Straight River Groundwater Management Area Monitoring and Analysis Report

April 2024

DEPARTMENT OF NATURAL RESOURCES

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The Clean Water Fund, which receives 33 percent of the sales tax revenue from the Clean Water, Land and Legacy Amendment, approved by voters in November 2008. The Clean Water Fund's purpose is to protect, enhance and restore water quality in lakes, rivers, streams, and groundwater.

At least 5 percent of the money is targeted for the protection of drinking water sources. The Legislature allocates funds for water quality work and drinking water protection based on recommendations from the Clean Water Council.

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Executive Summary

The Minnesota Department of Natural Resources (DNR) continues to work in the Straight River Groundwater Management Area (SRGWMA) to address groundwater-related resource challenges. The DNR is responsible for ensuring that groundwater use remains sustainable. The DNR recognizes that groundwater use is vital to the people and economy of the state of Minnesota including those within the SRGWMA. However, the DNR understands groundwater use may not be sustainable in certain areas because groundwater use may be having a negative impact on groundwater dependent features, such as aquifers, lakes, streams, or wetlands. The DNR has expanded hydrologic and climate monitoring to evaluate if groundwater use is sustainable within the SRGWMA. Combined with historical studies and analysis, recent data analyses provide an understanding of how current and past water use affects surface water and groundwater resources.

To assess Objective I. of the SRGWMA plan, the DNR has completed its initial analysis of the historic and expanded hydrologic and climate data and found the following:

- The SRGWMA can be divided hydrologically into two areas (Figure 1), the 1) Ponsford sub-management area, where there is a vertical downward hydraulic gradient (shallow groundwater flows down to deeper groundwater), and the 2) Park Rapids sub-management area, where there is a vertical upward hydraulic gradient adjacent to the Straight River (deeper groundwater flows up to shallower groundwater and surface water).
- Groundwater baseflow provides 93–97% of streamflow to the Straight River, its headwaters, and its tributaries. This baseflow is likely delivered continuously along the river and its tributary through hundreds of seeps, springs, and groundwater dependent wetlands.
- Average annual water use in the SRGWMA has increased 137% between 1988 and 2021, primarily driven by increases in agriculture irrigation. The increases are greater in the Ponsford sub-management area than in the Park Rapids sub-management area.
- August median baseflow is approximately 7.9 cfs for the downstream end of Ponsford sub-management area and 52.7 cfs for downstream end of the Park Rapids sub-management area. The amount of gain varies in intensity from 1.7–4.8 cubic feet per second per mile (cfs/mile) along the Straight River the SRGWMA (~1–3 million gallons per day every mile).
- The entire SRGWMA shows connection between the confined aquifers and the water table aquifers. Connections between the confined and water table aquifers in specific areas of the SRGWMA are strong enough to elicit concerns for water levels needed to sustain a cold-water habitat. It is likely that in some areas, especially at locations near the river, pumping from either aquifer diverts groundwater discharge to Straight River.
- There are multiple permits with irrigation wells close enough to the stream that appear to cause decreased groundwater levels and baseflow that would naturally flow to the Straight River. In the reach from Osage to US Hwy 71 in the Park Rapids sub-management area, the 11 closest wells to the river are permitted to pump at a cumulative rate of 7,600 gpm. Depending on how much of this groundwater would naturally flow to the river, it's possible that these 11 wells are reducing streamflow in excess of 15% of the August median baseflow (52.7 cfs). A groundwater flow model is likely needed to quantify the amount of streamflow diversion from these 11 as well as the 281 remaining wells more distant, yet still in the GMWA.

- In over 35 years of streamflow monitoring, there has not been any downward trend in total summer (May-September) streamflow at the outlet of the SRGWMA. Summer low streamflows don't appear to be getting any lower despite steady increases in annual appropriation, though many of the irrigation permits in the SRGWMA predate monitoring efforts.
- There are three locations in the lower Park Rapids area where annual streamflow has decreased by 4–10% from what was measured in the late 1980s and 1990s. This indicates that impacts from irrigation may not be immediately apparent during the irrigation season but may be more subtle and distributed in this particular area.
- There is no significant trend in seasonal or annual precipitation, but air temperatures are increasing decade to decade. Under the current water use and climatic conditions, safe yield does not appear to be a concern for the confined aquifers and the surficial water table aquifer throughout the SRGWM.

The DNR has identified geographic areas and resource concerns in need of further evaluation to understand specific relationships between water use and its effects on the surface and groundwater. Those include:

- Despite no discernable trend in discharges, lower portions of the Straight River regularly sustain inversions in groundwater flow during the irrigation season and elicit the need for monitoring.
- The water table aquifer in the Ponsford sub-management area in the upper portion of the SRGWMA appears to be able to sustain current demands with limited acreage available for future expansion. The period of record for streamflow in this area is not as extensive as downstream, so it will be important to continue surface water monitoring. This area also has numerous springs and groundwater seeps which provide the streamflow for the beginning of the Straight River. These features likely support groundwater dependent biota and will be sensitive to small and temporary changes in water levels.
- Nitrates above the drinking water standard have been measured in private drinking wells in both the Ponsford and Park Rapids sub-management areas. Nitrates are also much higher in the Straight River than they are in other streams in the region. Nitrates are a conservative indictor of water quality concerns. Residuals from pesticides have also been detected in multiple private drinking wells.
- While stream temperatures show no statistically significant increase, they strongly correlate to air temperatures. Although average stream temperatures over time appear adequate for Brown Trout, increasing air temperature, groundwater use, and climate change remains a concern.

The DNR remains committed to reporting SRGWMA monitoring activities, identifying areas of increased focus, and providing a framework for setting protection thresholds to determine if cumulative groundwater use is having a negative impact on the Straight River. This monitoring and analysis report along with other SRGWMA implementation actions will ensure the use of groundwater is sustainable and therefore will not harm ecosystems, water quality, or the ability of present and future generations to meet their needs.

Introduction

The DNR is responsible for managing the state's water resources to sustain healthy waterways, basins, and groundwater resources. The DNR plays an important role in supporting sustainable groundwater use through its permit programs, information collection and analysis activities, law enforcement responsibilities, education, and technical assistance opportunities.

Groundwater is at risk of overuse and contamination, and in some areas of the state this risk is a more urgent issue. To address concerns about long-term sustainable use of groundwater in the Straight River area, the DNR designated a Groundwater Management Area (GWMA) and finalized an implementation plan in March 2017. This plan was developed to guide DNR actions in managing the appropriation of groundwater within the GWMA over 5 years.

The GWMA boundary represents a geographic area where groundwater users share a distinct aquifer system or groundwater resource (Figure 1). Users include those who are required to have appropriation permits (high volume users: more than 10,000 gallons a day or 1 million gallons a year), those who do not (low volume users: less than 10,000 gallons a day or 1 million gallons a year) and the natural ecosystems. While the number of permitted water appropriations and irrigated acreage continues to increase (Figure 2) it is apparent that much of the land that is suitable for irrigated agriculture in the GWMA is already irrigated.

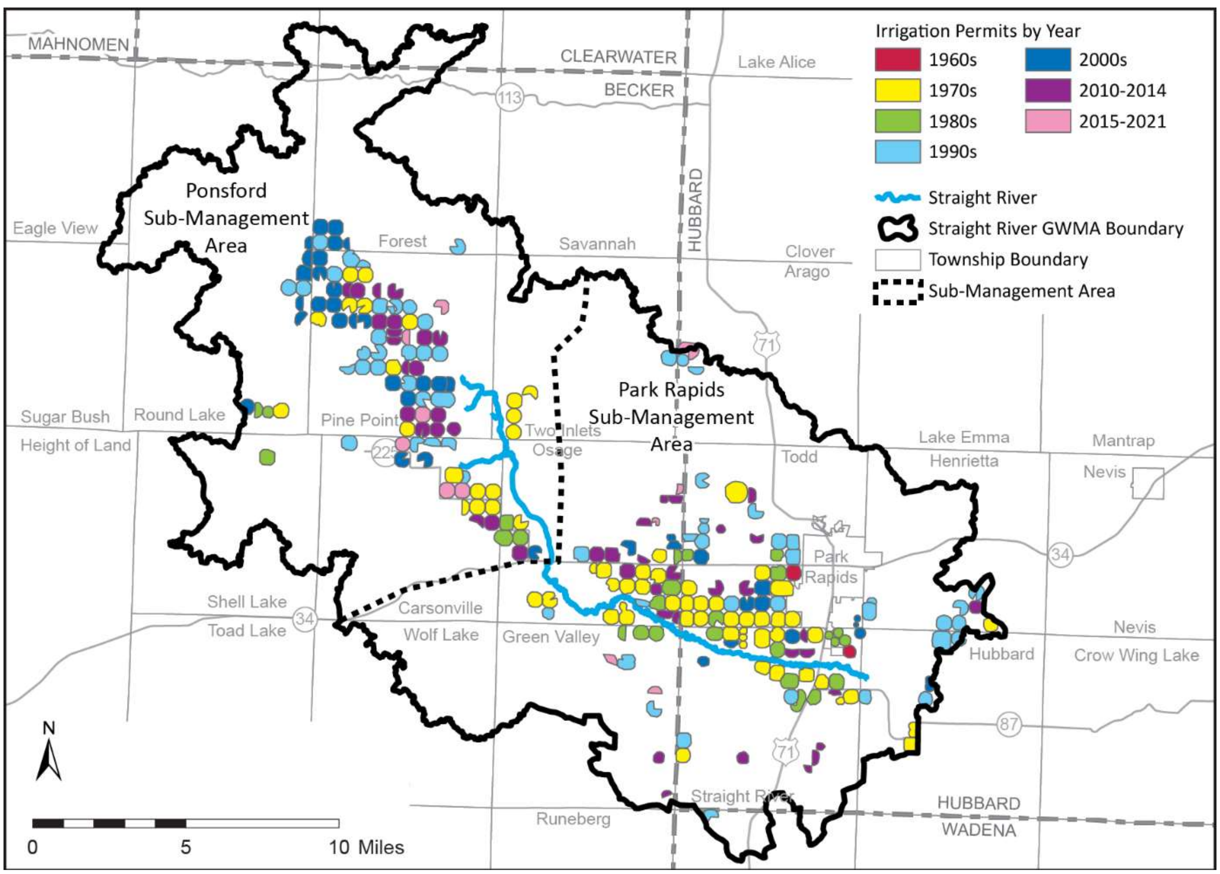

Figure 1. SRGWMA boundary, sub-management areas and irrigated landcover.

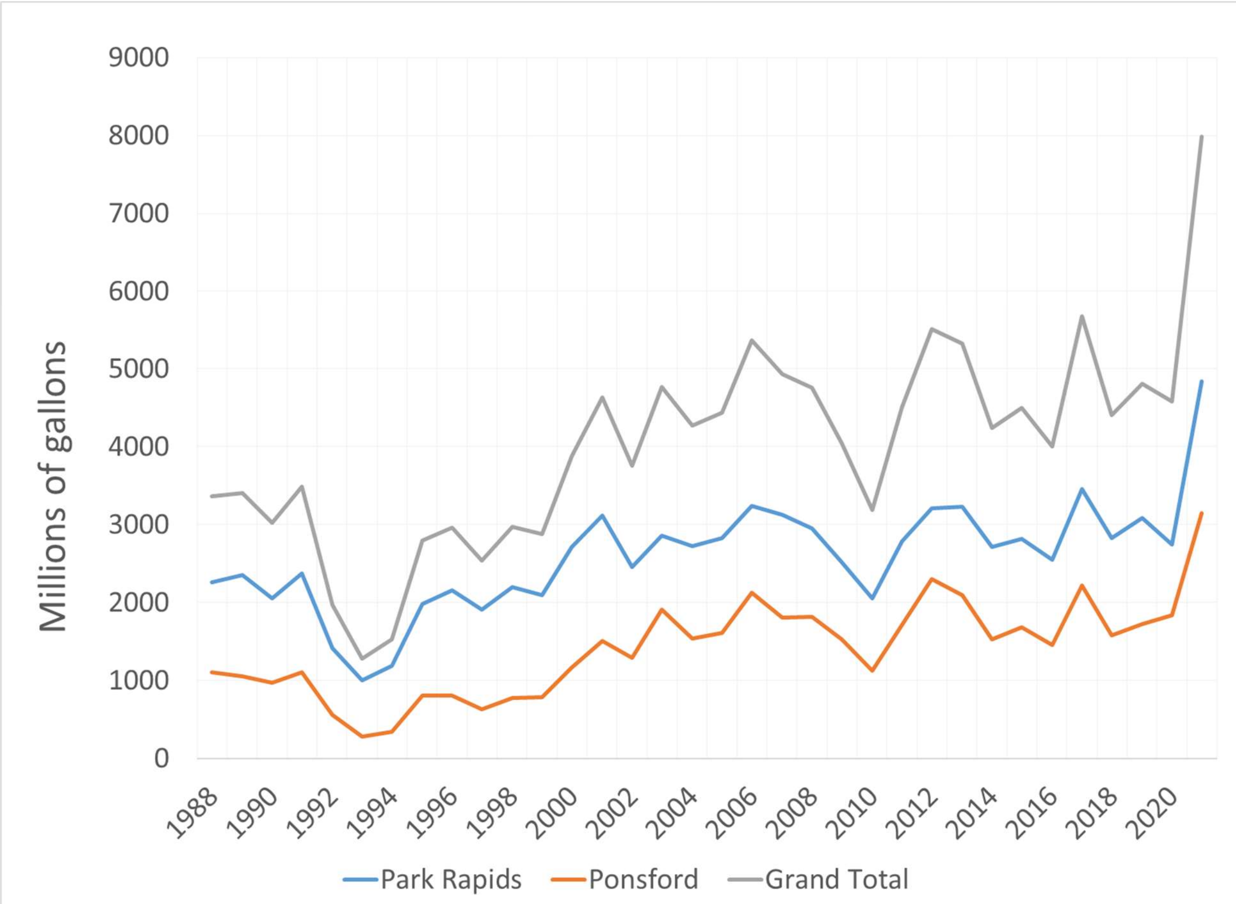

Figure 2. Reported Water Use from 1988–2021 for all sources within the SRGWMA and the two Sub-management areas [1].

[1] Minnesota Permitting and Reporting System (MPARS) electronic water use records date back to 1988.

The goal for the SRGWMA is: "*In the Straight River Groundwater Management Area, the use of groundwater will be sustainable and therefore will not harm ecosystems, water quality, or the ability of present and future generations to meet their needs.*"

To attain this goal, all five management objectives outlined in the 2017 SRGWMA plan must be achieved to ensure that use of groundwater is sustainable. The work and analysis reported throughout this document are actions associations with Objective I: "*Groundwater use in the GWMA does not harm aquifers and ecosystems and does not negatively impact surface waters.*" This report provides an up-to-date summary and analysis of monitoring activities, identifies areas of increased focus post SRGWMA 5-year plan, and describes the condition of the ground and surface water resources that can be used to inform further analysis of protection thresholds and water appropriation permitting decisions.

Summary of Monitoring Activities Implemented

Between 2015 and 2021, the DNR and partners expanded the hydrologic and climate monitoring system (Figures 3 and 4) and further expanded the understanding of the geologic and hydrologic system within the SRGWMA. Primary activities include the following:

- Installed 5 additional continuous stream gages along the Straight River for a total of 7 locations that report 15-minute streamflow data.
- Provide year-round surface water measurements to calculate groundwater streamflow to the Straight River using synoptic gauging at 11 stream locations every 40 to 60 days.
- Installed four additional stream temperature probes at stream gage locations to complement the eight long-term stream temperature monitoring locations managed by the DNR Section of Fisheries.
- Expanded groundwater level monitoring from 56 observation wells with 33 continuous data loggers in 2015 to 59 observation wells with 52 data loggers in 2020.
- Updated the DNR database with historic data from groundwater investigations from 11 groundwater observation wells.
- Installed two mesonet climate stations in the SRGWMA in 2016. These stations collect climate parameters for estimating local potential evapotranspiration values. These climate data will inform stakeholders of any changes in evaporative demand in the GWMA.
- Increased citizen precipitation observers in Hubbard County from 22 to 33 participants.
- Expanded lake-water-level monitoring on two lakes, Long and Straight lakes. Continued lake water level monitoring on six lakes, Bad Medicine, Long Lost, Two Inlets, Portage, Moran and Fish Hook lakes.
- Installed wetland monitoring gages in the spring of 2021 in two wetlands that will be used as reference wetlands. These reference wetlands will help characterize the hydrologic cycle of wetlands statewide and locally.
- The MGS completed the County Geologic Atlas Part A (geology) for Becker, Hubbard, and Wadena counties. MN DNR is completing Part B (groundwater) of the atlas are in Becker, Hubbard, and Wadena counties; all three are expected to be released in the upcoming year.

Past Studies

Previous studies provide a suitable reference for comparison with recently collected data. Three reports discuss baseflow interactions with surface waters and sustainability. Each of the studies are summarized below and shown on a timeline of the water use history at in the SRGWMA (Figure 2).

Helgesen 1977, "Ground-water appraisal of the Pineland Sands areas, central Minnesota"

In 1977, Helgesen estimated the long-term water budget in the Pineland Sands area water table aquifer. The study area in Helgeson's model was twice as large as the SRGWMA, 770 square miles, whereas the SRGWMA consists of 369 square miles within Helgeson's model area. Helgesen concluded that 90% percent of streamflow from the water table aquifer served as baseflow to streams and lakes. His models of the water table aquifer system concluded that withdrawals of 715 MGY had no significant impact on the system, whereas hypothetical withdrawals of 14,000–29,000 MGY resulted in aquifer declines of 12 feet in some places. He also noted that "most pumpage is derived from intercepted baseflow to streams, thus reducing streamflow" by 22–44%, depending on the pumping scenario. The most recent 10-year average of reported annual water use in SRGWMA is approximately 5,105 MGY from 215 permits. In an area that is half the size of Helgeson's modeled area this average is approaching half of his withdrawals that indicated hypothetical aquifer declines.

Stark et. Al, 1994, "Stream-aquifer Interactions in the Straight River Area, Becker and Hubbard Counties, Minnesota"

The United States Geological Survey (USGS) built a groundwater model and conducted intensive hydrologic monitoring in both the water table and confined aquifers for the Straight River area in 1994 (Stark et al., 1994). The objective of this study was to assess impacts on stream baseflow and instream temperatures from increased pumping in the watershed as it relates to trout habitat. They determined that the water table and confined aquifers in the study area are connected with downward leakage from the water table to the shallow confined aquifer in some of the area, while areas adjacent to the river have a vertically upward connection. Baseflow estimates from this study indicated that at least 95% of streamflow in the Straight River was derived from baseflow. They also modeled reductions of 34% in baseflow to the stream under 1988 pumping conditions (48 irrigation wells pumping 2,300 MG or 10.6 cfs. Modeling also estimated increases in stream temperature of 0.5 to 1.5 degrees Celsius under 1988 pumping scenarios, though they found little evidence to corroborate these modeled estimates. During periods of low flow, the stream lost water to the surficial aquifer due to groundwater withdrawal or from increased evapotranspiration.

Kruse and Frischman, 2002, "Surface water and Ground Water Interaction and Thermal Changes in the Straight River in North Central Minnesota"

Further analysis and monitoring were completed by the DNR during 1996–1998 (Kruse and Frischman, 2002). These analyses included baseflow separation, flow duration assessments, as well as streamflow and water temperature modeling. In this study, they found annually repeatable increases in streamflow of 2–4 cfs during winter months, which is a time when baseflow typically remains steady or declines. This was likely due to groundwater withdrawals reducing water levels in the summer with recovery during the winter after pumping ended for the season. They also identified natural streamflow losses in the lower portion of the Straight River that were likely exacerbated by groundwater withdrawals from nearby irrigation. Temperature modeling performed by Kruse and Frischman indicated that groundwater withdrawals affected stream temperatures by +1.0 to -1.9 degrees Celsius in the lower reaches of the Straight River.

Analysis of New Monitoring data

The 2017 SRGWMA plan calls for improved and expanded hydrologic, climate, and groundwater understanding associated with biological community monitoring in the project area. Expanded hydrologic monitoring provides valuable information for assessing cumulative impacts in the area. A valuable analysis that is possible with this expanded monitoring is the estimation of a water budget in the SRGWMA. In a manner like a checking account, these data help us to measure the amount of water that is coming into the system (precipitation) and the amount of water that is leaving the system (streamflow, pumping and evapotranspiration). Over many years, recording trends in the hydrologic budget inform managers of changes that might be occurring. As previously noted, hydrologic monitoring has increased considerably since the SRGWMA plan was approved. Figures 3 and 4 present the current hydrologic monitoring network within the SRGWMA, partitioned into two sub-management areas. Many of these sites have been actively monitored since the 1990s.

Park Rapids and Ponsford sub-management areas

For this report, the SRGWMA is split into two sub-management areas to better summarize monitoring and analysis (Figures 3 and 4). The two areas are divided by Straight Lake in the middle of the SRGWMA.

The **Park Rapids sub-management area** includes the main stem of the Straight River downstream from Straight Lake, comprising the study area from Stark et al. around Park Rapids. This sub-management area is characterized hydrologically by upward hydraulic gradients near the river where upward flow from the confined aquifer contributes baseflow to the Straight River. The Park Rapids sub-management area is also where water use was first concentrated in the 1970s and 1980s in the SRGWMA.

The **Ponsford sub-management area** includes the headwaters portion of Straight River upstream from Straight Lake in the Ponsford area, comprising most of the recent expansion of monitoring and irrigation in the SRGWMA. This sub-management area is characterized hydrologically by downward hydraulic gradients and a confined aquifer that does not experience seasonal drawdowns that are as severe as is recorded in the Park Rapids sub-management area.

