Ironwood Spring Dye Trace and Groundwater Assessment

Olmsted County, Minnesota

Tracing Conducted
October 2020 through June 2021

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Introduction

This report presents the findings of dye tracing that was conducted in 2020 - 2021 in southwestern Olmsted County, Minnesota. 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).

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.

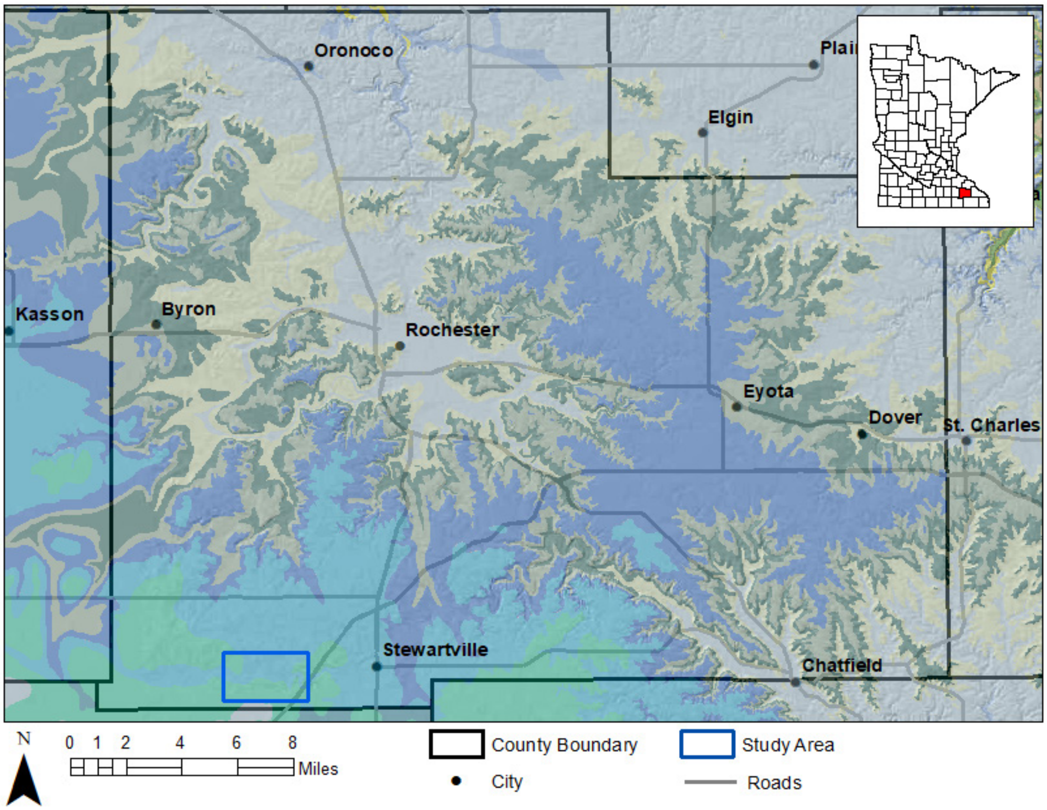

Figure 1. *Location of the Ironwood Springs study area in Olmsted County, Minnesota. Shading used to delineate bedrock geology loosely corresponds to the shading depicted in Figure 2. Geologic mapping from Steenberg (2020).*

Area Geology and Hydrogeology

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.

