Harmony West
Fillmore County, Minnesota

2018 Dye Trace Report

Tracing Conducted
May 31st through June 25th 2018

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CLEAN WATER LAND & LEGACY AMENDMENT

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Introduction

This report presents the findings of dye tracing that was conducted in 2018 west of the City of Harmony in southern Fillmore County, Minnesota. Previous dye tracing in the west Harmony area occurred in 1992 & 1993 in support of the Fillmore County Geologic Atlas (Alexander and others, 1996).

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).

Dye tracing and spring monitoring is being 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.

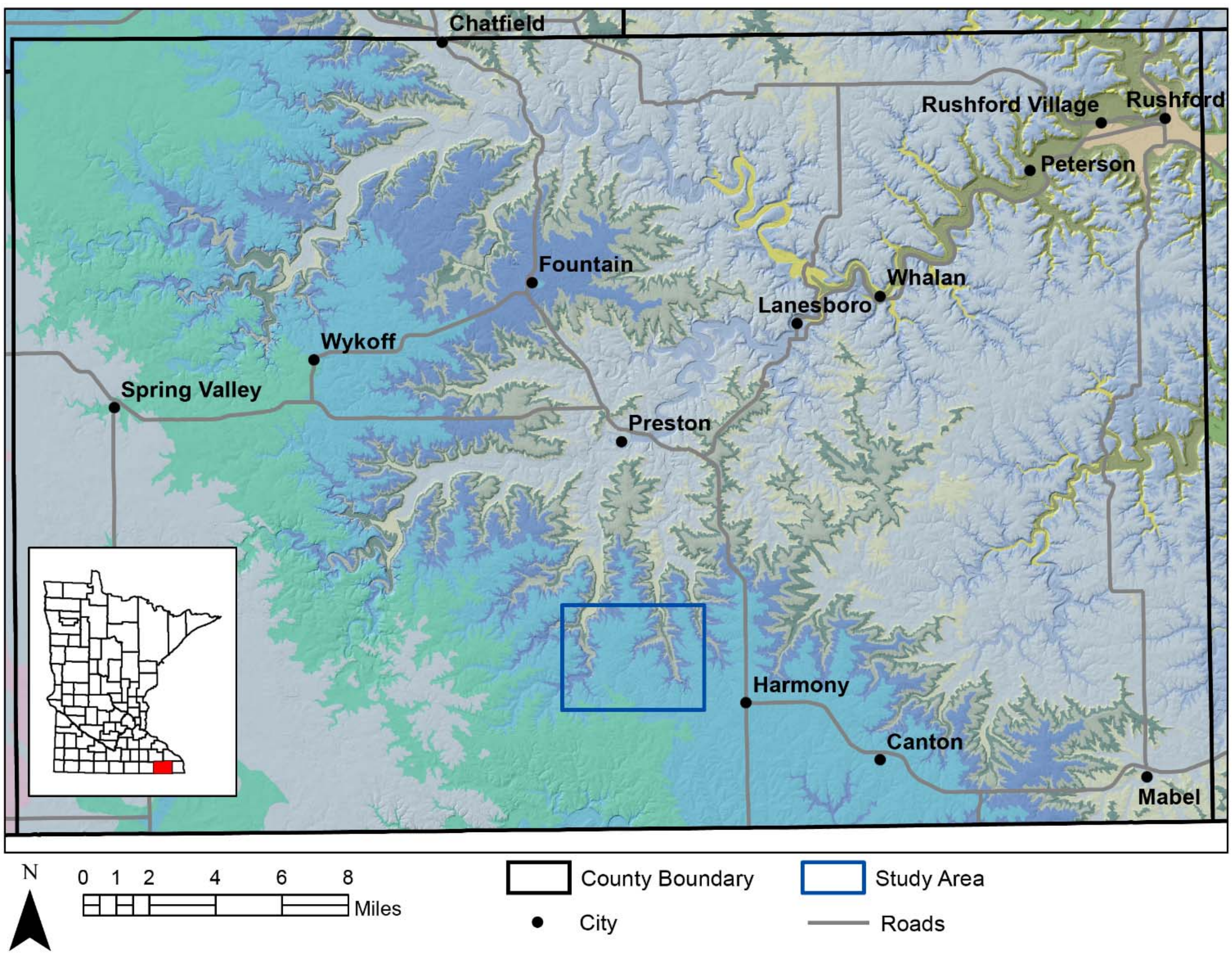

Figure 1. *Location map for the west Harmony study area. Geology base map unit's colors correspond with colors used in the Formation column of Figure 2.*