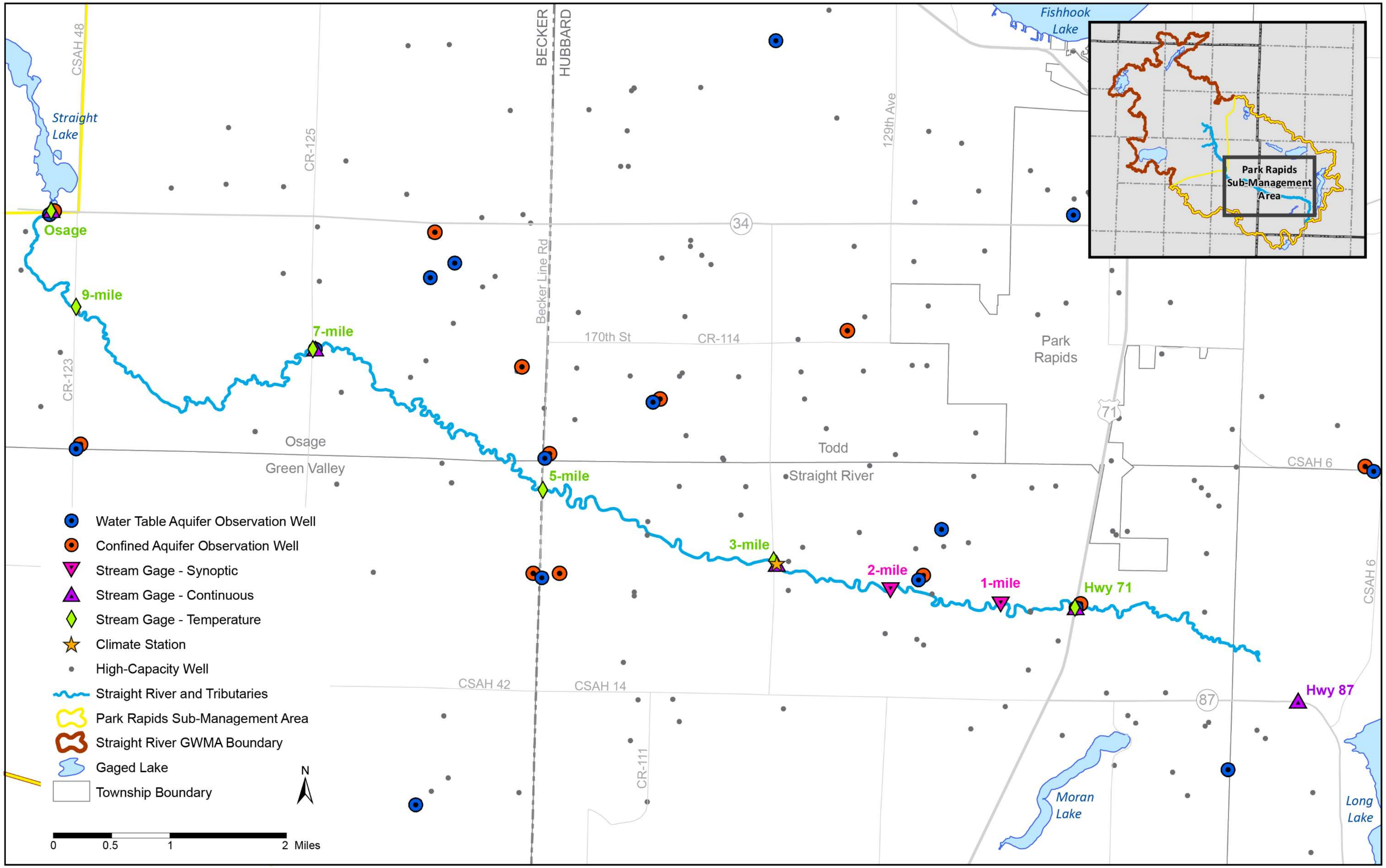

Figure 3. Monitoring in the Park Rapids sub-management area.

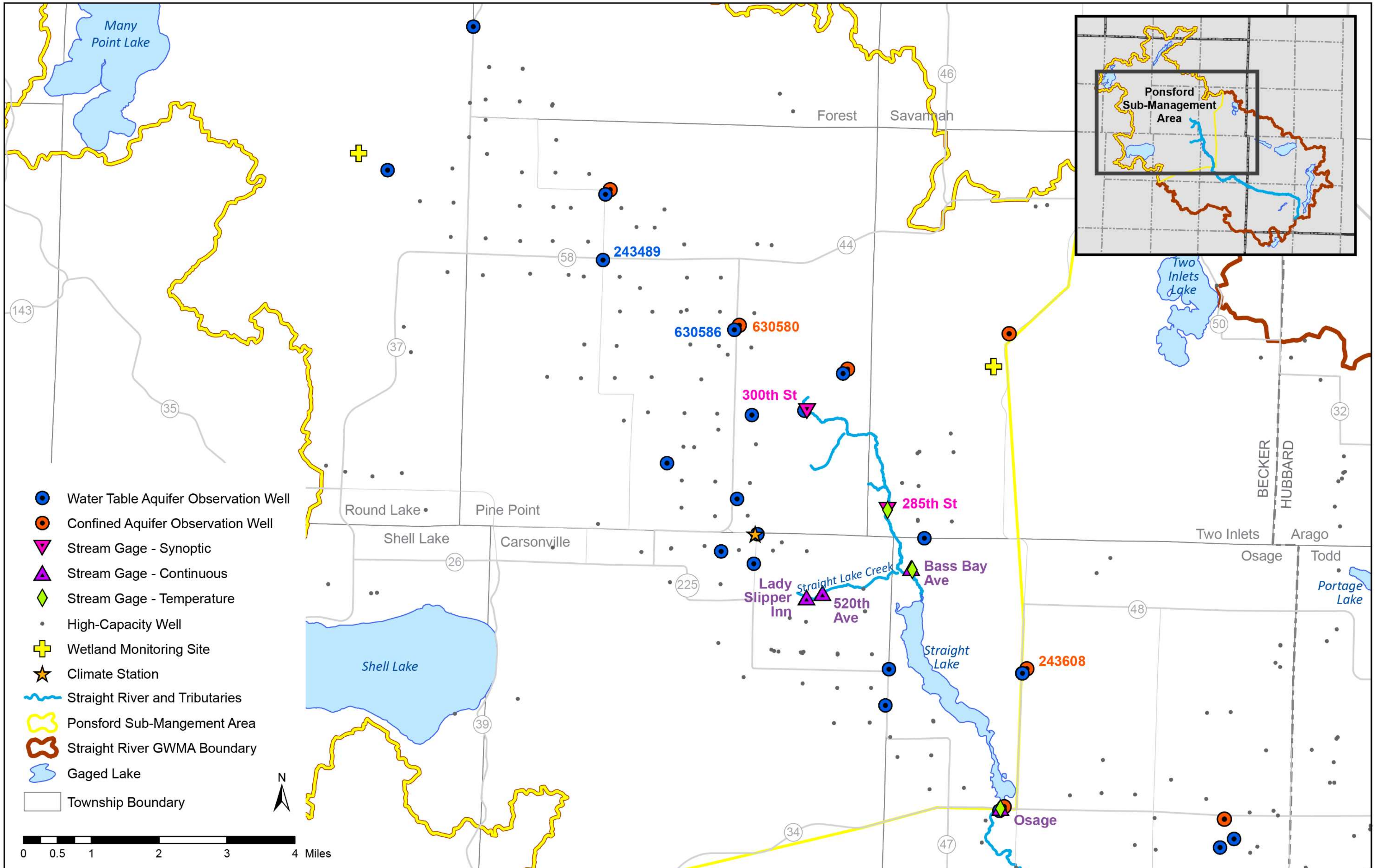

Figure 4. Monitoring in the Ponsford sub-management area.

Climate

Minnesota's climate is changing rapidly, and more changes are coming. These changes can have a direct impact on sustainability of groundwater resources altering aquifer recharge, usage trends, and surface water temperatures. In the past several decades, Minnesota has seen substantial warming—especially during winter and at night—along with increased precipitation and heavier downpours. The SRGWMA is within the Crow Wing River watershed which has warmed at a faster rate than statewide averages. Precipitation during the May-through-September growing season has increased very slightly (approximately 4%) in recent decades, and the trends in the SRGWMA match the regional tendency towards more frequent and sometimes heavier rainfall events.

Although annual average temperatures have tended to increase since the turn of the 20th century, warming rates in the SRGWMA jumped sharply in recent decades (Figure 5). Since 1970, the area has warmed at a rate of over +0.60 degrees F per decade, nearly 6 times faster than the warming rate of +0.11 degrees F per decade between 1895 and 1969.[i] Nine of the 10 warmest years on record back to 1895 occurred between 1987 and 2021; 6 of those top-10 years occurred between 2000 and 2021.

During the current period of rapid warming, nights (average daily minimum temperatures) have warmed approximately 30% faster than days (average daily maximum temperatures), winter has warmed over 3 times faster than summer, and winter nights have warmed 4–5 times faster than summer days. The average winter night is now over 6 degrees F warmer than it was around 1970; the average summer day is around 1.3 degrees F warmer.[ii]

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[i] Using the DNR Minnesota Climate Trends Tool (https://arcgis.dnr.state.mn.us/ewr/climatetrends/#), and selecting the Crow Wing River Watershed, annual average temperatures increased at a rate of 0.11 degrees F per decade between 1895 and 1969, but 0.63 degrees F per decade between 1970 and 2021.

[ii] Since 1970, the average daily minimum temperature increased 29% faster than daily maximum temperatures (0.71 degrees F per decade vs 0.55 degrees F per decade); December-through-February average temperatures increased at 3.09 times the rate of June-through-August average temperatures (1.08 degrees F per decade vs 0.35 degrees F per decade); December-through-February average minimum temperatures increased at 4.92 times the rate of June-through-August average maximum temperatures (1.23 degrees F per decade vs 0.25 degrees F per decade); the accumulated warming since 1970, estimated by multiplying the decadal warming rates by 5.2, is 6.40 degrees F for December-through-February average minimum temperatures, and 1.30 degrees F for June-through-August average maximum temperatures.

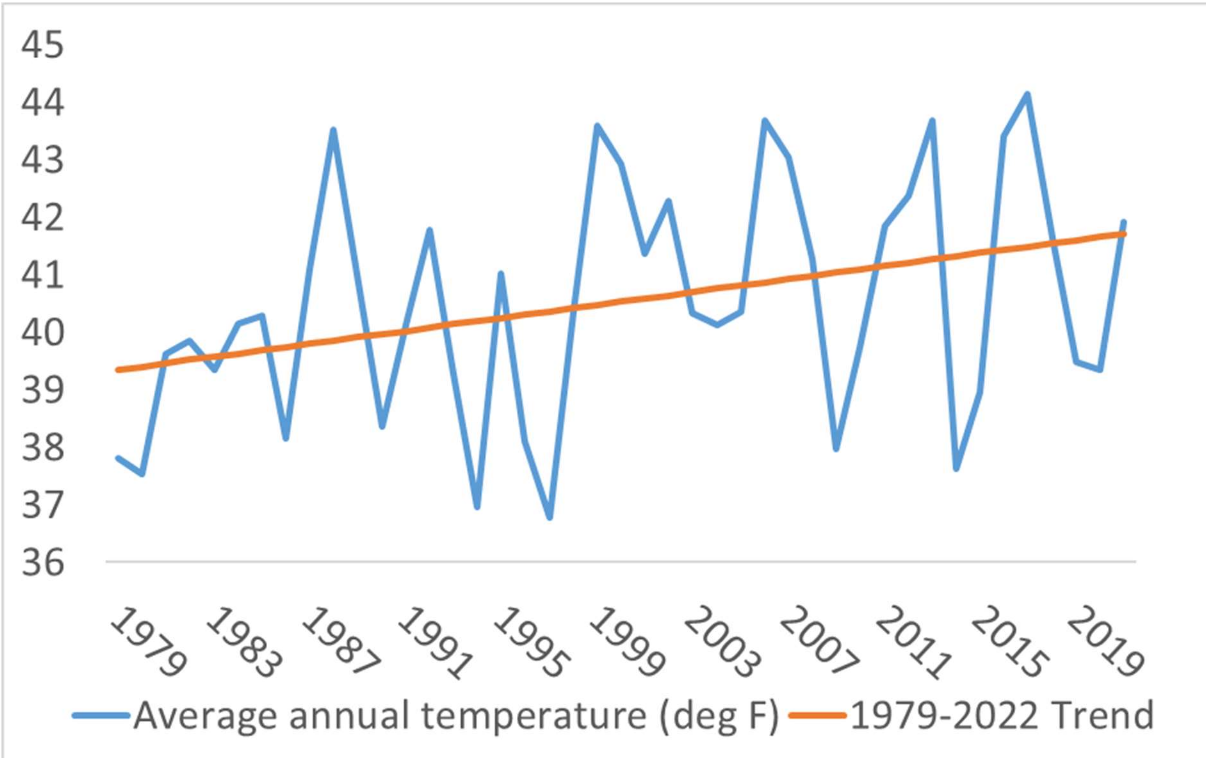

Figure 5. Average annual temperature for Crow Wing River watershed, which contains the SRGWMA from 1979-2021.

Precipitation in the SRGWMA has shown a long-term increase in annual precipitation since 1895, but slight decreases since 1970. In other words, the area is wetter than it was at the turn of the 20th century, but slightly drier than it was in the second half 20th century. The SRGWMA is therefore in a different hydroclimatic position than areas to the south and east in Minnesota, where the 2010s were wetter than any other decade on record. In the SRGWMA, the 2010s produced only near-average precipitation.

An increase in temperature generally results in increased evaporative demand, and the potential for increases in evapotranspiration in the SRGWMA does exist. However, in the SRGWMA this tendency may be offset by the lower warming rates of summer, and by the roughly 4% increase in May-September precipitation.[iii] To better document these changes, the DNR installed three climate monitoring stations in or near the SRGWMA in 2016. These stations were subsequently upgraded in 2022 and 2023.

The frequency and intensity of heavy precipitation events is increasing in the SRGWMA, even as annual precipitation remains largely unchanged. The seven nearest historical climate stations show long-term increases in the frequency of daily 1-inch rainfalls. These seven stations also show long-term increases in

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[iii] Annual precipitation increased at a rate of 0.13 inches per decade between 1895 and 2021 but has decreased at a rate of 0.09 inches per decade since 1970; the statewide average during that same time was +0.29 inches per decade (and even greater using other sources). May-through-September precipitation in the Crow Wing River Watershed has increased by 0.13 inches per decade in 1970.

in the largest daily rainfall of the year. [iv] In June of 2002, a "mega-rain" event produced rainfall totals of 6 inches or more over an area exceeding 1000 square miles, including parts of the SRGWMA.[v]

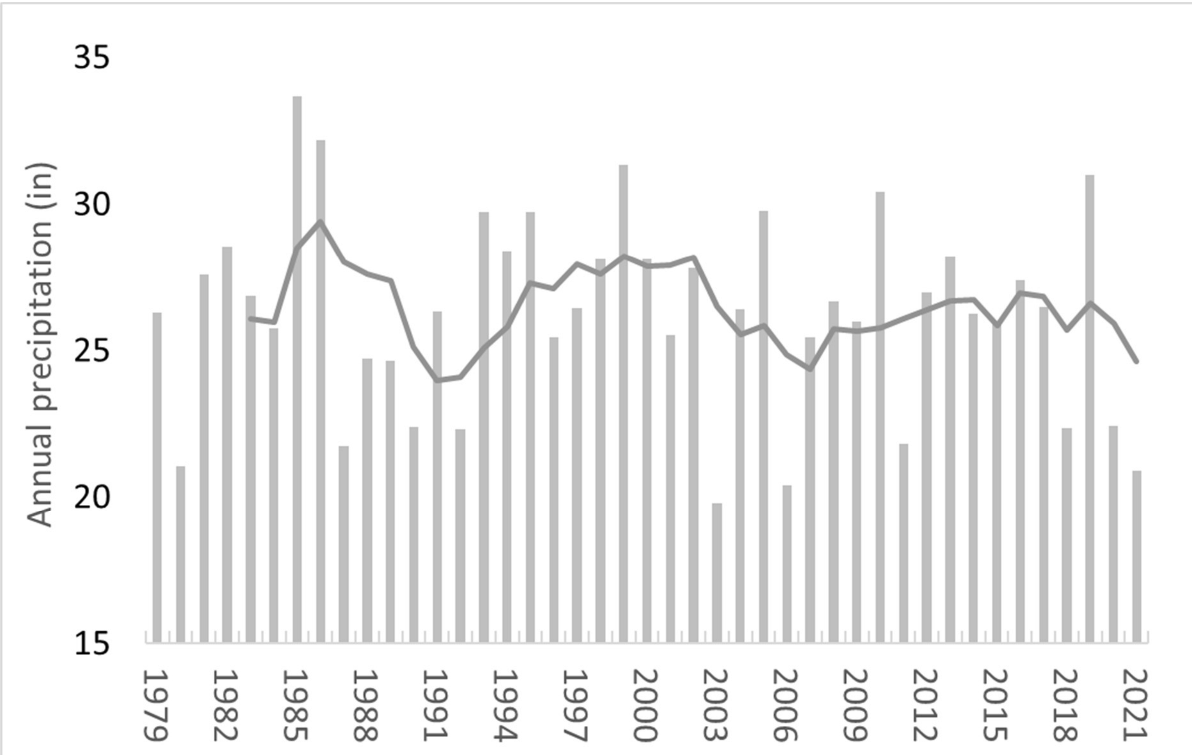

Figure 6. Annual precipitation for the SRGWMA with the 5-year moving average, an indicator of trends in precipitation.

The main driver of groundwater recharge and streamflow is climate, specifically precipitation and evapotranspiration. Evapotranspiration (ET) is the process where water is transferred from the land to the atmosphere by a combination of evaporation and transpiration from plants. Both are combined into one major loss in the water budget commonly referred to as ET. Surface waters and groundwaters in SRGWMA are impacted by ET through losses from the sun and wind (evaporation) as well as losses from streambank and nearby wetland transpiration. Stream gages along the Straight River fluctuate up and down on a daily cycle during the summer months (Figure 7). These "diurnal fluctuations" signal the daily variation of ET in the water budget. . In addition to ET, changes in precipitation amounts, intensities, areal distribution, and seasonality make noticeable impacts to groundwater levels and streamflow's in

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[iv] Based on analysis of National Weather Service Cooperative stations with daily precipitation data available in most years back to 1916 for: Park Rapids, Itasca/U of M, Cass Lake, Ada, Leech Lake Dam, Pine River Dam, and Winnibigoshish Dam.

[v] See https://www.dnr.state.mn.us/climate/summaries_and_publications/mega_rain_events.html, and https://climateapps.dnr.state.mn.us/doc/journal/flash_floods/ff020622-23.htm

the SRGWMA. Water levels in area observation wells and streamflow decline during periods of drought, conversely heavy rainfalls cause levels to temporarily increase in observation wells and streamflow.

Understanding and quantifying ET in the SRGWMA will be necessary as climate changes. ET has a noticeable impact on streamflow in the Straight River (Figure 7), and increasing air temperatures, particularly during the growing season, can result in increases in evapotranspiration and greater losses in the Straight River streamflow. Physically measuring ET is difficult, so various physically based equations help to estimate potential evapotranspiration (PET). Potential evapotranspiration is defined as a measure of water that would be lost to ET assuming enough water is available. PET is estimated at DNR climate stations using the Penman-Monteith equation that is commonly used to estimate PET. PET is greater than actual ET but serves as a good proxy for a difficult to measure, yet significant portion of the regular water budget.

From 2018 through 2020, the DNR mesonet station at the 3-mile stream gage experienced a 9° F range in annual mean daily high temperatures, from 42° F in 2018 to 51° F in 2020. The higher daily maximum temperatures in 2020 corresponded to 41 inches of annual potential evapotranspiration (PET), representing a 28% increase over the 2018 total of 32 inches. Although these three years are not indicative of a trend over time, they illustrate how future temperature increases may result in ET increases during dry or normal-precipitation periods. Increasing evapotranspiration can cause lower water levels in surface waters, wetlands, and shallow water tables, particularly if precipitation is not increasing. Increasing evapotranspiration is also likely to increase the need to irrigate in the SRGWMA, since higher temperatures are likely to drive irrigated crops to demand more water through increased transpiration.

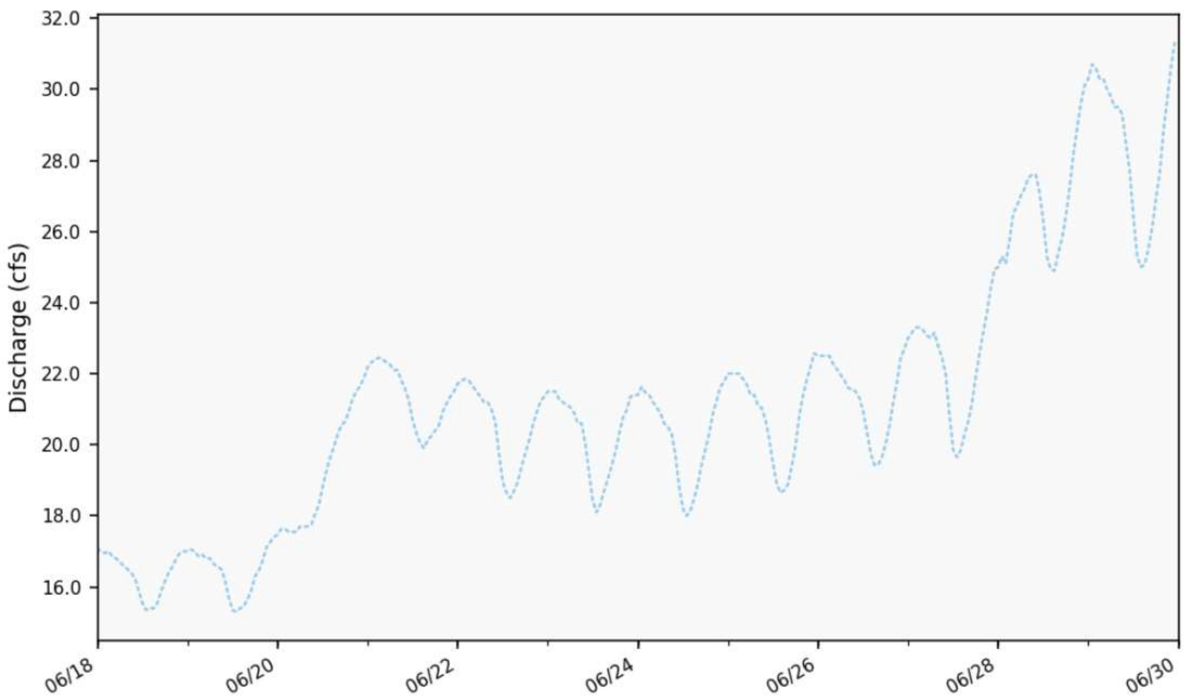


Figure 7. Recorded surface water streamflow over 10 days in the summer at 5-mile crossing. Diurnal fluctuations (saw teeth on the hydrograph) of more than 3 cfs in streamflow are a result of evapotranspiration.

