REPORT on the 2014-2015 dye traces conducted in the vicinity of Stockton Minnesota.

Winona County, Mn

Minnesota Department of Natural Resources

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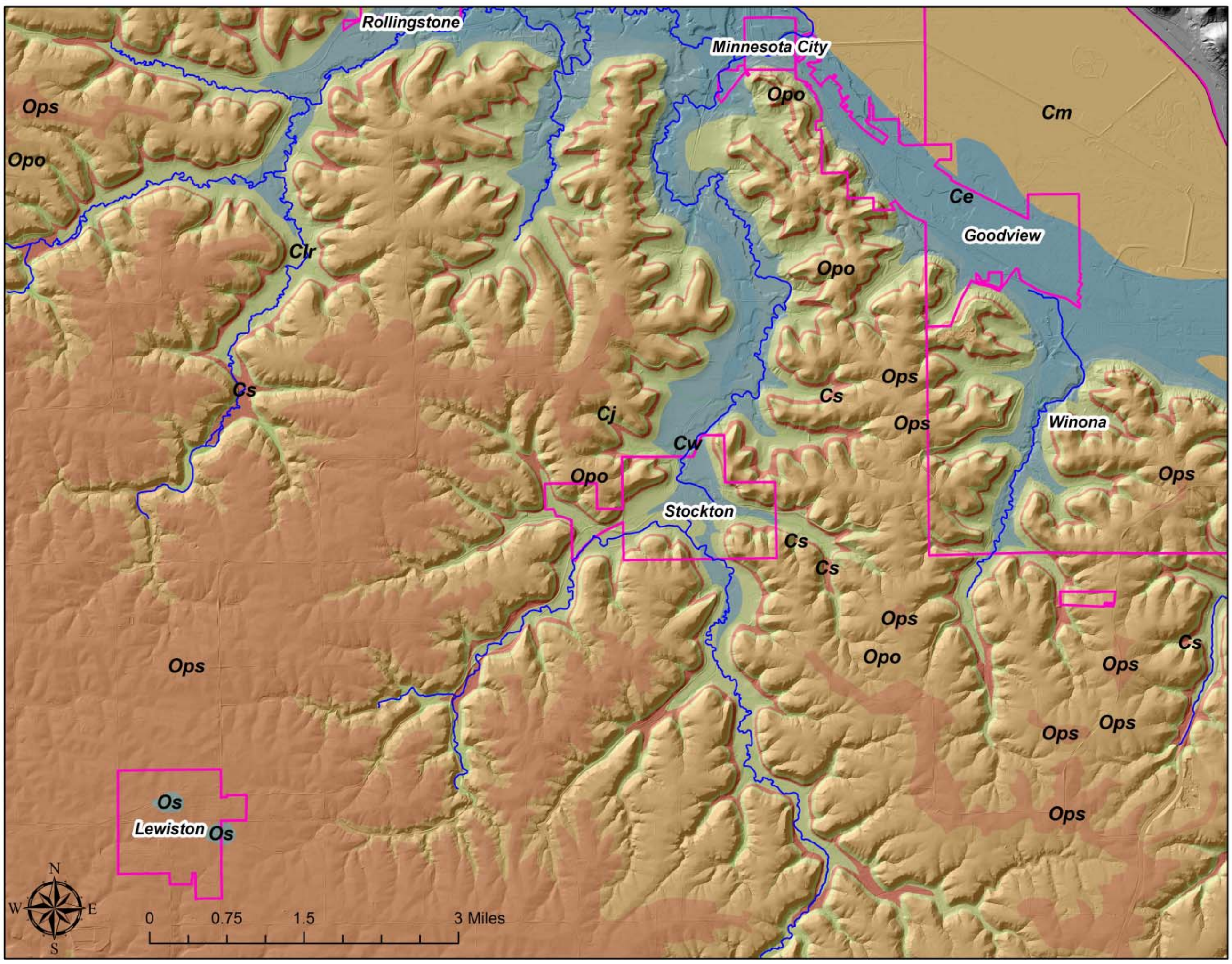
Introduction

