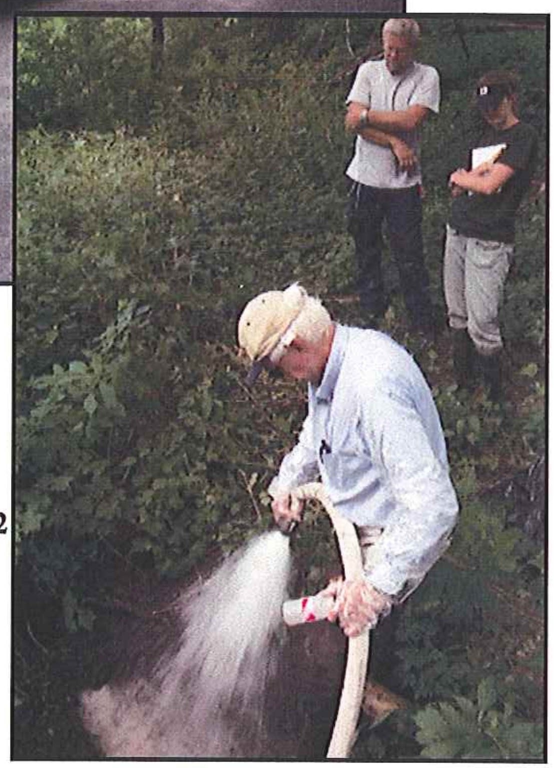
2 July 2007 Morehart Farm Dye Trace

Left: Trucks from Chatfield Fire Department.

Below: Introduction of Sulforhodamine B dye in sinkhole MN55:D0162.



by

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Abstract

Our research is designed to delineate springsheds feeding trout streams in Olmsted County, Minnesota. Trout streams are highly dependent on springs discharging large volumes of cool, clear spring water in order to sustain trout populations. Olmsted County is an area of Southeastern Minnesota with mature karst, and as such, the surficial bedrock aquifer is highly vulnerable to pollution and contamination. In particular, highly turbid ground water from storm events can reach springs and thereby adversely affecting trout populations. Fluorescent dye tracing was utilized to delineate springshed areas and conduit connections of springs feeding the east side of Kinney Creek in Pleasant Grove and Orion Townships. In late June 2007, background monitoring was started at selected locations and on 2 July 2007 a double dye trace was initiated by introducing the fluorescent dyes eosin (CAS 17372-87-1) and sulforhodamine B (CAS 3520-42-1) to sinkholes MN55:D0133 and MN55:D0162, respectively. Direct water samples and activated carbon detectors were analyzed by scanning spectrofluorometric methods revealing both introduction points to be in the springshed McConnell's Spring (MN55:A0006). Travel times were faster than three days per kilometer.

Introduction

Karst aquifers are both extremely productive and highly vulnerable to pollution and contamination. Protection and management of karst springs requires detailed knowledge of their hydrogeologic properties such as recharge areas (springsheds), discharge points (springs), and flow channels (conduits). The delineation of such features helps identify the source of pollution as well as enabling effective efforts at protection from water quality degradation.

Fluorescent dye tracing was utilized for springshed mapping for watershed management in Southeastern Minnesota, specifically for the protection of spring-fed trout streams. Fluorescent dye tracing provides an effective, environmentally sound way to trace groundwater flow in preferential flow systems where high resolution certainty is desired (Green, Alexander, and Alexander 2005).

In late June and early July 2007 a qualitative double dye trace, using eosine and sulforhodamine B, was conducted in Pleasant Grove and Orion Townships (Twp.), Minnesota. The purpose was to determine conduit connections and spring shed areas in Pleasant Grove Twp. and Orion Twp., of springs feeding the east side of Kinney Creek. Charcoal detectors were used to detect the dye in monitored springs and surface streams. The springs and most of the flow paths are located on and under the Harland Morehart farm. The locations of the monitored springs and surface water points are shown in Figure 7 and listed below in "Detector Locations".

Hydrogeologic Setting

Pleasant Grove Twp. and Orion Twp. are located in the active karst region of Olmsted County in Southeastern Minnesota (Figure 1). In Olmsted County the active karst is characterized by high sinkhole density, subsurface drainage and springs, many of which feed trout streams. The first and most important aspect in the development of karst is soluble bedrock. The Galena Group (Stewartville Formation, Prosser Limestone, and Cummingsville Formation) and the Prairie Du Chien Group (Shakopee Formation and Oneota Dolomite) are the first bedrock under much of Olmsted County and provide the first condition necessary for the formation of karst (Ford and Williams 1989, Olsen 1988). In this study area the Galena Group is the first bedrock and contains the surficial aquifer.

