South Orion Township Dye Trace

Olmsted County, Minnesota

Tracing Conducted

April 2021 through May 2021

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Introduction

This report presents the findings of dye tracing that was conducted in 2021 in south central Olmsted County, Minnesota (Figure 1). Previous dye tracing in southern and east central Olmsted County has been completed over decades in support of water resource management and springshed mapping (Kingston and Breslow, 1942; Alexander and others, 1991; Bunge and Alexander, 2005; Eagle and Alexander, 2007; Johnson and others, 2014; Larsen and others, 2016; Larsen and others, 2017; Barry and others, 2018a; Barry and others, 2018b; Barry and others, 2019; Larsen and others, 2019; Barry and others, 2020, Barry and others, 2021).

Collaboration between the Minnesota Department of Natural Resources, University of Minnesota Department of Earth Sciences, Minnesota Department of Agriculture, and Soil & Water Conservation Districts (SWCD) has led to many dye tracing investigations in southeastern Minnesota. The results of these investigations are available through an online *Minnesota Groundwater Tracing Database* application developed by the Minnesota Department of Natural Resources (https://www.dnr.state.mn.us/waters/programs/gw_section/springs/dtr-list.html). The application allows users to view the content in the figures below at different scales and to access data associated with this and other trace investigations.

Dye tracing and spring chemistry can be used to understand groundwater recharge characteristics, groundwater flow direction and velocity, and to assist in determining the size and areal extent of the groundwater springsheds that supply perennial groundwater discharge to springs.

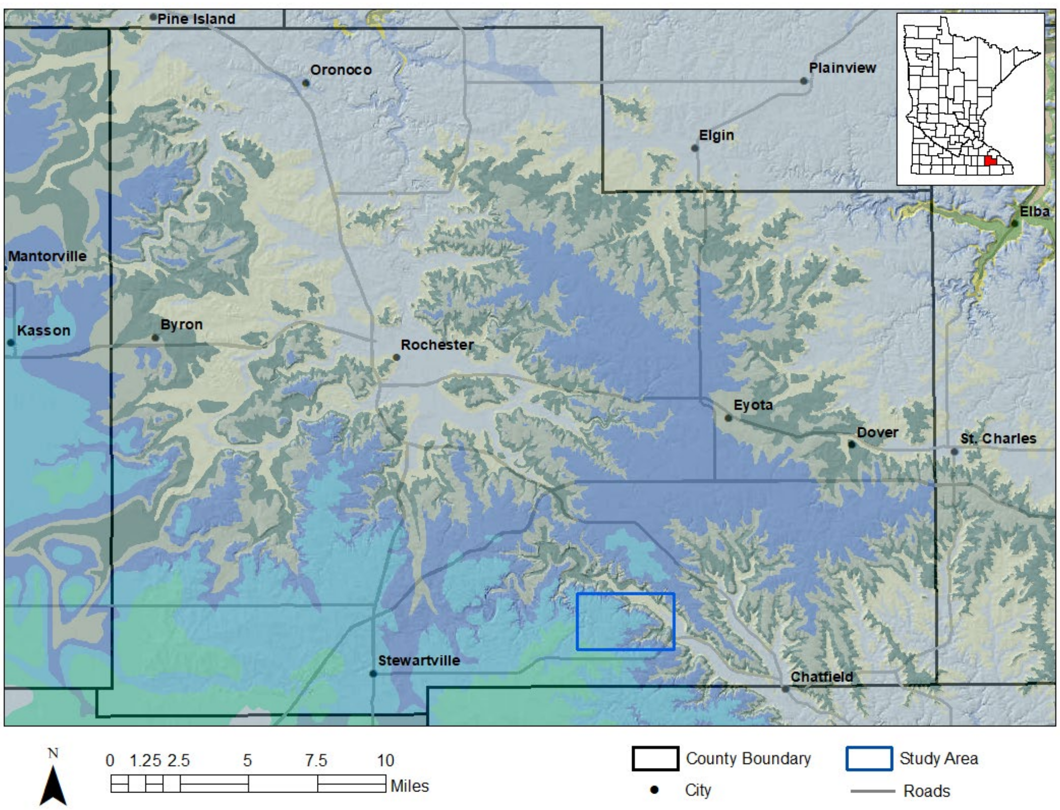

Figure 1. *Location of the study area in Olmsted County, Minnesota. Shading used to delineate bedrock geology loosely corresponds to the shading depicted in Figure 2. Geologic mapping from Steenberg (2020).*

