# South Branch Whitewater River Valley Dye Trace Report
# Elba/Altura,
# Winona County, Minnesota

Traces:
October 26th 1980
February 27th 1981
October 2nd 2008
July 9th 2010 (2)
August 4th 2011
July 16th 2012

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# Contents

# Introduction

This document summarizes results from dye traces near the Crystal Springs State Fish Hatchery (CSSFH) in 1980, 1981, 2008, 2010, 2011 and 2012. Tracing in this area (Figure 1) is of interest because spring-fed waters contribute to the South Branch Whitewater River (SBWR), which then flows into the Whitewater River. Both rivers are Minnesota designated trout streams. Water quality in spring fed streams requires careful management to preserve and protect trout stream resources. In addition, the Minnesota Department of Natural Resources (DNR) operates the Crystal Springs State Fish Hatchery (CSSFH), which utilizes water from two springs (85A1 and 85A316 in Figure 5) for rearing fish used to stock streams and lakes around the state. These two springs also contribute significant flow to the SBWR. Understanding surface water-groundwater interaction and how surface water may impact springs, which may impact fish health, is vital for keeping the hatchery in operation. Factors like pollutants from domestic and agricultural sources, as well as extreme events, like the Altura municipal sewage lagoon sinkhole collapses of 1976 (Alexander and Book, 1984), potentially threaten the health of these springs and streams. The CSSFH springs flow from the St. Lawrence Formation. Conceptual models of flow through the St. Lawrence have recently changed highlighting its ability to act as an aquitard in the vertical direction as tenuous but understanding that significant lateral flow occurs (Green et al., 2012, Barry et al. 2015).

