Water Tracing in the Crystal Creek Watershed in Minnesota

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Introduction

The Root River Field to Stream Partnership is a multi-agency effort led by the Minnesota Department of Agriculture (MDA). The primary goal is to characterize nutrient losses by agriculture to surface water and groundwater, and to apply sustainable best management practices (BMPs) to reduce those losses. One of the three study areas is the Crystal Creek Watershed (CCW), a 15 km² (3,700 ac) watershed located in the karst region of southeast Minnesota. In the CCW, 78% of the watershed land area is devoted to cropland with corn and soybeans making up 76% of the crop acres.

Beginning in 2010, the Partnership has collaborated with the University of Minnesota-Department of Earth Sciences and the Minnesota Department of Natural Resources to conduct dye tracing within and around the CCW. Tracing was employed to approximate the land area which supplies groundwater to springs (groundwater springsheds) that discharge directly to Crystal Creek.

Dye pour into sinking section of stream.

Photo credit John Barry, MDNR

Picture 1. Groundwater emanating from Twin Springs near the contact between the Prosser and Cummingsville Formations. August 26, 2016.

Picture 2. Dye flushed into sinkhole using tanker truck. Holy Grail North sinkhole, Starless River Springshed. April 21, 2016.

Picture 3. Dye trace using snowmelt runoff in Willow Pond Springshed. March 11, 2010.

Picture 4. Farmer field day discussing nitrogen best management practices to reduce economic and environmental risk. June 24, 2016.

Photo credit Paula Mohr, The Farmer Magazine.

Nitrates, Springs and Streams

Baseflow nitrate-nitrogen concentrations highlight a strong relationship between nitrates in springs and those measured in the receiving stream (Figure 1). This suggests the land area connected to the springs is vulnerable to nitrate leaching from cropland soil profiles. Therefore, defining the drainage area to these springs is an important step in evaluating the effectiveness of nitrogen BMPs.

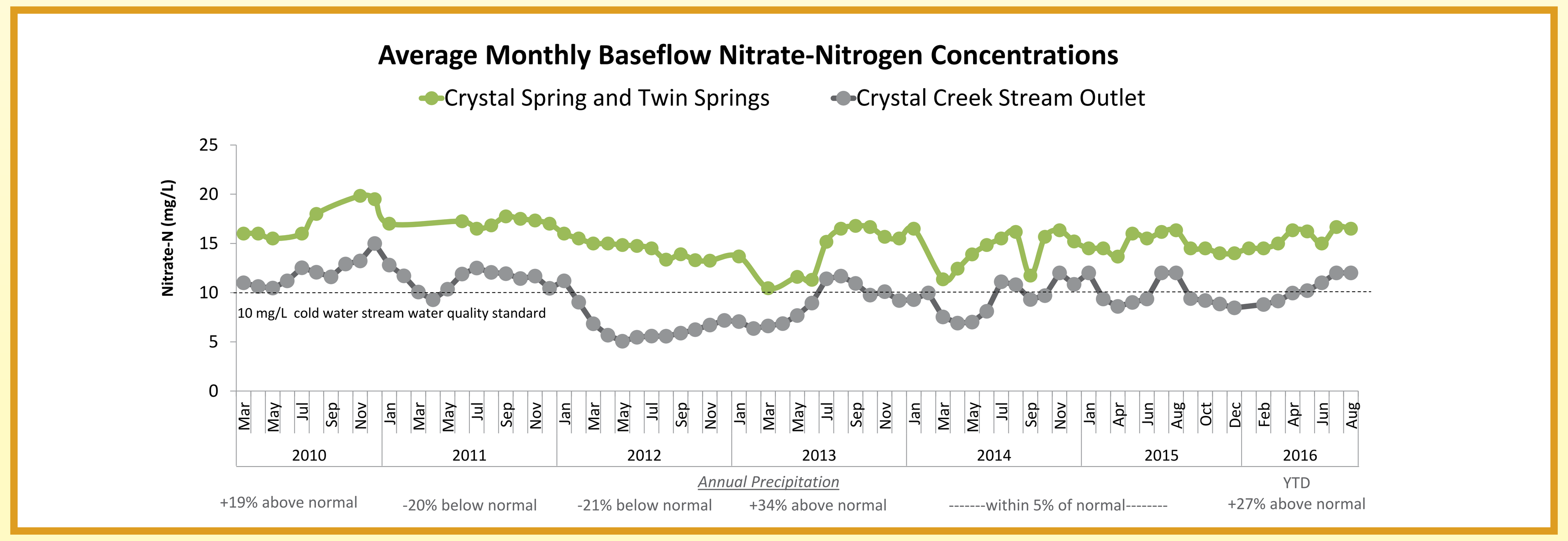

Figure 1. Average monthly spring and stream nitrate-nitrogen concentrations in CCW.

