A Quantitative Dye Trace in the Bat River System

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ABSTRACT: While in resent years a significant amount of work has been done to delineate the karst spring sheds of southeastern Minnesota. There has been little work done to document the characteristics of the spring sheds such as the resonance time of water with in the system. Bat River Cave and spring were the focal point for this trace, the spring being the sampling location. Four dyes were released, one in a drilled access shaft and three others into near by sinkholes. All four dyes were detected in Bat River Spring within twenty-four hours of there releases. The velocity of the system was found to be 651 ft/hr relative to cave passage and 258 ft/hr compared to the surface distance. This goes to highlight the Galena group's vulnerabilities and the difficulty of contamination containment.

INTRODUCTION

Little is know about Bat River Cave and the karst system in which it is located. The first know explorations into the cave, according to Ron Spong, were done in the mid 1950's and lasted until 1976. The cavers were stopped by a terminal sump at that time an estimated third to half mile of passage had been discovered. Interested in the cave reignited when in 2006 John Ackerman led a cave diving trip that pushed past the sump and discovered an open walking passage that stretched before them(Spong 2007). The cave has since been mapped to 2.2 miles and a shaft entrance has been drilled past the terminal sink opening up the cave to further exploration. Bat River Cave and Spring are located in the Galena Group which is composed of limestone and dolomites. The system travels west to east before emerging in the spring.

It is nearly impossible to predict the flow of groundwater in a karst region since groundwater boundaries often do not match the surface water boundaries; tracer testing is often the best tool to gain insight in the behavior of the system (Baedke 2000). A quantitative approach was chosen in the Bat River trace since a dye could be released at the base of the drilled shaft and then be sampled at the spring to produce an accurate breakthrough curve (BTC). The curve is the most valuable piece of data garnered from a quantitative trace, BTC give allow hydrologist to understand the aquifer, groundwater flow, contaminate transport and conduit networks with in the area (Pronk, 2008). Given that one good BTC was likely additional inputs were investigated with in the area.

The data gained from a quantitative trace within a delineated aquifer is the most useful information for scientists trying to mitigate contamination flow in a karst system. Knowledge of groundwater velocities and conduit networks can help determine the size of the area contaminated and the directions in which the contamination is moving. The BTC can help save time, money and additional areas from being contaminated by indicating the best mitigation strategy and remediation sight. Previous studies such as Baedke and Krothe's in the Beech Creek Aquifer have help develop an effective cleanup plan for groundwater contamination where previous pump and treat test have failed (Baedke 2000).

Do to the lack of accurate knowledge of the Galena groups conduit flow characteristics even one quantitative trace and BTC give an important starting point for clean up of spills within the region.

Fig. 1. Bat River Spring with ISCO 3700 auto samplers in place

METHODS

Bat River Cave and Spring were selected for a quantitative trace do to the knowledge a dye released in the passage below the drilled shaft entrance would reach Bat River Spring. On June 17, 2008, passive charcoal detectors were placed in springs radiating out from Bat River spring for background information. While in the area a survey was undertaken to identify sinkholes that could be used as additional dye inputs(fig. 2). At Bat River Spring(A13) a staff gage was put in place to monitor flow fluctuations.

The trace was initiated on June 26, 2008, three ISCO 3700 auto samplers were place at Bat River Spring and set at staggered 20 minute intervals for the first 24 hours before the dye was released. In addition to the collection of background bugs and placement of a new set. The first dye released was 300g of 91 wt % Phloxine(Lot #AJ7526 Warner-Jenkinson, K7054 1105 D&C Red No. 28) an estimated 100ft down stream of the drilled entrance shaft at 13:55. A previously identified spring and sinkhole were chosen as the second input do to the system being primed by the spring water and its ability to flush the dye. In this sinkhole 436.6g of 17.7 wt % Sulforhodamine B(Lot #082207D Chromatint, M93010X Red 0551) was released at 14:21. The next input was a grassy sinkhole at the edge of a corn field. The system was primed by pouring approximately 1000 gallons of water from a fire trunk. This was followed by 479.4g 33 % wt Eosine(Lot #020706 Chromatint, D13802, Red 0143) which was flushed with an additional 1000 gallons at 14:34. The final sinkhole was primed with 1000 gallons of water before 478.9g Uranine Hs(Lot #082207C Chromatint, D11006) was dump followed by 1000 gallons of water to flush the dye into the system.