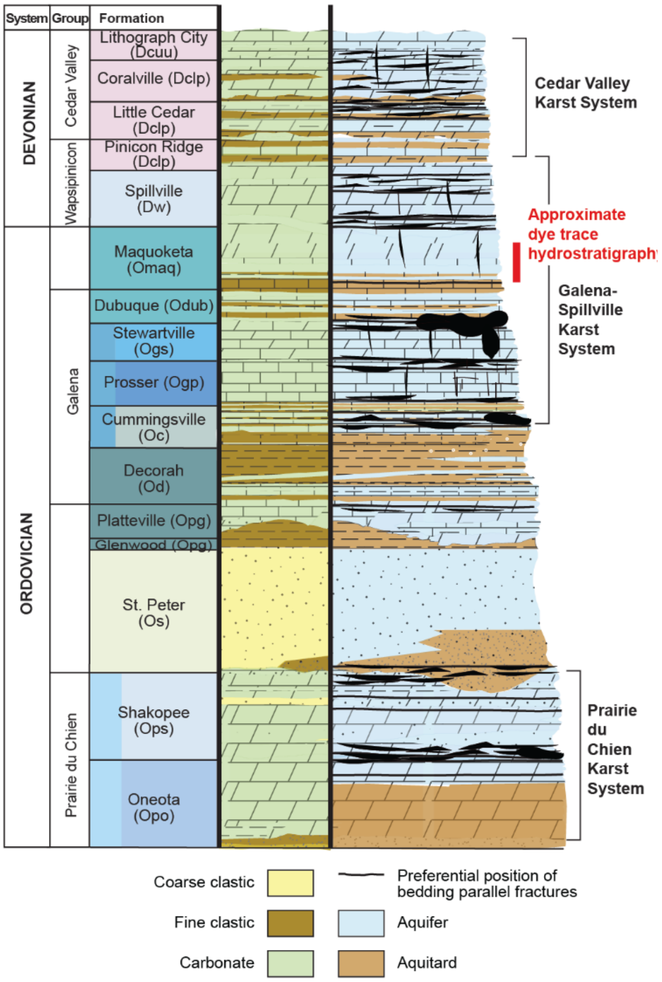

***Figure 2**. Geologic and hydrogeologic attributes of Paleozoic rocks in southeastern Minnesota.*

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. Ironwood Spring is a located near the geologic contact of the Maquoketa-Dubuque (Steenberg and Runkel, 2018).

Project Area and Trace Purpose

The project study area encompasses the area within and surrounding Ironwood Springs Christian Ranch (ISCR) and 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 direction, time of travel, and determine springshed boundaries within the county.

While the DNR was collecting data in support of the Olmsted Groundwater Atlas update, ISCR was being required by the Minnesota Pollution Control Agency (MPCA) to conduct a groundwater assessment for reissuance of their State Disposal System (SDS) Permit (MN0066818). ISCR is situated above the Maquoketa and Dubuque formations, two karstic geologic units for which the DNR has no tracing information for Olmsted County. As such, the DNR was willing to assist in a collaborative dye trace with the ISCR to assist in our understanding of groundwater flow direction and time of travel. In this unique collaboration, the DNR completed minor field work associated with spring and sinkhole mapping, trace plan development, dye introduction and dye trace interpretation, and reporting. ISCR assisted with inventorying potential springs and sinkholes and was responsible for changing passive monitoring packets (bugs) and analytical costs related to the dye trace monitoring. ISCR contracted directly with the University of Minnesota Department of Earth and Environmental Sciences (UofM) Hydrogeochemistry Lab for the analytical work.

ISCR is located approximately 4.8 miles west of Stewartville, Minnesota (Figure 1). Ironwood Spring, one of the most prominent springs in southwestern Olmsted County, is located on the south bank of the North Branch of the Root River (NBRR). The ISCR is situated on an interfluve between the NBRR and Robinson Creek, which have generalized stream elevations of 1233 ft. and 1248 ft. respectively (Figure 3). Robinson Creek is higher in elevation suggesting groundwater flow between these two features would be from Robinson Creek to the NBRR. Generalized groundwater contours of the Upper Carbonate Aquifer, which includes the Maquoketa and Dubuque formations, indicate that local groundwater flow is to the east underlying the ISCR and to the north from Robinson Creek (Kanivetsky, 1988). Depth to bedrock across the ISCR is likely 30 feet or less (Steenberg, 2020). Individual sinkholes are mapped to the southwest and southeast of Ironwood Spring and a large cluster of sinkholes is located approximately 0.5 miles to the east.

ISCR has several buildings with waste water connections that are all ultimately tied into a central drain field (Figure 5). Wastewater is pumped to the central drain field using pressure distribution systems.