Summary of climate analysis:

- Precipitation in the Straight GWMA has shown a long-term increase in precipitation, averaging +0.13 inches per decade from 1895 through 2021, but a slight decrease, averaging -0.09 inches of precipitation per decade since 1970.
- Since 1970, the area has warmed at a rate of over +0.60 degrees F per decade, nearly 6 times faster than the warming rate of +0.11 degrees F per decade between 1895 and 1969.
- Understanding and quantifying evapotranspiration in the SRGWMA will be necessary as the climate changes. The higher daily maximum temperatures of 2020 corresponded to a 28% increase in potential evapotranspiration over 2018, indicating that warmer future years may result in increased demand for groundwater.

Streamflow

Since the publication of the SRGWMA plan, expanded streamflow monitoring has enhanced the understanding of streamflow in the Straight River and Straight Lake Creek. Water levels in the river are measured continuously at seven locations, resulting in year-round records of streamflow every 15 minutes. Streamflow is also measured “synoptically” once every 30 to 40 days at 11 gage sites. Synoptic measurements of the SRGWMA are used to quantify the amount of gain or loss in streamflow between adjacent sites, which is assumed to be a measure of groundwater baseflow between those two sites through multiple springs, bank and channel seeps, and groundwater fed wetlands.

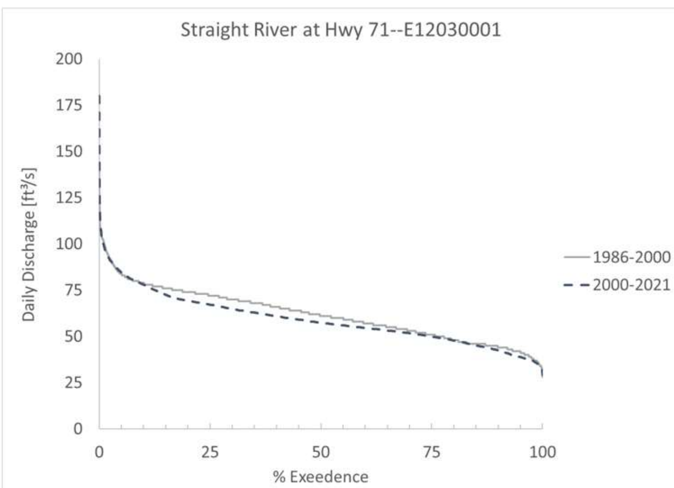
A study by the USGS from 1988 to 1990 concluded that groundwater appropriations would have impacted the Straight River by reducing flow up to 34% if groundwater appropriation rates had continued at the levels observed during the particularly hot, dry summer of 1988. (Stark et al., 1994). The DNR documented an atypical increase in winter streamflow along the river reach between the 7-mile crossing and the 3-mile crossing between 1996 and 1998 (Kruse, Merritt and Frischman, 2002). Normally, streamflow declines during the winter months because of the lack of direct recharge. The increase in streamflow during the winter months indicates that the groundwater levels are recovering from reduced levels due to pumping during the summer months. The recovered groundwater levels increase the amount of baseflow to the Straight River and cause increased streamflow during the winter. The calculated impact from water appropriations is between 2 to 4 cfs within that reach, or approximately 4% to 8% of the average streamflow during July and August. Stark et al. (1994) and Helgesen (1977) each noted flow losses in the Straight River between the 3-mile and Hwy 71 crossings and attributed these losses to natural conditions. Past reports and updated geologic mapping indicate that multiple buried sand and gravel deposits are overlain and seem to be hydrologically connected throughout. It is possible that these natural losses are exacerbated by groundwater appropriations during extremely low flows as documented in 1988 and 1989.

Streamflow comparisons

A flow duration curve is a graph that shows how often streamflow is equaled or exceeded over a set time. The shape of the curve is a result of the characteristics of the watershed and can indicate whether the stream receives primarily overland runoff, primarily groundwater inflow, or some combination thereof. Flow duration curves for the Straight River sites confirm that the stream is dominated by groundwater baseflow and is less responsive to precipitation. Streamflow at several SRGWMA sites throughout the watershed were compared over two time periods that have the similar sample intervals. The comparison of these curves from the same sites, over two time periods, show decreases in streamflow across the watershed. Some of the differences are not within the typical range of error in streamflow measurements and none of these comparisons were tested for statistical significance, however the results do indicate locations of the SRGWMA where there may be reason for concern.

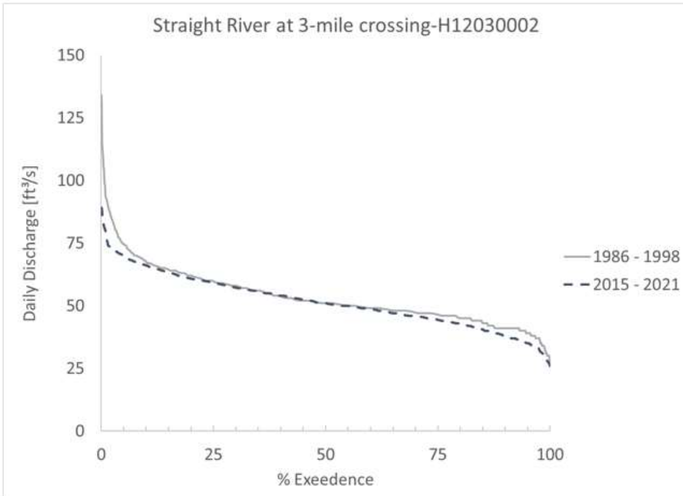
Comparing flow duration curves at the same site, but using data from different time periods, shows how streamflow has changed in the watershed over time. Due to limits in the monitoring record, equivalent time periods could not be analyzed. In order to compare separate time periods, each group was chosen so that an adequate amount of data were available for comparison. Flow duration curves can be established over any set period of time and are representative of the flows during that time period (Searcy, 1959). Without an adequately long period of record, the flow duration curve should not be used to forecast future conditions. Figure 8 compares the flow duration curves for daily streamflow at the Hwy 71 stream gage location over two time periods: 1986–2000 and 2000–2021. Although the time periods that are compared are not adequately long-term for forecasting, the difference between the two curves illustrates how flows at all magnitudes may have changed at these sites between two similarly sampled periods.

The table on the side of the graph lists the flows for each recurrence statistic. For example, the Q25 is a high streamflow that is only exceeded 25% of the time. For the period from 1986–2000 the Q25 at this site was 72 cfs. For the period from 2000–2021 the Q25 is 67 cfs., a 7% decrease without any test of statistical significance. The periods of comparison are different due to gaps in the monitoring record. In general, the flow data from the more recent period is lower than earlier period, indicating a potential decrease in streamflow over time. With precipitation over these periods showing no trend up or down, causes of this decrease in streamflow are likely a result of increased evapotranspiration and/or decreased baseflow to the stream. These decreases in daily streamflow are observed at other gage locations in the Park Rapids sub-management area (Figures 9 and 10) and amount to an average of 3–12% losses in streamflow.



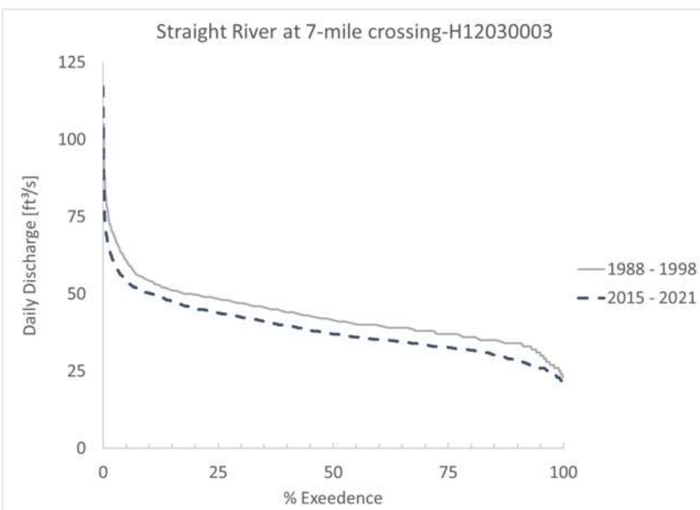
Hwy 71 E12030001	1986 – 2000 (N= 4355)	2000 – 2021 (N=7990)	% Difference
Q90	44	42	-4%
Q75	51	50	-2%
Q50	61	57	-6%
Q25	72	67	-7%

Figure 8. Streamflow duration curves and reference values for two time periods at Hwy 71 stream gage.



3-mile Crossing H12030002	1986 – 1998 (N=1801)	2015 – 2021 (N=2404)	% Difference
Q90	41	38	-7%
Q75	47	44	-5%
Q50	51	51	0%
Q25	60	59	-1%

Figure 9. Streamflow duration curves and reference values for two time periods at 3-mile stream gage. Due to gaps in monitoring, the earlier time period spans 13 years with 1,801 records, while the second period spans 7 years with 2,404 records.



7-mile Crossing H12030002	1988 – 1998 (N=1751)	2015 – 2021 (N=2403)	% Difference
Q90	34	28	-18%
Q75	37	33	-11%
Q50	42	37	-11%
Q25	48	44	-9%

Figure 10. Streamflow duration curves and reference values for two time periods at 7-mile stream gage. Due to gaps in monitoring, the earlier time period spans 11 years with 1,751 records, while the second period spans 7 years with 2,403 records.

The changes in streamflow in Park Rapids sub-management area were further analyzed by comparing the total summer streamflow during the months of May–September at the most downstream site with the longest, most continuous record, Straight River at Hwy 71 (Figure 11). Figure 11 presents the total summer streamflow from May through September at the US Hwy 71 gage location along with the 5-year average summer streamflow. Summer streamflow shows a correlation with precipitation trends in the area, notably during 1993–2002 with above average streamflow and above average rainfall. Annual responses to precipitation are also apparent in Figure 11. Summer streamflow from 2011 to 2012 dropped more than 35% largely because of a 28% drop in annual precipitation between 2010 and 2011.

The 2021 drought year was a result of sustained low rainfalls. In 2020 and 2021, 22.4 and 20.9 inches of rain fell, well below the area average of 26 inches per year. As a result, total streamflow over the 2021 summer season was the lowest since the drought of 1988–1990. What is most notable when comparing the two similarly dry years, 1990 and 2021, is that despite reported water use increasing over 180% from 1990 to 2021, total summer streamflow in 2021 was 20% greater than that was measured in 1990.

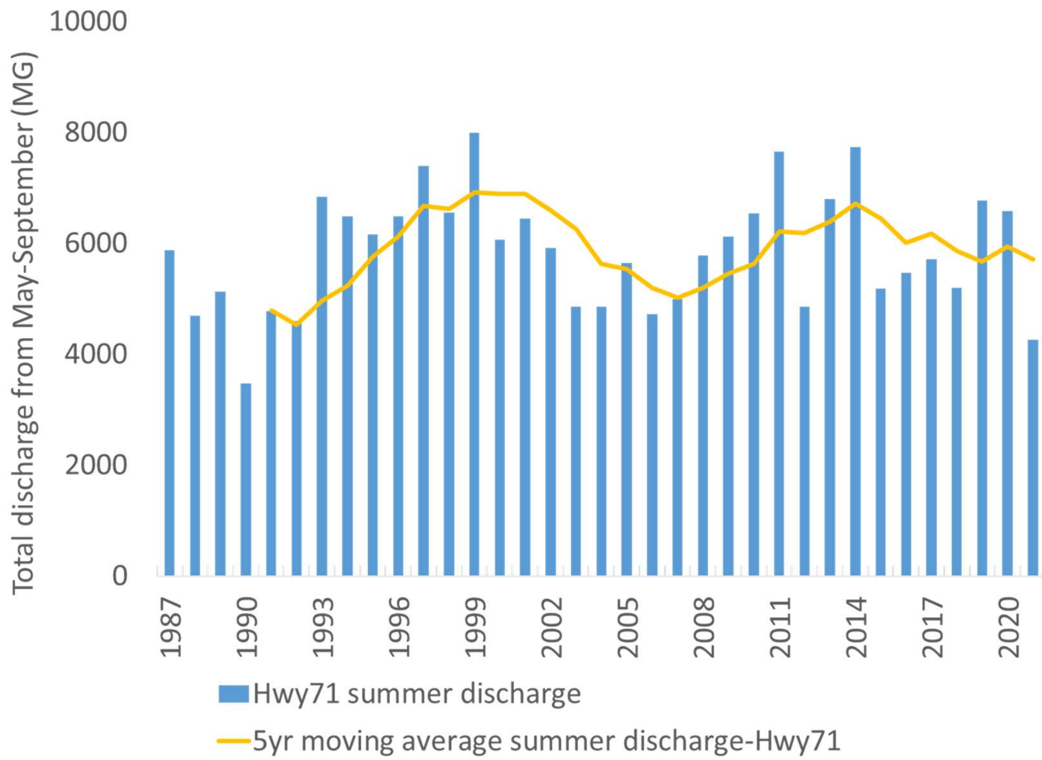


Figure 11. Total and 5-yr average summer streamflow (discharge) recorded at US Hwy 71, 1987-2021.

The 5-year average summer streamflow shows that there does not appear to be a strong signal of decreased total summer streamflow in the Straight River GWMA despite large increases in annual water use in the area (Figure 11). There doesn't appear to be seasonal or year-on-year losses of streamflow, but there are impacts that are localized and isolated (Figures 17, 18, 19, and 20). This system is currently resilient enough to recover from these concentrated impacts. The summer streamflow measured at the outlet of the SRGWMA, where the accumulation of impacts should be most apparent, is not showing a decline in annual or summer seasonal discharge. The exceedance curves in Figures 8, 9 and 10 show less streamflow in the stream at certain downstream sites between the two time periods, but the period of record is too brief to be significant. Continued monitoring in the GWMA will help to assess future changes in the Straight River or groundwater resources of the area. The GWMA is permitted to appropriate significantly more water than is typically reported (Figure 12), and so this system is situated to be at risk from prolonged drought or changes in climate.

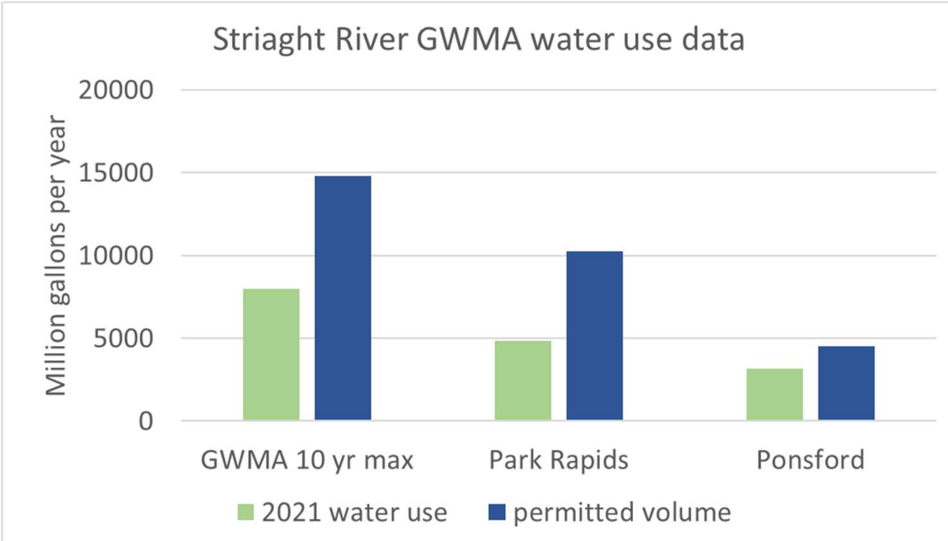


Figure 12. Total water use in 2021 with total permitted water use for the Straight River GWMA

Baseflow analysis

The Straight River watershed has no major tributaries or ditches that flow into the river and as discussed above, is primarily fed by groundwater baseflow. As a result, changes in streamflow between two consecutive locations is assumed to be a result of changes in groundwater baseflow. Groundwater baseflow has been documented numerous times to consist of more than 90% of all surface water streamflow in the Straight River. Two methods are employed for measuring the amount of groundwater contributions to surface water streamflow. The first method measures the change in streamflow measured on the same day at adjacent sites during synoptic measurements. Assuming conditions do not change over several hours between measurements, an increase in downstream streamflow is a result of groundwater baseflow to the river. Conversely, a decrease in downstream streamflow would be a result of streamflow losses to groundwater. The second method to estimate groundwater contributions to surface water streamflow is through an analytical method referred to as "baseflow separation". Using the mean daily streamflow at each of the seven stream gage locations in the SRGWMA, estimated baseflow is calculated using the USGS Groundwater Toolbox software for baseflow separation (Barlow et al., 2017. USGS). The results from this method provide analytical estimates of groundwater baseflow at each of the gage locations. Analytical methods are discussed in greater detail in (Barlow et al., 2014. USGS).

Beginning in the headwaters of the Straight River in the Ponsford sub-management area, the first two gaging locations that are measured synoptically are the 300th St. and 285th St. locations. Streamflows along this reach vary with the season and year, but gages on this reach show more water downstream than upstream, making it a gaining reach. The average gain in surface water streamflow from groundwater baseflow in this reach of the river is 3.7 cfs over 2.3 miles of river. Normalizing the gains in water per river mile makes it easier to compare a 2.3-mile reach with other reaches that are more than 5 miles long. In this reach, the river gains 1.6 cfs per river mile (cfs/mile).

The only tributary to Straight River is Straight Lake Creek. It is also one of the largest gaining reaches in the SRGWMA. On average, streamflow increases 1.3 cfs over approximately 0.27 river miles from the station at the Lady Slipper Inn down to the next station at 520th Ave for a reach average gain of 4.8 cfs/mile. The reach from 285th St. receives streamflow from Straight Lake Creek, but the average gain after this contribution is 3.0 cfs or 2.7 cfs/mile. Table 1 summarizes the average measured gains and the median August gains for the synoptic sites in the Ponsford sub-management area. The results from the analytical estimates also match closely with what is measured during the synoptics. Figure 12 shows the other reaches with Ponsford sub-management area with respective gain rates.

Ponsford sub-management area	Average measured synoptic gains (cfs)	Median August measured synoptic gains (cfs)	Median base flow separation gains (cfs)	Median base flow separation % of flow	Median August baseflow separation gains (cfs)
2.3-mile reach from 300th St. to 285th St.	3.7	1.8	NA	NA	NA
1.6-mile reach from 285th St. to Bass Bay Ave.	3.0	2.9	3.0	93%	6.5
0.3-mile reach from Lady Slipper to 520th Ave. (Straight Lake Creek)	1.3	1.0	1.3	95%	1.1

Table 1. Groundwater baseflow values for three reaches in the Ponsford sub-management area. Reaches without baseflow separation numbers are synoptic reaches and do not have the necessary data for statistical analysis.

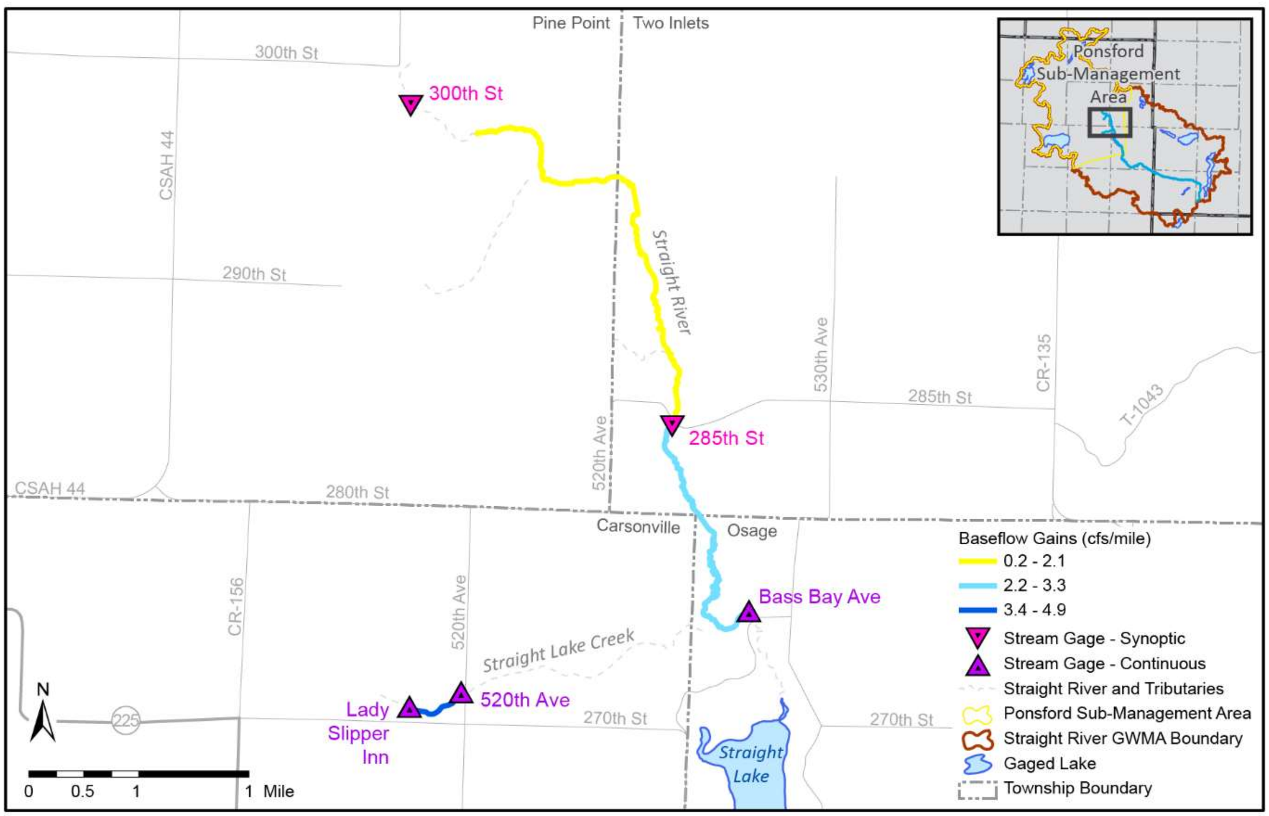


Figure 13. Streamflow gains from groundwater baseflow by reach, Ponsford sub-management area.