The first 71 water samples were collected on June 27, 2008 at 13:00 and the auto samplers were reset so a sample would be taken every 40 minutes. The next set of water samples was collected at 12:00 on June 29, 2008 and also at this time the bugs were collected form the near by springs and new bugs were placed. The samplers were reset to take a sample every hour. Another set was collected on July 2, 2008 at 11:00 and the auto samplers were reset to sample every 3 hours. The final set was collected July 12, 2008 in addition to the removal of all the bugs in the area.

All water and carbon samples were run as they were collected on a Shimadzu RF5000U Spectrofuorophotomter and analyzed using Peakfit software. The carbon samples were eluted in a liter solution of 70% isopropyl, 30% deionized water and 10 grams NaOH. Some of the water samples were found to be off chart and there for had to be systematically diluted. Standards of each dye were made to find a relationship between area and ppb. This original curve was found to be incorrect for the sulforhodamine b this is suspect to have been do to the dyes highly responsive changes due to temperature. A temperature equilibrated standard was made and a multiplication factor of .6964 was found to correct for the temperature.

Flow measurements were taken throughout the trace. Unfortunately due to an error in a data logger only two relevant flow measurements were available. There was a declining trend in the water levels during the trace noted through staff gage measurements. It was found that an exponentially decline in water levels best represented the flow for the period of the trace.

