to 3,000 mg/L, with a median near 900 mg/L (Table 11.4.1).

Permit Acquisition Status: There are currently no water permits or pending applications.

Additional Considerations: Little is known of this aquifer. Local exploration is advised before planning for development and use.

Citations:

Randich, P.G. and J.L. Hatchett. 1966. Geology and ground water resources of Burleigh County, North Dakota. County Ground Water Studies No. 42, Part III. North Dakota State Water Commission. Bismarck, ND. pp. 70-71.

Table 11.4.1. Summary of chemical properties of the Long Lake aquifer in Burleigh County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 675 | 678 | - | 7.5 | 502 | 450 | 7 | 12 | 5.6 | 1.2 | 1.8 | 28 | 0.1 | 288 | 0 | 2.7 | 0.5 | 0 |
| **Maximum** | 1,786 | 4,810 | - | 8.7 | 2,860 | 3,127 | 10.5 | 29 | 97.5 | 36.6 | 13 | 1,300 | 1.6 | 1,153 | 55 | 526 | 1,200 | 83 |
| **Points** | 10 | 25 | - | 22 | 13 | 25 | 6 | 12 | 19 | 19 | 19 | 22 | 19 | 22 | 22 | 22 | 22 | 22 |
| **Mean** | 1,329 | 1,592.9 | - | 8.1 | 1,099.9 | 1,029.6 | 8.4 | 24.87 | 42.81 | 18.74 | 6.09 | 336.36 | 0.67 | 652.55 | 5.23 | 222.75 | 78.65 | 5.8 |
| **Median** | 1,364.5 | 1,430 | - | 8.1 | 862 | 892 | 8 | 27.5 | 36.2 | 21.8 | 5.6 | 291 | 0.5 | 648 | 0.5 | 186 | 14.5 | 0.18 |
| **Std Deviation** | 367.92 | 815.24 | - | 0.28 | 598.04 | 533.12 | 1.3 | 5.28 | 26.8 | 10.71 | 2.5 | 252.26 | 0.47 | 204.33 | 14.25 | 140.72 | 255.93 | 18.38 |
| **Std Error** | 116.35 | 163.05 | - | 0.06 | 165.87 | 106.62 | 0.53 | 1.52 | 6.15 | 2.46 | 0.57 | 53.78 | 0.11 | 43.56 | 3.04 | 30 | 54.57 | 3.92 |

Table 11.4.2. Summary of chemical properties of the Long Lake aquifer in Burleigh County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 20 | 0 | 243 | 0 | 0.7 | - | 0.32 | 0 | - |
| **Maximum** | 394 | 95 | 611 | 1,015 | 71 | - | 0.98 | 0 | - |
| **Points** | 25 | 22 | 9 | 25 | 22 | - | 10 | 0 | - |
| **Mean** | 163.64 | 8.86 | 462 | 367.56 | 16.33 | - | 0.6 | 0 | - |
| **Median** | 138 | 0 | 489 | 490 | 12.5 | - | 0.57 | 0 | - |
| **Std Deviation** | 101.85 | 27.31 | 129.77 | 314.87 | 17.43 | - | 0.22 | 0 | - |
| **Std Error** | 20.37 | 5.82 | 43.26 | 62.97 | 3.72 | - | 0.07 | 0 | - |

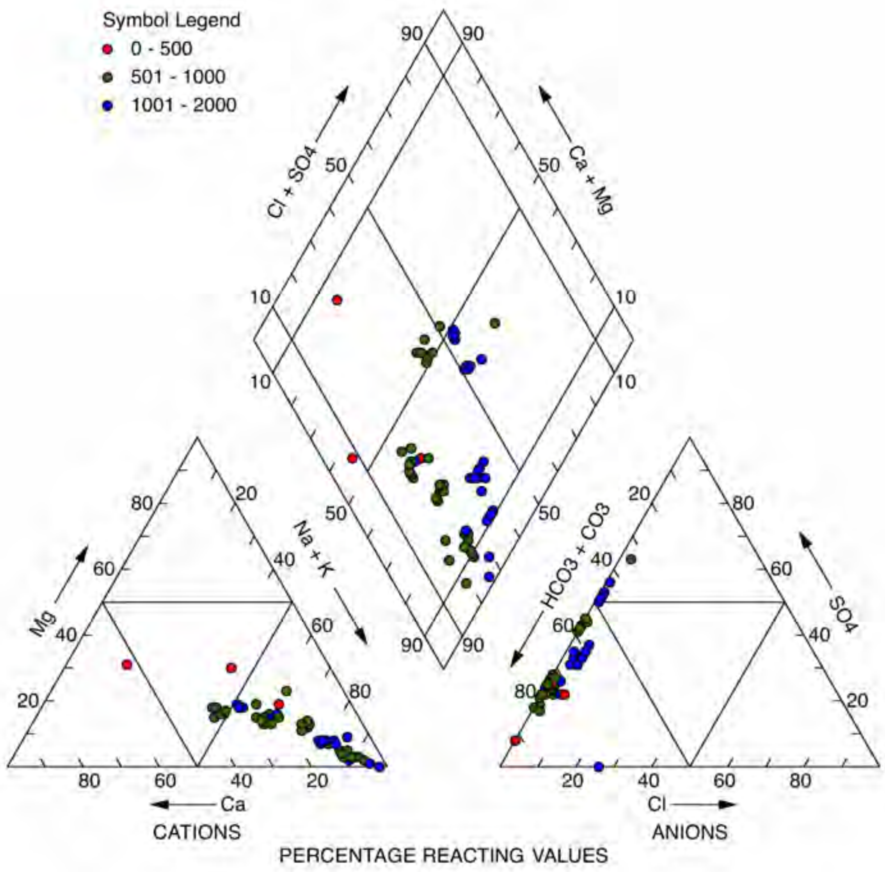
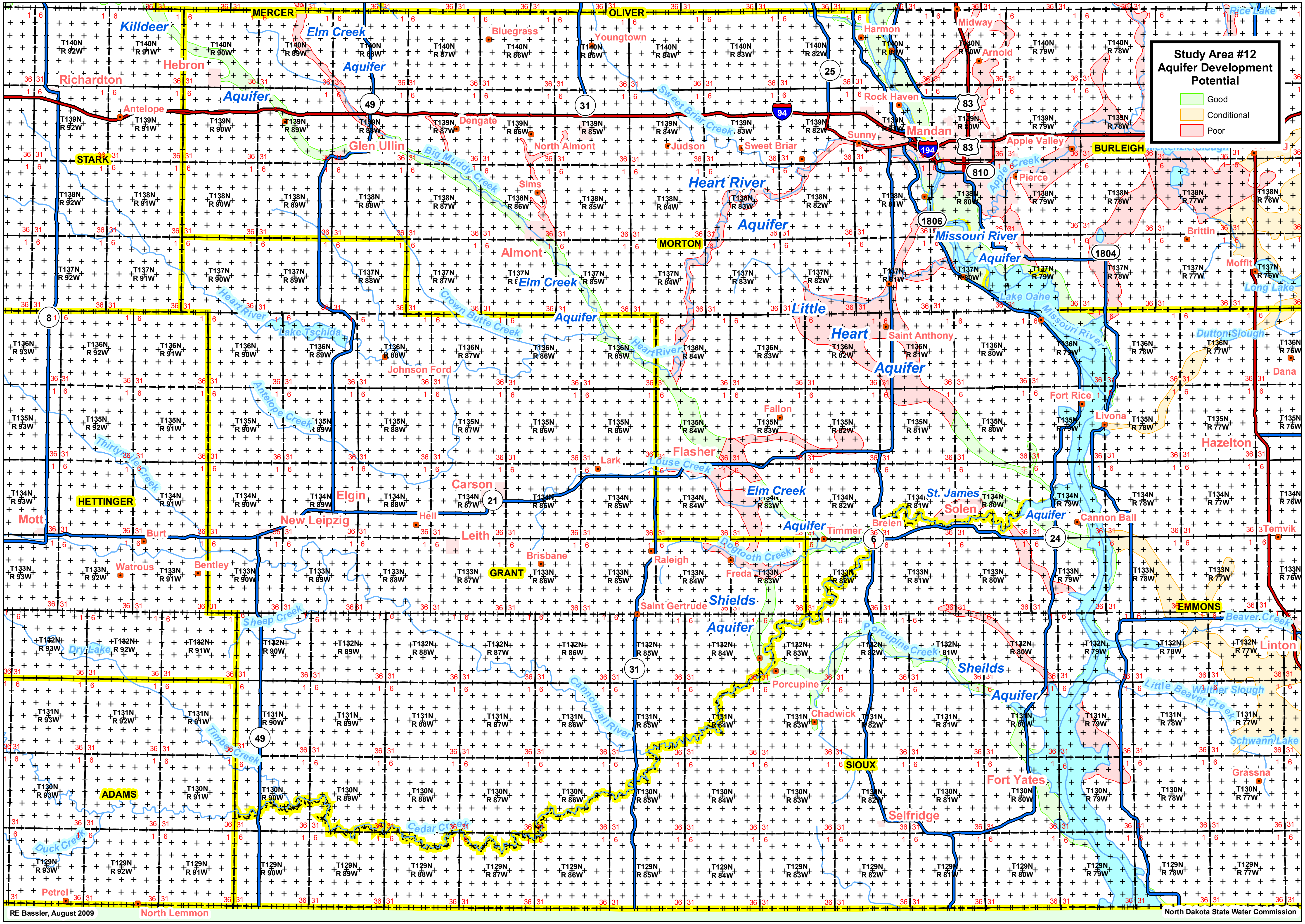


Figure 11.4.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Long Lake aquifer in Burleigh County.



RE Bassler, August 2009

North Dakota State Water Commission

## Study Area 12: Southwest North Dakota / Morton, Grant and Sioux Counties

### 12.1 Elm Creek Aquifer (Morton County)

The Killdeer aquifer, the Elm Creek aquifer, and Shields aquifer together could have been named as a single aquifer. As mapped, the Elm Creek aquifer begins along Elm Creek in southern Mercer County. In northwest Morton County, near Glen Ullin, the Elm Creek aquifer joins with the Killdeer aquifer, the resulting aquifer taking the 'Elm Creek' name. The Elm Creek aquifer continues southeast to the Flasher area, where it parallels, then joins with the Shields aquifer. The Elm Creek aquifer segment having the best potential for further beneficial use includes about 44 square miles between Glen Ullin and HWY 6 near Breien, with portions near Flasher and Almont excluded (Study Area #12 map).

Aquifer Composition: the Elm Creek aquifer consists of sand and gravel, along with finer sediments, that were deposited in a narrow buried valley, often less than a mile wide. The sand and gravel bodies may not necessarily have extensive lateral continuity. The sand and/or gravel is interbedded with layers of clay and silt. The coarsest and most permeable material tends to be found in the deeper portion of the aquifer and along the axis of the valley. One example of the Elm Creek aquifer lithology is provided on Appendix Figure B.12.1.1.

Aquifer Yield: Wanek (2009) stated that analysis of an aquifer test performed using an irrigation well north of Flasher, completed in the lower unit of the Elm Creek aquifer, suggests a transmissivity of 1,000 ft.$^2$/day and a storativity of $2 \times 10^{-4}$. According to Ackerman (1980) potential well yields range from about 10 to 1,500 gpm.

Aquifer Chemistry: Dissolved solids concentrations for 32 wells vary from about 500 to 5,200 mg/L with a median of 920 mg/L (Table 12.1.1). About 2/3 of the water samples vary between 500 and 1,500 mg/L (Wanek 2009). Aquifer chemistry would be expected to resemble Missouri River water near the river, and water from surrounding bedrock farther from the river. Water samples are primarily of the sodium-bicarbonate type, with some of the calcium magnesium-sulfate type and sodium-sulfate type (Figure 12.1.1). Higher sulfate and sodium concentrations corresponded to higher dissolved solids (Figure 12.1.1). Dissolved iron and manganese concentrations are both high (Table 12.1.3).

Permit Acquisition Status: The Elm Creek aquifer has three perfected water permits for an annual allocation of 683.4 acre-feet combined, but none are in the areas mapped as having potential for further development. The potential for additional development is better away from the irrigation in the Flasher area, and as the thickness of the aquifer allows in a particular location. Assuming one inch of recharge per year, up to 2,000 acre-feet of additional allocation may be available for development.

Additional Considerations: Local investigations are strongly advised.

Citations:

Ackerman, D.J. 1980. Ground-water Resources of Morton County, North Dakota. County Ground-Water Studies 27-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 58-67.

Wanek, Alan. Sept. 1, 2009. Ground water availability in western North Dakota. North Dakota State Water Commission Office Memorandum. pp. 31-33.

Table 12.1.1. Summary of chemical properties of the Elm Creek aquifer in Morton County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 910 | 889 | 0 | 7 | 588 | 555 | 6.11 | 6.7 | 3.84 | 1.2 | 1.73 | 27 | 0.2 | 469 | 0 | 0.3 | 0 | 0.09 |
| **Maximum** | 5,500 | 6,370 | 0 | 8.5 | 5,180 | 5,200 | 14.5 | 26.4 | 130 | 110 | 12 | 1,500 | 4.26 | 1,400 | 27 | 2,700 | 130 | 5.9 |
| **Points** | 23 | 32 | 0 | 32 | 20 | 32 | 10 | 31 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 |
| **Mean** | 1,865.7 | 1,724 | 0 | 8 | 1,193.9 | 1,147.2 | 9.21 | 19.68 | 69.44 | 35.15 | 5.15 | 309.87 | 1.08 | 729.16 | 3.63 | 357.07 | 10.35 | 0.84 |
| **Median** | 1,663 | 1,565 | 0 | 8.1 | 920.5 | 1,020 | 9 | 21.6 | 64.45 | 32 | 4.54 | 264 | 0.7 | 674 | 0 | 239 | 3.55 | 0.75 |
| **Std Deviation** | 926.72 | 995.14 | 0 | 0.34 | 1,036 | 824.13 | 2.26 | 4.92 | 42.03 | 21.96 | 2.37 | 278.17 | 1 | 227.13 | 7.11 | 469.04 | 25.09 | 1.27 |
| **Std Error** | 193.24 | 175.92 | 0 | 0.06 | 231.66 | 145.69 | 0.71 | 0.88 | 7.43 | 3.88 | 0.42 | 49.17 | 0.18 | 40.15 | 1.26 | 82.92 | 4.43 | 0.22 |

Table 12.1.2. Summary of chemical properties of the Elm Creek aquifer in Morton County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 15 | 0 | 384 | 0 | 0.5 | - | -0.24 | - | 0.76 |
| **Maximum** | 780 | 106 | 967 | 1,148 | 63.2 | - | 1.53 | - | 2.53 |
| **Points** | 32 | 32 | 12 | 32 | 32 | - | 20 | - | 20 |
| **Mean** | 318.19 | 7.94 | 630.42 | 469.75 | 11.19 | - | 1.04 | - | 2.04 |
| **Median** | 325 | 0 | 644.5 | 483.5 | 6.05 | - | 1.13 | - | 2.13 |
| **Std Deviation** | 173.46 | 20.59 | 195.51 | 326.48 | 14.35 | - | 0.43 | - | 0.43 |
| **Std Error** | 30.66 | 3.64 | 56.44 | 57.71 | 2.54 | - | 0.1 | - | 0.1 |

Table 12.1.3. Summary of chemical properties of the Elm Creek aquifer in Morton County: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 0.01 | - | - | - | - | - |
| Maximum | 1.5 | 22 | 0.54 | - | - | - | - | - |
| Points | 19 | 32 | 32 | - | - | - | - | - |
| Mean | 0.57 | 2.42 | 0.16 | - | - | - | - | - |
| Median | 0.43 | 1.22 | 0.12 | - | - | - | - | - |
| Std Deviation | 0.43 | 4.04 | 0.13 | - | - | - | - | - |
| Std Error | 0.1 | 0.71 | 0.02 | - | - | - | - | - |

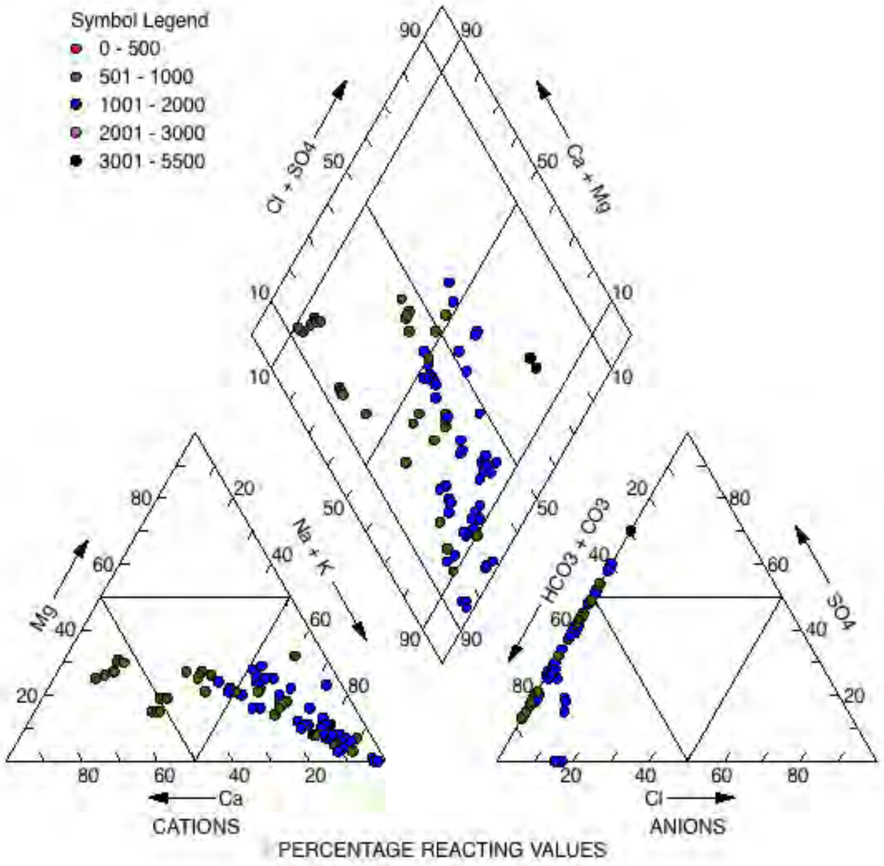


Figure 12.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Elm Creek aquifer in Morton County.

### *12.2 Little Heart Aquifer (Morton County)*

The Little Heart aquifer occupies a buried valley system and a glacial lake basin in eastern Morton County, roughly on a line from about six miles northwest of St. Anthony and the confluence of the Cannonball and Missouri Rivers. About eight miles upward from the confluence, water may be available for further development (Study Area #12 map).

Aquifer Composition: According to Ackerman (1980), the aquifer consists of sand and gravel interbedded with clay and silt. Coarsest materials are usually near the base of the aquifer. The aquifer thickness ranges from less than one foot to 260 feet, with an average thickness of about 60 feet. An example of the Little Heart aquifer lithology is on Appendix Figure B.12.2.1.

Aquifer Yield: Using particle size, Ackerman (1980) has estimated transmissivities from 100 to 25,000 $ft.^2$/day, with storage coefficients ranging from about 0.0001 in deeper confined units, to 0.2 in areas that are unconfined. He estimated potential well yields ranging from 10 to 1,700 gpm.

Aquifer Chemistry: Aquifer chemistry is predominantly of the sodium-bicarbonate type, ranging from a mixed calcium magnesium sodium-bicarbonate type to a calcium-bicarbonate type (Figure 12.2.1). The range of dissolved solids concentrations is about 450 to 2,800 mg/L, with a median near 1,200 gpm, similar to other nearby and related aquifers (Figure 12.2.1). Higher sodium is generally associated with higher dissolved solids. Water chemistry is similar to that of other nearby aquifers (Elm Creek, Killdeer, St. James and Shields). Iron and manganese concentrations are high (Figure 12.2.3).

Permit Acquisition Status: There are currently no competing water permits or water-permit applications from the Little Heart aquifer in the area designated as having potential for further development. Assuming about one inch per year of recharge, a small amount of water, perhaps up to 500 acre-feet per year, may be available for additional appropriation.

Additional Considerations: **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Ackerman, D.J. 1980. Ground-water Resources of Morton County, North Dakota. County Ground-Water Studies 27-Part III. North Dakota State Water Commission. Bismarck, ND. p. 33.

Table 12.2.1. Summary of chemical properties of the Little Heart aquifer in Morton County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}C$ | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 810 | 728 | 7.5 | 7.3 | 456 | 474 | 7 | 14 | 1.1 | 2.4 | 3.4 | 7 | 0 | 242 | 0 | 3.3 | 0.1 | 0 |
| **Maximum** | 3,700 | 3,990 | 7.5 | 8.4 | 3,780 | 3,670 | 11.1 | 28.8 | 514 | 288 | 17 | 906 | 1.1 | 1,380 | 44 | 2,310 | 675 | 7.1 |
| **Points** | 17 | 44 | 1 | 39 | 37 | 41 | 19 | 37 | 38 | 38 | 38 | 41 | 36 | 39 | 39 | 39 | 39 | 39 |
| **Mean** | 1,578.9 | 1,733 | 7.5 | 7.9 | 1,209.3 | 1,187.9 | 8.82 | 22.74 | 117.6 | 48.45 | 7.33 | 249.06 | 0.43 | 784.72 | 1.41 | 297.83 | 51.67 | 1.24 |
| **Median** | 1,388 | 1,685 | 7.5 | 7.9 | 1,210 | 1,190 | 8.9 | 23 | 110 | 37.4 | 7.05 | 245 | 0.4 | 779 | 0 | 229 | 14 | 1 |
| **Std Deviation** | 749.08 | 660.62 | 0 | 0.25 | 572.46 | 540.75 | 1.19 | 4.19 | 91.29 | 46.99 | 3.18 | 187.56 | 0.26 | 272.17 | 7.07 | 356.01 | 120.62 | 1.63 |
| **Std Error** | 181.68 | 99.59 | 0 | 0.04 | 94.11 | 84.45 | 0.27 | 0.69 | 14.81 | 7.62 | 0.52 | 29.29 | 0.04 | 43.58 | 1.13 | 57.01 | 19.32 | 0.26 |

Table 12.2.2. Summary of chemical properties of the Little Heart aquifer in Morton County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 17 | 0 | 478 | 0 | 1.4 | 0.85 | -0.75 | 1.85 | 0.25 |
| **Maximum** | 1,930 | 1,540 | 640 | 1,131 | 78 | 0.85 | 1.63 | 1.85 | 2.63 |
| **Points** | 44 | 37 | 5 | 44 | 42 | 1 | 33 | 1 | 33 |
| **Mean** | 456 | 51.81 | 566.2 | 507.73 | 8.77 | 0.85 | 1 | 1.85 | 2 |
| **Median** | 443.5 | 0 | 590 | 547.5 | 4.4 | 0.85 | 1.04 | 1.85 | 2.04 |
| **Std Deviation** | 282.69 | 253.27 | 79.91 | 347.77 | 15.52 | 0 | 0.42 | 0 | 0.42 |
| **Std Error** | 42.62 | 41.64 | 35.74 | 52.43 | 2.39 | 0 | 0.07 | 0 | 0.07 |

Table 12.2.3. Summary of chemical properties of the Little Heart aquifer in Morton County: selected trace elements.

|  | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.03 | 0.01 | 0.03 | - | - | - | - | - |
| Maximum | 11 | 1.6 | 11 | - | - | - | - | - |
| Points | 19 | 19 | 19 | - | - | - | - | - |
| Mean | 1.17 | 0.47 | 1.17 | - | - | - | - | - |
| Median | 0.12 | 0.17 | 0.12 | - | - | - | - | - |
| Std Deviation | 2.56 | 0.5 | 2.56 | - | - | - | - | - |
| Std Error | 0.59 | 0.11 | 0.59 | - | - | - | - | - |

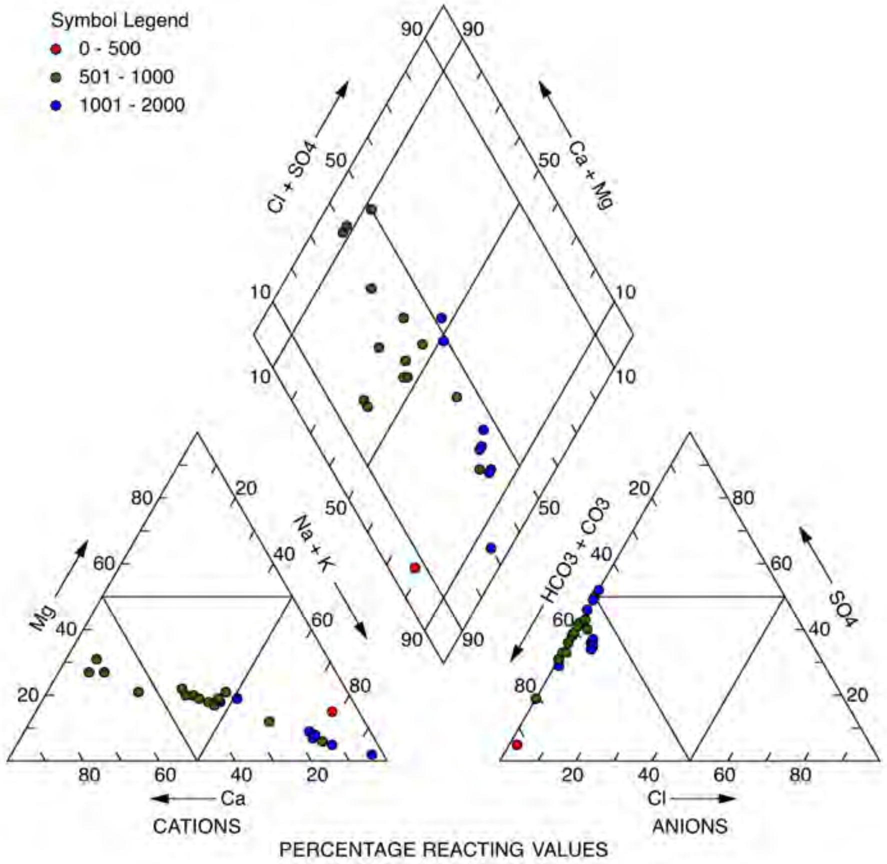


Figure 12.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Little Heart aquifer in Morton County.

