1980 to 2012 Dye Tracing in the South Branch Whitewater River Valley, Elba/Altura, Minnesota Area

by Kelsi R. Ustipak[1], Jeffrey A. Green[2], Betty J. Wheeler[1], E. Calvin Alexander, Jr.[1]

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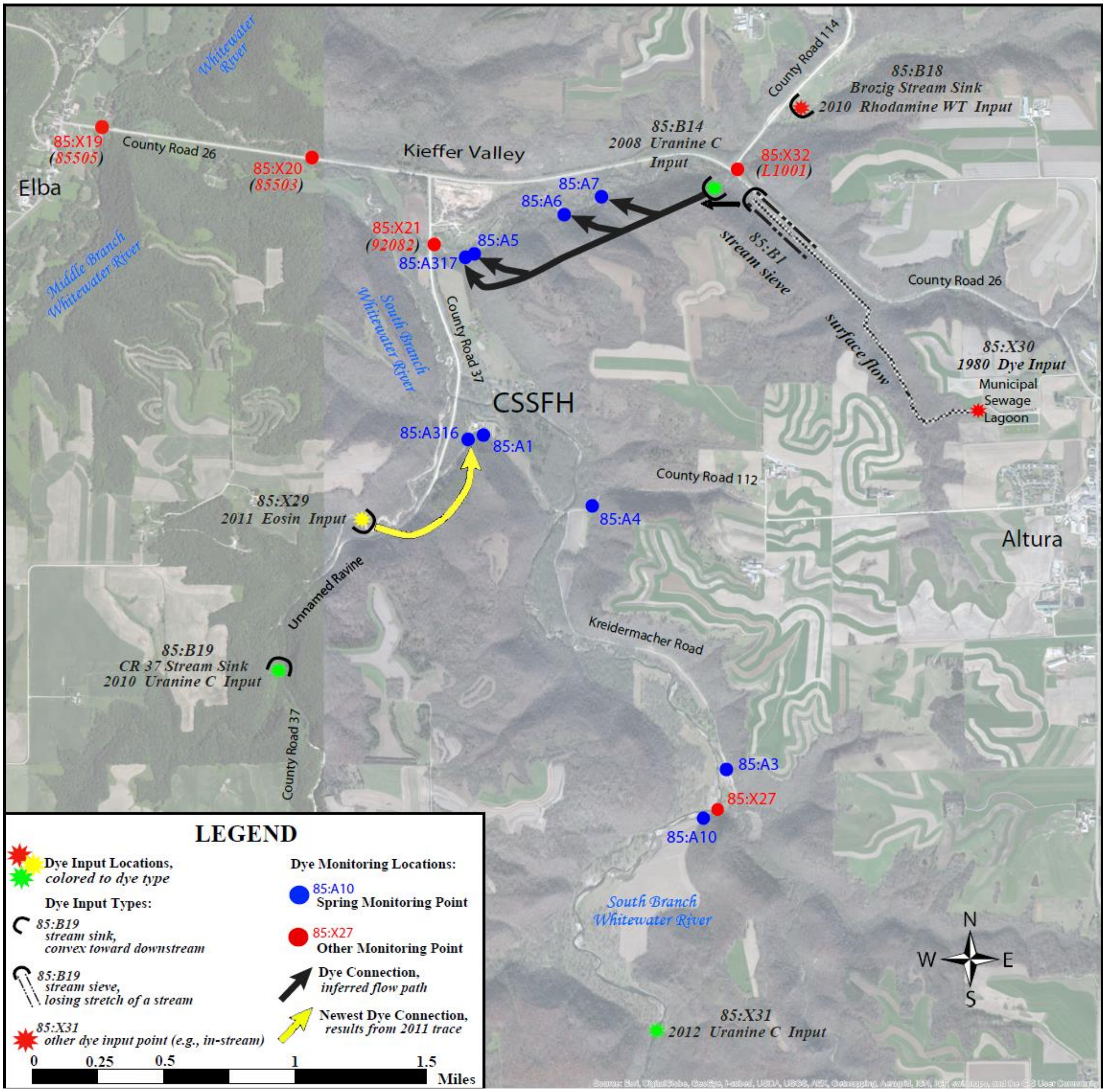

Figure 1. Summary map showing the locations and results of dye traces in the Crystal Springs/Altura/Kieffer Valley region of Winona County, Minnesota.