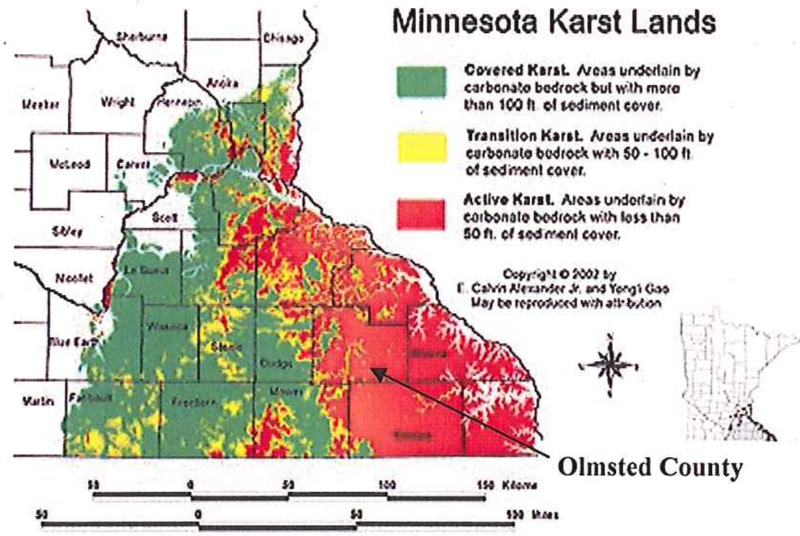

Figure 1. Minnesota Karst Lands (Alexander and Gao).

Key controls determining karst activity and development, including sinkhole probability, are the amount of surficial cover over the bedrock as well as the degree of historical karstification. These chemical processes creating the karst environment have been active more or less since their deposition in the Ordovician.

Due to the nature of multi-porosity karst aquifers, the groundwater of Olmsted County has varied residence times. This project deals with the fast-flow portion of the groundwater system in conduits, which has the shortest residence times and therefore the highest sensitivity to contamination (Olsen and Hobbs 1988). Figure 2 illustrates an idealized hydrogeologic cross section of the local karst system in Olmsted County where a hypothetical porous media water table, following a subdued version of the *surface topography*, is shown in red. The actual water table lies below a thicker unsaturated zone and is dominated by *bedrock topography*. Figure 3 below shows the relevant geologic formations in the Middle Ordovician.

Alexander and Maki's (1988) sinkhole mapping of Olmsted documented a sinkhole plain in Orion Township south of the US 52 Highway, north of the Middle Branch of the Root River ("Middle Branch" hereafter) and east of Kinney Creek. That effort also identified springs draining the sinkhole plain into Kinney Creek on the west and to the Middle Branch to the south.

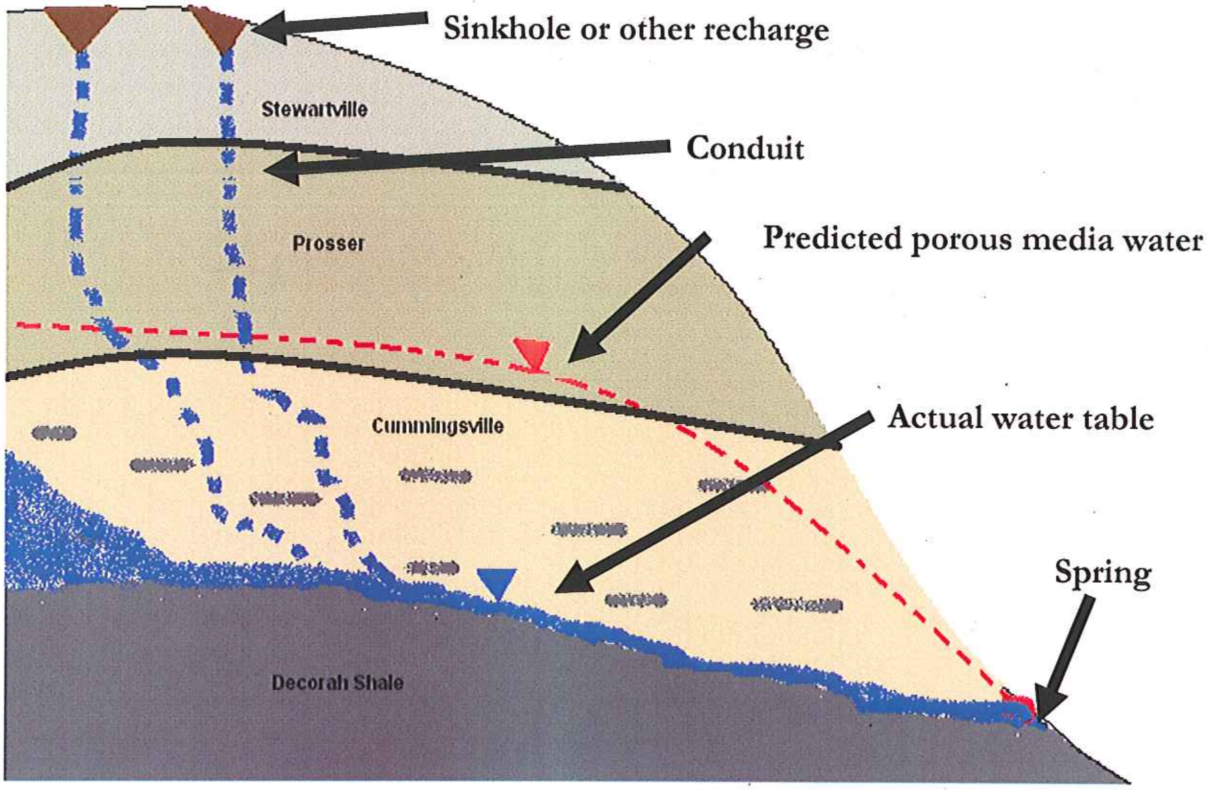

Figure 2. Hydrogeologic cross section.