### *12.3 Shields Aquifer (Morton and Sioux Counties)*

The Shields aquifer occurs in an interconnected complex of coarse glaciofluvial channel deposits located south of Flasher. The southwesternmost channel, continuing southeastward to the Missouri River near Fort Yates, is named the Shields aquifer. Near Flasher, the Shields and Elm Creek aquifers parallel each other with connecting buried valleys. About 44 square miles are potentially available for further development as indicated on Study Area #12 map.

Aquifer Composition Shields aquifer: According to Wanek (2009) the aquifer consists of a "narrow valley incised into the landscape and later filled with glacial sediment, including graded sand and some sand and gravel. The stratigraphy is similar to the Elm Creek aquifer; that is, it consists of sand and/or gravel interbedded with layers of clay and silt. The coarsest and most permeable material tends to be found in the deeper portions of the aquifer and along the axis of the valley. According to Ackerman (1980) thicknesses range from about 16 to 226 feet. One example of the lithology is shown on Appendix Figure B.12.3.1.

Aquifer Yield: Wanek (2009) stated that the pumping yield of the aquifer has not been tested, but speculated that it was likely similar to the Elm Creek aquifer, which has a similar history. Ackerman (1980) estimated (based on grain size) that hydraulic conductivities would vary from about 10 ft./day to about 130 ft./day, with transmissivities ranging from about 10 ft.$^2$/day to 13,000 ft.$^2$/day. He estimated that storage coefficients would "likely" be about 0.0001 where confined, and about 0.2 where unconfined. Ackerman estimated potential well yields of 10 to 1,000 gpm, depending on location.

Aquifer Chemistry: According to Wanek (2009) aquifer chemistry would be expected to be similar to the Elm Creek aquifer. Total dissolved solids concentrations for 34 wells sampled are about 1,000 milligrams per liter, ranging from 334 to 1,560 mg/l (Table 12.3.1). Water is primarily of the sodium-bicarbonate type, with some of the calcium magnesium and mixed calcium-bicarbonate type (Figure 12.3.1). Sodium concentrations increase with increasing dissolved solids. Iron and manganese concentrations are high (Table 12.3.3).

Permit Acquisition Status – Shields aquifer in Morton and Sioux Counties: there is some irrigation from ground water in the Flasher area, the city golf course and a nearby 211-acre irrigation development. Whether the irrigation is categorized as coming from the Elm Creek or Shields aquifer is of little importance since the two aquifers could be considered as one. There is no other permitted water use from the Shields aquifer. If we assume an inch per year recharge, between 1,000 and 2,000 acre-feet may potentially be available for development. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Additional Considerations: The best potential for development is away from the irrigation near Flasher. The aquifer has not been drilled extensively enough to say that one segment of the aquifer has better hydrologic characteristics than another.

Citations:

Ackerman, D.J. 1980. Ground-water Resources of Morton County, North Dakota. County Ground-Water Studies 27-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 31-32.

Wanek, Alan. Sept. 1, 2009. Ground water availability in western North Dakota. North Dakota State Water Commission Office Memorandum. pp. 23-24.

Table 12.3.1. Summary of chemical properties of the Shields aquifer in Morton and Sioux Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 700 | 558 | 0 | 7.7 | 321 | 334 | 7 | 15 | 7.6 | 1.9 | 1.6 | 29 | 0.5 | 362 | 0 | 15 | 0 | 0.7 |
| **Maximum** | 2,700 | 2,290 | 0 | 8.4 | 1,600 | 1,560 | 15 | 30 | 157 | 65 | 8.8 | 500 | 3 | 884 | 10 | 679 | 79 | 2.5 |
| **Points** | 22 | 27 | 0 | 26 | 26 | 27 | 24 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 |
| **Mean** | 1,707.7 | 1,471.7 | 0 | 8 | 972.69 | 970.15 | 8.42 | 23.27 | 52.64 | 19.39 | 5.34 | 275.12 | 1.01 | 651.23 | 0.5 | 255.81 | 10.1 | 1.32 |
| **Median** | 1,750 | 1,592 | 0 | 8.1 | 1,055 | 1,040 | 8 | 22.5 | 47.5 | 19.5 | 5.3 | 281 | 0.8 | 667.5 | 0 | 249 | 4.9 | 1 |
| **Std Deviation** | 533.79 | 469.14 | 0 | 0.16 | 349.84 | 331.61 | 1.63 | 3.69 | 30.41 | 12.73 | 1.98 | 127.82 | 0.6 | 149.2 | 2.02 | 169.88 | 16.69 | 0.62 |
| **Std Error** | 113.8 | 90.29 | 0 | 0.03 | 68.61 | 63.82 | 0.33 | 0.72 | 5.96 | 2.5 | 0.39 | 25.07 | 0.12 | 29.26 | 0.4 | 33.32 | 3.27 | 0.12 |

Table 12.3.2. Summary of chemical properties of the Shields aquifer in Morton and Sioux Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0 | 0 | 0.8 | 0 | 0.22 | 0 | 1.22 | 0 | 0 |
| **Maximum** | 0 | 725 | 34 | 0 | 1.5 | 0 | 2.5 | 0 | 0 |
| **Points** | 0 | 27 | 27 | 0 | 26 | 0 | 26 | 0 | 0 |
| **Mean** | 0 | 514.89 | 9.84 | 0 | 0.83 | 0 | 1.83 | 0 | 0 |
| **Median** | 0 | 543 | 7.9 | 0 | 0.8 | 0 | 1.8 | 0 | 0 |
| **Std Deviation** | 0 | 157.6 | 7.31 | 0 | 0.28 | 0 | 0.28 | 0 | 0 |
| **Std Error** | 0 | 30.33 | 1.41 | 0 | 0.05 | 0 | 0.05 | 0 | 0 |

Table 12.3.3. Summary of chemical properties of the Shields aquifer in Morton and Sioux Counties: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Maximum | 1.9 | 15 | 0.37 | 0 | 0 | 0 | 0 | 0 |
| Points | 27 | 26 | 26 | 0 | 0 | 0 | 0 | 0 |
| Mean | 0.83 | 2.24 | 0.12 | 0 | 0 | 0 | 0 | 0 |
| Median | 0.71 | 1.06 | 0.11 | 0 | 0 | 0 | 0 | 0 |
| Std Deviation | 0.46 | 3.68 | 0.1 | 0 | 0 | 0 | 0 | 0 |
| Std Error | 0.09 | 0.72 | 0.02 | 0 | 0 | 0 | 0 | 0 |

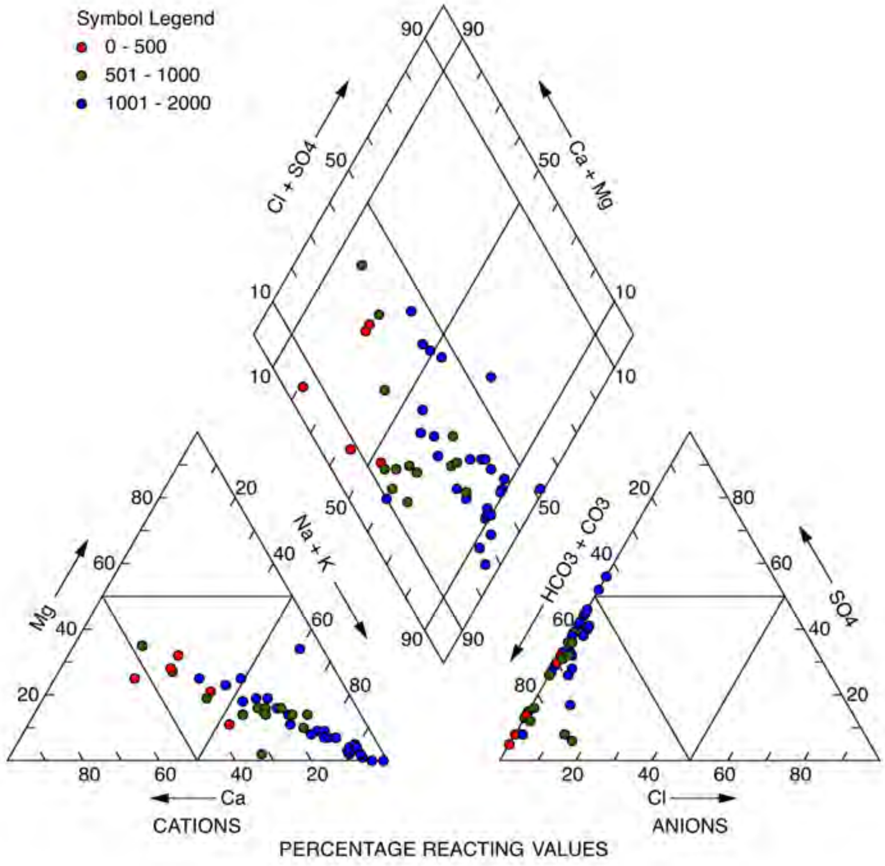


Figure 12.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Shields aquifer in Morton and Sioux Counties.

### *12.4 St. James Aquifer (Morton and Sioux Counties)*

The St. James aquifer occupies a buried valley in southern Morton County and northeastern Sioux County, extending approximately from Solen to just south of Cannonball. About ten square miles have been indicated to have potential for further development (Study Area #12 map).

Aquifer Composition: According to Ackerman (1980), the aquifer consists of sand and gravel interbedded with clay and silt. Coarsest materials are usually near the base of the aquifer. Thicknesses from nine test holes range from 5 to 157 feet. Lithologies are similar to other nearby aquifers (Elm Creek, Killdeer, St. James and Shields).

Aquifer Yield: Using grain composition, Ackerman (1980) estimates transmissivities of 100 to 18,000 ft.$^2$/day, with storage coefficients ranging from about 0.0005 for deeper confined units to 0.2 in unconfined areas. He estimates potential well yields ranging from 10 gpm to as high as 1,000 gpm.

Aquifer Chemistry: Four water samples from the aquifer had an average dissolved solids concentration of 1,200 mg/l. The water is of a sodium-bicarbonate type water, with some sulfate, similar to that of other nearby aquifers (Elm Creek, Killdeer, St. James and Shields).

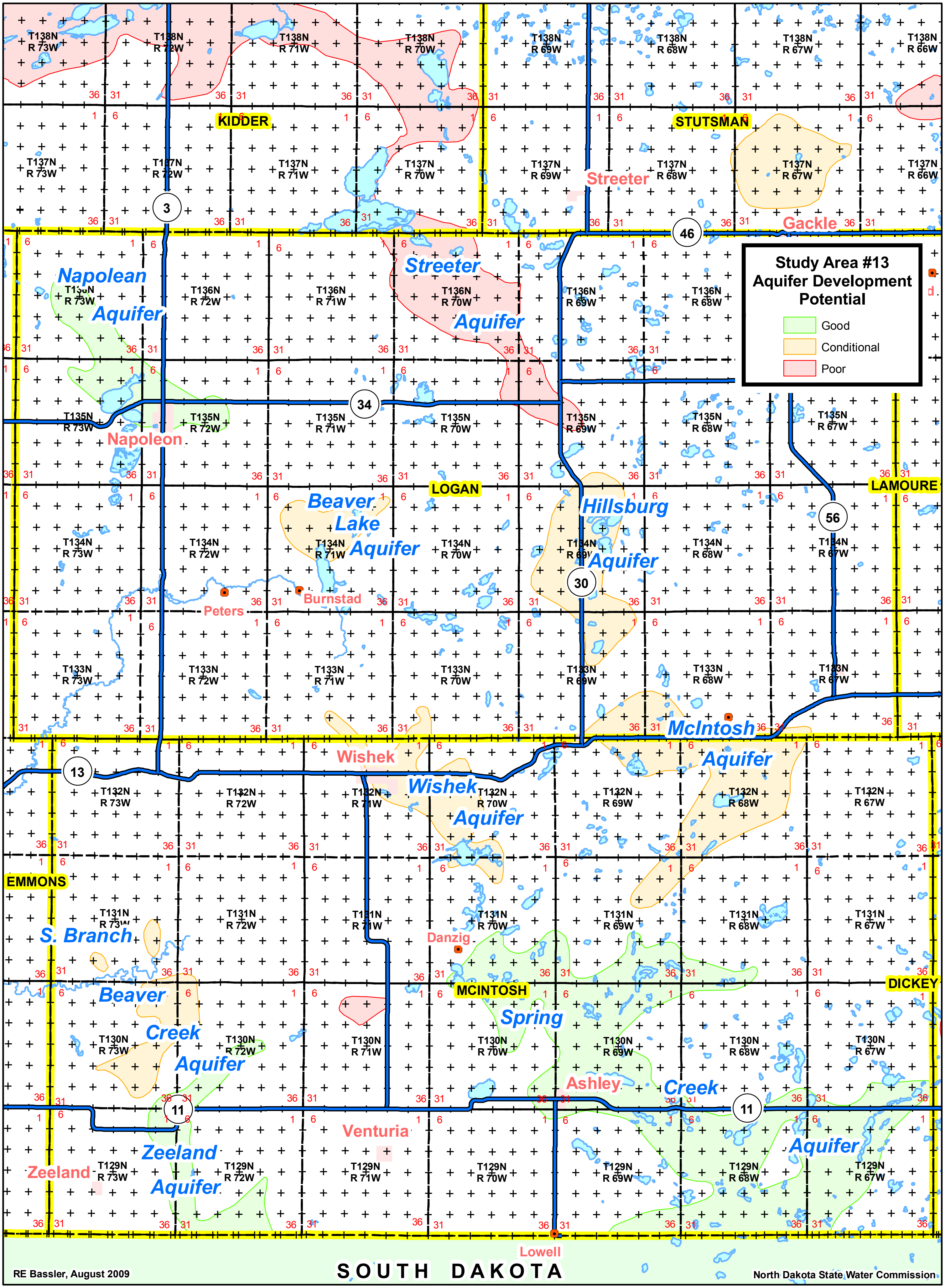
Permit Acquisition Status: There are currently no competing water permits or pending water-permit applications. Some water may be available along the limited extent of the aquifer. Assuming about one inch per year of recharge, up to about 500 acre-feet per year may be available for development and use.

Additional Considerations: In Sioux County the Standing Rock tribal government should be consulted regarding water use. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Ackerman, D.J. 1980. Ground-water Resources of Morton and Sioux Counties, North Dakota. County Ground-Water Studies 27-Part III. North Dakota State Water Commission. Bismarck, ND. p. 39.

Wanek, Alan. Sept. 1, 2009. Ground water availability in western North Dakota. North Dakota State Water Commission Office Memorandum. p. 24.


Study Area #13
Aquifer Development Potential
🟩 Good
🟨 Conditional
🟥 Poor
KIDDER
STUTSMAN
LOGAN
LAMOURE
EMMONS
MCINTOSH
DICKEY
SOUTH DAKOTA
Napolean Aquifer
Streeter Aquifer
Beaver Lake Aquifer
Hillsburg Aquifer
McIntosh Aquifer
Wishek Aquifer
S. Branch Beaver Creek Aquifer
Spring Creek Aquifer
Zeeland Aquifer
Streeter
Gackle
Napoleon
Peters
Burnstad
Wishek
Danzig
Ashley
Venturia
Zeeland
Lowell
3
46
34
56
30
13
11
T138N R 73W
T138N R 72W
T138N R 71W
T138N R 70W
T138N R 69W
T138N R 68W
T138N R 67W
T138N R 66W
T137N R 73W
T137N R 72W
T137N R 71W
T137N R 70W
T137N R 69W
T137N R 68W
T137N R 67W
T137N R 66W
T136N R 73W
T136N R 72W
T136N R 71W
T136N R 70W
T136N R 69W
T136N R 68W
T135N R 73W
T135N R 72W
T135N R 71W
T135N R 70W
T135N R 69W
T135N R 68W
T135N R 67W
T134N R 73W
T134N R 72W
T134N R 71W
T134N R 70W
T134N R 69W
T134N R 68W
T134N R 67W
T133N R 73W
T133N R 72W
T133N R 71W
T133N R 70W
T133N R 69W
T133N R 68W
T133N R 67W
T132N R 73W
T132N R 72W
T132N R 71W
T132N R 70W
T132N R 69W
T132N R 68W
T132N R 67W
T131N R 73W
T131N R 72W
T131N R 71W
T131N R 70W
T131N R 69W
T131N R 68W
T131N R 67W
T130N R 73W
T130N R 72W
T130N R 71W
T130N R 70W
T130N R 69W
T130N R 68W
T130N R 67W
T129N R 73W
T129N R 72W
T129N R 71W
T129N R 70W
T129N R 69W
T129N R 68W
T129N R 67W
RE Bassler, August 2009
North Dakota State Water Commission

## Study Area 13: Central North Dakota / Logan and McIntosh Counties

### *13.1 Beaver Creek Aquifer (McIntosh County)*

A small aquifer, underlying about ten square miles, has been mapped northwest of the Zeeland aquifer in southwestern McIntosh County (Study Area #13 map). It was not described or documented by Klausing (1981) in the original county studies.

Aquifer Composition: Two lithologic logs shown below (Appendix Figures B.13.1.1 and B.13.1.2) indicate that the Beaver Creek aquifer is similar to other area aquifers, consisting in places of about 20 feet of shallow surficial outwash, and about 20 feet of sand or gravel at a depth of about 100 feet bls. One site (130-73-01AAA) consists medium to coarse sand in a surficial deposit to 71 feet. Similarity to other area aquifers and proximity to the Zeeland aquifer, suggests similar depositional events and characteristics.

Aquifer Yield: Strictly by inference and similarity from other area aquifers described by Klausing (1981), it might be suggested that well yields of 50 to 200 gpm might be feasible.

Aquifer Chemistry: Limited data (water samples from four well sites) indicates that water chemistry is a bicarbonate type, with cation and anion distributions varying from calcium-bicarbonate and calcium magnesium-bicarbonate types, to a sodium-bicarbonate type (Figure 13.1.1). General chemistry properties and parameters are summarized on Tables 13.1.1 and 13.1.2. As with other area aquifers, iron and manganese concentrations (Table 13.1.3) are somewhat high.

Permit Acquisition: There are currently no water permits or competing permit applications that would delay consideration of a new application. If average overall recharge is 0.5 inches per year, with 10 square miles of surface area, about 200 to 300 acre-feet might be available for additional development.

Additional Considerations: Information on this aquifer is sparse, so that its extent and continuity is poorly-defined. Further local field investigations must be made before considering development. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Klausing, Robert L. 1981. Ground-water Resources of McIntosh County, North Dakota. County Ground-water Studies 30-Part III. North Dakota State Water Commission. Bismarck, ND. 37 pp.