RESULTS

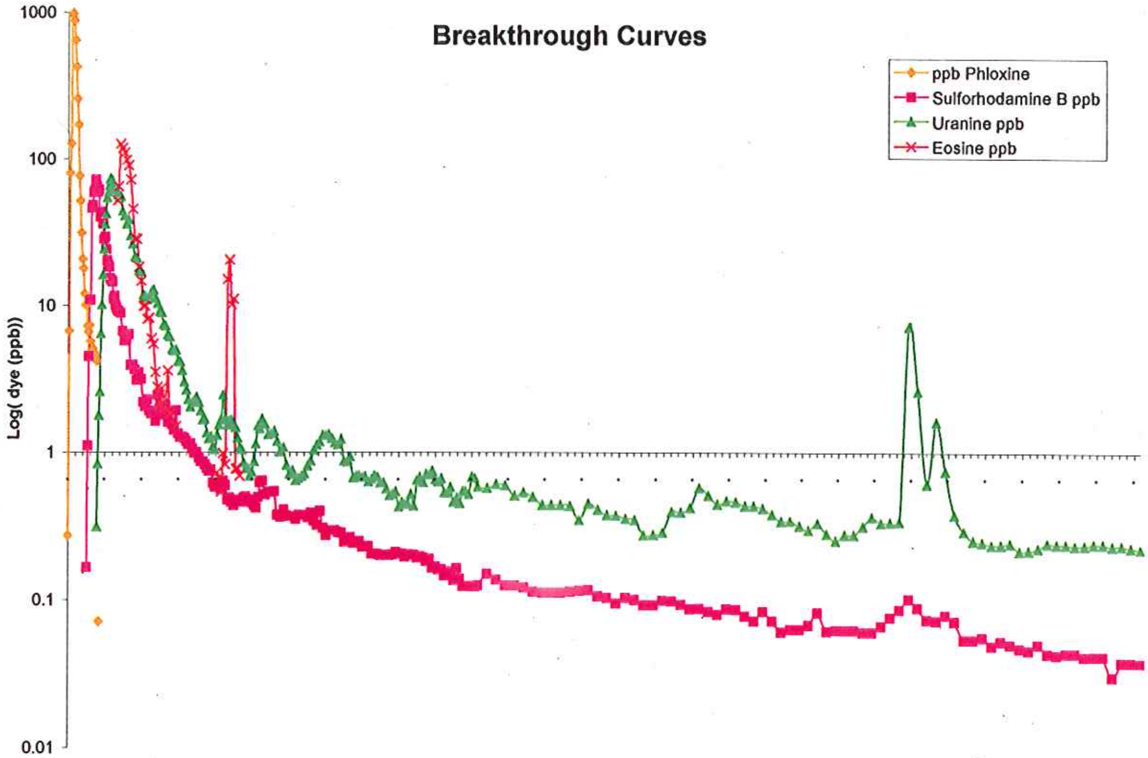


Fig. 2 Breakthrough curves for Bat River Dye Trace