In November of 2014 through March 2015, two dye traces were conducted in Hillsdale and Warren Townships in central Winona County, Minnesota (Figure 1). The traces took place in the immediate vicinity of the town of Stockton, Minnesota. Additional dye traces have been completed within an approximate ten mile buffer of this area. They include traces on the South Branch of the Whitewater River, Rush Creek, Crystal Springs State Fish Hatchery, and Ahrensfeld Creek. The majority of the previous traces were conducted to develop springshed mapping in support of trout stream management.

Figure 1. *The City of Stockton is located in central Winona County, Minnesota (the bright pink outlines show city limits). Streams identified as trout streams are shown with dark blue lines. The Prairie du Chien Group is depicted with dark and light brown hues. Upper Cambrian units are depicted with greenish hues and mid-Cambrian units are depicted with blue hues. The light brown hue in the north eastern portion of map is the lower Cambrian Mt. Simon Sandstone. Geologic map from Runkel et al., 2013. See Appendix 2 for definition of map symbols.*



The Stockton areas traces were conducted to further delineate springsheds in the area, characterize sinking streams in the Cambrian St. Lawrence Formation, and characterize surface water-groundwater interactions in the county. Characterizing sinking streams and their connection to cold water springs is important as numerous trout streams are located in southeastern Minnesota.

The traces were designed and executed by Jeff Green and John Barry of the Minnesota Department of Natural Resources (DNR). Sophie M. Kasahara, Betty J. Wheeler, and Scott C. Alexander of the University of Minnesota Earth Sciences Department assisted with dye sample analysis. E. Calvin Alexander, Jr., assisted with dye recovery interpretation.

Dye tracing entails using fluorescent dyes to track groundwater flow directions and travel times. The dye is poured into a sinking stream or sinkhole; from there it flows through a conduit system until it re-emerges at a spring. For the Stockton project, the dyes Eosin and Rhodamine WT were used for the traces. Table 1 identifies input locations and dye quantities used for each trace. Dye recovery was accomplished using passive dye detectors (packets of coconut charcoal, also known as "bugs"). All direct water samples and charcoal detectors were returned to the University of Minnesota Geology & Geophysics Department Hydrochemistry Laboratory for analysis. There, the charcoal detectors were opened, the charcoal was removed, and the fluorescent materials were extracted using an eluent solution of 70% isopropyl alcohol, 30% deionized water, and 10g/L NaOH. The eluent solution was then run through the Shimadzu RF5000U scanning spectrofluorophotometer to detect and record the spectra. Spectral components, including the background spectral components, were quantified using PeakFit software as described in Alexander (2005).

Trace Approach

Jeff Green of the DNR established contact with landowners who own property with relevant sinking stream points, stream access points, and springs. After gaining permission for property access, "background" bugs were placed at advantageous points throughout the investigation area. Background bugs are passive charcoal detectors that establish the level of dye, if any, that is present in a stream prior to the introduction of the trace dye. The first dye trace was initiated at 11:00 on November 5, 2015 with the introduction of 1.158 kilograms of Eosin dye solution into a discrete sinking stream point (MN85:B00022) on an unnamed creek (M-026-001-006-002) which is a tributary to Minnesota designated trout stream (Garvin Brook). A second dye was poured later the same day. At 18:10 1.114 kilograms of Rhodamine WT dye solution was poured into a different discrete sinking stream point (MN85:B00021) on a separate tributary to unnamed creek tributary (M-026-001-006-002). Jeff Green, John Barry, and Nic Borchardt of the DNR were present for the trace. Dye mass, description, lot number, estimated stream discharge, and notes collected during the trace are summarized in Table 1. Dye pour locations and passive sampling locations are shown in Figure 2.