[1] Department of Earth Sciences, University of Minnesota, 310 Pillsbury Drive SE, Minneapolis, MN 55455; (612) 624-3517, emails: ustip001@umn.edu , whee0023@umn.edu, alexa001@umn.edu

[2] Minnesota Department of Natural Resources, Division of Ecological and Water Resources, 3555 9th Street NW, Suite 350, Rochester, MN 55901; (507) 206-2853; email: jeff.green@state.mn.us

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Note on Feature Nomenclature

Karst features are assigned unique identifier codes in the Minnesota Karst Features Database (KFD). These identifier codes consist of an alphabetic state code (MN), a numerical county code (the number of the county in an alphabetized list of MN counties – 85 for Winona County in these traces), a colon, an alphabetic feature code (A = spring, B = stream sink, and X = miscellaneous feature – monitoring points in these traces) and a five digit number. For example, the KFD identifier code of the Main East Crystal Spring at the Crystal Springs State Fish Hatchery in Figure 1 is MN85:A00001. 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" = MN85:A00316 – a spring, "85B19" = MN85:B00019 – a stream sieve/sink, and "85X32" = MN85:X00032 – a charcoal detector location.

Introduction

This document reports on August 2011 and July 2012 dye traces near the Crystal Springs State Fish Hatchery (CSSFH) and summarizes past efforts of dye tracing in the region to the north and west of Altura, MN. Tracing in this area 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 trout streams requires careful management to preserve the resource. In addition, the Minnesota Department of Natural Resources (MN-DNR) operates the CSSFH, which utilizes water from two springs (85:A1 and 85:A316 in Fig. 1) to operate a trout fish hatchery CSSFH stocks streams and lakes around the region and state. These two springs also contribute significant flow to the SBWR. Understanding how surface pollution may impact the health of these springs is vital for keeping the hatchery in operation. A major goal of these traces is to begin the process of mapping springsheds that supply water to springs in and around CSSFH. 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), threaten the health of these streams. The Cambrian St. Lawrence Formation is another major reason why tracing is important in this area because the CSSFH springs flow from the St. Lawrence Formation. Conceptual models of flow in the St. Lawrence have recently changed (Green et al., 2012) and additional dye trace results are needed to refine the understanding of groundwater flow in the formation, so as to sustainably manage the health and productivity of Southeast Minnesota trout streams.

Background

In Minnesota's Wabasha, Winona, and Houston Counties, several dye traces have been conducted to investigate groundwater flow in the St. Lawrence. The St. Lawrence is a formation of interbedded fine-grained sandstone, siltstone, dolomite, and shale (Mossler, 2008). Previously published maps and the Minnesota Water Well Code categorize the St. Lawrence as a confining unit, or aquitard.

This new information has changed the conceptual models of how pollutants and groundwater travel in the regions where the St. Lawrence subcrops. The incised river valleys of the SBWR, Kieffer Valley, and their tributary streams and springs are one such area. Dye traces in this area have been conducted by releasing dye into stream sinks located stratigraphically in