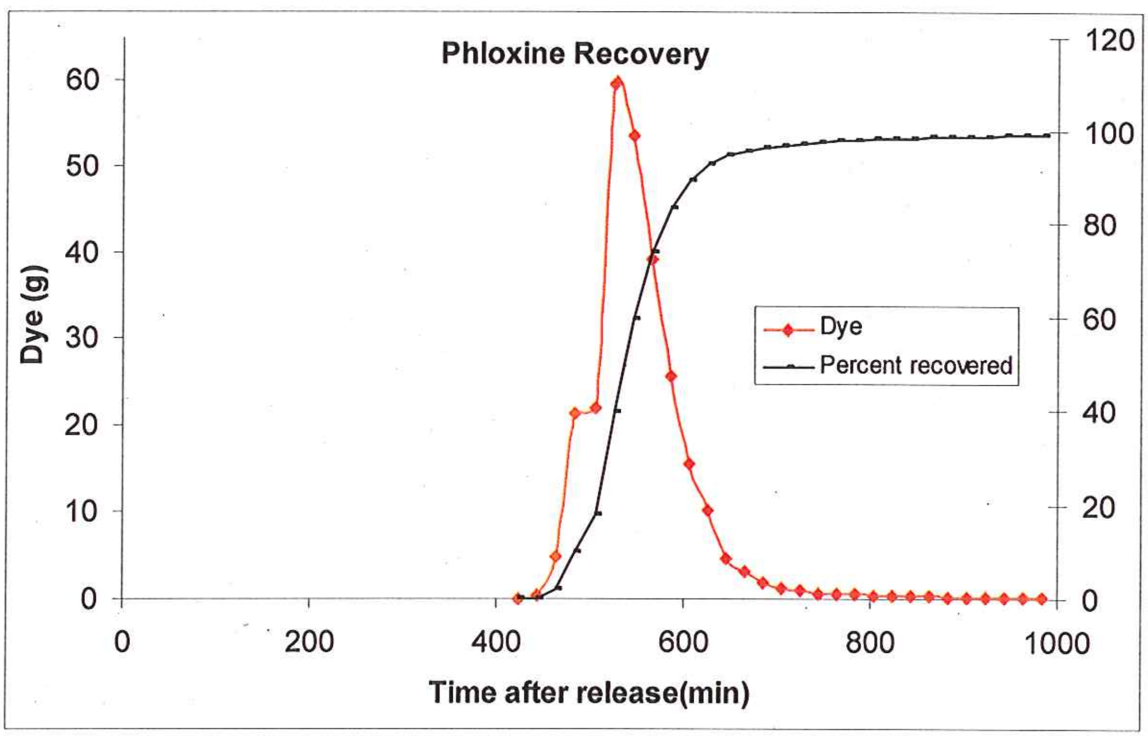


Fig. 3

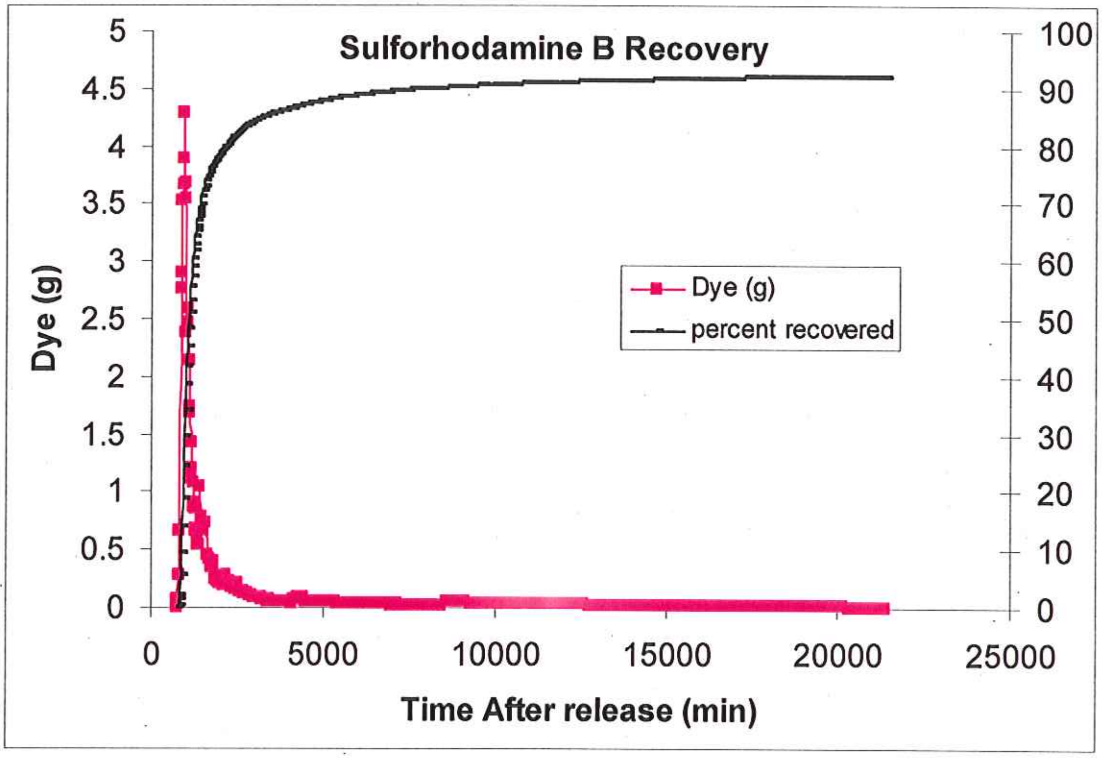
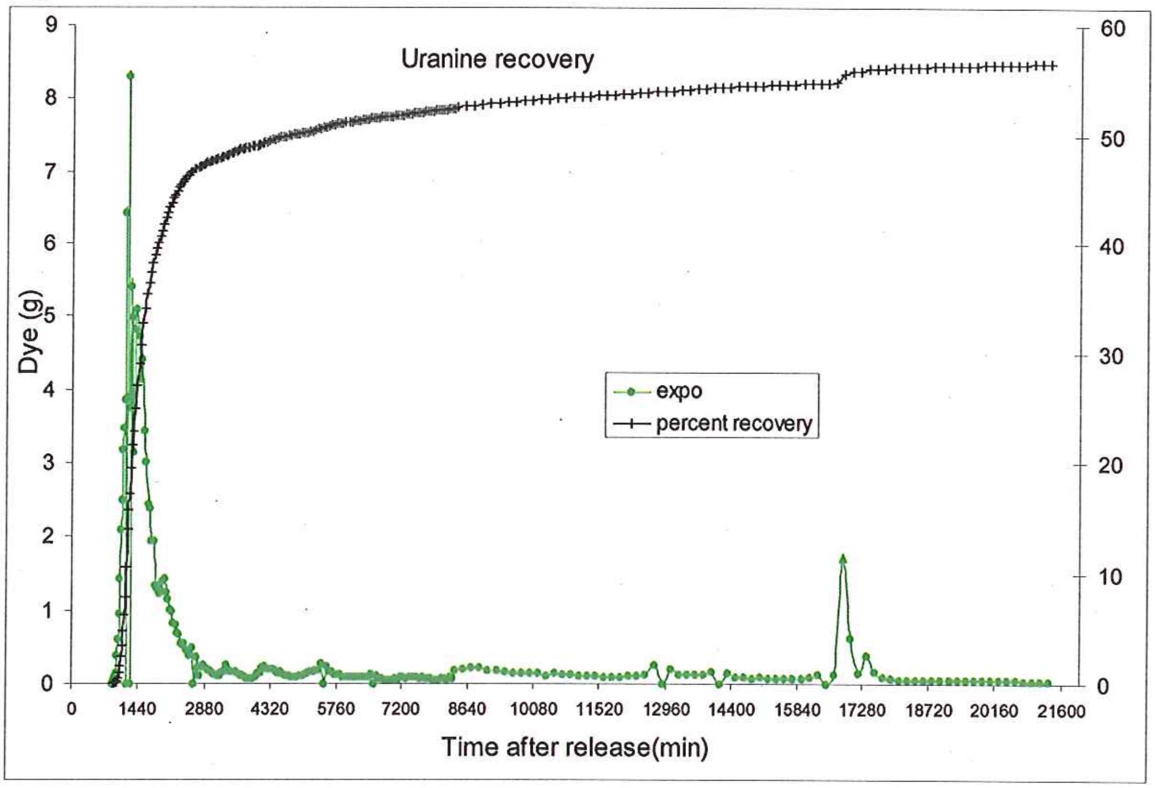