Area Geology and Hydrogeology

Underlying the relatively thin veneer of unconsolidated sediments, such as glacial till, loess, sand, and colluvium, in Fillmore County is a thick stack of Paleozoic bedrock units that range from the Devonian to Cambrian (Mossler, 1995). Devonian and Ordovician rocks are generally dominated by carbonates, whereas the Cambrian rocks are generally siliciclastic (Figure 2). In Fillmore County, broad plateaus are primarily underlain by resistant carbonate rocks of the Cedar Valley and Wapsipinicon Groups, the Maquoketa and Dubuque Formations, the Galena Group, or the Shakopee Formation (Mossler and Hobbs, 1995).

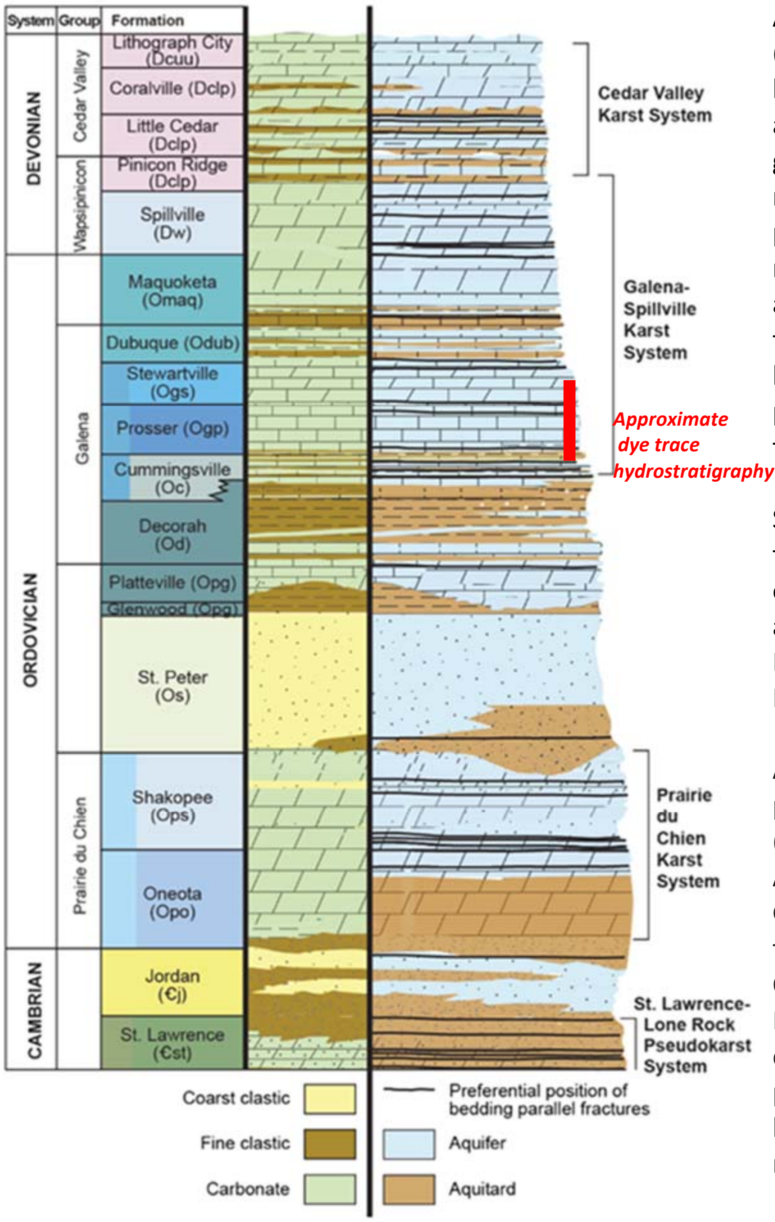

Figure 2. *Geologic and hydrogeologic attributes of Paleozoic rocks in southeastern Minnesota. Modified from Runkel et al. 2013.*

A generalized stratigraphic column for Fillmore County (Figure 2) shows lithostratigraphic and generalized hydrostratigraphic properties (modified from Runkel et. al. 2013). 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 fractures conductive enough to yield large quantities of water.

