Groundwater Report – North Fork Crow River Watershed

Minnesota Pollution Control Agency

April 2016

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Contributors/acknowledgements

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List of acronyms

BMPs best management practices
DTW depth to water
ECS Ecological Classification System
ET Evapotranspiration
HUC hydrologic unit code
MAU Monitoring and Assessment Unit
MCL maximum contaminant level
MDA Minnesota Department of Agriculture
MDH Minnesota Department of Health
MDNR Minnesota Department of Natural Resources
MGS Minnesota Geological Survey
MPCA Minnesota Pollution Control Agency
NFCRW North Fork Crow River Watershed
NFCRWD North Fork Crow River Watershed District
NLCD National Land Cover Database
NOAA National Oceanographic and Atmospheric Administration
NRCS Natural Resources Conservation Service
PMRs Pesticide Monitoring Regions
QBAA Quaternary Buried Artesian Aquifer
QBUA Quaternary Buried Unconfined Aquifer
QBUU Quaternary Buried Undifferentiated Aquifer
QWTA Quaternary Water Table Aquifer
SWUDS site-specific water-use data system
TMDL total maximum daily load
USDA U.S. Department of Agriculture
USGS United States Geological Survey
WIMN "What's In My Neighborhood?"

1. Introduction

Groundwater reviews are detailed reports on the condition of groundwater within the boundaries of one of the 81 major surface watersheds in Minnesota. This approach follows the Minnesota Pollution Control Agency's (MPCA) focus on watersheds as the starting point for water quality assessment, planning, implementation, and measurement of the watershed's condition. Though groundwater and surface watersheds do not always coincide, this method of investigating the condition of the hydrologic resource as a watershed unit can be usefully applied to groundwater because groundwater and surface water are dynamically linked. This linkage will be explored and explained in this report through the use of the water cycle, tracing the movement of water through the watershed from precipitation to runoff, recharge to withdrawal, and to conclude with evapotranspiration (Figure 1).

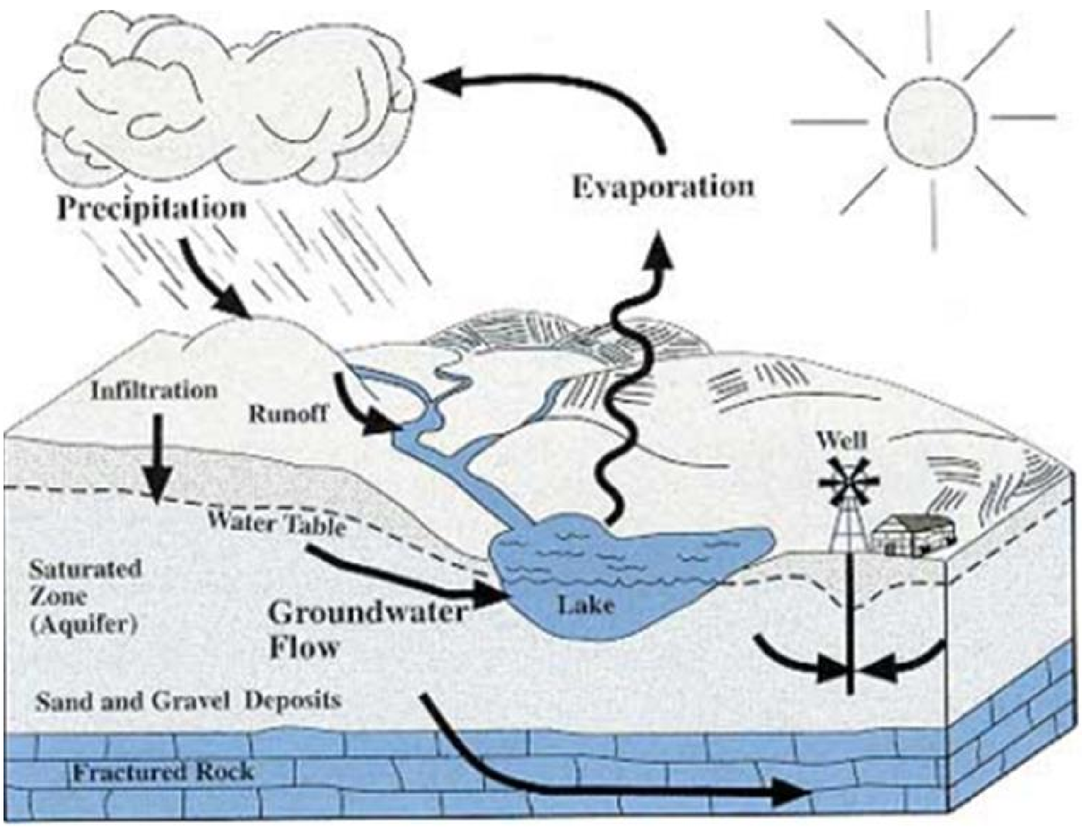

Figure 1: Simplified hydrologic cycle demonstrating the changing states of water above and below the earth's surface

The groundwater reports rely on the analysis of a wide spectrum of hydrologic datasets to provide context for the understanding of groundwater within the hydrologic cycle. The datasets analyzed include precipitation, streamflow, permitted high volume pumping, lake and groundwater elevations, evapotranspiration estimates, water quality samples, contaminant releases, estimates of recharge to surficial aquifers, and hydrogeological maps from local geological atlases.

The watershed monitoring approach

The watershed monitoring approach was adopted by the MPCA as a means to intensively monitor and assess the condition of Minnesota's lakes and streams at a watershed level. This was in compliance with the responsibility of the agency to the Clean Water Legacy Act to "protect, restore and preserve the quality of Minnesota's surface waters" (MPCA, 2009). The approach focused efforts on eight digit hydrologic unit code (HUC) watersheds during a 10-year cycle for all 81 major watersheds in Minnesota.

The Minnesota Department of Natural Resources (MDNR) (MDNR, 2015a) defines surface water and groundwater watersheds as follows:

> **Surface water watersheds** are generally delineated from topographic maps based on land elevations ("height-of-land" method). The MDNR completed a standard delineation of minor watershed boundaries for Minnesota in 1979. Using United States Geological Survey (USGS) quadrangle maps, the MDNR defined minor watershed outlets and delineated height-of-land minor watershed boundaries for all watersheds greater than five square miles. However, actual boundaries may be different due to map interpretation assumptions or human-induced changes that have occurred since the map was made. Field inspection of areas in question is required to be certain of actual boundaries.
>
> **Groundwater watersheds** are conceptually similar to surface water watersheds because groundwater flows from high points (divides) to low points (outlets, discharge areas). However, the boundaries of surface water and groundwater watersheds do not always coincide. Groundwater movement occurs in below ground aquifer systems and is subject to 1) hydraulic properties of the aquifer, 2) input to (recharge) and outflow from (discharge) the aquifer system, and 3) geological factors such as formations that block the flow of water and tilted formations that create a flow gradient. Surficial aquifers (the water table) generally mimic surface water watersheds, and their flow usually does not cross surface boundaries. Deeper (confined) aquifers, on the other hand, are less likely to conform to surface features and exhibit watersheds (or basins) determined by geologic factors. As described in the MDNR website:
> http://www.dnr.state.mn.us/watersheds/surface_ground.html. For the purposes of this report, groundwater watersheds will be treated as contiguous with surface water watersheds.

Watershed overview

The North Fork Crow River Watershed (NFCRW) (HUC 07010204) is located in a heavily agricultural region of central Minnesota, draining an area of 1,483 square miles (Figure 2). The vast majority of the watershed is within the North Central Hardwood Forest Ecoregion, with a small portion lying within the Western Cornbelt Plains Ecoregion. The watershed's surface waters are abundant with 679 lakes and 233 streams segments, or assessment units throughout the watershed. From its source at Grove Lake in Pope County, the North Fork Crow River runs east-southeast for a total length of 157 miles, flowing through Rice Lake and Lake Koronis until it meets the South Fork Crow River, where the confluence of the two rivers at Rockford forms the Crow River. The Crow River flows northeast until it meets the Mississippi River near Otsego and Dayton. The watershed consists of 949,107 acres and includes parts of Pope (3.7%), Stearns (16.0%), Kandiyohi (16.0%), Meeker (28.4%), Wright (31.7%), Hennepin (3.0%), Carver (0.1%), and McLeod (1.0%) counties (USDA, NRCS). The watershed elevation ranges from approximately 800 to 1,400 feet above sea level, decreasing from west to east (Figure 3).

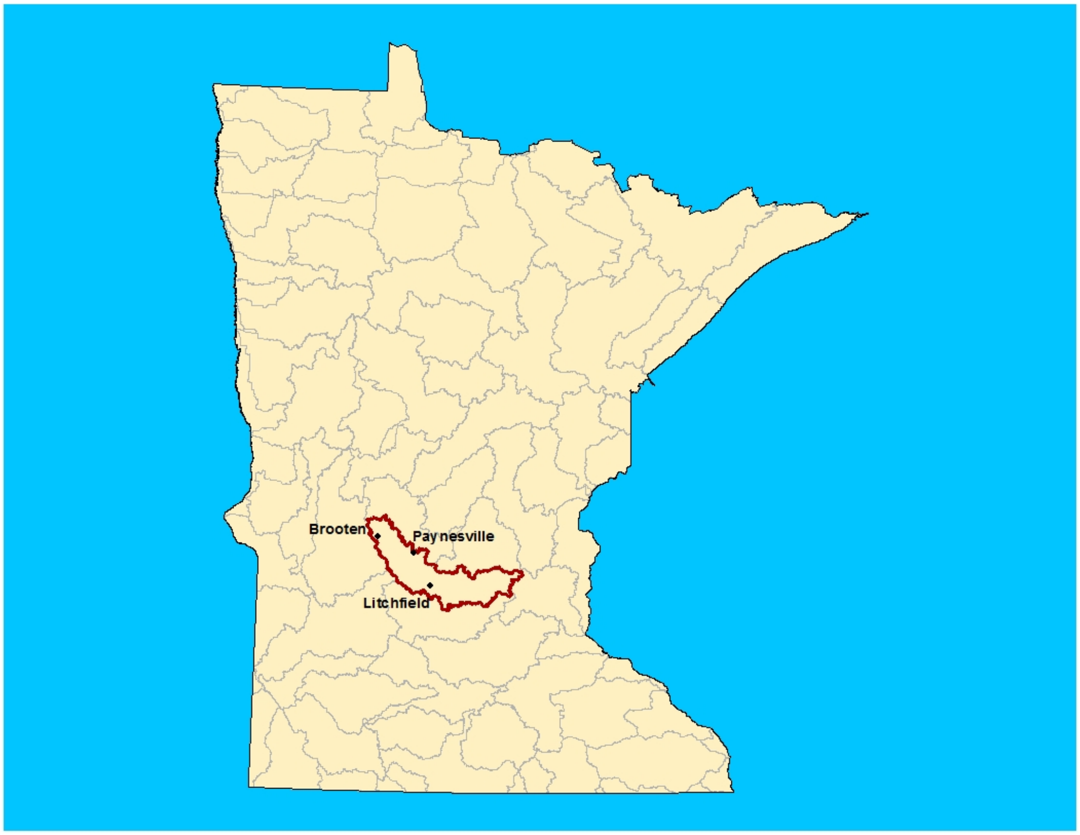

Figure 2: The location of the North Fork Crow River Watershed

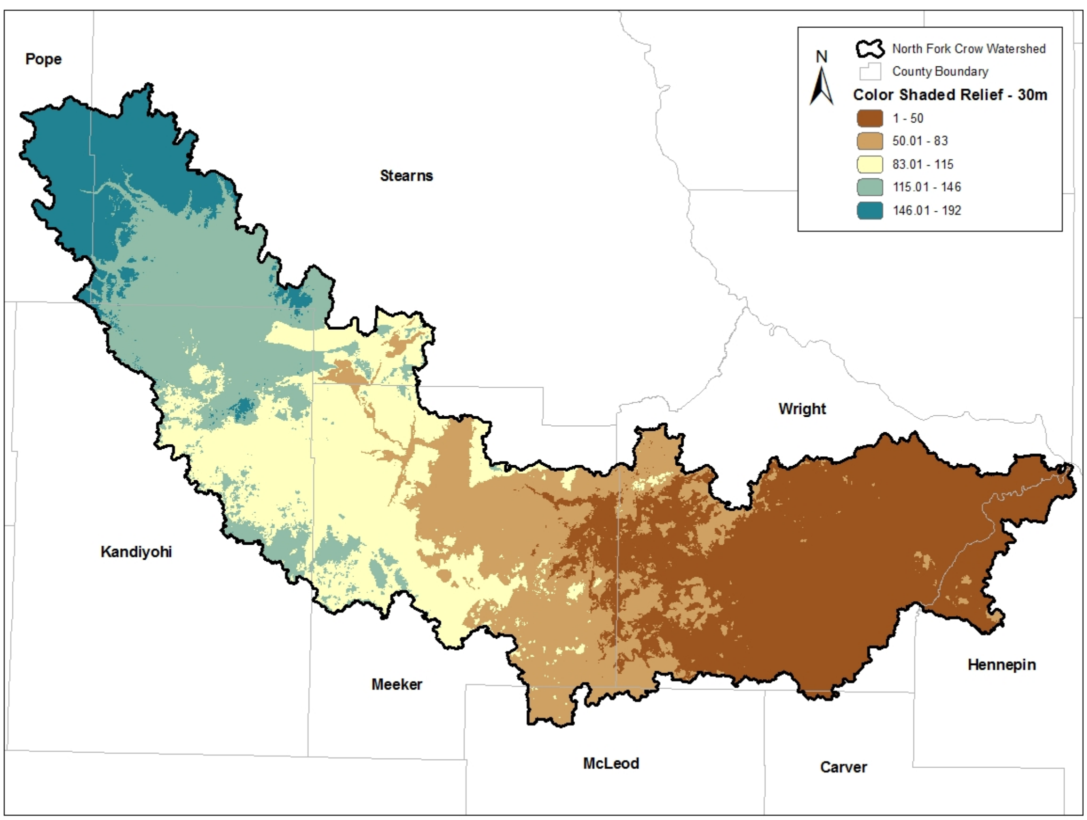

Figure 3: North Fork Crow River 8-HUC watershed relief (GIS Source: MDNR)

Land use

The land is heavily agricultural with 71.2% utilized for cropland and pasture (NLCD, 2011). The land is owned predominately by private owners (96.4%), while the remaining 4% are county (0.6%), federal (1.2%), state (1.7%), or conservancy land (0.1%) (USDA, NRCS). Land use and cover categories includes: forest/shrub (9.2%), wetlands (4.2%), open water (8.3%), rangeland (16.4%), cropland (54.8%), barren or mining (0.03%), and residential/commercial development (7.1%) (Figure 4) (NLCD, 2011; MPCA, 2011). The total population count of the watershed is 96,990 with an estimated 2,864 farms (MPCA, 2011; USDA, NRCS).

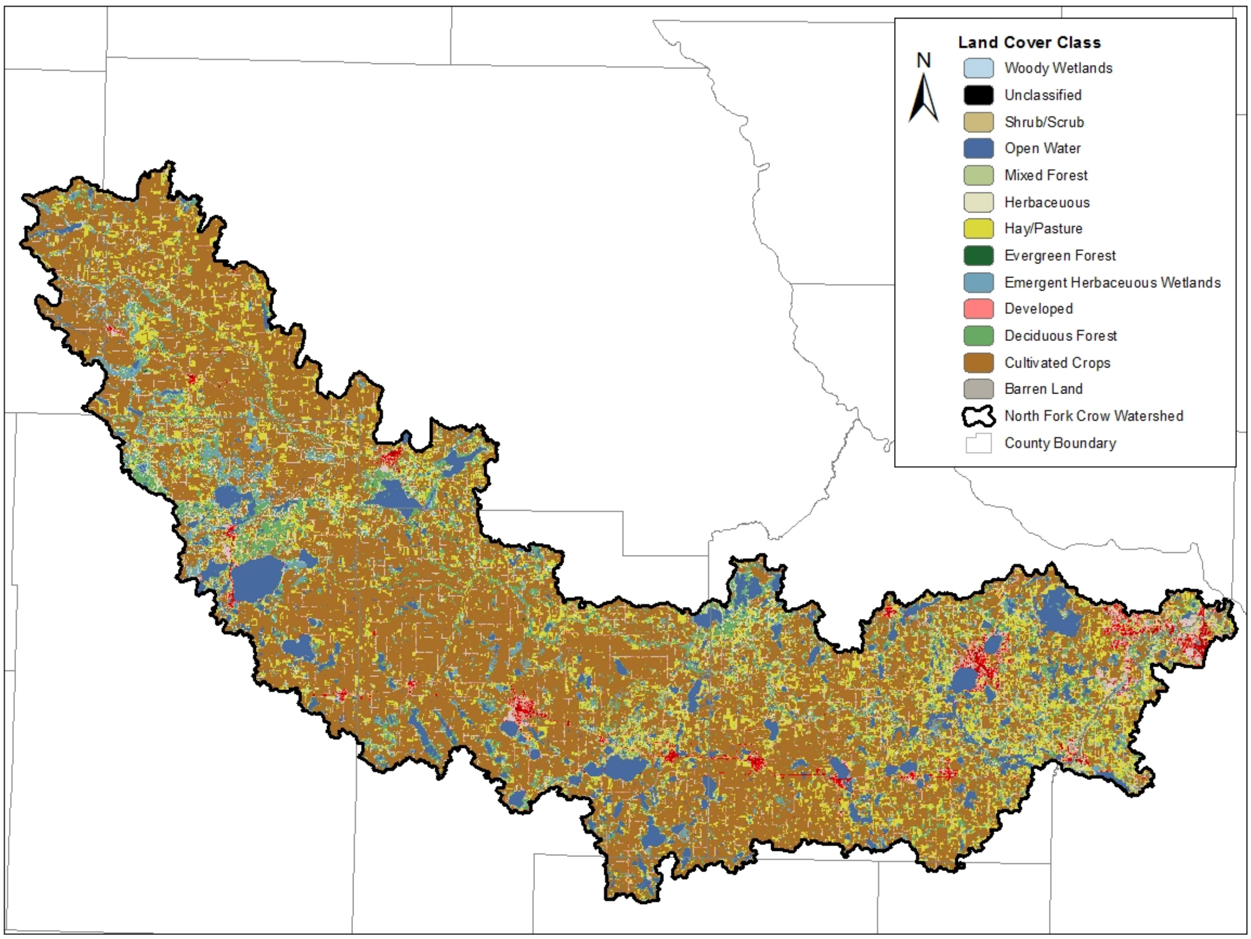

Figure 4: Land cover in the North Fork Crow River Watershed (GIS Source: NLCD, 2011)

Ecoregion and soils

The watershed is located within the North Central Hardwood Forest Ecoregion, with a small portion lying within the Western Cornbelt Plains Ecoregion. According to the Ecological Classification System (ECS), the NFCRW is located within the Prairie Parkland Province and the Eastern Broadleaf Forest Province, the North Central Glaciated Plains Section, and the Minnesota and Northeast Iowa Morainal Section. The watershed also lays within the ECS subsections Minnesota River Prairie (west), the Hardwood Hills (north central), and the Big Woods (east) subsections (Figure 5).

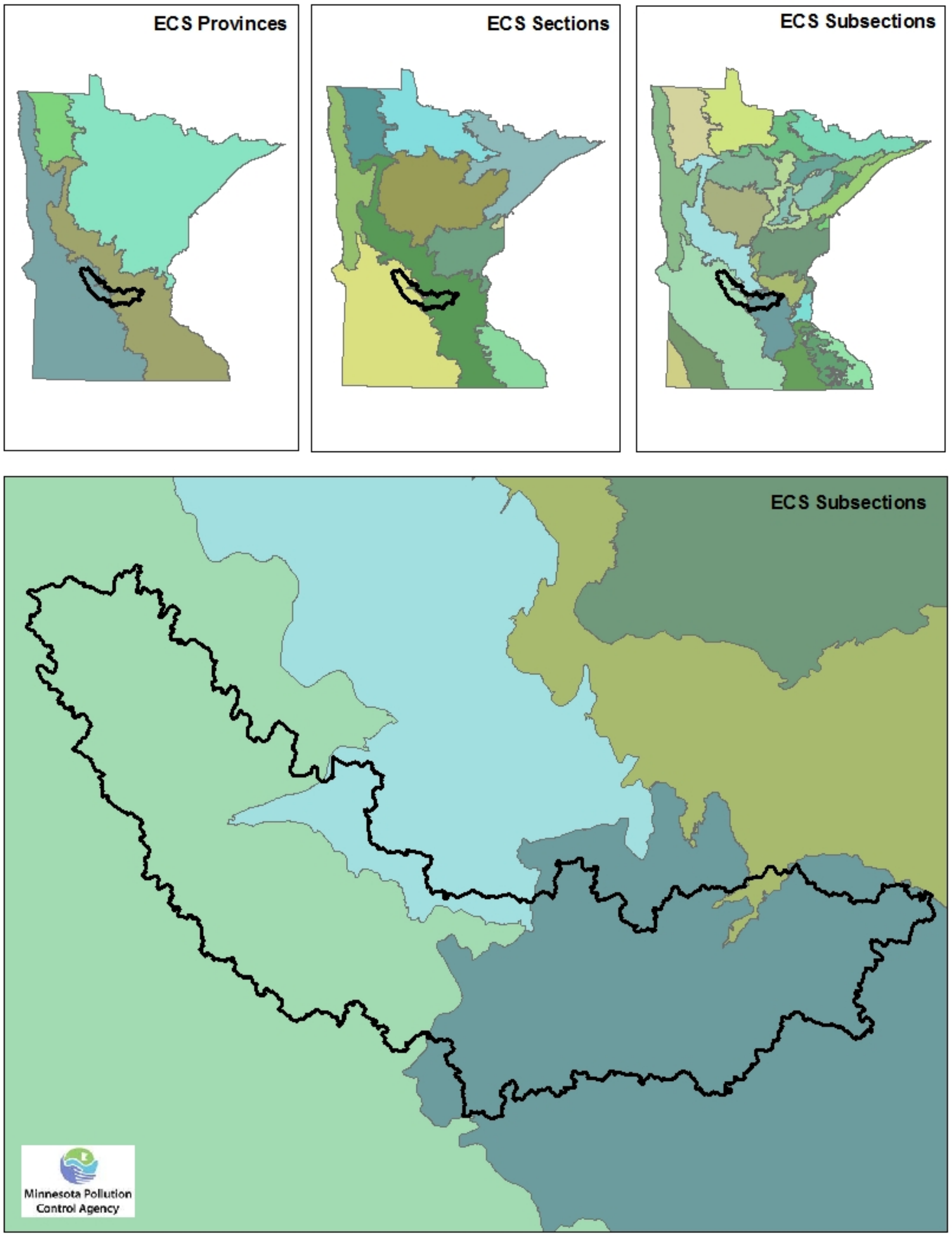

Figure 5: Three levels of Ecological Classification System for the North Fork Crow River Watershed

The watershed is comprised of calcareous glacial deposits of sand and gravel outwash from the Des Moines Lobe and Wadena Lobe, primarily of alluvium and outwash, steep drier moraines, steeper till, and rolling moraines. Soils in the lower watershed are primarily alfisols, while those in the upper watershed are primarily molliols (USDA, NRCS). Alfisols are formed from weathering processes under forests or mixed vegetation that contributes to high clay content; making them fertile with a high moisture holding capacity. Mollisols are characteristically found from grassland ecosystems under calcareous sediments with a thick, organic, rich, and fertile surface horizon. Both of these soils are considered very productive for agricultural soils, as demonstrated by the high percentage of land used for row crops and pasture. A more detailed list of the soil types can be found in Figure 6 (below).