Area Geology and Hydrogeology

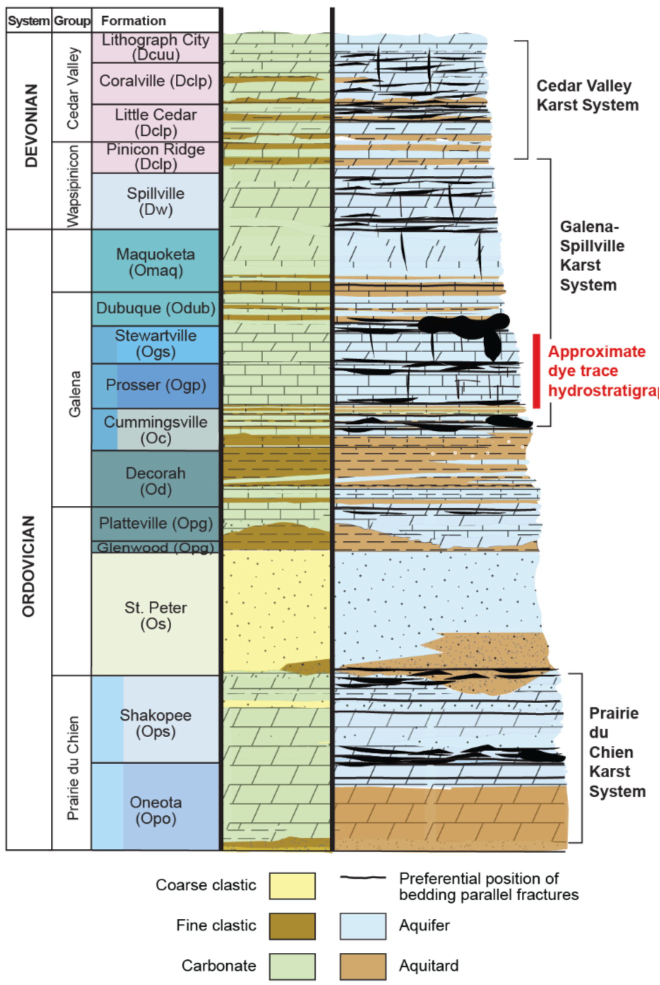

***Figure 2**. Geologic and hydrogeologic attributes of Paleozoic rocks in southeastern Minnesota.*

Underlying the relatively thin veneer of unconsolidated sediments in Olmsted County, such as glacial till, loess, sand, and colluvium, is a thick stack of Paleozoic bedrock units that range from middle Ordovician to Cambrian in age (Olsen, 1988). Ordovician rocks are generally dominated by carbonates, whereas the Cambrian rocks are generally siliciclastic (Figure 2).

A generalized stratigraphic column of Ordovician and Devonian units in Olmsted County (Figure 2) shows lithostratigraphic and generalized hydrostratigraphic properties (modified from Runkel and others, 2014). Hydrostratigraphic attributes have been generalized into either aquifer or aquitard based on their relative permeability. Layers assigned as aquifers are permeable and easily transmit water through porous media, fractures or conduits. Layers assigned as aquitards have lower permeability that vertically retards flow, hydraulically separating aquifer layers. However, layers designated as aquitards may contain high permeability bedding plane partings conductive enough to yield large quantities of water.

A hydrogeologic framework that describes prominent karst systems for southeastern Minnesota (Runkel and others, 2014) is based largely on the work of Alexander and Lively (1995), Alexander and others, (1996), and Green and others (1997, 2002). The systems described in this framework include the Devonian Cedar Valley, the Upper Ordovician Galena-Spillville, the Upper Ordovician Platteville Formation, and the Lower Ordovician Prairie du Chien Group. Karst characterization and sinkhole mapping in Olmsted County has delineated areas of active karst processes and high sinkhole probability (Alexander and Maki, 1988).

In southeastern Minnesota, springs and groundwater seepage frequently occur at the toe of bluff slopes and at specific hydrostratigraphic intervals. Common intervals include near the geologic contact of the Maquoketa-Dubuque, Dubuque-Stewartville, Stewartville-Prosser, Prosser-Cummingsville, Decorah-Platteville, St. Peter-Shakopee, Shakopee-Oneota, and Jordan-St. Lawrence.