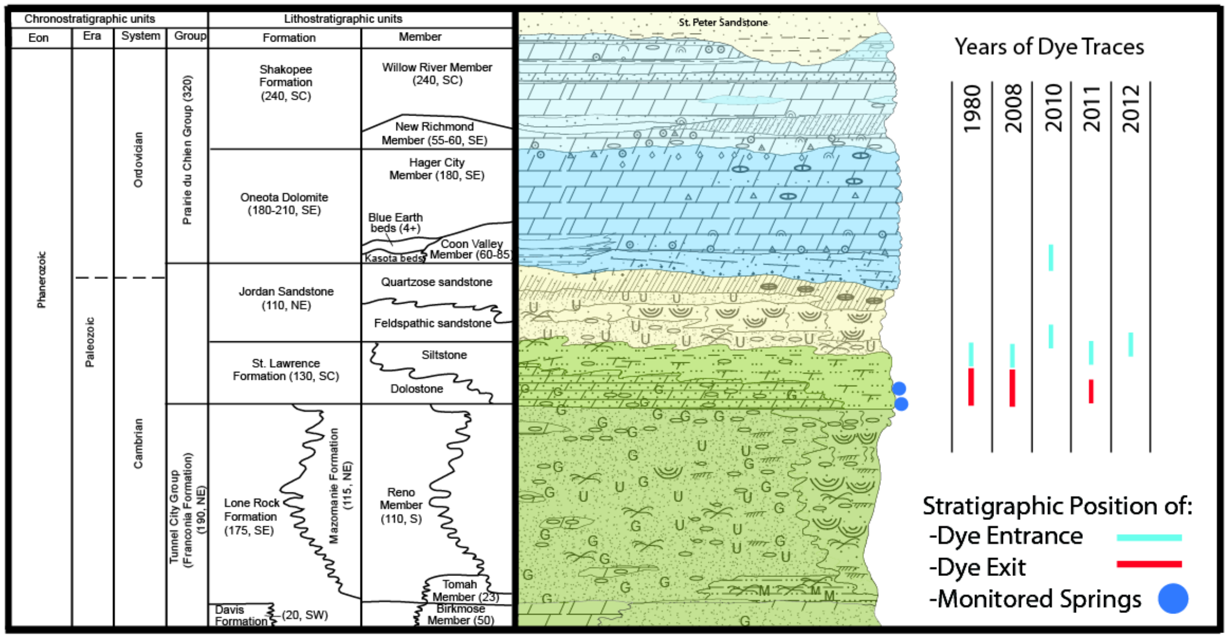

Figure 2a: A stratigraphic column that isolates rock units of interest to the Kieffer Valley dye traces. For each year that a trace was conducted, a vertical blue bar conceptually models the stratigraphic position at which dye was introduced. A red bar indicates the stratigraphic location where dye emerged in springs, which are typically in the middle and lower St. Lawrence. Figure adapted from Mossler (2008) and Green et al (2012).

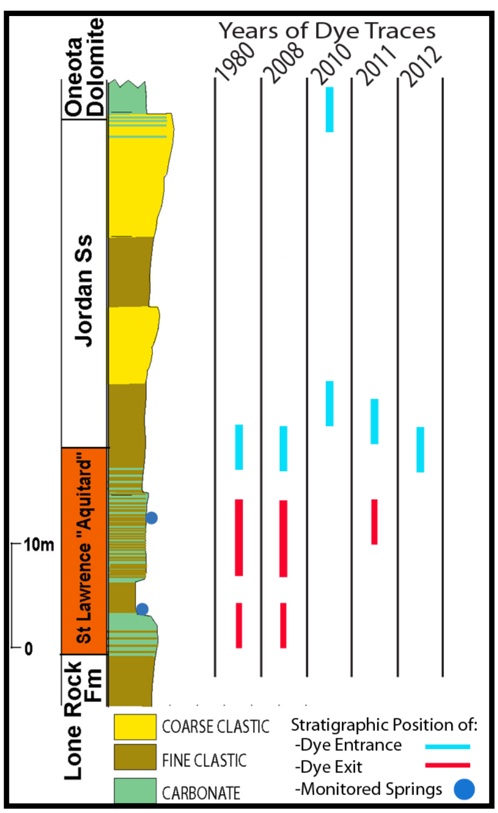

Figure 2b: A conceptualized stratigraphy that simplifies compositional variations in the section of interest. Adapted from Green et al (2012).

the lower Cambrian Jordan Sandstone and upper Cambrian St. Lawrence Formation (Figure 2a, Figure 2b). The dye emerges from springs in the stratigraphic middle and base of the St. Lawrence. Past traces demonstrate that there is both rapid horizontal and vertical conduit flow through the St. Lawrence, which are properties more commonly associated with aquifers (Green et al., 2012).

There have been five traces in the region between Elba, MN and Altura, MN over the past three decades. In 1976, sinkholes developed beneath a sewage storage pond at the Altura Waste Water Treatment Facility while it was discharging to surface water. The loss of the storage lagoon resulted in treated effluent being discharged overland into Kieffer Valley and directly into groundwater via the lagoon sinkholes. That surface discharged effluent entered the groundwater via stream sink MN85:B14 on top of the St. Lawrence formation. The 1980 Kieffer Valley dye trace introduced dye to that same stream sink. That water resurfaced at four springs in the Kieffer Valley in approximately one week (Alexander and Book, 1984). (See Figure 3.)