Sulforhodamine B Recovery
Dye (g)
Time After release (min)
Dye (g)
percent recovered
0
5000
10000
15000
20000
25000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
50
60
70
80
90
100

Fig. 4


Uranine recovery
Dye (g)
Time after release(min)
expo
percent recovery
0
1440
2880
4320
5760
7200
8640
10080
11520
12960
14400
15840
17280
18720
20160
21600
0
1
2
3
4
5
6
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0
10
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30
40
50
60

Fig. 5

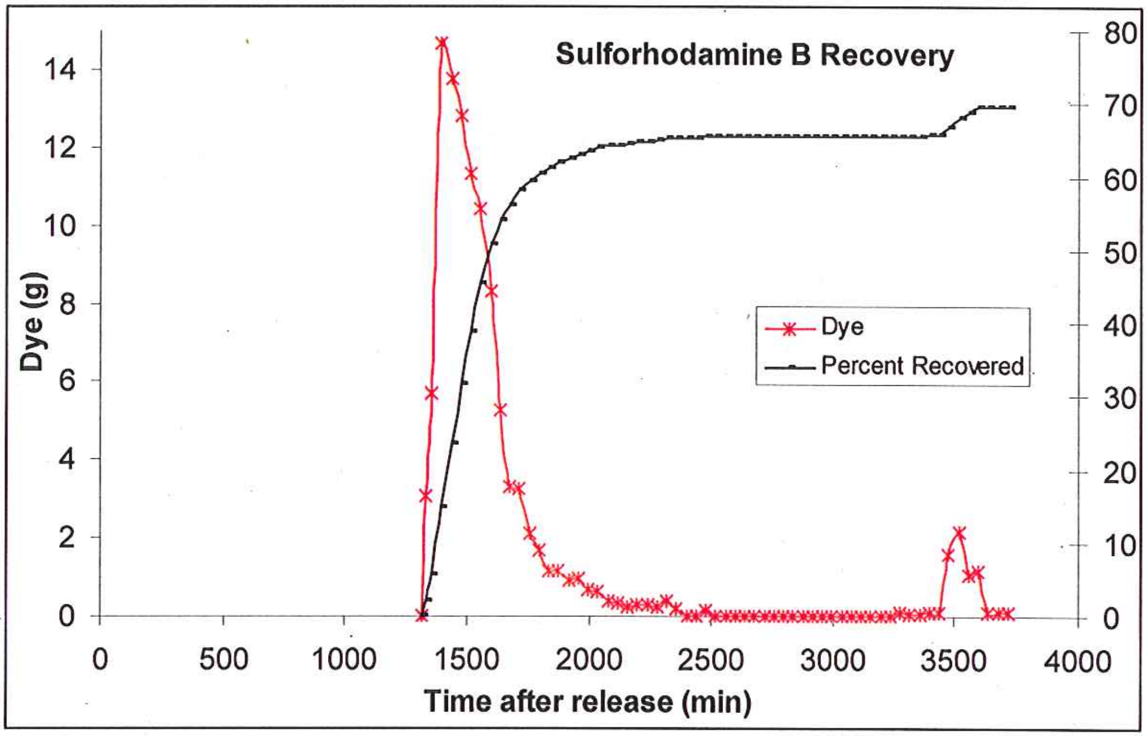