Table 1. *Stockton area dye trace input locations, dye types, trace dates, and estimated stream flow.*

Stockton Minnesota 2014 Trace		
	Unruh Stream Sink (MN85:B00022)	Hwy 20 Stream Sink (MN85:B00021)
Dye Input Date	11/5/2014	11/5/2014
Dye Input time	11:00	18:10
Dye	Eosin	Rhodamine WT
Dye Mass (g.)	1157.8	1113.7
Dye Desc.	D13800, Chromatint Red Liquid 0143, 33 wt % solution	D13800, Chromatint Liquid, 20 wt % solution
Dye Lot #	Chromatech Lot # 040711B	Chromatech Lot # 040811F
Estimated Stream Discharge (cfs)	~ 0.1-0.2	~ 0.2-0.3
Pour Notes:	Cleared channel of leafy debris and poured dye ~ 2 meters U.S.	Poured dye ~ 1 hour after sunset during light steady rain

Figure 2. *Stockton, Minnesota dye pour locations and passive sampling locations. Pour locations are shown as green points with dark centers and passive sampling locations are shown as red points. Two additional monitoring locations, Middle Branch Rolling Stone and Scherbring Spring Run, to the north of the study area where no dye was detected are not shown for simplicity. Geologic mapfrom Runkel et al., 2013. See Appendix 2 for definition of map symbols.*

Passive charcoal detectors were in place at sampling locations prior to the introduction of the dyes. Background bugs integrated waters from October 22, 2014 until November 5, 2014. A summary of passive sampling sites, including background bugs, in included as Appendix 1. Bold italicized cells with red or brown font in Appendix 1 emphasize the sites where either trace amounts or quantifiable amounts of Rhodamine WT or Eosin respectively were detected. No dye was detected at any of the background bugs prior to initiating the dye trace.

Results

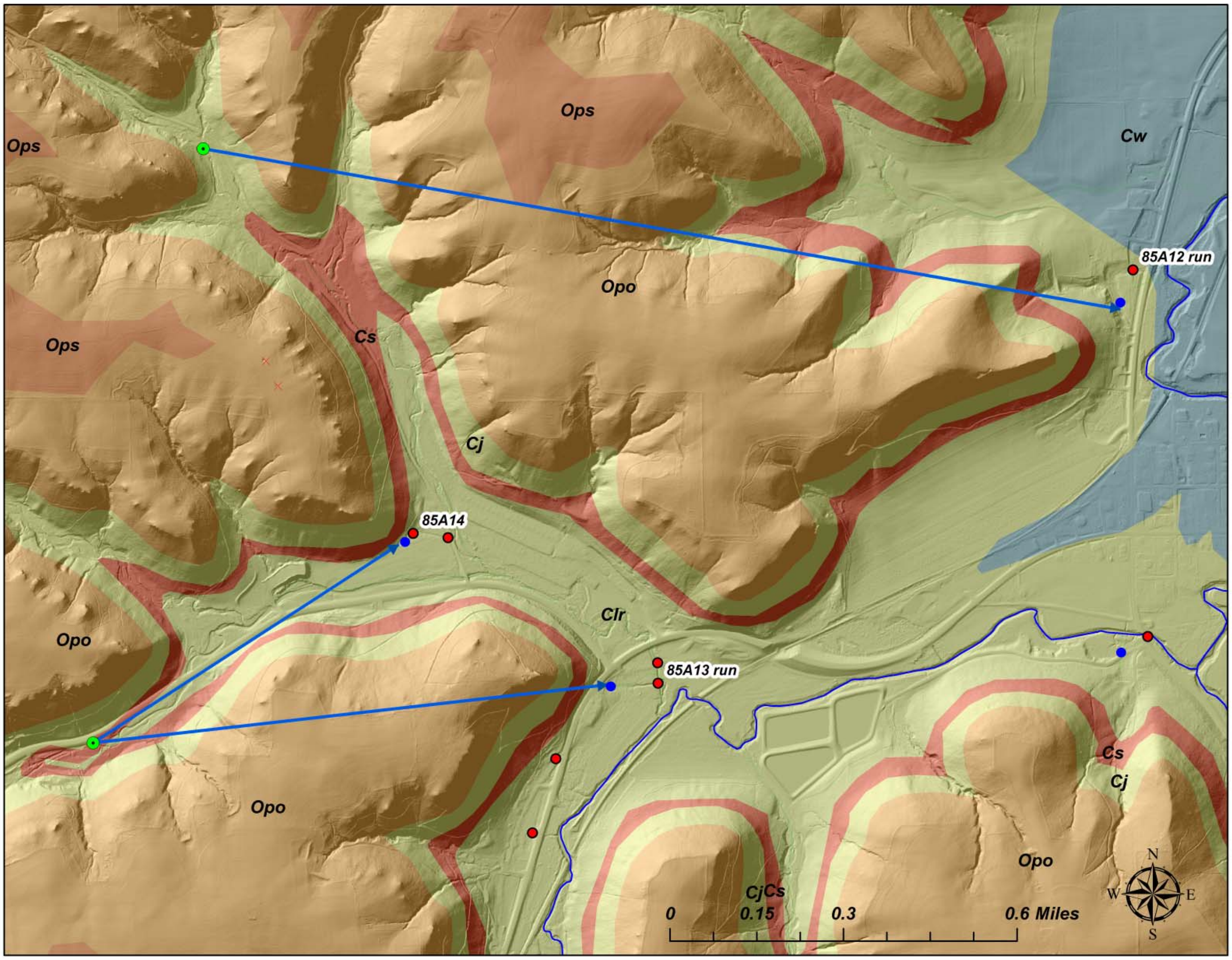
Rhodamine WT dye injected at the Highway 20 Stream Sink (MN85:B00021) was clearly detected in multiple bugs at Hasse Spring (85A14), in the Hasse Spring Run (85X45) and in the surface water sampling location known as Potter Stream Crossing (85X41). Rhodamine WT dye was also detected in five bugs, only one of which was above the 10 sigma quantifiable level, at Noeske Spring (85A13). This pattern is interpreted as a positive detection for the 85A13run sampling location.