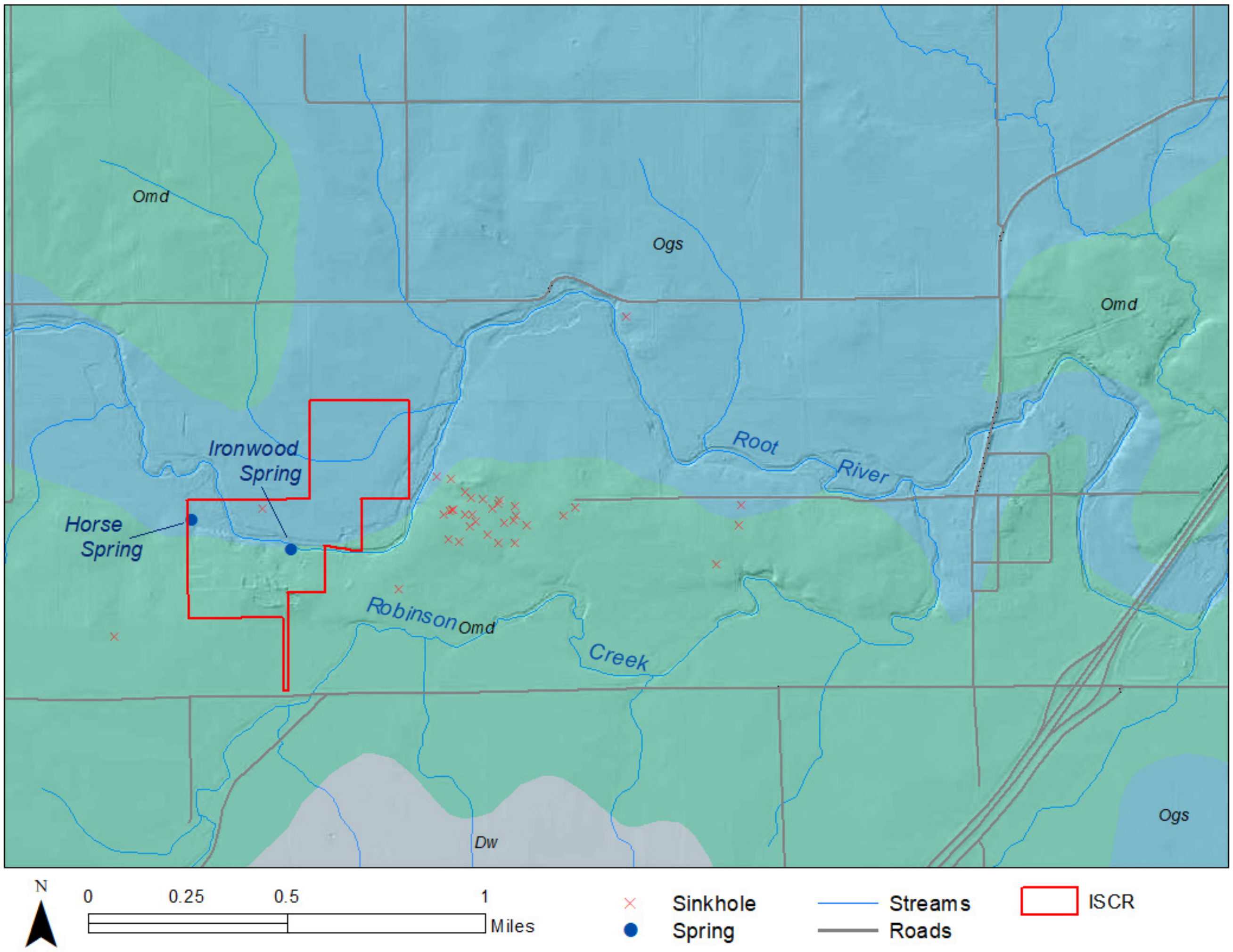

Figure 3. *Geology and karst features mapped in the project study area. Shading used to delineate bedrock geology loosely corresponds to the shading depicted in Figure 2. Map geologic unit codes correspond to those used in Figure 2 except the Omd, which combines Omaq and Odub into a single mapped unit. 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 Ironwood Spring and present in waters at the other monitoring points. After dyes were introduced, the bugs were changed periodically by ISCR staff and a citizen volunteer 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).