Measured gains in surface water streamflow from groundwater baseflow continue in the Park Rapids sub-management area (Table 2 and Figure 13). The entire length of the Straight River consistently gains in streamflow from groundwater up until the last reach of the river from the gaging station at 1-mile crossing to Hwy 71. Unlike the rest of the river, occasional losses are measured from the 1-mile crossing down to Hwy 71. These losses vary throughout the year. Of the 38 synoptic measurements, 23 indicate a loss on this reach, occurring in all months. These losses also occur in the areas of the SRGWMA where groundwater interacts with surface waters like the Straight River.

Park Rapids sub-management area	Average measured synoptic gains (cfs)	Median August measured synoptic gains (cfs)	Median base flow separation gains (cfs)	Median base flow separation % of flow	Median baseflow separation gains in August
5.3 mile reach from Osage to 7-mile	16.1	18.3	16.6	94%	15
6.9 mile reach from 7-mile to 3-mile	12.7	6.1	11.7	97%	6.4
1.3 mile reach from 3-mile to 2-mile	3.5	2.5	NA	NA	NA
1.4 mile reach from 2-mile to 1-mile	2.1	7.9	NA	NA	NA
1.0 mile reach from 1-mile to Hwy 71	-0.5	-4.3	8.6	97%	12.5

Table 2. Groundwater baseflow values for five reaches in the Park Rapids sub-management area. Reaches without basflow separation numbers are synoptic reaches and do not have the necessary data for statistical analysis.

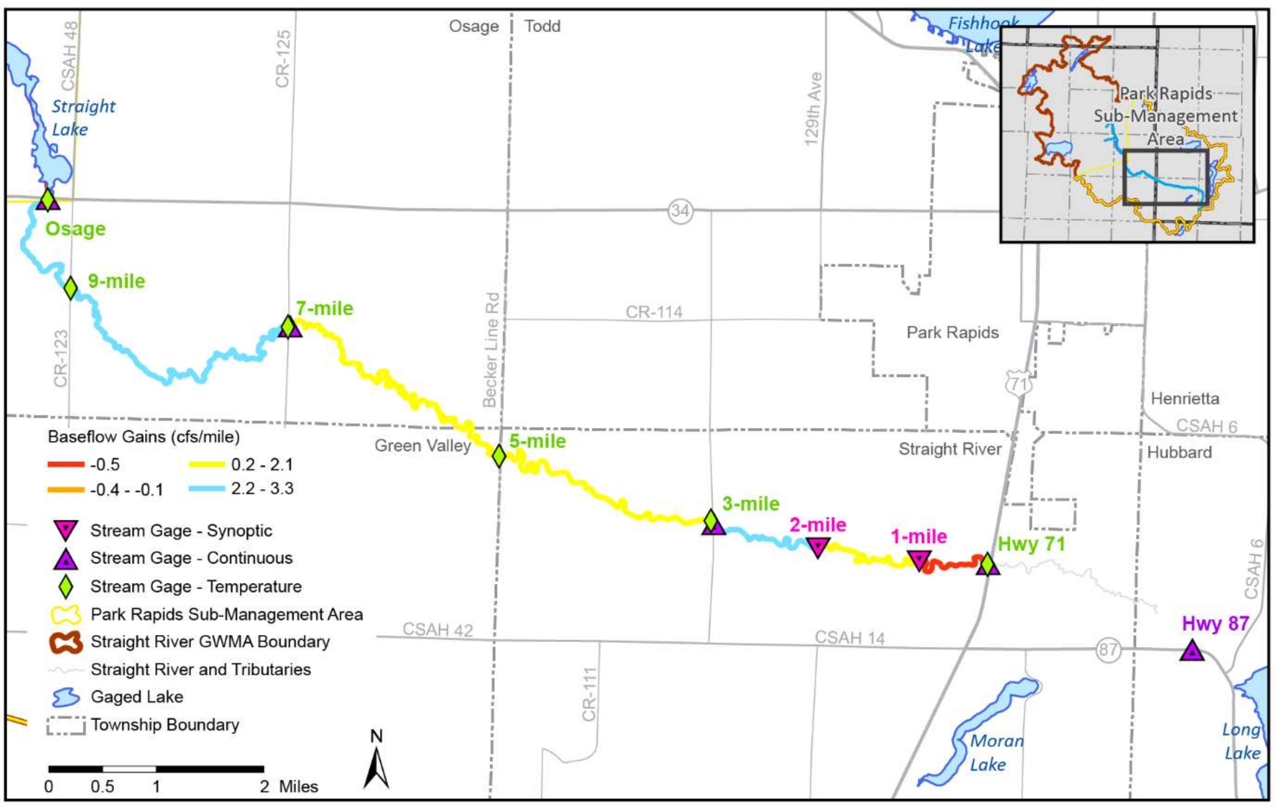


Figure 14. Streamflow gains from groundwater baseflow by reach, Park Rapids sub-management area.

It has been determined that the median August baseflow can be used to assist in threshold development as a value to preserve the seasonal variability of the natural hydrology and maintain geomorphology, water quality, connectivity, and biology of the system the vast majority of the time (MNDNR, 2016 - Report to the Minnesota State Legislature: Definitions and Threshold for Negative Impacts to Surface Waters). Table 3 provides the median August baseflow for seven stations in the SRGWMA.

Station	Median August Base flow (cfs)
Lady Slipper Inn	*0.3*
520th Ave	1.4
Straight Lake Creek	
Bass Bay Ave	*7.9*
Straight Lake	
Osage	*19*
7-mile	*34*
3-mile	40
Hwy 71	53

Table 3. Median August baseflow for seven stations in the SRGWMA

Summary of stream streamflow analysis:

- Groundwater baseflow provides 93–97% of streamflow throughout the SRGWMA
- Summer streamflow on the long-term gage on US Hwy 71 do not show a significant decline over the period of record
- Median reach gains vary from 1.5 cfs/mile to 3.1 cfs/mile (~1.1–2 million gallons per day (MGD)/mile) in the main stem and 4.8 cfs/mile (3.1 MGD/mile) in the Straight Lake Creek.
- The 1-mile to Hwy 71 reach in the SRGWMA is the only portion of the Straight River that loses water frequently to the underlying aquifer. The losses are not consistent and range from 0.5–4.3 cfs.
- Median August baseflow has been determined for seven locations on Straight Lake Creek and the Straight River.

Groundwater

The SRGWMA's geology is complex and varied. The area is covered with a mixture of thick glacially-deposited till, outwash and glacial-lake deposits. The till consists of poorly sorted clays, silts, sands, gravels, and boulders. Outwash was deposited by glacial rivers and ponds. Glacial-lake deposits (silt and clay) formed in the glacial lakes and ponds. This means that the aquifers (formed in the area's sands and gravels) and confining units (formed in the area's silts and clays) are not contiguous. In addition, the aquifers, and confining units thin and thicken in a variable pattern across the area. This variable geology affects the hydrologic properties of the aquifers in this area along with their interconnectedness. The Minnesota's Geologic Survey's County Geologic Atlas program has mapped the outwash deposits in this area (2016, 2018, 2018), which has contributed a great deal to the interpretation of groundwater resources in the area.

The Minnesota Geologic Survey (MGS) published County Geologic Atlases (CGA) for Becker, Hubbard, and Wadena counties since the commencement of SRGWMA plan. These atlases are an excellent reference for understanding the extent, depth, thickness, and potential interaction between different aquifer resources. Results from the atlases confirm past models of the water table aquifer that were developed by Helgeson, 1977; Stark et al., 1994; and Camp Dresser and McKee, 1999. Within Stark et al.'s area of investigation, the extent of the water table aquifer is similar between CGA water table results and Stark et al.'s results. Figure 14 shows the extent of surficial sand and gravel deposits in the SRGWMA as well as locations in that area where the thickness is over 100 feet thick. Generally, most of the surficial sand and gravel aquifers are 20–40 feet thick and are underlain with glacial tills that vary in extent and content.

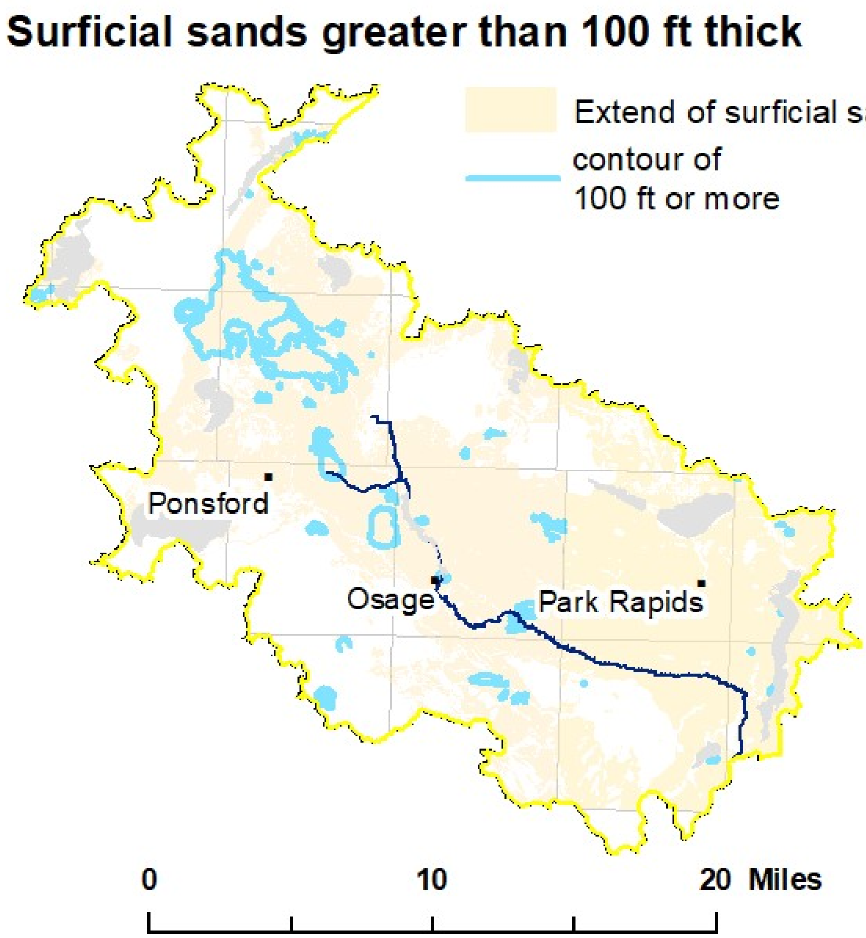


Figure 15. Extent of surficial sand and gravel deposits as presented in the County Geologic Atlas Part A for Becker and Hubbard counties.

The 2016 interpretation of confined aquifers by the MGS has significantly improved the understanding of these aquifers in the SRGWMA. Stark et al., 1994 defined a large continuous confined aquifer that spanned almost the entire area of the Park Rapids sub-management area. The three CGAs have refined the boundary and reduced the extent of the confined aquifer in the Park Rapids sub-management area, particularly near Osage (Figure 15). Confined aquifers could be more extensive than mapped in locations where there are gaps in drilling records that reach to the depths of the aquifers. Where drilling information is missing, the MGS default is to map the till unit that corresponds to each elevation interval. Where mapped, confined aquifers vary in thickness from 20 feet to more than 40 feet in areas around the town of Park Rapids, at the lower reaches of the Straight River near Hwy 71, and in the Ponsford area.

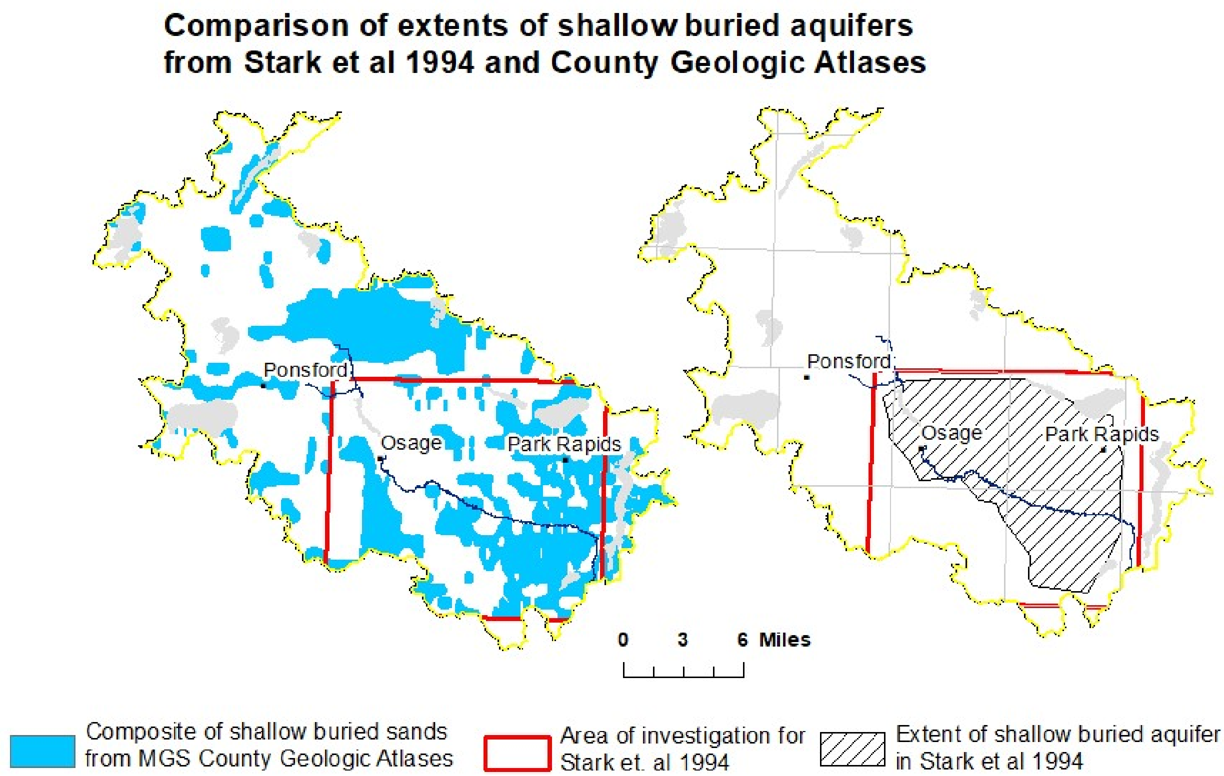


Figure 16. Comparison of shallow confined aquifers extents from Stark et al., 1994 and County Geologic Atlases.

The County Geologic Atlas also delivers data that helps to characterize the extent and thickness of confining layers. Where confining layers are thin or not mapped extensively, surficial water resources (surface waters and water tables) are likely connected with adjacent confined aquifers. Theoretically, confined aquifers are hydrologically separated from the surface by confining layers consisting of clay, glacial till, and other less permeable layers. These confining layers attenuate impacts from pumping the confined aquifer from propagating upwards and impacting surface waters. Areas of concern are outlined where the confining layer was less than 20 feet thick and beneath areas with surficial sand and gravel deposits (Figure 16). The Minnesota Department of Health states that a confining layer needs to be at least 10 feet thick, and with several of these tills containing more than 60% sand, a thickness of 10–20 feet is assumed to be conducive to a hydrologic connection with the water table and surface waters. It is possible that around these areas of concern, intensive and sustained pumping from the confined aquifer could capture water from the water table and surface waters at a rate that is greater than what is transferred in natural conditions.

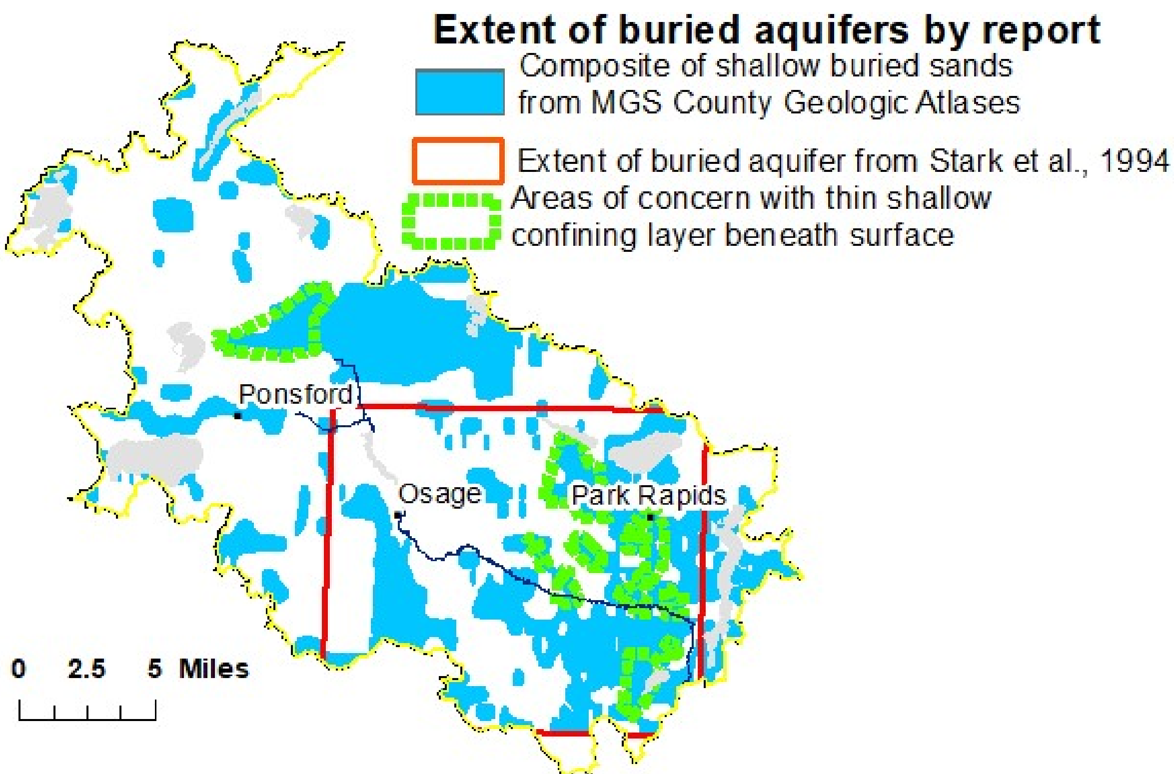


Figure 17. Extent of shallow buried sands and areas where thin confining layers are conducive to surface water–groundwater interactions.

Analysis of groundwater levels

As previously noted, since the SRGWMA plan was written, groundwater level monitoring expanded from 56 observation wells with 33 continuous data loggers in 2015 to 59 observation wells with 52 data loggers in 2022. These added wells have filled monitoring gaps in the area and replaced several older, dysfunctional wells. The increase in the number of wells that have data loggers recording hourly water levels has added to the quality of monitoring in the area. Of the 59 total observation wells, 40 monitor the water table aquifer and 19 monitor the confined aquifers in the SRGWMA.

Nested observation wells or well nests are a monitoring location where multiple observation wells monitor different aquifers at different depths. Well nests are important monitoring sites because they help to explain the vertical flow dynamics between aquifers at different depths as well as the interaction of groundwater and surface water. In the Park Rapids sub-management area, well nests adjacent to the Straight River show an upward vertical gradient. That is, the confined aquifer has a higher head than the water table aquifer, and because of this higher head, the groundwater in the deeper aquifer has a force driving it up. In addition, aquifer tests previously completed in this area, along with long-term monitoring at several well nests, show that pumping the confined aquifer causes drawdown in the water table aquifer.

Seasonal variation in groundwater levels

Park Rapids sub-management area

Seasonal fluctuations in the water table and confined aquifers follow an annual cycle that is driven by summer water use and local precipitation. Water levels in confined aquifer observation wells in this area show seasonal declines up to 12 feet due to pumping (#149510, #243874). Due to the difference in hydraulics between an observation well in the water table and a well in a confined aquifer, water levels in the water table observation wells do not show as pronounced of a seasonal decline. Despite this lack of hydrographic evidence, it is still reasonable to assume that intense, seasonal pumping in the water table aquifer from wells that are close to the stream does decrease groundwater baseflow that would naturally flow to the Straight River. In much of the Park Rapids sub-management area mostly in areas away from the Straight River, the natural vertical gradient is downward between the water table and confined aquifers. Near the Straight River, though the vertical gradient is upwards, it appears that pumping from confined aquifers near the Straight River is also impacting the amount of groundwater that would normally discharge into the river as streamflow.