Project Area and Trace Purpose

The project study area encompasses the area south of the North Branch of the Root River (NBRR) in Orion and Pleasant Grove Townships. This region is an active karst landscape where groundwater flow is partially governed by conduits and solution-enhanced fractures. The County Groundwater Atlas Program at the DNR is updating the Olmsted County Geologic Atlas and in 2019-2020 collected 100 groundwater samples countywide in support of the Olmsted update. In addition to groundwater sampling, the DNR is conducting dye trace investigations to assist in understanding groundwater flow directions, time of travel, and determining springshed boundaries within the county.

The study area is located approximately 6 miles west-northwest of Chatfield, Minnesota on the south bank of the NBRR (Figure 1). Here, sinkholes are common and a large cluster of sinkholes and karst lineaments is located within 700 feet of the river valley (Figure 3). A spring complex consisting of five springs is located within a deeply incised north-trending valley. The complex consists of four ephemeral overflow springs and one perennial spring, Bill Burnap West Spring (55A655). Generalized groundwater contours of the Upper Carbonate Aquifer, which includes the Maquoketa and Dubuque formations and the Galena Group, indicate that local groundwater flow is to the northeast towards the NBRR (Kanivetsky, 1988). Depth to bedrock across the study area is likely 30 feet or less (Steenberg, 2020).

Dye tracing requires thorough planning, careful dye introduction, and many weeks of follow-up field work to determine the presence or absence of dyes at monitoring sites. Dr. Calvin Alexander Jr. at the University of Minnesota developed a relationship with a family interested in learning more about the environment in which they live and had over the years volunteered on multiple occasions to assist with a hydrology investigation. For this study, Calvin worked directly with the Stacken family to ensure that follow-up field work offered them a chance to participate and collaborate in this joint investigation.

The Olmsted SWCD was instrumental in arranging sinkhole and spring access and the SWCD and DNR completed field work associated with spring and sinkhole mapping, trace plan development, and dye introduction. Dye trace interpretation and reporting was handled collaboratively between the DNR, UofM, Olmsted SWCD, and our volunteer partners.