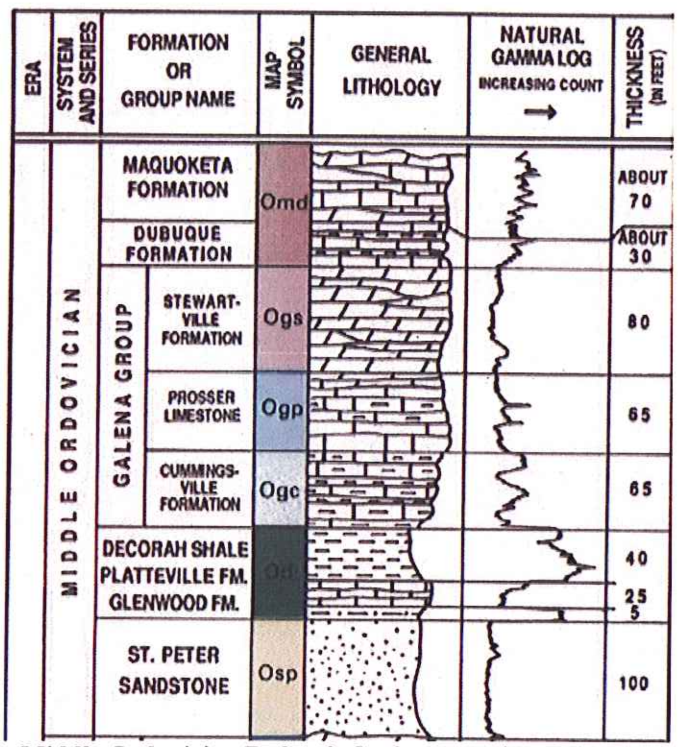

Figure 3. Middle Ordovician Bedrock Geology stratigraphic column (Olsen 1988).

Kinney Creek is one of southeastern Minnesota's trout streams. Dye tracing in the area began in the spring of 2002, Lopez Burgos and others (2003) conducted dye traces near the middle of the sinkhole plain and began to define springshed of the springs on the Burnap farm, which drain south into the Middle Branch (see Figure 4). Their work demonstrated the utility of structural contour mapping in mapping springsheds. This structural contour mapping was largely based on information from the County Well Index; Figure 5 shows wells, first bedrock contours representing the base of the given geologic member, as well as the elevation of the Decorah Shale.

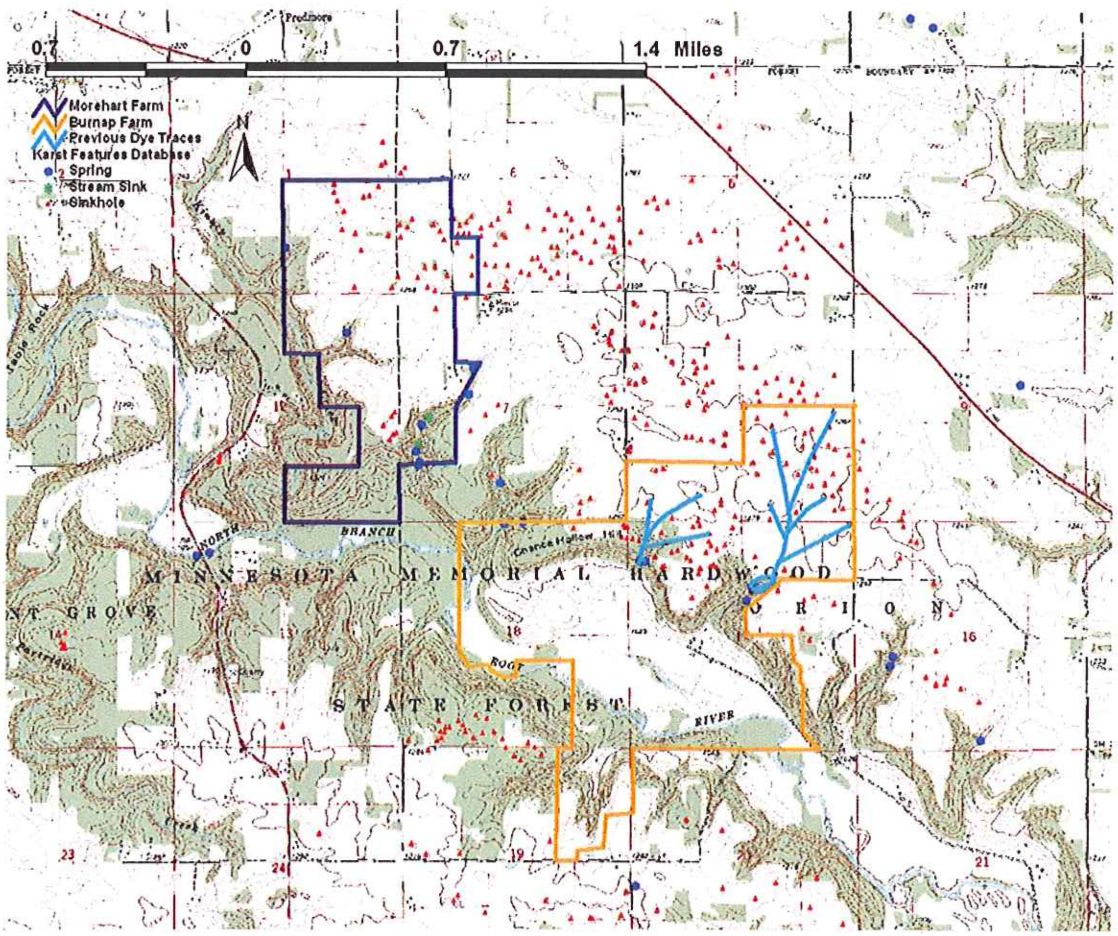

Figure 4. Previous Dye Traces.