Aquifer testing and long-term monitoring throughout Minnesota has shown that pumping stress causes confining layers to leak, which is possibly occurring at sites in the Park Rapids sub-management area. The addition in 2002 of a new irrigation well is an excellent example of what an additional, localized stress can do to water levels and groundwater baseflow to the Straight River. Levels in observation well #149510 do not begin a seasonal drawdown until 2002 and the drawdowns are likely a result of the replacement of a water table irrigation well with a confined aquifer irrigation well on the south side of the Straight River. In this instance the new, confined aquifer well that is south of the river most certainly causes drawdowns in the confined aquifer observation well to the north of the river. These drawdowns spread beneath the Straight River for several hundred feet in all directions. With the leaky confining conditions likely to be in this area, groundwater baseflow is depleted along this stretch of the Straight River. Under certain conditions where intense irrigation abuts the river and where aquifer materials are leaky and permeable, some reaches may encounter streamflow capture.

The well nests located at Hwy 71 near Park Rapids have three observation wells: two wells completed in the water table (#243392 shallow water table and #272084 deeper water table) and one well completed in the confined aquifer (#243870). A stream monitoring station is also at this site. For clarity, only two wells from this nest are shown in Figures 17 and 18. The relationship between the confined aquifer and the water table aquifer water levels and the stream levels is better demonstrated by focusing on one years' worth of data. The water table provides the main source of groundwater to the Straight River with levels in observation well #272084 typically higher than water levels in the river. Without groundwater pumping, the direction of groundwater flow at this site is upward from the confined aquifer to the water table aquifer and to the Straight River.

Beginning in May 2021 when irrigation begins, the confined aquifer observation well #243870 in this well nest responded with a typical sawtooth pumping pattern where water levels declined rapidly with the start of pumping and recovered when pumping stopped (Figure 17). On April 30, 2021, there was an upward vertical head difference of 0.97 ft from the confined aquifer up into the water table. Each pumping cycle progressively decreased the water levels in the confined aquifer. Over the month of May, water levels declined by 1 foot in the confined aquifer, 0.1 feet in the water table aquifer, and the vertical gradient changed direction from upward to downward. Assuming a hydrologic connection between the confined aquifer and the water table aquifer, over this time in May there was less water moving upward from the confined aquifer to the stream. Water levels in the confined aquifer eventually dropped below the water table, reversing the gradient between aquifers to downward. The downward vertical gradient persisted for 76 days at this site through all of June, most of July and half of August 2021. The downward vertical gradient was the largest on June 26 when the vertical head difference for the day was -0.83 ft (Figure 18). Water levels on June 26 were 2 feet lower in the confined aquifer and 0.2 feet lower in the water table aquifer than they were at the beginning of May. Water levels in the confined aquifer well remained above water levels at the stream gage, however. The vertical gradient did not consistently return to an upward direction until August 25, 2021 and did not return to the magnitude seen at the beginning of May 2021 until March 2022.

In this example at Hwy 71 it is worth noting that the vertical gradient only indicates a potential for groundwater to move upward. The actual movement of groundwater between the confined and water table aquifers is controlled by the thickness, composition, and continuity of the confining layer that separates the confined aquifer and water table aquifer. Over the last several miles of the Straight River in the SRGWMA, shallow confining layers are characterized as more than 60% sand and less than 15% clay (County Geologic Atlas Part A, 2026-2018), and as is shown in Figure 16, there are several large areas of the Park Rapids sub-management area where the confined aquifers are likely connected to the surface. These confining layers also appear to be spotty and inconsistent or previously eroded. Under these conditions it is likely that groundwater from the confined aquifer moves through the confining layer upward to supply the water table and Straight River with steady groundwater flow. Despite 2021 being a year of severe drought in the area, this reversal of the gradient is apparent in this well nest in 7 of the past 8 years of logger data.

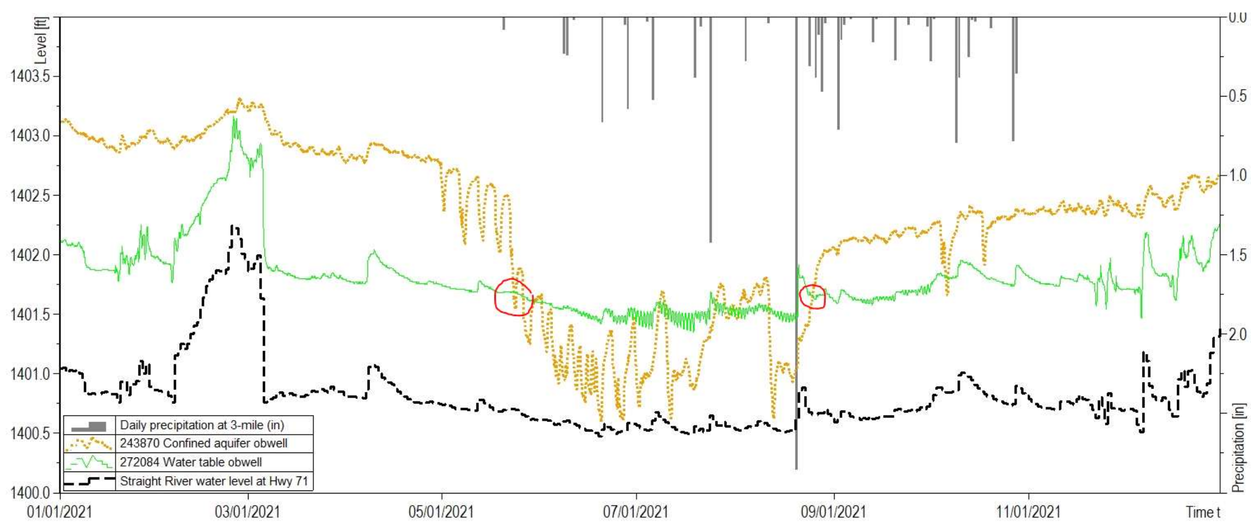


Figure 18. Well nest and stream level hydrographs with daily precipitation at Hwy 71 crossing. The red circles identify the start and end of the flip in vertical flow gradient observed at this site.

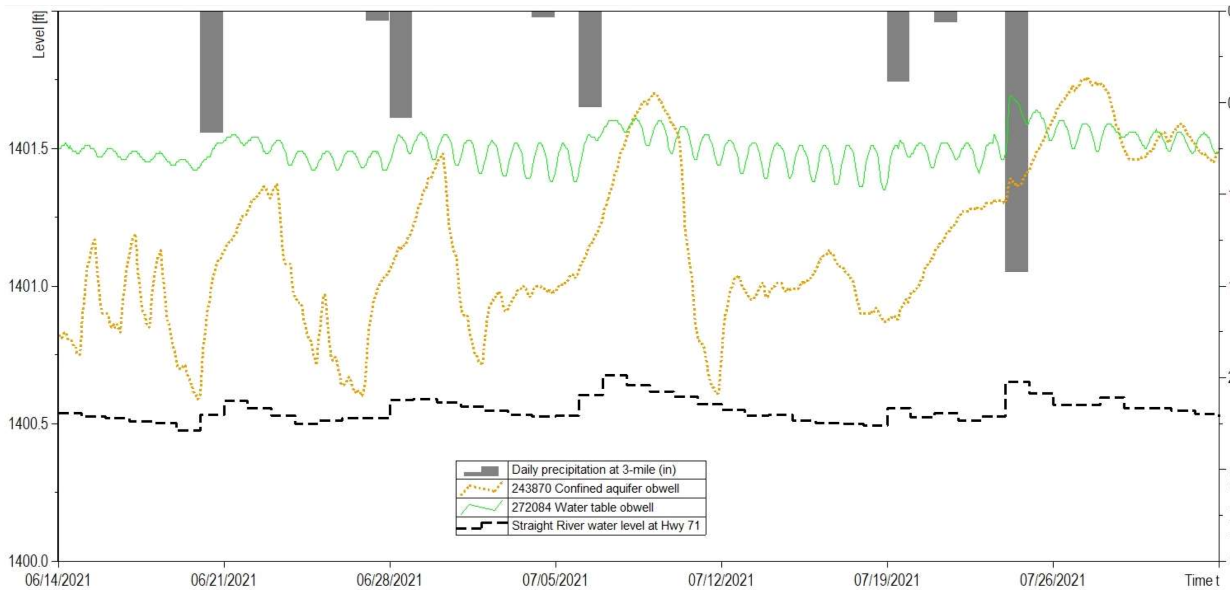


Figure 19. Seven weeks of the hydrograph at Hwy 71 during the drought of 2021.

The vertical gradient in the well nest at 2-mile crossing just upstream from the Hwy 71 shows a similar inversion (Figure 19). At this nest, water levels in the confined aquifer go below the level of the water table and drop below an estimated river elevation (Figure 20). There is not a continuous record of stage at the stream gage on 2-mile crossing, but 6 years of manually collected river elevations range from 1,412.5-1,413.9 feet in elevation. Water levels in #149510 fall below 1,412 feet for the duration of the summer irrigation season. Water levels return above the stream elevation and water table after the irrigation season stops in September. This is another instance in the lower Park Rapids sub-management area where pumping from the confined aquifer changes the hydraulics enough to switch as a source of groundwater flow to the water table during non-irrigation season to a sink for the water-table aquifer during irrigation season. If leaky confining conditions are present, which is a strong possibility in this setting, then these sustained inversions are likely to decrease the amount of streamflow present, either through the diminishing of baseflow or the capture of streamflow.

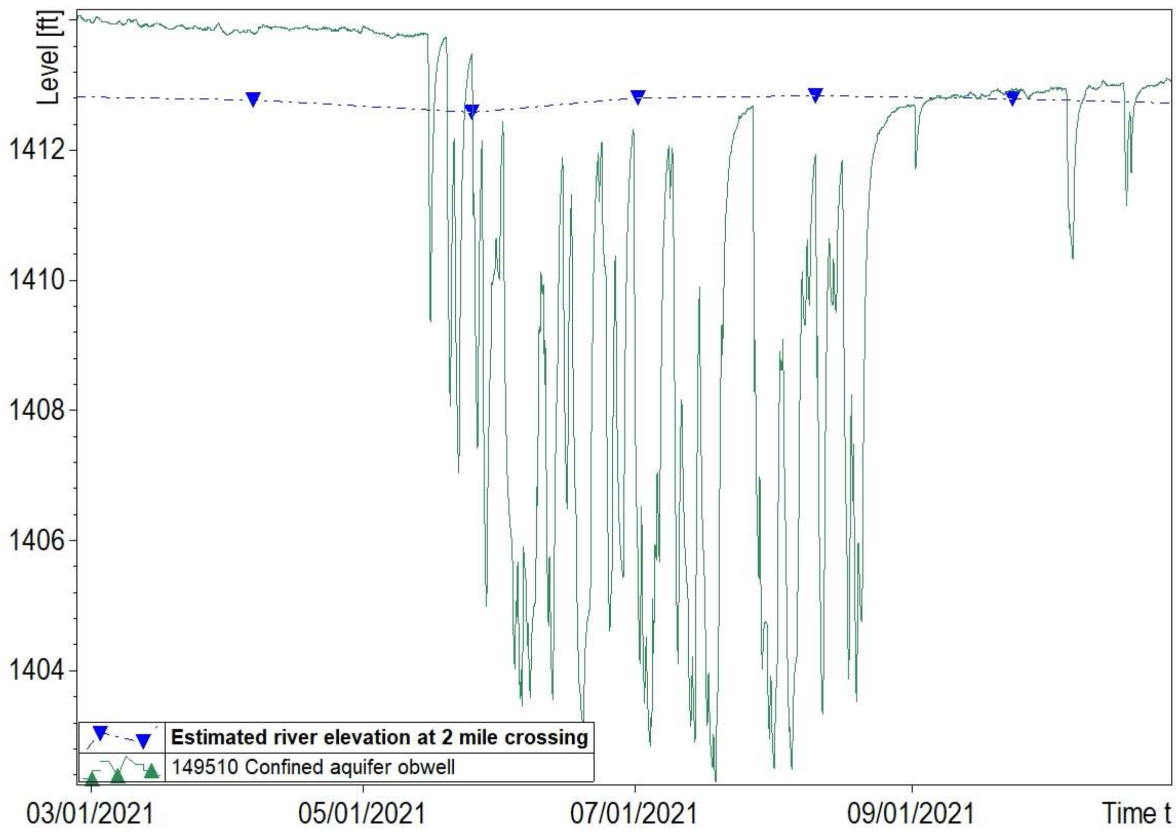


Figure 20. Well nest and stream level hydrographs 2-mile crossing. This site also indicates a change in vertical flow gradient.

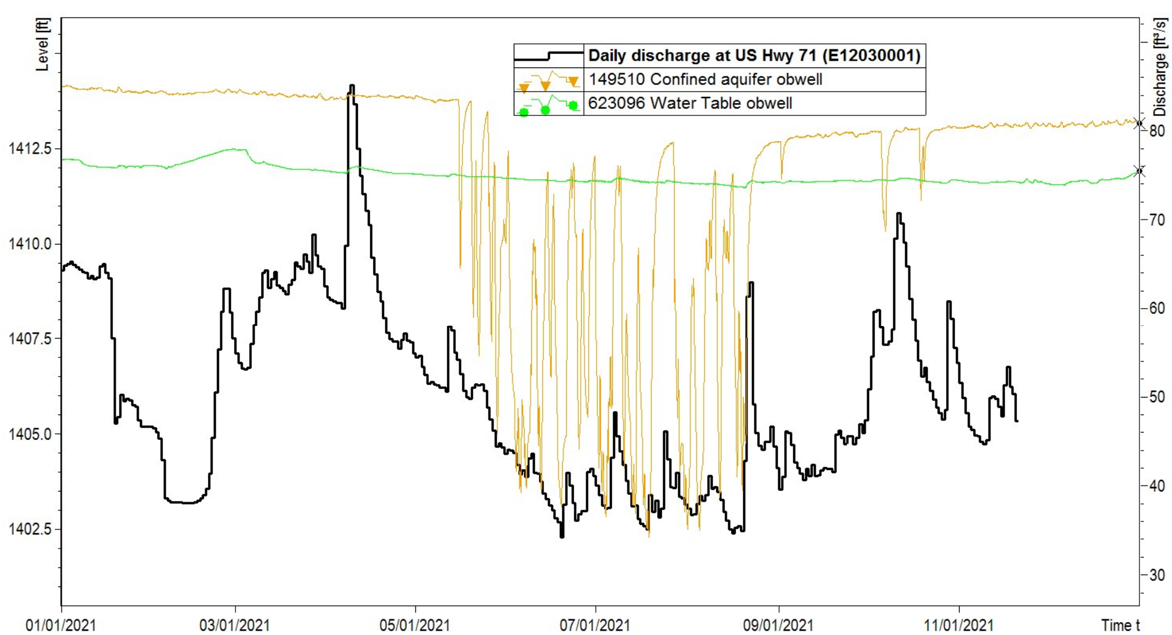


Figure 21. Well nest and stream streamflow hydrographs at 2-mile crossing showing another gradient inversion during the 2021 irrigation season and potential inversion beneath the stream stage.

The conditions change upstream of 3-mile crossing and away from the Straight River, but the connection between the confined aquifer and the water table is still apparent in several hydrographs. The well nest (243874,243875, 243371) northeast of 5-mile crossing shows an area with a naturally downward vertical gradient, which is different from the locations downstream and closer to the river. Drawdowns from the irrigation season in this well nest still lower the confined aquifer 10–15 feet each summer. Water levels in the water table well at this nest also appear to recede more rapidly in mid-summer due to maximum demand on the aquifer from evapotranspiration and pumping (Figure 21). Typically, at this nest site, the vertical gradient is 1–2 feet different in the downward direction. During the irrigation season the downward vertical gradient intensifies to 10 or more feet for nearly four months of the summer. The rate of recession of the water table levels at this nest increases during the last portion of the peak demand and evapotranspiration (ET). Pumping from the water table aquifer closer to the stream may be the greatest potential concern along this reach, but the seasonal impacts from pumping from the confined aquifer appear to be lowering water levels in the water table and surface waters.

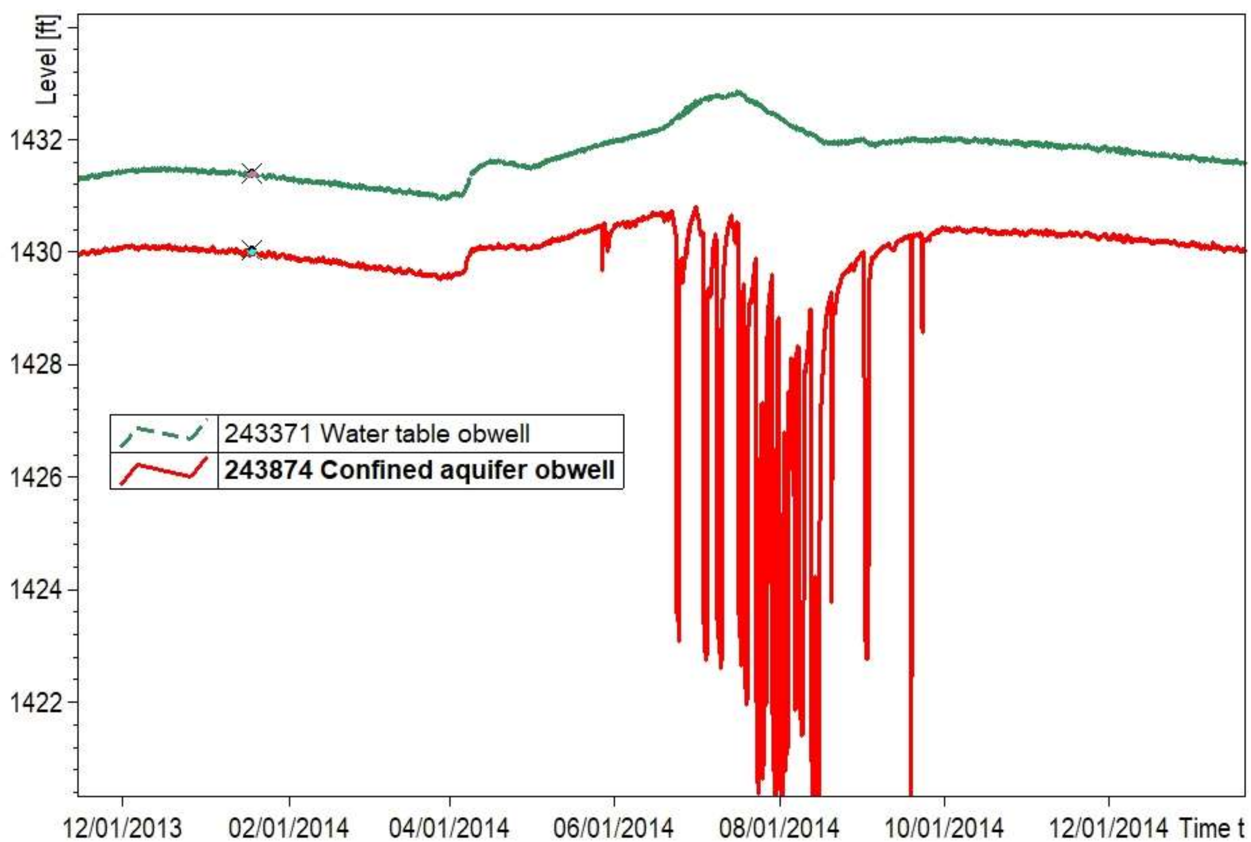


Figure 22. Interaction of water table and confined aquifer at a well nest in middle of Park Rapid sub-management area.

Ponsford sub-management area

The hydrologic setting changes in the Ponsford sub-management area. Sandy soils with buried sand and gravel deposits are present throughout the area and at depth. As a result, almost 80% of the wells permitted to irrigate in the Ponsford sub-management area are pumping from the water table aquifer. Only 35% of the wells in the Park Rapids sub-management area pump from the water table aquifer. The surficial sand and gravel aquifer in Ponsford is also thicker than the Park Rapids sub-management area, exceeding 100 feet over much of Pine Point township. The water table aquifer in the Park Rapids sub-management area is not this thick, which is why over 65% of the wells pump from the confined aquifer in the Park Rapids area. As a result, there are not as many well nests to compare in the Ponsford sub-management area, but there are several interesting locations that are near the Straight River tributaries or other major groundwater streamflow features that help to explain the hydrology in this area. Like the Park Rapids sub-management area, groundwater in the Ponsford sub-management area has a naturally downward vertical gradients from the water table to the confined aquifer. Vertical head differences are also similar between the two areas.

Groundwater recharge as predicted in the USGS model across the SRGWMA is the greatest in the Ponsford sub-management area due to the presence of extensive surficial sand and gravel deposits (Smith and Westenbroeck, 2015). Recharge rates have been estimated to exceed 7 inches per year through much of the irrigation district of this area, noticeably greater than the 4–6 inches per year that is predicted in the Park Rapids sub-management area. There also appears to be significant lateral recharge from the morainal uplands to the north and west of Ponsford. Much of this groundwater movement discharges into a wetland complex through numerous springs, seeps, and wetlands in the lowlands of the Two Inlets State Forest and hills north of Pine Point. This zone of groundwater streamflow has the potential to provide habitat for groundwater dependent biology in the area (MN DNR SRGWMA Plan, 2017).

The periods of record at stream locations and wells in the Ponsford sub-management area are shorter than those in the Park Rapids sub-management area, so it is not possible to evaluate long-term trends in streamflow and groundwater. Despite this limited length of record, there are several important locations in the area that help to characterize impacts from adjacent appropriators. In general, observation wells in the Ponsford sub-management area do not show drawdowns that are as large as those in the confined aquifers around Park Rapids. The only confined aquifer observation well in the Ponsford area that shows clear seasonal drawdowns is #630580 and those drawdowns are less than 2 feet. Like the Park Rapids sub-management area, the wells in the Ponsford area that do have seasonal drawdowns regularly recover in early fall after the completion of the irrigation season. Figure 22 is a hydrograph of a well nest in the Ponsford sub-management area (#630586 and #630580). This hydrograph shows the downward gradient from the water table to the confined aquifer and that the overall seasonal decline in water levels is about 2 ft. This is an indication that the aquifers are acting as one system, basically one large surficial water table aquifer.