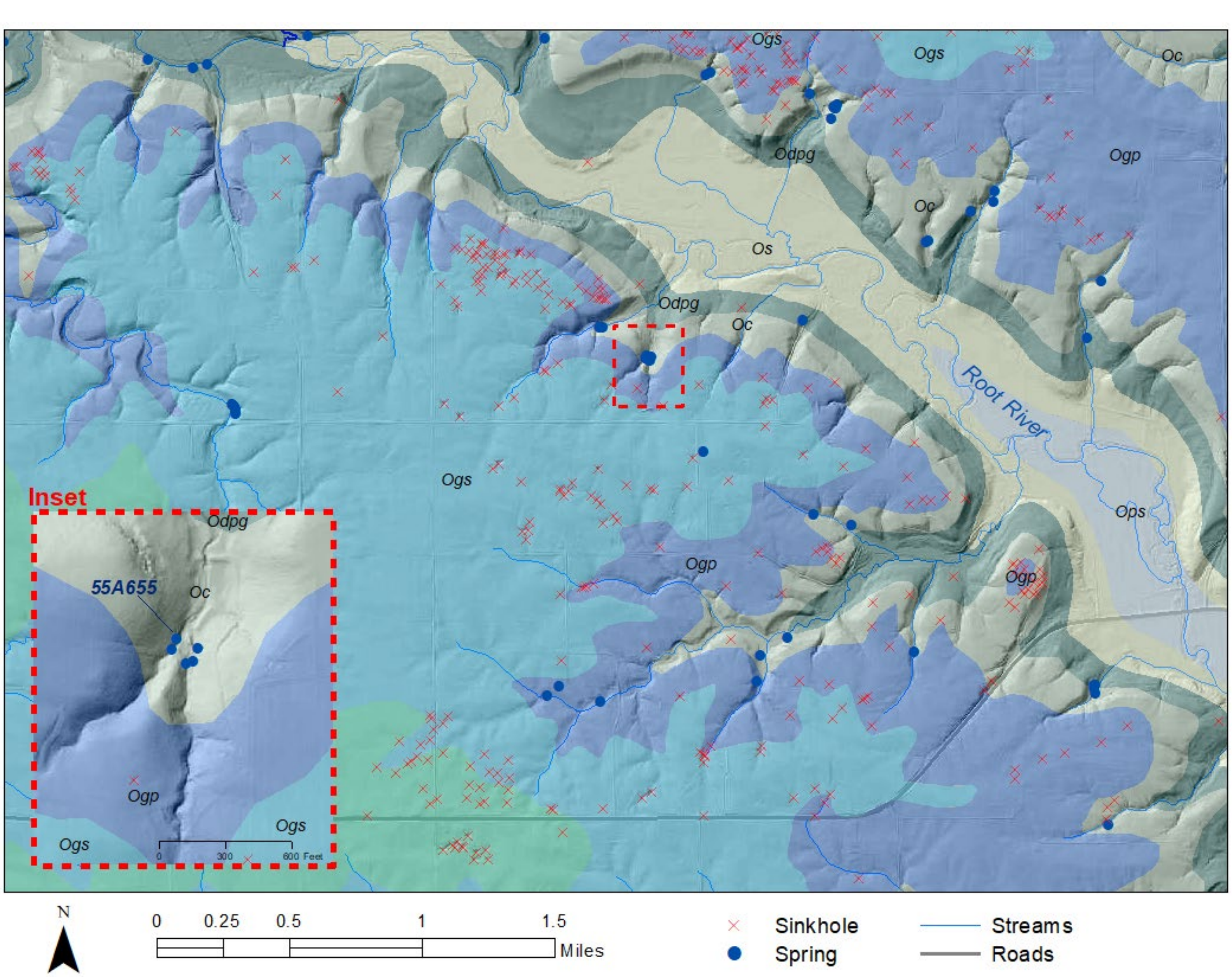

Figure 3. *Geology and karst features mapped in the project study area. Shading used to delineate bedrock geology loosely corresponds to the shading depicted in Figure 2. Map geologic unit codes correspond to those used in Figure 2 except the Omd, which combines Omaq and Odub into a single mapped unit. Inset depicts the Bill Burnap Spring Complex and the perennially flowing Bill Burnap West Spring (55A655). Geologic mapping from Steenberg (2020).*

Methods and Trace Descriptions

Dye tracing is a technique used to characterize the groundwater flow system to determine groundwater flow directions and rates. Traces are designed to establish connections between recharge points (septic systems, sinkholes, stream sinks, etc.) and discharge points (springs, streams and wells). Multiple successful traces are necessary to delineate the boundaries of a springshed. Dye tracing is accomplished using fluorescent dyes that travel at approximately the same velocity as water and are not lost to chemical or physical processes (conservative tracers). Fluorescent dyes used in tracing are non-toxic, simple to analyze, detectable at very low concentrations, and not naturally present in groundwater.

To detect the presence or absence of dye at springs and other monitoring locations, a combination of direct water sampling, passive charcoal detectors, or direct measurement s using field fluorometers can be used. For this investigation, passive charcoal detectors, often referred to as "bugs", were used. Bugs were deployed prior to introducing dye to determine background levels of fluorescence in the groundwater emerging at springs and monitoring points.

After dyes were introduced, the bugs were changed periodically by the Stacken family until the trace was terminated. Passive dye detectors were sent to the University of Minnesota, Department of Earth Sciences for analysis. Bugs were analyzed by extracting the dyes with an extract of water, sodium hydroxide and isopropanol. The solution was then analyzed using a Shimadzu RF5000 scanning spectrofluorophotometer and the resultant dye peaks were analyzed with a non-linear curve-fitting software. Dye breakthrough summary tables were developed using the analyzed data (Appendix A).