Eosin dye injected at the Unruh Stream Sink (85B22) was cleanly detected in two bugs at Butenhoff Spring (85A12). One bug from Garvin Brook (85X47) appeared to contain eosin at slightly below the 10 sigma quantification level. Since the eosin detection for that bug was below the 10 sigma quantifiable level and the Garvin Brook (85X47) location had no other detects, the 85X47 results for the period of time between February 24, 2015 and March 26, 2015 are ambiguous and not very likely.

Dye flow vectors are shown in Figure 3. Vectors start at the dye input locations and end at spring or spring run sampling receptor locations. Rhodamine dye was detected in a charcoal detector at Haase Spring within 1 to 8 days of dye input. Assuming a straight line distance of 3326 feet from the Highway 20 stream sink to Haase Spring, this translates to a minimum peak groundwater velocity of roughly 127 meters/day or greater (415 ft./day or greater). Rhodamine dye was also detected in a charcoal detector at Noeske Spring run between 30 and 36 days later. Assuming a straight line distance of 4729 feet from the Highway 20 stream sink to Noeske Spring run, this translates to a minimum peak groundwater velocity ranging from roughly 40 to 48 meters/day (131 ft./day to 158 ft./day).

Eosin dye was detected in a charcoal detector at Butenhoff Spring run (85A12) between 70 and 91 day of introducing the dye. Assuming a straight line distance of 8502 feet from the Unruh stream sink to Butenhoff Spring, this translates to a minimum peak groundwater velocity ranging from roughly 28 to 37 meters/day (93 ft./day to 121 ft./day).