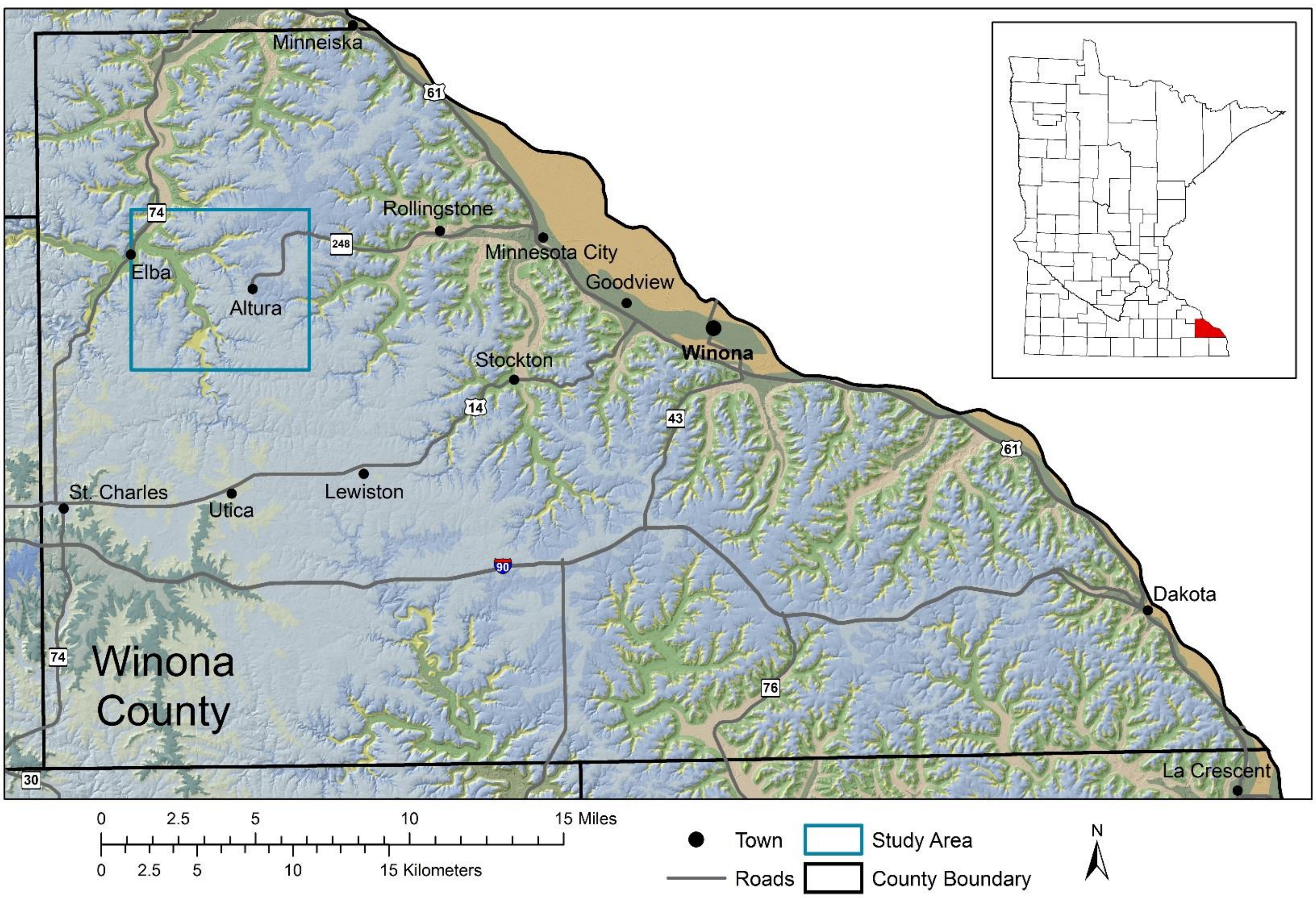


***Figure 1.*** *Location of Kieffer Valley Study Area*

In Winona county, bedrock units from the Upper Cambrian through the Upper Ordovician are generally within 15 meters of the land surface and are capped by unconsolidated sediments such as loess, sand, and colluvium (Steenberg, 2014ab; Lusardi et al., 2014). The topography is dominated by a broad plateau of resistant dolostone of the Ordovician Prairie du Chien Group (OPDC). A generalized geologic stratigraphic column for southeast Minnesota (Figure 2) shows lithostratigraphic and generalized hydrostratigraphic properties for each of the units (modified from Runkel et. al. 2013).

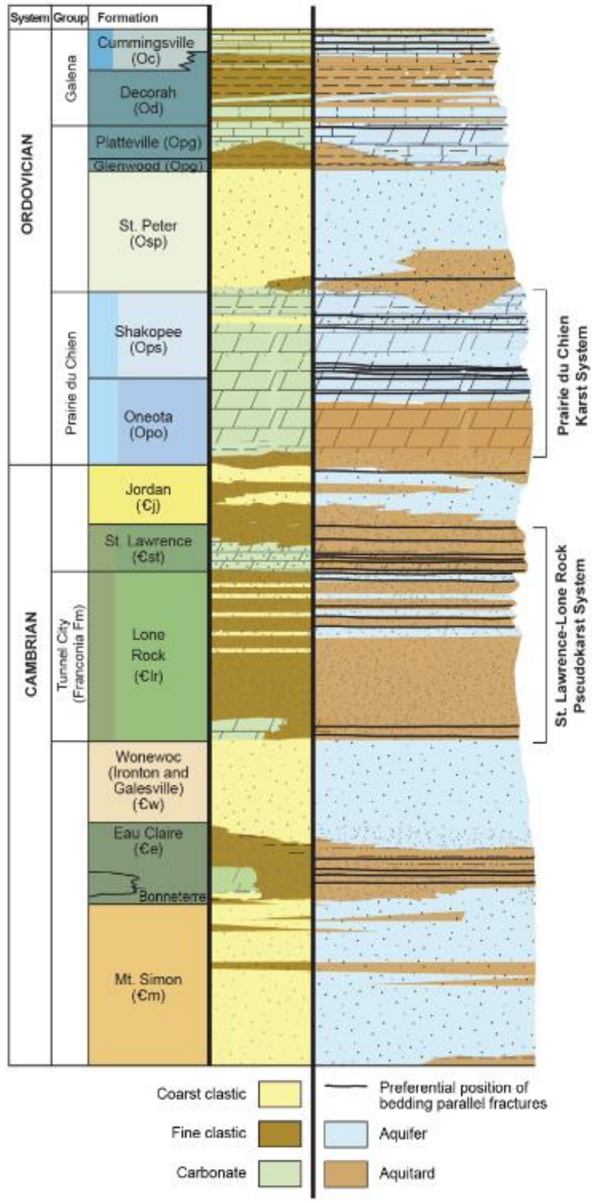


***Figure 2.*** *Geologic and hydrogeologic attributes of Paleozoic rocks in southeastern Minnesota. Modified from Runkel et al. 2013.*

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 aquitard have lower permeability that vertically retards flow, effectively separating aquifer layers hydraulically. However, layers designated as aquitards may contain high permeability bedding plane fractures conductive enough to yield large quantities of water (Green et al., 2012, Barry et al. 2015). The traces in this report demonstrate groundwater loss into the lower Jordan and Upper St. Lawrence Formations and reemergence in the Lower St. Lawrence and Upper Lone Rock Formations (Figure 3 and 6).