Bedrock Geology of Crystal Creek Watershed Area

This figure illustrates the bedrock geology and karst topography in the study area. It also shows how water soluble contaminants like nitrate can rapidly enter groundwater.

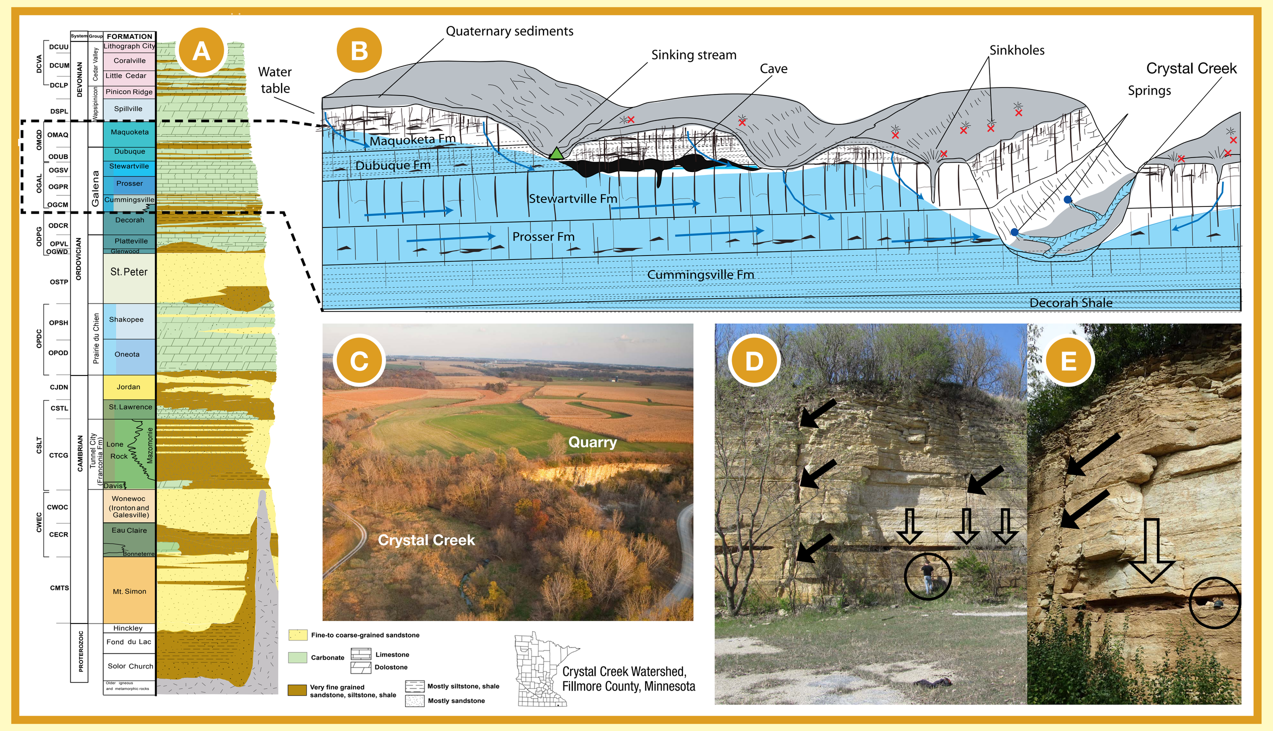

Figure 2. Bedrock Geology of Crystal Creek Watershed Area. *A) Stratigraphic column for bedrock of southeastern Minnesota. B) Conceptual depiction of karst features imprinted on the regional carbonate bedrock of the Crystal Creek Watershed. C) Typical landscape setting on the Upper Carbonate Plateau of southeast Minnesota and Crystal Creek Watershed. D) Quarry exposure of Prosser Formation in Crystal Creek Watershed showing a large bedding parallel solution conduit (hollow arrows) filled with pre-Pleistocene gravel. Selected solutionally-enlarged vertical joints noted with solid arrows. Person circled for scale. E) Close up view of quarry showing the gravel filled solution conduit and vertical joints. Hat circled for scale. Figure A modified from Mossler (1995) and Runkel et al. (2013). Figure B modified from Runkel et al. (2013) and Green et al. (2014). Figure D is from Runkel et al. (2013).*

Methods

Dye tracing was accomplished with the use of fluorescent dyes to determine groundwater flow directions and estimates of travel times. The dyes were flushed into sinkholes with either 3,786 liters (1,000 gallons) of water or utilizing snow melt running into sinkholes (Pictures 2 and 3). The dyes flowed through the karst bedrock system until they re-emerged at a spring, multiple springs or streams. Charcoal detectors are placed at various spring and stream locations to absorb the fluorescent dyes. If present, dye is removed from charcoal in NaOH eluent solution, which is then analyzed with a scanning spectroflurophotometer. Each dye is characterized by a unique emission wavelength. Sample analysis was completed by the University of Minnesota-Department of Earth Sciences Hydrochemistry Laboratory. Figure 3 shows the fluorescent spectrum results of a positive Uranine recovery from a charcoal detector in the spring run of Twin Springs from Nov. 15 to Nov. 19, 2010.