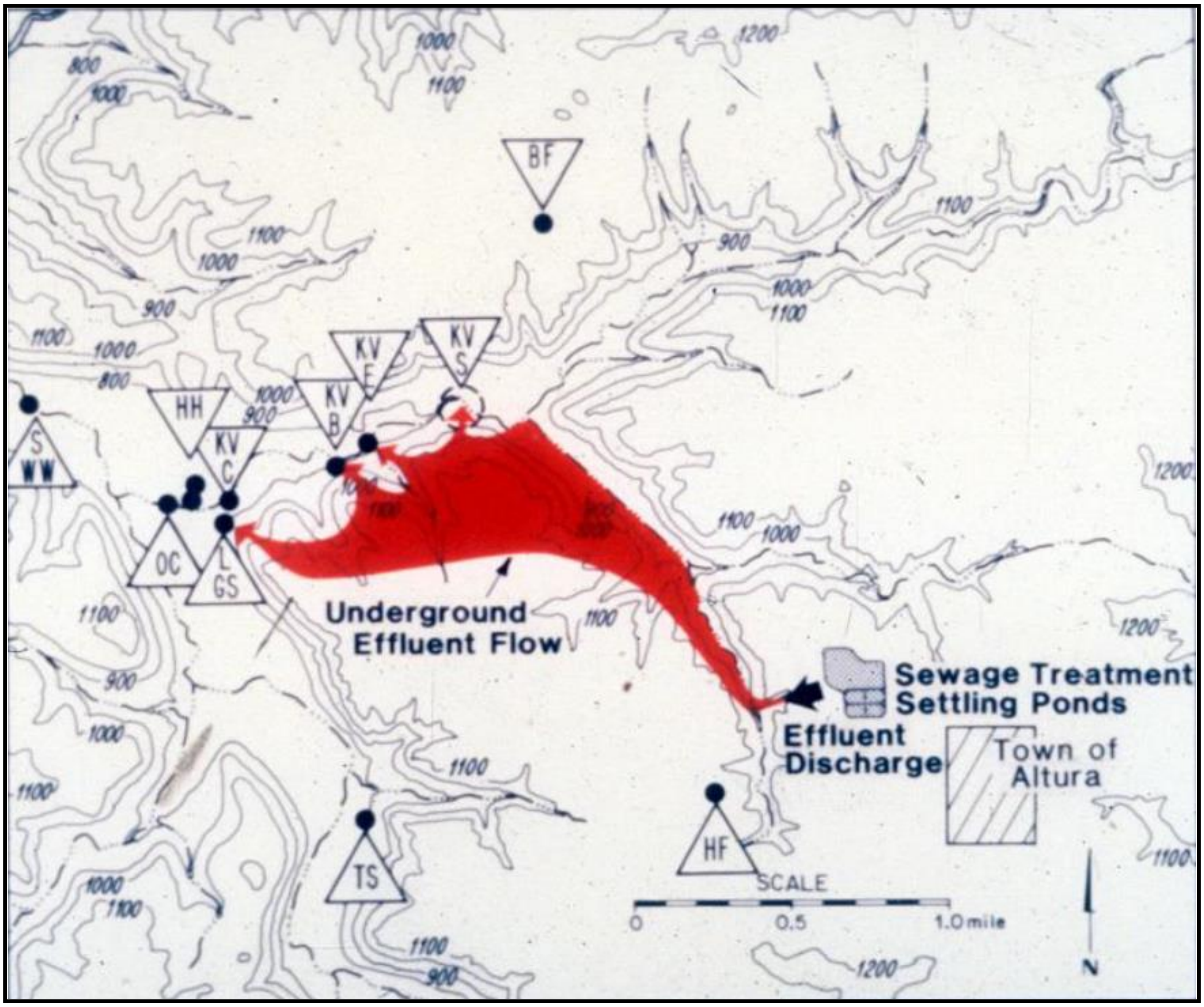

Figure 3: The trace results of the 1980 Kieffer Valley trace where dye released in KV S (85:B14) emerged at four springs: KV E (85:A7), KV B (85:A6), KV C (85:A5), and LGS (85:A317). In red, an early conceptual model of how sewage effluent traveled from the sewage pond to Kieffer Valley.

In October 2008, a dye trace was conducted to replicate the 1980 Kieffer Valley trace. Uranine C dye was introduced into a St. Lawrence stream sink slightly downstream of the 1980