Springs and groundwater seepage frequently occurs at the toe of bluff slopes and in meander scars comprised of St. Peter Sandstone, near the contact of the Platteville and Decorah Shale, and near the contact of the Prosser Limestone and Cummingsville Formation (Mossler and Hobbs, 1995).

A hydrogeologic framework that describes four prominent karst systems for southeastern Minnesota (Runkel et al., 2013) is based largely on the work of Alexander and Lively (1995), Alexander et al. (1996), and Green et al. (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. The dye tracing and spring monitoring presented in this report occurred in the Galena-Spillville karst, where groundwater velocity can reach up to 1-3 miles/day (Green and others, 2014).

Tracing Methods

Dye tracing is a technique used to characterize the groundwater flow system to determine groundwater flow direction and rate. Traces are designed to establish connections between recharge points (sinkholes and stream sinks) and discharge points (springs and streams). Multiple traces are necessary to delineate the boundaries of springsheds. Dye tracing was 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 are not naturally present in groundwater.

To detect the presence or absence of dye at springs and other monitoring locations, passive charcoal detectors were used. These detectors, often referred to as “bugs”, were deployed prior to introducing dye to determine background levels of fluorescence in the groundwater. After dyes were introduced on May 31, 2018, the bugs were changed periodically by Fillmore SWCD and Minnesota DNR staff until the trace was terminated. The time resolution of the dye arrival at the monitored points is limited to how long the charcoal packets were left in the water before being analyzed. Appendix A summarizes the monitoring locations and how frequently the passive detectors were changed.

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 Fityk version 1.20 non-linear curve-fitting software and summarized into a table (Appendix A).

The *Harmony West* traces were designed to establish connections between recharge points, the sinkholes located on the karst interfluve between Willow Creek and Camp Creek, and discharge points (springs) located at select locations along each creek (Figure 3). Property access and permission and tanker truck access and delivery was coordinated by Caleb Fischer of the Fillmore SWCD.