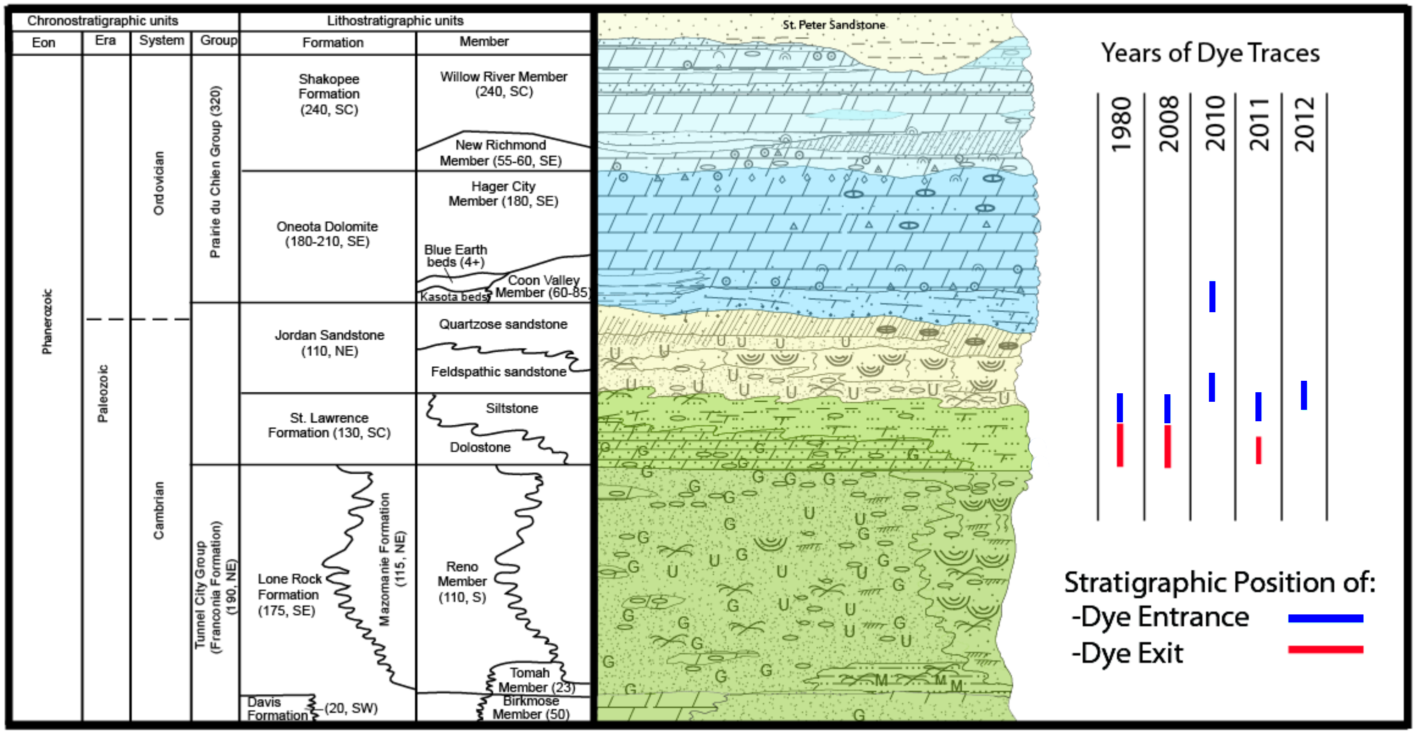


***Figure 3.*** *Generalized stratigraphic column depicting the Kieffer Valley dye traces. For each year that a trace was conducted, a vertical blue bar conceptually models the stratigraphic position at which dye was introduced. A red bar indicates the stratigraphic location where dye emerged in springs, which are typically in the middle and lower St. Lawrence. Figure adapted from Mossler (2008) and Green et al (2012).*