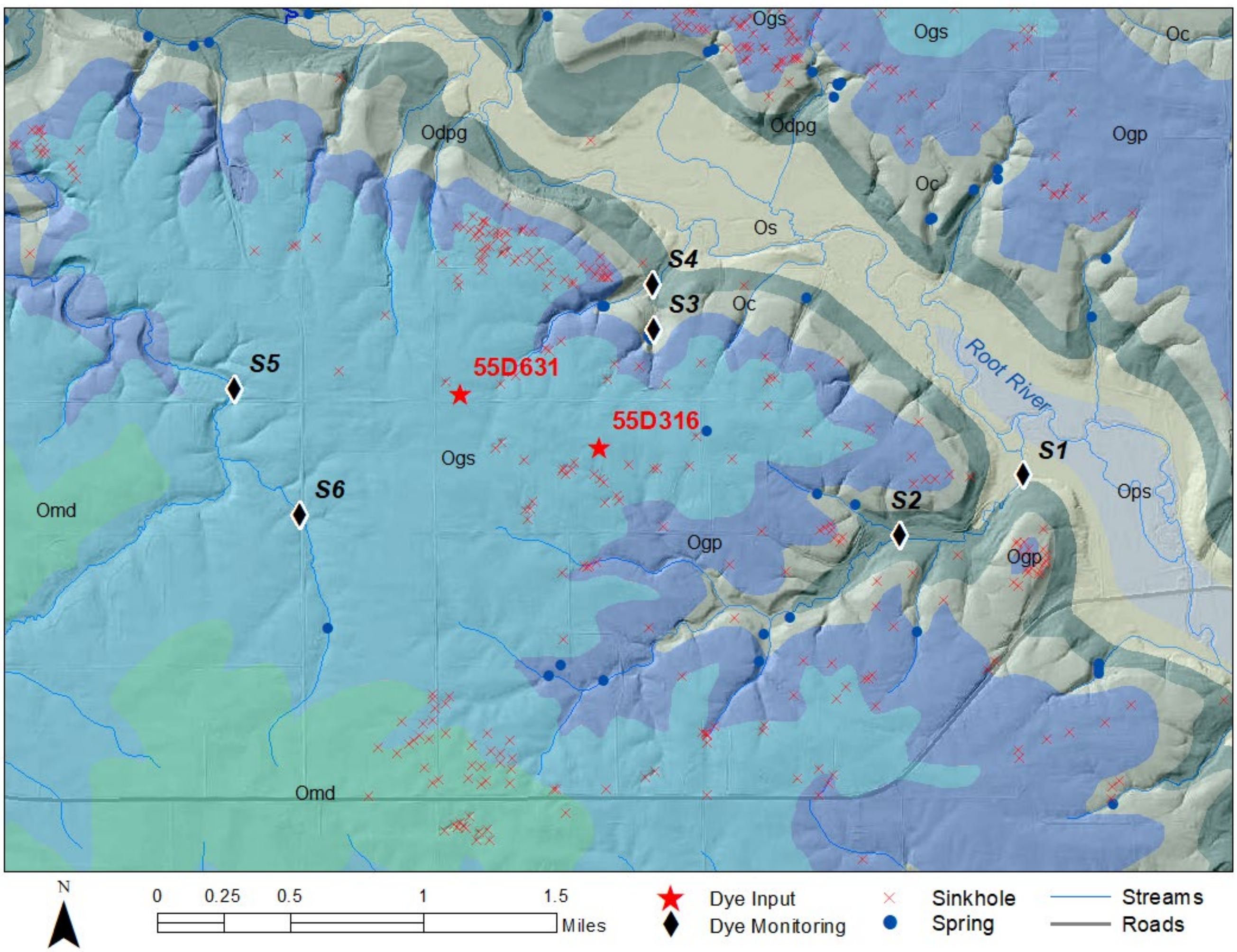

Figure 4. *Dye input locations, dye monitoring locations, bedrock geology, karst features, and surface water features of the study area. Geologic mapping from Steenberg (2020).*

Figure 5. Sinkhole 55D631

Dyes were introduced on April 26, 2021. The first injection was into a large approximately 50 foot deep sinkhole devoid of debris or trash cataloged as 55D631* (Figures 4 and 5). A mass of 647 grams of an eosin solution (Chromatint Red, D13802, Lot 2009-021) was injected at 6:25 p.m. following wetting of the sinkhole with approximately 200 gallons of water. Water used for flushing dyes came from the Byron, MN municipal wells and was absent of dyes (Appendix A). Following injection, dye was flushed with an approximate 800 gallons. An open throat was evident in the sinkhole and no water ponded during wetting or flushing.

*Geospatial data for dye traces, including the locations of karst features and springs, is stored in parallel databases that share a relatable unique identifier, the Minnesota Karst Feature Database (KFD), the Minnesota Spring Inventory (MSI), and the Minnesota Groundwater Tracing Database (MGTD). The unique identifier is a ten-character alpha-numeric field, but has been abbreviated for this report (e.g., 55D0000631 is abbreviated to 55D631).

A mass of 689 grams of sulforhodamine B solution (Chromatint Red, M93010X, Lot 2008-036) was injected into at 7:08 p.m. into sinkhole 55D316 (Figures 4 and 6). The sinkhole is approximately 40 feet deep and contains a mixture of agricultural debris and waste. Approximately 400 gallons of water was pumped into the sinkhole prior to injection. Ponding occurred while wetting with the initial 400 gallons, however due to debris we were unable to visually determine the infiltration rate. Following dye injection, an approximately 1,000 additional gallons were flushed into the sinkhole. Ponding occurred in the flushing stage as well.