Table 13.1.1. Summary of chemical properties of the Beaver Creek aquifer in McIntosh County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 483 | 453 | 7 | 7.8 | 473 | 281 | 8.5 | 17 | 51.7 | 14.1 | 5.57 | 25.9 | 0.18 | 230 | NA | 37.8 | 2.17 | 0.6 |
| **Maximum** | 800 | 825 | 8.7 | 8.5 | 555 | 540 | 10 | 29 | 93 | 33 | 10 | 45 | 0.5 | 448 | NA | 150 | 10 | 10 |
| **Points** | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | NA | 4 | 4 | 4 |
| **Mean** | 613.25 | 668.75 | 7.8 | 8.05 | 508.33 | 426.75 | 9.17 | 22.35 | 75.68 | 25.03 | 8.22 | 34.98 | 0.32 | 346.75 | NA | 74.95 | 5.72 | 3.03 |
| **Median** | 585 | 698.5 | 7.75 | 7.96 | 497 | 443 | 9 | 21.7 | 79 | 26.5 | 8.65 | 34.5 | 0.3 | 354.5 | NA | 56 | 5.35 | 0.76 |
| **Std Deviation** | 145.19 | 155.9 | 0.79 | 0.31 | 42.16 | 109.16 | 0.76 | 5.07 | 19.49 | 8.16 | 2.18 | 9.93 | 0.16 | 89.49 | NA | 52.22 | 3.23 | 4.65 |
| **Std Error** | 72.59 | 77.95 | 0.39 | 0.15 | 24.34 | 54.58 | 0.44 | 2.53 | 9.74 | 4.08 | 1.09 | 4.96 | 0.08 | 44.75 | NA | 26.11 | 1.61 | 2.32 |

Table 13.1.2. Summary of chemical properties of the Beaver Creek aquifer in McIntosh County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 187 | 0 | 188 | 0.6 | 188 | - | - | - | - |
| **Maximum** | 360 | 72 | 188 | 1.2 | 188 | - | - | - | - |
| **Points** | 4 | 4 | 1 | 4 | 1 | - | - | - | - |
| **Mean** | 291.75 | 18 | 188 | 0.91 | 188 | - | - | - | - |
| **Median** | 310 | 0 | 188 | 0.91 | 188 | - | - | - | - |
| **Std Deviation** | 80.62 | 36 | 0 | 0.26 | 0 | - | - | - | - |
| **Std Error** | 40.31 | 18 | 0 | 0.13 | 0 | - | - | - | - |

Table 13.1.3. Summary of chemical properties of the Beaver Creek aquifer in McIntosh County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.04 | 0.13 | 0.52 | - | - | - | - | - |
| Maximum | 0.24 | 0.73 | 1.32 | - | - | - | - | - |
| Points | 3 | 4 | 4 | - | - | - | - | - |
| Mean | 0.13 | 0.32 | 0.92 | - | - | - | - | - |
| Median | 0.11 | 0.21 | 0.92 | - | - | - | - | - |
| Std Deviation | 0.1 | 0.28 | 0.33 | - | - | - | - | - |
| Std Error | 0.06 | 0.14 | 0.16 | - | - | - | - | - |

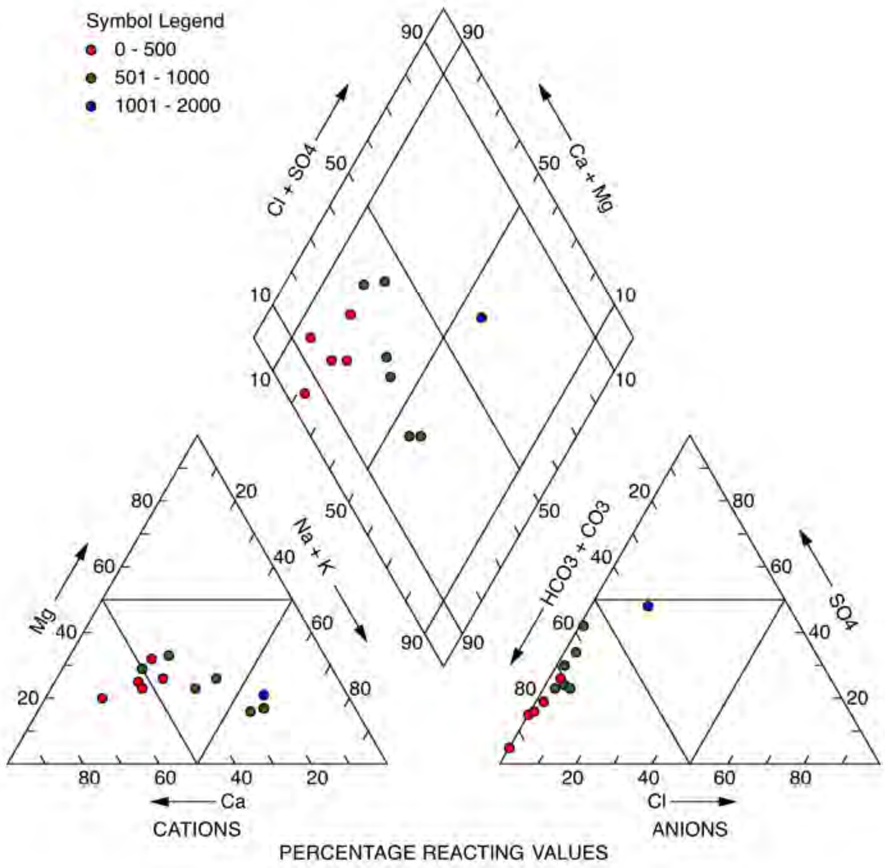


Figure 13.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Beaver Creek aquifer in McIntosh County.

### *13.2 Beaver Lake Aquifer (Logan County) and Undefined Deposit (Stutsman County)*

The Beaver Lake aquifer was described by Klausing (1981) as a system of sand and gravel deposits underlying about 16 square miles in southeastern Logan County. Another small aquifer, about 16 square miles in area, has been mapped a few miles north of Gackle (Study Area #13 map).

Aquifer Composition: According to Klausing (1981) the Beaver Lake aquifer consists of very fine to very coarse gravelly sand with a "considerable amount of interstitial clay and silt." The saturated thickness varies from 10 to 54 feet with a mean thickness of 28 feet. The undefined deposit mapped north of Gackle has been delineated based on drillers' logs. It may be similar to other area deposits: that is, shallow buried sand and gravel.

Aquifer Yield: Klausing (1981) has cited potential well yields of 50 to 200 gpm. The undefined deposit north of Gackle may be similar, but there is no documentation.

Aquifer Chemistry: Water chemistry for the Beaver Lake aquifer is undocumented in the SWC database, and there are no existing monitoring wells in either the Beaver Lake deposit or the unnamed deposit north of Gackle. The chemical characteristics for three samples collected from the Beaver Lake aquifer, described by Klausing (1981), seem to be very similar to those of the Hillsburg aquifer.

Permit Acquisition Status: There are currently no water permits or applications pending for water permits, so delays in processing new applications should not be affected by earlier competing applications. If average overall recharge is 0.5 inches per year, with 16 square miles of surface, about 400 additional acre-feet might be developed for beneficial use.

Additional Considerations: While there is further development potential for beneficial use, the recharge rates of deeper deposits are unknown, and if not connected to other shallower deposits recharge could be negligible. Further local investigation and exploration should be undertaken before assuming a dependable and sustainable long-term water supply for industrial use.

Citations:

Klausing, Robert L. 1981. Ground-water Resources of Logan County, North Dakota. County Ground-water Studies 30-Part III. North Dakota State Water Commission. Bismarck, ND. 37 pp.

### *13.3 Hillsburg Aquifer System (Logan County)*

The Hillsburg aquifer was described by Klausing (1981) as a system of sand and gravel deposits underlying about 24 square miles in southeastern Logan County (Study Area #13 map).

Aquifer Composition: According to Klausing (1981) the Hillsburg aquifer consists of two aquifer deposits: a surficial deposit composed of fine to coarse sandy gravel, usually overlain by till, and a deeper buried valley unit. The units vary in thickness from 8 to 34 feet, but the mean for the aquifer system is about 17 feet. Klausing stated that the connection between the deeper and shallower units was unknown, but believed that they were connected in some areas. Aquifer characteristics are illustrated on two lithologic logs (Appendix Figures B.13.3.1 and B.13.3.2).

Aquifer Yield*:* Klausing (1981) has cited potential well yields of 50 to 200 gpm in both upper and lower units. Wells screened in both units could yield double in some areas.

Aquifer Chemistry: The water chemical composition is mostly of a calcium-bicarbonate type and sodium-bicarbonate type, with some dissolved sulfate (Figure 13.3.1). Dissolved solids concentrations range from about 350 mg/L to 2,700 mg/L (Table 13.3.1) Higher dissolved solids concentrations tend to be more sulfatic. The median iron concentration is low (<0.3 mg/L, Table 13.3.3). The median manganese concentration is high (>0.05 mg/L, Table 13.3.3).

Permit Acquisition Status: There are currently no water permits or applications pending for water permits in the Hillsburg aquifer, so delays in processing new applications should not be affected by earlier competing applications. Assuming an average recharge rate of 0.5 inches per year, with 25 square miles of surface area, about 500 to 600 acre-feet of additional appropriation might be developed for beneficial use.

Additional Considerations: While there is further development potential for beneficial use, the recharge rates of deeper deposits are unknown, and if not connected to other shallower deposits recharge could be negligible. Further local investigation and exploration should be undertaken before assuming a dependable and sustainable long-term water supply for industrial use.

Citations:

Klausing, Robert L. 1981. Ground-water Resources of Logan County, North Dakota. County Ground-water Studies 30-Part III. North Dakota State Water Commission. Bismarck, ND. 37 pp.

Table 13.3.1. Summary of chemical properties of the Hillsburg aquifer in Logan County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 575 | 595 | 7.1 | 7.3 | 355 | 373 | 6.5 | 18 | 63 | 18 | 2.6 | 7.9 | 0.1 | 292 | 0 | 51 | 2 | <1 |
| **Maximum** | 2,800 | 2,800 | 9.3 | 8.4 | 2,640 | 2,380 | 13 | 30 | 360 | 220 | 18 | 390 | 0.4 | 505 | 0 | 1,500 | 280 | 760 |
| **Points** | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 0 | 13 | 13 | 13 |
| **Mean** | 1,361.2 | 1,429.3 | 7.76 | 7.85 | 1,059.6 | 986.77 | 8.5 | 24.08 | 129.69 | 60.46 | 8.07 | 104.68 | 0.22 | 395.46 | 0 | 330 | 54.21 | 78.87 |
| **Median** | 1,075 | 1,120 | 7.7 | 7.8 | 808 | 772 | 8 | 26 | 100 | 36 | 7.1 | 75 | 0.2 | 380 | 0 | 230 | 27 | 1 |
| **Std Deviation** | 730.94 | 762.77 | 0.6 | 0.31 | 695.81 | 619.96 | 1.56 | 4.66 | 79.87 | 62.38 | 4.39 | 114.89 | 0.1 | 72.01 | 0 | 401.66 | 75.4 | 209.48 |
| **Std Error** | 202.73 | 211.55 | 0.17 | 0.09 | 192.98 | 171.94 | 0.43 | 1.29 | 22.15 | 17.3 | 1.22 | 31.87 | 0.03 | 19.97 | 0 | 111.4 | 20.91 | 58.1 |

Table 13.3.2. Summary of chemical properties of the Hillsburg aquifer in Logan County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 54 | 0 | 209 | - | 0.1 | - | - | - | - |
| **Maximum** | 580 | 240 | 421 | - | 9.33 | - | - | - | - |
| **Points** | 24 | 24 | 12 | - | 24 | - | - | - | - |
| **Mean** | 299.58 | 38.5 | 300.42 | - | 1.54 | - | - | - | - |
| **Median** | 318 | 21 | 304.5 | - | 0.91 | - | - | - | - |
| **Std Deviation** | 103.5 | 56.51 | 53.67 | - | 1.97 | - | - | - | - |
| **Std Error** | 21.13 | 11.54 | 15.49 | - | 0.4 | - | - | - | - |

Table 13.3.3. Summary of chemical properties of the Hillsburg aquifer in Logan County: selected trace elements.

|  | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0 | 0 | 0.04 | - | - | - | - | - |
| **Maximum** | 0.5 | 0.71 | 1.9 | - | - | - | - | - |
| **Points** | 12 | 12 | 13 | - | - | - | - | - |
| **Mean** | 0.09 | 0.2 | 0.69 | - | - | - | - | - |
| **Median** | 0 | 0.08 | 0.4 | - | - | - | - | - |
| **Std Deviation** | 0.16 | 0.25 | 0.59 | - | - | - | - | - |
| **Std Error** | 0.05 | 0.07 | 0.16 | - | - | - | - | - |

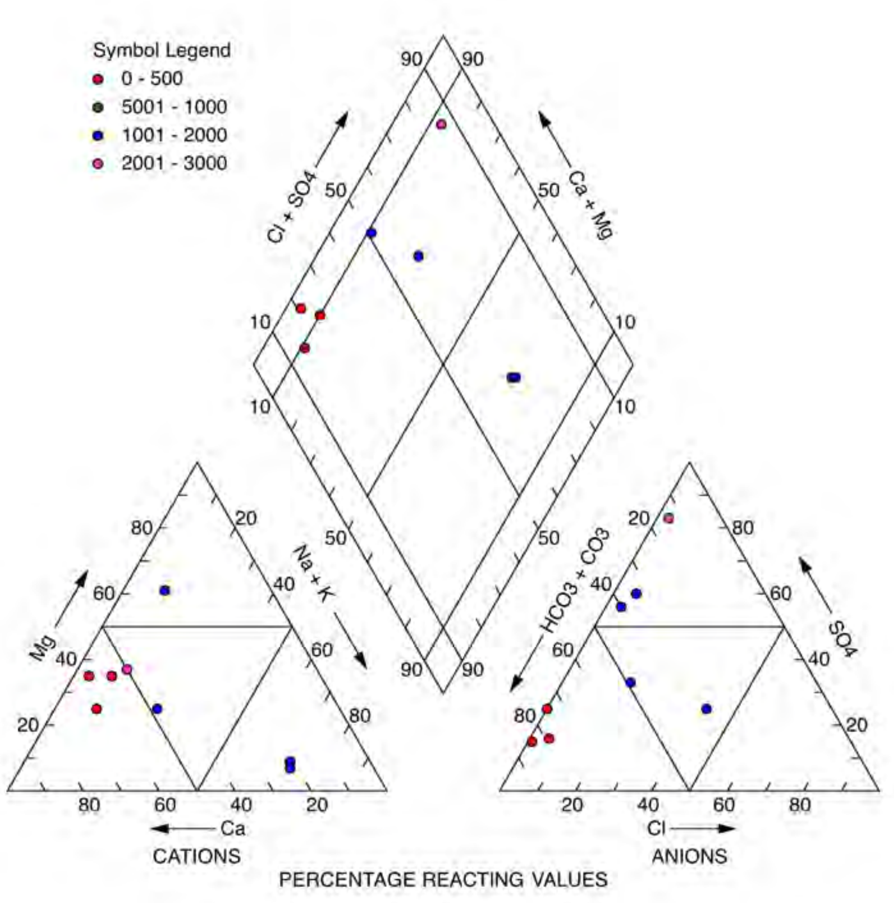


Figure 13.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Hillsburg aquifer in Logan County.

### *13.4 McIntosh Aquifer System (McIntosh County)*

The McIntosh aquifer was described by Klausing (1981) as a system of sand and gravel deposits underlying about 22 square miles in southeastern McIntosh County (Study Area #13 map).

Aquifer Composition: According to Klausing (1981) the McIntosh aquifer composition varies from fine to very coarse gravelly sand. Thicknesses vary from 5 to 53 feet. The aquifer is confined in some areas and unconfined in others. Aquifer characteristics are illustrated on two lithologic logs, both having saturated thicknesses of about 20 feet (Appendix Figures B.13.4.1 and B.13.4.2).

Aquifer Yield: Klausing (1981) has cited potential well yields of 50 to 200 gpm, perhaps as high as 500 gpm where the aquifer is thickest.

Aquifer Chemistry: Few water samples are available for evaluation. Dissolved solids concentrations range between about 250 and 1,300 mg/L (Table 13.4.1). The water is mainly of the calcium-bicarbonate type, but one sample is of the calcium magnesium sodium-sulfate type (Figure 13.4.1). Water having higher dissolved solids tends to be more sulfatic. Iron and manganese concentrations tend to be high (Table 13.4.3). No measurements of selenium or arsenic are available. Potential users should test for these trace elements.

Permit Acquisition Status: There are currently no water permits with established priority dates in the McIntosh aquifer. There are no competing or pending applications which would lengthen the time for consideration of a new application. Based on an average recharge rate of 0.5 inches per year, with 22 square miles of surface area, about 500 to 600 acre-feet of additional appropriation might be developed for beneficial use.

Additional Considerations: While there is further development potential for beneficial use, the recharge rates of deeper deposits are unknown, and if not connected to other shallower deposits recharge could be negligible. Further local investigation and exploration should be undertaken before assuming a dependable and sustainable long-term water supply for industrial use.[132]

Citations*:*

Klausing, Robert L. 1981. Ground-water Resources of McIntosh County, North Dakota. County Ground-water Studies 30-Part III. North Dakota State Water Commission. Bismarck, ND. 37 pp.

---

[132] Managing hydrologist, Royce Cline, has observed that this aquifer appears to consist of sand and gravel deposits at varying depths lumped together in one aquifer. In some areas there appear to be little or no aquifer.

Table 13.4.1. Summary of chemical properties of the McIntosh aquifer in McIntosh County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^{o}$C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 455 | 479 | 6.91 | 7.8 | 361 | 268 | 3.5 | 16 | 61.6 | 17.5 | 4.2 | 5.5 | 0.1 | 245 | 0 | 33.7 | 1.71 | 0.09 |
| **Maximum** | 1,590 | 1,850 | 8.24 | 8.7 | 1,420 | 1,390 | 10.9 | 28 | 190 | 110 | 14 | 120 | 0.3 | 479 | 13 | 690 | 40 | 87 |
| **Points** | 7 | 7 | 6 | 7 | 5 | 7 | 6 | 6 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| **Mean** | 973 | 1,051.9 | 7.5 | 8.09 | 876 | 731.43 | 7.63 | 22.53 | 125.23 | 48.79 | 8.27 | 48.79 | 0.16 | 386.29 | 2.14 | 271.53 | 10.74 | 12.95 |
| **Median** | 940 | 979 | 7.3 | 8.06 | 766 | 607 | 7.5 | 23.45 | 118 | 45 | 8.4 | 35 | 0.13 | 420 | 0 | 161 | 5.3 | 1 |
| **Std Deviation** | 442.87 | 492.17 | 0.61 | 0.31 | 474.91 | 426.91 | 2.5 | 5.5 | 49.44 | 30.58 | 3.93 | 45.75 | 0.08 | 98.58 | 4.81 | 262.3 | 13.48 | 32.65 |
| **Std Error** | 167.39 | 186.02 | 0.25 | 0.12 | 212.39 | 161.36 | 1.02 | 2.25 | 18.69 | 11.56 | 1.48 | 17.29 | 0.03 | 37.26 | 1.82 | 99.14 | 5.09 | 12.34 |

Table 13.4.2. Summary of chemical properties of the McIntosh aquifer in McIntosh County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^{o}$C | Langelier, Lab pH, 25$^{o}$C | Langelier, Field pH, 82$^{o}$C | Langelier, Lab pH, 82$^{o}$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 226 | 0 | 225 | 0 | 0.1 | -0.18 | 0.62 | 0.82 | 1.62 |
| **Maximum** | 900 | 510 | 385 | 393 | 1.7 | 1.25 | 1.72 | 2.25 | 2.72 |
| **Points** | 7 | 7 | 2 | 7 | 7 | 4 | 5 | 4 | 5 |
| **Mean** | 512.86 | 193.29 | 305 | 232.43 | 0.82 | 0.52 | 1.15 | 1.52 | 2.15 |
| **Median** | 440 | 96 | 305 | 281 | 0.6 | 0.51 | 1.04 | 1.51 | 2.04 |
| **Std Deviation** | 233.03 | 219.8 | 113.14 | 169.63 | 0.67 | 0.6 | 0.42 | 0.6 | 0.42 |
| **Std Error** | 88.08 | 83.08 | 80 | 64.11 | 0.25 | 0.3 | 0.19 | 0.3 | 0.19 |

Table 13.4.3. Summary of chemical properties of the McIntosh aquifer in McIntosh County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | nd | 0.02 | 0.23 | - | - | - | - | - |
| Maximum | 0.52 | 1.5 | 6.4 | - | - | - | - | - |
| Points | 4 | 7 | 7 | - | - | - | - | - |
| Mean | 0.32 | 0.52 | 1.69 | - | - | - | - | - |
| Median | 0.39 | 0.19 | 1.16 | - | - | - | - | - |
| Std Deviation | 0.23 | 0.56 | 2.12 | - | - | - | - | - |
| Std Error | 0.12 | 0.21 | 0.8 | - | - | - | - | - |

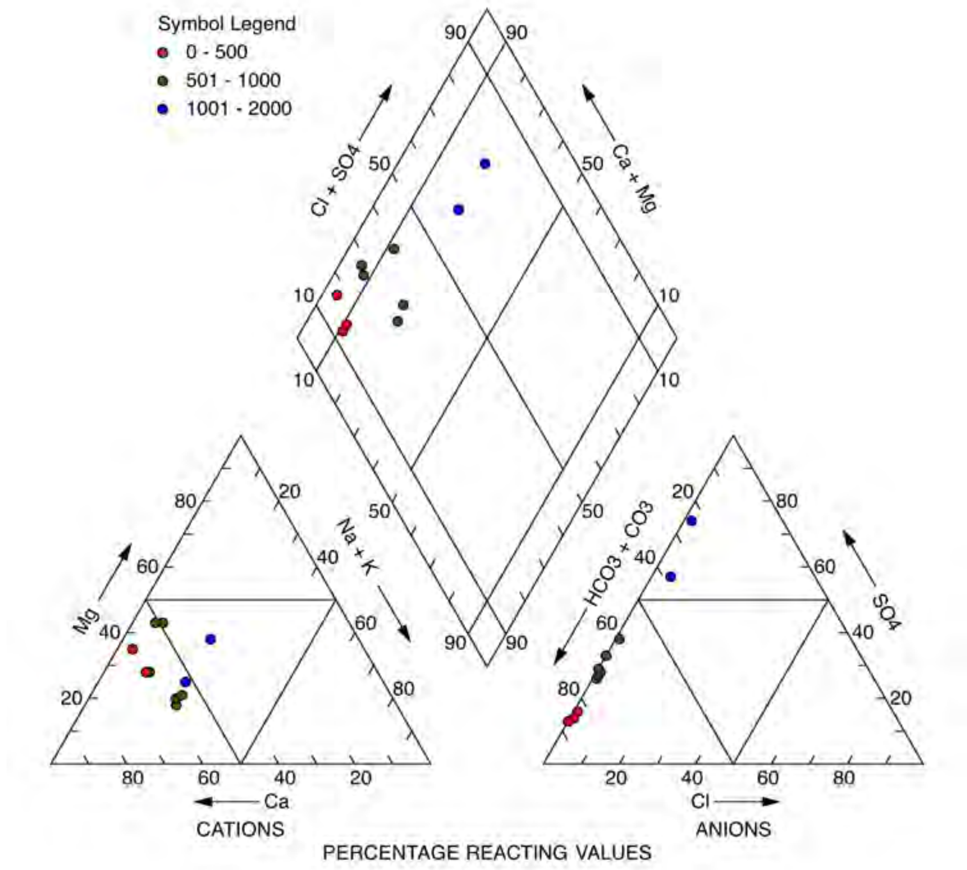


Figure 13.4.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the McIntosh aquifer in McIntosh County.

### *13.5 Napoleon Aquifer System (Logan County)*

The Napoleon aquifer system consists of two components: (1) a confined buried valley deposit, generally consisting of two sand and gravel layers, often divided by as much as 38 feet of till; and (2) an unconfined surficial outwash deposit (Klausing, 1983), located in northwestern Logan County, North Dakota. The entire deposit underlies an area of about 22 square miles (Study Area #13 map). The buried valley deposits are more prevalent in the northwestern portion of the aquifer, while the southeastern portion has more strongly expressed surficial deposits. The surficial outwash deposits are thickest near the Napoleon city well, where they are connected with underlying buried valley deposits.

<u>Aquifer Composition:</u> The Napoleon aquifer was laid down in several different events, and its composition is variable. The shallower buried deposit was described by Klausing (1993) as varying from very fine clayey silty sand to sandy medium gravel, with thicknesses from 6 to 57 feet. The deeper buried deposit was described as ranging from 7 to 93 feet, and ranging from very fine to fine silty and clayey sand to coarse sandy gravel. In some places, the two layers have been shown to coalesce. The underlying bedrock is the Fox Hills sandtone. The surficial outwash deposits vary in thickness from less than one foot at the edges to as much as 66 feet. The mean saturated thickness is about 17 feet. The deposits range from very fine to very coarse gravelly sand to fine to medium sandy gravel. Lithologies for four sites are shown on Appendix Figures B.13.5.1. through Figure B.13.5.4.

<u>Aquifer Yield:</u> Potential well yields for the buried valley aquifer have been described by Klausing (1983) as ranging from 40 to 700 gpm in the upper bed, and 50 to 400 gpm in the lower bed. In areas where they coalesce, Klausing speculated that the aquifer could yield as much as 1,000 gpm per well. For the surficial outwash aquifer, well yields were predicted to range from about 50 to 200 gpm, with possible local well yields of 500 gpm.