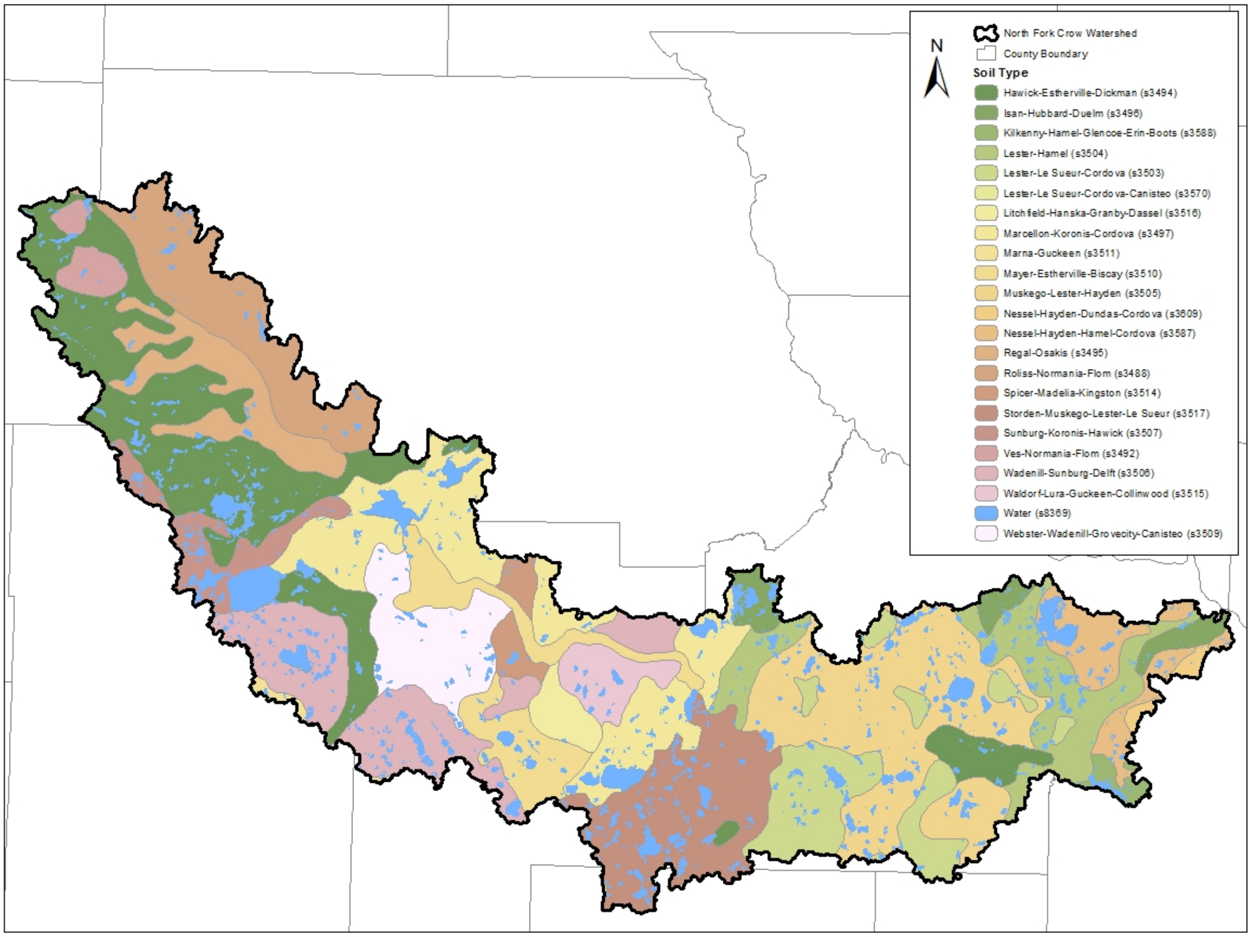

Figure 6: Soil classification for the North Fork Crow River Watershed (GIS Source: USDA NRCS, 2006)

II. Climate and precipitation

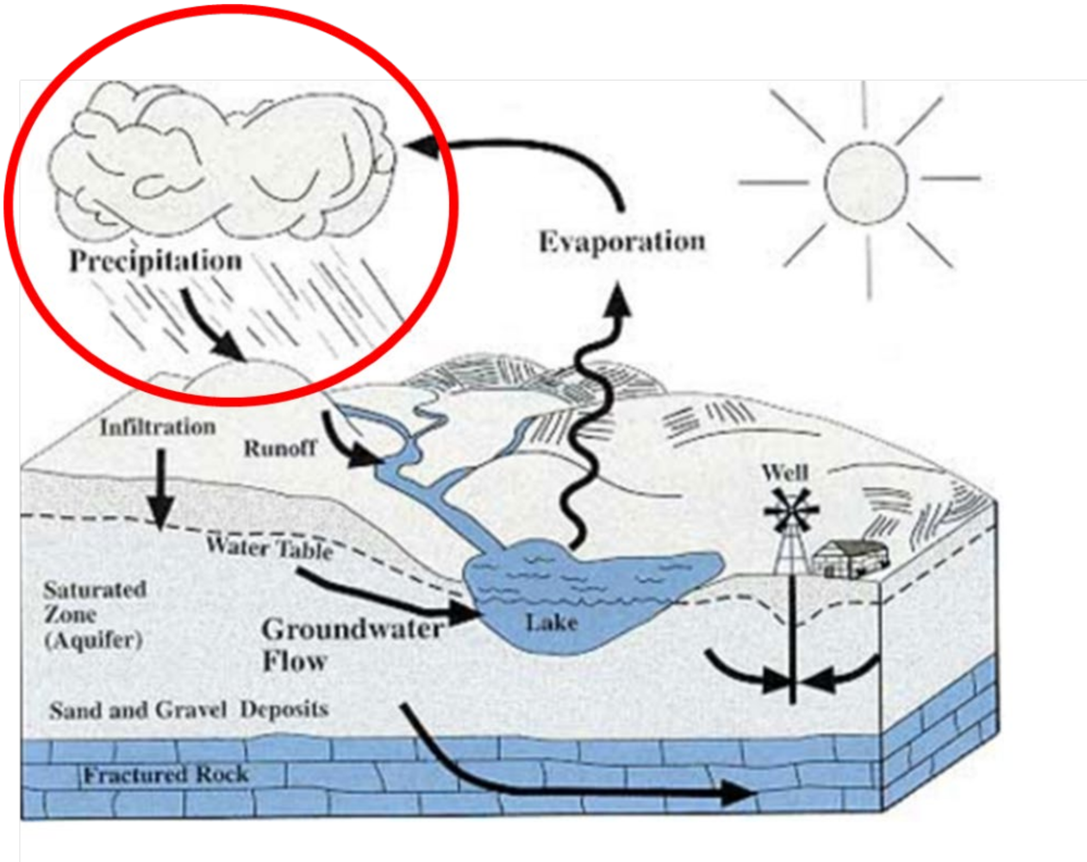

Figure 7: Precipitation within the hydrologic cycle

Minnesota has a continental climate, marked by warm summers and cold winters. The mean annual temperature for the state is 4.6˚C (NOAA, 2016); the mean summer temperature for the NFCRW is 20.0˚C and the mean winter temperature is -10.6˚ C (MDNR: Minnesota State Climatology Office, 2003).

Precipitation is an important source of water input to a watershed. Figure 8 shows two representations of precipitation for calendar year 2014. On the left is total precipitation, showing the typical pattern of increasing precipitation toward the eastern portion of the state. According to this figure, the NFCRW area received 28 to 36 inches of precipitation in 2014. The display on the right shows the amount those precipitation levels departed from normal. For the NFCRW, the map shows that precipitation ranged from two inches below normal to six inches above normal.

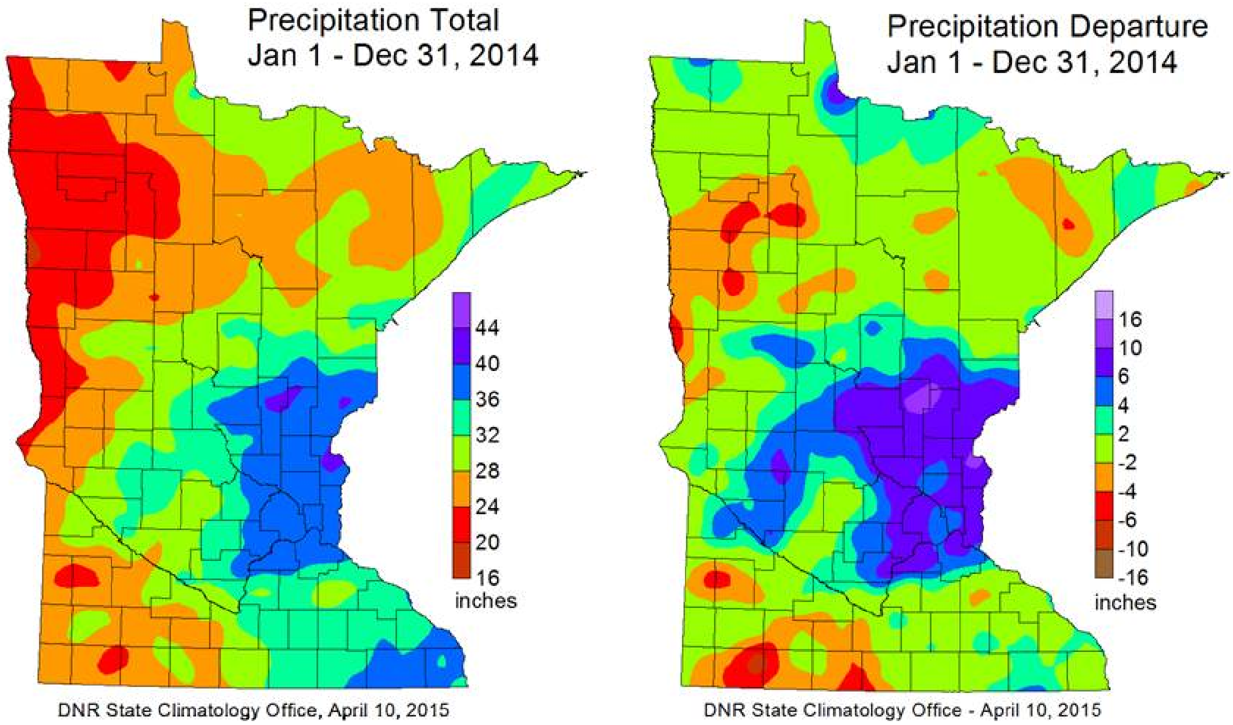

Figure 8: Statewide precipitation levels during 2014 (Source: MDNR State Climatology Office, 2015)

The NFCRW is located in the central precipitation region. Figure 9 and 10 (below) display the areal average representation of precipitation in central Minnesota for 20 and 100 years, respectively. An areal average is a spatial average of all the precipitation data collected within a certain area presented as a single dataset. Though rainfall can vary in intensity and time of year, rainfall totals in the central region display no significant trend over the last 20 years. However, precipitation in central Minnesota exhibits a significant rising trend over the past 100 years (p=0.001). This is a strong trend and matches similar trends throughout Minnesota.

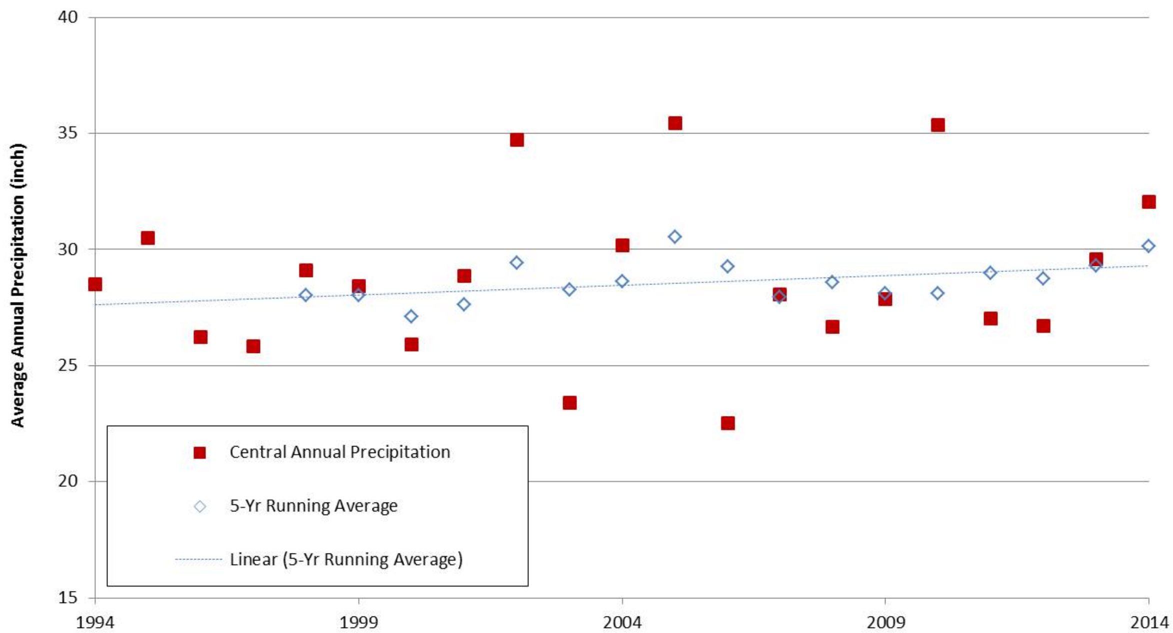

Figure 9: Precipitation trends in central Minnesota (1994-2014) with five-year running average

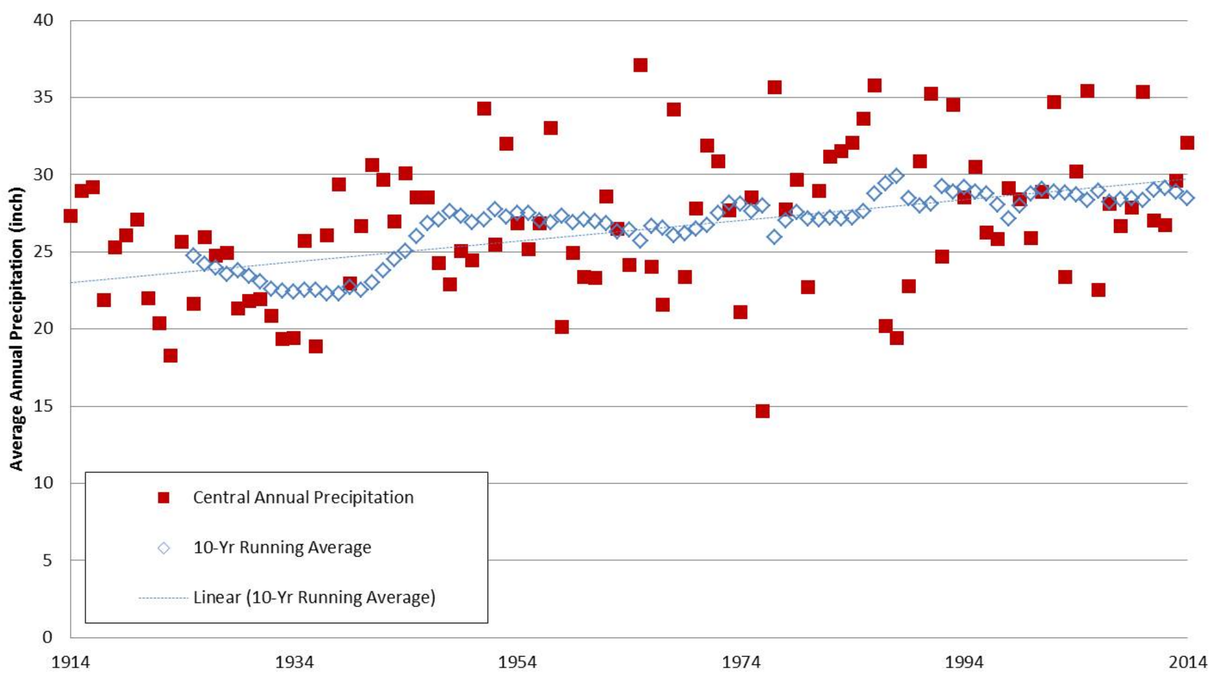

Figure 10: Precipitation trends in central Minnesota (1914-2014) with 10-year running average

III. Surface water hydrology

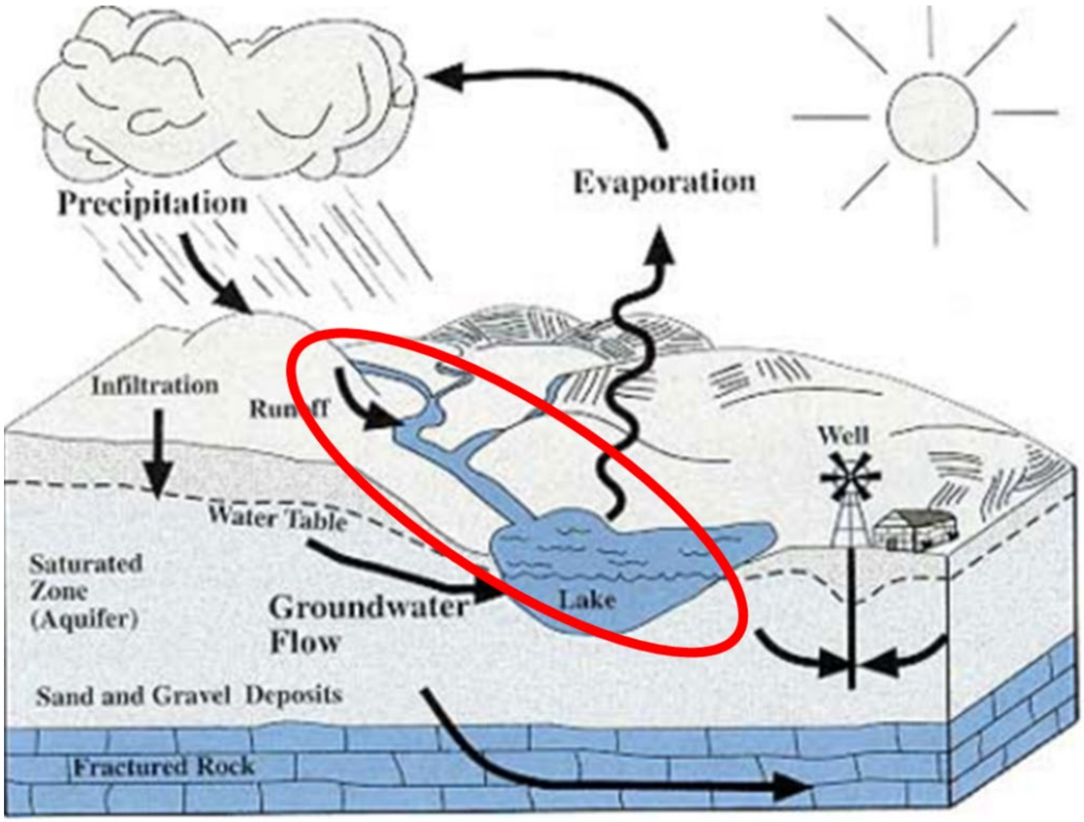

Figure 11: Surface water within the hydrologic cycle

The NFCRW's surface hydrology is a water-rich area, with 1,983 stream miles, 679 lakes, and 39,594 acres of wetlands (Figure 12) (USDA, NRCS; NLCD, 2011; MPCA, 2014; NFCRWD, 2011). Its namesake river begins at Grove Lake in Pope Count and travels 120 miles before joining the South Fork Crow River at Rockford where they form the Crow River. The Crow then flows northeast until it joins the Mississippi River at Dayton (MPCA, 2011). Other major rivers and creeks in the watershed include Jewitts Creek, Grove Creek, and Mill Creek and major lakes include Diamond Lake, Green Lake, Rice Lake, and Lake Koronis (MPCA, 2015a).

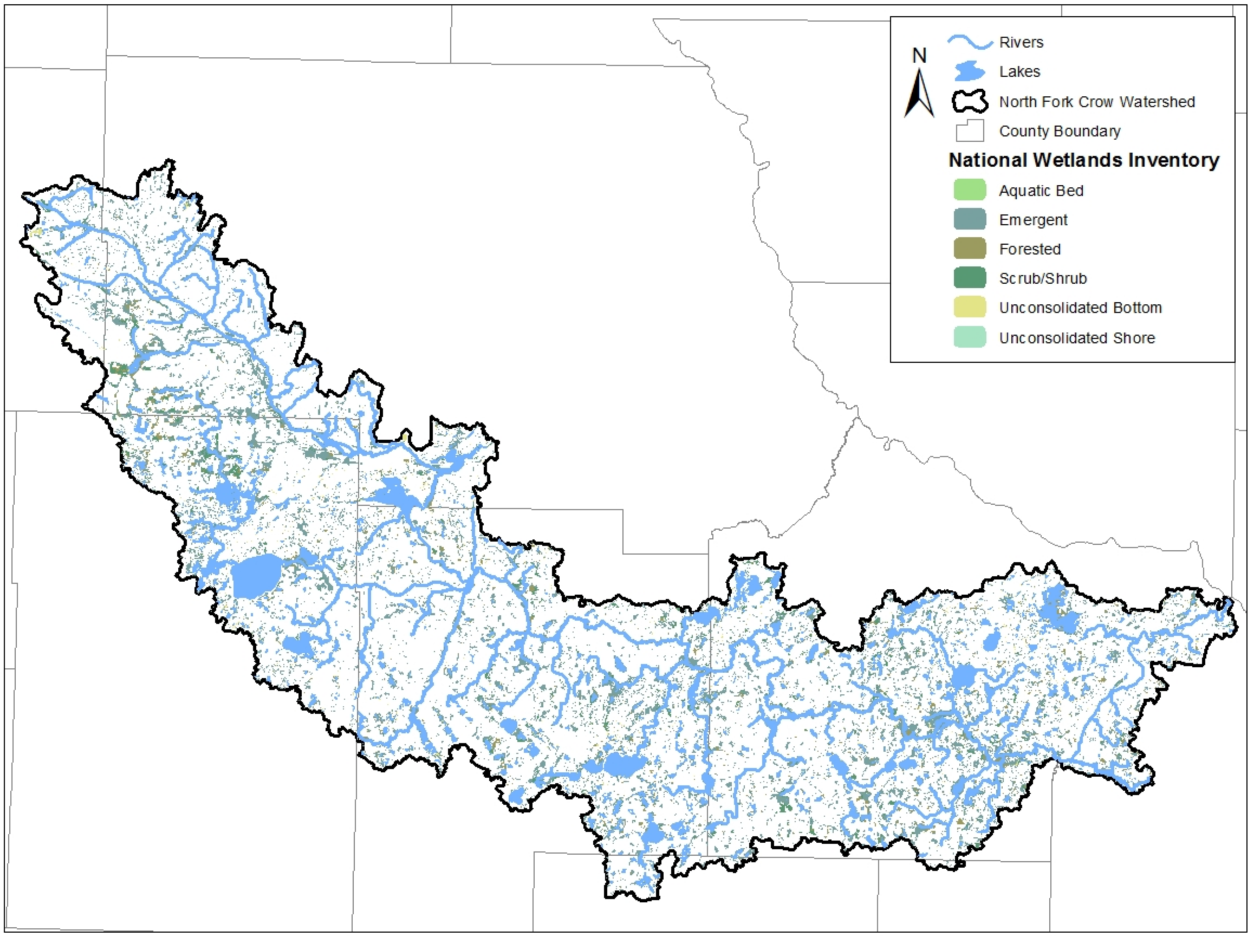

Figure 12: Lakes, wetlands and waterbodies in the North Fork Crow River Watershed

Streamflow

Stream flow data from USGS's real-time streamflow gaging stations for one river in the NFCRW was analyzed for annual mean discharge and summer monthly mean discharge (July and August). Figure 13 is a display of the annual mean discharge for the Crow River at Rockford, Minnesota from water years 1995 to 2014. The data shows that although streamflow appears to be slightly increasing, there is no statistically significant trend. Figure 14 displays July and August mean flows for water years 1995 to 2014 for the same water body. The data appear to be increasing in July and decreasing in August, but not at a statistically significant rate. By way of comparison at a state level, summer month flows have declined at a statistically significant rate at a majority of streams selected randomly for a study of statewide trends (Streitz, 2011). For additional streamflow data throughout Minnesota, please visit the USGS website: http://waterdata.usgs.gov/mn/nwis/rt.