It can be informative to compare sites near groundwater use to sites with minimal pumping drawdown, although local hydrogeologic differences complicate any such comparisons. Comparing #630586 with another water table observation well #783250, which is east of the irrigation zone and about 1.5 miles from the nearest irrigation well, indicates that the water table at #630586 declines by about the same amount at these two locations during the irrigation season (Figure 22). Water levels in #783250 do recover more quickly beginning in late August. Short-term rises and dips are larger in general at #783250. These lower summer water levels annually recover. The water table at #630586 declined at a quicker rate during the winter months, however, reflecting a much larger rise in the water table during the previous two years (not shown in Figure 22). Local differences in hydrology and aquifer physical properties contribute to differences in the magnitude and timing of water-table changes at these two locations. Well #783250 is located about 350 feet from a wetland where the water table is shallower than at #630586, and the water table aquifer is much thinner at #783250 (< 25 feet at #783250 vs. about 80 feet at #630586). Wetland storage and the shallow depth to the water table may reduce the overall range of fluctuations in the water table at #783250, but wetland evapotranspiration may increase summer water-table declines at this location, for example. It may be that the effects of groundwater pumping in the vicinity of #630586 are similar to the effects of nearby groundwater ET at #783250 during the summer.

It appears that impacts from irrigation in the Ponsford sub-management area are localized in their influence and temporary to the irrigation season and adjacent months. There are no discernable trends in water levels collected outside of the frozen or irrigation season (i.e., March, April, and May). This means that there does not appear to be long-term sustainability concerns for the Ponsford sub-management area. Because of the interconnectivity of the aquifer system to surface water features we expect reduced groundwater baseflow to the Straight River in specific locations where pumping is close to groundwater discharge areas and the river.

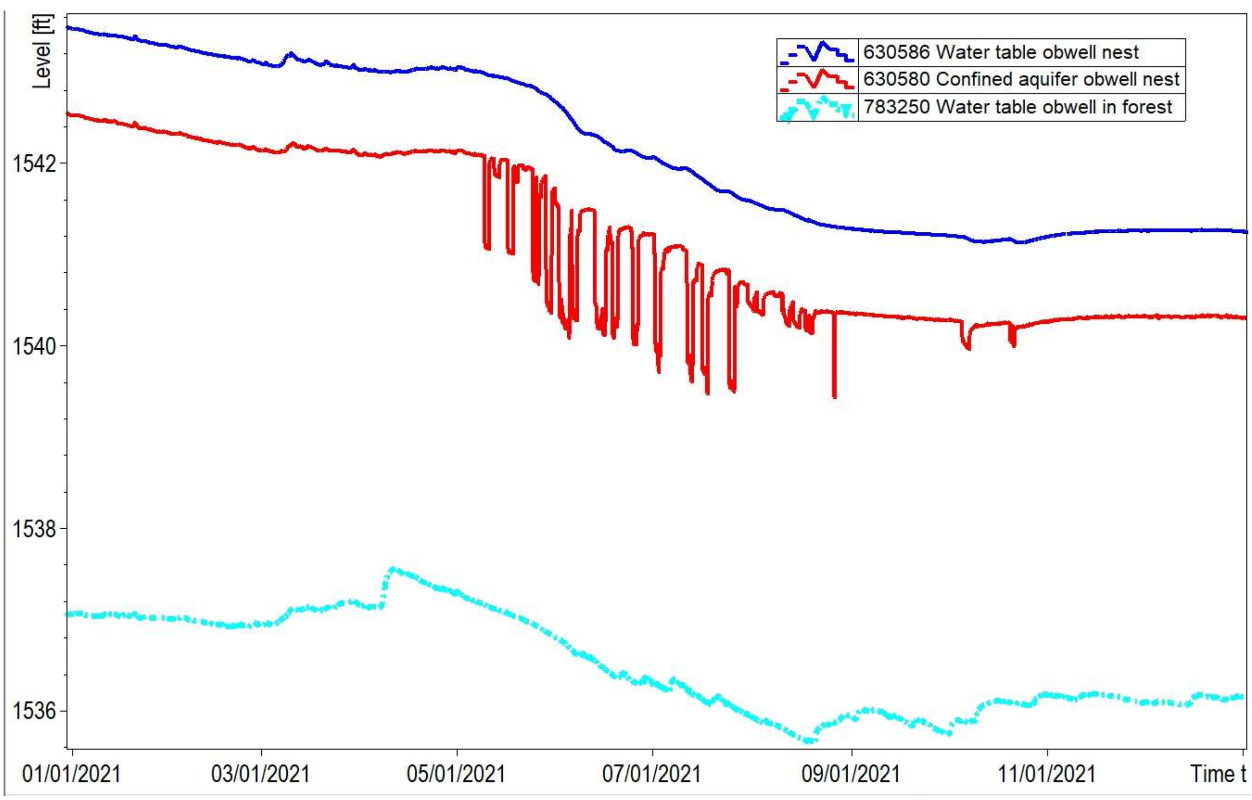


Figure 23. Seasonal drawdowns are observed in the confined aquifer in the Ponsford sub-management area though impacts to the water table and streams are not pronounced.

The proximity of pumping to the Straight River or Straight Lake Creek is the variable that has the most impact on streamflow. The drawdown at a pumping well is greatest right next to the pumping well and gradually decreases as the distance from the well increases. The irrigation wells that are closest to the streams are the sites that have the potential to cause the largest impact to streamflow. The Theis equation is an analytical method that is used to estimate drawdowns at a specific distance from a well that is pumping at a constant rate. Using general parameters for an unconfined aquifer (Transmissivity=30,000 ft^2/day, storativity of 0.3, and aquifer thickness of 100 ft.), a cone of depression was estimated using the Theis equation and mapped for a sample area where irrigation is nearby the Straight River and pumping from the water table aquifer (Figure 23). Each of the circles in Figure 23 show where 30 days of pumping at one well could create a decline in the water table of approximately 1 foot. The circles are about 2,000 feet in diameter and do not typically extend beyond the field that is irrigated, but the declines are greater within the circles as one moves closer to the pumping well. Water level data collected during DNR permit reviews of water appropriation permits 1999-1165, 1999-1164, 1999-1163 and 1999-1167 all in Figure 23, indicate that drawdowns extend to the edge of the quarter section. Note that the first three of these permits cover the three irrigated ¼'s at the top of the figure. Water appropriation permit 1999-1165 includes a discussion of impacts observed in the water table well at the 630580 and 630586 well nest to the west of Figure 23.

It does not appear that any of these cones of depression reach the stream, but they do combine to create multiple sinks in the water table that slows the lateral movement of groundwater that naturally flows from the northwest to the southeast. Drawdowns like this are variable and decreasing as one moves away from the pumping well, but Figure 24 visualizes how these irrigation wells capture water from an area that likely would have discharged to the wetlands or directly to the stream. The white circles have about 1 foot of water table decline, but the center of the circles can have up to 5 feet of decline. Well #630580 is less than 100 feet from the pumping well and experiences about 2 feet of drawdown with each irrigation cycle. The drawdown at the stream caused by an individual well may be relatively small, but the cumulative impact of this many cones of depression in one season is likely to result in less groundwater reaching the streamflow zone. It is likely that continued, additional monitoring in this area is merited to monitor a delicate hydrologic setting more thoroughly.

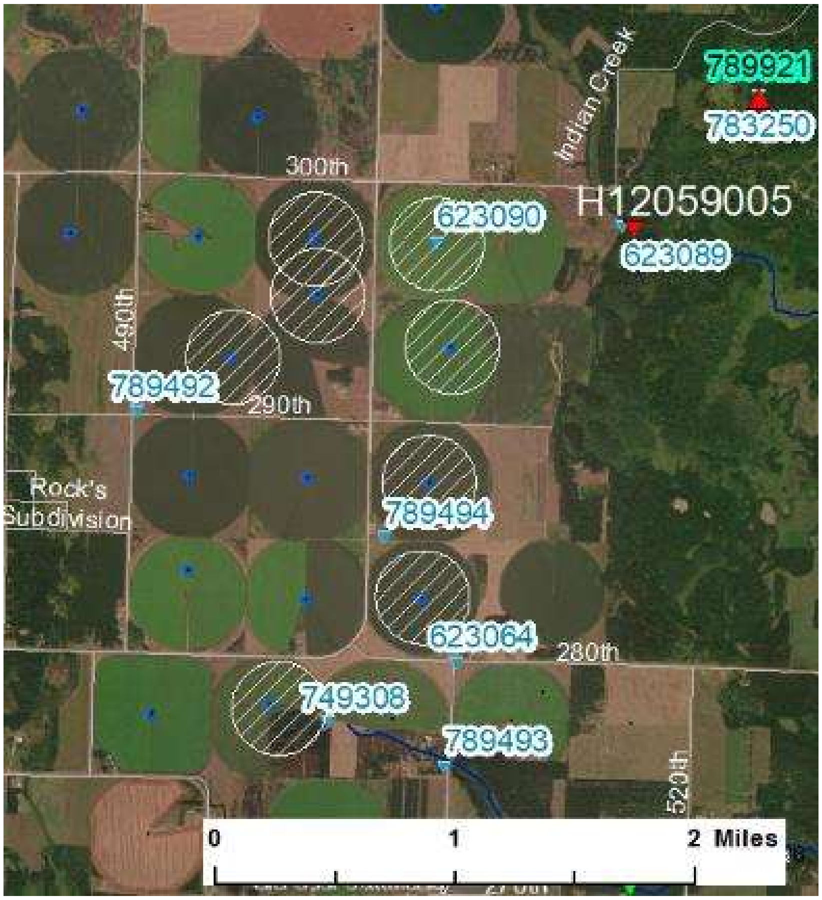


Figure 24. Simulated cones of depression where irrigation is adjacent to Straight River headwaters.

Concentrated, seasonal pumping in the water table and confined aquifers is likely diverting more than 15% of August median baseflow water from the Straight River. In the Park Rapids sub-management area there over 130 installations that are permitted to pump a cumulative 87,000 gallons per minute. These wells have different impacts and pump at different times. Pumping closest to the stream is likely to have the strongest influence on streamflow and there are 11 permitted irrigation wells within 2,000 feet of the Straight River. These wells are permitted to pump a cumulative 8,550 gallons per minute (gpm), which is equivalent to 17 cfs if all pumping at the same time. The August median baseflow along the reach of the Straight River from Osage down to US Highway 71 is 33.8 cfs. Since these wells are so close to the river and due to the previously discussed hydrogeologic connections between the confined aquifer and water table and surface waters, it is likely that some portion of the water pumped from these 11 wells is diverted groundwater that would naturally discharge to the Straight River as baseflow. Depending on how much of the pumped water is diverted baseflow, these 11 permittees are potentially pumping more than 15% of the August median baseflow. There is only one permit in the Ponsford sub-management area that is within 2,000 feet of the Straight River that is permitted to pump 1.3 cfs (600 gpm). The August median baseflow in this sub-management area is 7.9 cfs. This targeted analysis does not account for the remaining hundreds of permitted wells that are farther from the river and have an unquantified but recognized impact on groundwater baseflow to the Straight River. It is likely that additional analysis through groundwater modeling will be necessary to quantify how much baseflow is depleted from groundwater pumping in this area.

A comparison of water table elevations adjacent to a large groundwater streamflow zone shows that water table declines during dry years occur at a greater rate from what is observed in wet years. Figure 24 shows two water table observation wells (623089 and 623090) from the groundwater streamflow zone near the headwaters of the Straight River. These wells are also nearby a spring location where the DNR synoptically measures streamflow (this area has numerous springs and groundwater seeps). There was a significant drought in the summer of 2021. A comparison between 2019 and 2021 is helpful because it helps to compare a wet year to a historically dry year. Observation well 623090 is immediately adjacent to an irrigation well and the hydrograph from 2021 at this well shows frequent and numerous irrigation cycles with water level declines in the water table of 1–2 feet per irrigation cycle. These pumping-cycle drawdowns are not visible in the hydrograph for 623089 which is about 4,000 feet away, but the seasonal decline is still apparent in 623089. Water levels in 623089 drop at a rate of about 0.07 feet per week and water levels in 623090 drop at a rate of 0.26 feet per week during the irrigation season in 2021. In 783250, which is east of the irrigation area and discussed above, water levels drop at a rate of about 0.1 feet per week during this period. These rates were 0.04 feet per week and 0.23 feet per week, in 623089 and 623090 respectively in 2019, a year with 10 more inches of annual precipitation and 64% less water pumped at this site than was used in 2021. The observation well 783250 which is outside of the irrigation area, has the same rate of decline over the wet and dry periods observed in 2019 and 2021. The wells to the west in the irrigation area have an increased rate of decline during the summer for 2021 when conditions were significantly drier and irrigation use was more intense. It is difficult to identify the cause of these impacts at 623089 and 623090, since water use is concurrent with dry periods, and water-table hydrographs are affected by local conditions such as the depth to the water table, proximity to a streamflow feature, and aquifer transmissivity. It is likely that these three impacts all contributed to water table declines but quantifying each impact will require additional analysis or modeling. It is likely that seasonal pumping drawdown is small at this location given the distance between 623089 and the pumping wells to the west, but the changes in horizontal gradient across this streamflow zone are potentially diminishing the amount of baseflow that would normally have discharged.

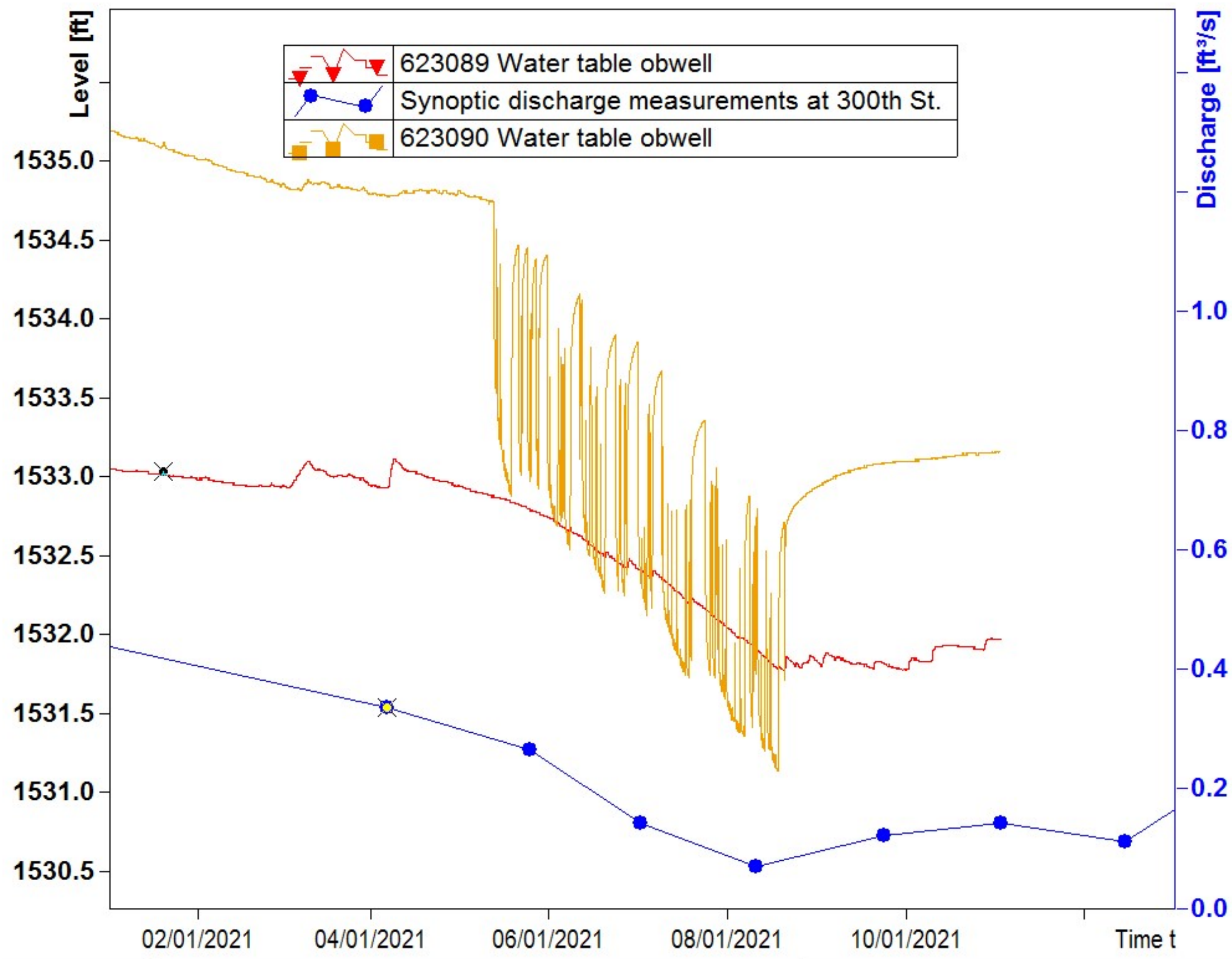


Figure 25. Hydrograph of two water table observation wells near the 300th St. streamflow measurement location during the drought of 2021.

The hydrograph for 2021 in Figure 25 shows how the hydraulic gradient between these two water table wells changes with intense, seasonal use in the area. In this case the horizontal hydraulic gradient decreases with each irrigation cycle and during times of heavy irrigation as in 2021. The horizontal hydraulic gradient is a measure of how rapidly water levels change over a distance, like a measure of the slope of a land surface. The horizontal hydraulic gradient is directly related to the amount of water that will pass through an area. A large horizontal hydraulic gradient indicates that a lot of groundwater moves through the water table. A small horizontal hydraulic gradient decreases the amount of water that is moving, and a negative horizontal hydraulic gradient changes the direction of horizontal flow all together. In this example, the horizontal gradient is reversed near the pumping well, but does not reverse all the way out near the stream. Regardless, the localized impact of this change in the horizontal gradient results in less groundwater discharging to the river and surrounding wetlands.

In May of 2021, the horizontal hydraulic gradient between these two observation wells was clearly positive from west to east. This was the natural gradient between these two wells before irrigation. With irrigation, the seasonal drawdown began, and by early June the horizontal gradient was reversed at and near the pumping well. With continued irrigation the reversal of the gradient reached its maximum in August of 2021 when the gradient was reversed. This implies that between these two observation wells, instead of water moving from west to east toward the Straight River, which is normal, the gradient in this area after a drought-filled summer of irrigation is directed from east to west, away from the Straight River. At some point beyond the area of influence of the pumping well, the flow will continue to move west to east, but the localized impacts of this one well compound with multiple pumping wells in their area.

This reversal of horizontal hydraulic gradients at this site occurs in the record 11 out of the 15 years of available data. The reversal in 2021 was the longest lasting (almost 50 days). The gradient is certainly decreased over some summer months and even though water from the Straight River is not captured during these periods, it is likely that there is a decrease in groundwater streamflow to the streamflow location at 300th St. This is observed in the graph of streamflow measurements in Figure 21. The lowest streamflow ever measured at this site occurred in early August 2021 when the seasonal drawdown was at its greatest. After irrigation stops, the gradient quickly returns to the eastward direction.

The monitored streamflow location is at one of many springs and seeps in the area; it is likely that all would show impacts of varying severity. There are not sufficiently long or sufficiently continuous records in the Ponsford sub-management area to reach a definitive conclusion on impacts to the stream, but during times of drought and stress to the water table, discharges in the headwaters springs and seeps are sensitive to declines. The closer that pumping is to the creek the larger the impact on stream flows.

Stream flow measured at Straight Lake Creek shows the impacts to streamflow from the drought of 2021 (Figure 26). Flows at this site were regularly small, but for two sustained durations in early August of 2021 and in late September 2021, staff hydrologists measured zero flow at the Lady Slipper Inn location. The nearby water table observation well #623064 did not show the sawtooth pattern of a well impacted by nearby pumping, but the seasonal decline documented in other water table observation wells, which were impacted by pumping is apparent at this well. The flattening of the water table at this well observed in late August interestingly did not drop lower or recover after the irrigation season. In fact, levels in this well did not rebound until early spring 2022 when daily temperatures began to get above freezing and spring recharge began.

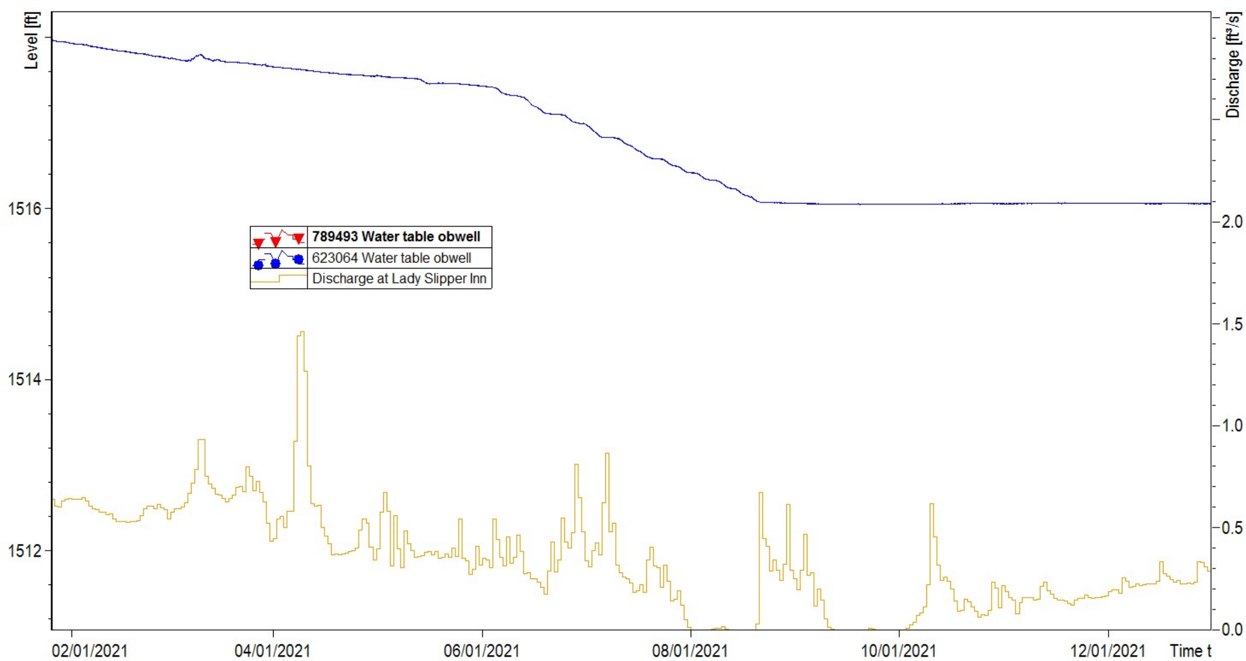


Figure 26. Hydrograph of the Straight Lake Creek at Lady Slipper Inn and an adjacent water table observation well.