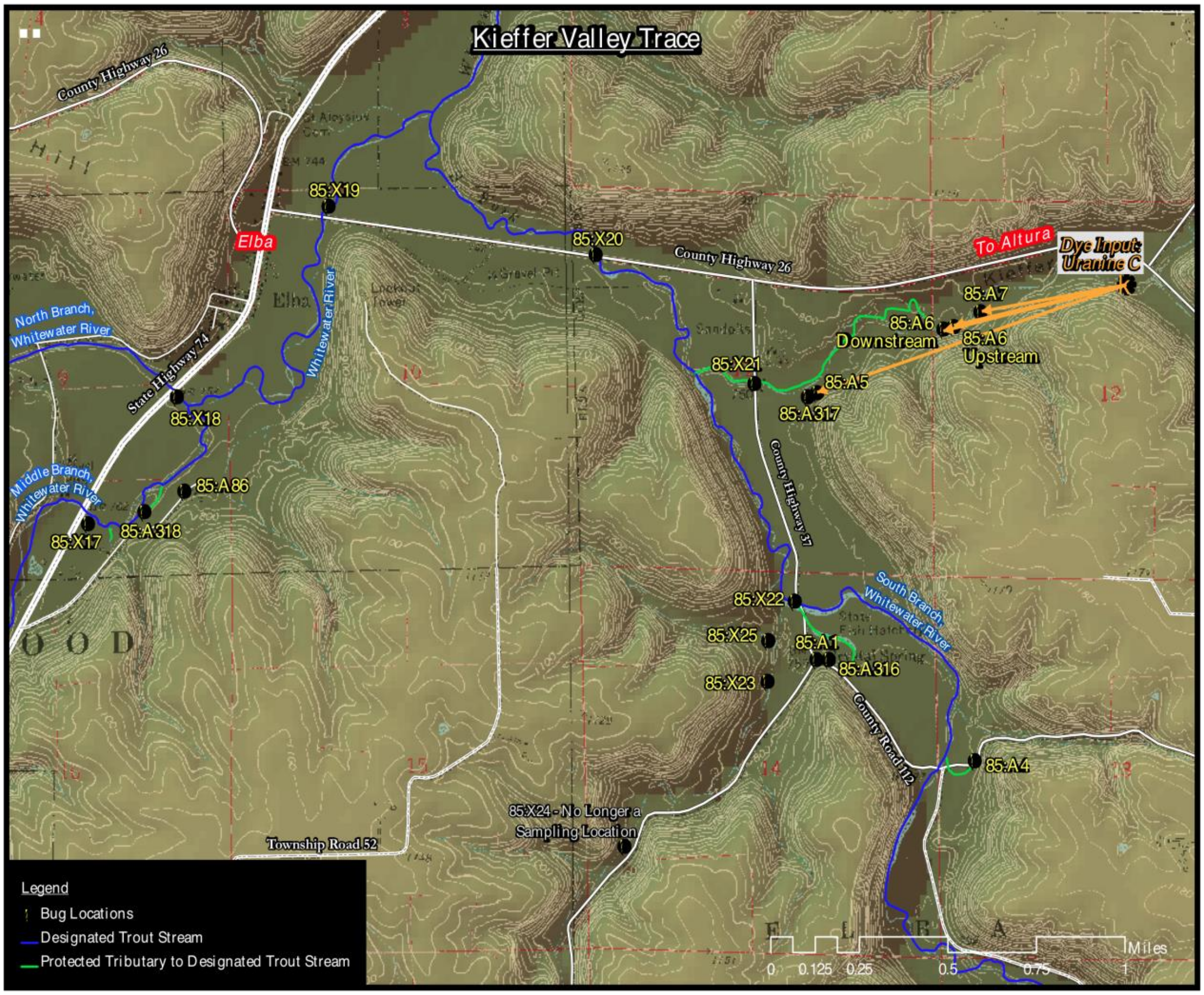

Figure 4: Result map for 2008 Kieffer Valley Dye Trace conducted in October 2008.

Kieffer Valley trace and reappeared in the same four springs (85:A7, 85:A6, 85:A5 and 85:A317) within seven days (Figure 1, Figure 4). The inferred straight-line travel velocity is at least 709 feet per day to the most distant spring from dye input (A5 and A317). The stream sink is located on top of the St. Lawrence Formation. The springs from which dye emerges are located in the middle of the formation and base of the formation. This trace confirmed that fluid can flow rapidly in horizontal and vertical directions through the St. Lawrence Formation on a timescale of at least days to weeks (Green et al., 2012).

In July 2010, two dye traces were conducted as part of a National Science Foundation funded Research Experience for Undergraduates (REU) program. Rhodamine WT was introduced to a stream sink one half mile upstream (northeast) of the 2008 input site, in the lower Jordan Sandstone. Uranine C was introduced to a stream sink in the Coon Valley Member of the Oneota Dolomite, 1.25 miles southwest of the CSSFH, along County Road 37 in an unnamed ravine. Neither dye was detected for this trace during six months of monitoring. (See Figure 5.)