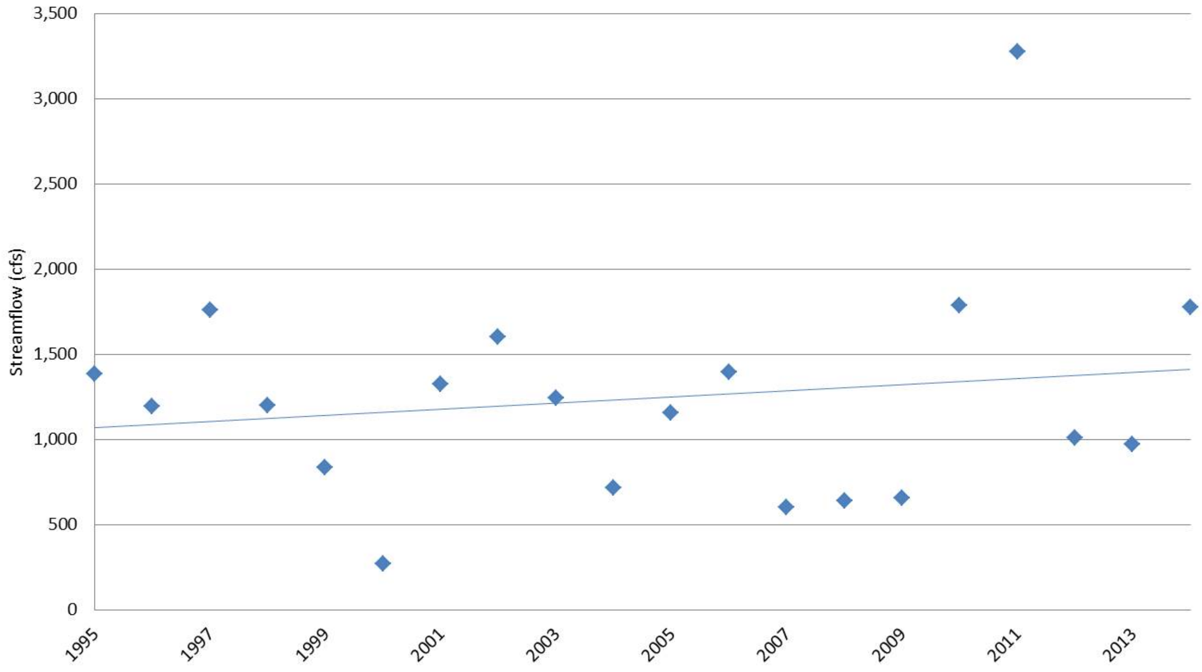

Figure 13: Annual mean discharge for Crow River at Rockford, MN (1995-2014)

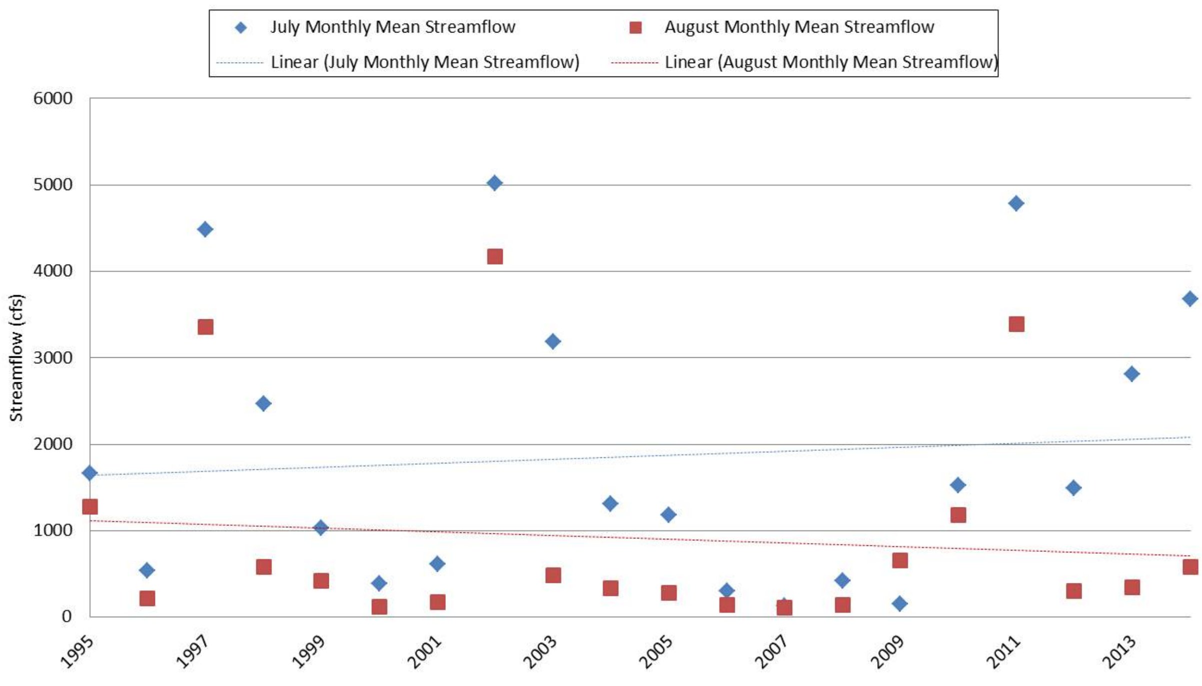

Figure 14: Mean monthly discharge for Crow River at Rockford, MN (1995-2014)

Lake levels

Lake Washington (Inventory Number 47004600) in Meeker County is located near Darwin in the central area of the watershed (Figure 15). The area of the lake is 2,422 acres with a maximum depth of 17 feet and an average lake water elevation of 1067.77 feet (MPCA, 2015b). The lake's use classification is 2B, 3C, which is defined as a healthy warm water aquatic community; industrial cooling and materials transport use without a high level of treatment. The overall condition is described as "suitable for swimming and wading, with good clarity and low algae levels throughout the open water season" (MPCA, 2015b).

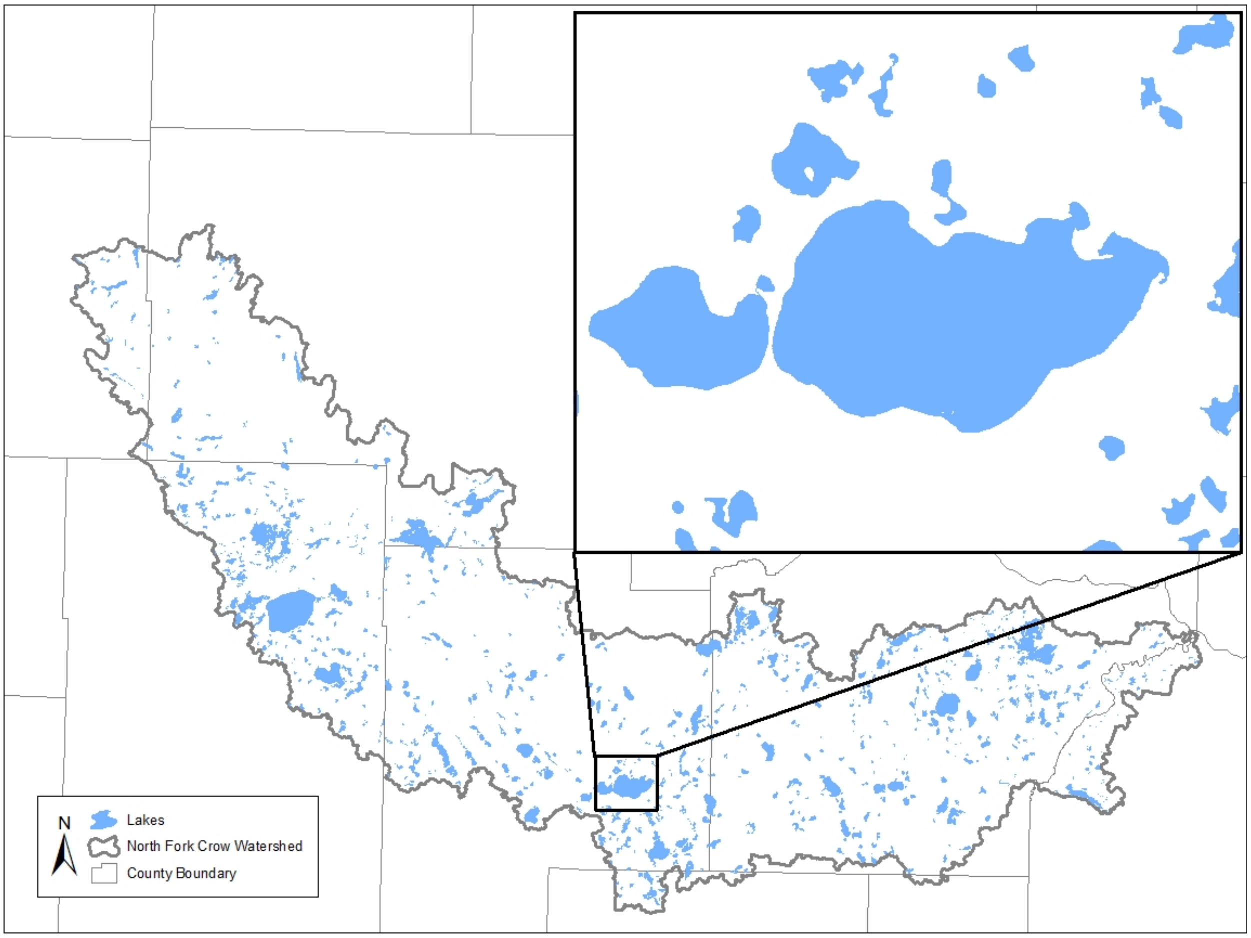

Figure 15: Lake Washington within North Fork Crow River Watershed

A 2014 survey by the MDNR determined the dominant bottom substrate of the lake to be sand. There were 31 varieties of aquatic plants were present with an average water clarity of 3.3 feet, which is considered poor and was associated with an algal bloom (MDNR, 2015b). The shoreline is heavily developed with 85% developed for residential purposes. The lakeshed is heavily agricultural, primarily used for row crop corn and soybeans. Over the last 20 years, lake level elevation has remained constant, altering for seasonal fluctuations (Figure 16). Lake elevation data can be found from the MDNR Lake Finder website: http://www.dnr.state.mn.us/lakefind/index.html.

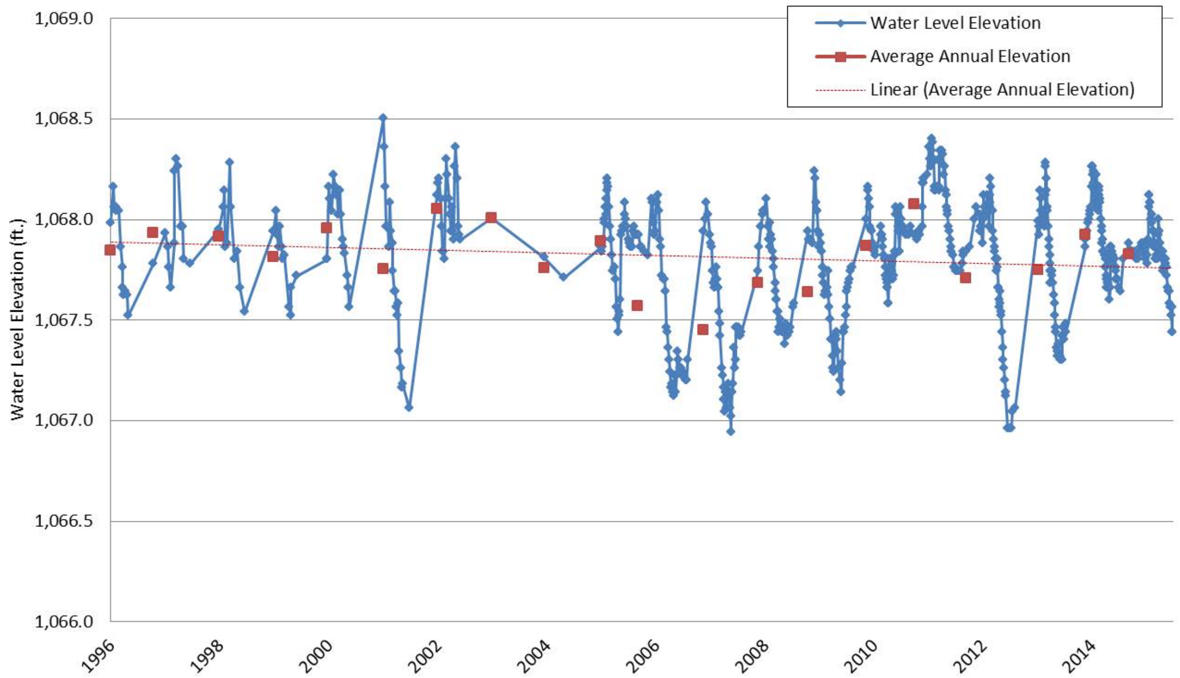

Figure 16: Lake Washington water level elevations (1996-2015)

Pelican Lake (Inventory Number 86003100) in Wright County is located near Annandale in the eastern area of the watershed (Figure 17). The area of the lake is 2,336 acres with a maximum depth of 9 feet and an average lake water level elevation of 953.1 feet (MPCA, 2015c). The lake's use classification is 2B, 3C; but the overall condition is described as "not always suitable for swimming and wading due to low clarity or excessive algae caused by the presence of nutrients, such as phosphorus in the water" (MPCA, 2015c).

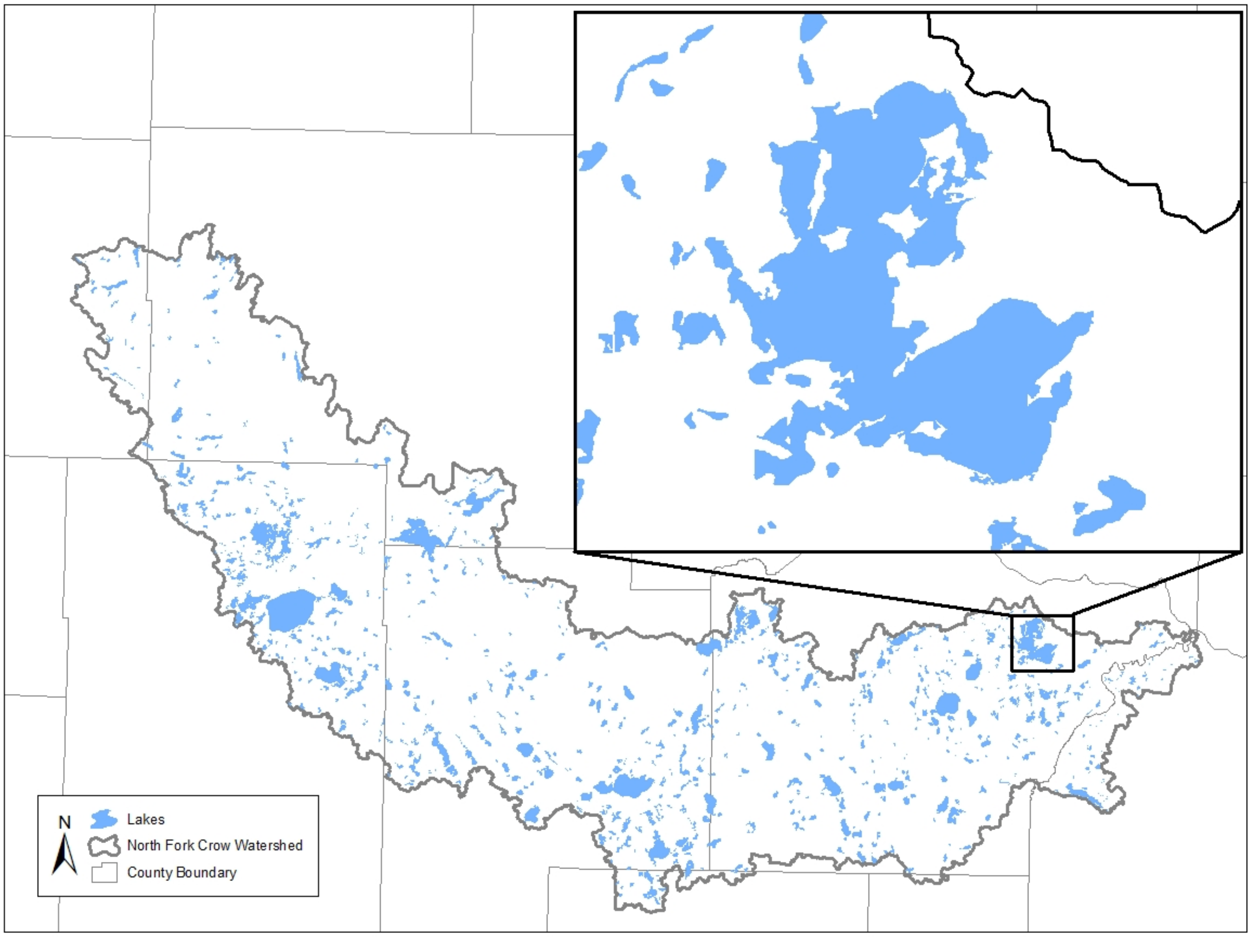

Figure 17: Pelican Lake within the North Fork Crow River Watershed

Pelican Lake has been identified as a state wildlife lake in 1977 – one of the 48 in Minnesota – due to diver duck species utilizing the lake as a spring and fall migration habitat. The lake is also currently undergoing an enhancement project by the MDNR Wildlife Division. The purpose of the project is to improve water quality and enhance waterfowl habitat (MDNR, 2015c). As seen in Figure 18, water levels have been rising consistently over time ($p=0.05$), and according to the MDNR, this rise has reached almost five feet over the last 28 years. The lake has experienced frequent, severe fish kills due to flooding of aquatic vegetation and nutrient and sediment loading. This has led to increased water level and fishery management efforts via wetland restoration, stabilization of stream channels, temporary water level drawdown and potentially stocking predator fish species.

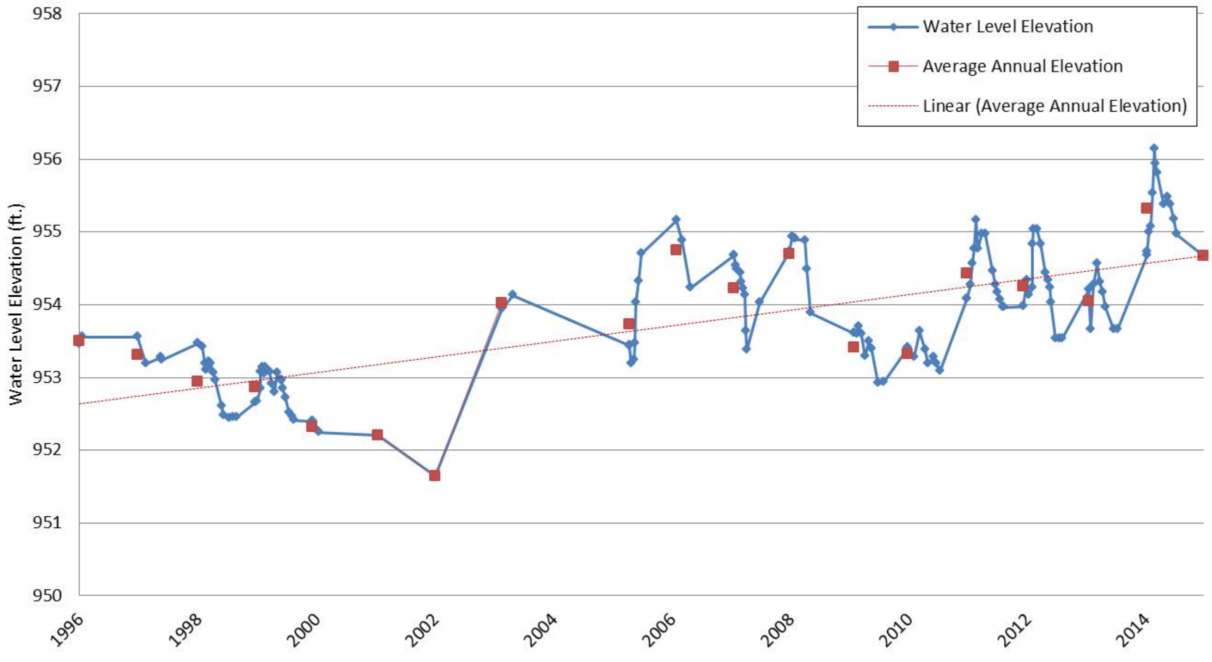

Figure 18: Pelican Lake water level elevations (1996-2015)

Green Lake (Inventory Number 34007900) in Kandiyohi County is located at Spicer in the western area of the watershed (Figure 19). The area of the lake is 5,534 acres with a maximum depth of 110 feet and an average lake water level elevation of 1156.4 (MPCA, 2015d). The lake's use classification is 2B, 3C; and the overall condition is described as "suitable for swimming and wading, with good clarity and low algae levels throughout the open water season" (MPCA, 2015d).

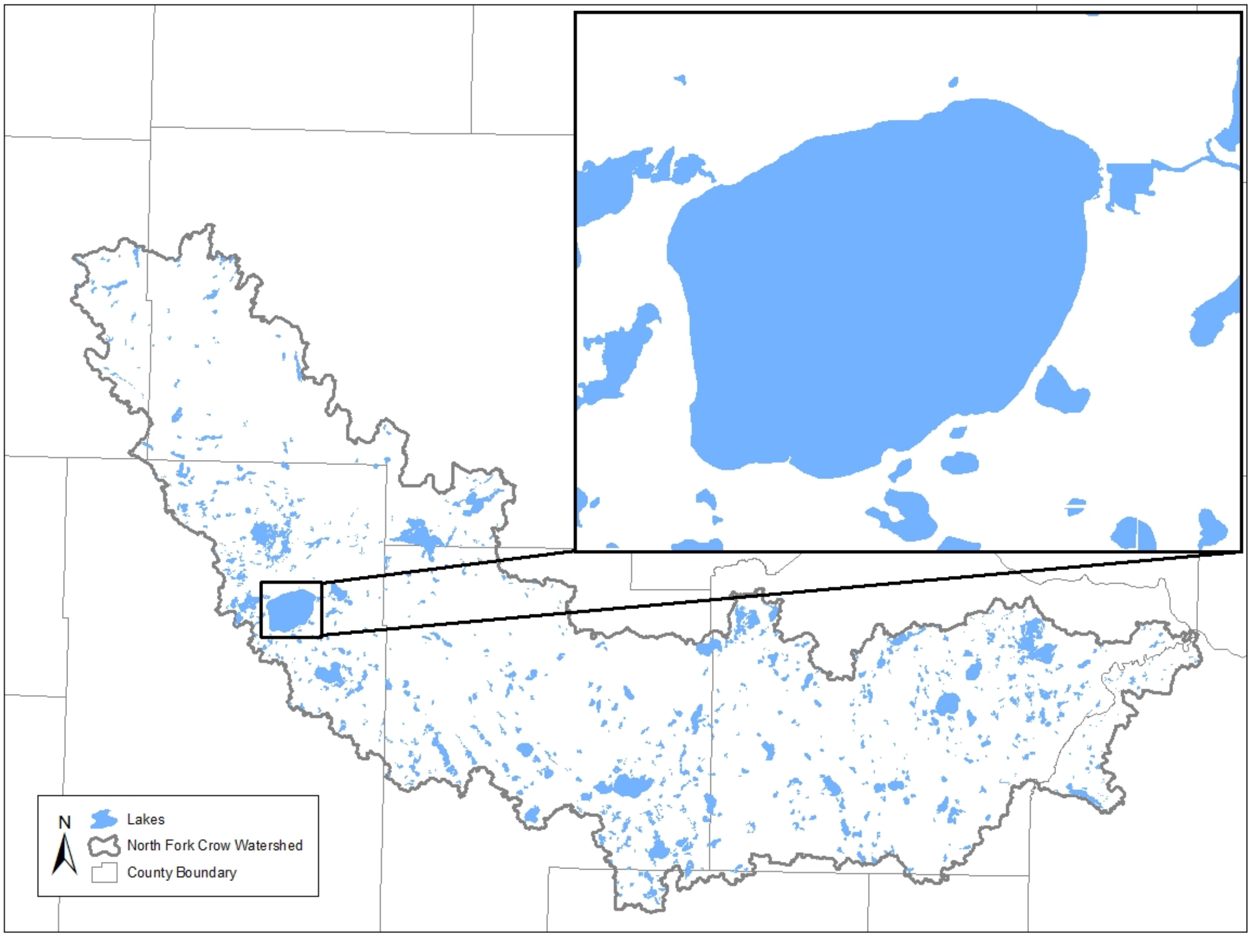

Figure 19: Green Lake within North Fork Crow River Watershed

A 2014 survey by the MDNR determined that the lake had low water clarity (average 9.7 feet). Runoff into the lake is contributed from the heavily developed shoreline (690 homes), the city of Spicer (residential, highways), and agricultural runoff from row crops from the Middle Fork Crow River, the largest inlet into Green Lake (MDNR, 2015d). Although there are seasonal fluctuations throughout the year, lake level elevation has remained relatively constant during the last 20 years (no statistical trend) (Figure 20).