Figure 6. *Sinkhole 55D316*

Trace Results

Dyes injected into each of the sinkholes were detected at Bill Burnap's Spring West (55A655). Dye breakthrough time of travel for these traces was calculated using the straight-line distance from the dye injection to Bill Burnap West Spring, divided by the time elapsed before the dye was detected in passive charcoal detectors from the monitoring locations. The straight-line distance was multiplied by 1.5 to include the tortuosity of the actual paths (Fields and Nash, 1997) and divided by the first arrival time "window".

Both the eosin and sulforhodamine dyes were recovered emerging from 55A655, arriving at the spring between the day of the pour and 7 days following introduction of the dyes (Figure 7, Table 1).

Table 1. Summary of groundwater travel time calculations.

Pour Date	Sinkhole	Spring Detect	Dye Detected	Straightline Distance X 1.5 (ft.)	Earliest Arrival Date	Latest Arrival Date	Arrival Days (early)	Arrival Days (late)	Rate Early (ft./day)	Rate Late (ft./day)
26Apr21	55D631	55A655	eosine	5,883	4/28/2018	5/3/2021	2	7	2,942	840
26Apr21	55D316	55A655	sulforhodamine B	3,686	4/26/2018	4/28/2021	0	2	3,686	1,843

The approximate minimum peak groundwater time of travel for the eosin trace ranged between 840 to 2,942 feet/day. The approximate minimum peak groundwater time of travel for the sulforhodamine B trace ranged between 1,843 to 3,686 feet/day. These rates are similar to rates previously characterized in shallowly buried Galena karst in Minnesota.

Based on these two traces an initial estimation of the Bill Burnap West (55A655) springshed is shown in Figure 7. The area shown in Figure 7 is probably a significant under estimate of the true area of the springshed. Additional tracing from other sinkholes in the area is needed to fully define this springshed and adjoining springsheds.