This study focused on the west edge of the sinkhole plain where springs feed the east side of Kinney Creek (see Figure 7).

Methods

Prior to dye trace initiation, detector locations were determined and background sampling was initiated. Land in Olmsted County, with the exception of relatively small parcels of land

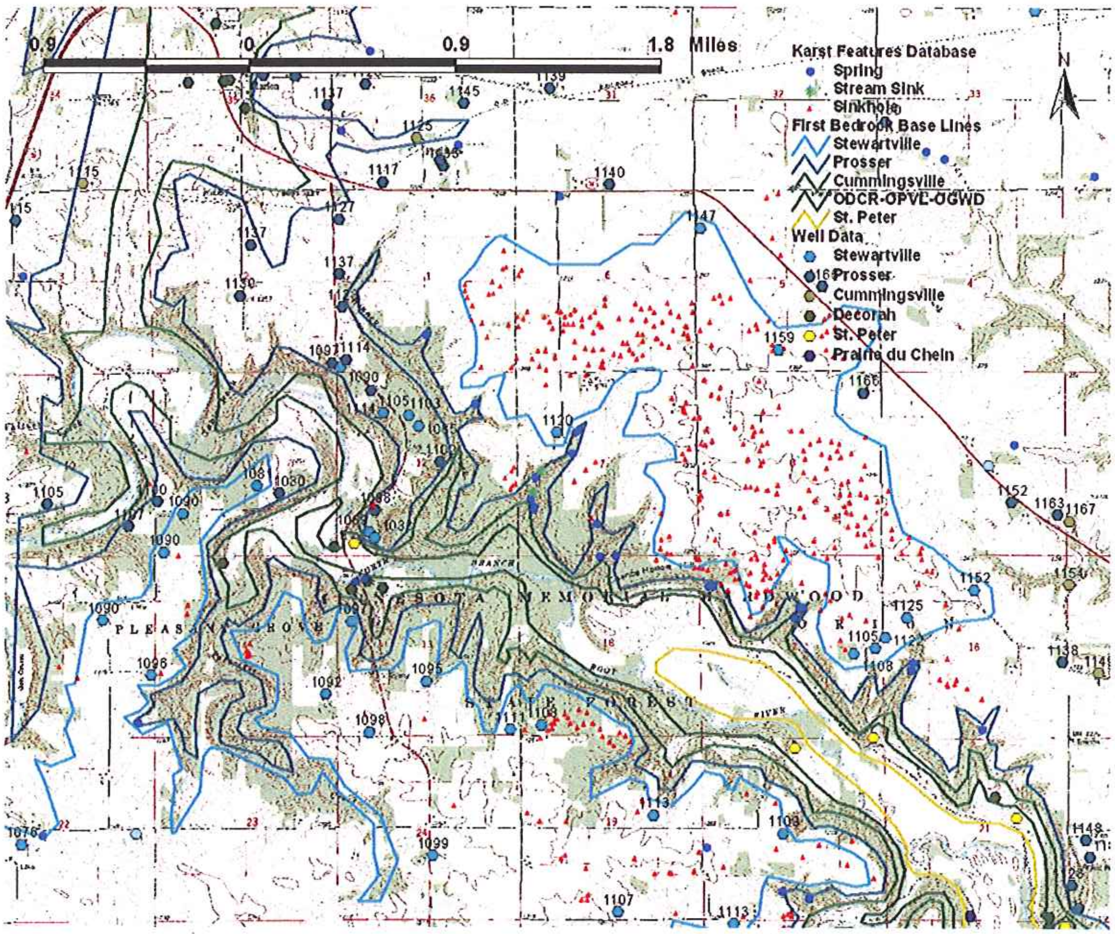

Figure 5. Well Data with Bedrock Contours.

belonging to the Minnesota Department of Natural Resources, is privately owned. In order to conduct this field research it was necessary to contact landowners and gain their permission to sample on their property. Four out of the six detector locations were on the property of a single landowner, Harland Morehart. In the first weeks of the research Mr. Morehart was on vacation and the field research was brought to a standstill until communication was established.

Additionally, many of the detection locations and potential dye introduction points had difficult or restricted access. For example, some of the detectors were located across creeks (Figure 6), in ravines, and some were surrounded by growing crops. Some potential introduction points were no longer accessible due to filling of historic sinkholes to return the land to crop production..