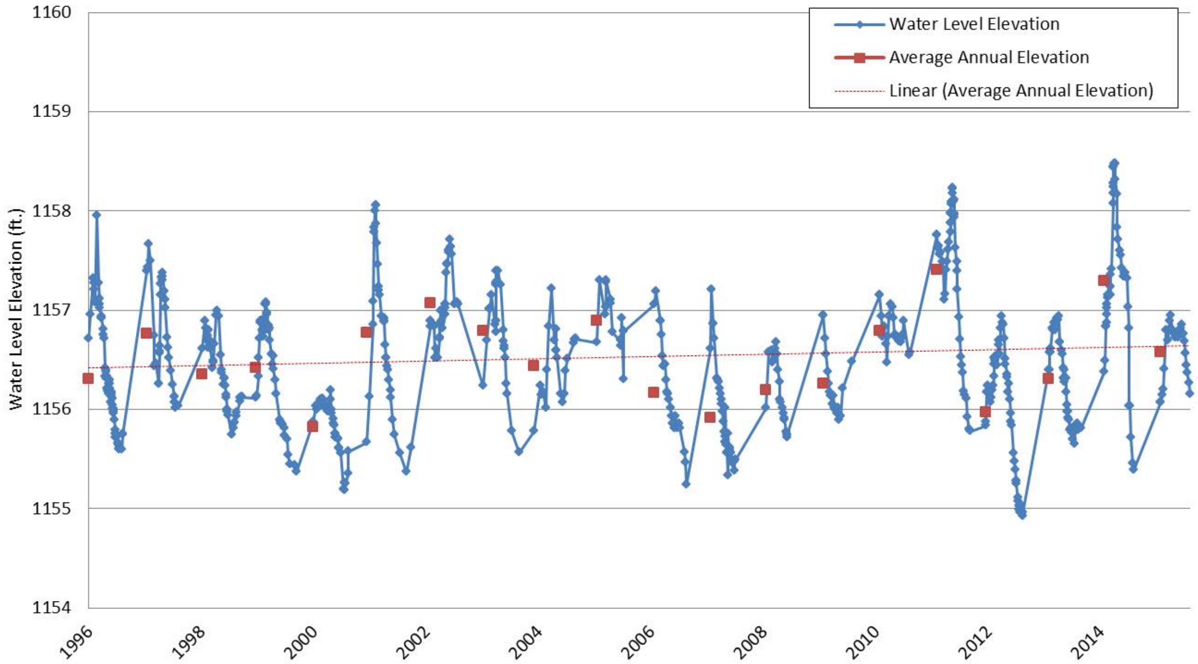

Figure 20: Green Lake water level elevations (1996-2015)

IV. Hydrogeology

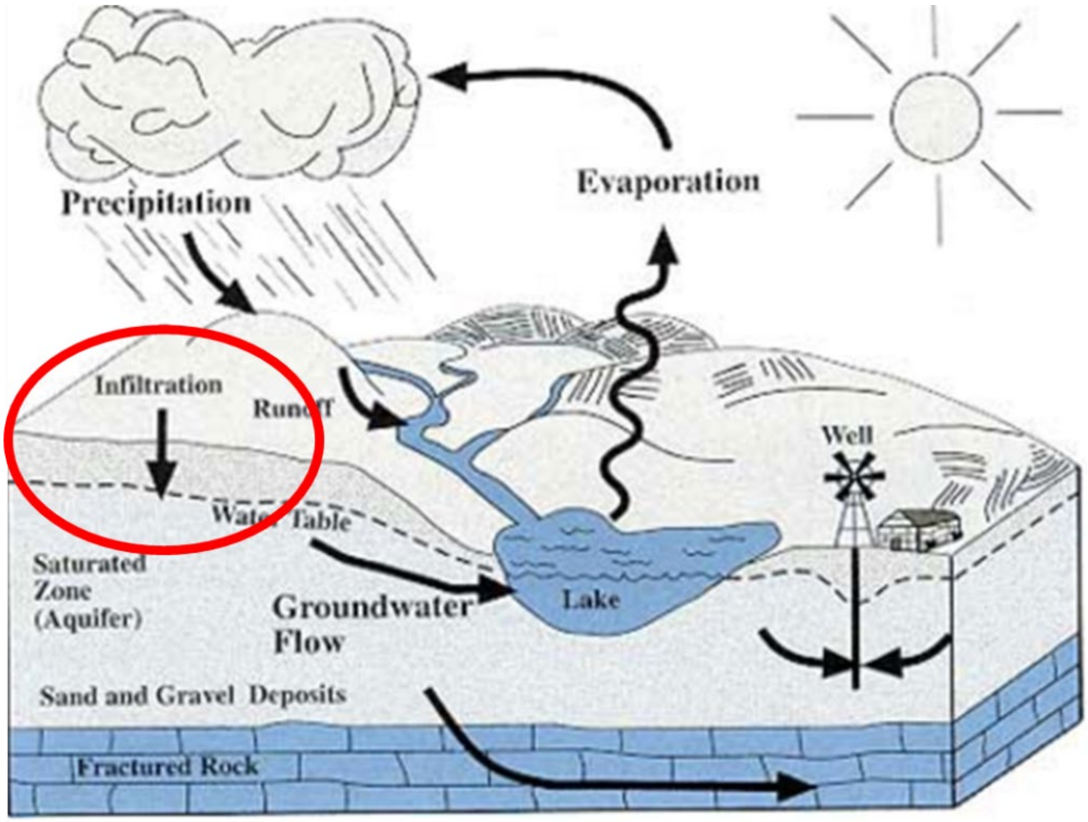

Figure 21: Groundwater within the hydrologic cycle

Hydrogeology is the study of the interaction, distribution and movement of groundwater through the rocks and soil of the earth. The geology of a region strongly influences the quantity of groundwater available, the quality of the water, the sensitivity of the water to pollution and how quickly the water will be able to recharge and replenish the source aquifer. This branch of geology is important to understand as it indicates how to manage groundwater withdrawal and land use and can determine if mitigation is necessary.

Surficial and bedrock geology

The MDNR and Minnesota Geological Survey (MGS) have collaborated to develop the County Geologic Atlas Program, with the purpose of eventually developing maps and reports of the geology and hydrogeology for all the counties in Minnesota. Each completed county atlas consists of a Part A (geology by MGS) and Part B (hydrogeology by MDNR). For the NFCRW, Part A is complete for Pope, Stearns, Meeker, Wright, Hennepin, Carver, and McLeod counties and Part B is complete for Pope, Stearns, Hennepin, McLeod, and Carver counties. Due to the small fraction of the watershed within McLeod, Hennepin, and Carver counties, the Stearns (southwest corner), Pope (eastern edge), Meeker, and Wright County atlases were primarily used for this report (Figure 22). For more information on the County Geologic Atlases available, please visit: http://www.dnr.state.mn.us/waters/groundwater_section/mapping/index.html.

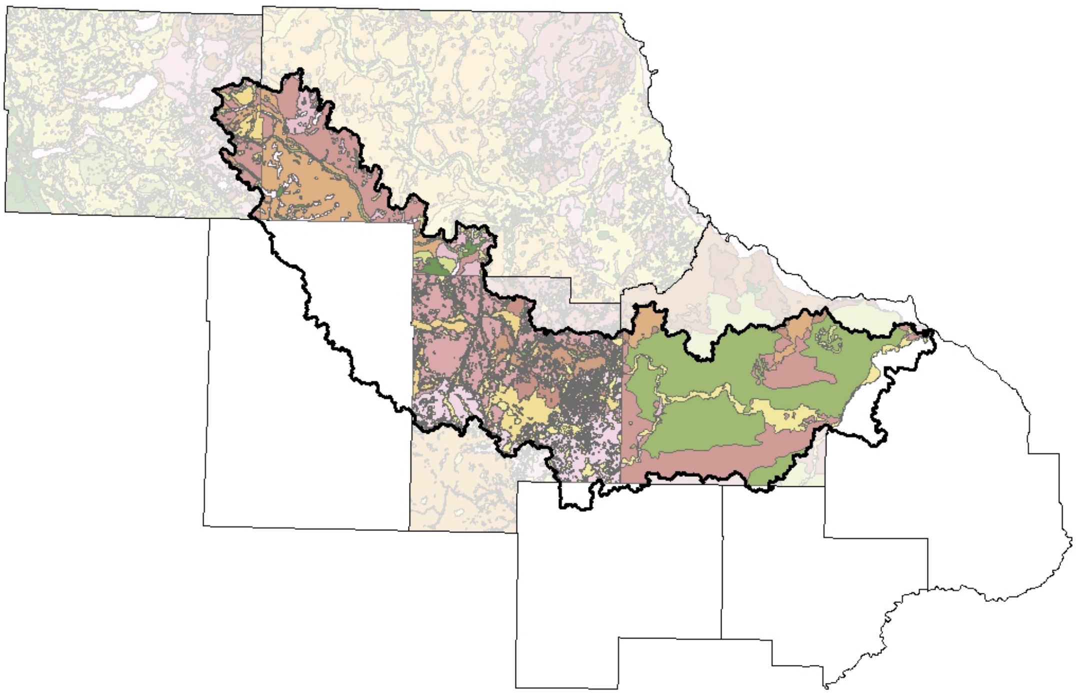

Figure 22: Geologic county atlases, Part A surficial geology for available North Fork Crow River Watershed counties

Surficial geology is identified as the earth material located below the topsoil and overlying the bedrock. Glacial sediment is at the surface in much of the NFCRW and is the parent material for the soils that have developed since glaciation. The depth to bedrock ranges from 18 to 675 feet and is buried by deposits of the various ice lobes that reached this watershed during the last glacial period (Wadena, Rainy, and Des Moines lobes), as well as during previous glaciations in the last 2.58 million years. The majority of glacial sediment at the surface is associated with the Des Moines Lobe. Also at the surface are generally thin postglacial sediments which consist primarily of alluvium and peat, but also include lake silt and clay, lake sand, muck or bogs, and Aeolian sand.

Quaternary deposits in this watershed can be divided into two time periods: the Pleistocene Epoch (2 Ma to 10 ky) and the Holocene Epoch (10 ky to present). The Wisconsinan Episode occurred during the Pleistocene Epoch, which includes a number of different formations (basic rock units) over the watershed. The glacial sediments can be grouped by material texture: 1) sand and gravel deposited by flowing meltwater, 2) clay, silt, and fine-grained sand deposited in still water of a glacial lake, and 3) an unsorted mixture deposited by ice (till).

The till in the area is typically calcareous and has a loamy to sandy loam matrix texture (nearly equal parts sand, silt and clay), with larger clasts suspended in the matrix (pebbles to boulders). Minor units include ice-contact stratified deposits, modified till and other tills (loamy till; sandy till; washed till; loam to sandy loam textured), coarser stream sediment (sand, gravelly sand, and cobbly gravel), fine offshore and slightly coarser nearshore lake sediment, and deltaic sediment. See the respective atlases for a complete legend of units (Meyer, 2015; Harris & Knaeble, 2003; Meyer & Knaeble, 1995; Hobbs, 2013).

Bedrock is the main mass of rocks that form the Earth, located underneath the surficial geology and can only be seen in only a few places where weathering has exposed the bedrock. The bedrock geology of the North Fork Crow Watershed region includes Precambrian and Paleozoic sedimentary rocks in the lower watershed, Cretaceous rocks in the central region, and Precambrian crystalline rocks in the upper watershed (Figure 23) (USDA, NRCS). The uppermost bedrock is the cretaceous bedrock, which is described as sandstone layers interbedded with thick layers of shales and are often used as the local water source (MDNR, 2001). The cretaceous bedrock includes the Dakota Formation, comprised of interbedded sandstone, siltstone and mudstone, undifferentiated rocks, red-brown to pale olive mudstone and siltstone with interbedded yellow gray, very fine to medium-grained sandstone, or undivided rocks, which are poorly lithified rocks with sandstone, siltstone, shale and sometimes marl (Boerboom, Setterholm & Chandler, 1995; Steenberg & Chandler, 2013; Chandler & Steenberg, 2015). The Paleozoic bedrock consists of the Wonewoc, Eau Claire and Mount Simon Sandstones (sandstone, siltstone and shale), the Decorah, Platteville, Glenwood, and St. Peter (shale, limestone and sandstone), the Jordan, St. Lawrence and Tunnel City Group (siltstone, shale and dolostone), and the Prairie du Chien Group (dolostone and sandstone). The Precambrian bedrock covers the extent of the watershed, displaying evidence of volcanic activity. The main terrane groups include east-central Minnesota batholith (gabbro or granite), Minnesota River Valley subprovince (granitic orthogneiss and migmatite, amphibolitic to dioritic gneiss), Little Falls Formation (greywacke, mudstone, and schist and slate), North, South Range and Mille Lacs Group (mafic metavolcanic and hypabyssal intrusive rocks, argillite, slate, graywacke), and Hinckley, Fond du Lac, Solar Church (sandstone, siltstone, conglomerate). Mafic intrusion with pyroxenite, peridotite, gabbro and lamprophyre are also prevalent throughout the watershed.

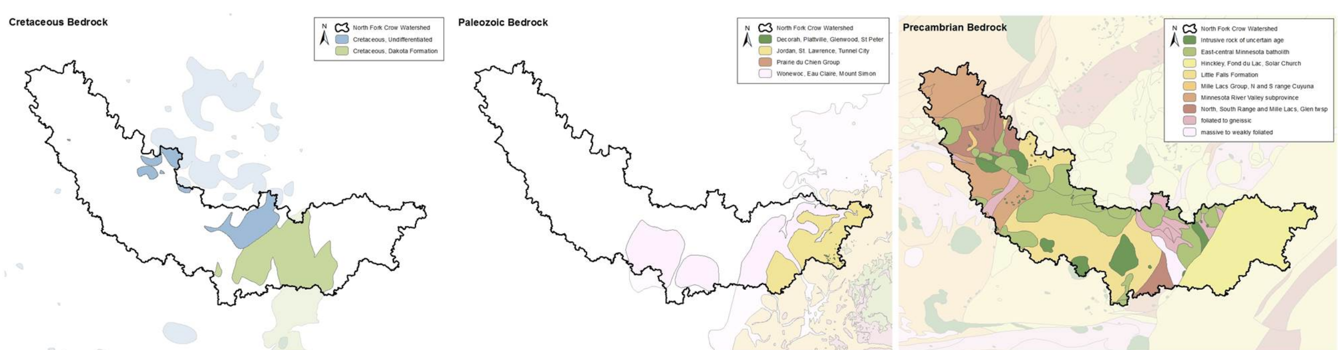

Figure 23: Bedrock geology of the North Fork Crow River Watershed: Cretaceous, Paleozoic and Precambrian (GIS Source: MGS, 2011)

Groundwater provinces

The NFCRW falls within two of Minnesota's six groundwater provinces: the Central and Metro Provinces (Figure 24). The majority of the watershed lies within the Central Province which is characterized by "sand aquifers in generally thick sandy and clayey glacial drift overlying Precambrian and Cretaceous bedrock" (MDNR, 2001). The eastern portion of the watershed is within the Metro Province which is characterized by "sand aquifers in generally thick (greater than 100 feet) sandy and clayey glacial drift overlying Precambrian sandstone and Paleozoic sandstone, limestone, and dolostone aquifers" (MDNR, 2001).

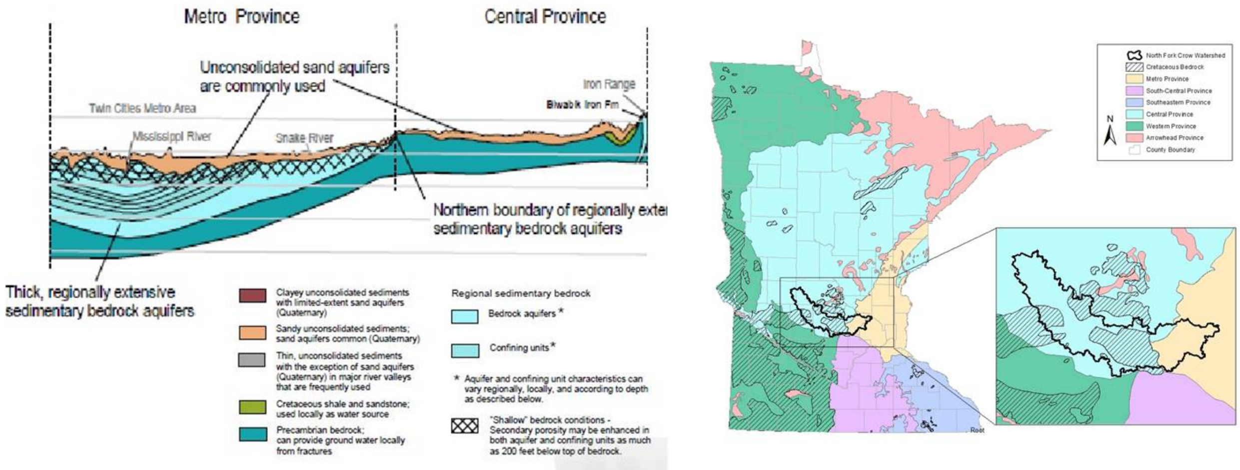

Figure 24: Metro and Central Province generalized cross section (Source: MDNR, 2001)

Aquifers

Groundwater aquifers are layers of water-bearing rocks that readily transmit water to wells and springs (USGS, 2015a). As precipitation hits the surface, it infiltrates through the soil zone and into the void spaces within the geologic materials underneath the surface, saturating the material and becoming groundwater (Zhang, 1998). The water table is the uppermost portion of the saturated zone, where the pore-water pressure is equal to local atmospheric pressure. The geologic material determines the permeability and availability of water within the aquifer. Sand and gravel materials are considered highly permeable and are utilized as aquifers, while till layers are less permeable and are considered confining units.

Minnesota's groundwater system is comprised of three types of aquifers: 1) igneous and metamorphic bedrock aquifers, 2) sedimentary rock aquifers, and 3) glacial sand and gravel aquifers (Figure 25). The first group, igneous and metamorphic rock aquifers, is restricted to water available within the fractures of the rock and typically holds limited quantities of water (MPCA, 2005). These aquifers are utilized only when the other two groups are not available, such as in northeastern Minnesota. The second group, sedimentary rock aquifers, consists of sandstone, limestone and shale, which occur primarily in southern and extreme western Minnesota (MPCA, 2005). This type of aquifer contains large quantities of groundwater due to fractures, higher porosity and weathering capabilities of the rocks. The third group is the glacial sand and gravel aquifers. These are shallow aquifers that occur as a result of glacial influences and are found in outwash plains, along river and in old lake beds throughout the state (MPCA, 2005). Also included in this group are deeper, buried glacial aquifers that cover the entire state, except the Arrowhead region and some areas in central and southwest Minnesota (MPCA, 2005). These aquifers are highly utilized since they contain large and useable quantities of groundwater due to high porosity and permeability and are also less expensive to drill.

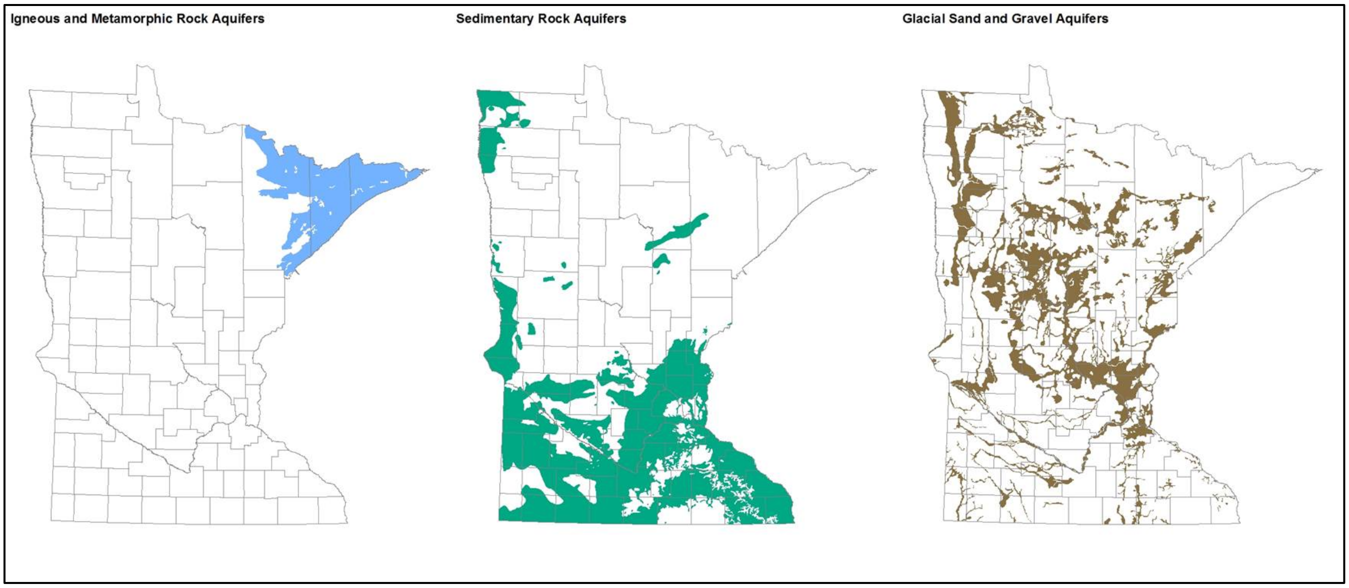

Figure 25: Minnesota's three basic types of aquifers (MPCA, 2005)

The Central Province contains four types of aquifers: surficial and buried aquifers, Cretaceous bedrock, Precambrian bedrock and Biwabik Iron Formation. The Metro Province contains surficial and buried aquifers, the St. Peter Aquifer, Prairie du Chien-Jordan, Franconia Ironton-Galesville and Mt. Simon-Hinckley aquifers. The buried sand and gravel aquifers include the Quaternary Buried Artesian Aquifer (QBAA), the Quaternary Buried Unconfined Aquifer (QBUA), and the Quaternary Buried Undifferentiated Aquifer (QBUU). It is from these aquifers that the majority of wells in this region of Minnesota yield the greatest amount of groundwater (MPCA, 1998). Other important sources of groundwater are the surficial sand and gravel aquifers, which consist of well-sorted outwash deposits left behind from the Des Moines Lobe. Two main aquifers included in this category are the Quaternary Water Table Aquifer (QWTA) and the Quaternary Undifferentiated Unconfined Aquifer. For the NFCRW, the QBAA and QWTA aquifers are the primary sources for groundwater withdrawal.