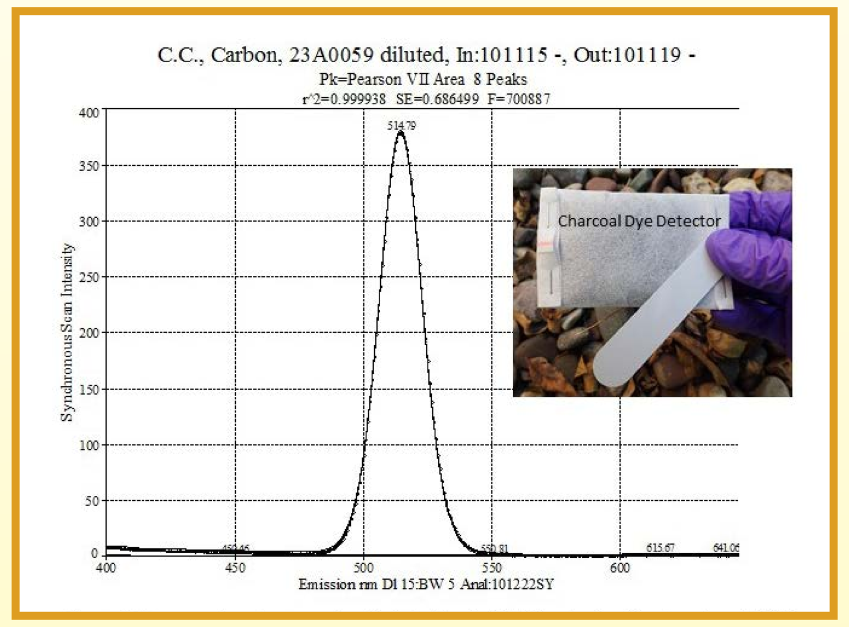

Figure 3. Fluorescent spectrum results at Twin Springs in 2010. The Uranine C peak centered at about 515 nm indicates a positive recovery because the peak is much higher than the quantification limit and no Uranine C was present in the background charcoal detectors.

Results and Discussion

Results from the dye traces are shown in Figure 4. From 2010 through 2016, a total of 14 dye traces were conducted in the CCW. In 10 of 14 traces, a positive connection was confirmed between the sinkhole dye input and a monitored spring or creek. These traces help approximate the boundaries for five springsheds: Starless River, Crystal Spring, Twin Springs, Trout Pond and Willow Pond. The size of the delineated springsheds ranges from 25 ha (62 ac) to over 2,833 ha (7,000 ac).

Groundwater Flow Velocities and Pathways - Groundwater flow velocities in the Galena group can be extremely rapid and conduit pathways can extend for several miles. Groundwater velocities for the Twin Springs springshed during a 2011 trace were at least 2.4 kilometers/day (1.5 miles/day). This velocity is consistent with the range of peak groundwater flow velocities (1.6-4.8 km/day, 1-3 miles/day) from previous traces conducted in the Spillville-Galena Karst (Green and others, 2014). The longest flow path in this set of traces was 8.0 km (5 miles), while the shortest was .64 km (0.4 miles).

Springshed Boundaries Cross Surface Watershed Divides - As expected, springshed boundaries were found to cross surface watershed divides. For example, about 49 ha (120 acres) of the springshed for Trout Pond spring is located outside of the CCW surface watershed boundary. Conversely, trace results for Willow Pond springshed document groundwater flowpaths originating in CCW that do not connect to CCW springs. This suggests that infiltration in this particular area (covering about 10 ha (25 ac)) may not be contributing to the nitrate loading in CCW as monitored at the Crystal Creek outlet. The far upstream southwest part of CCW may also serve as recharge areas for springs outside of CCW, but more traces are needed to confirm the springshed boundaries.