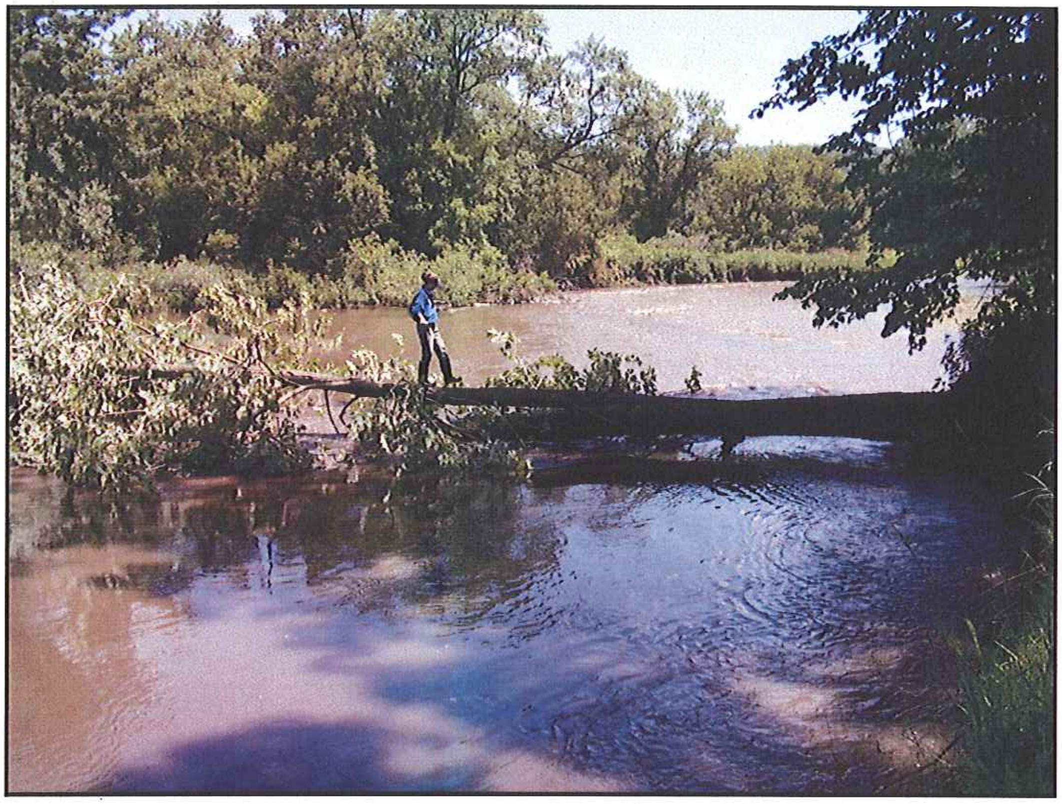

Figure 6. Challenging access to detector location X-8.

Detector Locations:

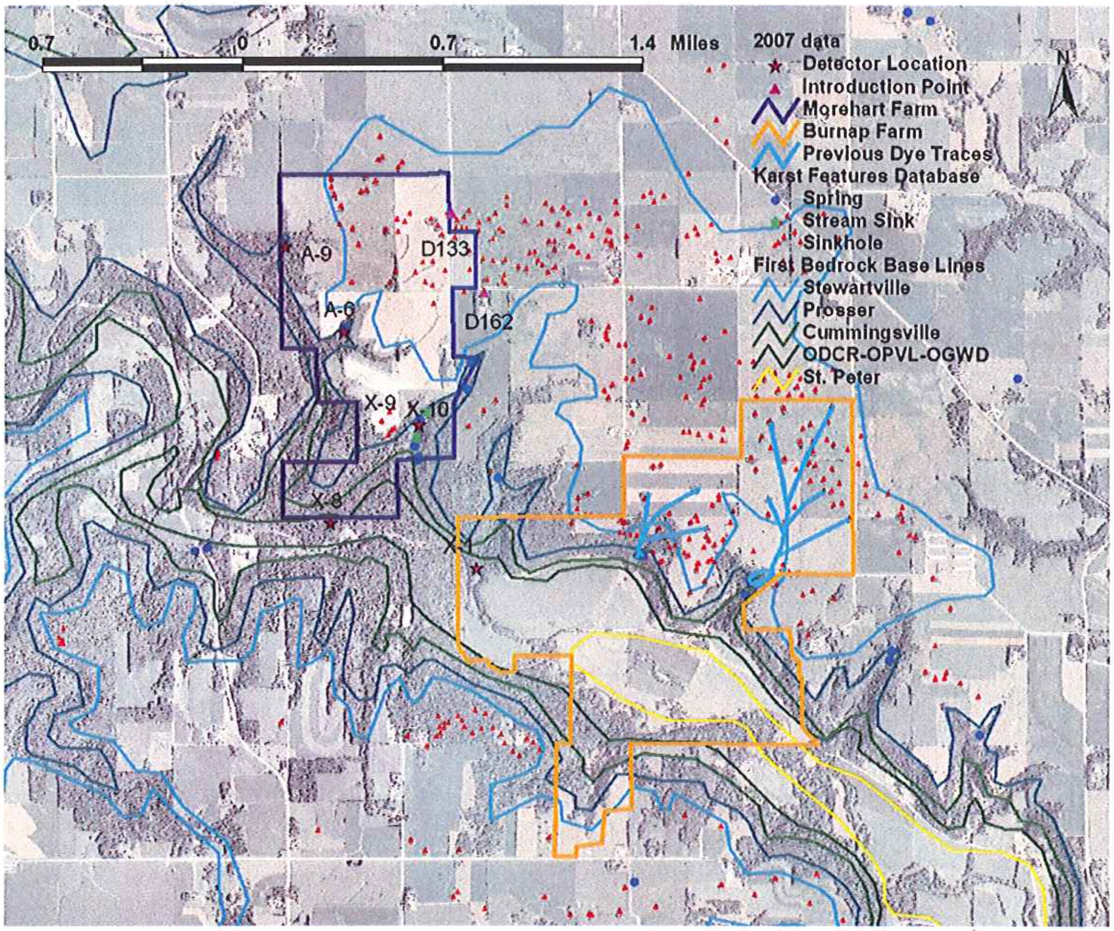

Figure 7. Detector Locations and First Bedrock Data.

A-6 McConnell's Spring: MN55:A0006; 554,344 E, 4,862,923 N (± 6.5 m), ~1210' elevation, in sec 12, Pleasant Grove Twp. Bug was placed in main discharge channel of spring and tied to protruding bedrock (Figure 8).

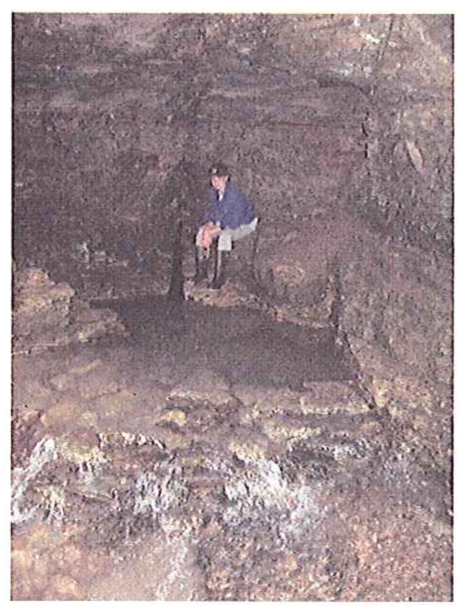

Figure 8. Detector location A-6, McConnell's Spring.

A-9 Old Jug Spring: MN55:A0009; 553,932 E, 4,863,520 N (± 5.0 m), ~1210' elevation, in sec 1, Pleasant Grove Twp. Bug was placed in main discharge channel and tied to a protruding rock on the north side of spring steep head (Figure 9).

Figure 9. Detector location A-9, Old Jug Spring.

X-1 Chance Hollow Stream: 555,273 E, 4,861,262 N (± 3.8 m), ~ 1025' elevation, in sec 18, Orion Twp. Bug was placed in the stream that drains Chance Hollow.

X-8 Mouth of Kinney Creek: 554,251 E, 4,861583 N (± 6.2 m), ~1033' elevation, in sec 13, Pleasant Grove Twp. Bug was placed in Kinney Creek upstream of its junction with the Middle Branch of the Root River Figure 10).

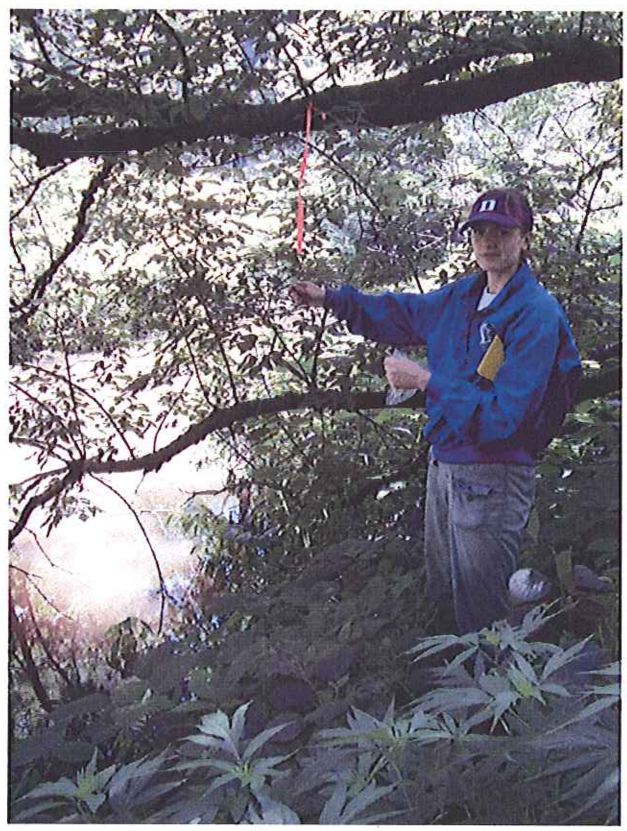

Figure 10. Detector location X-8, mouth of Kinney Creek.

(X-9) A-40 Morehart Ravine Spring: MN55:A0040; 554,869 E, 4,862,268 N (± 6.0 m), ~1125' elevation, in sec 7, Orion Twp. Bug was placed inside a small spring orifice.

X-10 Morehart Ravine Stream; 554,873 E, 4,862,277 N, ~1125' elevation, in sec 7 Orion Twp. Bug was placed in the stream draining the Morehart Ravine about 10 m upstream of X-9.