Groundwater pollution sensitivity

When defining and discussing groundwater pollution sensitivity, refer to the MDNR website: http://www.dnr.state.mn.us/waters/groundwater_section/mapping/sensitivity.html.

> "The DNR defines an area as sensitive if natural geologic factors create a significant risk of groundwater degradation through the migration of waterborne contaminants. Migration of contaminants dissolved in water through unsaturated and saturated sediments is affected by many things, including biological degradation, oxidizing or reducing condition and contaminant density. General assumptions include: contaminants move conservatively with water; flow paths are vertical; and permeability of the sediment is the controlling factor.
>
> The pollution sensitivity of buried sand and gravel aquifers and of the first buried bedrock surface represents the approximate time it takes for water to move from land surface to the target (residence time). Groundwater chemistry is used to support hypotheses relating geologic factors to travel time. Dye traces, naturally occurring chemicals, and other human-introduced chemicals are used to date groundwater and better understand flow paths and residence times" (MDNR, 2015e).

Since bedrock aquifers are typically covered with thick till, they are normally better protected from contaminant releases at the land surface. It is also less likely that withdrawals from these wells would have a direct and significant impact on local surface water bodies. In contrast, surficial aquifers are typically more likely to 1) be vulnerable to contamination, 2) have direct hydrologic connections to local surface water, and 3) influence the quality and quantity of local surface water. The MDNR is currently working on a hydrogeological atlas focused on the pollution sensitivity of the bedrock surface. It is being produced county-by-county and is not completed for the NFCRW at this time. Until the hydrogeological atlas is finished, a 1989 statewide evaluation of groundwater contamination susceptibility completed by the MPCA is utilized to determine aquifer pollution vulnerability. This display is not intended to be used on a local scale, but as a regional-scale screening tool. According to this data, the NFCRW is estimated to have primarily medium level contamination susceptibility (Figure 26) (Porcher, 1989).

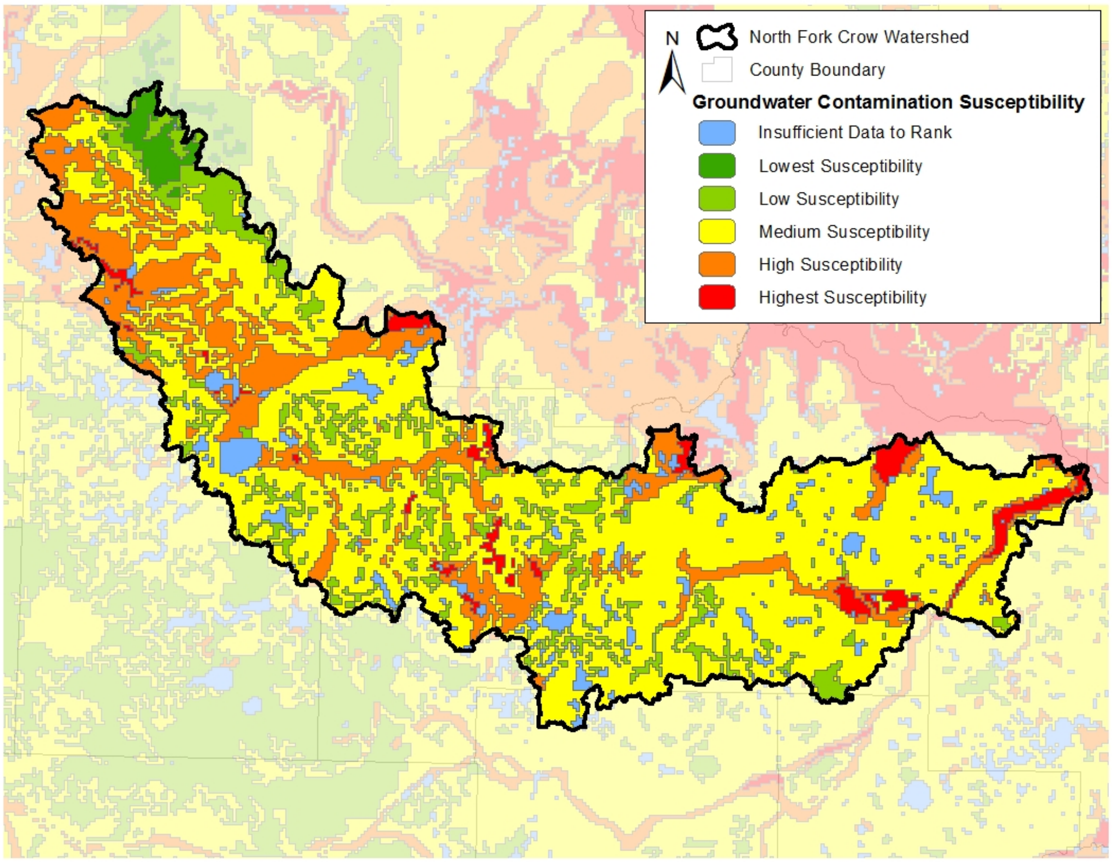

Figure 26: Groundwater contamination susceptibility for the North Fork Crow River Watershed (GIS Source: MPCA, 1989)

Groundwater potential recharge

Groundwater recharge is one of the most important parameters in the calculation of water budgets, which are used in general hydrologic assessments, aquifer recharge studies, groundwater models, and water quality protection. Recharge is a highly variable parameter, both spatially and temporally, making accurate estimates at a regional scale difficult to produce. The MPCA contracted the USGS to develop a statewide estimate of recharge using the SWB – Soil-Water-Balance Code. The result is a gridded data structure of spatially distributed recharge estimates that can be easily integrated into regional groundwater studies. The full report of the project as well as the gridded data files are available at: https://gisdata.mn.gov/dataset/geos-gw-recharge-1996-2010-mean

Recharge of these aquifers is important and limited to areas located at topographic highs, those with surficial sand and gravel deposits, and those along the bedrock-surficial deposit interface (Figure 27). Typically, recharge rates in unconfined aquifers are estimated at 20 to 25% of precipitation received, but can be less than 10% of precipitation where glacial clays or till are present (USGS, 2007). For NFCRW, the average annual potential recharge rate to surficial materials ranges from 1.3 to 10.5 inches per year, with an average of 5.5 inches per year (Figure 28). The statewide average potential recharge is estimated to be 4 inches per year with 85% of all recharge ranging from 3 to 8 inches per year (Figure 29). When compared to the statewide average potential recharge, the NFCRW receives a higher average and range of potential recharge, mostly likely attributed to the variability of the surficial sediment distribution of the area.

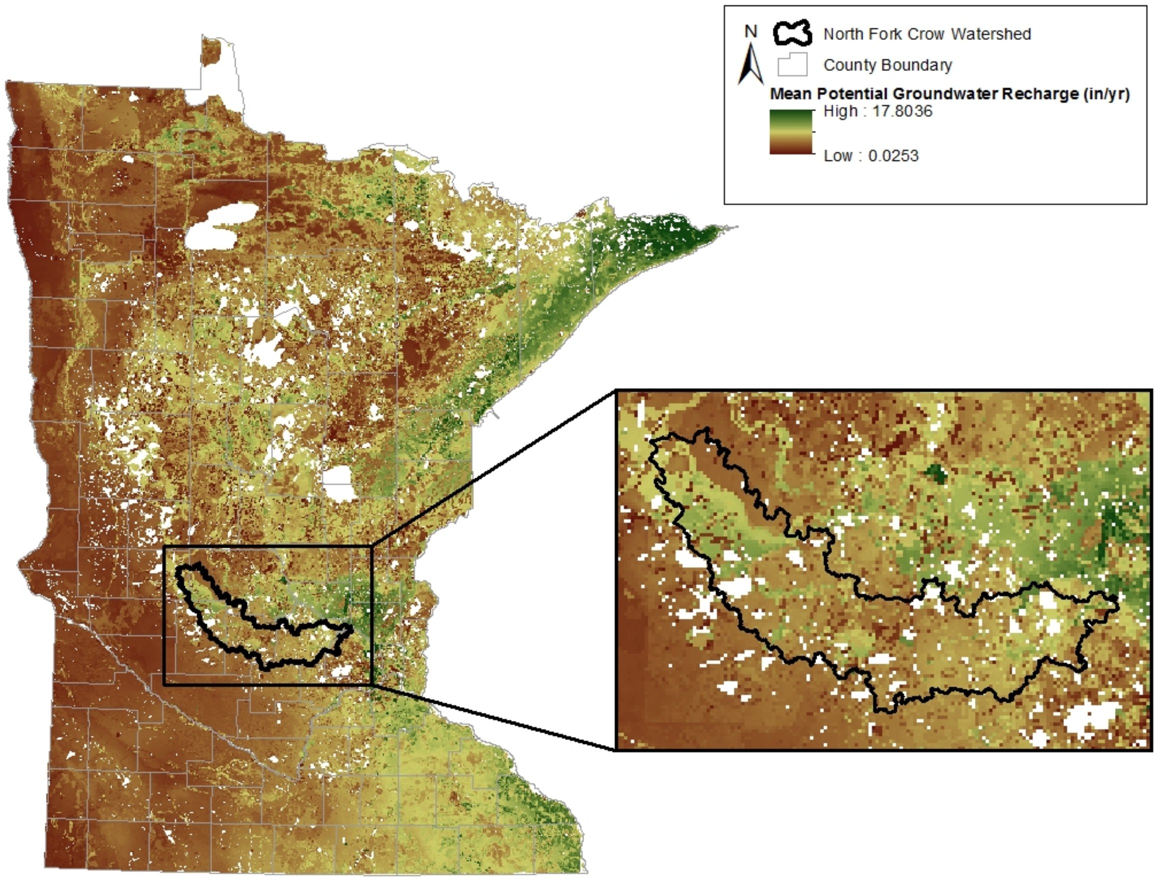

Figure 27: Average annual potential recharge rate to surficial materials in North Fork Crow River Watershed (1996-2010)

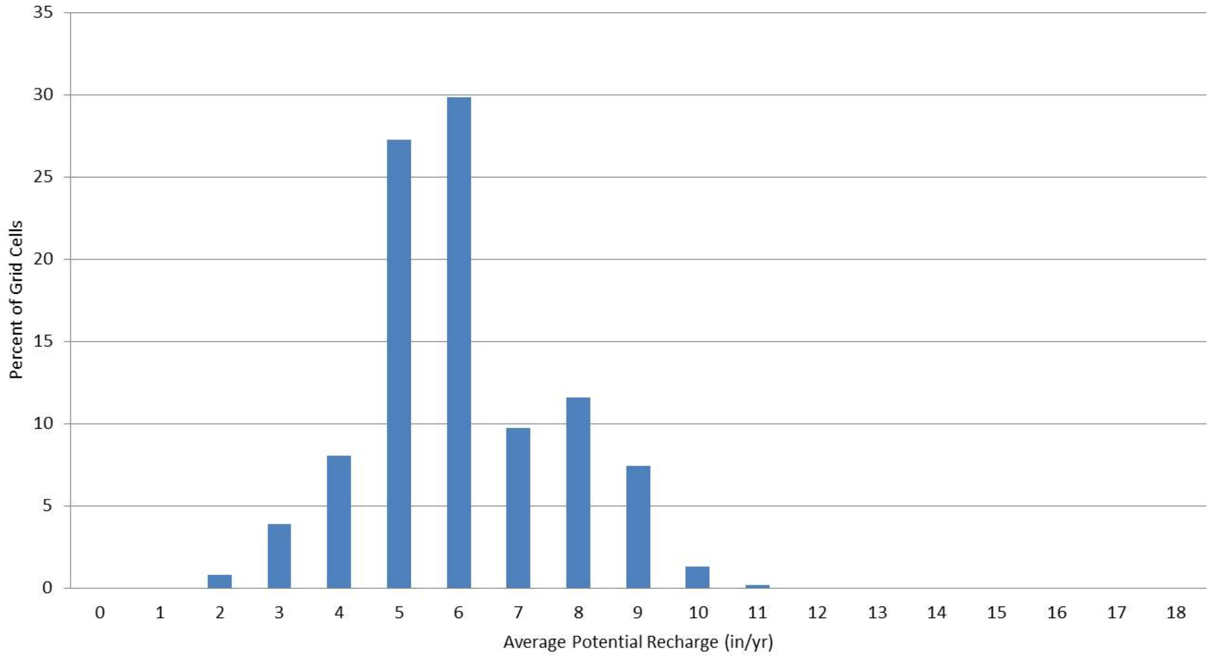

Figure 28: Average annual potential recharge rate percent of grid cells in the North Fork Crow River Watershed (1996-2010)

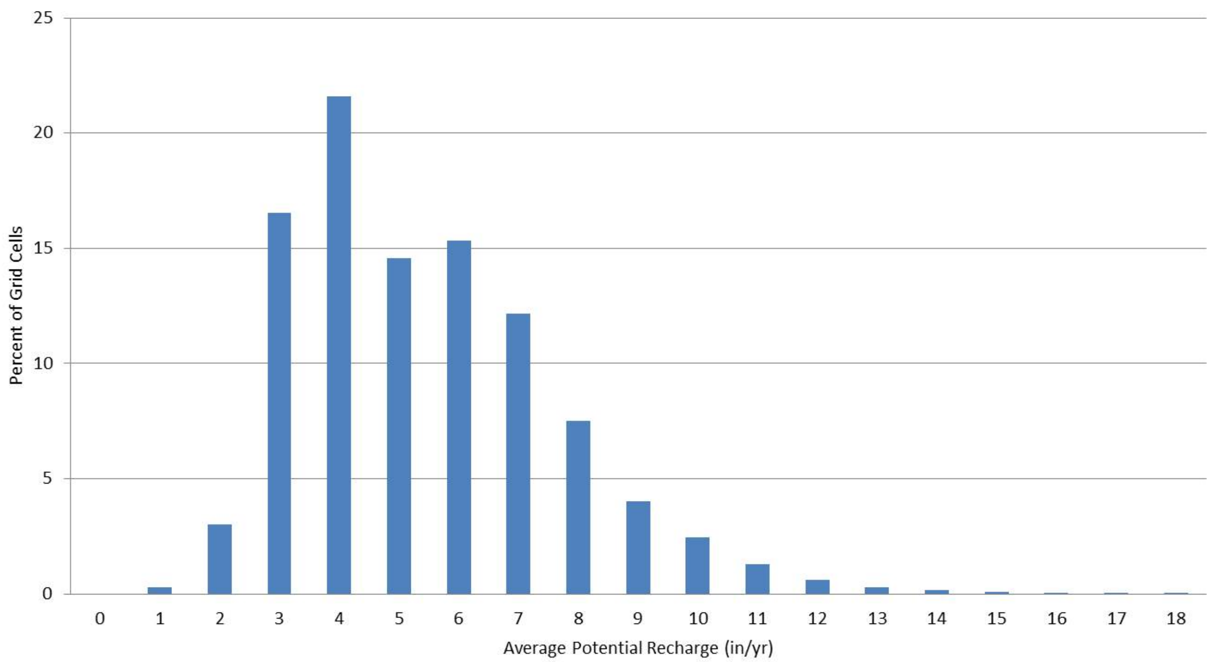

Figure 29: Average annual potential recharge rate percent of grid cells statewide (1996-2010)

V. Groundwater quality

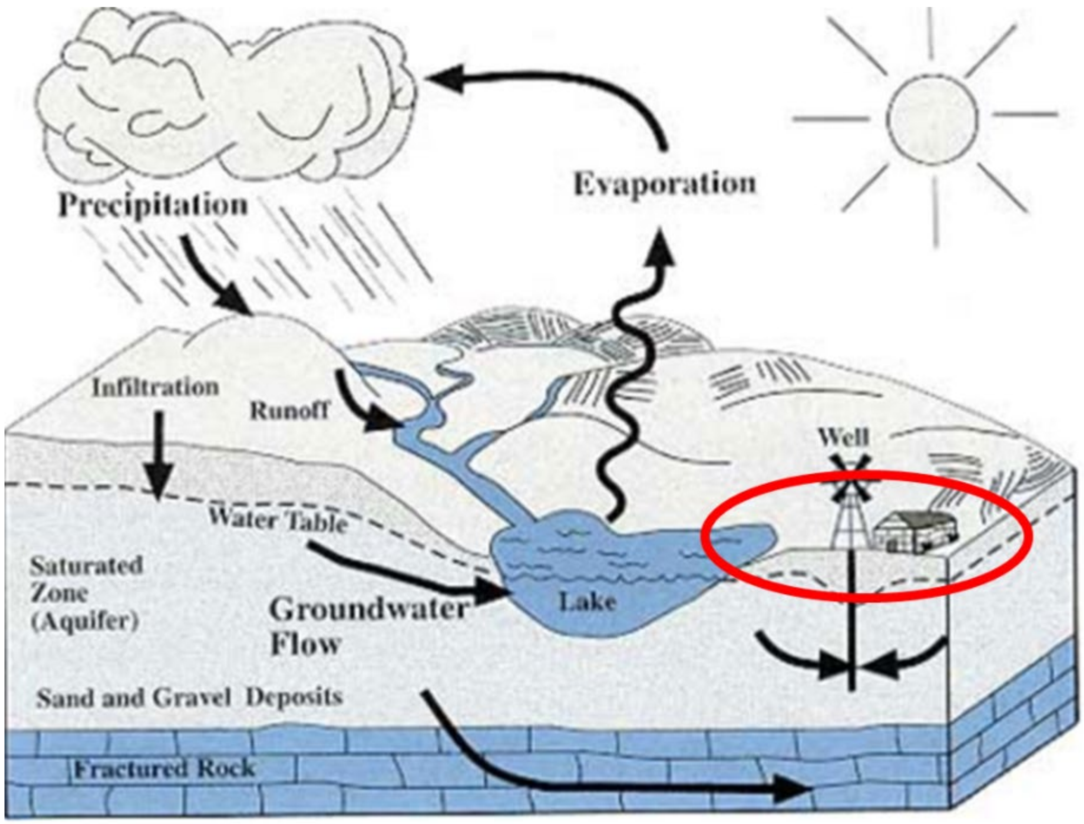

Figure 30: Groundwater quality within the hydrologic cycle

Ambient groundwater network

Approximately 75% of Minnesota's population receives their drinking water from groundwater, undoubtedly indicating that clean groundwater is essential to the health of its residents. The MPCA's Ambient Groundwater Monitoring Program monitors trends in statewide groundwater quality by sampling for a comprehensive suite of chemicals including nutrients, metals, and volatile organic compounds. These ambient wells represent a mix of deeper domestic wells and shallow monitoring wells. The shallow wells interact with surface waters and exhibit impacts from human activities more rapidly. Available data from federal, state, and local partners are used to supplement reviews of groundwater quality in the region.

There is currently one MPCA Ambient Groundwater Monitoring well (domestic) within the NFCRW. Figure 31 displays the locations of ambient groundwater wells within and around the specified watershed.

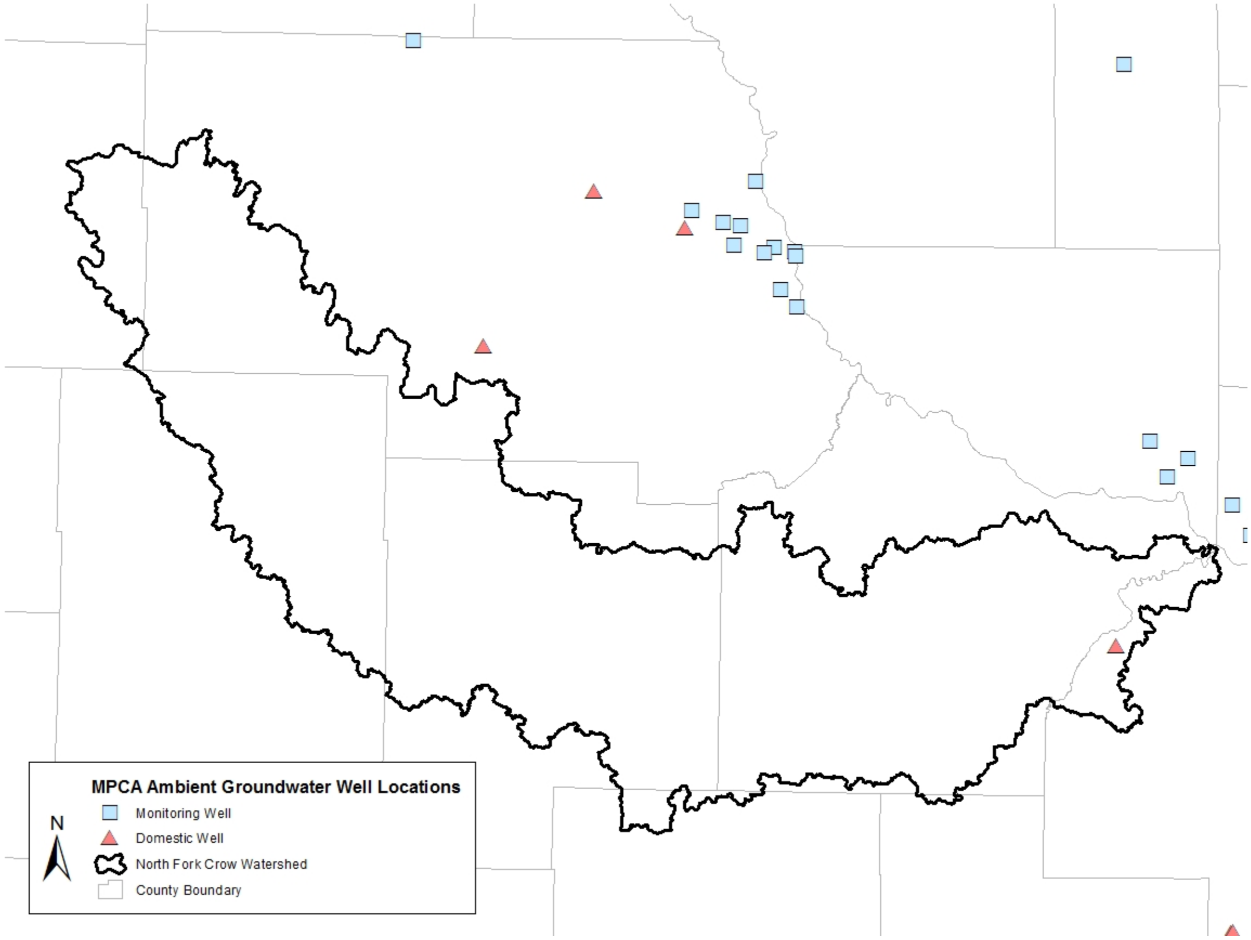

Figure 31: MPCA ambient groundwater monitoring well locations near the North Fork Crow River Watershed

Regional groundwater quality

From 1992 to 1996, the MPCA conducted baseline water quality sampling and analysis of Minnesota's principal aquifers based on dividing Minnesota into six hydrogeologic regions: Northwest, Northeast, Southwest, Southeast, North Central and Twin Cities Metropolitan Regions. The North Fork Crow lies primarily within the Southwest and North Central Hydrogeologic Regions. The baseline study determined that the groundwater quality in the Southwest Region is considered poor when compared to other areas with similar aquifers, with exceedances of drinking criteria in antimony, beryllium, boron, manganese, nitrate, vanadium and zinc (MPCA, 1998a). The groundwater quality in the North Central Region is considered very good, but identified exceedances in arsenic, beryllium, boron, manganese, nickel, nitrate, selenium, thallium and vanadium (MPCA, 1998b). The exceedances identified were contributed to natural sources, such as geology, residence times and well construction. However, nitrate concentration was identified as the primary concern in both hydrogeologic regions, which is associated with anthropogenic sources. Volatile organic compounds were also detected in both regions with the most commonly detected compounds associated with fuel oils, gasoline and well disinfection (MPCA, 1998a; MPCA, 1998b).