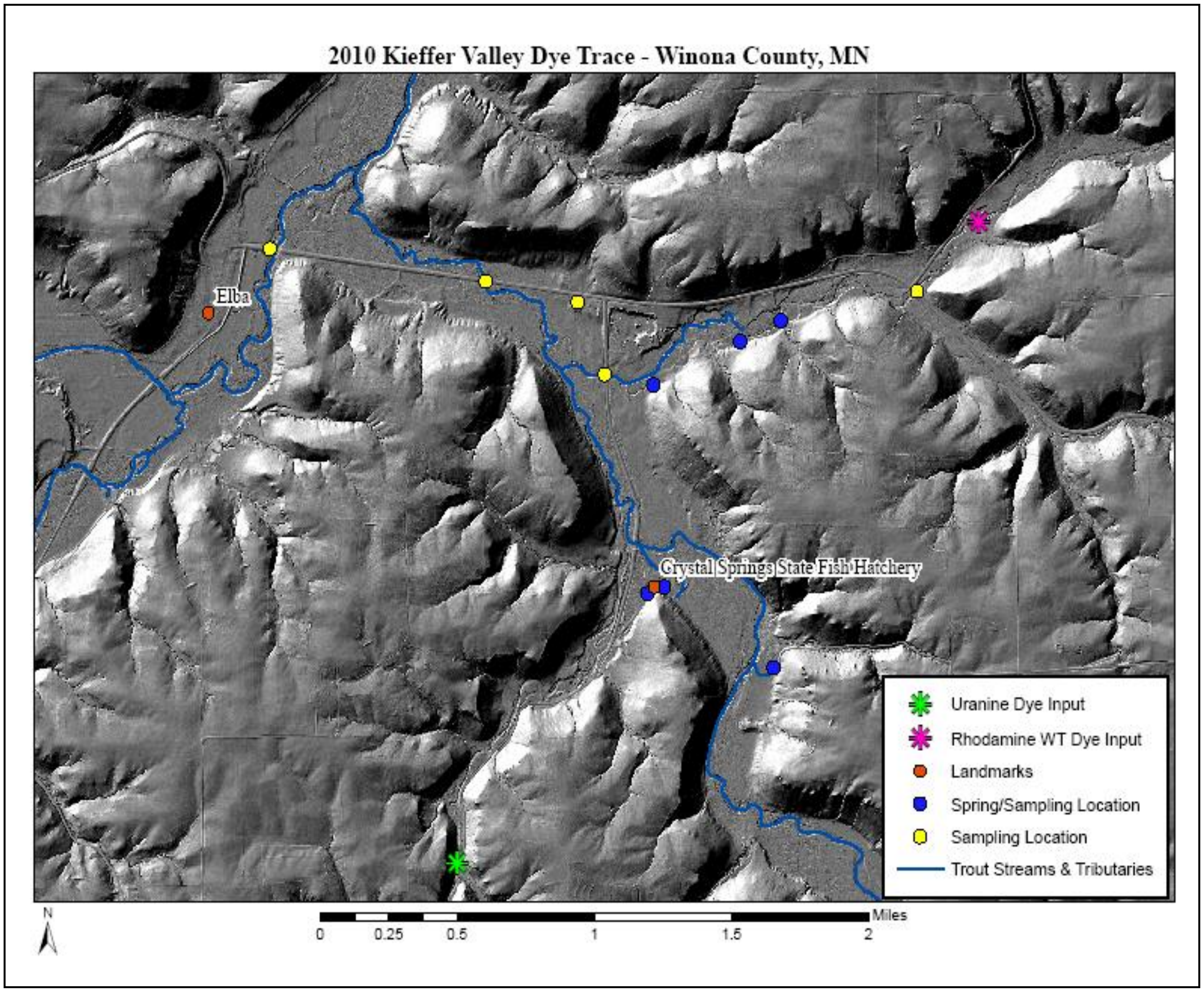

Figure 5: Map indicating sampling points and dye release points in 2010 traces. Ladd and Alexander, 2010.

Methods

The methods of conducting a dye trace are generally described here, followed by details specific to the August 2011 and July 2012 dye traces around the CSSFH. Exact input coordinates and dye information is listed in the Appendix.

Prior to dye release, passive charcoal detectors ("bugs") are placed into creek or spring locations to determine if any background amounts of dye are present in the groundwater system. The locations are chosen based on the most likely places to detect dye, often in a circle around the point of intended dye release. Following dye release, charcoal detectors are exchanged regularly and returned to the Dilute Solutions Laboratory in the University of Minnesota's Department of Earth Sciences for analysis. Fluorescent dye is extracted from the charcoal sampled from individual bugs using 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 (Alexander, 2005).