Declining Observation Wells

Many of the groundwater level observation wells in the SRGWMA have records that date back to before 1990, which provides valuable periods of record to assess long-term trends in water levels. Declining trends in groundwater levels would be an indication of a sustainability concern where the aquifers were being drawn down faster than they were being recharged. The nonparametric Mann-Kendall trend test was performed on a shrinking window of time for each of the wells that had suitable records for analysis. The time windows assessed for trends in the assumed minimum elevation for each year began in 1975 and advanced 5 years in the record with each test (1980–2020, 1985–2020, etc.). Shrinking the window of record allows for different starting points, which helps to better assess if a trend might be the result of antecedent climate conditions that could influence the trend (i.e., coming out of a drought, or at the end of a sustained wet period). Trends that persist between multiple of adjacent starting points also help to indicate the trend is continuous.

Only two observation wells in the SRGWMA network showed a statistically significant declining trend over one or more period of analysis. The water table well #243489 had a statistically significant declining trend from 1995–2020. It is apparent in the hydrograph that the highest of high-water levels are 1–2 feet lower than from the late 1990's and 1985. The low water levels also appear lower since 1995. The other well that appeared to have a declining trend over multiple time periods of analysis was #149510 near the outlet of the SRGWMA at the 2-mile crossing. There were significantly declining water levels in this well during the 1980–2020, 1985–2020, and 1990–2020 time periods. These declines were in fact a step change due to the addition of adjacent groundwater users in 2002 lowering water levels. As such there is no real trend since the additional pumping is causing the change, but it does highlight a sustained lowering of the water table during long durations of the season at a site that is less than 1,000 feet from the Straight River.

Groundwater Safe Yield Thresholds

Safe yield is defined in Minnesota Rule 6115.0630 and has a different definition for water table and confined aquifers. In the water table aquifer, safe yield means that the long-term average withdrawal rate does not exceed the long-term average recharge rate to the aquifer and the quality of the water. In a confined aquifer, safe yield is defined as maintaining water quality and a confined condition in the aquifer. A confined aquifer occurs where water levels stay above the top of the aquifer. To ensure the aquifer remains confined, the DNR evaluates the available head (amount of water above the top of the aquifer) in a well completed in the confined aquifer. The available head is calculated by subtracting the depth to the top of the aquifer from the nonpumped water level (static water level). The DNR uses safe yield thresholds of 50% and 25% of the available head in the aquifer to ensure pumping does not convert the confined aquifer to an unconfined aquifer. At the 50% threshold, the water level has reduced to 50% of the available head in the well (halfway between the static water level and the top of the aquifer). This is a warning that the aquifer use is not sustainable, and an alternate water source may be needed. At the 25% threshold, groundwater use must be managed to ensure the aquifer does not become unconfined.

Observation well #243870 is categorized as a confined aquifer observation well and the safe yield test for confinement shows that water levels are well above the 50% safe yield thresholds. What stands out at 243870 and several other well nest locations in the lower Park Rapids sub-management area is that confined observation wells have numerous days over the record where the vertical gradient is reversed from gaining to the stream and water table to losing to the confined aquifer. It is likely that this diminishes groundwater baseflow to the stream. For example at 243870, the percent time when the water level in the QBAA obwell was beneath the levels in the water table is shown in Table 4. This isn't a change in the confining status of the well, but it is an observed period of time when a nearby seasonal drawdown from local supply wells change the direction of groundwater flow. In a River that is 97% reliant on groundwater flow it is possible that these gradient inversions are present in other regions of the GWMA. (Figures 18, 20, 21, and 22).

Table 4. Percent of the time when water levels in confined observation well 243870 were below the water table, which results in an inversion of the vertical hydraulic gradient.

Month	Percent time of the month where levels were inverted at 243870
1	0%
2	0%
3	0%
4	0%
5	5%
6	24%
7	25%
8	33%
9	10%
10	2%
11	0%

12	0%

Observation well #149510 is a confined aquifer well and exhibits the largest seasonal drop in water levels of the wells measured in this area. The top of the aquifer is reported at 1,289 ft above sea level. The maximum available head (nonpumping water level) observed in the spring of each season is around 1,414 ft. above sea level. This means that the available head in this well is 125 feet. The 50% threshold for safe yield is then 1,351 ft above sea level and the 25% threshold is 1,320 ft above sea level. The lowest water level measured in this well was around 1,403 ft above sea level, leaving more than 50 feet of head above the 50% threshold (Figure 27). Safe yield was evaluated at the other confined observation wells and none of the wells that were evaluated had minimum elevations that went below 80% of available head.

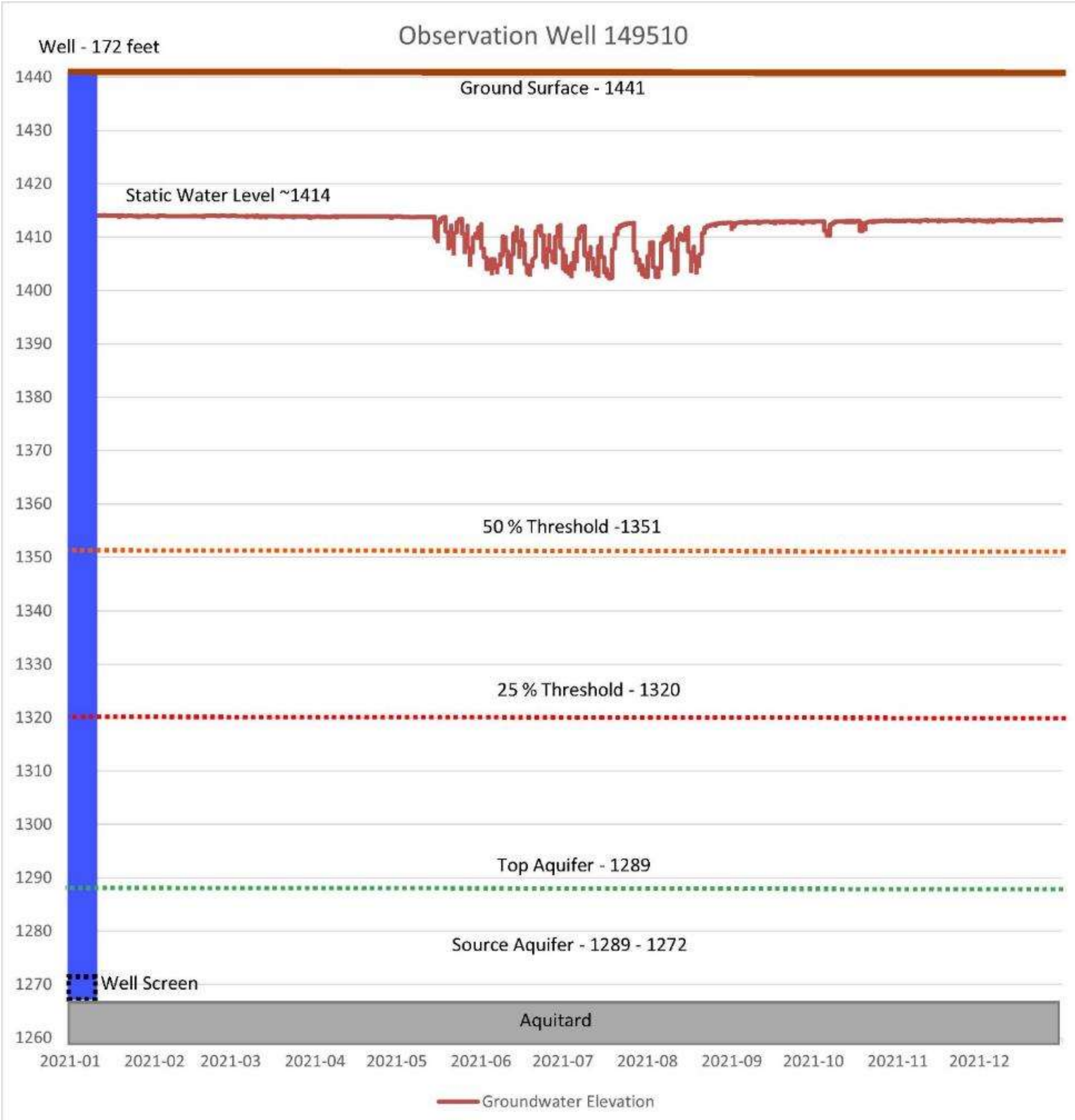


Figure 27. Two-tiered aquifer thresholds of 25% and 50% of prepumping available head.

Average annual water use from both the water table and the confined aquifer in the irrigation area around the Park Rapids sub-management area is at or below 1 inch per year when calculated across the entire area including irrigated acres as well as wetland, forest, residential, etc. The USGS estimates groundwater recharge for SRGWMA ranges between 5.1 and 6 inches per year. At the current rate of use, safe yield in the SRGWMA water table is not exceeded.

Our basic water budget for the SRGWMA (summarized in Table 4) illustrates the challenge in separating the effects of pumping from the variation in precipitation and evapotranspiration. When normalized across the entire SRGWMA, streamflow at the Hwy 71 gage amounts to an average of 2.2 inches of water per year. Average water use in the SRGWMA is 0.9 inches per year. These two values and the year-to-year fluctuations in these values are overshadowed by annual precipitation and potential evapotranspiration (PET), which are 1–2 orders of magnitude greater. The drought of 2021 resulted in more than 6 inches below average precipitation, with 0.6 inches less streamflow, 0.3 inches more of irrigation, and 8 more inches of PET. When evaluating these records, it is difficult to separate out the signals. Precipitation and ET represent the two largest components of the water budget. Irrigation water use is typically the highest when precipitation is low and ET demand is high, all three of these components will result in reduced streamflow.

Table 5**. Average annual components of the water budget in SRGWMA for 2017–2021.**

	Crow wing river precipitation	Straight River discharge	Potential evapotranspiration	SR GWMA average annual water use	USGS estimated annual GW recharge*
inches/year	24.6	2.2	43.2	0.9	5.6

*recharge rates are estimated for 1996–2010

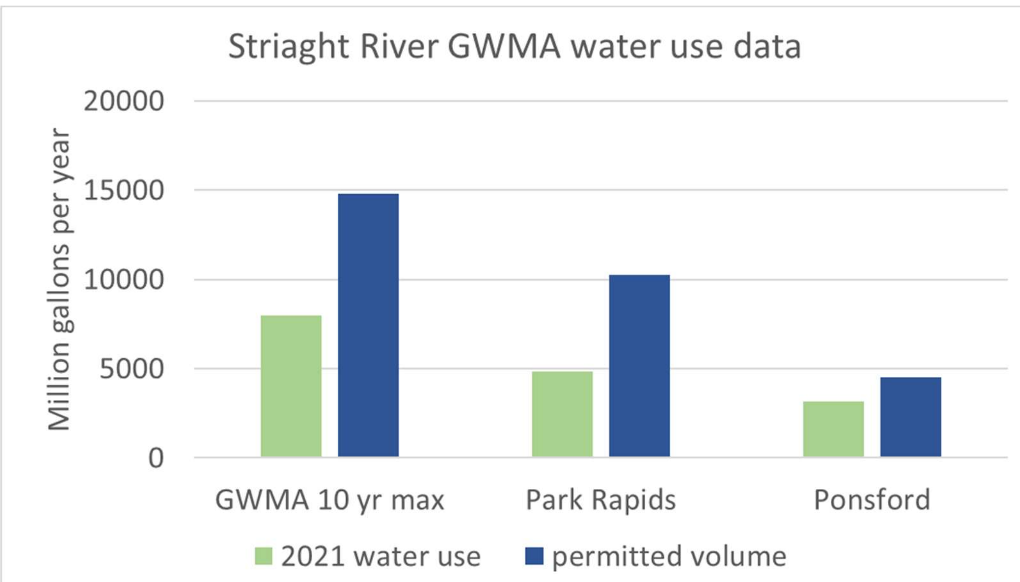


Figure 28. Comparison of 2021 reported water use to permitted water use across the SRGWMA

It seems that in general that the amount of water authorized for use greatly exceeds the amount that is used on annual basis. The drought in 2021 was the worst recent drought in the area with the most amount of water use reported in the past 10 years. Figure 28 shows that water use under a very dry scenario did not approach the volume that is permitted.

Summary of groundwater analysis:

- The confined and water table aquifers are variably connected throughout the SRGWMA and act as one large aquifer system. In some areas, such as near the Straight River in the Park Rapids sub-management area, deeper groundwater has a strong upward vertical gradient, ultimately discharging to the surface in the river valley. In other areas farther from major streamflow features there is a downward vertical gradient from the water table to underlying confined aquifers.

- Results from the recently published County Geologic Atlas indicate that the buried sand and gravel aquifers, also known as the confined aquifers, are less extensive than what had been modeled in past studies and possibly more connected with unconfined aquifers and surface water bodies than previously assumed. Confined aquifers could be more extensive than mapped in some locations where there are remaining gaps in drilling records of sufficient depth.
- Data analyzed from observation wells in the SRGWMA show that Park Rapids sub-management area experiences measurable, sustained, and concentrated drawdowns in the water table and confined aquifers over the summer irrigation season. Drawdowns in the Ponsford sub-management area are less than 2 feet in wells where they are apparent.
- Seasonal hydrographs of several observation well nests in the Park Rapids sub-management area near the Straight River show that high-capacity pumping has diminished or reversed the normal upward flow of groundwater from the confined aquifer to the water table during the irrigation season. These seasonal drawdowns change the hydraulics enough to switch a source of groundwater flow to the water table during non-irrigation season to a sink for the water-table aquifer during irrigation season. If leaky confining conditions are present (a strong possibility in this setting) these sustained inversions along with direct pumping from the water table near the river are likely to decrease the amount of streamflow present, either through the diminishing of baseflow or the capture of streamflow.
- There does not appear to be long-term sustainability concerns for the Ponsford sub-management area but there are specific locations where pumping close to the stream and other groundwater streamflow areas limit the amount of baseflow reaching the stream.
- The term "safe yield" is used in Minnesota groundwater rules as a measure of limits on allowable groundwater use and is defined in the SRGWMA plan. Current groundwater use has not reduced groundwater levels in the confined or water table aquifers below safe yield thresholds in either of Ponsford or Park Rapids sub-management areas.

Groundwater and Surface Water Quality

Concerns about water quality in both the surface water and groundwater of the SRGWMA have been noted in past studies and reports. The Minnesota Department of Agriculture (MDA) has implemented several efforts to better understand and manage nitrogen in groundwater including a nitrogen fertilizer management plan, groundwater protection rules, a long-term private well monitoring program, and a township testing program. Additional information on these efforts can be found at on the Monitoring Nitrate in Groundwater page.

Of these efforts the township nitrate testing program samples water from domestic wells and tests the water for nitrate. From 2016–2018 the MDA tested water samples from over 500 wells for nitrate in five different townships (Pine Point, Carsonville, Osage, Todd and Straight River) wholly within in the SRGWMA (MDA Township Testing Program). In the first round of testing, 60 out of 557 wells (~11% of wells tested) tested above the drinking water standard for nitrate (10 milligrams of nitrate per liter of water-mg/L). In the second round of testing, 34 out of 514 wells tested exceeded the standard (~7% of all wells tested). MDA also performed follow-up tests for pesticide in 357 wells that had nitrate detections in each of the three counties containing the SRGWMA. At least one pesticide detection was found in 204 of those wells (57%). Figure 29 is a composite of the results including both Henrietta and Hubbard townships which include a portion of their township in the SRGWMA. Figure 30 shows the private wells that exceed the 10 mg/L drinking water standard. Most of these wells are in the Park Rapids sub-management area, east of Long Lake as well as near the town of Park Rapids.

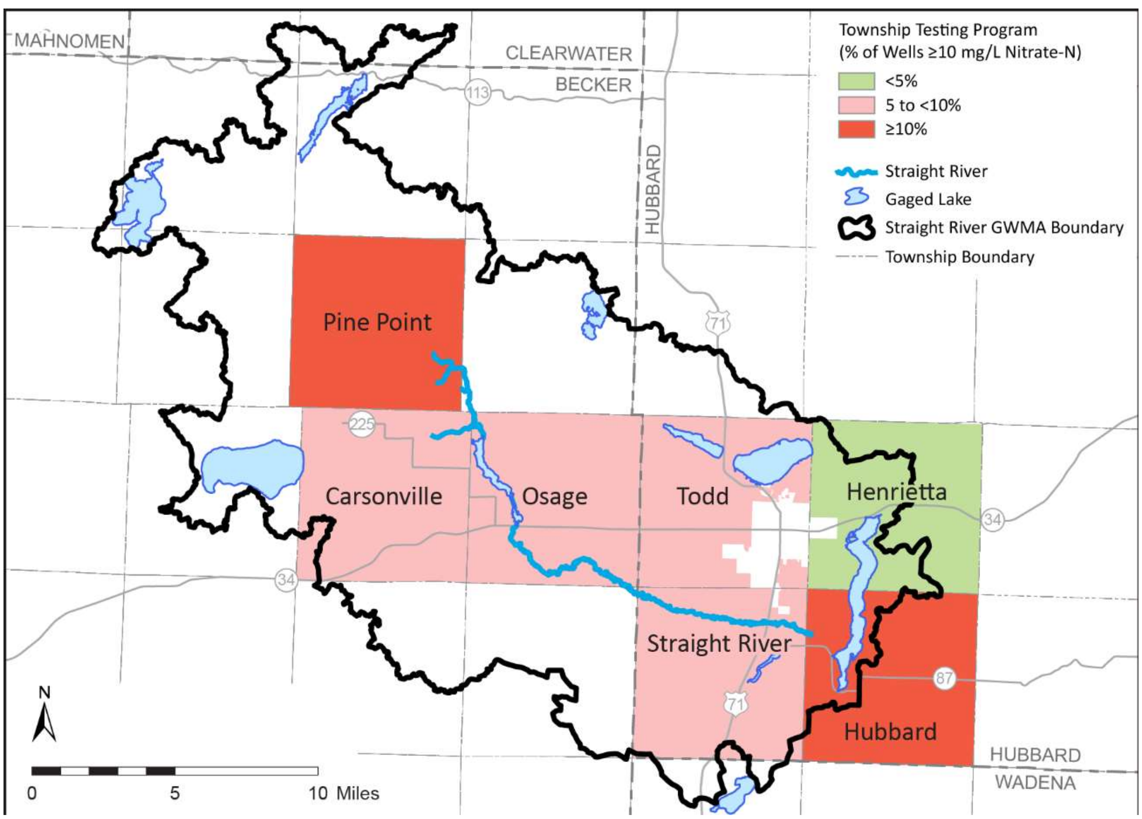


Figure 29. Results from Minnesota Department of Agriculture nitrate township testing program.

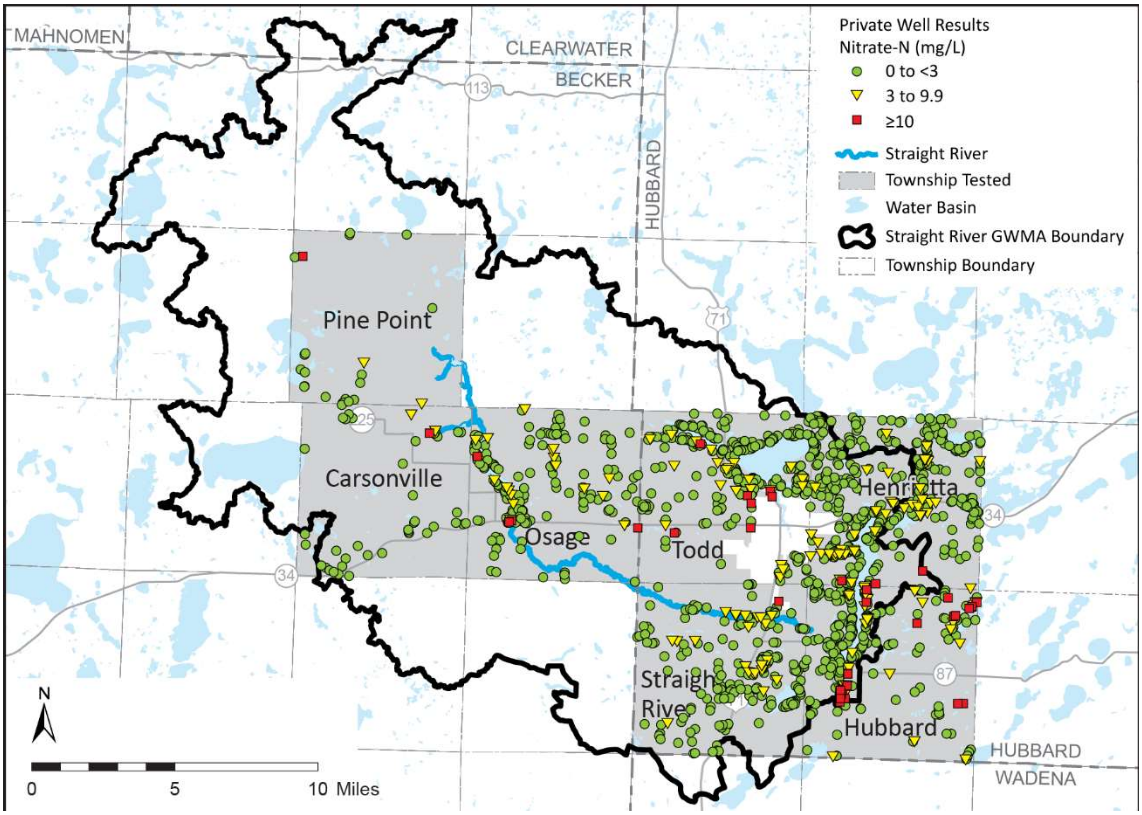


Figure 30. Results from Minnesota Department of Agriculture nitrate township testing program.