## Note on Feature Nomenclature

Karst features are assigned unique identifier codes (RELATEID) in the Minnesota Karst Features Database (KFD; Gao, 2002). These identifier codes consist of a numerical county code (85 for Winona County in these traces), an alphabetic feature code (A = spring, B = stream sink, D = sinkhole, and X = miscellaneous feature or monitoring location) followed by a seven digit unique number. For example, the KFD identifier code of the Main East Crystal Spring at the Crystal Springs State Fish Hatchery in Figure 1 is 85A0000001. The KFD codes are simplified for graphical purposes in this report to the county code, feature code and number (omitting leading zeros). For example, “85A316” = 85A0000316 a spring – or “85B19” = 85B0000019 – a stream sieve/sink, and “85X32” = 85X0000032 – a charcoal detector location. The remainder of this report text will use the shorthand version (in quotations above) to refer to KFD features.

# Methods

*Dye Input Descriptions*

**Table 1.** Dye Input Summary Table

| Date | KFD # | Dye | Description |
|---|---|---|---|
| [1] 26 Oct 1980 | 85B14 | Rhodamine WT | In 1976, sinkholes developed beneath a sewage storage pond at the Altura Waste Water Treatment Facility. In an effort to understand the fate of the effluent lost during the failure, dye was introduced near the sewage lagoon effluent outfall pipe and flowed approximately 1.8 miles (2.9 kilometers) to the terminal sinking point (85B14). |
| [1] 27 Feb 1981 | 85D1 | Uranine C | Dye was poured directly into the largest of the sinkholes (85D1) in the former sewage effluent storage pond where the collapses occurred in 1976. |
| [2] 02 Oct 2008 | 85B14 | Uranine C | Dye trace to begin groundwater springshed mapping in the area. |
| [3] 09 Jul 2010 | 85B18 | Rhodamine WT | Dye was introduced into the lower Jordan Sandstone. |
| [3] 09 Jul 2010 | 95B19 | Uranine C | Dye was introduced into the Coon Valley Member of the Oneota Dolomite approximately 1.25 miles southwest of the CSSFH along County Road 37 in an unnamed ravine. |
| [4] 04 Aug 2011 | 85X29 | Eosine | Dye was introduced into the lower Jordan Sandstone. Half of the dye was released into the head of a pool that loses flow, while the other half of the dye was released into a riffle located five meters upstream of exposed bedrock near the terminal sinking point of the stream. |
| [4] 16 Jul 2012 | 85X31 | Uranine C | Dye was introduced into a riffle of the South Branch Whitewater River in Kreidermacher Valley. This trace was conducted to see if the SBWR sinks upstream of the CSSFH. |

[1] *Book and Alexander, 1984 a,b*
[2] *Green et al. 2012*
[3] *Ladd and Alexander, 2010*
[4] *Ustipak et al. 2016*

*Sampling and Analytical Methods*

Due to the time span covered in this report, dye tracing methods are generally described here. Dye tracing is most often accomplished with the use of fluorescent dyes to determine groundwater flow directions and estimates of minimum groundwater travel times. Charcoal detectors, referred to as "bugs" or passive detectors, are placed at various spring and stream locations where dye detection is feasible and are left for some period of time to allow any dye in the water flowing around them to adsorb to the charcoal surface. A round of bugs is placed and removed before the introduction of dye to identify and account for any background signals of the dye(s) used. Dyes are then flushed into sinking streams or sinkholes utilizing natural stream flow, water from a tank, or snowmelt and bugs are changed at various frequencies to approximate the time it took for dye to arrive at the monitoring locations. Following removal from the monitoring locations, the bugs are brought to the University Of Minnesota Department Of Earth Sciences Hydrochemistry Lab for analysis. The bugs are bathed in an eluent solution of 70% isopropyl alcohol, 30% deionized water, and 5 grams of sodium hydroxide per half liter of solution. The eluent is pipetted into a clean test tube and analyzed on a Shimadzu RF5000U Scanning Spectrofluorophotometer. The resulting spectra are then analyzed using PeakFit® software. Each dye is characterized by an emission wavelength with distinct characteristics and can therefore be distinguished from one another (Alexander, 2005). The locations of the dye input points and sampling locations for these studies is shown in Figure 5.