Figure 3. *Stockton, Minnesota trace sampling locations and dye flow vectors. Springs are depicted as blue circles. Dye detected at surface water locations downstream of spring sampling locations are not labeled in this figure. The table in Appendix 1 summarizes such locations. Geologic map from Runkel et al., 2013. See Appendix 2 for definition of map symbols.*



Discussion

Figure 4 is a schematic of the stratigraphy and the dye trace vectors from the Unruh sink to the Butenhoff Spring. The Unruh stream sink occurs in the lower Jordan Sandstone. Dye was recovered from a spring that resurges in the Tunnel City Group. Dye traveled vertically through the entire St. Lawrence Formation and emerged from a spring in the Tunnel City Group.

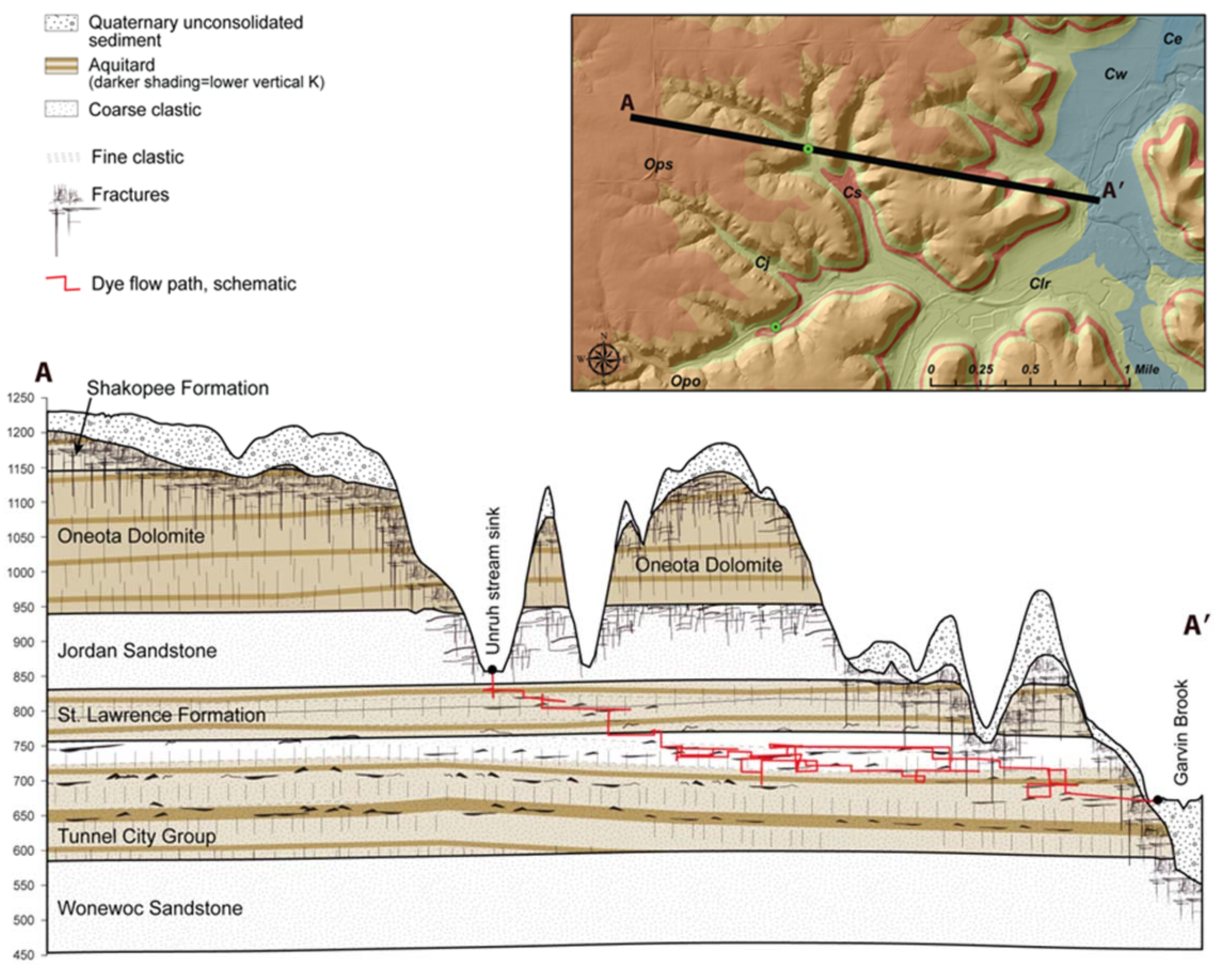
Rhodamine WT dye injected at the Highway 20 Stream Sink was detected in multiple bugs at Hasse Spring and the Noeske Spring run. The Highway 20 stream sink occurs in St. Lawrence Formation.