Fig. 6

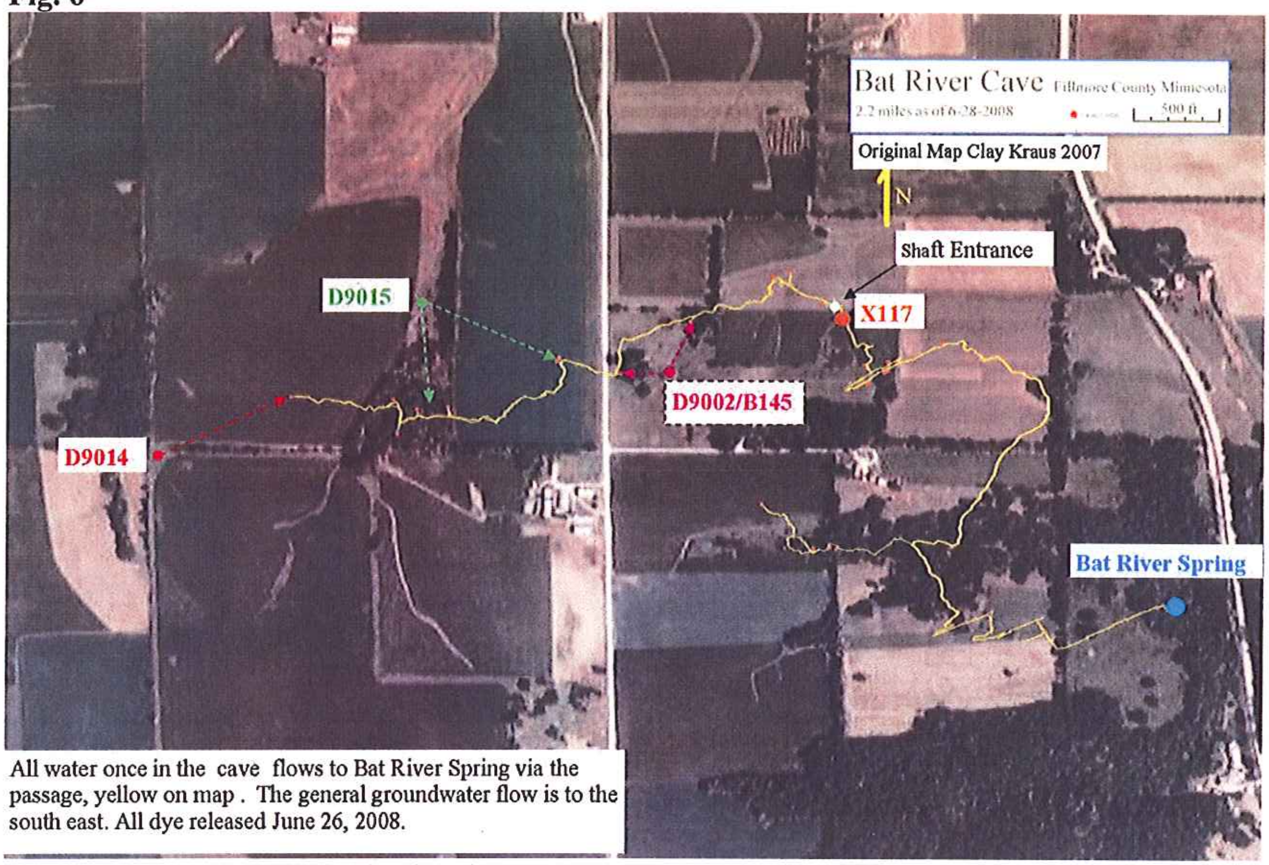

Fig. 7 Map of Dye Input Distributions and Suspected Subsurface Dye Flows

	Percent Recovered	Breakthrough(hr)	Peak(hr)	Half Mass(hr)	Surface Distance (ft)	Subsurface Distance (ft)	Suface Velocity(ft/hr)	Subsurface Velocity(ft/hr)
Phloxine	99.07	7.08	8.75	8.91	2553	5802	258.27	650.69
Sulforhodamine B	92.17	12.65	16.65	17.31	3201	7302	184.92	421.84
Uranine	56.55	15.18	19.51	23.85	4674	7757	195.97	325.24
Eosine	69.61	22.38	25.28	24.95	6049	9952	242.45	398.88