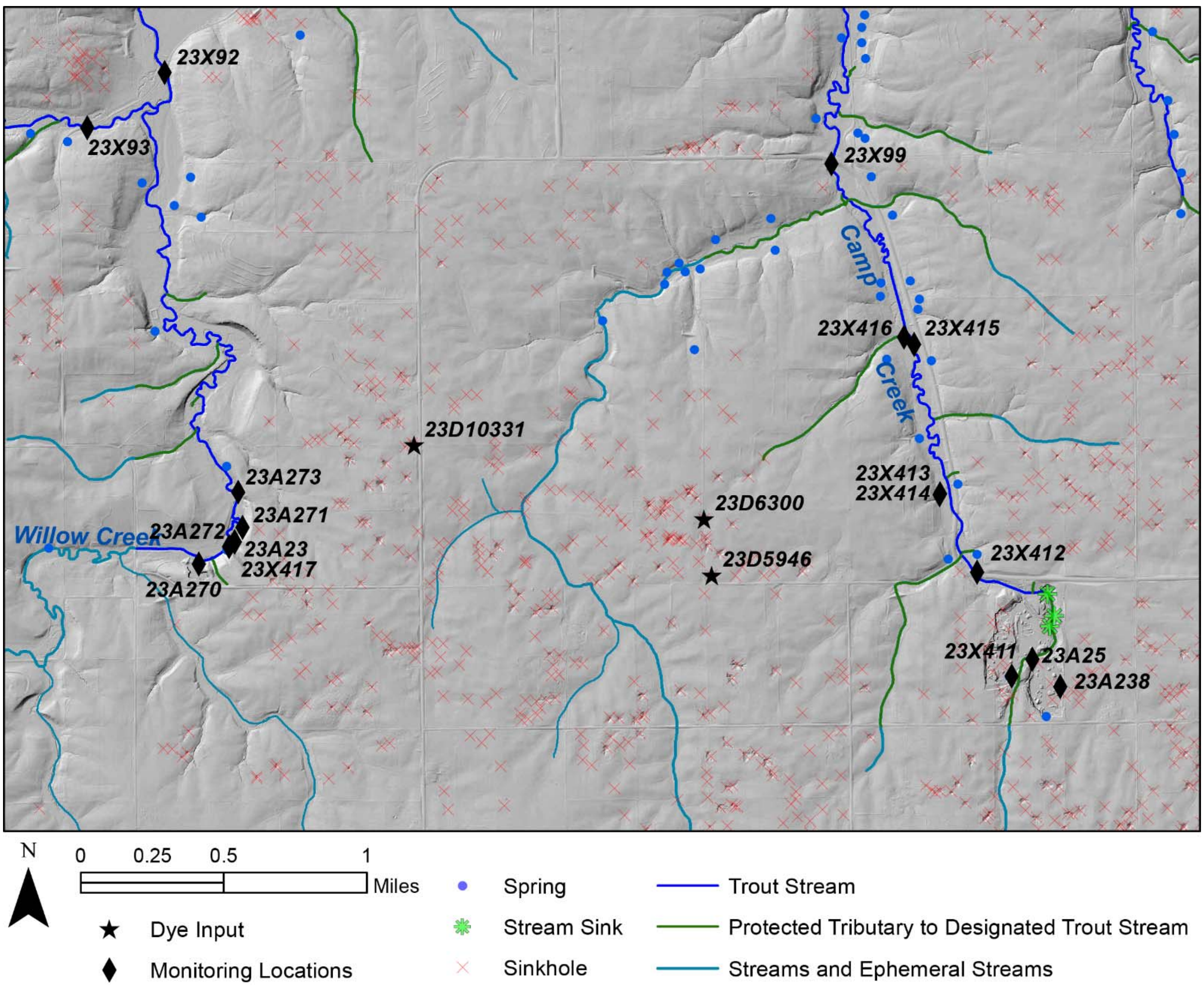

Figure 3. *Dye input points and sampling locations for the* 2018 traces.


Figure 4. Preparation of 500 gallon tanker trucker.

Since the three dye introduction points for these traces were dry sinkholes, dyes were flushed into the sinkholes with water from a tanker truck graciously lent to the project from the Preston Fire Department (Figure 4). Each sinkhole was wetted with approximately 100 gallons of water prior to the dye being manually poured into the sinkhole. Dyes were then back-flushed with approximately 250-300 additional gallons. All three dyes were poured on May 31, 2018 at the sinkhole locations summarized in Table 1. The Karst Feature Database identifiers are typically ten character alpha-numeric, but have been abbreviated for the table and figures. (e.g. 23D0006300 is abbreviated to 23D6300).

Date of Dye Input	Location (KFD #)	Dye Type	Mass (grams)
31-May-18	23D5946	Uranine C	584.57
31-May-18	23D6300	Sulforhodamine B	510.3
31-May-18	23D10331 (inside of 23D6626)	Eosin	403.04

Table 1. *Summary of pour locations, dye types, and masses.*

Trace Results

Inferred Groundwater Flow Direction and Springshed Delineation

Each of the three dyes that were introduced in this trace flowed west to a series of springs located on the east bank of Willow Creek (Figure 4 and Appendix A). Groundwater flow directions determined in this trace are similar to the groundwater flow directions found in the 1993 tracing that occurred as part of mapping for the Fillmore County Geologic Atlas. The springshed delineated during the 1993 work was coined the Rapture River springshed and equaled 458.7 acres in area. The revised springshed determined through the addition of the 2018 tracing equals 865.8 acres.