<u>Aquifer Chemistry:</u> Klausing (1983) reported that chemistry of the Napoleon outwash aquifer and the Napoleon buried valley aquifers was similar. He reported that the water was generally hard, ranging from a calcium-bicarbonate type where recharge waters are influenced primarily by seepage through glacial materials, to a sodium-bicarbonate type where the Napoleon aquifer is in proximity to the underlying Fox Hills aquifer. Klausing believed that the pressurized Fox Hills water was a recharge source for the Napoleon aquifer. Summary data (Table 13.5.1) indicate that the median dissolved solids concentration is about 600 mg/L, depending on the measurement method (calculated or determined). Ninety percent of 27 wells on 19 sites have dissolved solids below 800 mg/L. Sulfate is generally low, with 90% of the wells having concentrations below 175 mg/L. The Piper plot indicates that all of the water samples range from calcium-bicarbonate to sodium-bicarbonate types (Figure 13.5.1). There is a slight, but weakly-expressed tendency toward more of a sodium-bicarbonate type with higher dissolved

solids, probably from mixing with water from the underlying Fox Hills bedrock aquifer. Generally, the Napoleon aquifer has good quality water, with reference to drinking water standards.

All of the trace elements listed on Table 13.5.3 have median concentrations below levels of toxicological concern. Maximum concentrations for arsenic and selenium are slightly above the EPA-MCL (10 μg/L for each), but during pumpage local high concentrations would likely be diluted when averaged with the entire well capture area.

Permit Acquisition Status: There are currently five water permits, three perfected and two conditional, for a total annual allocation of 963.5 acre-feet from the Napoleon. Approved pumping rates vary from 100 gpm, to 1,199 gpm for the city of Napoleon. There are currently no pending applications. Because of its limited size, this aquifer has moderate potential for further development, perhaps double or slightly more than double its current approved allocation of 963.5 acre-feet.

Additional Considerations: Prospective water users should be aware of the proximity of the Fox Hills sandstone to the source water at the point of diversion. It is likely that water in aquifer deposits near the Fox Hills aquifer will increase in sodium content, and possibly in TDS, under large pumping stress, because of an increased capture of Fox Hills water. Project proponents and planners should consult with SWC managing hydrologists for further guidance, before proceeding with plans for placement of facilities and their water supplies. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Klausing, Robert L. 1983. Ground-water Resources of Logan County, North Dakota. County Ground-water Studies 34-Part III. North Dakota State Water Commission. Bismarck, ND. 42 pp.

Table 13.5.1.  Summary of chemical properties of the Napoleon aquifer in Logan County: general chemistry.

| | **SC-f µS/cm** | **SC-l µS/cm** | **pH-f** | **pH-l** | **TDS-d mg/L** | **TDS-c mg/L** | **T °C** | **Si mg/L** | **Ca mg/L** | **Mg mg/L** | **K mg/L** | **Na mg/L** | **Fl mg/L** | **Bicarb mg/L** | **Carb mg/L** | **Sulfate mg/L** | **Cl mg/L** | **NO3 mg/L** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 490 | 445 | 7 | 7.4 | 308 | 275 | 7 | 10 | 8.5 | 13.6 | 3.9 | 6.3 | 0.07 | 207 | 0 | 3.6 | 0.9 | 0 |
| **Maximum** | 2,140 | 2,180 | 9 | 8.9 | 1,390 | 1,380 | 13 | 29 | 140 | 120 | 39 | 244 | 0.6 | 1,240 | 25 | 661 | 110 | 4.69 |
| **Points** | 51 | 54 | 43 | 54 | 34 | 54 | 25 | 35 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 52 |
| **Mean** | 844.98 | 896.63 | 7.8 | 8 | 571.91 | 568.85 | 8.51 | 23.48 | 72.98 | 28.84 | 8.99 | 89.17 | 0.21 | 459.09 | 1.63 | 110.15 | 11.16 | 0.78 |
| **Median** | 780 | 819 | 7.9 | 8 | 537.5 | 509 | 8 | 26 | 77 | 25.5 | 7.85 | 71.65 | 0.19 | 440 | 0 | 92.5 | 4.05 | 0.8 |
| **Std Deviation** | 288.48 | 329.42 | 0.5 | 0.3 | 203.02 | 217.38 | 1.33 | 5.5 | 30.01 | 17.72 | 6.19 | 63.07 | 0.13 | 155.64 | 4.41 | 89.81 | 19.97 | 0.95 |
| **Std Error** | 40.4 | 44.83 | 0.1 | 0 | 34.82 | 29.58 | 0.27 | 0.93 | 4.08 | 2.41 | 0.84 | 8.58 | 0.02 | 21.18 | 0.6 | 12.22 | 2.72 | 0.13 |

Table 13.5.2. Summary of chemical properties of the Napoleon aquifer in Logan County: use parameters.

| Hardness | Hardness **mg/L** | NCH **mg/L** | ALK_ as_CaCO3 **mg/L** | ALK Calculated **mg/L** | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| Minimum | 129 | 0 | 186 | 0 | 0.19 | -0.14 | 0.21 | 0.86 | 1.21 |
| Maximum | 705 | 125 | 580 | 1,016 | 6 | 1.3 | 1.38 | 2.3 | 2.38 |
| Points | 54 | 54 | 20 | 54 | 54 | 30 | 34 | 30 | 34 |
| Mean | 301.04 | 12.65 | 366.2 | 248.41 | 2.35 | 0.59 | 0.78 | 1.59 | 1.78 |
| Median | 312.5 | 0 | 347 | 308 | 2.16 | 0.65 | 0.7 | 1.65 | 1.7 |
| Std Deviation | 115.47 | 25.58 | 108.67 | 214.93 | 1.69 | 0.41 | 0.27 | 0.41 | 0.27 |
| Std Error | 15.71 | 3.48 | 24.3 | 29.25 | 0.23 | 0.07 | 0.05 | 0.07 | 0.05 |

Table 13.5.3. Summary of chemical properties of the Napoleon aquifer in Logan County: selected trace elements.

|  | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium μg/L | Mercury μg/L | Arsenic μg/L | Lithium μg/L | Molybdenum μg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 1 | 3.82 | 3.95 | 3 | 0.1 | 2 | 180 | 3 |
| Maximum | 30 | 54 | 54 | 13 | 11 | 13 | 11 | 11 |
| Points | 0.29 | 0.21 | 1.12 | 0.62 | 0.01 | 0.71 | 121.82 | 0.82 |
| Mean | 0.24 | 0.1 | 1.19 | 0 | 0 | 1 | 100 | 0 |
| Median | 0.26 | 0.53 | 0.74 | 1.12 | 0.03 | 0.76 | 42.15 | 1.08 |
| Std Deviation | 0.05 | 0.07 | 0.1 | 0.31 | 0.01 | 0.21 | 12.71 | 0.33 |
| Std Error | 1 | 3.82 | 3.95 | 3 | 0.1 | 2 | 180 | 3 |

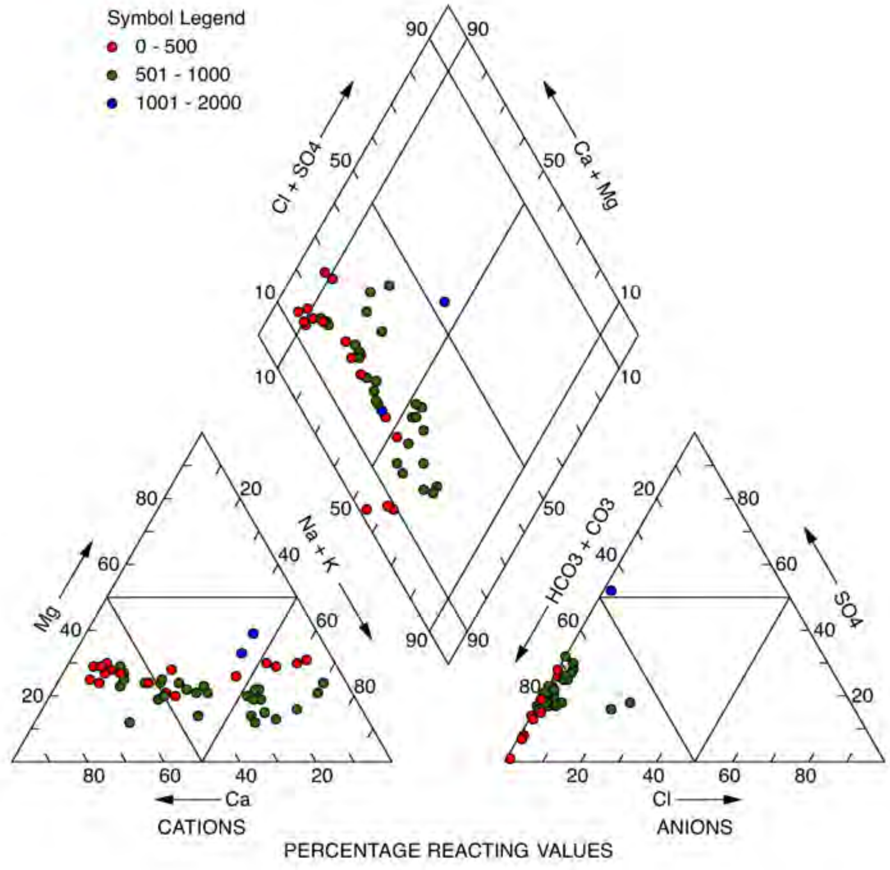


Figure 13.5.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Napoleon aquifer in Logan County.

### *13.6 Spring Creek Aquifer (McIntosh County)*

The Spring Creek aquifer was described by Klausing (1981) as a system of sand and gravel deposits underlying about 88 square miles in southeastern McIntosh County (Study Area #13 map).

Aquifer Composition: The Spring Creek aquifer consists of at least four laterally extensive deposits, including buried valley deposits and buried outwash deposits. According to Klausing (1981) the aquifer composition varies from "very fine sand to coarse gravel: the predominant lithology is coarse to very coarse gravelly sand. The aquifer system has a maximum aggregate thickness of 91 feet and a mean saturated aggregate thickness of 39 feet." Lithologies for four sites are shown on Appendix Figures B.13.5.1 through Figure B.13.5.4. It can be seen that depths and extents of the deposits vary widely, with some locations having single beds, others two or three, and depths varying from 30 to 40 feet to more than 200 feet. The "plumbing" of these deposits, that is, how and where they are connected, is not well known.

Aquifer Yield: Potential well yields for the buried valley aquifer have been described by Klausing (1983) as varying from 50 to 1,000 gpm, with yields of 500 to 1,000 gpm where the aquifer is thicker than 30 feet. Klausing described one 100-hour aquifer test for a location having a saturated thickness of about 34 feet, as having an average transmissivity of about 10,000 $ft.^2$/day, and a specific capacity of 26.8 gpm/ft. While substantial pumping rates are possible, the sustainability of use is dependent on the recharge and discharge characteristics of the aquifer, and aquifer continuity.

Aquifer Chemistry: Klausing (1983) reported that chemistry of the Spring Creek aquifer was mixed, most commonly being of the sodium-bicarbonate and sulfate type and calcium sodium magnesium-bicarbonate type. The wide range of chemical types are shown on the Piper plot (Figure 13.6.1). Summary statistics for all 96 water samples collected from 52 wells on 42 sites are shown on Tables 13.6.1, 13.6.2 and 13.6.3. Dissolved solids concentrations vary from about 400 mg/L to about 2,000 mg/L, with the median near 750 mg/L. About 30% of the median dissolved solids for individual wells were above 1,000 mg/L. Ninety percent of all median sulfate concentrations for individual wells were below 500 mg/L. Klausing observed that water chemistry was not related to the depths of deposits. Iron and manganese concentrations (Table 13.6.3) are somewhat high. Arsenic and selenium concentrations are all below levels of toxicological concern (10 μg/L).

Permit Acquisition Status: There are currently two water permits with established priority dates in the Spring Creek aquifer, both perfected. They are: the city of Ashley, for an annual appropriation of 470 acre-feet, and the Ashley School District for 10 acre-feet annually. There are no competing or pending applications which would lengthen the time for consideration of a new application. Current aquifer use is relatively small. Based on an average recharge rate of 0.5 inches per year, with 88 square miles of surface area, about 2,000 to 2,500 acre-feet of additional appropriation may be available.

Additional Considerations: Deeper deposits, in unoxidized till, may have low recharge rates, unless connected to shallower deposits. While there is further development potential for beneficial use, the recharge rates of deeper deposits are unknown, and if not connected to other shallower deposits recharge could be negligible. Further local investigation and exploration should be undertaken before assuming a dependable and sustainable long-term water supply for industrial use.

Because of the large variability of local chemical characteristics, potential large-scale water users should also consider the likelihood of changes in water chemistry over the period of use. Pumping will tend to capture more distant waters associated with flanking boundary materials, which may alter water chemistry. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Klausing, Robert L. 1981. Ground-water Resources of McIntosh County, North Dakota. County Ground-water Studies 30-Part III. North Dakota State Water Commission. Bismarck, ND. 37 pp.

Table 13.6.1. Summary of chemical properties of the Spring Creek aquifer in McIntosh County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 610 | 680 | 6.43 | 6.96 | 467 | 445 | 7 | 8.1 | 1.4 | 9.7 | 5.5 | 8.6 | 0 | 12 | 0 | 71 | 0 | 0 |
| **Maximum** | 2,500 | 2,660 | 10 | 9.2 | 2,110 | 2,020 | 18 | 32 | 280 | 260 | 100 | 435 | 0.7 | 590 | 72 | 1,000 | 310 | 85 |
| **Points** | 82 | 93 | 73 | 96 | 86 | 93 | 59 | 69 | 93 | 93 | 96 | 96 | 95 | 96 | 96 | 96 | 96 | 92 |
| **Mean** | 1,243.9 | 1,228.2 | 7.86 | 8.09 | 857.58 | 839.87 | 9.54 | 26.11 | 94.7 | 34.83 | 11.35 | 141.77 | 0.25 | 384.68 | 3.16 | 299.59 | 41.29 | 2.22 |
| **Median** | 1,157.5 | 1,160 | 7.9 | 8.07 | 790.5 | 764 | 9 | 27 | 95 | 31 | 9.95 | 125 | 0.2 | 399.5 | 0 | 275 | 27.05 | 1 |
| **Std Deviation** | 368.54 | 332.84 | 0.54 | 0.33 | 260.14 | 252.68 | 2.16 | 4.89 | 40.74 | 27.61 | 9.6 | 91.59 | 0.13 | 112.65 | 8.75 | 143.8 | 43.54 | 8.88 |
| **Std Error** | 40.7 | 34.51 | 0.06 | 0.03 | 28.05 | 26.2 | 0.28 | 0.59 | 4.22 | 2.86 | 0.98 | 9.35 | 0.01 | 11.5 | 0.89 | 14.68 | 4.44 | 0.93 |

Table 13.6.2. Summary of chemical properties of the Spring Creek aquifer in McIntosh County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 110 | 0 | 116 | 0 | 0.2 | -1.09 | -0.79 | -0.09 | 0.21 |
| **Maximum** | 1,200 | 670 | 474 | 600 | 17.6 | 3.03 | 2.01 | 4.03 | 3.01 |
| **Points** | 96 | 93 | 10 | 96 | 93 | 63 | 83 | 63 | 83 |
| **Mean** | 376.28 | 95.46 | 340.1 | 294.74 | 3.74 | 0.66 | 0.94 | 1.66 | 1.94 |
| **Median** | 360 | 40 | 364.5 | 320.5 | 2.9 | 0.69 | 0.95 | 1.69 | 1.95 |
| **Std Deviation** | 167.48 | 138.11 | 104.47 | 129.51 | 3.53 | 0.63 | 0.42 | 0.63 | 0.42 |
| **Std Error** | 17.09 | 14.32 | 33.04 | 13.22 | 0.37 | 0.08 | 0.05 | 0.08 | 0.05 |

Table 13.6.3. Summary of chemical properties of the Spring Creek aquifer in McIntosh County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0 | 0.02 | 0 | 0 | 0 | 130 | 0 |
| Maximum | 1.3 | 5.1 | 7.4 | 2.54 | 0.1 | 2 | 150 | 5 |
| Points | 66 | 96 | 92 | 8 | 6 | 8 | 6 | 6 |
| Mean | 0.5 | 0.33 | 1.46 | 0.48 | 0.02 | 0.95 | 143.33 | 3.17 |
| Median | 0.42 | 0.08 | 1.3 | 0 | 0 | 1 | 145 | 3.5 |
| Std Deviation | 0.33 | 0.75 | 1 | 0.94 | 0.04 | 0.88 | 8.17 | 1.72 |
| Std Error | 0.04 | 0.08 | 0.1 | 0.33 | 0.02 | 0.31 | 3.33 | 0.7 |

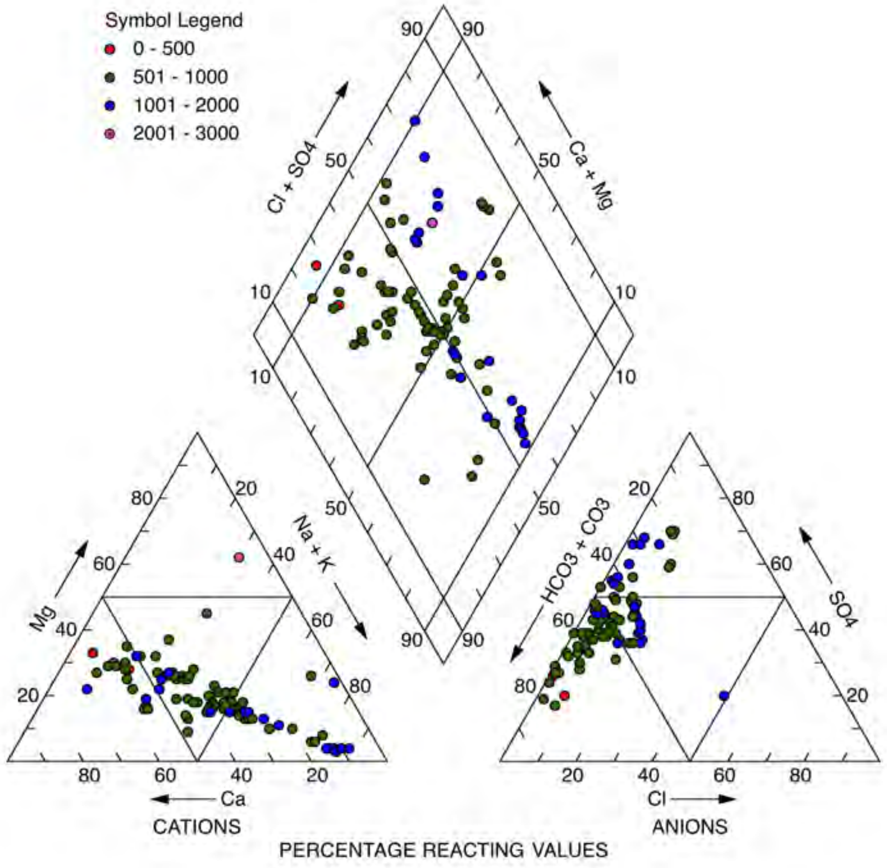


Figure 13.6.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Spring Creek aquifer in McIntosh County.

### *13.7 Wishek Aquifer System (McIntosh County)*

The Wishek aquifer was described by Klausing (1981) as a system of sand and gravel deposits underlying about 21 square miles in southeastern McIntosh County (Study Area #13 map).

Aquifer Composition: According to Klausing (1981) the Wishek aquifer consists of two aquifers: a surficial aquifer composed of coarse to very coarse gravelly sand and overlain in some areas by till, and a deeper buried unit composed of coarse gravelly sand. The maximum aggregate saturated thickness (both units combined) was stated to be about 80 feet, while the mean was about 30 feet. Aquifer characteristics are illustrated on two lithologic logs (Appendix Figures B.13.7.1 and B.13.7.2).

Aquifer Yield: Klausing (1981) suggested potential well yields of 50 to 500 gpm may be possible in the upper unit, and 50 to 1,500 gpm in the lower unit.

Aquifer Chemistry: Water chemistry parameters for 24 sites are shown on Tables 13.7.1, 13.7.2 and 13.7.3. The water chemistry is almost exclusively of the calcium-bicarbonate type, except for two samples of the calcium magnesium and sodium-sulfate type (Figure 13.7.1). Klausing (1981) stated that parts of the aquifer border the Fox Hills aquifer. Higher sulfate and sodium may be derived from the Fox Hills aquifer, or may, alternately, be derived from proximity to evaporative discharge zones. Klausing reported that discharge occurs through evaporation from sloughs on the western end of the aquifer. Iron and manganese concentrations tend to be high (Table 13.7.3). A single water sample indicates low arsenic and selenium concentrations.

Permit Acquisition Status: There are currently three water permits, two perfected and one conditional for an annual allocation of 866.5 acre-feet from the Wishek aquifer. There are no applications pending for water permits, so delays in processing new applications should not be affected by earlier competing applications. Based on an average recharge rate of 0.5 inches per year, and 21 square miles of surface area, perhaps as much as 200l acre-feet of additional allocation might be available for beneficial use.

Additional Considerations: While there is further development potential for beneficial use, the recharge rates of deeper deposits are unknown, and if not connected to other shallower deposits recharge could be negligible. Further local investigation and exploration should be undertaken before assuming a dependable and sustainable long-term water supply for industrial use. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Klausing, Robert L. 1981. Ground-water Resources of McIntosh County, North Dakota. County Ground-water Studies 30-Part III. North Dakota State Water Commission. Bismarck, ND. 37 pp.