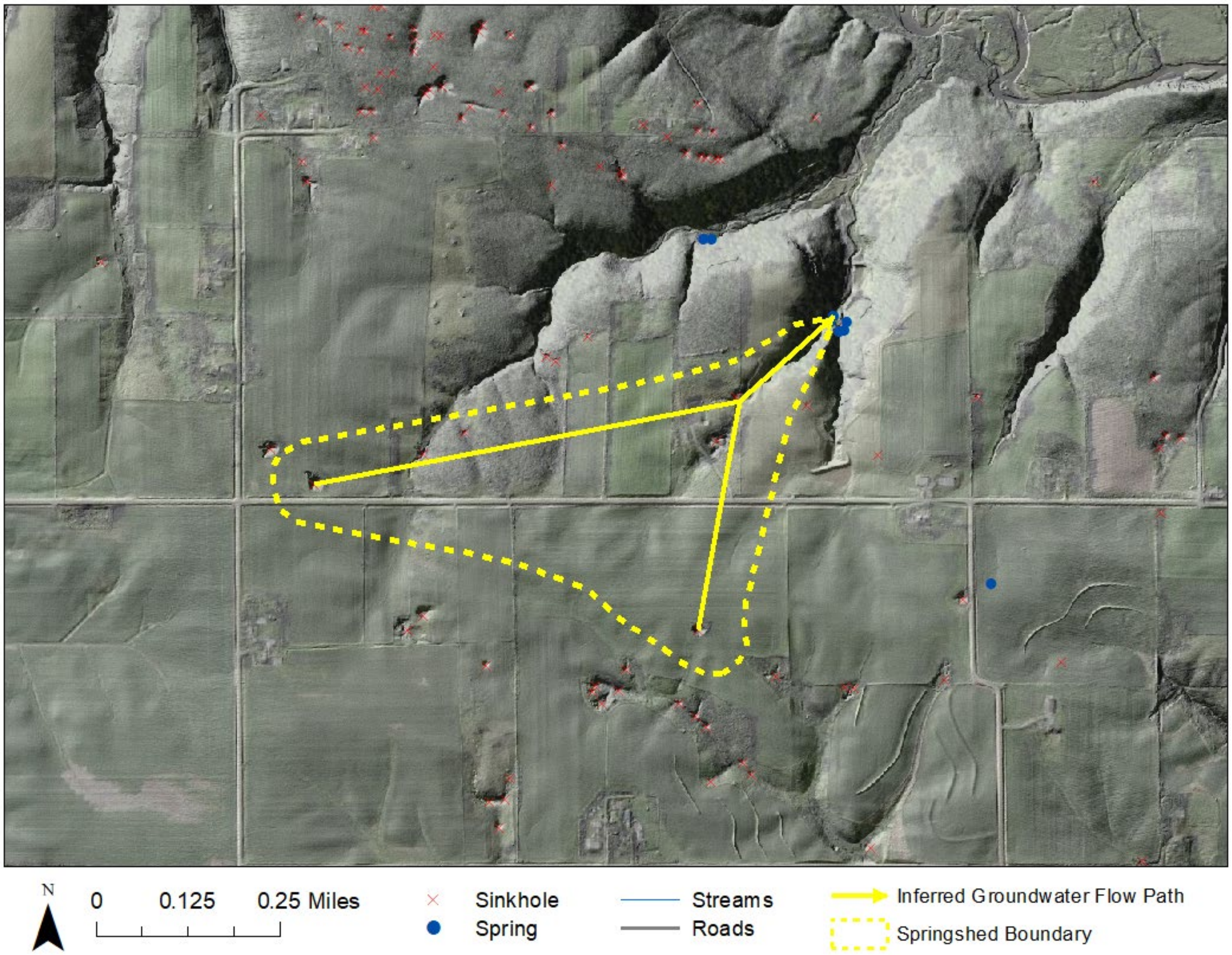

Figure 7. *Inferred groundwater flow directions and estimated springshed to Bill Burnap West Spring (55A655).*

Chemistry Results

Groundwater chemistry was collected at the Burnap Springs by the Olmsted SWCD to support long-term water quality monitoring and to support the upcoming Olmsted County Groundwater Atlas. The results are presented as Table 2.

Water chemistry can be used to determine water sources, flow paths, and the approximate travel time of groundwater. Specific concentrations can indicate high pollution sensitivity from the land surface or problems with naturally occurring geologic contaminants. Human caused (anthropogenic) occurrences of chloride and nitrate-nitrogen (nitrate) are relatively widespread in the water-table aquifer of Olmsted County (Barry, in preparation). The water-table aquifer is present in both sand and gravel (where present) and in bedrock units. Bedrock varies across the county and is generally comprised of the Maquoketa-Dubuque in the southwest, the Stewartville-Cummingsville in the south, and the St. Peter-Shakopee, Shakopee-Oneota, and Jordan elsewhere (Steenberg, 2020).

Table 2. Water chemistry results of grab sampling at the Burnap's South Spring complex.

Date/Time	Spring	Minnesota Spring Inventory	Collection Agency	Nitrate-N (mg/L)	Chloride(mg/L)	Sulfate (mg/L)
9/15/2021 13:23	Bill Burnap West Spring	55A0000655	Olmsted SWCD	7.5	15.8	13.0
9/15/2021 12:37	Bill Burnap Southwest Spring	55A0000657	Olmsted SWCD	7.4	16.2	13.1

In Olmsted County, elevated levels of chloride and nitrate most commonly occur in springs and wells completed in aquifers located above the first regionally competent aquitard, the Decorah Shale (Barry, in preparation). Nitrate can occur naturally at low concentrations (<1.0 ppm) but elevated concentrations indicate impacts from fertilizer and animal or human waste (MDH, 1998; Wilson, 2012). Concentrations may lessen with time (denitrification) in deep and confined aquifers where there is little oxygen available. Nitrate concentration is commonly elevated in southeastern Minnesota in the root zone and shallow aquifers underlying row-crop agriculture. Nitrate concentration from lysimeters in cultivated row crop settings averaged 22.3 ppm, but are highly variable with a typical range from 8.0 to 28.0 ppm (Kuehner and others, 2020). Nitrate at the Burnap South spring complex is elevated above natural conditions, but is below the drinking water standard of 10 mg/L. Although concentrations were below the drinking water standard, *drinking untreated water from the Burnap springs is not advisable*.

In Minnesota, chloride concentrations of groundwater samples greater than 5 mg/L indicate the aquifer has been impacted by activities on the land surface. In Minnesota, most aquifers with residence time greater than 70 years (as determined from non-detectable tritium) that are not mixed with natural residual brine typically have chloride concentrations less than 5 ppm (Unpublished analysis of DNR Groundwater Atlas Database, 2020).

Conclusions

This work has identified connections between two sinkholes south of the NBRR in Orion Township and a prominent spring in a tributary valley of the river. The two positive connections allow for mapping of a new springshed in Olmsted County. Additional tracing is required to more definitively define its boundaries.

Groundwater time of travel from this investigation is rapid and consistent with rates in similar shallow Galena karst of southeastern Minnesota and further refines time of travel for this aquifer system.