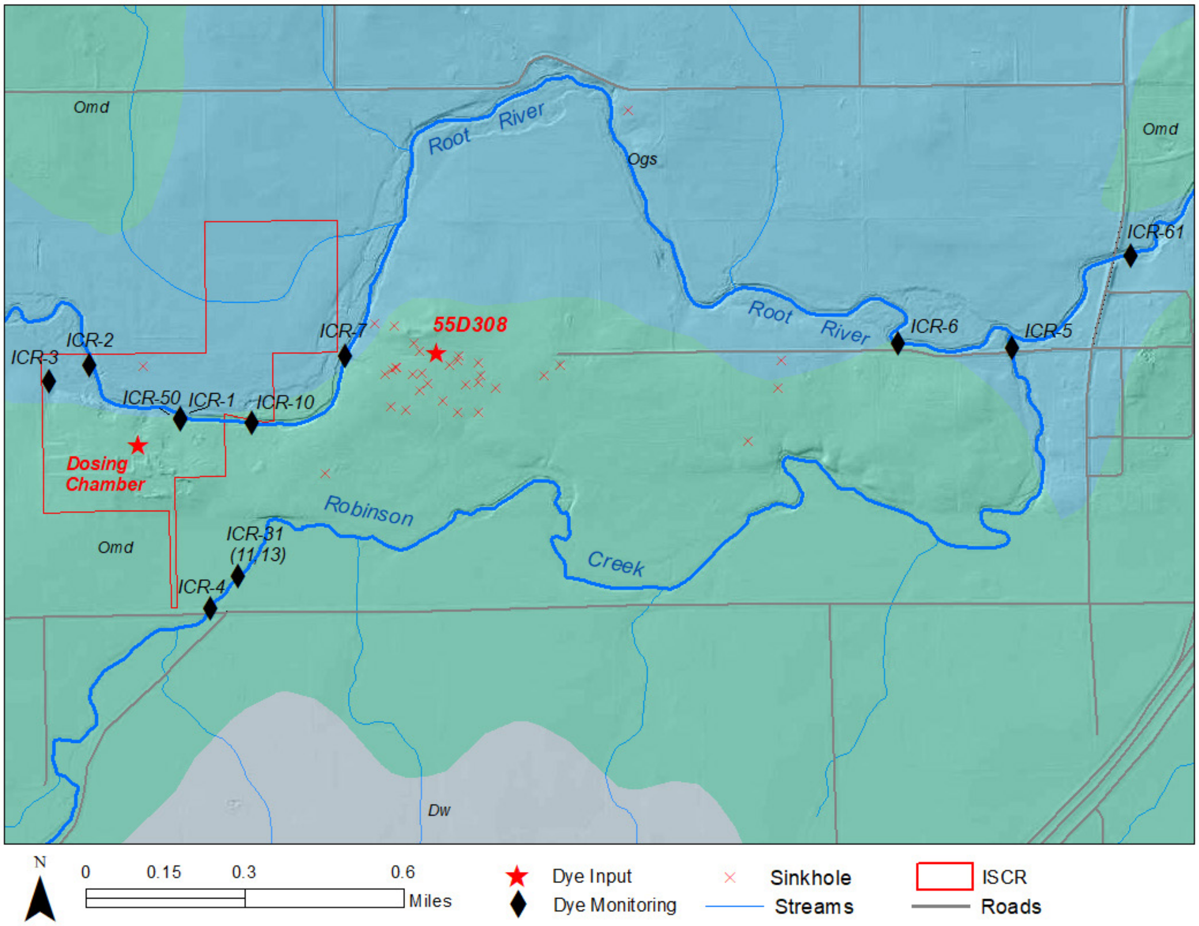

Figure 4. *Dye input locations, dye monitoring locations, bedrock geology, karst features, and surface water features of the Ironwood Study Area. Geologic mapping from Steenberg (2020).*

Dyes were introduced on October 28, 2020 to sinkhole 55D308* east of the camp facility and to the wastewater dosing chamber located to the southwest of the Founders Lodge (Figure 4). A mass of 2.022 kilograms of a sulforhodamine B solution (Chromatech Lot 2003-042) was injected into sinkhole 55D308 at 11:30 a.m. following wetting of the sinkhole with approximately 500 gallons of water. No open throat was evident in the sinkhole, therefore an additional 1,500 gallons was added following introduction of the dye. Water ponded in the sinkhole and drained slowly.