Table 1

DISCUSSION

The flow data indicates that flow in minor /side conduits is significantly slower than in the main passage. Given how close the surface flow velocity of the Eosine is to the Phloxine it indicates that D9014 is very close to if not on top of the main cave passage. The Bat River Trace data shows the speed and irregularities that are found in karst systems. This trace could provide a useful tool in: future traces, showing the conduit flow properties of the Galena Group and working with contamination mitigation efforts.

ACKNOWLEGMENTS

The help of many individuals was required to conduct this trace especially time frame that was available. An acknowledgement of these individuals is the least we can do. John Ackerman for his access and continued efforts to preserve and map the karst lands of Southern Minnesota through the Minnesota Karst Preserve. Duane Schmidt, Carolyn Meyer and the Gladys for letting us access the various sinkholes and springs on their properties. The Chatfield Fire Department for providing a tanker truck to help flush dyes. Clay Kraus for his help, maps and knowledge of the cave. The National Science Foundation for generous funding. Finally Calvin Alexander, Scott Alexander and Andrew Luhmann, whom all took time out of their busy summer schedules to help with this trace. Their patients was immeasurable as they answered the same simple questions over and over for me.

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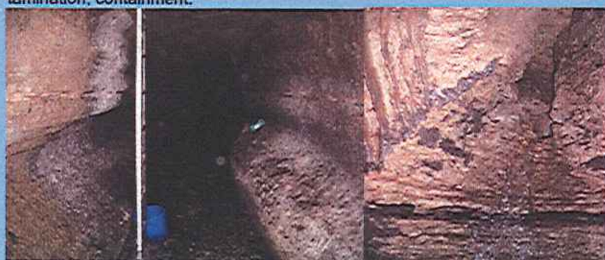


Fig. 1: Right a Stream passage Typical of the Bat River Cave System
Left: Side conduit entering and eroding into the main passage

Quantitative Tracing:

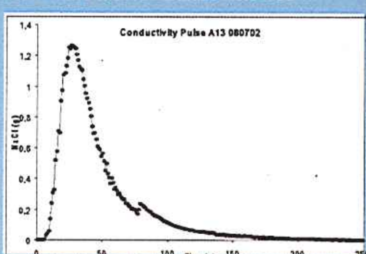
Quantitative traces are a more in depth and labor intensive than a qualitative trace. They are often under taken in areas which have already been delineated. In quantitative trace auto samplers are placed in the spring is know to be the systems outlet to take frequent sample. These samplers are started before the dye is released to get a background and complete breakthrough curve(BTC). The BTC is a combinations of flow and dye concentrations(ppb) in comparison to the time past since the dye has been released. The curve is the most valuable piece of data garnered from a quantitative trace, BTC give allow hydrologist to understand the aquifer, groundwater flow, contaminate transport and conduit networks with in the area (Pronk, 2008).

Dye Recovery= $\sum Flow*PPB(dye)*dt$

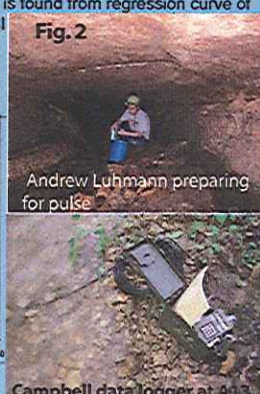
Flow

Flow was calculated using NaCl pulses measured with data logging conductivity probes recording at one second intervals. Mass is found from regression curve of know samples with know concentrations of NaCl and measured conductivities.

Mass recovered= $\sum mass*dt$
Flow=Mass recovered/Mass Released



Mass passing Probe During Conductivity Pulse



Andrew Luhmann preparing for pulse

Campbell data logger at A13

Bat River Spring with ISCO 3700 Auto Samplers

Bat River Spring Green from Uranine

Bat River Trace:

For the Bat River Trace four dye inputs were selected. The first was at the base of the drilled shaft entrance to the cave, it is the reference since the distance and path to the spring are know. Three sinkholes were selected as additional dye input sights through field work done in the weeks proceeding the trace(fig. 1).