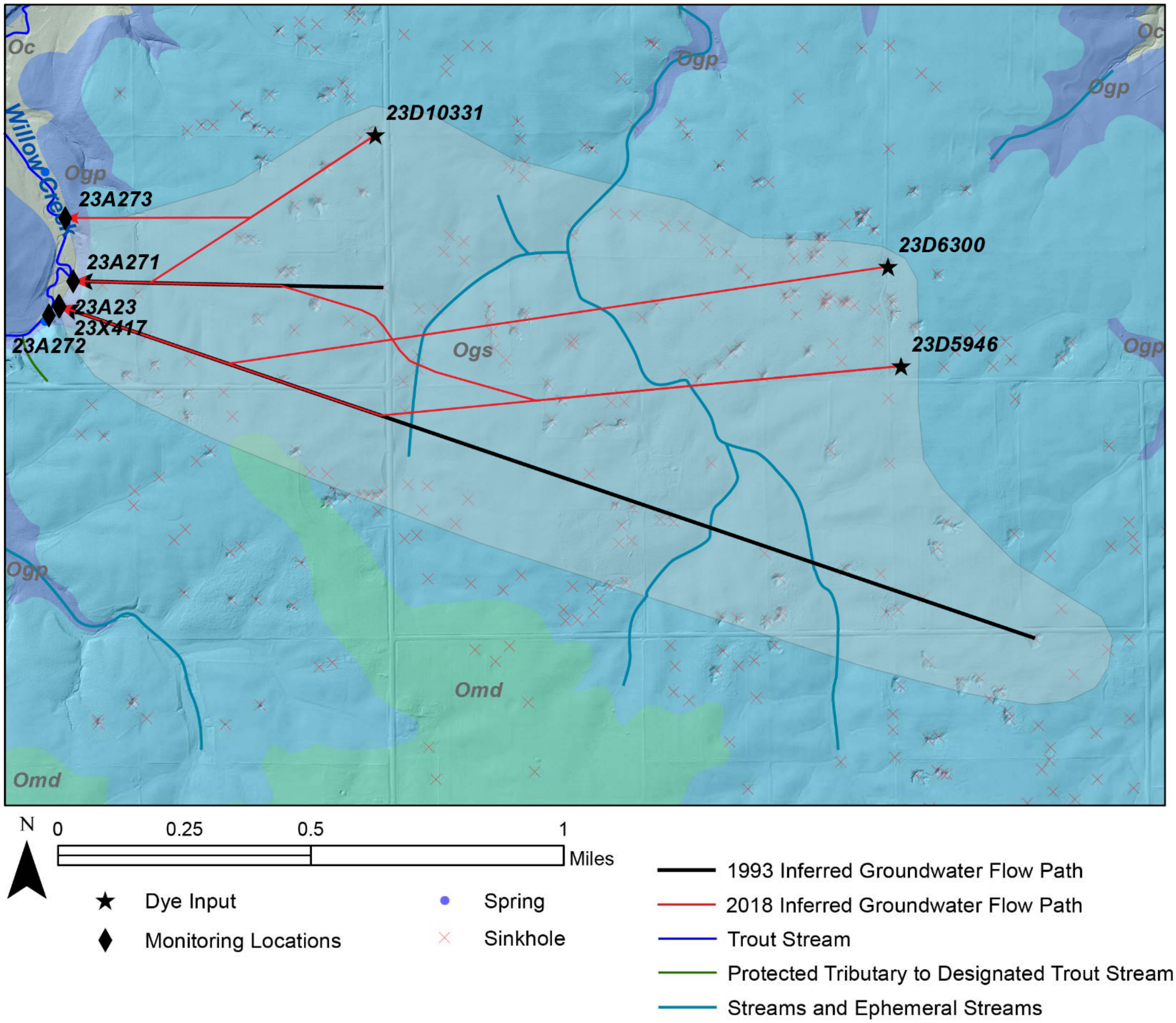

Figure 4. *Inferred groundwater flow paths and aerial extent of the Engle Spring Group springshed.*