**Geospatial data for dye traces, including the locations of karst features and springs, are stored in parallel databases that share a relatable unique identifier. This unique identifier is used in 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., 55D0000308 is abbreviated to 55D308).

A mass of 3.8 kilograms of eosin solution (Chromatech Lot 021119A) was injected into the main drainfield dosing chamber at 1:03 p.m. and was pumped to the drainfield by manually running the dosing chamber pump. Due to the COVID-19 pandemic, ISCR was at a much reduced guest capacity during the trace investigation. However, a moderate flow of approximately 2,000 to 4,000 gallons per day was maintained flowing into the wastewater system during the full period of the trace activity. Flow was continued through light guest activity or through artificially generating flow into the system via continually running water faucets.

Trace Results

Dye injected into the dosing chamber of the wastewater system was detected at Ironwood Spring. Dye breakthrough time of travel for this trace was calculated using the straight-line distance from the dye injection to Ironwood Spring (1,139 feet), divided by the time elapsed before the dye was detected in passive charcoal detectors from the monitoring locations.

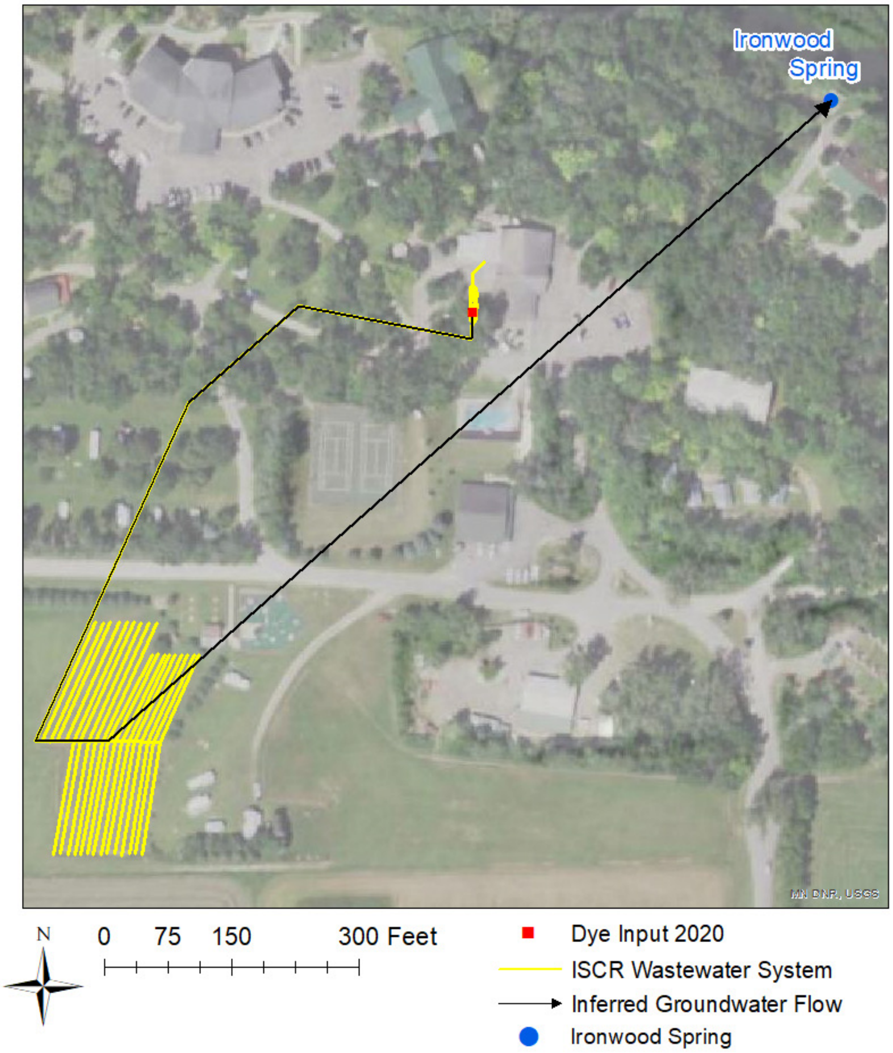

Figure 5. *Inferred groundwater flow direction from the ISCR wastewater system to Ironwood Spring (55A152).*

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”. Only eosin dye was recovered at Ironwood Spring (55A152), arriving at the spring between 135 and 156 days following introduction of the dye. The approximate minimum peak groundwater time of travel ranged between 11 to 12.7 feet/day. These values are much slower than those typical in shallowly buried karst in Minnesota.