On June 26, 2008 at 13:00 the auto samplers were put in place and set to sample every 20 minutes over the first 24 hours(fig. 3). Passive charcoal detectors were placed in near by springs to see if all the dye went through Bat River Spring or was diffused through multiple springs.

Dye Releases went as follows:

X117/Shaft Entrance: 300g of 91 wt % Phloxine at 13:55
D9002/B145/Sinkhole Spring: 436.6g of 17.7 wt % Sulforhodamine B(SRB) at 14:21
D9014/Grassy Sinkhole: 479.4g 33 % wt Eosine at 14:34
D9015/Pasture: 478.9g 50% wt Uranine Hs at 15:09

At locations without a natural water flow the system was initially primed with 1000 gallons of water before and then flushed with 1000 gallons of water after the release: D9014 and D9015(fig. 5).

Releasing uranine into D9015

A special thanks is due to: John Ackerman for cave access. The land owners; Duane Schmidt, Carolyn Meyer and the Gladys. Clay Kraus for his maps and knowledge of the cave. The Chatfield Fire Department for providing a pumper truck. The National Science Foundation for funding. Most importantly the individuals who guided me through this Andrew Luhmannn, Calvin Alexander and Scott Alexander.

References:

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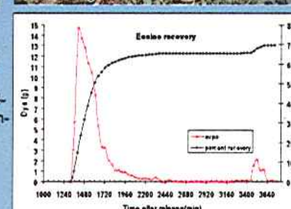


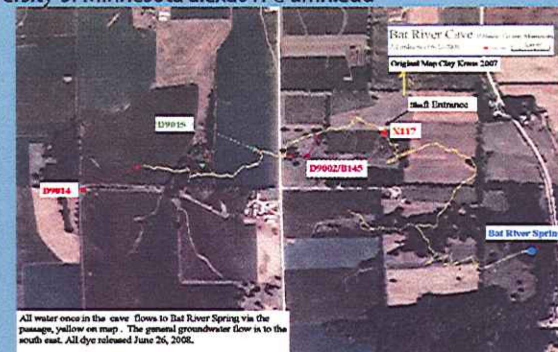
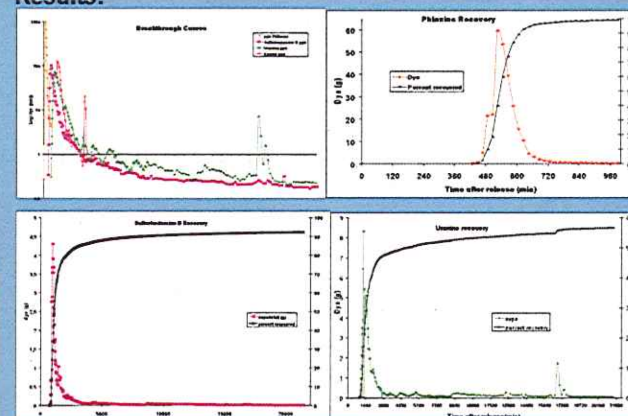


Fig. 6 The Bat River Trace dye input distribution and suspected dye flow.

Results:



Dye	Recovery	Time(hr)	Velocity(ft/hr) (relative to surface)	Velocity(ft/hr) (relative to passage)
Phloxine	99.07	8.92	258	650.7
SRB	92.17	17.98	178.05	389.43
Uranine	56.55	23.85	195.97	352.28
Eosine	69.61	24.95	242.45	398.88

Discussion:

The flow data indicates that flow in minor /side conduits is significantly slower than in the main passage. Given how close the surface flow velocity of the Eosine is to the Phloxine it indicates that D9014 is very close to if not on top of the main cave passage. The Bat River Trace data shows the speed and irregularities that are found in karst systems. This trace could provide a useful tool in showing the conduit flow proporties of the Galena Group, especially when working with contamination clean up efforts.