Table 13.7.1. Summary of chemical properties of the Wishek aquifer in McIntosh County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 433 | 448 | 7 | 7.38 | 319 | 242 | 6.5 | 7.67 | 11.8 | 6 | 4.3 | 6 | 0.1 | 255 | 0 | 1 | 2.15 | 0.09 |
| **Maximum** | 1,620 | 1,500 | 8.69 | 8.63 | 1,160 | 1,130 | 15.5 | 28.8 | 140 | 56 | 11 | 158 | 3.8 | 457 | 28 | 530 | 18 | 17 |
| **Points** | 22 | 24 | 20 | 24 | 12 | 24 | 20 | 18 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 23 |
| **Mean** | 741.05 | 757.71 | 7.78 | 7.97 | 489.58 | 468.96 | 9.41 | 23.7 | 77.8 | 25.54 | 6.65 | 50.65 | 0.35 | 359.46 | 2.67 | 110.98 | 8.22 | 2.31 |
| **Median** | 697 | 739.5 | 7.78 | 7.98 | 442 | 445.5 | 9.05 | 27.7 | 84 | 25.85 | 6.2 | 35.6 | 0.2 | 354.5 | 1 | 90.85 | 7.45 | 0.35 |
| **Std Deviation** | 241.34 | 209.54 | 0.43 | 0.3 | 223.06 | 172.18 | 1.85 | 6.8 | 28.53 | 8.79 | 1.77 | 44.3 | 0.74 | 46.21 | 6.29 | 106.64 | 4.95 | 4.73 |
| **Std Error** | 51.45 | 42.77 | 0.1 | 0.06 | 64.39 | 35.15 | 0.41 | 1.6 | 5.82 | 1.79 | 0.36 | 9.04 | 0.15 | 9.43 | 1.28 | 21.77 | 1.01 | 0.99 |

Table 13.7.2. Summary of chemical properties of the Wishek aquifer in McIntosh County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 54 | 0 | 209 | 0 | 0.1 | -0.06 | 0.02 | 0.94 | 1.02 |
| **Maximum** | 580 | 240 | 421 | 421 | 9.33 | 1.38 | 1.18 | 2.38 | 2.18 |
| **Points** | 24 | 24 | 12 | 24 | 24 | 8 | 12 | 8 | 12 |
| **Mean** | 299.58 | 38.5 | 300.42 | 177.5 | 1.54 | 0.57 | 0.74 | 1.57 | 1.74 |
| **Median** | 318 | 21 | 304.5 | 268.5 | 0.91 | 0.48 | 0.7 | 1.49 | 1.7 |
| **Std Deviation** | 103.5 | 56.51 | 53.67 | 157.09 | 1.97 | 0.48 | 0.34 | 0.48 | 0.34 |
| **Std Error** | 21.13 | 11.54 | 15.49 | 32.07 | 0.4 | 0.17 | 0.1 | 0.17 | 0.1 |

Table 13.7.3. Summary of chemical properties of the Wishek aquifer in McIntosh County: selected trace elements.

|  | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.15 | 0.01 | 0.02 | nd | 0.1 | nd | 20 | 3 |
| Maximum | 0.6 | 4.46 | 2.1 | nd | 0.1 | nd | 20 | 3 |
| Points | 6 | 23 | 24 | 1 | 1 | 1 | 1 | 1 |
| Mean | 0.34 | 0.48 | 0.99 | nd | 0.1 | nd | 20 | 3 |
| Median | 0.3 | 0.09 | 1.1 | nd | 0.1 | nd | 20 | 3 |
| Std Deviation | 0.2 | 1 | 0.58 | nd | nd | nd | nd | nd |
| Std Error | 0.08 | 0.21 | 0.12 | nd | nd | nd | nd | nd |

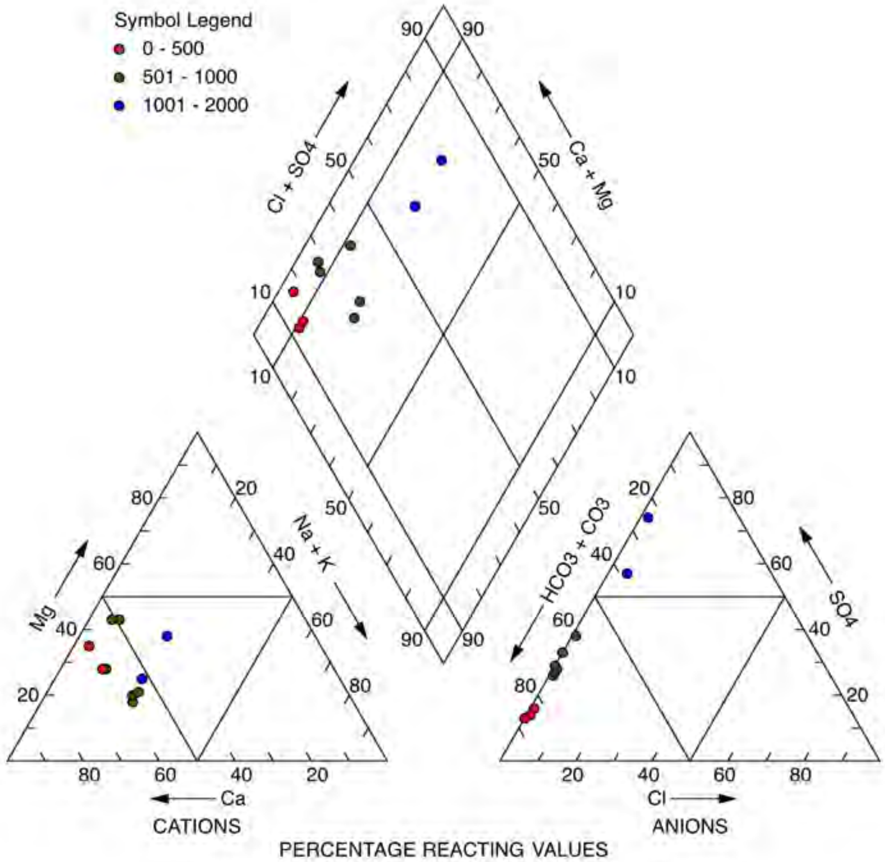


Figure 13.7.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Wishek aquifer in McIntosh County.

### *13.8 Zeeland Aquifer (McIntosh County)*

The Zeeland aquifer is a confined aquifer underlying about 16 square miles in southeastern McIntosh County (Study Area #13 map).

Aquifer Composition: According to Klausing (1981), "the Zeeland aquifer consists of very fine to very coarse sand intermixed with gravel; but the predominant lithology consists of coarse to very coarse gravelly sand. Klausing indicated that the mean maximum saturated thickness is about 20 feet, while the maximum saturated thickness is about 56 feet. Lithologies for three locations are shown on Appendix Figures B.13.8.1 and B.13.8.2.

Aquifer Yield: Potential well yields have been described by Klausing (1981) as ranging from 50 to 500 gpm. Klausing speculated that the aquifer could yield as much as 1,000 gpm in its thickest parts. An aquifer test conducted at well site 129-073-24DDD5 by R. B. Shaver was cited as having a specific capacity of 7.7 gpm/ft., a transmissivity of about 3,800 ft.$^2$/day, and a storage coefficient of 0.0001. The saturated thickness was 20 feet. The depth to the water table varies from 6 to 7 feet bls in the south to more than 20 feet bls in the north.

Aquifer Chemistry: Klausing (1981) reported that the chemistry of the Zeeland aquifer varies mainly from a sodium magnesium calcium-bicarbonate type to a sodium calcium magnesium-bicarbonate type. The water chemistry for 40 water samples is summarized on Tables 13.8.1, 13.8.1 and 13.8.3. Dissolved solids concentrations vary from 468 mg/L to 3,370 mg/L, but dissolved solids and sulfates are highly skewed by three calcium-sulfate type water samples (Figure 13.8.1) collected from a single well. Median dissolved solids concentrations for all other wells (22 wells at 19 locations) were below 1,000 mg/L, and sulfate values for all other wells were below 500 mg/L. Iron and manganese concentrations tend to be high (Table 13.8.3). There are only two to three determinations for trace elements: arsenic, mercury and selenium, and all are below levels of toxicological concern for drinking water.

Permit Acquisition Status: There is currently one perfected water permit for an annual allocation of 54 acre-feet from the Zeeland aquifer. Although the aquifer is relatively small, there is potential for development, and as of August 2009, there are no pending water permit applications. Using a conservative half-inch per year recharge rate and 16 square miles to estimate surficial recharge contributions, about 400 to 500 acre-feet of additional appropriation might be sustainable.

Additional Considerations: The amount of water available for development is unknown, and depends on the actual surficial extent of the aquifer and its recharge capture zone as well as its discharge characteristics. The chemical signature of the water would seem to indicate a mixture of Fox Hills bedrock water (sodium bicarbonatic water) and recharge through the till (calcium bicarbonatic water). At the depths indicated, the overlying till may be oxidixed and fractured in some areas, and unoxidized with low permeability in others. While the pumping capacity seems to be sufficient, long-term sustainability is unknown. In addition, if the aquifer is partially recharged by the Fox Hills aquifer and surficial recharge is limited, it is suspected that the water may become more sodic as it is pumped. While further development from the Zeeland aquifer may be possible, further site specific investigations are recommended.

Citations:

Klausing, Robert L. 1981. Ground-water Resources of McIntosh County, North Dakota. County Ground-water Studies 30-Part III. North Dakota State Water Commission. Bismarck, ND. 37 pp.

Table 13.8.1. Summary of chemical properties of the Zeeland aquifer in McIntosh County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 730 | 790 | 7.1 | 6.9 | 488 | 500 | 7 | 20 | 41 | 18.5 | 8.3 | 70 | 0.1 | 199 | 0 | 75.8 | 5.4 | 0.1 |
| **Maximum** | 3,280 | 3,480 | 8.6 | 8.6 | 1,020 | 2,160 | 11 | 34 | 555 | 182 | 22.9 | 220 | 0.5 | 631 | 15 | 2,120 | 23.4 | 3.4 |
| **Points** | 19 | 20 | 12 | 20 | 18 | 20 | 16 | 15 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 19 |
| **Mean** | 1,182.4 | 1,171.5 | 7.8 | 8 | 718.94 | 798.55 | 8.78 | 28.86 | 108.27 | 39.43 | 11.08 | 124.46 | 0.3 | 469.5 | 3.05 | 297.04 | 11.73 | 0.87 |
| **Median** | 1,025 | 1,004.5 | 7.7 | 8.1 | 700.5 | 721.5 | 8.5 | 29 | 83.5 | 30.5 | 10 | 115 | 0.3 | 460 | 0 | 195 | 10.4 | 1 |
| **Std Deviation** | 555.24 | 578.5 | 0.5 | 0.4 | 165.24 | 360.13 | 1.41 | 2.98 | 107.97 | 34.9 | 3.24 | 41.57 | 0.13 | 89.44 | 4.82 | 439.64 | 5.45 | 0.85 |
| **Std Error** | 127.38 | 129.36 | 0.1 | 0.1 | 38.95 | 80.53 | 0.35 | 0.77 | 24.14 | 7.8 | 0.72 | 9.29 | 0.03 | 20 | 1.08 | 98.31 | 1.22 | 0.19 |

Table 13.8.2. Summary of chemical properties of the Zeeland aquifer in McIntosh County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25°C | Langelier, Lab pH, 25°C | Langelier, Field pH, 82°C | Langelier, Lab pH, 82°C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 200 | 0 | 163 | 0 | 1.5 | 0.13 | -0.3 | 1.13 | 0.7 |
| **Maximum** | 2,140 | 1,980 | 354 | 517 | 5.6 | 1.7 | 1.51 | 2.7 | 2.51 |
| **Points** | 20 | 20 | 2 | 20 | 20 | 10 | 18 | 10 | 18 |
| **Mean** | 433 | 103.55 | 258.5 | 363.9 | 2.82 | 0.77 | 1.01 | 1.77 | 2.01 |
| **Median** | 315 | 0 | 258.5 | 378 | 2.8 | 0.73 | 1.09 | 1.73 | 2.09 |
| **Std Deviation** | 411.98 | 441.95 | 135.06 | 132.91 | 0.91 | 0.53 | 0.43 | 0.53 | 0.43 |
| **Std Error** | 92.12 | 98.82 | 95.5 | 29.72 | 0.2 | 0.17 | 0.1 | 0.17 | 0.1 |

Table 13.8.3. Summary of chemical properties of the Zeeland aquifer in McIntosh County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese mg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.04 | 0 | 0.42 | - | - | - | - | - |
| Maximum | 1.2 | 3.99 | 6.42 | - | - | - | - | - |
| Points | 15 | 20 | 20 | - | - | - | - | - |
| Mean | 0.42 | 0.31 | 1.59 | - | - | - | - | - |
| Median | 0.38 | 0.04 | 1.25 | - | - | - | - | - |
| Std Deviation | 0.33 | 0.91 | 1.23 | - | - | - | - | - |
| Std Error | 0.09 | 0.2 | 0.27 | - | - | - | - | - |

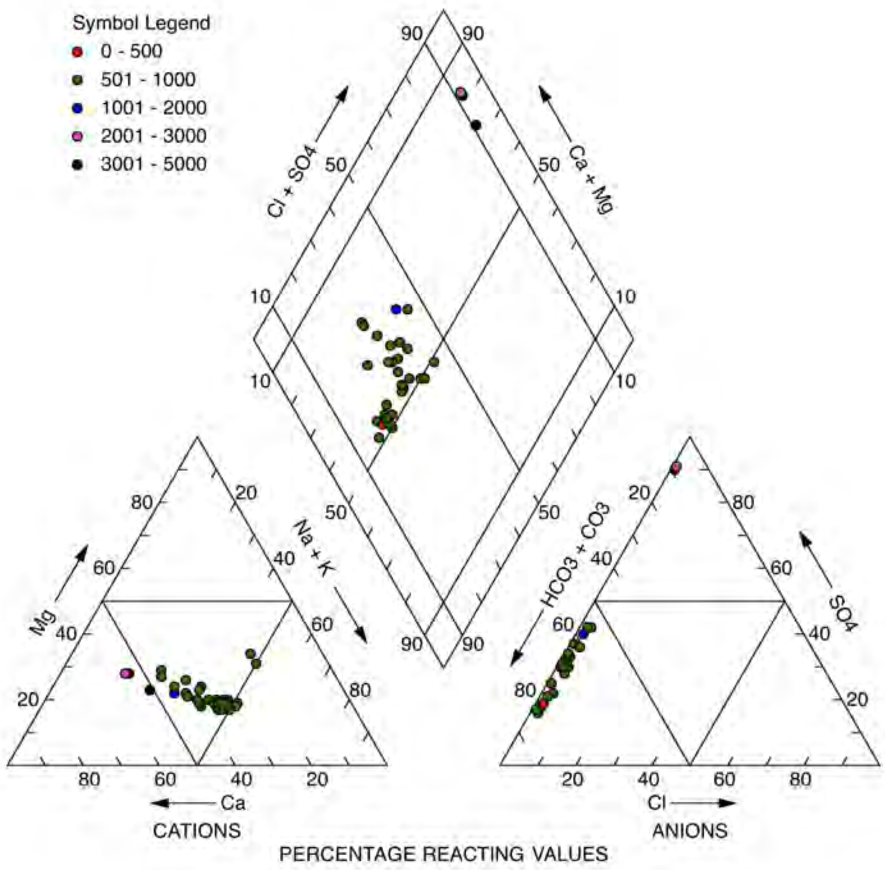
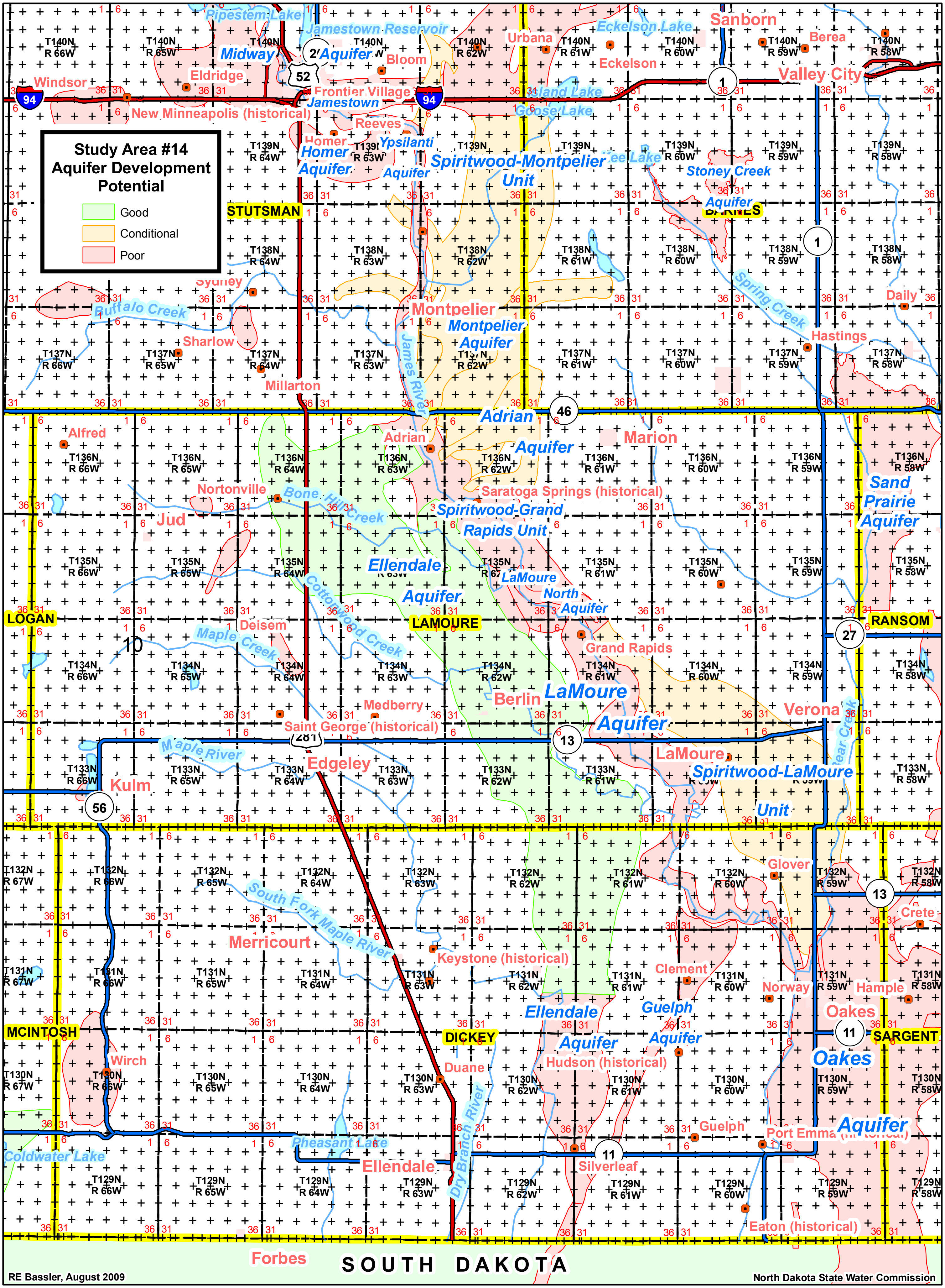


Figure 13.8.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Zeeland aquifer in McIntosh County.



## Study Area 14: Southeast North Dakota / Dickey, LaMoure, and Southern Barnes and Stutsman Counties

### *14.1 Ellendale Aquifer (LaMoure and northern Dickey Counties)*

The Ellendale aquifer is a confined aquifer that underlies about 188 square miles, extending from the west side of the James River in northern LaMoure County to its junction with the Guelph aquifer in southern Dickey County (Study Area #14 map). This discussion includes the portion of the aquifer mapped as having "good potential" for water use development in LaMoure and northern Dickey Counties.

Aquifer Composition: Armstrong (1980) described the Ellendale aquifer as a "lenticular deposit of sand and gravel interbedded with silt and silty clay." It is usually located beneath 50 to 95 feet of glacial till, but may be found as deep as 165 feet. Thicknesses vary from about 5 feet to as much as 81 feet. Two examples of aquifer lithology are provided on Appendix Figures B.14.1.1 and B.14.1.2 .

Aquifer Yield: Armstrong estimated that well yields from 50 gpm to as much as 500 gpm may be obtained, depending on location and well construction.

Aquifer Chemistry: The chemistry of the Ellendale aquifer is primarily sulfatic, ranging from a calcium-sulfate type to a sodium-sulfate type (Figure 14.1.1). Some of the fresher water samples are of the calcium-bicarbonate type. Dissolved solids concentrations range from about 400 mg/L to 4,000 mg/L, with a median near 1,100 mg/L. About 95% of the water samples have dissolved solids less than 2,000 mg/L (Table 14.1.1). Sulfate and sodium generally increase with increasing dissolved solids. Iron and manganese concentrations are both high (Table 14.1.3).

Permit Acquisition Status: There are currently two perfected water permits for a total annual allocation of 402 acre-feet. As of this report, an additional annual appropriation of 1,120 acre-feet has been applied for by Frontier Dairy, LLP. The overlying Ellendale aquifer forms a continuous section with the Spiritwood aquifer in the area of the Frontier Dairy application. The Frontier Dairy point of diversion will likely be in the Spiritwood aquifer.

The area of the Ellendale aquifer mapped as having "good" potential for further development underlies about 200 square miles. Rough computations have estimated recharge to the nearby LaMoure unit of the Spiritwood aquifer at about 0.25 inches per year. Assuming a range of 0.25 to 0.5 inches per year (the Ellendale aquifer is shallower than the Spiritwood aquifer), and accounting for current permits and applications (1,522 acre-feet if fully granted), there may possibly be as much as 1,000 to 3,500 acre-feet of water available for further allocation.

Additional Considerations: The Ellendale aquifer in northern LaMoure County has been revised to include part of the Nortonville and Spiritwood aquifers. The aquifer may be absent at some locations within the area mapped due to poor definition of channels and boundaries.[133] **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Armstrong, C.A. 1980. Ground-water Resources of Dickey and LaMoure Counties, North Dakota. County Ground-Water Studies 28-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 26-30.

---

[133] Royce Cline. Written communication. June 4, 2010.

Table 14.1.1. Summary of chemical properties of the Ellendale aquifer in LaMoure and northern Dickey Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T $^oC$ | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 750 | 726 | 7.5 | 7.2 | 475 | 446 | 5 | 17 | 48.2 | 12.4 | 7.3 | 19 | 0.1 | 342 | - | 61 | 4.68 | 0.09 |
| **Maximum** | 4,360 | 4,880 | 8.5 | 8.3 | 1,380 | 4,260 | 14 | 32.4 | 522 | 135 | 23.7 | 657 | 0.4 | 666 | - | 2,500 | 579 | 4.5 |
| **Points** | 31 | 31 | 17 | 31 | 9 | 31 | 29 | 28 | 31 | 31 | 31 | 31 | 31 | 31 | - | 31 | 31 | 30 |
| **Mean** | 1,797.2 | 1,862.8 | 7.8 | 7.8 | 1,121.2 | 1,304.9 | 9.81 | 26.7 | 147.09 | 41.52 | 13 | 232.22 | 0.23 | 503.48 | - | 557.1 | 56.73 | 0.77 |
| **Median** | 1,693 | 1,710 | 7.8 | 7.9 | 1,230 | 1,170 | 10.3 | 27.7 | 133 | 36.7 | 13 | 180 | 0.23 | 512 | - | 464 | 24.8 | 0.2 |
| **Std Deviation** | 663.84 | 749.23 | 0.3 | 0.3 | 306.71 | 653.54 | 2.24 | 4.37 | 84.49 | 21.73 | 3.34 | 158 | 0.09 | 93.62 | - | 414.23 | 103.11 | 1.25 |
| **Std Error** | 119.23 | 134.57 | 0.1 | 0 | 102.24 | 117.38 | 0.42 | 0.83 | 15.17 | 3.9 | 0.6 | 28.38 | 0.02 | 16.82 | - | 74.4 | 18.52 | 0.23 |

Table 14.1.2. Summary of chemical properties of the Ellendale aquifer in LaMoure and northern Dickey Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^o$C | Langelier, Lab pH, 25$^o$C | Langelier, Field pH, 82$^o$C | Langelier, Lab pH, 82$^o$C |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 172 | 0 | 297 | - | 0.4 | 0.54 | 0.56 | 1.54 | 1.56 |
| **Maximum** | 1,860 | 1,320 | 546 | - | 13.5 | 0.79 | 1.04 | 1.79 | 2.04 |
| **Points** | 31 | 31 | 22 | - | 31 | 4 | 9 | 4 | 9 |
| **Mean** | 538.84 | 169.29 | 447.41 | - | 4.87 | 0.64 | 0.8 | 1.64 | 1.79 |
| **Median** | 484 | 128 | 458.5 | - | 3.95 | 0.62 | 0.78 | 1.62 | 1.78 |
| **Std Deviation** | 297.01 | 240.33 | 59.97 | - | 3.78 | 0.11 | 0.21 | 0.12 | 0.21 |
| **Std Error** | 53.34 | 43.17 | 12.79 | - | 0.68 | 0.06 | 0.07 | 0.06 | 0.07 |

Table 14.1.3. Summary of chemical properties of the Ellendale aquifer in LaMoure and northern Dickey Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.06 | 0.02 | 0 | - | - | - | - | - |
| Maximum | 0.88 | 4.19 | 4.5 | - | - | - | - | - |
| Points | 10 | 31 | 31 | - | - | - | - | - |
| Mean | 0.49 | 0.91 | 1.15 | - | - | - | - | - |
| Median | 0.5 | 0.52 | 1.1 | - | - | - | - | - |
| Std Deviation | 0.28 | 0.99 | 0.93 | - | - | - | - | - |
| Std Error | 0.09 | 0.18 | 0.17 | - | - | - | - | - |

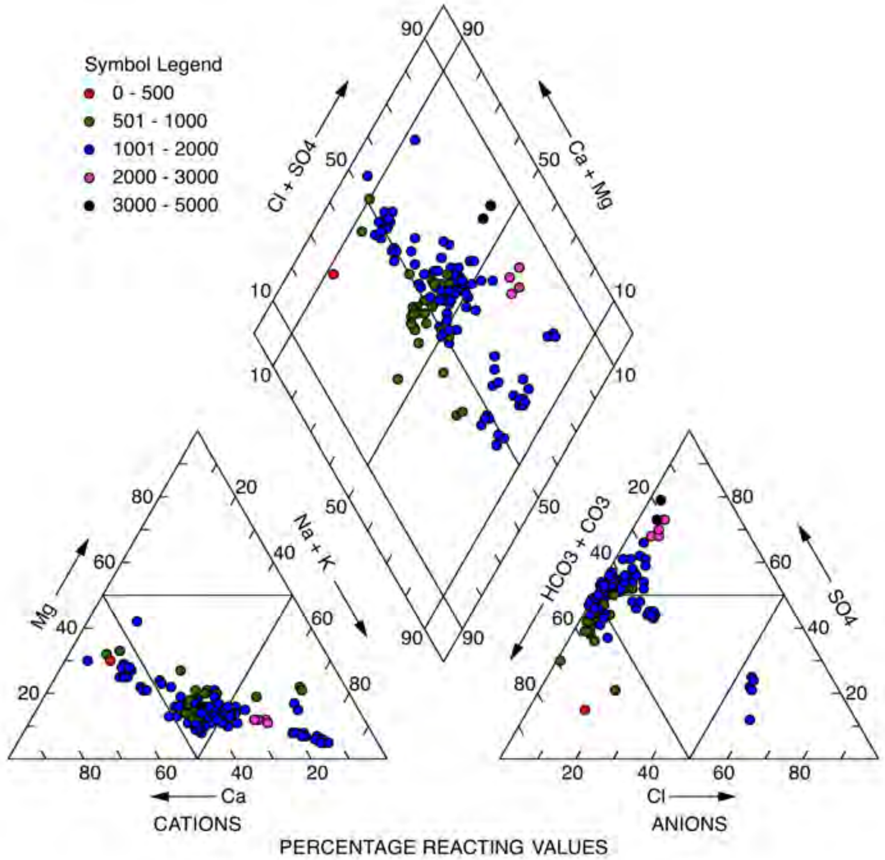


Figure 14.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Ellendale aquifer in LaMoure and northern Dickey Counties.