On 4 August 2011, at 15:45 CDT, eosin was introduced in the same unnamed ravine as the July 2010 trace, but into a different sinking stream location in the lower Jordan Sandstone (Figure 2). 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.

On 16 July 2012, at 20:30 CDT, uranine C was released 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.

Results & Discussion

In the August 2011 Crystal Springs Hatchery Trace, eosin first appeared in the West Spring #2 (MN85:A316) of the CSSFH within 21 days; this gives a straight-line flow velocity of 125 feet per day. This is a flow rate consistent with flow through mixed composition sedimentary units like the Lower Jordan Sandstone and Cambrian St. Lawrence Formation. This trace provides evidence that the stream sinks in the unnamed ravine southwest of CSSFH have conduit connections to the West Spring at CSSFH (Figure 1, Figure 6).

In the July 2012 SBWR Trace, fluorescein was only detected in the downstream bug location at MN85:X20 in the South Branch Whitewater River itself. Dye was not recovered from any spring locations or creek locations other than the one directly downstream from the dye release point. Notably, there was still eosin sporadically emerging from CSSFH West Spring #2 (MN85:A316), indicating that it is possible to have relatively rapid flow accompanied by long periods of storage in the lower Jordan Sandstone and upper Cambrian St. Lawrence Formation. The July 2012 trace provides no evidence that the SBWR sinks upstream from the CSSFH springs.

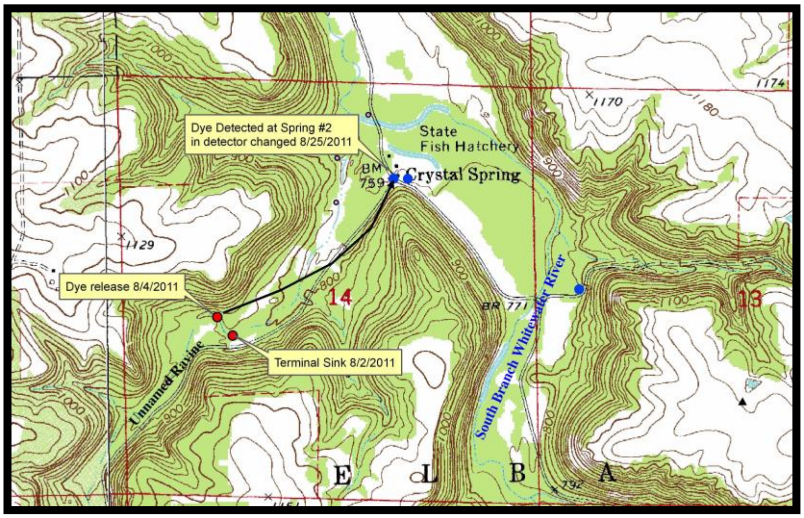

Figure 6: A topographic map of the region around the Crystal Springs State Fish Hatchery. Black line with arrow indicates dye flow path. Red dots indicate dye release points. Blue dots indicate springs in the area.

Conclusion

Dye tracing in the Kieffer Valley demonstrates that water moves horizontally and vertically in the Cambrian St. Lawrence Formation. Dye introduced at the top of the St. Lawrence moves rapidly to springs that emerge at the bottom of the formation. The 1980 and 2008 Kieffer Valley Dye Traces show that conduit connections within the St. Lawrence moves water from a stream sink to a spring at straight-line 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 top of the St. Lawrence; the dye can also be retained for months to years, resulting in long tails in the dye breakthrough curve. The dye introduced into the SBWR also was not recovered in monitored St. Lawrence springs.

Results of dye tracing have important implications for the CSSFH and trout streams in Winona, Wabasha and Houston Counties. Sinking streams in the lower Jordan and upper St. Lawrence appear to have developed flow conduits that connect to springs in the middle and lower St. Lawrence. Surface pollution near these stream sinks potentially impacts the health of spring-fed trout streams. In April 2013, MN-DNR employees at the CSSFH noted that the East Spring #1 (85:A1) had sediment and debris-laden water discharging at record-high flow rates, a unique event in the history of the hatchery's operation. Spring #1 has never had dye emerge from it in any of the traces conducted since 1980. This event is a cause for concern and warrants additional investigation into possible upstream or upland sinking points that connect to East Spring #1.