After the selection of detection locations, at least one round of pre-dye introduction sampling was conducted in order to quantify the natural, background fluorescence. The number of background samples varies for each detector location because as the research progressed, detector locations were added; see Table 1 sampling dates of charcoal detectors. On 2 July 2007 the double dye trace was initiated using the xanthene dyes eosine and sulforhodamine B to sinkholes MN55:D0133 and MN55:D0162, respectively. With the assistance of the Chatfield Fire Department, sulforhodamine dye was washed into the D162 with 1,200 gallons of water and eosine dye was washed into D133 with 1,500 gallons of water. The water moved the dye through the dry sinkholes into the subsurface conduits and diluted the concentrated dyes to reasonable concentrations.

Dye Introduction Points:

Sinkhole D162: MN55:D0162; 555,324 E, 4,863,195 N, T105N, R12W (Orion Twp., Olmsted Co.) sec 7, BAABBD, ~1285' elevation. At 14:30 CDT on 2 July 2007 100.3 grams of **sulforhodamine B** dye (CAS 3520-42-1) (286.6 g of 35 wt. % sulforhodamine B dye solution) was introduced into an open swallow hole in D162 with 1,200 gallons of water. (About 1/3 of the water was poured into the sinkhole, the dye was poured and then the remaining 2/3 of the water was poured into the sinkhole.)

Figure 11. Introduction of sulforhodamine B to sinkhole D162.

Sinkhole D133: MN55:D0133; 555,101 E, 4,863,745 N, T105N, R12W (Orion Twp., Olmsted Co.,) sec 6, CACBCB, ~1285' elevation. At 15:00 CDT on 2 July 61.39 grams of **eosine** CAS 17372-87-1) dye 2007 (175.4 g of 35 wt. % eosin dye (solution) was introduced into an open swallow hole in D133 with 1,500 gallons of water. (About 1/3 of the water was poured into the sinkhole, the dye was poured and then the remaining 2/3 of the water was poured into the sinkhole.)

Figure 12. Calvin Alexander introducing water and eosine dye into sinkhole D133.

On 5 July 2007, three days after dye introduction, water samples were taken at the detection sites and the charcoal detectors were replaced by a set of fresh detectors. Charcoal detectors were also replaced on 9 July, 2007 and the final set of detectors was collected on 19 July 2007; water samples were taken on these two dates, as well.

All charcoal detectors and water samples 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 using an eluent solution of 70% isopropyl alcohol, 30% deionized water, and 10g/L NaOH, the fluorescent materials were then extracted for analysis. This elutant was then run through the Shimadzu RF5000U scanning spectrofluorometer to detect and record the spectra; the water samples were analyzed in the same fashion. Spectral components, including the background spectral components, were quantified using PeakFit software as described in Alexander (2005).

Results and Discussion

The results of the charcoal detectors and water samples are summarized in Table 1 and 2, respectively. The fitted spectra for both the charcoal detectors and water samples are found in the appendix.

Table 1. Results of Charcoal Detectors.

Site	14 - 23 June	23 - 29 June	27 June - 29 June[1]	29 June - 2 July	2 - 5 July	5 -9 July	9 - 19 July
A-6	---	nd	---	nd	eos, SRB	eos, SRB	eos, SRB
A-9	---	nd	---	nd	nd	nd	nd
X-1	nd	nd	---	nd	nd	nd	nd
X-8	nd	nd	---	nd	eos, SRB	eos, SRB[2]	SRB[4]
X-9	---	---	nd	nd	nd	nd	nd
X-10	---	---	---	nd	nd	nd[3]	nd

Table Notes: set = charcoal detectors installed, **nd** = no dye detected, **---** = no detector installed, **eos** = eosine dye detected, **SRB** = Sulforhodamine B dye detected.

[1] On 27 June only one charcoal detector was installed and none of the preexisting charcoal detectors were replaced.

[2] On 9 July charcoal detector X-8 was found out of the creek channel and strung in a bush on the bank, likely caused by thunderstorm event in the previous day.

[3] On 9 July charcoal detector X-10 was found out of the stream trough it was placed in, likely caused by the thunderstorm event in the previous day.

[4] On 19 July charcoal detector X-8 was found on dry surface of the creek channel, due to dramatically decreased flow.

Table 2. Results of Water Samples.

Site	5 July	9 July	19 July
A-6	eos, SRB	SRB	eos, SRB
A-9	nd	nd	nd
X-1	nd	nd	nd
X-8	SRB	SRB	SRB
X-9	nd	nd	nd
X-10	nd	nd	nd

Table Notes: set = charcoal detectors installed, **nd** = no dye detected, **eos** = eosine dye detected, **SRB** = sulforhodamine B dye detected.

As shown in both the charcoal detectors (Table 1) and the water samples (Table2), the two dyes were detected at McConnell's Spring (MN55:A0006) and at the mouth of Kinney Creek (X-8). (Charcoal detector X-8 was located downstream from A-6.) The recharge area encompassing the two introduction locations, sinkholes MN55:D0162 and MN55:D0133, are in the springshed of McConnell's Spring. This connection is shown diagrammatically by the magenta lines in Figure 13.