Groundwater Time of travel

Groundwater time of travel in the Galena group in Fillmore County, determined from decades of dye tracing, is extremely rapid and conduit pathways can extend for miles. Large conduit systems have been encountered throughout the county and cave systems such as Niagara Cave and Holy Grail Cave are within roughly 5 miles of this trace. Groundwater time of time of travel for the Twin Springs springshed, located just west of the project area, during a 2011 trace was at least 1.5 miles/day (Kuehner and others, 2017). Dye-breakthrough time of travel for this trace was calculated using the straight line distance from the dye injection, divided by the time elapsed before the dye was detected in passive charcoal detectors from the monitoring locations. All three dyes arrived at springs in the Engle Spring group from 1 to 7 days after introduction. Approximate minimum peak groundwater time of travel ranged between approximately 2240 feet/day to 1.7 miles/day for the uranine dye, approximately 2100 feet/day to 1.6 miles/day for the sulforhodamine B dye, and approximately 500 feet/day to 870 feet/day for the eosin.

Engle Spring recharge response and chemistry

Engle Spring (23A023) is the largest of a group of perennial springs in the Engle Spring group that emanate from bedding planes in the Cummingsville Formation of the Galena Group (Steenberg and Runkel, 2018). Spring monitoring at Engle Spring is being completed through collaboration between the DNR, MPCA, MDA, Olmsted County SWCD, and partners at the Fillmore SWCD. Spring level, temperature, nitrate concentration, and flow are the emphasis of the effort (Figure 5).

The intent of the monitoring is to collect data to facilitate understanding of aquifer recharge and aquifer characteristics following precipitation and snowmelt events.