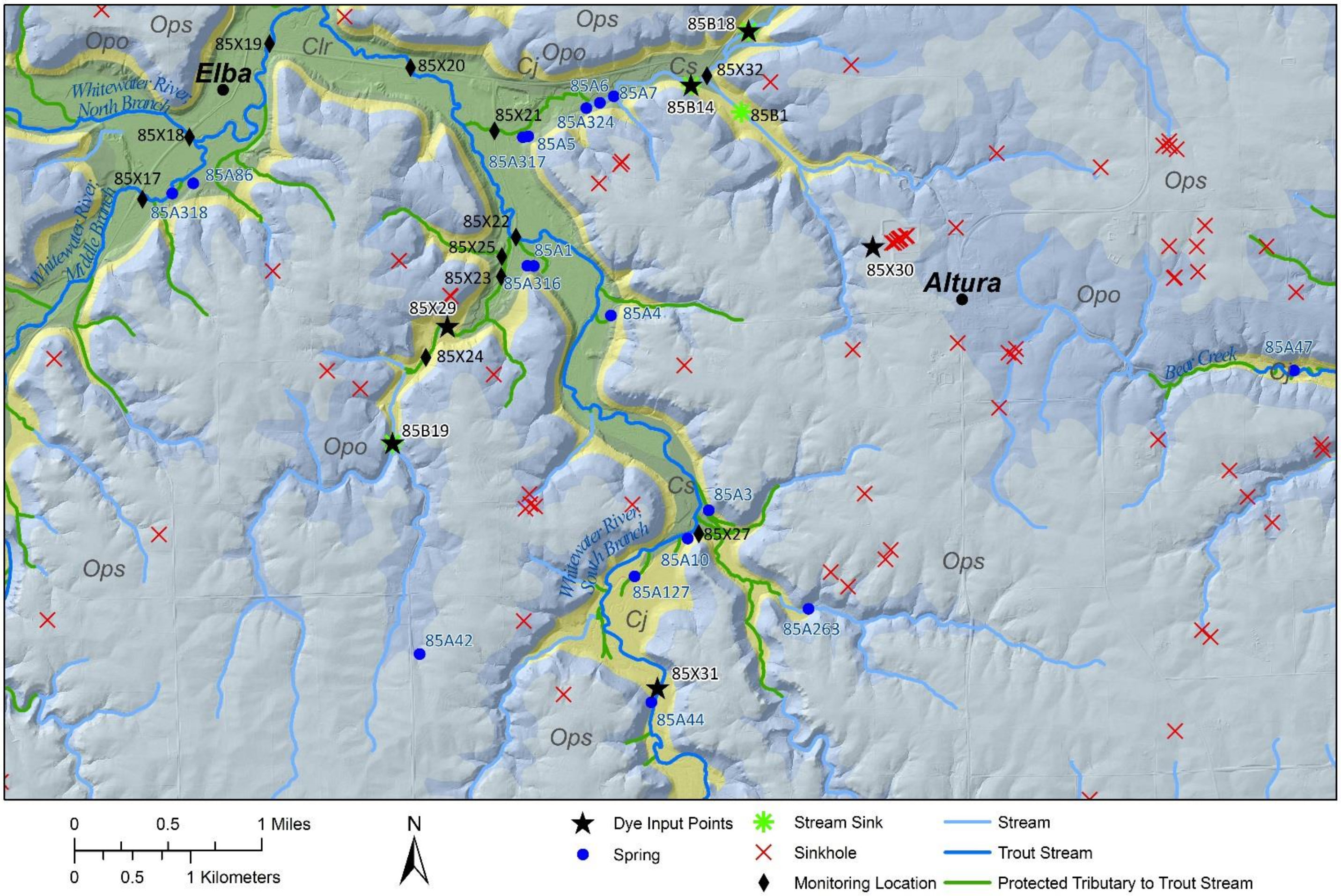


***Figure 5.*** *Map indicating sampling points, dye release points and karst features in the study area for the traces conducted over the years 1980-2012. Shading correlates loosely to shading from Figure 2.*

# Results & Discussion

Tabulated results for the charcoal bug analyses from the 2011 and 2012 traces are included in their original report (Ustipak et al. 2016). Tabulated results for the 1980 and 1981 traces can be found in the unpublished manuscript (Alexander and Book, 1984a) and further synthesis in the proceedings paper from First Multidisciplinary Conference on Sinkholes (Alexander and Book, 1984b). Tabulated results for the 2008 and 2010 traces were not included in their original reports (Green et al. 2012 and Ladd et al. 2010, respectively) and are therefore not included here.