### *14.2 Spiritwood Aquifer (Southern Stutsman, LaMoure, and northern Dickey Counties)*

The Spiritwood aquifer is a glaciofluvial deposit that extends from South Dakota to Canada through all of North Dakota. While mapped as a continuous feature, the aquifer is highly heterogeneous, and the composition and connectivity varies within and between locations. For the purpose of this report we combine the Spiritwood-Montpelier unit, the overlying Montpelier aquifer, and the Adrian aquifer, which is probably a northern extension of the Ellendale aquifer separated by the James River valley; and the Spiritwood-LaMoure unit, farther south, as one group (see Study Area map #14). The total surface area of the combined aquifers is about 200 square miles.

Aquifer Composition: The Spiritwood aquifer (Montpelier unit) has been described by Huxel and Petri (1965) as deposits of sand and gravel varying in thickness from less than one foot to 120 feet and overlain by 75 to 200 feet of till. The Spiritwood aquifer (LaMoure unit) has been described by Armstrong (1980) as consisting of "lenticular deposits of sand and gravel intermixed with silt and clay," having thickness varying from less than one foot to 137 feet, and an average thickness of about 50 feet. Examples of the aquifer lithology are shown on Appendix Figures B.14.2.1 and B.14.2.2.

Aquifer Yield: A pump test north of Oakes was reported to have a transmissivity of 18,500 to 31,700 ft.$^2$/day, with a storage coefficient of 0.0003 to 0.0005. Armstrong estimated that individual well yields of 500 gpm to 1,000 gpm may be possible in some locations.

Aquifer Chemistry: The Spiritwood aquifer in Study Area #14 ranges from a calcium-bicarbonate type and a calcium magnesium sodium-bicarbonate type, to a sodium-bicarbonate type (Figure 14.2.1). The northern (Montpelier) unit is fresher and is characterized by more water samples of the calcium-bicarbonate type than the south (LaMoure) unit. The data distributions differ somewhat, with a range of dissolved solids concentrations between about 240 mg/L and 1,800 mg/L for the Montpelier unit (Table 14.2.1b), compared with 474 to 1,240 mg/L for the LaMoure unit (Table 14.2.1a); but median dissolved solids are similar at 746 mg/L and 803 mg/L, respectively. Some water samples from both units are of the sodium-sulfate type. Higher sulfate is associated with higher dissolved solids. A single water sample from the Montpelier aquifer is of the calcium-bicarbonate type (Table 14.2.1b) and has a dissolved solids concentration below the median value for the Spiritwood aquifer. While data is sparse, it is considered probable that the water chemistry of the shallower Adrian and Montpelier aquifers is no less fresh than that of the Spiritwood aquifer, and may be slightly fresher. Iron and manganese concentrations are high for both Spiritwood units. An arsenic concentration for one water sample from the north unit has a concentration above the EPA-MCL (10 μg/L), while arsenic concentrations for two water water samples from the south unit are both below the EPA-MCL (Tables 14.2.3a and 14.2.3b)

Permit Acquisition Status: There are currently a total of 26 water permits, 17 perfected, three conditional and six pending, for a total annual appropriation of 13,363 acre-feet in the combined area of the Spiritwood aquifer mapped as having potential for future development. Of these water permits most (18 permits for an annual appropriation of 11,408 acre-feet) are located in the Spiritwood LaMoure subunit.

Additional Considerations: When considering further development, the Spiritwood-LaMoure subunit offers the least potential because of large existing appropriations and a connection and interaction with the Oakes aquifer, which will require careful consideration with respect to impact on prior appropriations before granting new permits. The potential for further development and use of water from the northern (Spiritwood-Montpelier) subunit of the aquifer will be best with distance in a southerly direction from the northern mapped boundary near Interstate HWY I-94, because of hydrologic interaction with the highly appropriated Spiritwood-Cargill reach of the aquifer, north of the highway. The managing hydrologist for the Spiritwood aquifer system in Study Area #14 should be consulted for enquires concerning potential future allocations. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Armstrong, C.A. 1980. Ground-water Resources of LaMoure County, North Dakota. County Ground-Water Studies 28-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 26-30.

Christensen, P.K. and J.E. Miller. 1988. The hydrologic system of the lower James River, North Dakota. Water-Resources Investigation 2, Part II. North Dakota State Water Commission. Bismarck, ND. pp. 26-28.

Huxel Jr., C.J. and L.R. Petri. 1965. Ground-water Resources of Stutsman County, North Dakota. County Ground-Water Studies 2-Part III. North Dakota State Water Commission. Bismarck, ND. pp. 35-36.

Table 14.2.1a. Summary of chemical properties of the Spiritwood aquifer (LaMoure unit) in southern LaMoure and northern Dickey Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 424 | 443 | 7.7 | 6.82 | 249 | 238 | 14.9 | 13.9 | 9.84 | 4.5 | 2.1 | 11.3 | 0.1 | 254 | NA | 13 | 2.04 | - |
| **Maximum** | 2,710 | 2,930 | 8.19 | 8.46 | 406 | 1,820 | 22 | 45.4 | 218 | 57.5 | 11.7 | 502 | 0.45 | 699 | NA | 399 | 691 | - |
| **Points** | 39 | 41 | 2 | 41 | 3 | 41 | 2 | 16 | 41 | 41 | 41 | 41 | 41 | 41 | NA | 41 | 41 | - |
| **Mean** | 1,158.7 | 1,232.9 | 7.95 | 7.86 | 321.67 | 765.76 | 18.45 | 30.13 | 78.4 | 24.13 | 7.7 | 151.16 | 0.23 | 457.46 | NA | 170.59 | 73.6 | - |
| **Median** | 1,088 | 1,170 | 7.95 | 7.92 | 310 | 746 | 18.45 | 29.55 | 73 | 24.3 | 7.85 | 136 | 0.22 | 462 | NA | 162 | 31.1 | - |
| **Std Deviation** | 399.43 | 467.54 | 0.35 | 0.29 | 79.15 | 296 | 5.02 | 6.31 | 42.71 | 11.25 | 1.53 | 111.06 | 0.08 | 85.67 | NA | 97.11 | 141.95 | - |
| **Std Error** | 63.96 | 73.02 | | 0.04 | 45.7 | 46.23 | | 1.58 | 6.67 | 1.76 | 0.24 | 17.35 | 0.01 | 13.38 | NA | 15.17 | 22.17 | - |
| **13706203ddd2 Montpelier** | 879 | 924 | | 7.9 | | 573 | | 30.4 | 129 | 34.3 | 8.33 | 39.6 | 0.23 | 387 | <1 | 177 | 6.67 | <0.09 |

Table 14.2.1b. Summary of chemical properties of the Spiritwood aquifer (Montpelier unit) in southern Stutsman and northern LaMoure Counties: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T °C | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | NO3 mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 424 | 443 | 7.7 | 6.82 | 249 | 238 | 14.9 | 13.9 | 9.84 | 4.5 | 2.1 | 11.3 | 0.1 | 254 | NA | 13 | 2.04 | - |
| **Maximum** | 2,710 | 2,930 | 8.19 | 8.46 | 406 | 1,820 | 22 | 45.4 | 218 | 57.5 | 11.7 | 502 | 0.45 | 699 | NA | 399 | 691 | - |
| **Points** | 39 | 41 | 2 | 41 | 3 | 41 | 2 | 16 | 41 | 41 | 41 | 41 | 41 | 41 | NA | 41 | 41 | - |
| **Mean** | 1,158.7 | 1,232.9 | 7.95 | 7.86 | 321.67 | 765.76 | 18.45 | 30.13 | 78.4 | 24.13 | 7.7 | 151.16 | 0.23 | 457.46 | NA | 170.59 | 73.6 | - |
| **Median** | 1,088 | 1,170 | 7.95 | 7.92 | 310 | 746 | 18.45 | 29.55 | 73 | 24.3 | 7.85 | 136 | 0.22 | 462 | NA | 162 | 31.1 | - |
| **Std Deviation** | 399.43 | 467.54 | 0.35 | 0.29 | 79.15 | 296 | 5.02 | 6.31 | 42.71 | 11.25 | 1.53 | 111.06 | 0.08 | 85.67 | NA | 97.11 | 141.95 | - |
| **Std Error** | 63.96 | 73.02 | | 0.04 | 45.7 | 46.23 | | 1.58 | 6.67 | 1.76 | 0.24 | 17.35 | 0.01 | 13.38 | NA | 15.17 | 22.17 | - |
| **13706203ddd2 Montpelier** | 879 | 924 | | 7.9 | | 573 | | 30.4 | 129 | 34.3 | 8.33 | 39.6 | 0.23 | 387 | <1 | 177 | 6.67 | <0.09 |

Table 14.2.2a . Summary of chemical properties of the Spiritwood aquifer (LaMoure unit) in southern LaMoure and northern Dickey Counties: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^oC$ | Langelier, Lab pH, 25$^oC$ | Langelier, Field pH, 82$^oC$ | Langelier, Lab pH, 82$^oC$ |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 93 | 0 | 312 | - | 1.25 | 0.23 | 0.73 | 1.23 | 1.73 |
| **Maximum** | 826 | 490 | 534 | - | 12.6 | 0.23 | 0.8 | 1.23 | 1.8 |
| **Points** | 48 | 48 | 46 | - | 48 | 1 | 2 | 1 | 2 |
| **Mean** | 252.96 | 10.21 | 393.22 | - | 5.65 | 0.23 | 0.77 | 1.23 | 1.77 |
| **Median** | 247.5 | 0 | 392.5 | - | 5.39 | 0.23 | 0.77 | 1.23 | 1.77 |
| **Std Deviation** | 103.58 | 70.73 | 38.63 | - | 2.68 | - | 0.05 | - | 0.05 |
| **Std Error** | 14.95 | 10.21 | 5.7 | - | 0.39 | - | - | - | - |

Table 14.2.2b. Summary of chemical properties of the Spiritwood aquifer (Montpelier aquifer) in southern Stutsman and northern LaMoure Counties: use parameters.

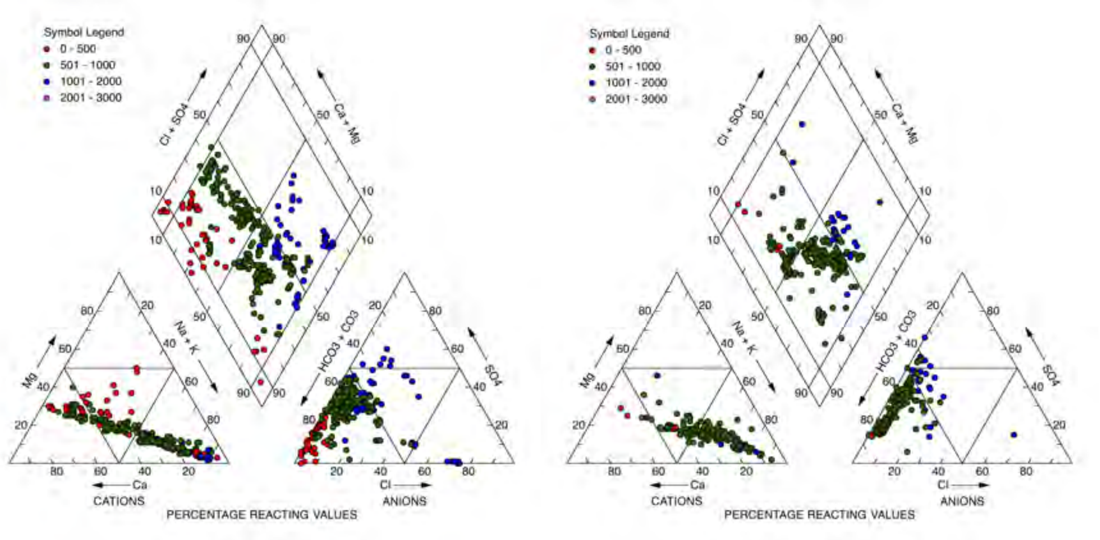
| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25$^oC$ | Langelier, Lab pH, 25$^oC$ | Langelier, Field pH, 82$^oC$ | Langelier, Lab pH, 82$^oC$ |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 43 | 0 | 279 | - | 0.27 | - | -1.19 | - | -0.19 |
| **Maximum** | 782 | 321 | 589 | - | 18.3 | - | 0.69 | - | 1.69 |
| **Points** | 41 | 41 | 38 | - | 41 | - | 3 | - | 3 |
| **Mean** | 295.24 | 26.46 | 384.45 | - | 4.81 | - | -0.18 | - | 0.82 |
| **Median** | 270 | 0 | 380.5 | - | 3.19 | - | -0.04 | - | 0.96 |
| **Std Deviation** | 149.08 | 63.75 | 65.78 | - | 4.62 | - | 0.95 | - | 0.95 |
| **Std Error** | 23.28 | 9.96 | 10.67 | - | 0.72 | - | 0.55 | - | 0.55 |
| **13706203ddd2 Montpelier** | 464 | 146 | 317 | - | 0.8 | - |  | - |  |

Table 14.2.3a. Summary of chemical properties of the Spiritwood aquifer (LaMoure unit) in southern LaMoure and northern Dickey Counties: selected trace elements.

| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.63 | - | 0.04 | - | - | 14.7 | - | - |
| Maximum | 0.63 | - | 0.86 | - | - | 14.7 | - | - |
| Points | 1 | - | 48 | - | - | 1 | - | - |
| Mean | 0.63 | - | 0.25 | - | - | 14.7 | - | - |
| Median | 0.63 | - | 0.17 | - | - | 14.7 | - | - |
| Std Deviation | 0 | - | 0.21 | - | - | 0 | - | - |
| Std Error | 0 | - | 0.03 | - | - | 0 | - | - |

Table 14.2.3b. Summary of chemical properties of the Spiritwood aquifer (Montpelier unit) in southern Stutsman and northern LaMoure Counties: selected trace elements.

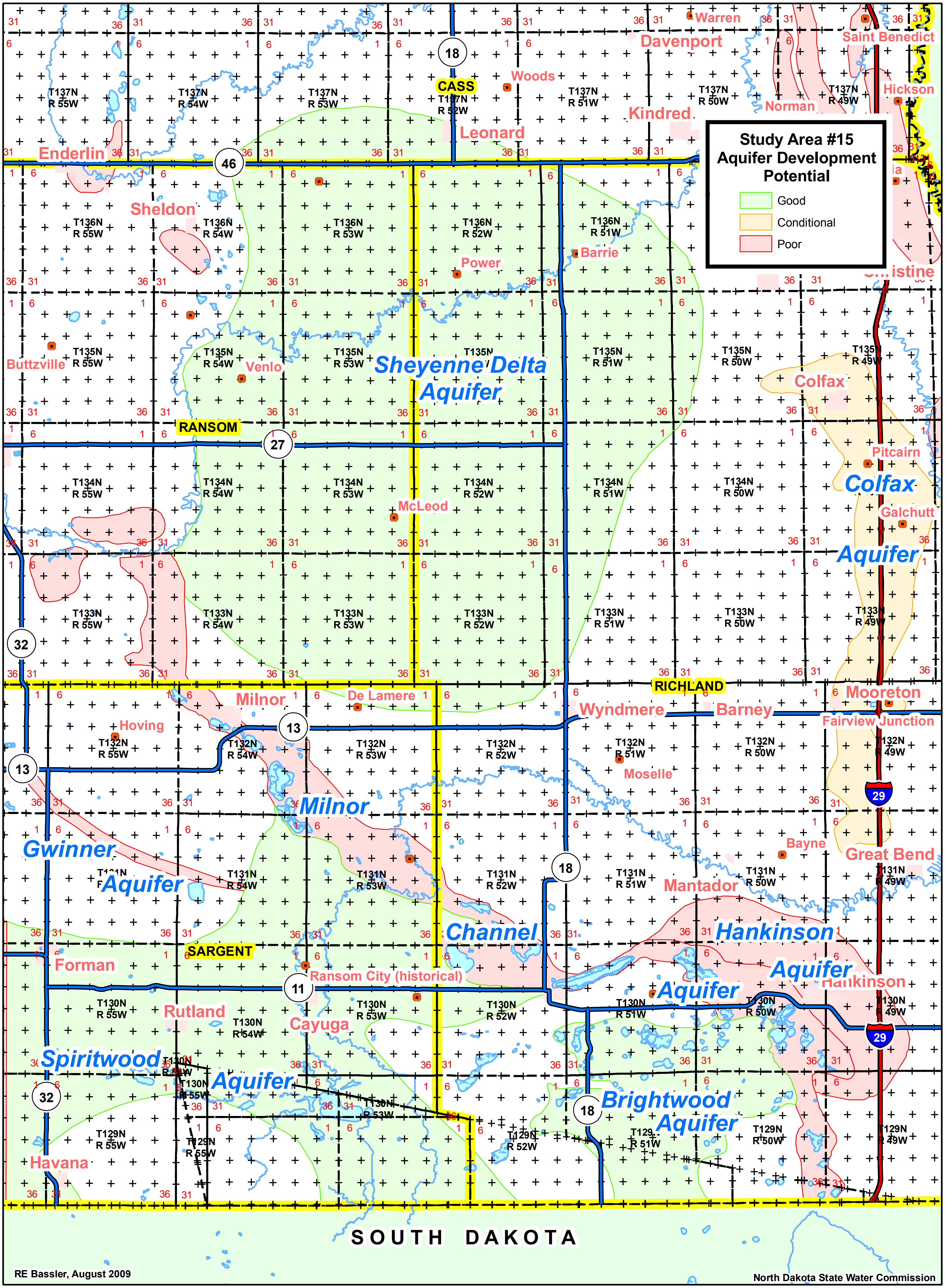
| | **Boron mg/L** | **Iron mg/L** | **Manganese mg/L** | **Selenium µg/L** | **Mercury µg/L** | **Arsenic µg/L** | **Lithium µg/L** | **Molybdenum µg/L** |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0.37 | 0.01 | 0.02 | - | - | 1.93 | 78.9 | 3.85 |
| Maximum | 0.37 | 5.96 | 2.55 | - | - | 7.92 | 78.9 | 3.85 |
| Points | 1 | 41 | 41 | - | - | 2 | 1 | 1 |
| Mean | 0.37 | 0.99 | 0.81 | - | - | 4.93 | 78.9 | 3.85 |
| Median | 0.37 | 0.41 | 0.8 | - | - | 4.93 | 78.9 | 3.85 |
| Std Deviation | 0 | 1.45 | 0.6 | - | - | 4.24 | 0 | 0 |
| Std Error | 0 | 0.23 | 0.09 | - | - | 3.4e+38 | 0 | 0 |



Spiritwood Aquifer – Montpelier Unit

Spiritwood Aquifer – LaMoure Unit

Figure 14.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Spiritwood aquifer Montpelier and LaMoure units.



Study Area #15
Aquifer Development Potential
🟩 Good
🟨 Conditional
🟥 Poor
CASS
RANSOM
RICHLAND
SARGENT
SOUTH DAKOTA
Sheyenne Delta Aquifer
Colfax Aquifer
Milnor Channel
Gwinner Aquifer
Hankinson Aquifer
Spiritwood Aquifer
Brightwood Aquifer
Warren
Davenport
Saint Benedict
Woods
Hickson
Norman
Kindred
Leonard
Enderlin
Sheldon
Barrie
Power
...istine
Buttzville
Venlo
Colfax
Pitcairn
McLeod
Galchutt
Milnor
De Lamere
Mooreton
Wyndmere
Barney
Fairview Junction
Hoving
Moselle
Bayne
Great Bend
Mantador
Forman
Ransom City (historical)
Hankinson
Rutland
Cayuga
Havana
18
46
27
32
13
11
29
T137N R 55W
T137N R 54W
T137N R 53W
T137N R 52W
T137N R 51W
T137N R 50W
T137N R 49W
T136N R 55W
T136N R 54W
T136N R 53W
T136N R 52W
T136N R 51W
T135N R 55W
T135N R 54W
T135N R 53W
T135N
T135N R 51W
T135N R 50W
T135N R 49W
T134N R 55W
T134N R 54W
T134N R 53W
T134N R 52W
T134N R 51W
T134N R 50W
T133N R 55W
T133N R 54W
T133N R 53W
T133N R 52W
T133N R 51W
T133N R 50W
T133N R 49W
T132N R 55W
T132N R 54W
T132N R 53W
T132N R 52W
T132N R 51W
T132N R 50W
T132N R 49W
T131N R 54W
T131N R 53W
T131N R 52W
T131N R 51W
T131N R 50W
T131N R 49W
T130N R 55W
T130N R54W
T130N R 53W
T130N R 52W
T130N R 51W
T130N R 50W
T130N R 49W
T130N R 51W
T130N R 55W
T130N R 53W
T129N R 55W
T129N R 55W
T129N R 52W
T129N R 51W
T129N R 50W
T129N R 49W
RE Bassler, August 2009
North Dakota State Water Commission

## Study Area 15: Southeastern North Dakota / Sargent, Ransom and Richland Counties

### *15.1 Brightwood Aquifer (Richland County)*

The Brightwood aquifer consists of about 67 square miles of thick sand and gravel deposits in southwestern Richland County (Study Area #15 map). There are no major towns located over the aquifer. Lidgerwood lies about two miles northwest of its northwestern boundary, and Hankinson lies about two miles northeast of its northeastern boundary. Baker and Paulson (1967) identified only northeastern portion of the aquifer (about 13 square miles) near Lake Elsie. They identified that the Brightwood aquifer deposits have a higher elevation than Lake Elsie and the Milnor Channel aquifer. The Brightwood Channel aquifer discharges into Lake Elsie, and some underflow to the Milnor Channel has been identified.