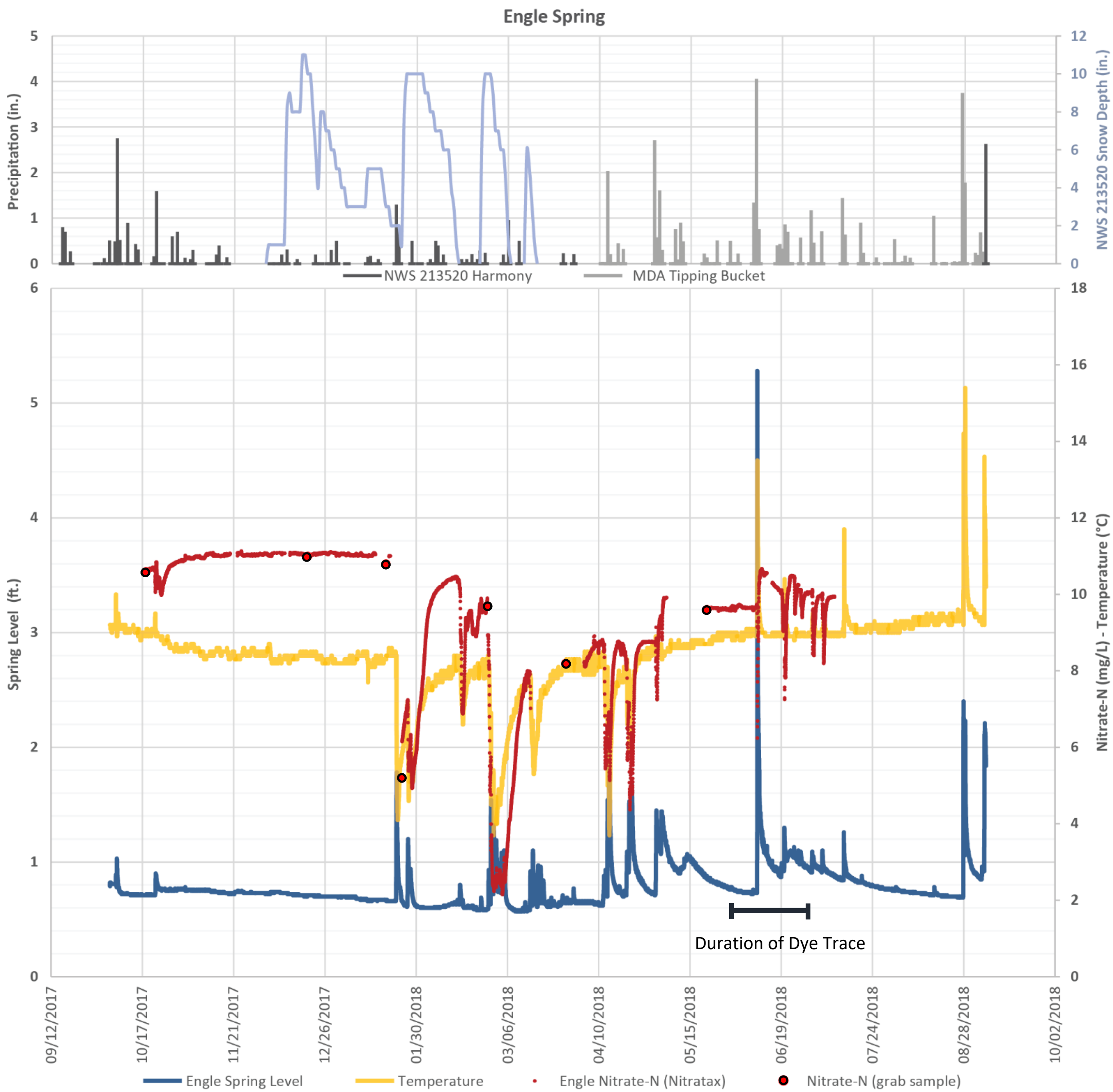

Figure 5. *Engle Spring level, temperature, and nitrate response to snowmelt and precipitation events.*

The upper panel of Figure 5 shows the snow depth (in blue) and the daily cumulative precipitation (in black) recorded at the nearby National Weather Service station (213520) located in Harmony. A subset of the cumulative precipitation, shown in gray, was recorded roughly 1 mile away by MDA collaborators. The precipitation received during this period of monitoring greatly exceeds average precipitation for the area.

The lower panel of Figure 5 shows Engle Spring's water level, temperature and nitrate concentration responses to snowmelt and precipitation events. The rapid water level response of the spring to recharge from snowmelt and precipitation events indicate that the spring is integrated into the local karst hydrologic system. The base flow temperature of the spring ranges from about 8.5 C to a little over 9 C seasonally. Recharge events produce rapid, short term, strong temperature fluctuations in the spring. Cold winter precipitation and snow melt recharge decreases the spring water temperature to less than 4 C. Warm summer precipitation events can raise the spring water temperature to over 15 C. These temperature fluctuations correlate with the large, prompt flow pulses produced by precipitation and snowmelt recharge events. Surface recharge reaches the spring on time scales of less than a day.

Nitrate concentrations greater than 1 part per million are greater than background conditions and indicate that an aquifer has been impacted by activities on the land surface (Minn. Dept. of Health, 1998 and Wilson, 2012). The baseflow nitrate-nitrogen levels at Engel Spring during the roughly one year of monitoring shown in Figure 5 were in the 9 to 11 ppm -- at or above the drinking water standard of 10 ppm. The flow pulses from snowmelt and winter and summer precipitation events briefly dilute the high nitrate levels of the spring's baseflow. The late February early March snowmelt flow pulse briefly diluted the nitrate-nitrogen level in the spring down to 2 ppm.

Discussion and Conclusions

The successful 2018 tracing in the west Harmony area expanded and refined the springshed area of the Engle Spring group and further defined the boundary between the Engle springshed and the Big Spring Quarry. Although the springshed has been approximated using the techniques outlined in this report, the lateral extent of the springshed is not a sharp boundary and moves dynamically, both horizontally and vertically, in response to changes in groundwater levels. Tracing to the Engle Spring group shows the complicated interconnection of the conduit network underlying the Willow-Camp Creek interfluve. Multiple precipitation events during this trace changed head levels in the underlying karst aquifer system, changing the direction of groundwater flow and time of travel. The inferred groundwater flow paths shown in Figure 4 and the results presented in Appendix A illustrate the complex patterns determined through this work.