The Straight River is listed as impaired due to limited dissolved oxygen in the 2010 Impaired Waters List identified by the Minnesota Pollution Control Agency (MPCA). The 2014 Crow Wing River Watershed Total Maximum Daily Load (TMDL) report described water temperature as the primary stressor to low dissolved oxygen levels in the Straight River. Additional data was collected from 2010–2011 by the MPCA as part of the Crow Wing River Watershed Monitoring and Assessment and confirmed the impairment listing. In 2015 the Watershed Restoration and Protection Strategy report was prepared by MPCA as the final phase of the Crow Wing River watershed assessment process. The report notes that "changes in the groundwater and surface water interactions in the streams, particularly near Park Rapids, are resulting in altered stream hydrology that is stressing fish communities."

The MPCA has measured water quality at several locations along the Straight River and other streams within the region. Results show that the summer nitrate/nitrite concentration in the Straight River is much higher than in most other rivers within the Crow Wing River, Pine River, Leech Lake River, and Mississippi River watersheds. For example, the upper Straight River had a nitrate concentration greater than 1.50 mg/L which is 30 times higher than the 0.05 mg/L or less concentration found elsewhere in the Crow Wing River/Pine River/Leech Lake River/Mississippi River Headwaters Watershed (Figure 31) (MN PCA. Strom. 2022).

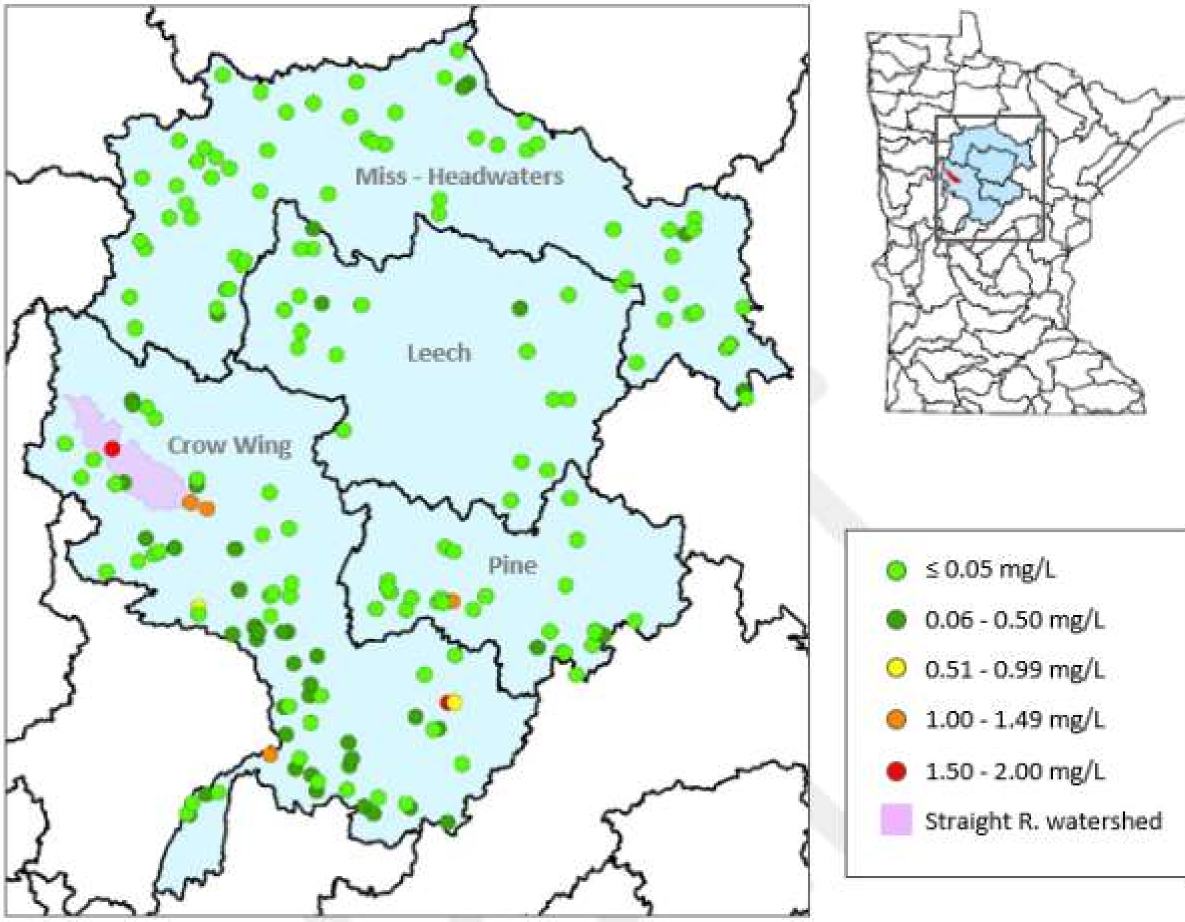


Figure 31. Crow Wing River Watershed nitrate concentrations from all IWM biological monitoring sites in the Crow Wing River, Mississippi River - Headwaters, Leech Lake River, and Pine River Watersheds from first cycle intensive watershed monitoring projects.

Another example is the Straight River at Hwy 71. In winter, the nitrate/nitrite concentration nearly doubles (Figure 32). The MPCA theorizes that row crop agriculture is substantially more-densely practiced in the area surrounding the Straight River than elsewhere in the Crow Wing River Watershed, which is leading to these increases of in-stream nitrate/nitrite concentrations. Nitrate/nitrite levels in the 2020–2022 dataset appear to be moderately higher than the 2015–2016 dataset, suggesting nitrate/nitrite levels in the river are continuing to increase. Essentially the whole polynomial trendline for the 2020–2022 dataset is higher than the 2015–2016 line. The gap between the two trendlines is much less that that between the 2004–2010 and 2015–2016 trendlines. The difference between the two most recent trendlines may not be statistically-significantly different. Statistical testing will be completed when the current dataset is completed in summer 2022. Even if not statistically confirmed to be higher than in 2015–2016, the current dataset shows that no improvement has occurred in river nitrate concentrations. Additionally, the highest nitrate concentration of the complete dataset from 2004–2022 occurred on February 3, 2021 (3.9 mg/L) (MN PCA. Strom. 2022).

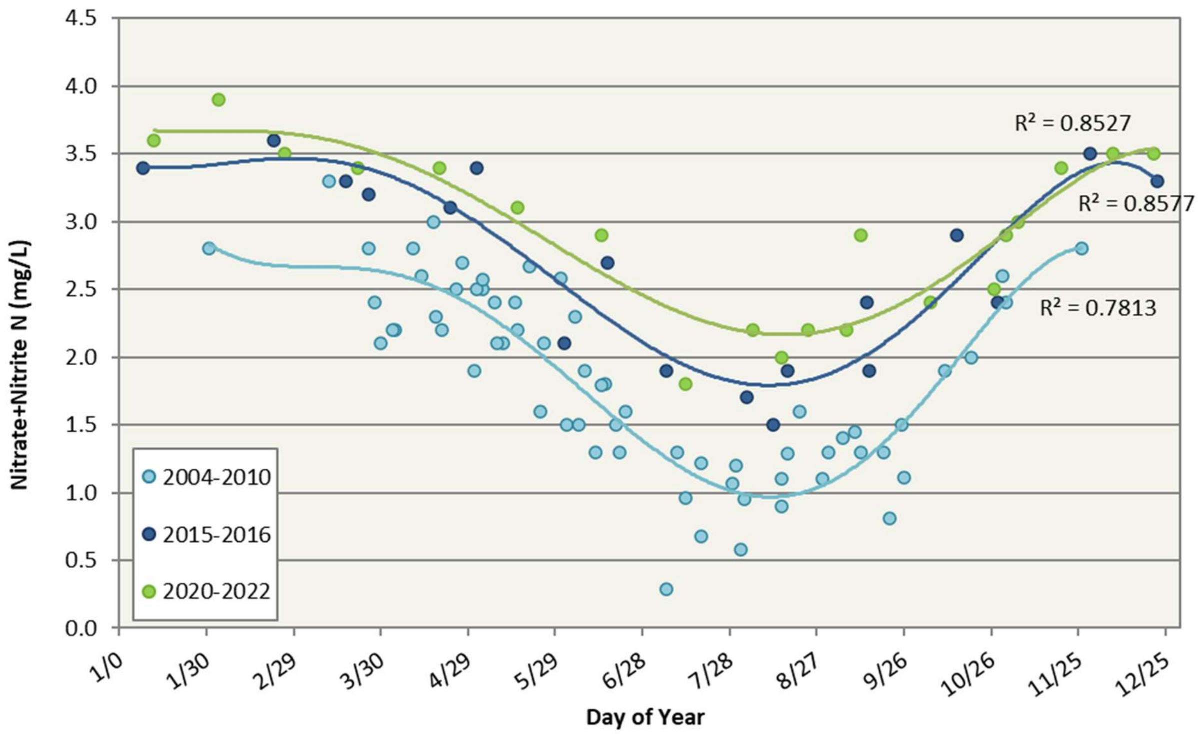


Figure 32. Nitrate Nitrite data at Hwy 71 (S002-960), 2004–2010 vs. 2015–2016 vs. 2020–2022 periods. Curved lines are 4th order polynomial regression lines with accompanying R^2 values.

One of the main limiting factors that affects the support of brown or brook trout in a river is high summer water temperatures. In Minnesota, the months with the highest water temperatures are usually July and August. Because of the importance of cold-water temperatures, DNR fisheries deploys data loggers to record water temperature from June through September in reaches above and below Straight Lake at 8 locations. Each trout species has different requirements for water temperatures, so much of the data is compared to the temperature regimes (Table 5) for each species described in *Brown, H. W. 1974.*

Table 6. Temperature requirements for trout in the Straight River.

Temperature Regime	Brown Trout (Straight River)	Brook Trout (Upper Straight Creek)	Threshold (% of readings)
Range below which growth occurs	<40.9* F	<45.9* F	
Range of growth	41 - 73.4* F	46 – 67.9* F	
Range of thermal stress	73.5 - 79.4* F	68 - 76.9* F	< 20%
Lethal threshold	>79.5* F	>77* F	< 3%

The Osage - Hwy 34 station is located directly below Straight Lake dam; therefore, the water temperature readings reflect the lake surface water temperature (Figure 33). Water temperatures exceed the range of thermal stress and lethal threshold for Brown Trout at the Osage station. At the 9-mile station about a mile downstream from Osage, the groundwater influence in this stretch of river cools the water enough to support Brown Trout, and cold temperatures continue downstream through the rest of the stream to the Hwy 71 station.

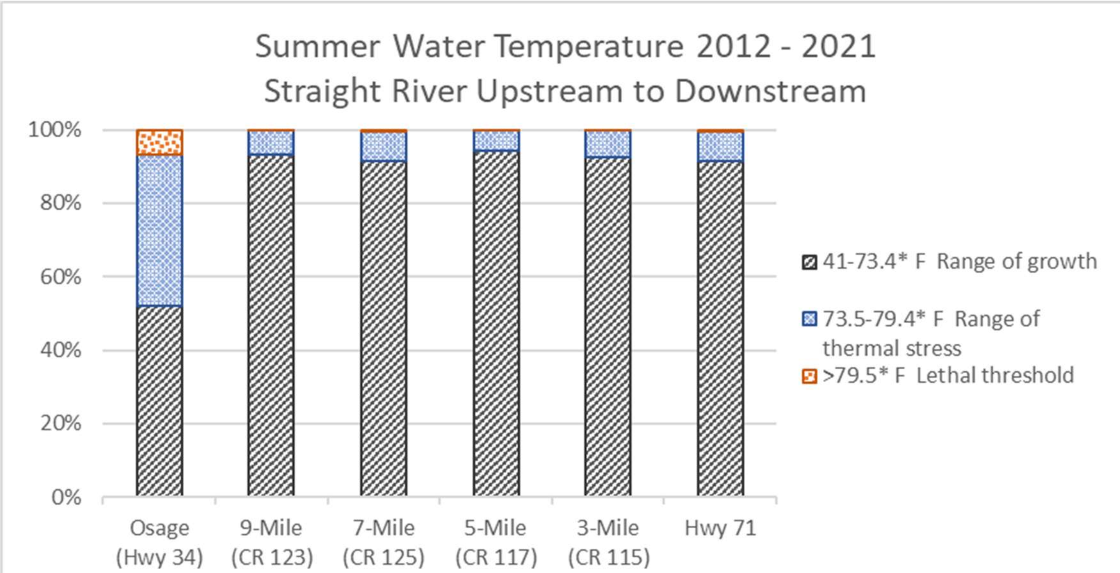


Figure 33. Water temperature frequency observed at 6 locations in the Park Rapids sub-management area.

Although average water temperatures over time at these sites appear adequate for Brown Trout, increased percentages of readings that are in the stressful or lethal range may be a concern, which justifies continued water temperature monitoring. Figure 34 illustrates variation in summer temperatures over the years 2012–2021 at 7-mile location.

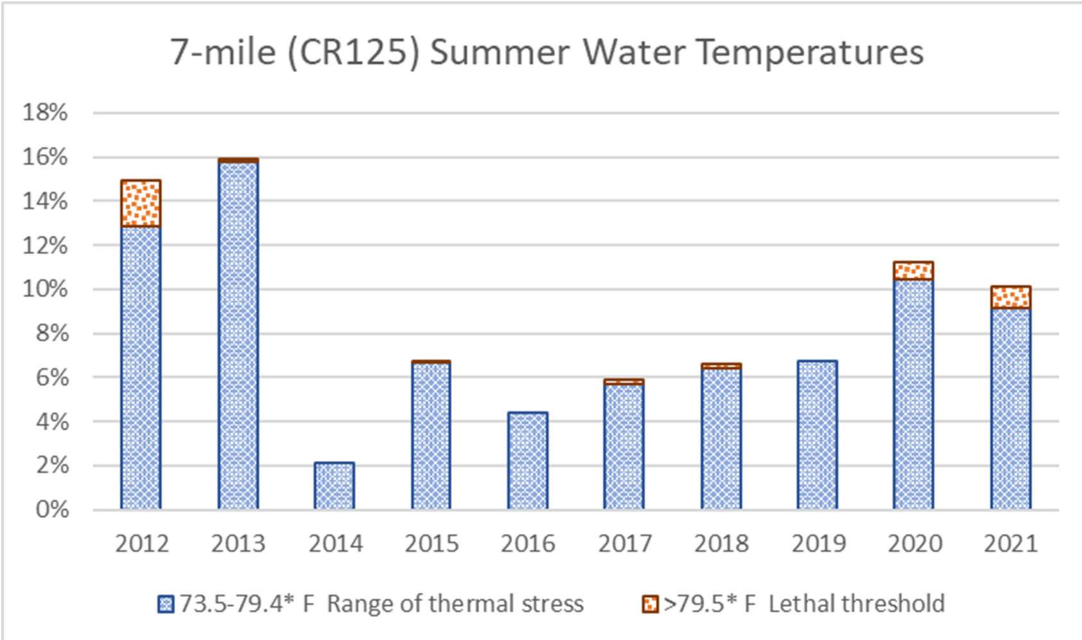


Figure 34. The percentage of readings of summer water temperatures in the range of thermal stress or exceeding the lethal threshold for brown trout, at 7-mile crossing for 10 years of data.

Past studies have reached varied conclusions on changes in stream temperature. The most recent study by DNR Fisheries, which used up to 19 years of summer stream temperatures from 8 stream locations, showed no statistically significant increase in stream temperatures at any of the analyzed sites. The same analysis was completed for each month of the summer with no apparent trend in stream temperatures during specific months for each of the years. Average monthly stream temperatures are consistently cooler than air temperatures, which is indicative of a groundwater fed system, but are also strongly correlated with air temperatures.

Summary of surface water and groundwater quality analysis:

- Nitrate concentration in the Straight River during the summer is at least 100 times higher than in most other areas of the Crow Wing River/Pine River/Leech Lake River/Mississippi River–Headwaters Watersheds.
- Nitrate concentrations above the drinking water standard have been measured in private drinking wells in both the Ponsford and Park Rapids sub-management area. Nitrates are also much higher in the Straight River than they are in other streams in the region. Pesticide degredates have also been detected in multiple private drinking wells.
- Stream temperatures show no statistically significant increases over the period of record, and they strongly correlate to air temperatures. Although average stream temperatures over time at these sites appear adequate for Brown Trout, increasing air temperature, groundwater use, and climate change remains a concern.

Conclusions

This report focused on analysis of data related to Objective I of the Straight River Groundwater Management Plan: "Groundwater use in the GWMA does not harm aquifers and ecosystems and does not negatively impact surface waters." Connections between groundwater and surface water in the Straight River are well documented, with streamflow consisting of 97% groundwater rather than overland runoff. The DNR expanded its hydrologic and climate monitoring in the SRGWMA to determine if groundwater use is sustainable. This expanded monitoring provides valuable data that we used to evaluate how current and past water use affected surface water and groundwater resources in the area. Our analysis of the data as presented here suggests the following:

1. Groundwater baseflow provides 93-97% of streamflow throughout the SRGWMA.
2. Summer streamflow at the outlet of the SRGWMA has shown no downward trend.
3. Aquifer levels have been stable and resilient through the extensive period of record, and the DNR is not concerned about long-term aquifer sustainability.
4. The streamflow data we analyzed includes a period of irrigation water use. It is possible that the decades of intensive and concentrated irrigation in the SRGWMA has resulted in decreased baseflow to the Straight River before monitoring efforts began. A groundwater model would be needed to further quantify any cumulative impact from water use on streamflow.
5. There are specific locations where pumping close to the stream and other groundwater streamflow areas limit the amount of baseflow reaching the stream.
    a. Seasonal hydrographs of several observation well nests near the Straight River in the Park Rapids sub-management area show high-capacity pumping has diminished or reversed the normal upward flow of groundwater from the confined aquifer to the water table during multiple irrigation seasons. The recent County Geologic Atlases also indicate that shallow confined aquifers are separated by thin, intermittent, and leaky confining layers that create connections between the confined and water table aquifers as well as surface waters.
    b. Significant surficial sand aquifers are mapped in the Ponsford sub-management area that provide ample supply for past uses, but concentrated pumping near the stream and connected wetlands likely limits the amount of baseflow reaching the stream.
6. Water quality data from the township well testing by the Minnesota Department of Agriculture shows that nitrates may be exceeding drinking water standards in some wells, and pesticide degredates were detected in some domestic wells.

Understanding and quantifying evapotranspiration in the SRGWMA will be necessary as the climate changes. The higher daily maximum temperatures of 2020 corresponded to a 30% increase in potential evapotranspiration over 2018, indicating that warmer future years may result in increased demand for groundwater. The findings in this report can be used to inform future data collection and monitoring and to consider if and/or when additional actions will be necessary.

Glossary

Aquifer – any water-bearing bed or stratum of earth or rock capable of yielding groundwater in sufficient quantities that can be extracted (Minn. Rule, part 6115.0630, subp. 2)

Appropriating – withdrawal, removal, or transfer of water from its source regardless of how the water is used (M.S. 103G.001, Subd.4)

Artesian aquifer or confined aquifer – a water body or aquifer overlain by a layer of material of less permeability than the aquifer. The water is under sufficient pressure so that when it is penetrated by a well, the water will rise above the top of the aquifer. A flowing artesian condition exists when the water flow is at or above the land surface (Minn. Rule, part 6115.0630, subp. 4).

Basin – a depression capable of containing water which may be filled or partly filled with waters of the state. It may be a natural, altered, or artificial depression (Minn. Rule, part 6115.0630, subp. 5)

Buried artesian – an aquifer composed of glacially associated sands and/or gravels, over which a confining layer of clay or till was deposited

Evapotranspiration – the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

Groundwater – subsurface water in the saturated zone. The saturated zone may contain water under atmospheric pressure (water table condition), or greater than atmospheric pressure (artesian condition) (Minn. Rule, part 6115.0630, subp. 11)

Native plant community – a group of plants that interact with each other and with their environment in ways not greatly altered by modern human activity or by introduced organisms

Negative Impact – refers to the relationship of groundwater use to surface waters. See Minn. Stat., section 103G.287, subd. 2 which states "Groundwater appropriations that will have negative impacts to surface waters are subject to applicable provisions in section 103G.285" (this affects altered and natural watercourses, which includes trout streams and basins).

Nested Observation wells (well nests) – Two or more adjacent water-level observation wells completed in different aquifers, or different depths within the same aquifer. Used to determine vertical differences in groundwater levels or heads.

Normal (climate) – the average of a climate variable such as precipitation or temperature over a standard 30-year period (e.g. 1981–2010)

Observation well – a water-level observation well in the DNR network

Potential evaporation or free water surface evaporation – evaporation from a thin film of water having no appreciable heat storage (Farnsworth et al., 1982).

Recharge – the addition of water to the groundwater system

Storativity - the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer

Transmissivity - the rate at which groundwater flows horizontally through an aquifer

Transpiration – the process of transport of water from plant roots to above ground parts where it is released to the atmosphere as vapor

Water table aquifer or unconfined aquifer – an aquifer where groundwater is under atmospheric pressure (Minn. Rule, part 6115.0630, subp. 17)

Water-use conflict – A situation where the available supply of waters of the state in a given area is limited to the extent that there are competing demands among existing and proposed users which exceed the reasonably available waters (Minn. Rule, part 6115.0740. subp. 1).

Well interference – A situation where an appropriation reduces water levels beyond the reach of public water supply and private domestic wells constructed according to Minn. Rules, part 4725 (Minn. Stat., sec. 103G.287, subd. 5; Minn. Rules, part 6115.0730).

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