The timing of this trace, beginning in October 28, 2020 may help explain the slow flow rates. Only one large rain event occurred after dye injection (approximately 1.9” on November 9-10, 2020), following that frozen-ground conditions that limited recharge began in December. Previous dye tracing (Barry and others, 2018b) in shallow karst of Olmsted County during frozen ground conditions found atypical groundwater flow rates that were inconsistent with previous flow rates and were interpreted as the dye being immobile above the water table in low recharge frozen-ground conditions. Following springtime recharge, dye was mobilized and subsequently detected at monitoring locations.

Dye injected into sinkhole 55D308 has not been detected. There are several possible explanations for the failure to detect the sulforhodamine B dye. They include:

1) a potential dye path, based on groundwater contours developed by Kanivetsky (1988), is to the east-northeast towards the Root River. It’s possible that the bug locations on the Root River did not intercept dye or that dilution from the river limited detection.

2) the dye moved preferentially downward into the underlying Stewartville Formation.

3) the dye is bound in soil within the sinkhole.

4) the dye took longer than the sampling period to reach one or more of the other sampling stations.

Chemistry Results

Groundwater chemistry was collected in 2020 at Ironwood Spring (55A152) in support of the Olmsted County Groundwater Atlas. An additional sample was collected during the dye trace to determine potential variability in the spring’s chemistry results. The results are presented as Table 1.

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 progress). 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).

The approximate time that has elapsed since water infiltrated the land surface to the time it resurges at a spring or is pumped from a well is called groundwater residence time. Short residence time generally suggests short travel paths and/or high recharge rates; long residence time suggests long travel paths and/or low recharge rates. The residence time of a groundwater sample from Ironwood Spring was estimated using isotopic analysis of the radioactive element tritium and by using the history of tritium deposition from precipitation in the general location (DNR and MDH, 2020). The Ironwood Spring sample had 4.0 tritium units and is interpreted to be modern water that entered the ground since approximately 1953. This result was expected, as shallow karst aquifers have high recharge rates.

Table 1. Water chemistry results of two sampling events at ISCR.

Date/Time	Sample	Collection	Bromide (mg/L)	Chloride (mg/L)	Cl/Br	Nitrate-N (mg/L)	Tritium (TU)	Tritium Age
1/23/2020 11:00	Ironwood Spring	DNR GW Atlas Program	0.022	20.2	918	7.24	4	Modern
10/28/2020 13:15	Ironwood Spring	Olmsted SWCD	N/A	23.3	N/A	7	N/A	N/A
10/28/2020 13:20	NBRR	Olmsted SWCD	N/A	23.8	N/A	6.6	N/A	N/A

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 progress). 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 Ironwood Spring 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 Ironwood spring 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). Anthropogenically elevated chloride can be distinguished from natural brine using Cl/Br ratios (Davis and others, 1998; Panno and others, 2006). In general, samples with chloride-to-bromide ratios greater than 300 are waters that have been influenced by human activity. Chloride-to-bromide ratios greater 1,000 indicate an anthropogenic halite source such as road salt, water softener salts, or fertilizers. Chloride at Ironwood Spring is elevated above natural conditions. The chloride to bromide ratio of 918 suggest a halite source for the elevated levels, however at the present time it is unclear what the source is.

A water sample taken from the NBRR the day of the trace was also analyzed for anion chemistry (Table 1). Nitrate (6.6 mg/L) and chloride (23.8 mg/L) levels from the river grab sample were very similar to those taken at Ironwood Spring, suggesting that for this synoptic sampling set the spring is not a major contributor of nitrate-nitrogen to the NBRR.