The Minnesota Department of Agriculture (MDA) monitors pesticides and nitrate on an annual basis in groundwater across agricultural areas in the state. The MDA also separates the state into regions, which consist of 10 regional water quality monitoring networks that are referred to as Pesticide Monitoring

Regions (PMRs) The NFCRW lies within the regional water quality monitoring networks for Region 4 (PMR 4) and Region 8 (PMR 8). PMR 4 is also referred to as the Central Sands Region and PMR 8 is referred to as the South Central Region.

The Monitoring and Assessment Unit (MAU) of the MDA sampled 167 sites throughout Minnesota for pesticides in groundwater in 2014. Within the NFCRW, the MAU sampled sites in the northwestern area for the presence of pesticides (Figure 32). Although some wells detected up to five common detection pesticides or degradants, which include acetochlor, alachlor, atrazine, metolachlor and metribuzin, no detections exceeded drinking water standards for human consumption (MDA, 2015).

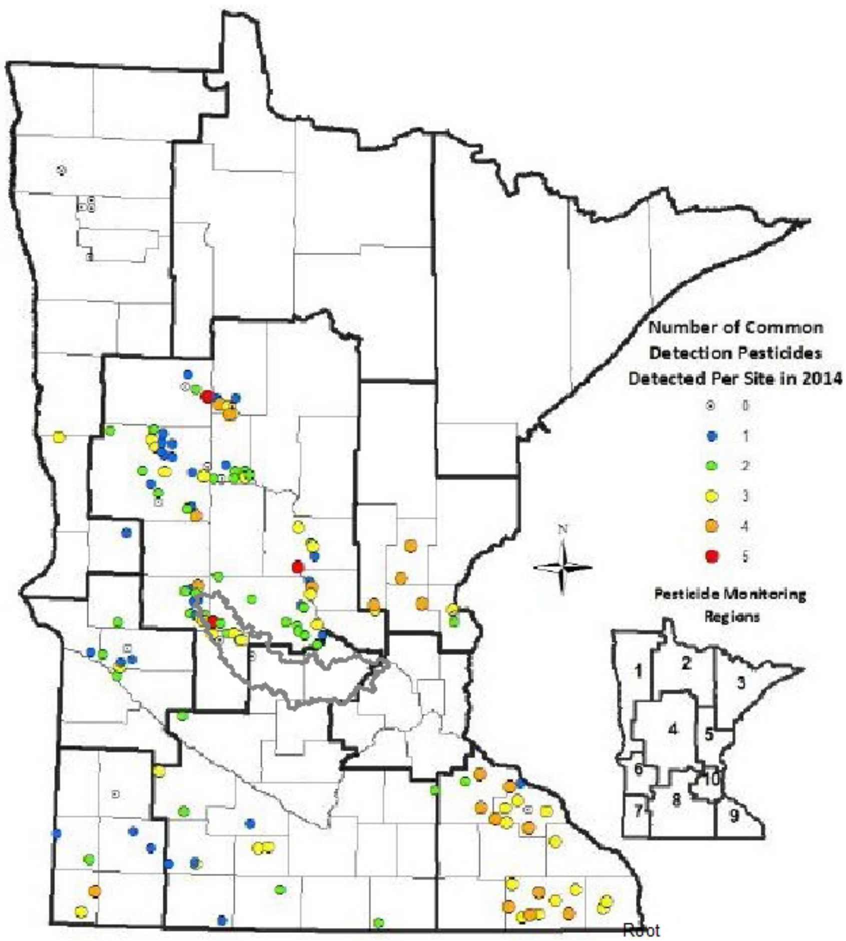

Figure 32: Pesticide detections within the North Fork Crow River Watershed (Source: MDA, 2015)

Although there are limited sampling sites specifically within the watershed, both PMRs displayed high levels of nitrogen-nitrate detections. The 2014 Water Quality Monitoring Report determined that nitrate-nitrogen was detected in 97% of the wells sampled in PMR 4 with a median concentration of 15.55 milligrams per liter (mg/L) (MDA, 2015). Of those samples, 14% were at or below background level of 3.00 mg/L, 23% were within 3.01 and 10.00 mg/L, and 59% were above drinking water standard of 10.00 mg/L (MDA, 2015). For PMR 8, nitrate-nitrogen was detected in 67% of samples with a median of 1.00 mg/L, 22% were at or below background level of 3.00 mg/L, 14% were within 3.01 and 10.00 mg/L, and 25% were above drinking water standard of 10.00 mg/L (MDA, 2015). Additionally, an MPCA report on the statewide condition of Minnesota's groundwater found that Central and Southwestern Regions have the greatest nitrate concentrations in the state, with approximately 20% of the shallow sand and gravel aquifer wells exceeding the maximum contaminant level (Kroening & Ferrey, 2013).

Another source of information on groundwater quality comes from the Minnesota Department of Health (MDH). Mandatory testing for arsenic, a naturally occurring but potentially harmful contaminant for humans, of all newly constructed wells has found that 10.7% of all wells installed from 2008 to 2015 have arsenic levels above the maximum contaminant level (MCL) for drinking water of 10 micrograms per liter (MDH, 2015). In the NFCRW, the majority of new wells are within the water quality standards for arsenic levels, but there are exceedances to the MCL. When observing concentrations of arsenic by percentage of wells that exceed the MCL of 10 micrograms/liter per county, the watershed lays within counties that range from 5 to greater than 20%. By county, the percentages of wells identified with concentrations exceeding the MCL are as follows: Pope (16.1%), Stearns (7.0%), Wright (19.7%), Hennepin (15.5%), Carver (23.0%), McLeod (37.9%), Meeker (29.6%), and Kandiyohi (29.1%) (Figure 33). For more information on arsenic in private wells, please refer to the MDH's website: http://www.health.state.mn.us/divs/eh/wells/waterquality/arsenic.html.

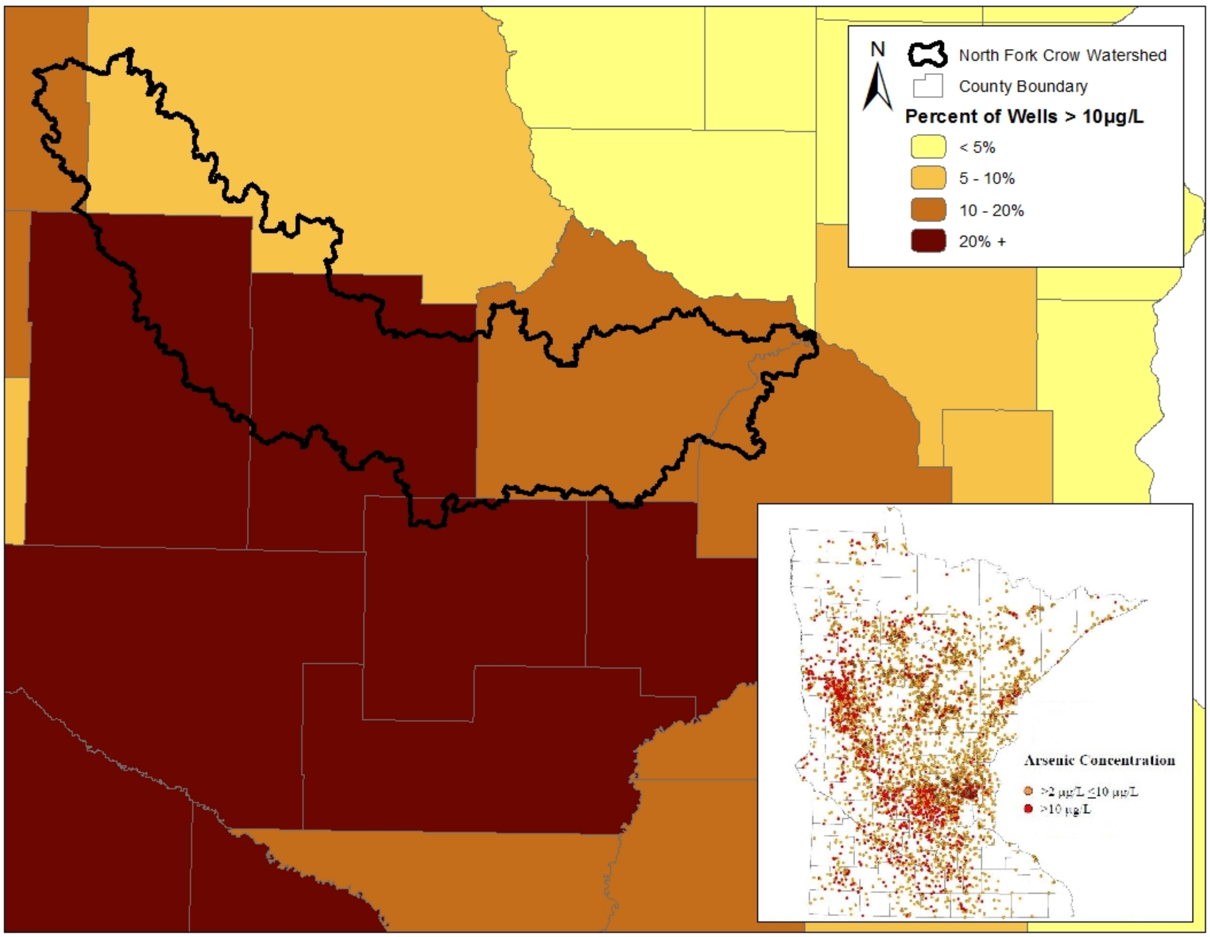

Figure 33: Percent wells with arsenic occurrence greater than the maximum contaminant level per county for the North Fork Crow River Watershed (2008-2015) (Source: MDH, 2014)

A statewide dataset of potentially contaminated sites and facilities with environmental permits and registrations is available at the MPCA's website, through a web-based application called, "What's In My Neighborhood" (WIMN). This MPCA resource provides the public with a method to access a wide variety of environmental information about communities across the state. The data is divided into two groups. The first is potentially contaminated sites, and includes contaminated properties, formerly contaminated sites, and those that are being investigated for suspicion of being contaminated. The second category is made up of businesses that have applied for and received different types of environmental permits and registrations from the MPCA. An example of an environmental permit would be for a business acquiring a permit for a stormwater or wastewater discharge, requiring it to operate within limits established by the MPCA. In the NFCRW, there are currently 5,079 sites identified by WIMN: 90 air quality sites, 1,339 feedlots sites, 1,104 hazardous waste sites, 157 investigation and cleanup sites, 32 solid waste sites, 961 tanks and leaks, and 1,396 water quality sites (Figure 34). For more information regarding WIMN, refer to the MPCA webpage at http://www.pca.state.mn.us/index.php/data/wimn-whats-in-my-neighborhood/whats-in-my-neighborhood.html.

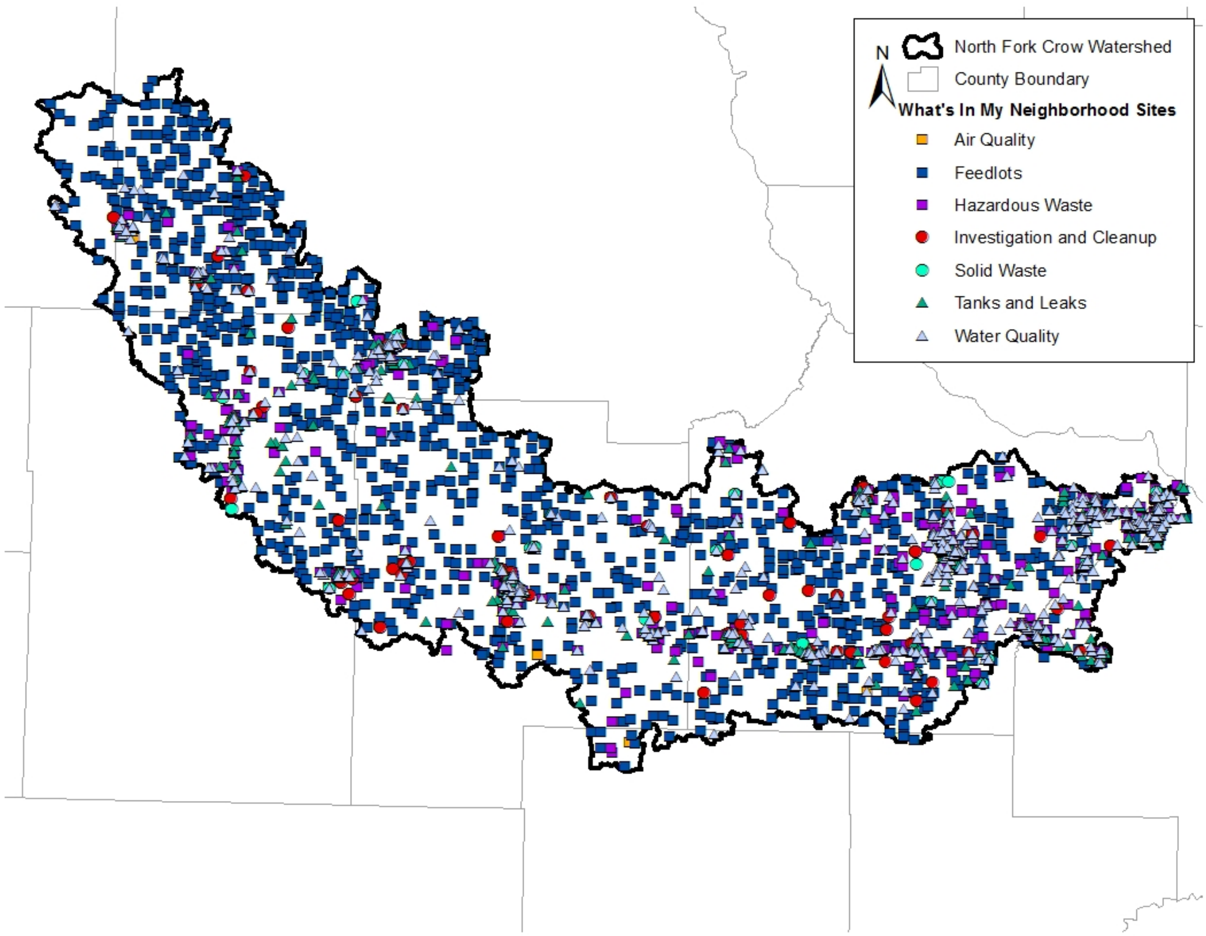

Figure 34: "What's In My Neighborhood" site programs and locations for the North Fork Crow River Watershed

VI. Groundwater quantity

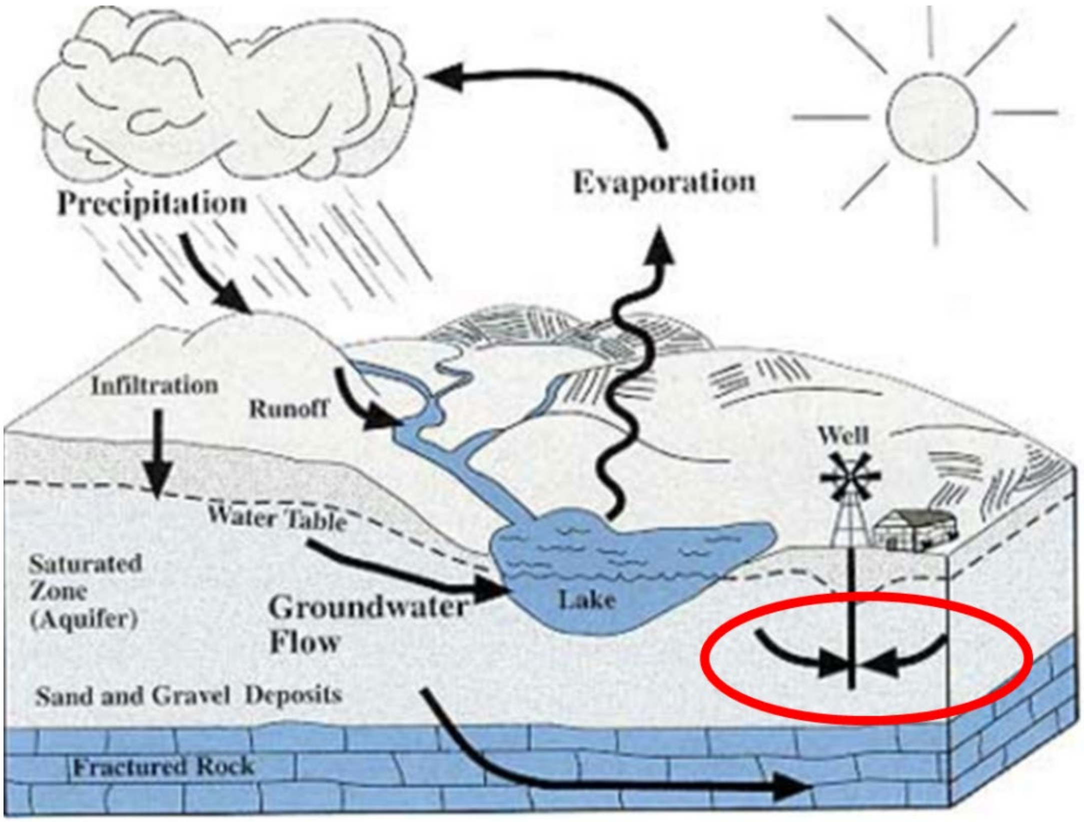

Figure 35: Groundwater quantity within the hydrologic cycle

Groundwater and surface water withdrawals

The MDNR permits all high capacity water withdrawals where the pumped volume exceeds 10,000 gallons per day or one million gallons per year. Permit holders are required to track water use and report back to the MDNR yearly. The changes in withdrawal volume detailed in this groundwater report are a representation of water use and demand in the watershed and are taken into consideration when the MDNR issues permits for water withdrawals. Other factors not discussed in this report but considered when issuing permits include: interactions between individual withdrawal locations, cumulative effects of withdrawals from individual aquifers, and potential interactions between aquifers. This holistic approach to water allocations is necessary to ensure the sustainability of Minnesota's groundwater resources.

The three largest permitted consumers of water in the state (in order) are power generation, public water supply (municipals), and irrigation (MDNR, 2015f). According to the most recent USGS site-specific water-use data system (SWUDS), in 2013 the withdrawals within the NFCRW are primarily utilized for agricultural irrigation (70.0%). The remaining withdrawals include: water supply (predominantly municipal) (17.9%), special categories including pollution containment, dust control, aquaculture and livestock watering (6.9%), non-crop irrigation (2.5%), industrial processing (1.9%), water level maintenance (0.7%), and heating and cooling purposes (0.09%) (Figure 36). From 1994 to 2013, withdrawals associated with non-crop irrigation and water supply have increased significantly (p=0.001), agricultural irrigation also increased (p=0.01), special categories and industrial processing have also increased statistically (p=0.05 and p=0.1, respectively). Water level maintenance has remained relatively constant over this time period. Heating and cooling has increased significantly over this time period (p=0.001), but due to the very minimal percentage of water withdrawn (0.09%), this is not considered substantial.

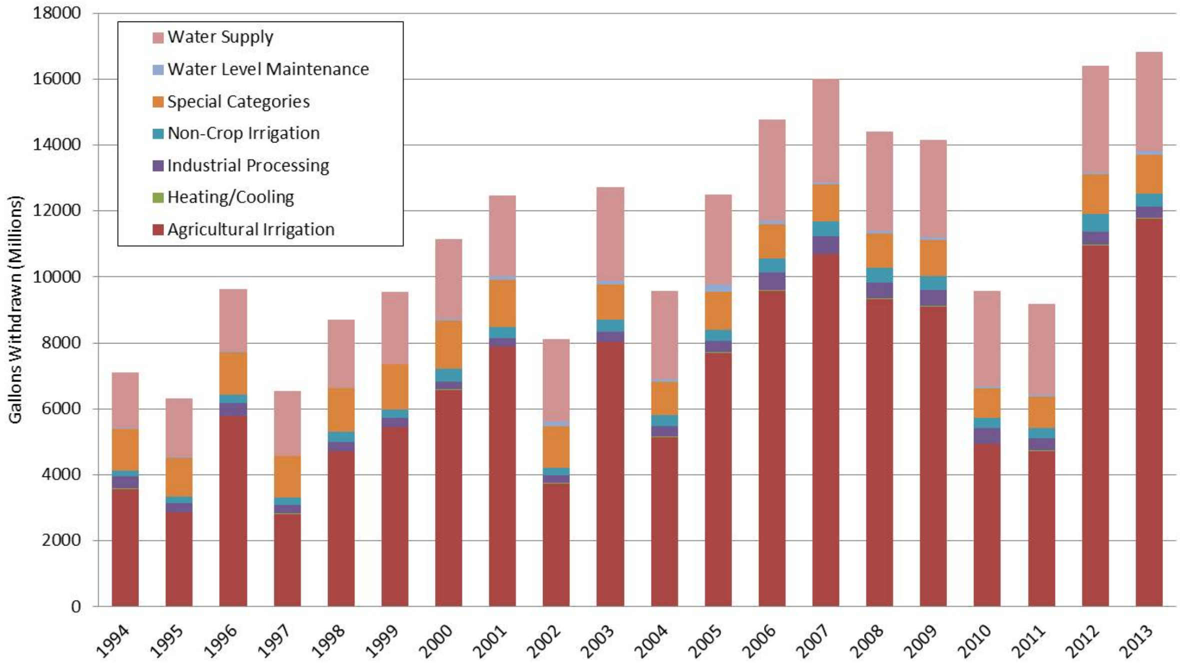

Figure 36: Groundwater and surface water permitted withdrawals by category for the North Fork Crow Watershed (1994-2013)

Figure 37 displays total high capacity withdrawal locations within the watershed with active permit status in 2013. Permitted groundwater withdrawals are displayed below as blue triangles and surface water withdrawals as red squares. During 1994 to 2013, groundwater withdrawals within the NFCRW exhibit a significant increasing withdrawal trend (p=0.001) (Figure 38), while surface water withdrawals are decreasing with a significant trend (p=0.01) (Figure 39). Water table (QWTA) withdrawals, which account for approximately 34.6% of all groundwater withdrawals, emulate the overall groundwater withdrawal trend with a statistically significant increase over time (p=0.01) (Figure 40).

The increase in groundwater withdrawals can be quantified further by the SWUDS data. In 1994, the number of active permits within the watershed for groundwater sources that reported withdrawal quantities was 409, pumping a reported amount of approximately 5.7 billion gallons of water. In 2013, the number of active permits for groundwater that reported withdrawal quantities was 755, withdrawing 15.6 billion gallons of water. For surface water withdrawals in 1994, the number of active permit holders was 20 and withdrew 690 million gallons, while in 2013, the number of active permit holders increased to 41, but the amount withdrawn decreased to 589 million gallons.