The Haase spring emerges near the contact of the St. Lawrence formation and Lone Rock formation of the Tunnel City Group. The Noeske spring emerges from the Lone Rock formation of the Tunnel City Group.

Rhodamine WT dye was consistently detected in the surface water sampling location known as Potter Stream Crossing. The Potter Stream Crossing location is in close proximity to the Noeske Spring run location and both are located in unconsolidated alluvial fill. There is possibility of flow through the alluvial sediment between the Potter Crossing bug and the Noeske Spring run bug, although based on field conditions we believe the possibility is low as there is a gradient and constant flux of water coming from the Noeske Spring run.

Groundwater velocities determined for the 2014-2015 Stockton, Minnesota traces are generally consistent with previous traces in the St. Lawrence and Tunnel City Group (Appendix 2). The groundwater velocity from the trace from the Unruh sink to the Butenhoff Spring is the lowest velocity determined from traces in Southeastern Minnesota. The groundwater velocities determined from the input at the Highway 20 stream sink are consistent with lower end velocities determined from previous traces.

Figure 4. *Hydrogeologic cross section A – A′, hydrogeologic cross section of the Unruh Stream Sink trace to Butenhoff spring.*



Acknowledgements

The work presented in this report could not have occurred without the permission of landowners who graciously allowed access to their property. Special thanks is given to David Unruh who gave us permission to explore and pour dye at his property. Additional thanks are given to Gale Haase, Lee Potter, Joanne Fritz, and Marilyn Wachholz.

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References

Alexander, Scott C. (2005) "Spectral Deconvolution of Natural Organics and Man-Made Fluorescent Dyes." *Tenth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst*, San Antonio, 441-448.

Steenberg, J.R., 2014, Bedrock Geology, plate 2, Geologic Atlas of Winona County, Minnesota, Minnesota Geological Survey County Atlas C-34, 4 pls., scale 1:100,000.