Previous MPCA analysis of nitrogen loading to streams found cropland sources of nitrogen contributing an estimated 72.9% to 78.9% of the statewide nitrogen load to streams and lakes during an average year (MPCA, 2013). Septic systems, combined with feedlot runoff, groundwater, and urban stormwater are estimated to contribute to less than 3% of the statewide nitrogen load to surface waters during an average precipitation year (MPCA, 2013).

Conclusions

This work has identified a connection between the ISCR drainfield and Ironwood Spring. Water chemistry of Ironwood Spring shows that it is relatively young groundwater with elevated levels of nitrate and chloride from anthropogenic sources. The demonstrated connection between the drainfield and spring verifies that Ironwood Spring can serve as a downgradient compliance sampling point as outlined in the January 14, 2020 memo from Leonard Rice Engineers, Inc. (LRE) to the MPCA.

Groundwater time of travel from this investigation is inconsistent with rates in similar shallow karst of southeastern Minnesota. Time of travel was likely impacted by limited recharge during the winter months combined with lesser volumes of wastewater flowing through the system due to limited guests during the period the camp was closed due to the covid-19 pandemic.

Acknowledgments

Appreciation is given to Tracy Bashore and Dan Ostergard of ISCR for arranging facility access, a water tanker for the sinkhole trace, and changing passive detectors. Appreciation is given to Jeff Green (formerly of the DNR) for also assisting with siting and changing passive detectors. Acknowledgment is given to Barb Hill and John Regehr for their help in providing access to sinkhole 55D308.

Trace planning and design by John Barry, Jeff Green, and Calvin Alexander, as outlined in the 05/14/2020 memo from the DNR to LRE and ISCR.

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Appendix A

Bug name	KFD, MSI #	In Date	Out Date	Results	UTM, NAD83, Zone 15 Easting/Northing
ICR-1	55A152	15-Jun-2020	22-Jun-2020	**Urn**	533,411 / 4,854,906
Ironwood Spring		22-Jun-2020	30-Jun-2020	nd	
		30-Jun-2030	8-Jul-2020	nd	
		8-Jul-2020	28-Oct-2020	nd	
		28-Oct-2020	30-Oct-2020	nd	
		30-Oct-2020	4-Nov-2020	nd	
		4-Nov-2020	13-Nov-2020	nd	
		13-Nov-2020	23-Nov-2020	nd	
		23-Nov-2020	7-Dec-2020	nd	
		7-Dec-2020	16-Dec-2020	nd	
		16-Dec-2020	13-Jan-2021	nd	
		13-Jan-2021	12-Mar-2021	nd	
		12-Mar-2021	2-Apr-2021	**Eos**	
		2-Apr-2021	20-Apr-2021	**Eos**	
		20-Apr-2021	30-Apr-2021	**Eos**	
		30-Apr-2021	19-May-2021	**Eos**	
		19-May-2021	3-Jun-2021	**Eos**	
		3-Jun-2021	17-Jun-2021	**Eos**	

ICR-2	55X082	15-Jun-2020	22-Jun-2020	nd	533,133 / 4,855,071
NBRR Up Stream		22-Jun-2020	30-Jun-2020	nd	
		30-Jun-2030	8-Jul-2020	nd	
		8-Jul-2020	11-Dec-2020	nd	
		28-Oct-2020	30-Oct-2020	nd	
		30-Oct-2020	4-Nov-2020	nd	
		4-Nov-2020	13-Nov-2020	*Eos*	
		13-Nov-2020	23-Nov-2020	nd	
		20-Nov-2020	11-Dec-2020	nd	