<u>Aquifer Composition:</u> The thickness of the Brightwood outwash has been described as ranging from 70 to 130 feet, with an average thickness of about 100 feet (Baker and Paulson (1967). Materials were described as consisting of coarse sand to medium gravel, well sorted. Samples of four local lithologies are shown on Appendix Figures B.15.1.1 through B.15.1.4. Parkin[134] has described aquifer materials as generally somewhat finer in the southward direction. Baker and Paulson found water levels to be about 50 to 60 feet below land surface, with annual variations of about 4 feet. They described the water as under "water table" (unconfined) conditions. In more recent years, and with a wetter climate, the water table elevation has risen to about 40 feet below land surface in the northeast, and generally between 20 and 30 feet below land surface in the southern and western portions of the aquifer. In a few locations water tables have been measured near land surface. In the southern portions of the aquifer, Parkin[135] has found the aquifer to be confined.

<u>Aquifer Yield:</u> Baker and Paulson (1967) reported that the permeabilities of laboratory samples were 86 to 160 ft./day. They estimated that individual well yields of up to 500 gpm should be possible in places.

<u>Aquifer Chemistry:</u> Total dissolved solids concentrations range from about 400 mg/L to as high as 2,000 mg/L (Table 15.1.1). The median dissolved solids concentrations are between 800 and 850 mg/L, depending on the method of determination (determined or calculated). The water is generally hard. Water having dissolved solids less than 1,000 mg/L is predominantly of the calcium bicarbonate type. Above 1,000 mg/L dissolved solids, the water is increasingly sulfatic. Arsenic may be problematic in some areas of the aquifer (Table 15.1.3). The maximum dissolved arsenic measurement was 55 μg/L,

---

[134] Parkin, Scott. August 12, 2009. Verbal communication.

[135] Ibid.

5.5 times the EPA-MCL (10 μg/L). The median and mean dissolved arsenic concentrations are about double the EPA-MCL.

Permit Acquisition Status**:** There are currently no large-scale users of water from the aquifer, and virtually all pumping is for domestic and livestock use. As of August 2009, there were no completed water permits, and one industrial application for 200 acre-feet per year at a withdrawal rate of 600 acre-feet was pending. There is substantial potential for future allocations of water (perhaps 1,000 to 2,000 acre-feet) from this aquifer.

Other Considerations**:** Because the Brightwood aquifer contributes recharge to the Milnor Channel aquifer near its northeast boundary, the potential for conflict with prior appropriators would be minimal further south and/or west. However, no area of the aquifer is categorically excluded from potential use. The Brightwood aquifer is one of the few aquifers of the state with large potential for future development and use.[136] Both the need for arsenic removal, and the disposal of the arsenic filtrate or residue should be considered when planning for use of Brightwood aquifer water. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations***:***

Baker, Claud H. Jr., and W.F. Paulson. 1967. Geology and Ground Water Resources of Richland County, North Dakota: Part III. Ground Water Resources. North Dakota State Water Commission. 48 pp.

---

[136] Parkin, Scott. August 12, 2009. Verbal communication.

Table 15.1.1. Summary of chemical properties of the Brightwood aquifer in Richland County: general chemistry.

| | **SC-f µS/cm** | **SC-l µS/cm** | **pH-f** | **pH-l** | **TDS-d mg/L** | **TDS-c mg/L** | **T oC** | **Si mg/L** | **Ca mg/L** | **Mg mg/L** | **K mg/L** | **Na mg/L** | **Fl mg/L** | **Bicarb mg/L** | **Carb mg/L** | **Sulfate mg/L** | **Cl mg/L** | **N mg/L** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 673 | 706 | 7.3 | 6.7 | 503 | 407 | 8.9 | 21 | 86 | 19 | 4.8 | 3.8 | 0.06 | 302 | - | 97.5 | 0 | 0 |
| **Maximum** | 2,070 | 2,260 | 8.3 | 8.1 | 1,720 | 1,770 | 17.8 | 30.4 | 340 | 104 | 12.5 | 120 | 0.5 | 528 | - | 1,020 | 14 | 1 |
| **Points** | 23 | 26 | 10 | 26 | 6 | 26 | 16 | 25 | 26 | 26 | 26 | 26 | 26 | 26 | - | 26 | 26 | 13 |
| **Mean** | 1,295.3 | 1,322.8 | 7.8 | 7.4 | 882.33 | 893.31 | 10.76 | 27.62 | 186.47 | 54.2 | 8.14 | 35.09 | 0.22 | 438.35 | - | 428.6 | 5.06 | 0.16 |
| **Median** | 1,242 | 1,220 | 7.8 | 7.5 | 779 | 819 | 10.1 | 28.4 | 179.5 | 50.5 | 7.93 | 25.25 | 0.2 | 451.5 | - | 375 | 3.59 | 0.13 |
| **Std Deviation** | 393.51 | 416.94 | 0.3 | 0.4 | 430.67 | 338.7 | 2.2 | 2.69 | 68.85 | 23.13 | 2.25 | 25.9 | 0.1 | 66.62 | - | 244.94 | 3.23 | 0.27 |
| **Std Error** | 82.05 | 81.77 | 0.1 | 0.1 | 175.82 | 66.43 | 0.55 | 0.54 | 13.5 | 4.54 | 0.44 | 5.08 | 0.02 | 13.07 | - | 48.04 | 0.63 | 0.07 |

Table 15.1.2. Summary of chemical properties of the Brightwood aquifer in Richland County: use parameters.

| Hardness | Hardness **mg/L** | NCH **mg/L** | ALK_ as_CaCO3 **mg/L** | ALK Calculated **mg/L** | SAR | Langelier, Field pH, 25oC | Langelier, Lab pH, 25oC | Langelier, Field pH, 82oC | Langelier, Lab pH, 82oC |
|---|---|---|---|---|---|---|---|---|---|
| Minimum | 296 | 0 | 273 | - | 0.06 | - | 0.28 | - | 1.28 |
| Maximum | 1,280 | 847 | 432 | - | 2.9 | - | 1.16 | - | 2.16 |
| Points | 26 | 26 | 20 | - | 26 | - | 6 | - | 6 |
| Mean | 690.12 | 330.42 | 358.9 | - | 0.6 | - | 0.72 | - | 1.72 |
| Median | 665.5 | 270 | 370 | - | 0.53 | - | 0.66 | - | 1.66 |
| Std Deviation | 261.97 | 220.68 | 52.8 | - | 0.53 | - | 0.32 | - | 0.32 |
| Std Error | 51.38 | 43.28 | 11.81 | - | 0.1 | - | 0.13 | - | 0.13 |

Table 15.1.3. Summary of chemical properties of the Brightwood aquifer in Richland County: selected trace elements.

| | Boron | Iron | Manganese µg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| Minimum | 0 | 0.05 | 0.23 | - | 0 | 1 | 120 | 3 |
| Maximum | 0.48 | 5 | 0.94 | - | 0 | 54.5 | 120 | 3 |
| Points | 13 | 26 | 23 | - | 1 | 10 | 1 | 1 |
| Mean | 0.18 | 1.63 | 0.58 | - | 0 | 22.33 | 120 | 3 |
| Median | 0.15 | 1.14 | 0.56 | - | 0 | 21.6 | 120 | 3 |
| Std Deviation | 0.14 | 1.35 | 0.19 | - | 0 | 16.72 | 0 | 0 |
| Std Error | 0.04 | 0.26 | 0.04 | - | 0 | 5.29 | 0 | 0 |

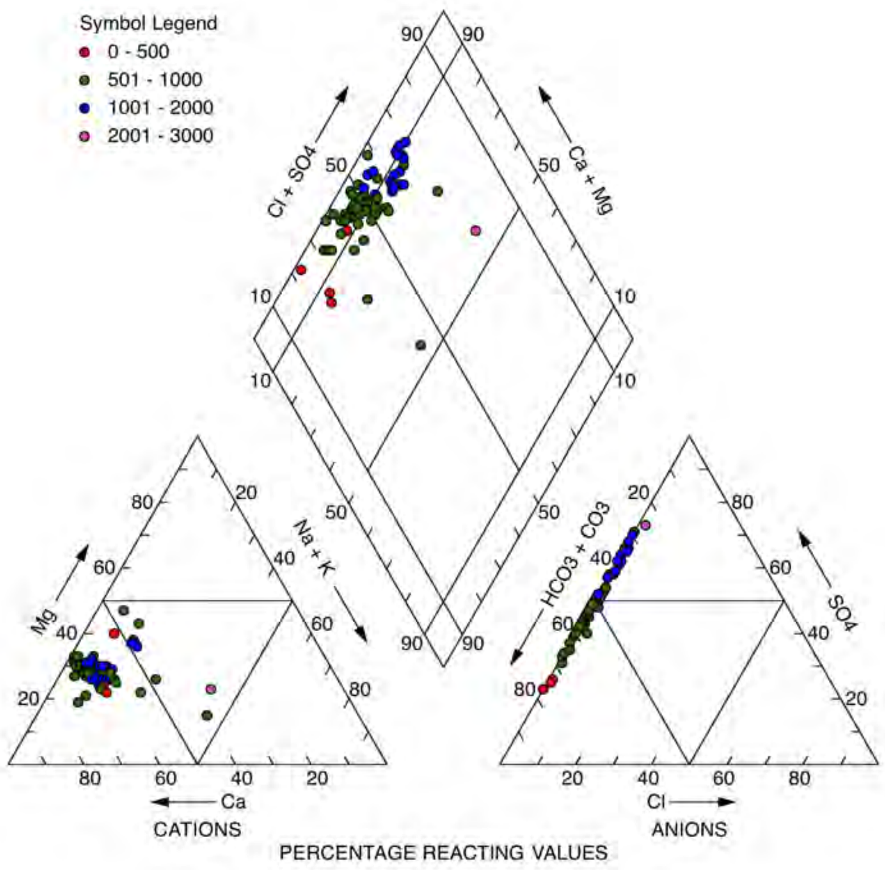


Figure 15.1.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Brightwood aquifer in Richland County.

### *15.2 Colfax Aquifer (Richland County)*

The Colfax aquifer is a buried sand deposit described by Baker and Paulson (1967) as underlying about 100 square miles of northeastern Richland County (Study Area #15 map).

Aquifer Composition: The aquifer composition is not well known. Generally, medium and fine sand deposits have been located between about 100 and 150 feet below land surface. Thicknesses vary from a few feet to as much as 52 feet. Baker and Paulson (1967) have conjectured that the deposits may represent “a sizeable body of buried outwash.” The exact nature and interconnection of the aquifer has not been clearly defined. Two sample lithologies are shown on Appendix Figures B.15.2.1 and B.15.2.2.

Aquifer Yield: Baker and Paulson (1967) have suggested that large well yields may be possible in some areas of the aquifer, based on local thicknesses and permeabilities of the medium sand. Sustained yields, however, would depend on local characteristics; predominantly whether they are isolated or connected to more extensive deposits of suitable thickness and permeability. Detailed local exploration, including long-term aquifer tests should be undertaken before selecting a site for a water supply from this aquifer.

Aquifer Chemistry: Water quality has been reported as somewhat salty, having dissolved solids concentrations of 2,160 mg/L and 2,390 mg/L measured for water samples from two wells Baker and Paulson (1967). The water was also reported to be high in sodium, sulfate, chloride, and fluoride, and generally of poor quality for drinking. Water samples from seven sites documented in the SWC database are primarily of the sodium-sulfate type (Figure 15.2.1). Total dissolved solids concentrations are all between 1,300 mg/L and 2,500 mg/L, depending on the method of determination (calculated or determined). Laboratory pH varies from 7.2 to 7.9. The maximum fluoride is 3.7 mg/L (Table 15.2.1). Measured sulfate values vary from about 600 to 1,120 mg/L, with a median value of 950 mg/L. The sodium adsorption ratio (SAR) varies from 6 to 22, indicating that the water is highly dispersive of soil particles. Hardness varies from 210 mg/L to 580 mg/L, with a median value of 430 mg/L. Only two water samples were measured for dissolved arsenic, and they indicate lower arsenic concentrations than commonly found in other glacial aquifers in the area (Table 15.2.3). High dissolved solids and elevated chloride may indicate upward flow of water from the underlying Dakota bedrock aquifer.

Permit Acquisition Status: There is only one water permit for the Colfax aquifer, held by the North Department of Game and Fish, for an annual appropriation of 122 acre-feet and a pumping rate of 35 gpm. An application for a water permit for industrial use would have a reasonably good chance of success, subject to consideration of effects on local farm and domestic wells.

Other Considerations: Prospective water users would have to be willing to accept water that is fairly high in sulfate and sodium, with dissolved solids concentrations between 1,000 and 2,500 mg/L. A site investigation, including a long-term aquifer test, would be advisable for potential users of this aquifer. Large-scale pumping may increase the upflux of Dakota aquifer water, which may result in further degradation of water quality, depending on the local characteristics of Dakota aquifer water. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Baker, Claud H. Jr., and W.F. Paulson. 1967. Geology and Ground Water Resources of Richland County, North Dakota: Part III. Ground Water Resources. North Dakota State Water Commission. 48 pp.

Table 15.2.1. Summary of chemical properties of the Colfax aquifer in Richland County: general chemistry.

| | **SC-f µS/cm** | **SC-l µS/cm** | **pH-f** | **pH-l** | **TDS-d mg/L** | **TDS-c mg/L** | **T oC** | **Si mg/L** | **Ca mg/L** | **Mg mg/L** | **K mg/L** | **Na mg/L** | **Fl mg/L** | **Bicarb mg/L** | **Carb mg/L** | **Sulfate mg/L** | **Cl mg/L** | **NO3 mg/L** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 1,990 | 2,030 | 0 | 7.2 | 1,480 | 1,490 | 9 | 23 | 58 | 15 | 11 | 300 | 0.5 | 283 | 0 | 730 | 89 | 3 |
| **Maximum** | 3,420 | 3,550 | 0 | 7.9 | 2,460 | 2,430 | 15 | 28 | 140 | 56 | 48 | 730 | 3.7 | 354 | 0 | 1,120 | 328 | 9.9 |
| **Points** | 3 | 6 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **Mean** | 2,793.3 | 2,983.3 | 0 | 7.6 | 2,128.3 | 2,115 | 11.85 | 24.33 | 102 | 37.5 | 27.33 | 538.5 | 1.65 | 317.33 | 0 | 976.67 | 243.83 | 6 |
| **Median** | 2,970 | 3,165 | 0 | 7.6 | 2,215 | 2,210 | 11.6 | 23.5 | 104 | 37 | 21 | 572 | 1.1 | 318.5 | 0 | 985 | 290 | 5.1 |
| **Std Deviation** | 731.19 | 564.26 | 0 | 0.3 | 376.53 | 359.99 | 2.3 | 1.97 | 30.7 | 16.2 | 16.56 | 159.14 | 1.39 | 24.57 | 0 | 141.8 | 101.48 | 3.24 |
| **Std Error** | 422.15 | 230.36 | 0 | 0.1 | 153.72 | 146.96 | 0.94 | 0.8 | 12.53 | 6.61 | 6.76 | 64.97 | 0.57 | 10.03 | 0 | 57.89 | 41.43 | 1.32 |

Table 15.2.2. Summary of chemical properties of the Colfax aquifer in Richland County: use parameters.

| | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25oC | Langelier, Lab pH, 25oC | Langelier, Field pH, 82oC | Langelier, Lab pH, 82oC |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 210 | 0 | - | 232 | 6.1 | - | - | - | - |
| **Maximum** | 580 | 332 | - | 290 | 22 | - | - | - | - |
| **Points** | 6 | 6 | - | 6 | 6 | - | - | - | - |
| **Mean** | 409.17 | 154 | - | 260.17 | 12.45 | - | - | - | - |
| **Median** | 410 | 145.5 | - | 261 | 11.5 | - | - | - | - |
| **Std Deviation** | 141.08 | 125.99 | - | 20.04 | 5.9 | - | - | - | - |
| **Std Error** | 57.6 | 51.44 | - | 8.18 | 2.41 | - | - | - | - |

Table 15.2.3. Summary of chemical properties of the Colfax aquifer in Richland County: selected trace elements.

| | **Boron** mg/L | **Iron** mg/L | **Manganese** µg/L | **Selenium** µg/L | **Mercury** µg/L | **Arsenic** µg/L | **Lithium** µg/L | **Molybdenum** µg/L |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0.4 | 0.06 | 0.09 | 0 | 0 | 1 | 140 | 7 |
| **Maximum** | 2.2 | 2.1 | 0.26 | 0 | 0 | 3 | 190 | 9 |
| **Points** | 6 | 6 | 3 | 2 | 2 | 2 | 2 | 2 |
| **Mean** | 1.29 | 1.12 | 0.16 | 0 | 0 | 2 | 165 | 8 |
| **Median** | 1.28 | 1.25 | 0.13 | 0 | 0 | 2 | 165 | 8 |
| **Std Deviation** | 0.66 | 0.79 | 0.09 | 0 | 0 | 1.41 | 35.36 | 1.41 |
| **Std Error** | 0.27 | 0.32 | 0.05 | 0 | 0 | 1 | 25 | 1 |

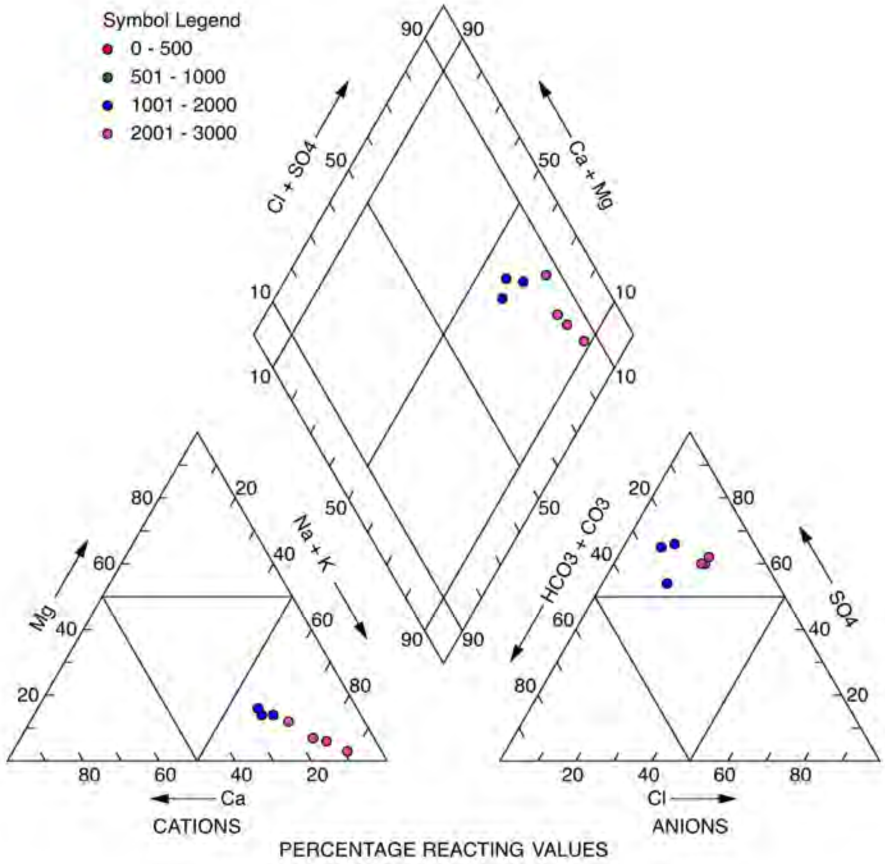


Figure 15.2.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Colfax aquifer Richland County.

### *15.3 Sheyenne Delta Aquifer (Richland, Cass, Ransom and Sargent Counties)*

The Sheyenne Delta aquifer is unconfined, and occupies about 750 square miles in Richland, Cass, Ransom and Sargent Counties in southeastern North Dakota (Study Area #15 map).

Aquifer Composition: According to Armstrong (1982) "the deposits in Ransom and Sargent Counties grade from predominantly medium to coarse sand with lenses of gravelly sand and finer sand and silt in the southwest to predominantly fine to medium sand with a larger proportion of fine sand and silt lenses in the north and east." The water table is shallow, usually within a few feet of land surface. Armstrong (1982) reported saturated thicknesses ranging from 6 to 87 feet, with a mean saturated thickness of about 41 feet. Downy and Paulson (1974) reported a mean thickness of 97 feet, with a maximum thickness of 140 feet in Richland County. A sample of five distributed lithology logs is provided on Appendix Figures B.15.3.1 through B.15.3.5.

Aquifer Yield: Reported well yields vary from a few gallons per minute near the western edge of the aquifer to about 1,000 gal/min where more than 35 feet of gravelly sand are found. However, sustained maximum yields of 500 gpm are more likely in many areas. According to Armstrong (1982), most of the area will yield about 250 gallons per minute for properly completed wells.

Aquifer Chemistry: Dissolved solids in Sheyenne Delta aquifer water range from about 200 to 3,000 mg/L (Table 15.3.1); however, 75% of 71 sites sampled had dissolved solids less than 500 mg/L, and 90% of water samples had less than 900 mg/L. Water under 1,000 mg/L is predominantly of the calcium-bicarbonate type, with some gradation to sodium sulfatic waters (Figure 15.3.1). Water samples with higher dissolved solids are more sulfatic and are likely found in evaporative discharge areas, or in waters in close contact with glacial till. Some water samples having sodium and calcium magnesium-sulfatic waters were sampled in areas where water from flowing wells screened in the underlying Dakota Formation has discharged and mixed with Sheyenne Delta aquifer water. Dissolved iron content can be as high as 16 mg/L Arsenic may be problematic in some areas of the aquifer (Table 15.3.3). The maximum dissolved arsenic concentration was 96 μg/L, 5.5 times the EPA-MCL. The median and mean dissolved arsenic concentrations are about double the EPA-MCL.

Permit Acquisition Status: There are currently 80 water permits for the Sheyenne Delta aquifer, 62 perfected and 14 conditional. Of the perfected permits, two are for rural water systems, and the rest are for irrigation. Total permitted water in the aquifer is 27,975 acre-feet per year. Permitted water allocations total 22,822 acre-feet per year. Approved pumping rates vary from 110 to 3,600 gpm, with a mean of about 1,084 gpm (+/- 100 gpm at 95% confidence) and a median of 850 gpm. As of August 2009, there were six pending water permit applications with established priority dates, requesting a total annual appropriation of 3,750 acre-feet and pumping rates varying from 200 gpm to 2,000 gpm.