Implications- Springshed maps will help improve nitrate-nitrogen yield loss computations and computer models used to measure the effectiveness of nitrogen practices. It will also inform where nitrogen management surveys and BMPs should be concentrated. When discussing the importance of strategies to minimize nitrate-nitrogen losses from agricultural activities, the dye trace maps have proven to be effective in helping elevate nitrogen BMP discussions with area farmers and crop advisors. The information has been shared at numerous one to one meetings and watershed field days at local farms. Additional dye trace studies are planned in future years to further refine springshed boundaries and help improve the understanding of complex surface water-groundwater interactions in the CCW (Picture 4).

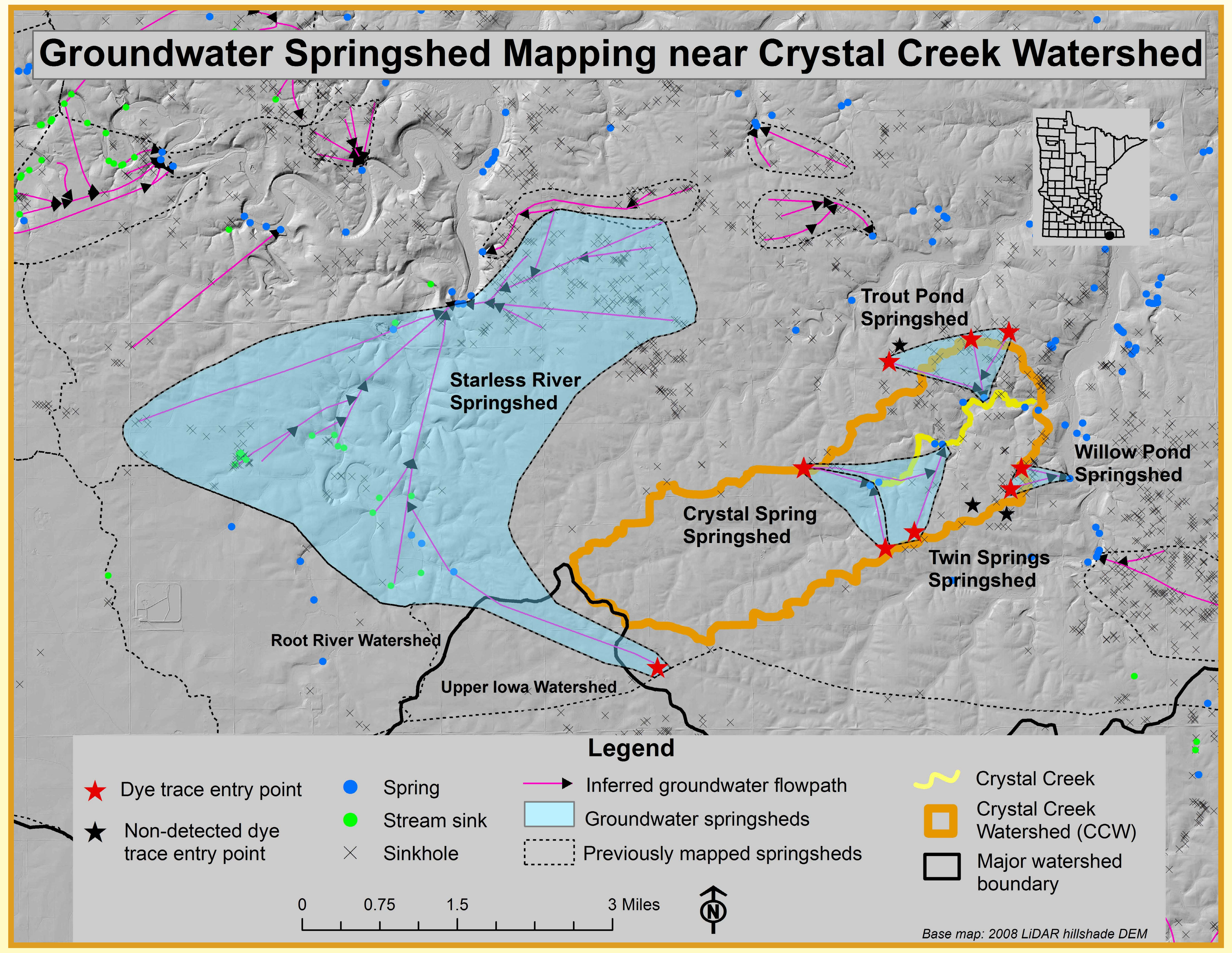

Figure 4. Inferred groundwater flowpaths and delineated springsheds. Pink lines show the underground flow direction of dye tracers from where they were added to sinkholes (red stars) to where they reappeared in a spring (blue symbol). Notice how the groundwater flowpaths cross surface watershed boundaries.

Acknowledgments and References

Acknowledgments

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