Bug name	KFD, MSI #	In Date	Out Date	Results	UTM, NAD83, Zone 15 Easting/Northing
ICR-3	55A153	15-Jun-2020	22-Jun-2020	nd	533,008 / 4,855,023
Horse Spring		22-Jun-2020	30-Jun-2020	nd	
		30-Jun-2030	8-Jul-2020	nd	
		8-Jul-2020	28-Oct-2020	nd	
ICR-4	55X083	15-Jun-2020	22-Jun-2020	nd	533,502 / 4,854,333
Robinson Creek		22-Jun-2020	30-Jun-2020	nd	
Up Stream		8-Jul-2020	28-Oct-2020	nd	
		28-Oct-2020	30-Oct-2020	nd	
		28-Oct-2020	30-Oct-2020	nd	
		30-Oct-2020	4-Nov-2020	nd	
		4-Nov-2020	13-Nov-2020	nd	
		13-Nov-2020	23-Nov-2020	nd	
		20-Nov-2020	11-Dec-2020	nd	
		12-Mar-2021	2-Apr-2021	nd	
ICR-5	55X084	15-Jun-2020	22-Jun-2020	nd	535,944 / 4,855,123
Robinson Creek		22-Jun-2020	30-Jun-2020	nd	
Down Stream		30-Jun-2030	8-Jul-2020	nd	
		28-Oct-2020	30-Oct-2020	nd	
		30-Oct-2020	4-Nov-2020	nd	
		4-Nov-2020	13-Nov-2020	nd	
		13-Nov-2020	23-Nov-2020	nd	
		23-Nov-2020	7-Dec-2020	nd	
		7-Dec-2020	12-Mar-2021	nd	
		12-Mar-2021	2-Apr-2021	nd	
		2-Apr-2021	20-Apr-2021	nd	
		30-Apr-2021	19-May-2021	nd	
		25-May-2021	3-Jun-2021	nd	
		3-Jun-2021	17-Jun-2021	nd	

Bug name	KFD, MSI #	In Date	Out Date	Results	UTM, NAD83, Zone 15 Easting/Northing
ICR-6	55X085	15-Jun-2020	22-Jun-2020	nd	535,595 / 4,855,137
NBRR Down Stream		22-Jun-2020	30-Jun-2020	nd	
		28-Oct-2020	30-Oct-2020	nd	
		30-Oct-2020	4-Nov-2020	nd	
		13-Nov-2020	23-Nov-2020	nd	
		2-Apr-2021	20-Apr-2021	nd	
		30-Apr-2021	19-May-2021	nd	
		19-May-2021	3-Jun-2021	nd	
		3-Jun-2021	17-Jun-2021	nd	
ICR-7	55X086	15-Jun-2020	22-Jun-2020	nd	533,910 / 4,855,101
NBRR Middle		22-Jun-2020	30-Jun-2020	nd	
		30-Jun-2030	8-Jul-2020	nd	
		8-Jul-2020	28-Oct-2020	nd	
		28-Oct-2020	30-Oct-2020	nd	
		30-Oct-2020	4-Nov-2020	nd	
		4-Nov-2020	13-Nov-2020	nd	
		13-Nov-2020	23-Nov-2020	nd	
		23-Nov-2020	7-Dec-2020	nd	
		7-Dec-2020	16-Dec-2020	nd	
		7-Dec-2020	30-Apr-2021	nd	
		30-Apr-2021	19-May-2021	*Eos*	

Bug name	KFD, MSI #	In Date	Out Date	Results	UTM, NAD83, Zone 15 Easting/Northing
ICR-10	55X--- *	16-Dec-2020	13-Jan-2021	nd	533,411 / 4,854,909
NBRR Down Stream		13-Jan-2021	12-Mar-2021	nd	
moved bug		12-Mar-2021	2-Apr-2021	nd	
		2-Apr-2021	20-Apr-2021	nd	
ICR-11	55X--- *	16-Dec-2020	13-Jan-2021	nd	533,584 / 4,854,430
Robinson Creek		13-Jan-2021	12-Mar-2021	nd	
Up Stream		12-Mar-2021	2-Apr-2021	nd	
Moved Bug		2-Apr-2021	20-Apr-2021	nd	
ICR-31 (13)	55X--- *	2-Apr-2021	20-Apr-2021	nd	533,584 / 4,854,430
Robinson Creek					
Down Stream					
ICR-50 NBRR	55X--- *	20-Apr-2021	30-Apr-2021	nd	533,411 / 4,854,909
at Spring Deck		30-Apr-2021	24-May-2021	nd	

Notes:

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

55X-- *Karst Features Database is currently being re-coded and is unavailable to provide unique numbers