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South Branch Whitewater River -- Kieffer Valley Dye Traces 2011-2012 (2 Traces)

Charcoal (Bug) Analysis Results

Site Name	KFD # s	UTMs (NAD 83, Zone 15) Easting	UTMs (NAD 83, Zone 15) Northing	8 Oct to 12 Nov 2010	4 Aug 2011 Dye Input	12 Aug to 25 Aug 2011	7 Dec 2011 to 23 Mar 2012	23 Mar to 10 Jul 2012	10 Jul to 16 Jul 2012	16 Jul 2012 Dye Input	16 Jul to 24 Jul 2012	24 Jul to 31 Jul 2012	31 Jul to 6 Aug 2012	6 Aug to 23 Aug 2012	23 Aug to 30 Aug 2012	30 Aug to 18 Sep 2012	18 Sep to 11 Oct 2012	11 Oct to 12 Nov 2012	12 Nov to 13 Dec 2012	13 Dec 2012 to 8 May 2013
CSSFH Spring 1 (aka, CSSFH East Spring) (aka, Main Spring)	**MN85:A00001**	581239	4880669	Uran * (3.2σ)		**nd**	**nd**	**nd**	**nd**		**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**
CSSFH Spring 2 (aka, CSSFH West Spring)	**MN85:A00316**	581184	4880670	Uran * (7.1σ)		Eos (27 σ)		**nd**	**nd**		Uran * (9.0 σ) Eos 35 σ)	Eos (22 σ)	Eos (6.1 σ)	Eos (6.2 σ)	Eos (6.8 σ)	**nd**	**nd**	Eos (12 σ)	Eos (19 σ)	Eos (59 σ)
Chaffe Springs	**MN85:A00003**	582745	4878568								**(lost)**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**
Kreidermacher Spring (aka, Kobler Spring) (aka, Co. Rd. 112 Bug)	**MN85:A00004**	581904	4880243						**nd**		Uran * (14 σ) Eos * 7.5 σ)	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**(lost)**
Sweet Springs	**MN85:A00010**	582565	4878324								**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**(lost)**
Highway Bridge 85503 (Hwy 26 Bridge over South Branch Whitewater River)	**MN85:X00020**	580179	4882375	**nd**		Eos (31 σ)			**nd**		Uran * (> 100 σ)	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**(lost)**

South Branch Whitewater River -- Kieffer Valley Dye Traces 2011-2012 (continued)

Site Name	KFD # s	UTMs (NAD 83, Zone 15)		8 Oct to 12 Nov 2010	4 Aug 2011 Dye Input	12 Aug to 25 Aug 2011	7 Dec 2011 to 23 Mar 2012	23 Mar to 10 Jul 2012	10 Jul to 16 Jul 2012	16 Jul 2012 Dye Input	16 Jul to 24 Jul 2012	24 Jul to 31 Jul 2012	31 Jul to 6 Aug 2012	6 Aug to 23 Aug 2012	23 Aug to 30 Aug 2012	30 Aug to 18 Sep 2012	18 Sep to 11 Oct 2012	11 Oct to 12 Nov 2012	12 Nov to 13 Dec 2012	13 Dec 2012 to 8 May 2013
		Easting	Northing																	
Willow Crossing (aka, Co. Rd. 37 Culvert)	**MN85:X00021**	580902	4881832	Uran * (7.7σ)					**nd**		**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**
Kreidermacher's Crossing (aka, Kreidermacher Road)	**MN85:X00027**	582659	4878365								**nd**	**nd**	**nd**	**nd**	**nd**		**nd**	**nd**	**nd**	**(lost)**

nd = no dye detected

--- = no detector installed

lost = bug lost

yellow highlighted cell = no bug was received at the lab

Eos = Eosine detected

Eos * = Eosine from unknown source or possible lab contamination

Uran * = Uranine from unknown source or possible lab contamination

Dye Poured 4 Aug 2011 at 1545. Eosine (992 g, 33 weight % solution) was input into an unnamed stream along County Road 37 (MN85:B00019, 580025 E / 4879148 N, NAD 83, Zone 15), at the terminal sink point on this date.

Dye Poured 16 Jul 2012 at 2030. Uranine C (1193 g, 35 weight % solution) was input into the South Branch Whitewater River (MN85:X00031, 582299 E / 4877040 N, NAD 83, Zone 15). Below this point, the river may have a losing reach that is difficult to pinpoint by observation.