Table 2. Trace Results Summary Table

| Date | KFD # | Dye | Result |
|---|---|---|---|
| 26 Oct 1980 | 85B14 | Rhodamine WT | 85A7, 85A6, 85A5 and 85A317 |
| 27 Feb 1981 | 85D1 | Uranine C | No Detection |
| 02 Oct 2008 | 85B14 | Uranine C | 85A7, 85A6, 85A5 and 85A317 |
| 09 Jul 2010 | 85B18 | Rhodamine WT | No Detection |
| 09 Jul 2010 | 95B19 | Uranine C | No Detection |
| 04 Aug 2011 | 85X29 | Eosine | 85A316 |
| 16 Jul 2012 | 85X31 | Uranine C | 85X20 |

Dye from the 1980 trace resurfaced at four springs (85A7, 85A6, 85A5 and 85A317) in the Kieffer Valley in approximately one week (Alexander and Book, 1984) (Figure 6). The 1981 storage pond sinkhole trace was never detected.

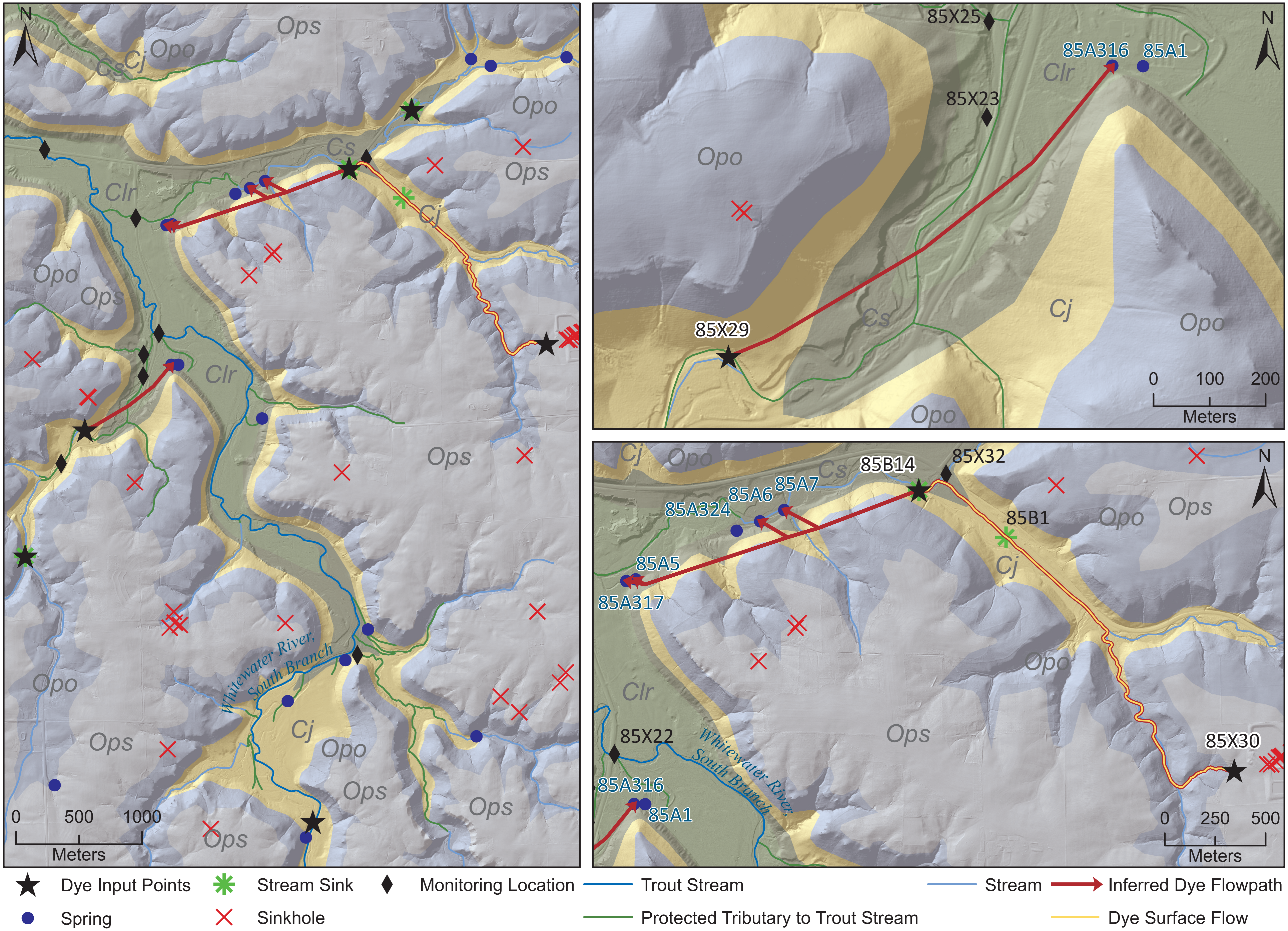


***Figure 6.*** *Summary of dye tracing results from all six years using inferred groundwater flowpaths. Shading correlates loosely to shading from Figure 2.*

The 2008 trace reappeared in the same four springs (85A7, 85A6, 85A5 and 85A317) as the 1980 trace within seven days (Figure 6). The inferred straight-line travel minimum groundwater velocity was at least 709 feet per day to the most distant spring from dye input (A5 and A317). This trace confirmed rapid groundwater flow in horizontal and vertical directions through the St. Lawrence Formation on a timescale of at least days to weeks (Green et al., 2012).

2010 traces. Neither dye was detected for the 2010 traces during six months of monitoring. In general, undetected dye could indicate a number of things. Perhaps the dye did not reach the detection points within the monitored period. While other tracing in the Kieffer Valley Area indicates that flow times are rapid, that does not necessarily exclude the possibility that the dye in these traces was flowing much slower and did eventually reach the monitoring locations. It is possible that the dye was diluted below the detection limit (not enough dye was used), the dye may have been adsorbed onto organic material along its flow path, the dye was chemically altered rendering it unrecognizable to Peakfit software, or the dye could have flowed to unmonitored locations. Where the Jordan was encountered (as in the trace introduced into 85B19) it is also possible that the non-systematic nature of fractures in that formation prevent conduit flow for any significant distance.