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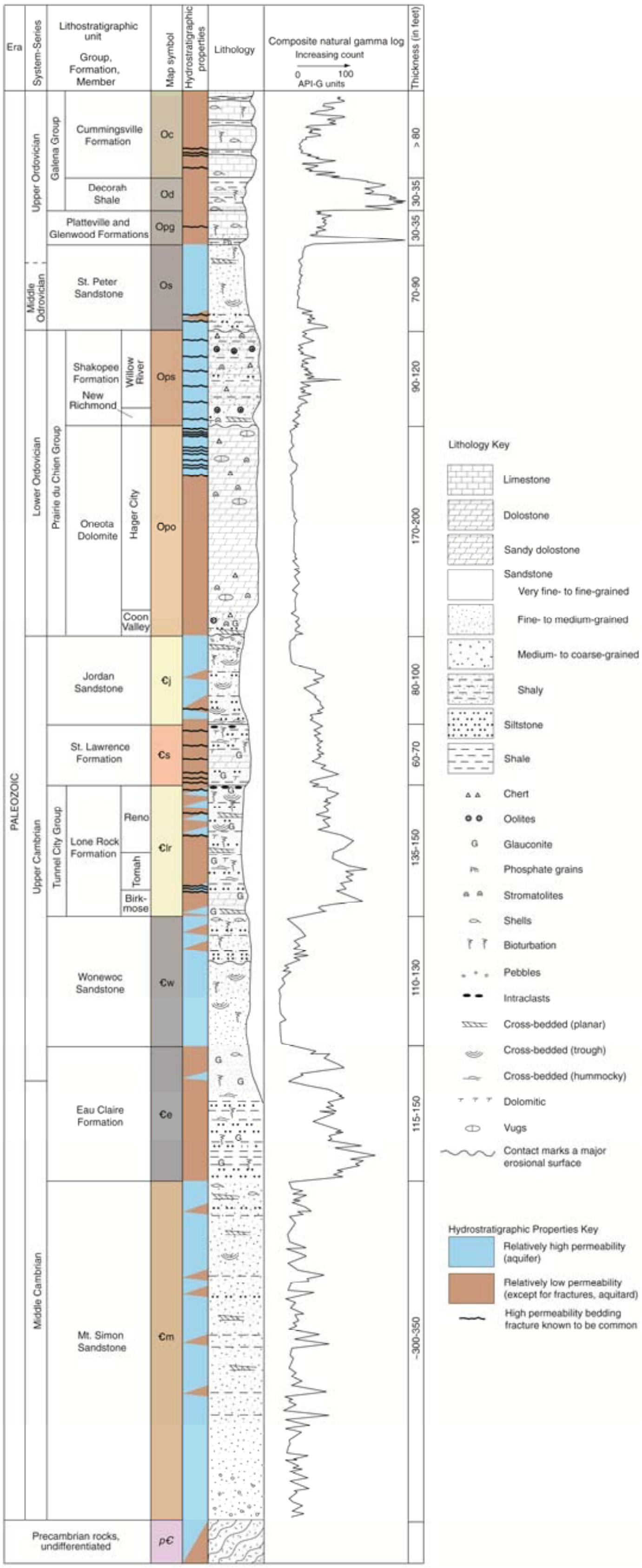
Appendix 1- 2014-2015 Trace Summary

	KFDB #	Site Type	UTM Easting	UTM Northing	Background Results (In: 22-Oct-14; Out: 5-Nov-14)	Dye Inputs 5-Nov-2014	Results In: 5-Nov-14 Out: 13-Nov-14	Results In: 13-Nov-14 Out: 21-Nov-14	Results In: 21-Nov-14 Out: 26-Nov-14	Results In: 26-Nov-14 Out: 5-Dec-14	Results In: 5-Dec-14 Out: 11-Dec-14	Results In: 11-Dec-14 Out: 14-Jan-15	Results In: 14-Jan-15 Out: 04-Feb-15	Results In: 04-Feb-15 Out: 24-Feb-15	Results In: 24-Feb-15 Out: 26-Mar-15
85A12 Run (aka, MN85:A00012 Run) (aka, Butenhoff Spring)	MN85:X00043	spring run	598,572	4,876,376	not detected		not detected	not detected	not detected	not detected	not detected	not detected	Eosin 20 σ	not detected	Eosin 35 σ
85A13 Run (aka, MN85:A00013 Run) (aka, Noeske Spring)	MN85:X00044	spring run	597,250	4,875,225	not detected		not detected	not detected	RhWT trace (4.7 σ) not quantifiable	not detected	RhWT trace (7.4 σ) not quantifiable	RhWT trace (9.1 σ) not quantifiable	RhWT 13 σ	RhWT trace (6.0 σ) not quantifiable	not detected
85A14 U.S. ("spring head") (aka, MN85:A00014) (aka, Hasse Spring)	MN85:A00014	spring run	596,553	4,875,637			RhWT 88 σ	RhWT 235 σ	RhWT 73 σ	RhWT 190 σ	RhWT 368 σ	RhWT 211 σ	RhWT 138 σ	RhWT 128 σ	RhWT 80 σ
85A14 Run (aka, MN85:A00014 Run)	MN85:X00045	spring run	596,665	4,875,630	not detected		RhWT 223 σ	RhWT 565 σ	RhWT 80 σ						
Arches	MN85:X00048	stream	595,122	4,872,733	not detected		not detected	not detected	not detected	not detected	not detected	not detected	not detected	not detected	not detected
Beach Spring	MN85:A00327	spring	596,900	4,874,809	not detected		not detected	not detected (13-Nov-14 to 26-Nov-14)		not detected (26-Nov-14 to 26-Mar-15)					
Farmers Park	MN85:X00046	stream	595,152	4,872,698	not detected		not detected	not detected	not detected	not detected	not detected	not detected	not detected	not detected	not detected
Garvin Brook	MN85:X00047	stream	596,534	4,874,095			not detected	not detected	not detected	not detected (26-Nov-14 to 24-Feb-15)	not detected	not detected	not detected		Eosine trace (9.7 σ) not quantifiable
Potter Stream Crossing	MN85:X00041	stream	597,249	4,875,283	not detected		RhWT 116 σ	RhWT 201 σ	RhWT 78 σ	RhWT 86 σ	RhWT 84 σ	RhWT 126 σ	RhWT 44 σ	RhWT trace (4.6 σ) not quantifiable	RhWT trace (8.8 σ) not quantifiable
Shell Well	MN85:X00049	well	596,966	4,875,016	not detected										
Wachholz Spring Run	MN85:X00042	spring run	596,545	4,874,101			not detected	not detected (13-Nov-14 to 26-Nov-14)				not detected (11-Dec-14 to 26-Mar-15)			
Garvin Brook at Stockton	MN85:X00038	stream	598,618	4,875,355									not detected	RhWT 20 σ	not detected
Middle Branch Rolling Stone	MN85:X00040	stream	596,459	4,880,557									not detected (23-Jan-15 to 04-Feb-15)	not detected	
Scherbring Spring Run	MN85:X00039	spring run	596,455	4,880,584									not detected (23-Jan-15 to 04-Feb-15)	not detected	