Acknowledgments

Partial funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen on Minnesota Resources (LCCMR). Martin Larsen arranged site access and hauled a water tanker for this tracing. Acknowledgment is given to the Burnap family for access to the springs. Access to sinkhole 55D631 was graciously provided by the Harland Morehart family. Access to sinkhole 55D316 was provided by the Bill Rehm family and is much appreciated.

Scott Alexander of the UofM Department of Earth and Environmental Sciences performed laboratory analysis and peak fitting.

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Appendix A

Bug name	KFD, MSI #	In Date	Out Date	Results	UTM, NAD83, Zone 15 Easting/Northing
1S - Co. Rd. 139	55X0000040	31-Mar-2021	15-Apr-2021	**Urn**	558,303 / 4,858,787
Crossing		15-Apr-2021	26-Apr-2021	nd	
		26-Apr-2021	28-Apr-2021	nd	
		28-Apr-2021	3-May-2021	nd	
		3-May-2021	10-May-2021	nd	
		10-May-2021	17-May-2021	nd	
		17-May-2021	24-May-2021	**Urn**	
		24-May-2021	31-May-2021	nd	
2S - Co. Rd. 139	55X0000--- *	31-Mar-2021	26-Apr-2021	nd	557,558 / 4,858,426
West Crossing		26-Apr-2021	28-Apr-2021	nd	
		28-Apr-2021	3-May-2021	nd	
		3-May-2021	10-May-2021	nd	
		10-May-2021	17-May-2021	nd	
		17-May-2021	24-May-2021	nd	
		24-May-2021	31-May-2021	nd	
3S - Bill Burnap	55X0000--- *	31-Mar-2021	15-Apr-2021	**Urn**	556,072 / 4,859,669
West Spring		15-Apr-2021	26-Apr-2021	nd	
		26-Apr-2021	28-Apr-2021	**SrhB**	
		28-Apr-2021	3-May-2021	**Eos, SrhB**	
		3-May-2021	10-May-2021	**Eos, SrhB**	
		10-May-2021	17-May-2021	**Eos, SrhB**	
		17-May-2021	24-May-2021	**Eos, SrhB**	
		24-May-2021	31-May-2021	**Eos, SrhB**	

Bug name	KFD, MSI #	In Date	Out Date	Results	UTM, NAD83, Zone 15 Easting/Northing
4S - Twin Springs	55X0000--- *	31-Mar-2021	15-Apr-2021	**Urn**	556,066 / 4,859,940
		15-Apr-2021	26-Apr-2021	nd	
		26-Apr-2021	28-Apr-2021	nd	
		28-Apr-2021	3-May-2021	nd	
		3-May-2021	10-May-2021	nd	
		10-May-2021	17-May-2021	nd	
		17-May-2021	24-May-2021	nd	
		24-May-2021	31-May-2021	nd	
5S - Sam Adams	55X0000--- *	26-Apr-2021 (water sample)		nd	553,539 / 4,859,307
Spring		26-Apr-2021	28-Apr-2021	nd	
		28-Apr-2021	3-May-2021	nd	
		3-May-2021	10-May-2021	nd	
		10-May-2021	17-May-2021	nd	
		17-May-2021	24-May-2021	nd	
		24-May-2021	31-May-2021	nd	
6S - Co. Rd. 19	55X0000042	26-Apr-2021 (water sample)		nd	553,935 / 4,858,545
Crossing		26-Apr-2021	28-Apr-2021	nd	
		28-Apr-2021	3-May-2021	nd	
		3-May-2021	10-May-2021	nd	
		10-May-2021	17-May-2021	nd	
		17-May-2021	24-May-2021	nd	
		24-May-2021	31-May-2021	nd	

Bug name	KFD, MSI #	In Date	Out Date	Results	UTM, NAD83, Zone 15 Easting/Northing
Tank 1	N/A	N/A	26-Apr-2021 (water sample)	nd	N/A
Tank 2	N/A	N/A	26-Apr-2021 (water sample)	nd	N/A

Notes:

Abbreviation	Definition
nd =	no dye detected in bug
Urn =	Uranine dye present in bug
Urn =	Uranine dye possibly detected
Eos =	Eosin dye present in bug
Eos =	Eosin dye possibly detected
SrhB =	Sulforhodamine B dye detected in bug
SrhB =	Sulforhodamine B dye possibly detected
55X0000--- *	Karst Features Database is currently being re-coded and is unavailable to provide unique numbers