In the August 2011 Crystal Springs Hatchery Trace, Eosin first appeared at 85A316 of the CSSFH within 21 days; a minimum groundwater flow velocity of 125 feet per day. This velocity is consistent with flow through mixed composition sedimentary units like the Lower Jordan Sandstone and Cambrian St. Lawrence Formation. This 2011 trace provides evidence that the stream sinks in the unnamed ravine southwest of CSSFH have conduit connections to the CSSFH (Figure 6).

In the July 2012 SBWR Trace, Uranine C was only detected at 85X20 in the South Branch Whitewater River which is downstream of the dye release point (Figure 6). Dye was not recovered from any other monitored spring or creek location. Eosin from the 2011 trace sporadically emerged from 85A316 over the course of monitoring, indicating that it is possible to have relatively rapid flow accompanied by long periods of storage in the lower Jordan Sandstone and the St. Lawrence Formation. The July 2012 trace provides no concrete evidence that the SBWR sinks upstream from the CSSFH springs.

## Conclusion

Dye tracing in the Kieffer Valley has demonstrated that water moves horizontally and vertically in the St. Lawrence Formation. Dye introduced at the top of the St. Lawrence moves rapidly to springs that emerge near the bottom of the formation. The 1980 and 2008 Kieffer Valley Dye Traces show that conduit connections within the St. Lawrence can route water from surface karst features to nearby springs at straight-line minimum groundwater velocities of hundreds of feet per day. Dye introduced into the Oneota Dolomite and mid-lower Jordan Sandstone did not reappear in monitored St. Lawrence springs. The 2011 Crystal Springs Hatchery Trace shows that dye introduced into the bottom of the Jordan Sandstone can move quickly into the the St. Lawrence and can be retained for months to years.

Results of dye tracing have important implications for the CSSFH and trout streams in southeastern Minnesota. Sinking streams in the lower Jordan and upper St. Lawrence appear to have developed conduits that connect to springs in the middle and lower St. Lawrence. Surface pollution near these stream sinks can potentially impact the water quality of spring-fed trout streams. In April 2013, DNR employees at the CSSFH noted that 85A1 had sediment and debris-laden water discharging at record-high flow rates, a unique event in the history of the hatchery's operation. This spring has never had dye emerge from it in any of the traces conducted since 1980. The source of the sediment that resurged is unclear and future dye tracing in the vicinity may help uncover surface sources to this spring.

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