(yellow) Indicates no bug or sample was received by the lab

Appendix 2 - ***Geologic and Hydrogeologic attributes of Paleozoic rocks in southeastern Minnesota.*** **Modified from Steenberg, 2014.**



Appendix 3 - Southeast Minnesota Dye Trace Velocities of the St. Lawrence Formation and Tunnel City Group

Site	*Unit*	*Peak Velocity*	*Peak Velocity*	*Sample Type*
Ahrensfeld 1	*CSTL*	*150-300 m/day*	*492-984 ft/day*	*Charcoal detector*
Ahrensfeld 2	*CSTL*	*400-600 m/day*	*1,312-1,968 ft/day*	*Direct Water Samples*
Borson Northeast	*CSTL*	*75-110 m/day*	*246-361 ft/day*	*Charcoal detector*
Bridge Creek 1 (downstream)	*CSTL-CTCG*	*146-205 m/day*	*480-670 ft/day*	*Charcoal detector*
Bridge Creek 2 (upstream)	*CSTL-CTCG*	*314 m/day*	*1,031 ft/day*	*Direct Water Samples*
Campbell Valley	*CSTL-CTCG*	*82-124 m/day*	*270-405 ft/day*	*Charcoal detector*
Daley Creek	*CSTL*	*180-360 m/day*	*590-1,181 ft/day*	*Charcoal detector*
Gilbert Creek	*CSTL*	*137-198 m/day*	*450-650 ft/day*	*Charcoal detector*
Girl Scout Creek	*CSTL-CTCG*	*> 88-154 m/day*	*> 290-504 ft/day*	*Charcoal detector*
Indian Springs Creek	*CSTL*	*80-285 m/day*	*262-935 ft/day*	*Charcoal detector*
Kiefer Valley	*CSTL*	*260-580 m/day*	*853-1,902 ft/day*	*Charcoal detector*
Stockton, Minnesota	*CSTL-CTCG*	*28-127 m/day*	*93-415 ft/day*	*Charcoal detector*
Sullivan Creek	*CSTL*	*35-240 m/day*	*115-787 ft/day*	*Charcoal detector*