This refined springshed map can help improve nitrate-nitrogen yield loss computations and computer models used to measure the effectiveness of nitrogen practices. It may also be informative in determining where nitrogen management surveys and BMPs should be concentrated. When discussing the importance of strategies to minimize nitrate-nitrogen losses from agricultural activities, the dye trace maps have proven to be effective in helping elevate nitrogen BMP discussions with area farmers and crop advisors (Kuehner, personal communication, 2018).

Acknowledgments

This project would not have been possible without the cooperation of landowners in project area and the Preston Volunteer Fire Department. Funding for this project was provided by the Minnesota Clean Water Land and Legacy Amendment and the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR). Scott Alexander at the University Of Minnesota Department Of Earth Sciences analyzed samples and performed peak fitting. Holly Johnson provided graphic editing assistance and review.

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Bug Locations					Results									
Bug Label	Type	UTM E	UTM N	KFD #	21 May 2018 31 May 2018	23 May 2018 31 May 2018	29 May 2018 31 May 2018	31 May 2018 1 Jun 2018	31 May 2018 4 Jun 2018	1 Jun 2018 4 Jun 2019	4 Jun 2018 7 Jun 2018	7 Jun 2018 14 Jun 2018	14 Jun 2018 19 Jun 2018	19 Jun 2018 25 Jun 2018
Willow Creek Drainage														
A270	spring	572,276	4,824,176	23A270	nd	---	---	nd	---	nd	nd	Uran	nd	nd
A272	spring	572,445	4,824,271	23A272	nd	---	---	Eos	---	nd	nd	bug lost	nd	Uran
A23L	spring	572,480	4,824,299	23X417	---	---	---	---	---	Uran & SrhB	Uran & SrhB	Uran & SrhB	Uran & SrhB	Uran
A23, Engle Spring	spring	572,476	4,824,300	23A23	nd	---	---	nd	---	Uran & SrhB	Uran & SrhB	bug lost	Uran	Uran
A0271, Spring Below Engle	spring	572,523	4,824,379	23A271	nd	---	---	---	Eos	---	Uran & Eos	Uran & Eos	Uran & Eos	Uran & Eos
A0273	spring	572,497	4,824,580	23A273	nd	---	---	nd	---	nd	nd	Uran & Eos	Eos	Eos
CCO/CCOH	stream	571,649	4,826,632	23X93	---	Eos	---	nd	---	nd	nd		nd	nd
WCOJ	stream	572,085	4,826,943	23X92	---	---	nd	Eos	---	Eos & SrhB	lost bug		Uran & Eos	Uran & Eos
Camp Creek Drainage														
SVR South	spring run	576,442	4,824,565	23X414	---	nd	---	nd	---	nd	nd	nd	nd	nd
SVR North	spring run	576,444	4,824,571	23X413	---	nd	---	nd	---	nd	nd	nd	nd	nd
CMP Camp Nolan/Creek	stream	576,299	4,825,412	23X416	---	nd, nd	---	nd	---	nd	nd	nd	nd	nd
NLN Spring	spring run	576,241	4,825,454	23X415	---	nd	---	nd	---	nd	nd	nd	nd	nd
Hwy 22 Camp Creek North	stream	575,833	4,826,429	23X99	---	nd	---	nd	---	nd	nd	nd	nd	nd
Big Springs Quarry Area														
(HBSE) East Wall Big Spring	spring	577,121	4,823,486	23A238	---	---	---	---	nd	---	---	nd	nd	---
(HBSW) Quarry SW Wall	spring	576,848	4,823,545	23A25	---	---	---	---	nd	---	nd	nd	---	---
BS Quarry Bridge Culvert	stream	576,964	4,823,640	23X411	---	---	---	---	nd	---	nd	nd	nd	---
Quarry Outlet at Hwy 22	stream	576,652	4,824,130	23X412	---	---	---	---	---	nd	nd	---	nd	nd
Quarry West Wall Flow	spring	-	-	-	---	---	---	---	nd	---	---	---	---	---

nd = no dye detected from this bug from this location during this time interval

"---" = no bug from this location during this time interval

Eos = Eosin dye detected.

Uran = Uranine dye detected

SrhB = SulforohodamineB dye detected