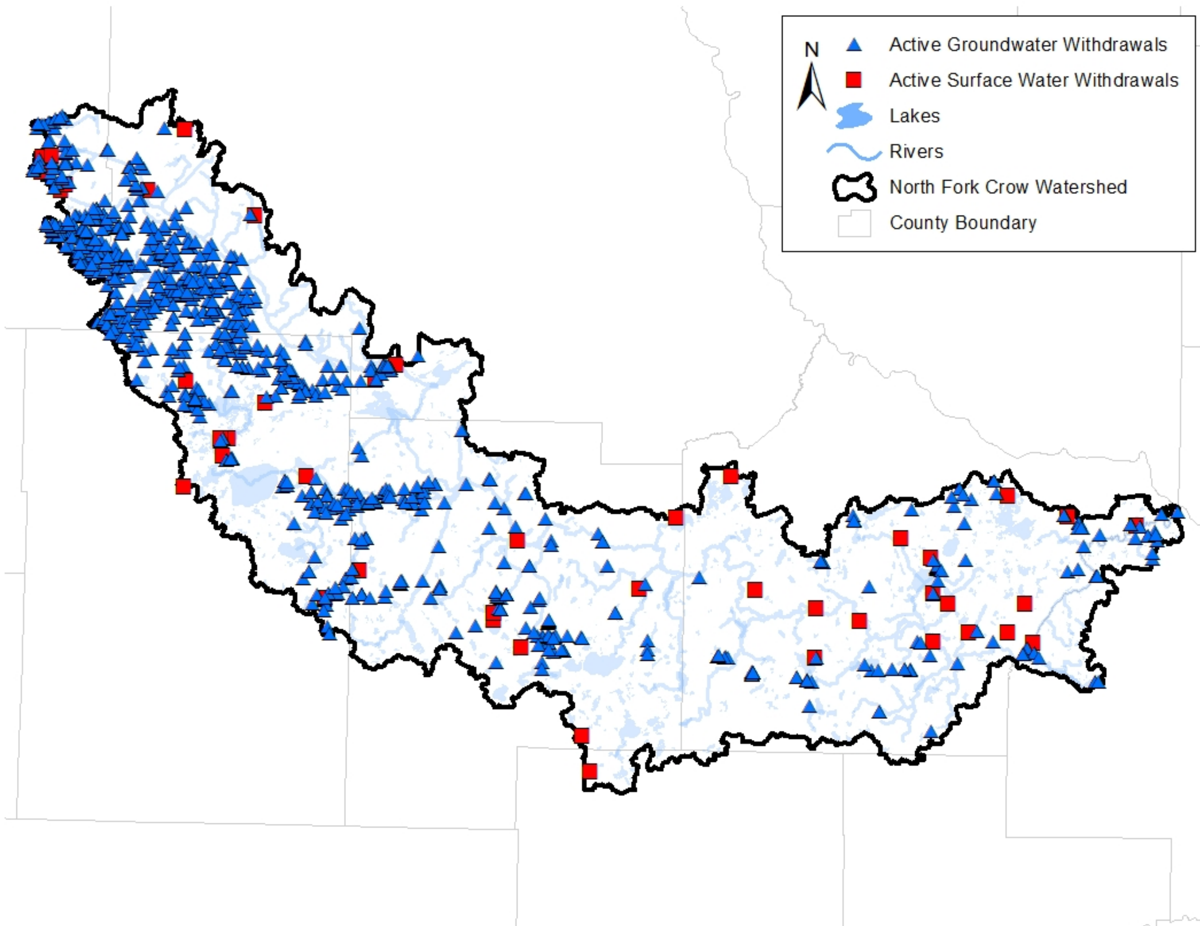

Figure 37: Locations of active status permitted high capacity withdrawals in 2013 within the North Fork Crow River Watershed

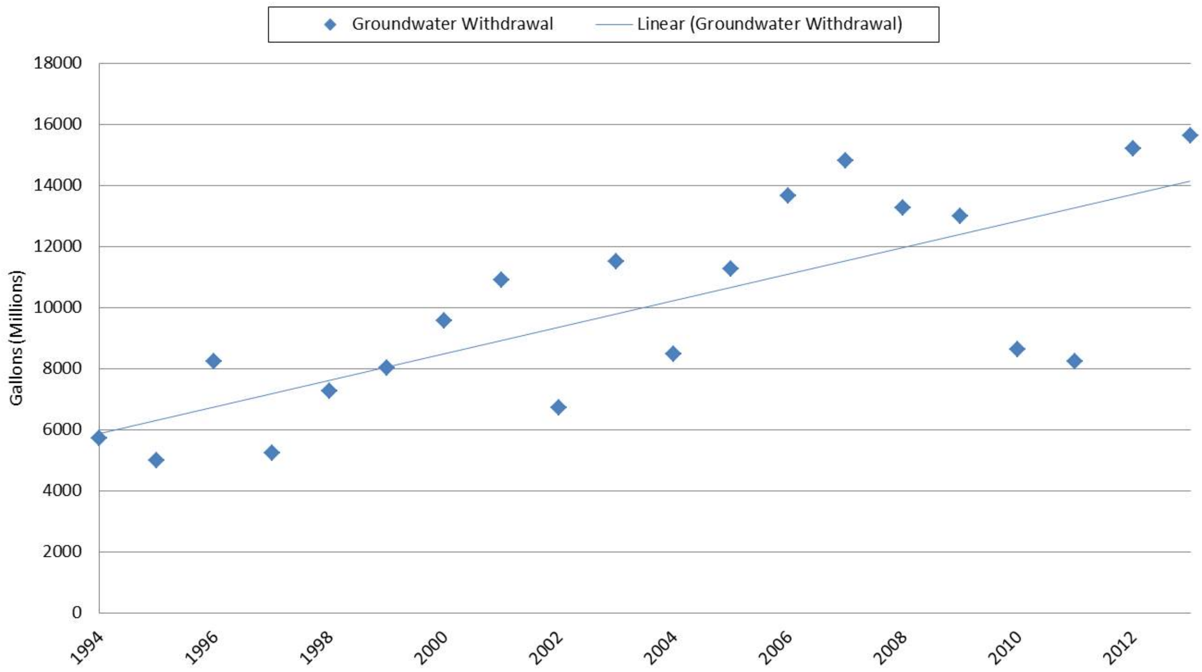

Figure 38: Total annual groundwater withdrawals in the North Fork Crow River Watershed (1994-2013)

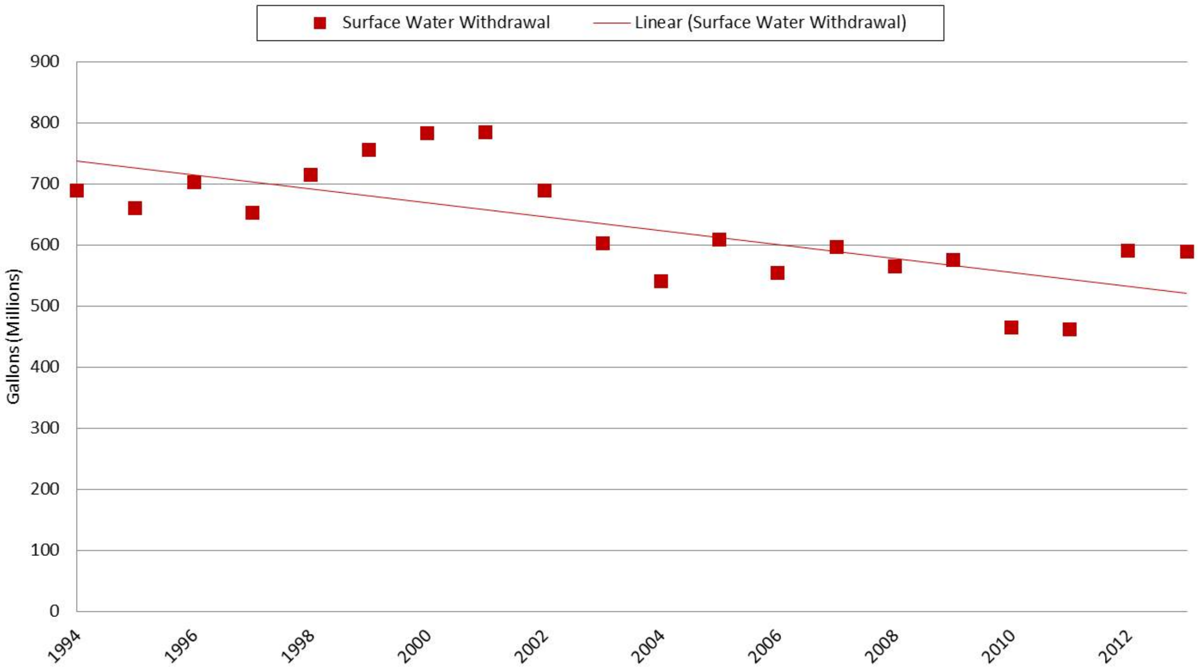

Figure 39: Total annual surface water withdrawals in the North Fork Crow River Watershed (1994-2013)

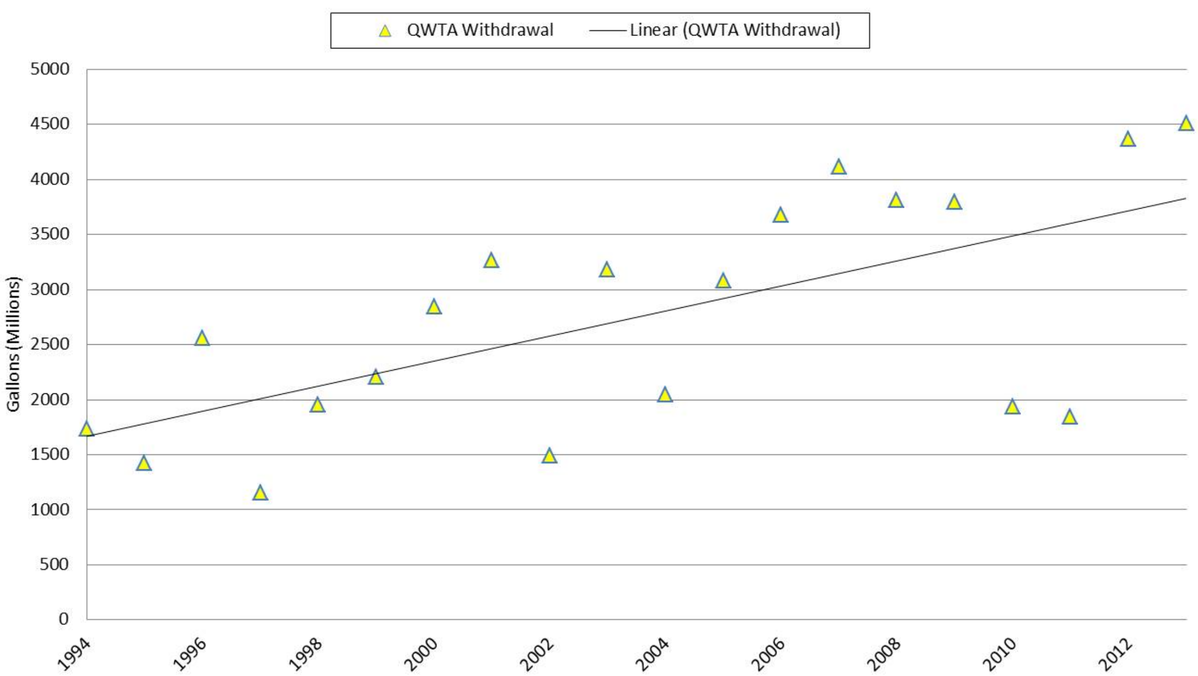

Figure 40: Total annual quaternary water table withdrawals in the North Fork Crow River Watershed (1994-2013)

MDNR observation wells

Monitoring wells from the MDNR Observation Well Network track the elevation of groundwater across the state. The elevation of groundwater is measured as depth to water in feet and reflects the fluctuation of the water table as it rises and falls with seasonal variations and anthropogenic influences. To access the MDNR Observation Well Network, please visit http://www.dnr.state.mn.us/waters/cgm/index.html.

Three MDNR Observation Wells (86003, 47000 and 34002) throughout the NFCRW were chosen based on data availability and geologic location within the watershed (Figure 41). Depth to Water (DTW) was collected on a monthly basis and the average annual DTW was calculated.

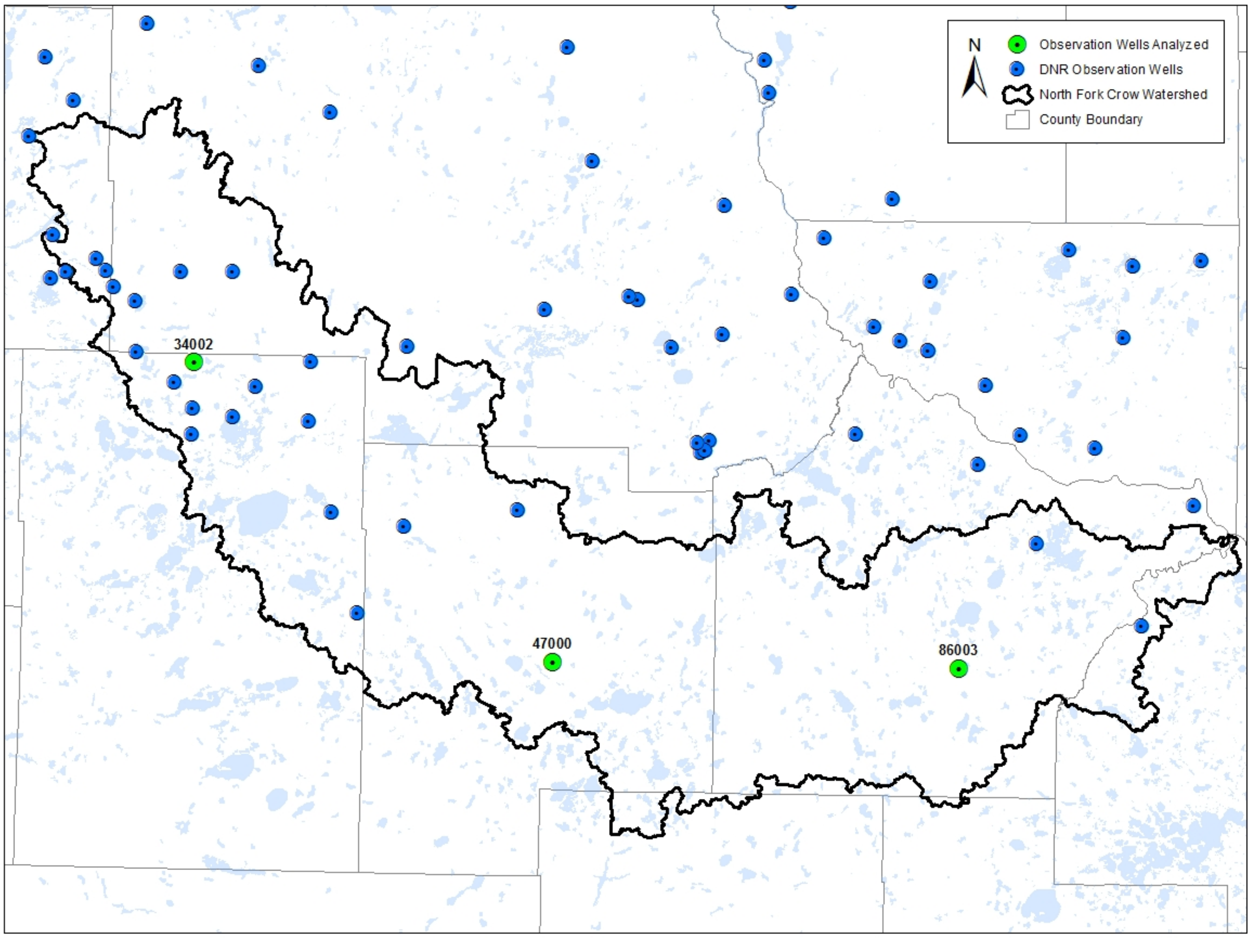

Figure 41: MDNR water table observation well locations within the North Fork Crow River Watershed

For Observation Well 86003 located near Montrose in the eastern region of the watershed (Figure 42), Observation Well 47000 near Litchfield near the center of the watershed (Figure 43), and Observation Well 34002 near Belgrade in the western region (Figure 44), there is no statistical trend in depth to groundwater on an average annual basis.

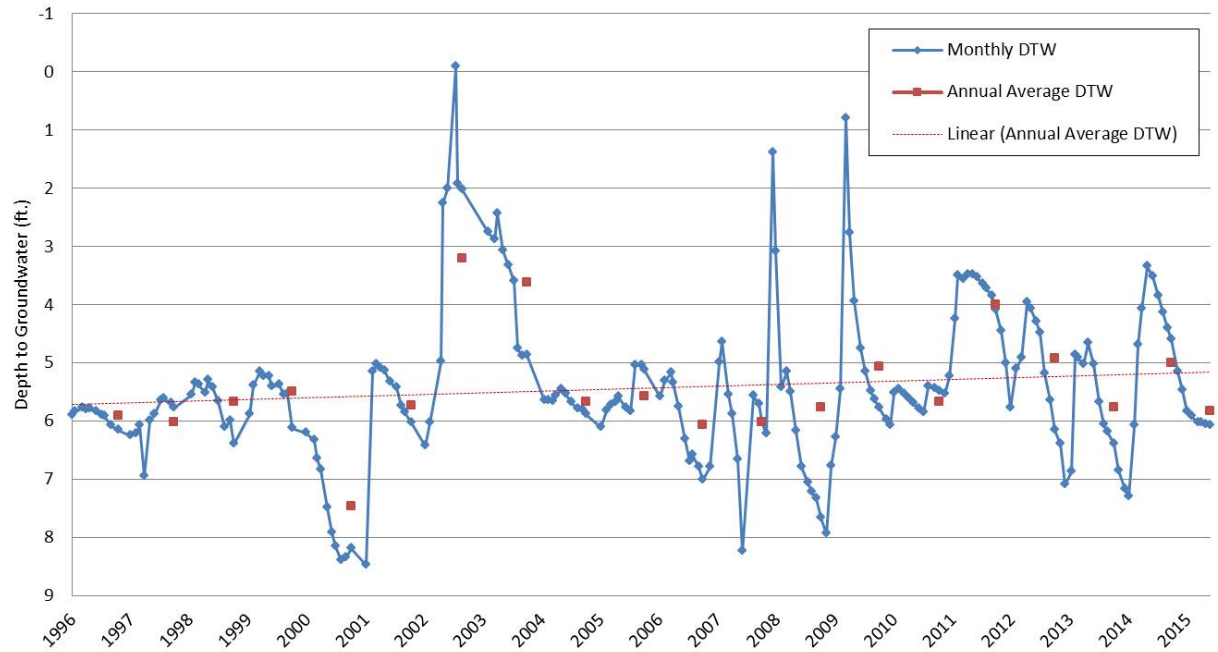

Figure 42: Depth to groundwater for observation well 86003 near Montrose (1996-2015)

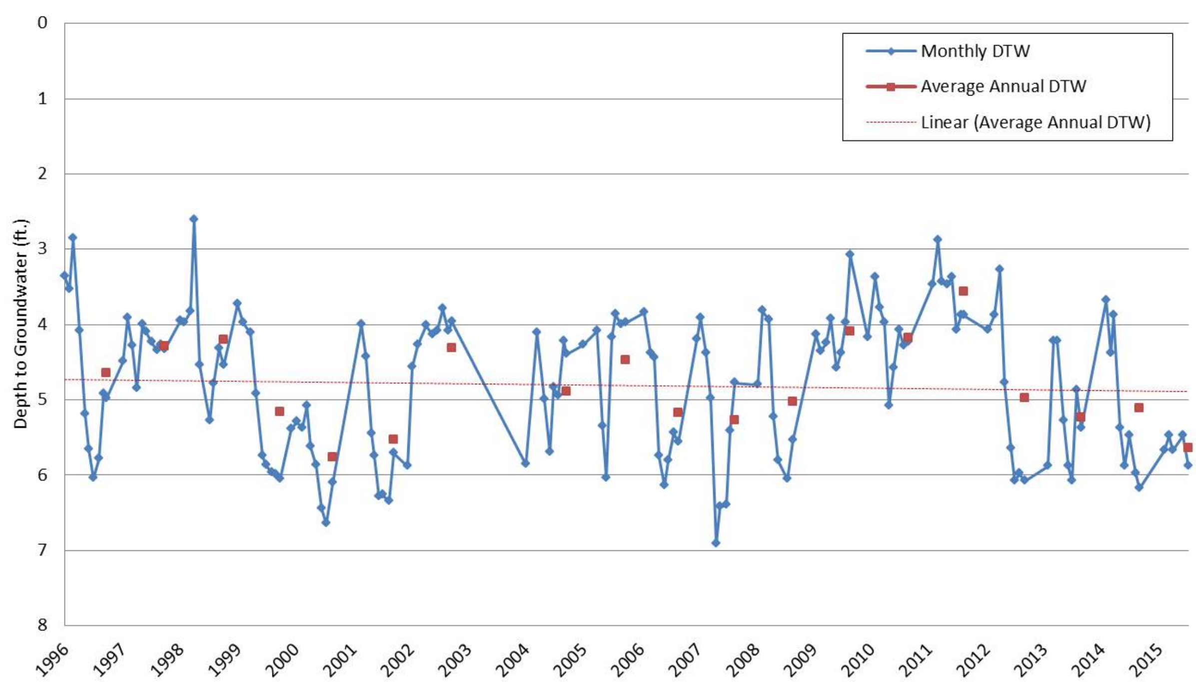

Figure 43: Depth to groundwater for observation well 47000 near Litchfield (1996-2015)

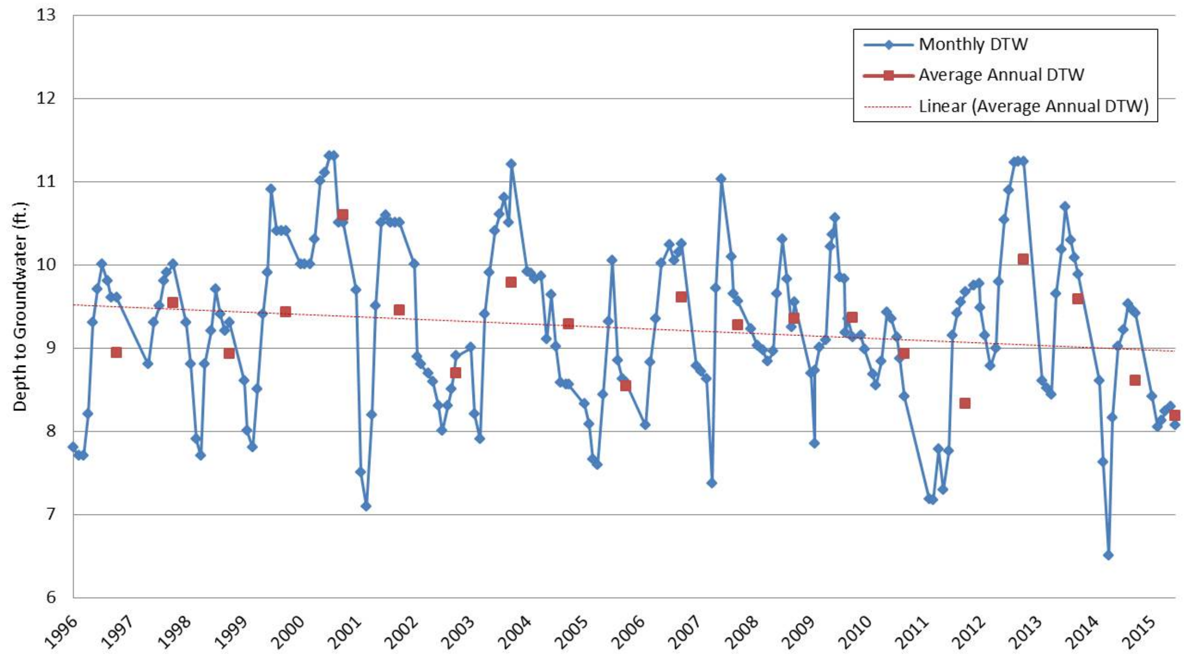

Figure 44: Depth to groundwater for observation well 34002 near Belgrade (1996-2015)

VII. Evapotranspiration

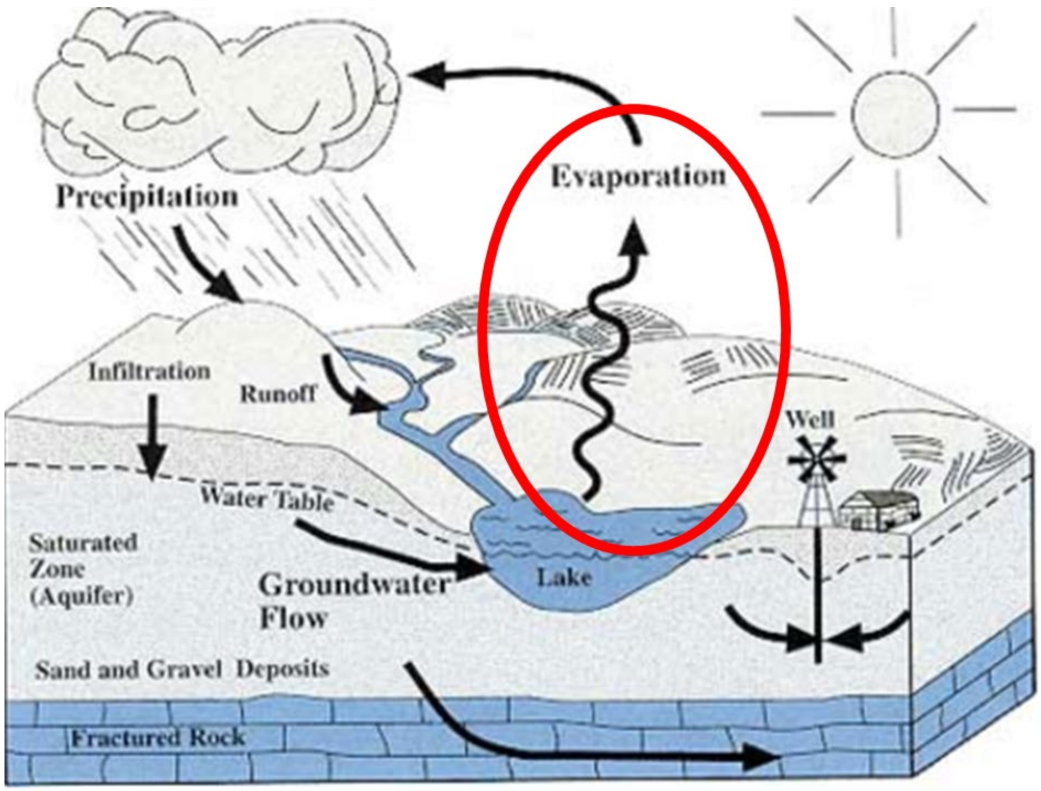

Figure 45: Evapotranspiration within the hydrologic cycle

Evapotranspiration definition

Evapotranspiration (ET) is the sum of evaporation and transpiration. ET can come from surface water bodies, the ground surface, evaporation from the capillary fringe in the near surface water table, and the transpiration of groundwater by plants whose roots draw water from the capillary fringe. Transpiration is mostly derived from the evaporation of water from plant leaves, and accounts for roughly 10% of the moisture in the atmosphere, with the other 90% coming from evaporation from surface water bodies (USGS, 2015b).