Dye was present in the charcoal detectors from McConnell's Spring and the mouth of Kinney Creek, which were change three days after dye introduction. The flow through time is therefore less than three days.

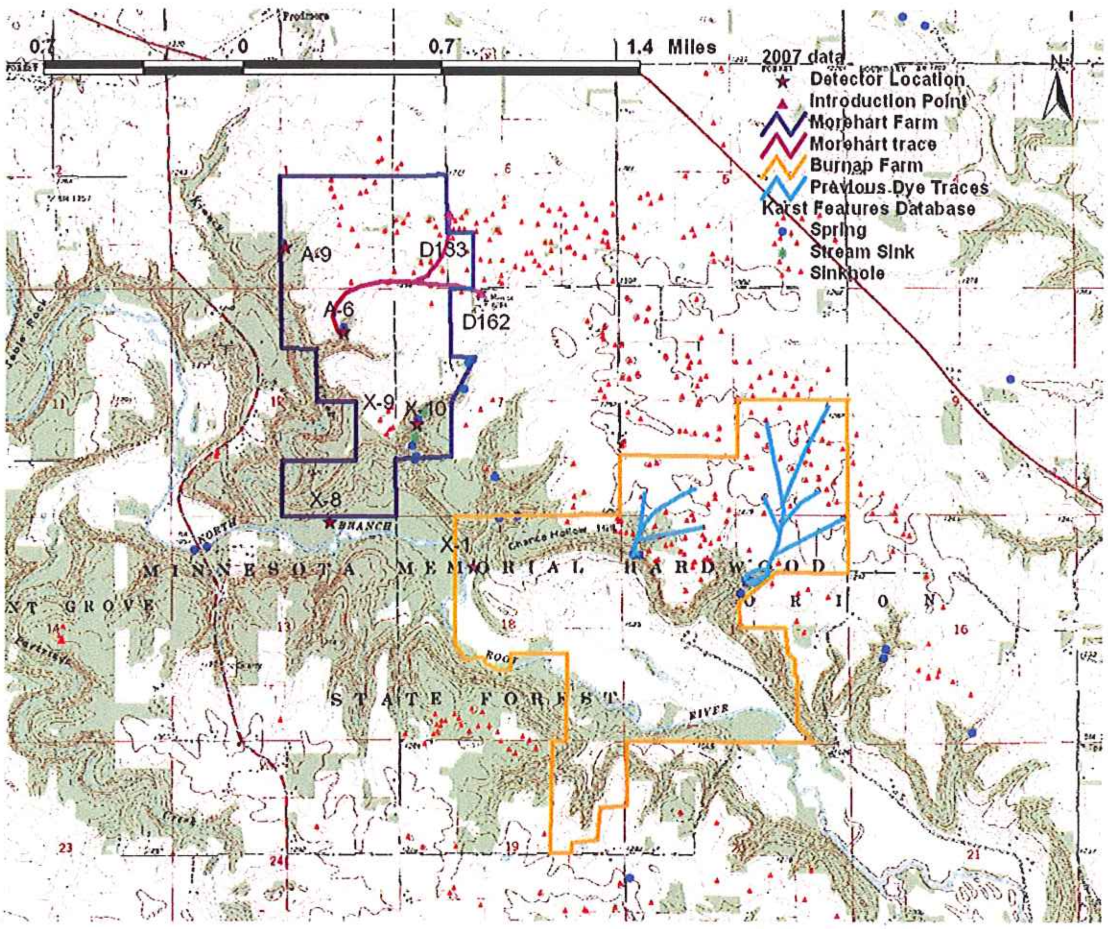

Figure 13. Springshed of McConnell's Spring: MN55:A0006

This trace was the initial determination of sinkhole to spring connection in the west part of the Orion Sinkhole Plain. It begins to define the springshed of McConnell's Spring and of the springsheds feeding Kinney Creek. Further traces are necessary to define the springsheds of the several springs in the study are. Future quantitative tracing can refine the conduit flow velocity determinations and refine knowledge of the relationships between the adjacent springsheds.

Acknowledgments

Many individuals and organizations assisted in making this research possible. First, The National Science Foundation Research Experience for Undergraduates Program made it possible for me to spend my summer at the University of Minnesota Department of Geology and Geophysics. Because of this program I was able to work with E. Calvin Alexander, Jr., whom guided and advised me in nearly every aspect of both this research and the finer facets of field work in Southeastern Minnesota. Thank you to my REU contacts here at the University of Minnesota, Marc Hirschmann and Sharon Kressler. Mr. Harland Morehart consented to our presence on his property to map this springshed. Thank you to the Chatfield Fire Department for the 2,700 gallons of water necessary for the trace and specifically to Tony Lammers and Brian Burkholder for their assistance on the day of the dye introduction. Lastly, thank you to Scott Alexander for being consistently approachable about all things laboratory and software related, Daniel Callahan, who never tired of the drive down Highway 52 and wild parsnip, and Viviana Lopez Burgos, a former REU intern, for her previous research.

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Appendix

Dye Analysis Spectra

Copies of the spectral decompositions of all of the scanning spectrofluorophotometric spectra from the water and charcoal eluent from samples analyzed in this work are available in pdf format from the authors on request.