Water permits are still being granted from the Sheyenne Delta aquifer. Any new permits must be located so that these prior appropriators are not adversely affected. New industrial applicants should consult the managing area hydrologist (State Water Commission) for advice on possible supply areas least likely to face competition, and least likely to have adverse impact on existing permitted water users.

<u>Additional Considerations:</u> There is currently a moratorium on further water withdrawals from the Sheyenne River. The Sheyenne River is a "gaining stream" throughout the delta area of Ransom and Richland Counties (Paulson, 1964, p. 180). A water permit would not be granted for water withdrawal from the aquifer through a well placed in a position that would intercept waters currently discharging to the river. This means that, in general, applications for water permits having points of diversion more distant from the river would be advantageous. However, not all locations near the river valley would necessarily impede discharge. Paulson (1964) observed that "a significant part of the increase in the discharge measurements [for the Sheyenne River over the extent of the Sheyenne Delta aquifer] is due to inflow from short tributaries which head on the Sheyenne delta and whose base flow consist wholly of ground-water discharge from the deltaic deposits. Examination of U.S. Geological Survey 7 ½ -minute topographic quadrangle maps reveals several tributaries extending back into the deltaic deposits from both sides of the Sheyenne River valley between stations…The largest of these enters the valley from the south, a short distance east of the west boundary of Richland County." These observations, and recent models of the Sheyenne Delta aquifer have indicated that discharge likely occurs in limited areas where backward erosion has caused gullies that intercept the aquifer. Consultation with the managing hydrologist, before selecting a site for an industrial application, will help applicants to select sites having the best probability of success.

Both the need for arsenic removal, and the disposal of the arsenic filtrate or residue should be considered.

**Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

<u>Citations:</u>

Armstrong, C.A. 1982. Ground-water Resources of Ransom and Sargent Counties, North Dakota. County Ground-water Studies 31-Part III. North Dakota State Water Commission. Bismarck, ND. 51 pp.

Downey, J.S., and Q.F. Paulson. 1974. Predictive modeling of effects of the planned Kindred Lake on ground-water levels and discharge, southeastern North Dakota: U.S. Geological Survey Water-Resources Investigations 30-74. 22 pp.

Paulson, Q.F. 1964. Geologic factors affecting discharge of the Sheyenne River in southeastern North Dakota. U.S. Geological Survey Professional Paper 501-D, Pages D177-D-181.

Table 15.3.1. Summary of chemical properties of the Sheyenne Delta aquifer in Richland, Cass, Ransom and Sargent Counties: General Chemistry.

| | SC-f | SC-l | pH-f | pH-l | TDS-d | TDS-c | ToC | Si | Ca | Mg | K | Na | Fl | Bicarb | Carb | Sulfate | Cl | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 355 | 334 | 0 | 6.6 | 221 | 206 | 6 | 13 | 28 | 9.3 | 0.6 | 1.6 | 0.05 | 99 | 0 | 0 | 0 | 0 |
| **Maximum** | 4,430 | 4,680 | 9.6 | 8.5 | 3,200 | 3,030 | 17.2 | 40 | 637 | 253 | 20 | 584 | 0.9 | 1,170 | 19 | 2,150 | 461 | 88.5 |
| **Points** | 169 | 193 | 87 | 193 | 104 | 193 | 95 | 96 | 193 | 193 | 193 | 193 | 193 | 193 | 190 | 193 | 190 | 191 |
| **Mean** | 742.33 | 761.63 | 7.6 | 7.6 | 511.73 | 473.44 | 9.58 | 26.64 | 95.27 | 30.28 | 4.43 | 26.89 | 0.21 | 395.75 | 0.86 | 86 | 15.11 | 1.9 |
| **Median** | 628 | 634 | 7.7 | 7.6 | 413 | 390 | 9.3 | 27.8 | 86 | 24.8 | 3.3 | 10 | 0.2 | 357 | 1 | 28 | 3.69 | 0.1 |
| **Std Deviation** | 485.96 | 521.9 | 1.1 | 0.3 | 417.8 | 364.81 | 1.74 | 4.2 | 51.07 | 25.05 | 3.58 | 65.2 | 0.09 | 157.76 | 2.12 | 227.05 | 49.67 | 8.47 |
| **Std Error** | 37.38 | 37.57 | 0.1 | 0 | 40.97 | 26.26 | 0.18 | 0.43 | 3.68 | 1.8 | 0.26 | 4.69 | 0.01 | 11.36 | 0.15 | 16.34 | 3.6 | 0.61 |

Table 15.3.2. Summary of chemical properties of the Sheyenne Delta aquifer in Richland, Cass, Ransom and Sargent Counties: use parameters.

| | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mE/L | ALK Calculated mE/L | SAR | Langelier, Field pH, 25oC | Langelier, Lab pH, 25oC | Langelier, Field pH, 82oC | Langelier, Lab pH, 82oC |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 129 | 0 | 0 | 128 | 0 | 0.05 | -2.23 | 1.05 | -1.23 |
| **Maximum** | 2,630 | 1,740 | 957 | 700 | 11 | 1.7 | 1.89 | 2.7 | 2.89 |
| **Points** | 193 | 187 | 90 | 104 | 193 | 56 | 189 | 56 | 189 |
| **Mean** | 362.35 | 57.26 | 326.22 | 320.75 | 0.53 | 0.89 | 0.74 | 1.89 | 1.74 |
| **Median** | 316 | 3 | 290.5 | 292.5 | 0.23 | 0.94 | 0.68 | 1.94 | 1.68 |
| **Std Deviation** | 220.64 | 174.69 | 159.3 | 101.42 | 1.11 | 0.46 | 0.48 | 0.46 | 0.48 |
| **Std Error** | 15.88 | 12.78 | 16.79 | 9.94 | 0.08 | 0.06 | 0.04 | 0.06 | 0.04 |

Table 15.3.3. Summary of chemical properties of the Sheyenne Delta aquifer in Richland, Cass, Ransom and Sargent Counties: selected trace elements.

| | **Boron** | **Iron** | **Manganese** | **Selenium** | **Mercury** | **Arsenic** | **Lithium** | **Molybdenum** |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0 | 0 | 0.01 | 0 | 0 | 0 | - | - |
| **Maximum** | 2.4 | 67 | 3.65 | 9.99 | 95.6 | 2.4 | - | - |
| **Points** | 110 | 192 | 182 | 53 | 53 | 110 | - | - |
| **Mean** | 0.13 | 2.67 | 0.59 | 1.84 | 19.52 | 0.13 | - | - |
| **Median** | 0.05 | 1.31 | 0.52 | 1 | 8.46 | 0.05 | - | - |
| **Std Deviation** | 0.25 | 5.73 | 0.44 | 2.28 | 23.81 | 0.25 | - | - |
| **Std Error** | 0.02 | 0.41 | 0.03 | 0.31 | 3.27 | 0.02 | - | - |

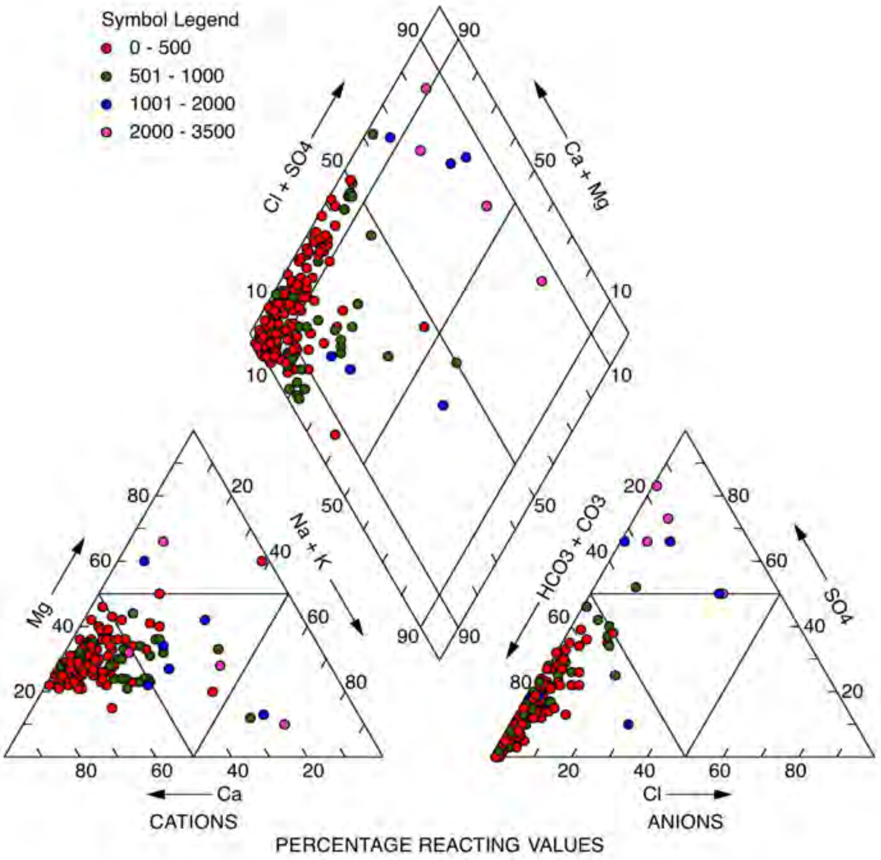


Figure 15.3.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Sheyenne Delta aquifer in Richland, Cass, Ransom and Sargent Counties.

### *15.4 Spiritwood Aquifer (Sargent County)*

The Spiritwood aquifer is a confined buried valley aquifer that extends from South Dakota to Canada, and has been identified in 12 North Dakota counties, extending from Sargent and Dickey Counties in the south to Towner and Rolette counties on the northern boundary. The water-use status of the Spiritwood is complex, in some areas fully appropriated, while in some other areas it is connected with other aquifers that may be fully appropriated. There are, however, some portions of the aquifer in which further development for beneficial use is feasible. About 200 square miles of the Spiritwood aquifer, located in Sargent County, is presented as having potential for further development (Study Area #15 map). The mapped portion of the Spiritwood consists of what may be considered a "main channel" extending in an arc from the southeast (T129N R58W) to the northeast limit (T130N, R55W), and a northeast extension underlying parts of townships 130N and 131N, and Ranges 53W and 54W. The northeastern extension is based on more recent exploration and its relationship with the Spiritwood and other area aquifers has not been clearly identified. For practical purposes it will be treated here with the Spiritwood aquifer. Municipalities overlying this portion of the Spiritwood aquifer include Lidgerwood on the eastern border, Genesco, Cayuga, Forman, Cogswell, and Brampton. The approximate area of the area mapped as having good potential for development is about 200 square miles.

Aquifer Composition: The Spiritwood aquifer in Sargent County was described by Armstrong (1982) as consisting of "lenticular deposits of sand and gravel interbedded with clay and silt." Sand and gravel deposits were described as ranging in thickness from less than one foot near the boundaries to 124 feet, and as having an "aggregate thickness of about 50 feet." Lithologies for four sites in the main channel are shown on Appendix Figures B.15.3.1 through B.15.3.4 below. The upper boundaries of sand and gravel deposits are generally between 120 and 170 feet. While thicknesses are substantial (50 to 60 feet), the upper boundaries are shallower, beginning at about 60 feet. Two lithologies within the "unidentified" aquifer materials shown as a northeast extension of the Spiritwood aquifer are shown on Appendix Figures B.15.3.5 and B.15.3.6.

Aquifer Yield: Local Spiritwood aquifer well yields were described by Armstrong (1982) as being between 500 and 1,000 gpm in the thicker and coarser sand and gravel lenses, but generally less than 500 gpm in areas where sand lenses are thinner and have greater interstitial clay content, such as in the vicinity of Foreman and Cogswell. Long-term well yields depend on the extent and geometry of local deposits, and their connection to other local sand and gravel deposits. These have not yet been clearly identified.

Aquifer Chemistry: Armstrong (1982) stated that dissolved solids concentrations varied from about 626 mg/L to 2,260 mg/L, and that "water from the Spiritwood aquifer system generally is a sodium or sodium calcium-sulfate type. However, locally, calcium, magnesium, or bicarbonate are the predominant ions." Dissolved solids concentrations from SWC data for the Spiritwood aquifer vary from about 150 mg/L to between 2,000 and 2,300 mg/L, with a mean of about 950 mg/L and a median of about 900 mg/L, depending on the method of determination (Table 15.4.1). The Piper plot (Figure 15.4.1) for Sargent County data confirms Armstrong's analysis, with the additional observation that samples having dissolved solids below 1,000 mg/L tend to be of the calcium and magnesium-bicarbonate type, but grade increasingly toward more sodium-sulfatic type approaching and exceeding 1,000 mg/L.

There are no arsenic measurements for water samples collected from the Spiritwood aquifer in Sargent County. By extending the data sample to include 20 measurements from nearby Dickey and LaMoure Counties, dissolved arsenic concentrations were found to vary from as low as 3 mg/L to as high as 40 mg/L (four times the EPA-MCL). The mean (13.1 mg/L) and median (10 mg/L) dissolved arsenic concentration both match or exceed the EPA-MCL. It is possible that the local Spiritwood aquifer in Sargent County shares the relatively high arsenic characteristics common to other nearby glacial aquifers.

Permit Acquisition Status: There are currently three perfected water permits for 584.5 acre-feet from the portion of the Spiritwood aquifer mapped as having good potential for further water-use development in Study Area #15. Using an estimated annual recharge of 0.25 to 0.5 inches, there may be as much as 2,200 to 5,000 acre-feet available for further allocation from the Spiritwood aquifer in Sargent and Richland Counties.

Additional Considerations: Thorough site investigation, including a long-term aquifer test would be advisable before making a final site selection for a large-scale water supply. Water treatment plans for industrial use will likely need to consider appropriate arsenic removal methods, and disposal plans for arsenic filtered or precipitated from Spiritwood water during treatment. **Important: read pages 136 through 139 for a general description of estimation methods and limitations.**

Citations:

Armstrong, C.A. 1982. Ground-water Resources of Ransom and Sargent Counties, North Dakota. County Ground-water Studies 31-Part III. North Dakota State Water Commission. Bismarck, ND. 51 pp.

Table 15.4.1. Summary of chemical properties of the Spiritwood aquifer in Sargent County: general chemistry.

| | SC-f µS/cm | SC-l µS/cm | pH-f | pH-l | TDS-d mg/L | TDS-c mg/L | T oC | Si mg/L | Ca mg/L | Mg mg/L | K mg/L | Na mg/L | Fl mg/L | Bicarb mg/L | Carb mg/L | Sulfate mg/L | Cl mg/L | N mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 8.35 | 219 | 7 | 6.3 | 145 | 146 | 8 | 5 | 3.5 | 1 | 1.3 | 24 | 0.05 | 69 | 0 | 0.8 | 1.5 | 0 |
| **Maximum** | 5,300 | 2,770 | 8.9 | 8.9 | 1,920 | 1,980 | 15.5 | 34.1 | 215 | 60 | 18 | 650 | 1.02 | 715 | 20 | 910 | 780 | 9.6 |
| **Points** | 80 | 83 | 37 | 83 | 52 | 83 | 57 | 64 | 83 | 83 | 83 | 83 | 83 | 83 | 53 | 83 | 83 | 60 |
| **Mean** | 1,440.4 | 1,443 | 7.8 | 7.7 | 971.9 | 963.49 | 9.93 | 27.58 | 111.08 | 31.6 | 11.37 | 170.16 | 0.3 | 463.01 | 0.43 | 344.44 | 46.31 | 1.43 |
| **Median** | 1,277 | 1,320 | 7.7 | 7.7 | 881 | 896 | 9.7 | 30 | 102 | 29 | 11 | 140 | 0.24 | 467 | 0 | 283 | 21 | 1 |
| **Std Deviation** | 721.84 | 537.31 | 0.6 | 0.4 | 426.61 | 386.09 | 1.82 | 6.77 | 42.43 | 10.68 | 2.8 | 116.68 | 0.18 | 88.04 | 2.77 | 227.83 | 89.48 | 1.89 |
| **Std Error** | 80.7 | 58.98 | 0.1 | 0 | 59.16 | 42.38 | 0.24 | 0.85 | 4.66 | 1.17 | 0.31 | 12.81 | 0.02 | 9.66 | 0.38 | 25.01 | 9.82 | 0.24 |

Table 15.4.2. Summary of chemical properties of the Spiritwood aquifer in Sargent County: use parameters.

| Hardness | Hardness mg/L | NCH mg/L | ALK_ as_CaCO3 mg/L | ALK Calculated mg/L | SAR | Langelier, Field pH, 25oC | Langelier, Lab pH, 25oC | Langelier, Field pH, 82oC | Langelier, Lab pH, 82oC |
|---|---|---|---|---|---|---|---|---|---|
| **Minimum** | 13 | 0 | 192 | NA | 0.6 | 0.07 | -2.28 | 1.07 | -1.28 |
| **Maximum** | 749 | 400 | 481 | NA | 70 | 1.36 | 1.35 | 2.36 | 2.35 |
| **Points** | 83 | 83 | 31 | NA | 83 | 10 | 52 | 10 | 52 |
| **Mean** | 407.57 | 68.65 | 393.48 | NA | 4.48 | 0.42 | 0.58 | 1.42 | 1.58 |
| **Median** | 390 | 0 | 400 | NA | 3.07 | 0.25 | 0.61 | 1.25 | 1.61 |
| **Std Deviation** | 144.21 | 95.18 | 59.68 | NA | 7.77 | 0.43 | 0.58 | 0.43 | 0.58 |
| **Std Error** | 15.83 | 10.45 | 10.72 | NA | 0.85 | 0.14 | 0.08 | 0.14 | 0.08 |

Table 15.4.3. Summary of chemical properties of the Spiritwood aquifer in Sargent County: selected trace elements.

| | Boron mg/L | Iron mg/L | Manganese µg/L | Selenium µg/L | Mercury µg/L | Arsenic µg/L | Lithium µg/L | Molybdenum µg/L |
|---|---|---|---|---|---|---|---|---|
| **Minimum** | 0.21 | 0.02 | 0.01 | - | - | - | - | - |
| **Maximum** | 2.5 | 44 | 1.7 | - | - | - | - | - |
| **Points** | 50 | 83 | 83 | - | - | - | - | - |
| **Mean** | 0.81 | 2.22 | 0.53 | - | - | - | - | - |
| **Median** | 0.65 | 1 | 0.53 | - | - | - | - | - |
| **Std Deviation** | 0.53 | 5.91 | 0.32 | - | - | - | - | - |
| **Std Error** | 0.08 | 0.65 | 0.03 | - | - | - | - | - |

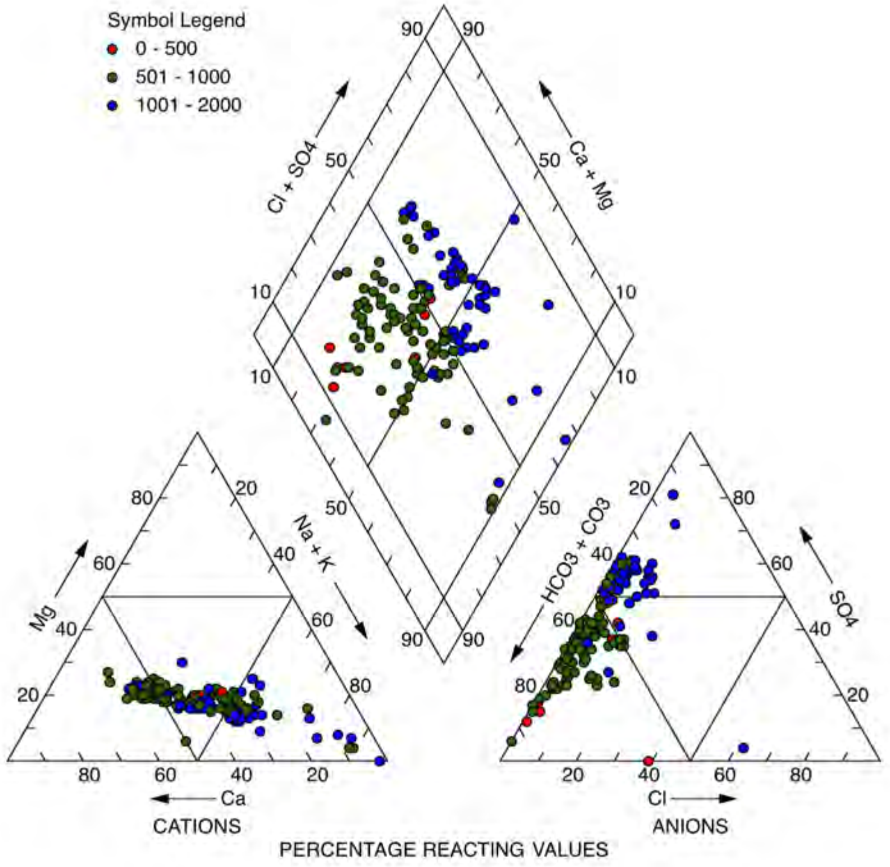


Figure 15.4.1. Piper plot illustrating the relative distribution of anions and cations in water samples collected from the Spiritwood aquifer in Sargent County.

# **Citations**

Armstrong, C.A. 1969. Ground-water Resources of Williams County, North Dakota. County Ground Water Studies 9: Part III. North Dakota State Water Commission, Bismarck, ND. 82 pp.

Armstrong, C.A. 1971. Ground-water Resources of Burke and Mountrail Counties. County Ground Water Studies 14: Part III. North Dakota State Water Commission, Bismarck, ND. 86 pp.

Bredehoeft, J.D., C.E. Neuzil, an P.C.D. Milly. 1983 Regional flow in the Dakota aquifer: a study of the role of confining layers. U.S. Geological Survey Water-Supply Paper 2237. U.S. Government Printing Office. 45 pp.

Doering, E.J. and L.C. Benz. 1972. Pumping an artesian source for water table control. Journal of Irrigation and Drainage Division, Proceedings. American Society of Civil Engineers. 98:275-287.

Hutchinson, R.D. 1977. Ground-water Resources of Cavalier and Pembina Counties, North Dakota. County Ground Water Studies 20: Part III. North Dakota State Water Commission, Bismarck, ND. 68 pp.

Kelly, T.E. and Q.F. Paulson. 1970. Geology and ground water resources of Grand Forks County. County Ground Water Studies 13: Part III. North Dakota State Water Commission, Bismarck, ND. pp. 17-20.

Kurz, Bethany A., Richard E. Shockey and Daniel J. Stepan. October 2009. Water supply potential of the Dakota sandtone aquifer in eastern North Dakota: (Draft Topical Report prepared for the Northern Great Plains Water Consortium of the Energy and Environmental Research Center. 33 pp.

Ripley, Dave. March, 1990. An overview of North Dakota's water resources. North Dakota Water Quality Symposium. NDSU Extension Service. Fargo, ND. p. 10.

Stepan, Daniel J., Richard E. Shockey, Bethany A. Kurz, Nicholas S. Kalenze, Robert M. Cowan, Joshua J. Ziman, and John A. Harju. April, 2010. Bakken Water Opportunities Assessment – Phase I. Report 2010-EERC-04-03, Energy and Environmental Research Center. Grand Forks, ND. 27 pp.

Trapp, Henry. 1968. Ground-water Resources of Eddy and Foster Counties. County Ground Water Studies 5: Part III. North Dakota State Water Commission, Bismarck, ND. 110 pp.

U.S. Geological Survey. 1996. Ground Water Atlas of the United States: Segment 8, Montana, North Dakota, South Dakota, Wyoming. Hydrological Investigations Atlas 730-1. USGS. Reston, Virginia. 124 pp.