Evapotranspiration variation across Minnesota

Regarding evapotranspiration in Minnesota, the MDNR describes this process as:

> The presence of moist versus dry air masses also helps to determine the atmosphere's ability to absorb water vapor evaporating from soil and open-water surfaces, or transpiring from leaf surfaces. Western Minnesota, more frequently under the influence of dry air masses, has higher evapotranspiration rates than the eastern half of the state. Temperature plays an important role in determining the amount of energy available for evapotranspiration. Because spatial temperature patterns are determined mainly by latitude, southern Minnesota experiences more evapotranspiration than in the north.

Due to its position in the continent, Minnesota is located on the boundary between the semi-humid climate regime of the eastern U.S., and the semi-arid regime to the west. Semi-humid climates are areas where average annual precipitation exceeds average annual evapotranspiration, leading to a net surplus of water. In semi-arid areas, evapotranspiration exceeds precipitation on average, creating a water deficit. In Minnesota, the boundary between the climate regimes cuts the State roughly into east-west halves, as seen in an analysis of the difference between annual precipitation and evapotranspiration in Figure 46 (MDNR, 2015g).

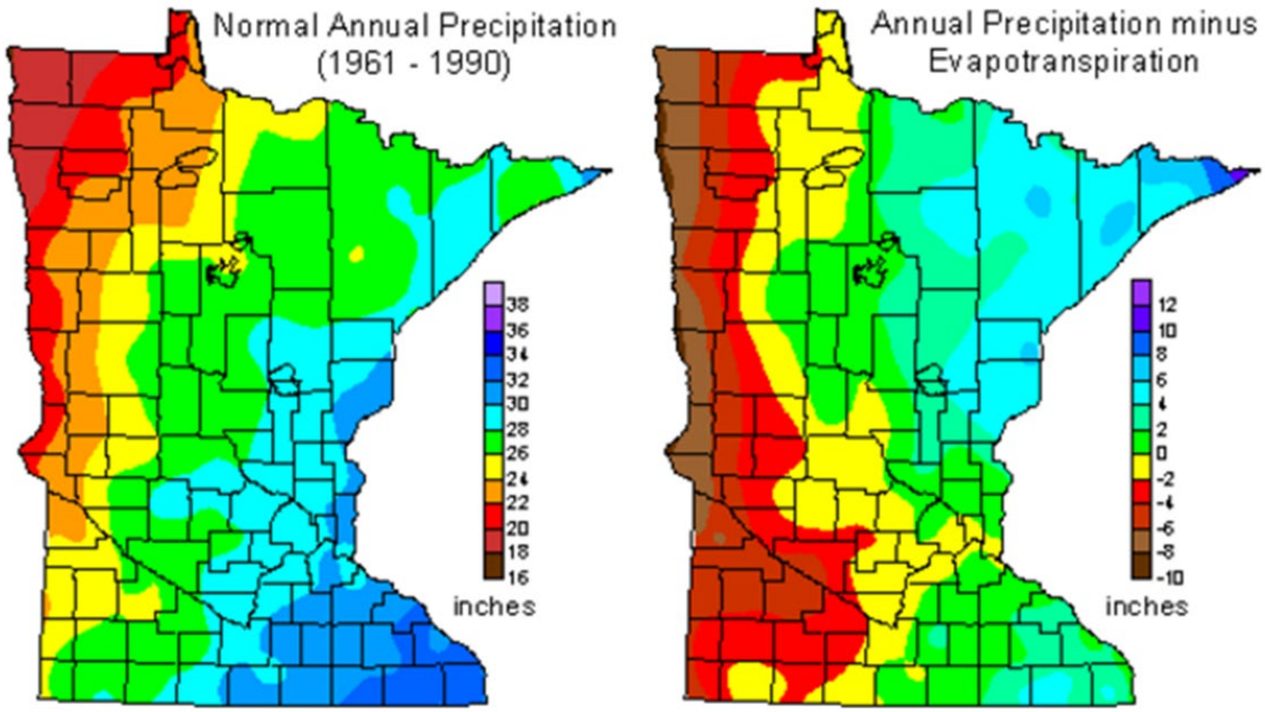

Figure 46: Minnesota annual precipitation and precipitation minus evapotranspiration (1961-1990)

VIII. Conclusion: statement of groundwater condition

For this report, the key issues that will be focused on are the surface water quality and groundwater protection. According to the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), the County Soil and Water Conservation Districts within the NFCRW identified and listed issues they believe should be considered as top priority for conservation and cost sharing efforts (USDA NRCS). Those issues include: soil and surface water quality, animal waste management, groundwater protection, windbreak maintenance, wildlife habitat, and wetland management.

Surface water quality

Surface water quality can be degraded by a number of different factors, but due to the watershed being largely agricultural, two main contributors likely are sedimentation from eroded soils and excess nutrients from runoff from nearby farm fields. Surface water impairments in the watershed are consistent with these sources. According to the MPCA's surface water impairment list for 2012, the NFCRW included a total of 65 lakes, 23 stream reaches, and 1 wetland that were identified as impaired (MPCA, 2015e). A 2014 Total Maximum Daily Load (TMDL) report of the watershed included a total of 46 listings for bacterial, turbidity or lake nutrients in 40 assessment unit IDs (Wenck Associates, 2014). For more information on impaired waters, please refer to the MPCA's Guidance Manual for Assessing the Quality of Minnesota Surface waters for the Determination of Impairment, 305(b) Report and 303(d) List: https://www.pca.state.mn.us/sites/default/files/tmdl-guidancemanual04.pdf.

Turbidity is a measure of the cloudiness of water from suspended or dissolved substances (Wenck Associates, 2014). Sediment can enter a stream or water body by erosion of soils on the landscape or from stream banks. When the sediment enters the surface water body, it can decrease the amount of light availability to the aquatic life and harm their growth (Metropolitan Council, 2014). The South Fork Crow River, which joins the North Fork Crow River at Rockford and merges into the Crow River, has been identified as transporting an average of 55 million pounds of sediment each year into the Mississippi River (Metropolitan Council, 2014).

Although nutrients, such as nitrogen and phosphorus, are necessary for stream health, excess levels can cause algal blooms, which decrease the amount of light and oxygen available for aquatic plants and organisms. The South Fork Crow River has also been identified for the highest concentration of nitrate and phosphorus in the Mississippi River basin (Metropolitan Council, 2014). The total number of acres treated with one or more chemicals, including insecticides, herbicides, wormicides and fruiticides is 279,154 acres, or approximately 30% of the watershed (USDA NRCS).

Groundwater protection

Groundwater protection should be considered both for quantity and quality. Quantity is based on the amount of water withdrawn versus the amount of water being recharged to the aquifer. Groundwater withdrawals in the watershed have increased nearly 3.4 times from 1994 to 2013. With population increases, the demand for agriculture has increased, causing greater amounts of land to be converted to row crops or pastures for livestock. With greater row crop agriculture also comes a greater need for irrigation, which has increased statistically ($p=0.01$) over this time period (Figure 47). Also, population increase has created more urbanization and development. It is estimated that the development pressure is moderate to considerable in some parts of the watershed where land is converted from farms, timberland and lakeshore into home development (USDA NRCS). This increase in development is also seen with an increase in municipal water supply, which has significantly increased (p=0.001) from 1994 to 2013.

Figure 47: Aerial view of irrigated farm fields near Brooten, Minnesota in northwestern North Fork Crow River Watershed

While the amount of water being withdrawn from aquifers has increased greatly over time, there is no statistical evidence of a groundwater table drawdown from the MDNR observation wells. There are fluctuations due to seasonal variations, but long term changes have not been observed from this data. This may be due to a higher rate of potential groundwater recharge to surficial materials throughout the watershed (Figure 48). When comparing the location of the permitted groundwater withdrawals, they are primarily correlated with areas of higher potential recharge. However, if water usage continues to increase at its current rate, the probability of the water table being drawn downwards also increases. It is for this reason that the MDNR monitors and takes precautions when permitting water use appropriations.

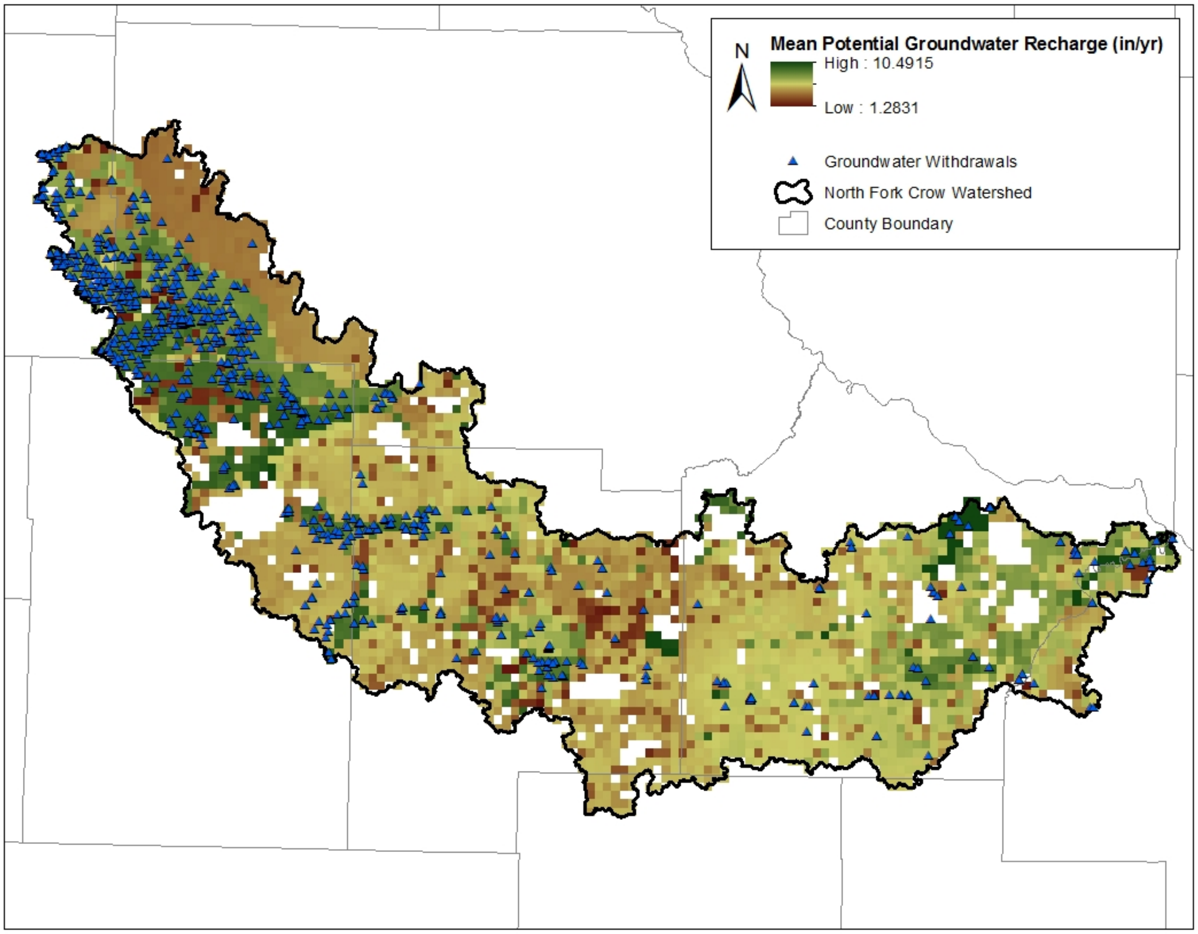

Figure 48: Mean potential groundwater recharge and groundwater permit locations in the North Fork Crow River Watershed

Groundwater quality is based on the sensitivity of the aquifers and the effects of naturally occurring and anthropogenic constituents found in the water. Factors affecting aquifer sensitivity include: 1) whether the aquifer is shallow or deep, 2) whether the aquifer is unconfined or confined, 3) the material of the aquifer, and 4) groundwater recharge rates. Typically, aquifers that are shallow, unconfined, low clay content with cobbles and gravel materials and high recharge tend to have greater sensitivity to contamination. Sources of contamination can be naturally occurring, such as atmospheric deposition or weathering processes, or anthropogenic influences, such as leaking storage tanks, septic systems, landfills, uncontrolled hazardous waste, and chemical applications to agricultural landscapes or for deicing roads, parking lots, or sidewalks. The MPCA's WIMN program has identified a number of these potentially contaminated sites and facilities within the NFCRW. These types of sites include feedlots, hazardous waste, investigation and cleanup, solid waste, and tanks and leaks sites that have been identified as a potential, current or past contamination site or a site that is not a contamination risk, but required an environmental permit or registration from the MPCA (Figure 49). Feedlots are especially predominant throughout the watershed with approximately 2,864 farms and a total animal count of 3,727,905 (USDA NRCS). A high number of livestock and poultry can increase the risk of water pollution, especially in areas of increased contamination susceptibility.

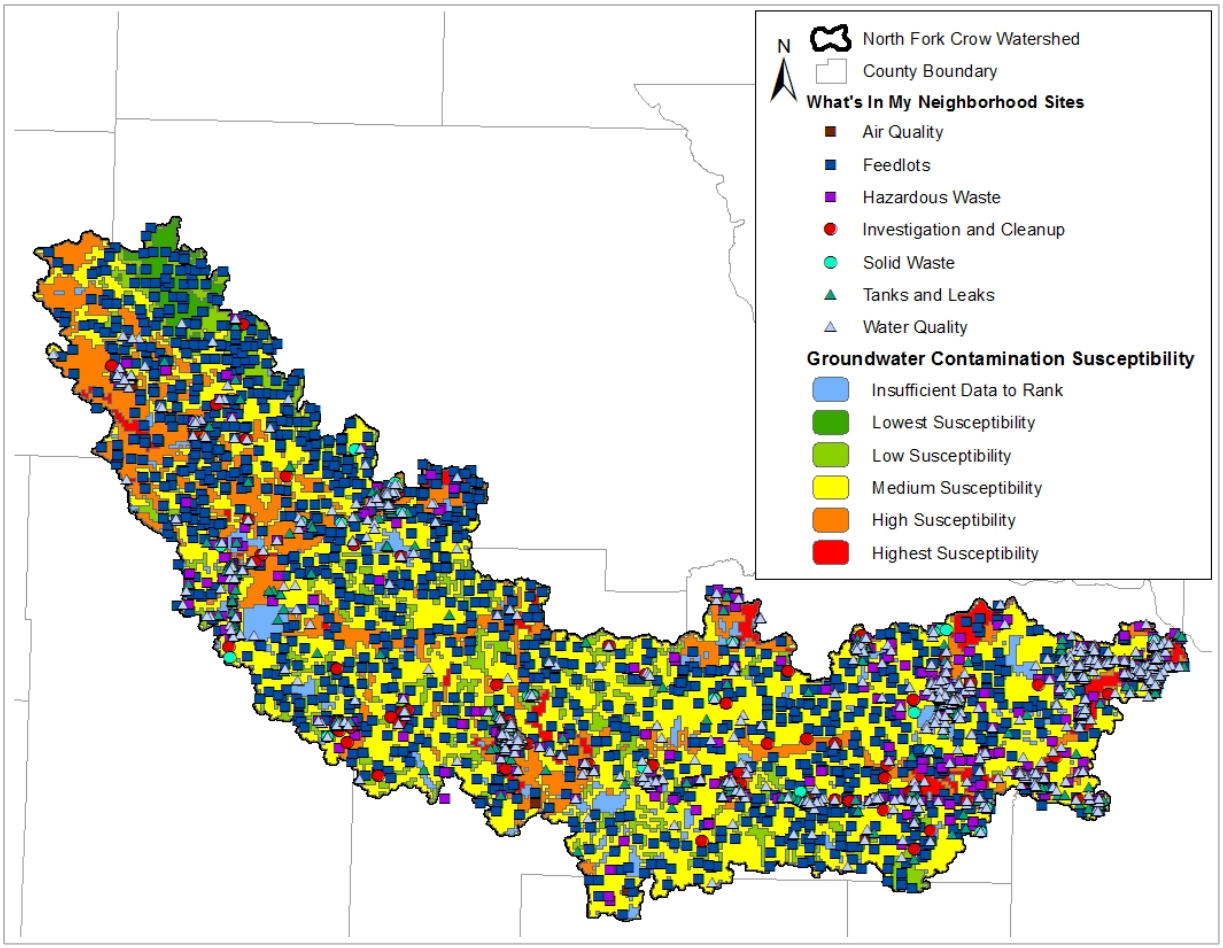

Figure 49: Groundwater contamination susceptibility and WIMN sites within the North Fork Crow River Watershed

The watershed is located within two hydrogeologic regions, the Southwest and North Central Region. During the MPCA's baseline study, the groundwater quality in the Southwest Region was determined to be poor, while the North Central Region groundwater quality was considered very good. Although exceedances were found for many different constituents within the regions, including pesticides and arsenic, the primary contaminant of concern was nitrate. Nitrate was detected in 97% of the wells in the Pesticide Monitoring Region 4, with 59% above the drinking water standard while in Pesticide Monitoring Region 8 nitrates were detected in 67% of samples with 25% above the drinking water standard. Up to five different pesticides were found in some of the sites sampled in the watershed, but none at a level of concern. Chloride, which is often a concern from deicing procedures, was not a concern in the watershed, due the primarily rural land use. Arsenic monitoring conducted by the MDH, determined that concentrations exceeded the water quality standard of 10 micrograms per liter in more than 20% of the private wells in four of the watershed counties, three counties had 10 to 20% exceeding the standard, and one county with 5 to 10% exceeding the arsenic standard.

The MPCA monitors one well within the watershed. The purpose of this network is to investigate the background chemistry and impact of chemicals on the groundwater. Statistical analysis can be completed on this well for 117 different constituents and parameters to determine concentration, frequency and possible trends. However, due to the limited available data (one well) and the well type (deep domestic with no near surface environmental influences), no statistical analysis was completed on this data.

In addition, the NFCRW contains an extensive tile drainage system. There are 15 county ditch systems consisting of 100 miles of ditches, private ditches that have not been quantified, and a buried tile system of 11,280 feet of underground drainage tile (Jasperson, 2014). Tile drainage systems, although important for agricultural landscapes, have been identified as potential causes of fish and invertebrate impairments (Jasperson, 2014). A drainage system alters the natural pathway of water and typically increases peak runoff rates, sediment, and pollutant loads to surface water resources (Blann et al, 2009).

Recommendations

As often is the situation, additional monitoring would benefit the understanding of the health of the watershed, especially its groundwater resources. Expansion of the MPCA's Ambient Groundwater Network would profit the watershed by providing current monitoring of the surficial groundwater specific to the watershed. Greater monitoring efforts increases understanding and aids in identifying the extent of issues that may be present and the risks that may be associated with them.

Due to the extensive agricultural land use throughout the watershed, best management and conservation practices should be implemented, especially in areas of concern, such as locations in close proximity to water bodies, wetlands and high groundwater contamination vulnerable areas. Best management practices (BMPs) in agricultural areas can be grouped into three categories: avoid, control, and trap (MDA, 2012). Avoid methods include practices that minimize the introduction of pollutants, such as implementing conservation cover and cover crops, crops rotation, contour farming and buffer strips, livestock exclusion/fencing, grade stabilization, and nutrient and pest management. Control methods are practices that control the risk of unavoidable pollutants and include controlled drainage, grassed waterways, irrigation management, rotational grazing, two stage ditches and terraces. Trap methods are used to reduce the extent of pollution by targeting the pollutant near its source and includes filter strips and field borders, sediment basins, wetland restoration and constructed wetlands and woodchip bioreactors. Utilizing large scale planning tools for the Mississippi River Basin, the five most effective BMPs to reduce nitrogen were cover crops, optimal fertilizer rates, marginal land converted to perennials, wetland construction, and saturated buffers (Wall, 2016). The same tools identified that the five most effective BMPs for phosphorus reduction were cover crops, riparian buffers, reduced tillage slopes less than 2%, optimal fertilizer rates and controlled drainage (Wall, 2016). Essentially, perennial vegetation helps reduce the amount of erosion from the landscape while differing root lengths and increased biodiversity can increase infiltration and recharge to the Quaternary aquifers. Buffers and wetlands can slow and spread the flow of water discharged from runoff and tile drainage systems and managing the amount of fertilizer application to the optimal quantity both reduces excess nutrients and minimizes cost. In addition, alternative methods of resource management can provide additional habitat for wildlife and diversify the landscape. For more information on the effectiveness and efficiency of BMPs in agricultural settings, please refer to MDA's The Agricultural BMP Handbook for Minnesota.

As population and development grows, so too do irrigation and water supply demands. The MDNR permits and tracks water use by permit holder and rising demand suggests that the department be cautious in granting future permits. Another factor to consider is climate change. Climate change is stimulating changes in precipitation, seasonal length, and droughts, which all can contribute to alterations in groundwater availability. The current state of the NFCRW may be able to maintain the current demand, but with changes in demand and climate, the status quo may not be sustainable.

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