

**MEASUREMENT OF CONTAMINATED
GROUNDWATER DISCHARGE TO SURFACE
WATER AT SEVEN MILE CREEK, NICOLLET
COUNTY, MINNESOTA**

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Under the supervision of Professor James Welsh

ABSTRACT

Seven Mile Creek, a tributary of the Minnesota River, is located in Nicollet County, Minnesota. Its watershed is used primarily for agriculture suggesting possible contamination. Previous research at Seven Mile Creek has overlooked the interaction between groundwater and surface water. By finding discharge zones and sampling both groundwater and surface water at these sites, I was able to determine the impact that contaminated groundwater has on surface water. Concentrations of nitrate in groundwater at discharge zones were typically under 5 mg/l and chloride concentrations were under 25 mg/l, although surface water concentrations at these sites were typically higher. Groundwater does not enter the surface water with harmful concentrations of nitrate and chloride at most sites, suggesting that other factors such as runoff also contribute to surface water contamination.

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INTRODUCTION

Surface water contamination in southern Minnesota is potentially a severe problem (MPCA 2001; Lundy 2003). There is concern about levels of suspended sediments, excess nutrients (primarily nitrogen and phosphorus), pathogens, and biological oxygen demand in the waters of this region (MPCA 2001). Studies in this region have focused primarily on sources such as run-off and artificial drainage problems from agricultural practices. However, contaminated groundwater may contribute to excessive levels of pollutants in surface water.

Bedrock aquifers and surficial aquifers in southern Minnesota are susceptible to elevated levels of nitrate (MPCA 2001). The town of St. Peter mixes water taken from the Jordan aquifer with water from other aquifers to dilute the high nitrate levels found in the Jordan (MPCA 2001). Minnesota River tributaries such as Seven Mile Creek may be polluted due to contaminated groundwater from agricultural practices in the watershed. The purpose of this study is to understand the interactions between surface water and groundwater at Seven Mile Creek, and determine the contribution of contaminated groundwater in the pollution of the creek.

Geographic Location

Seven Mile Creek is located in Nicollet County, Minnesota, in the Minnesota River Valley, between the towns of Mankato and St. Peter, on the Mankato West 7.5-minute Quadrangle (figure 1). The creek, a tributary of the Minnesota River, is 6.1 miles long, dropping 210 feet before reaching the Minnesota (vertical gradient = 34.4 ft/mile). Its watershed is 23,551 acres, or 36.8 square miles (figure 2).

Seven Mile Creek is an optimal site for the proposed study, mainly because of the predominance of agricultural land use in the watershed (figure 3). Eighty-six percent of the surrounding watershed is farmed for corn and soybeans (Antinoro 2003). Because Seven Mile Creek is a designated trout stream, and its watershed contains a county park, high water quality is needed for recreational activities and biological diversity.

Geologic Setting

Bedrock geology at Seven Mile Creek consists of Cambrian sedimentary formations of sandstone, shale, and siltstone (Quade and Rongstad 1991; figure 4; figure 5). The lithology of individual bedrock units is nearly uniform throughout Nicollet County due to the continuous nature of the geologic processes that formed them (Quade and Rongstad 1991). The oldest rock exposed at Seven Mile Creek is part of the Jordan Formation. The Jordan Formation is Paleozoic in age, and consists of a medium to coarse-grained quartzose sandstone (Quade and Rongstad 1991). Jordan sandstone formed from deposition of sand on the floor and beaches of a warm shallow sea over 500 million years ago (Johnson 2004; Quade and Rongstad 1991). Layers and cross beds evident in the Jordan outcroppings in the park indicate tidal currents from the sea (Johnson 2004). Oneota dolomite, part of the Prairie Du Chen Formation typically overlies the Jordan in the Minnesota River Valley (Quade and Rongstad 1991). Oneota dolomite is not present at Seven Mile Creek due to erosion from rivers that cut through this region prior to the last Ice Age (Johnson 2004).

Overlying the bedrock are glacial deposits from the Pleistocene Epoch, which began about two million years ago, and ended 10,000 years ago (Johnson 2004; Matsch

1983). The Des Moines Lobe, the most recent glacier, moved through southern Minnesota and into Iowa 12,700 years ago (Matsch 1983). Retreating to the north, it left behind a rich loamy till, called New Ulm till (Matsch 1983; Johnson 2004).

The retreat of the Des Moines Lobe caused glacial Lake Agassiz to form near present day southeast North Dakota (Matsch 1983; Johnson 2004; figure 6). Glaciers blocked the usual drainage routes of the lake to the north, so Lake Agassiz drained to the south, in the form of glacial River Warren (Matsch 1983). River Warren moved massive amounts of sediment, carving the Minnesota River Valley (Matsch 1972). This sudden trenching of the valley caused the river's tributaries to form deep ravines (Johnson 2004). Seven Mile Creek is located in one of these ravines and has been cutting downward through the till and sandstone for the last 10,000 years (Johnson 2004).

Local Hydrogeology

The groundwater in Nicollet County exists in New Ulm till and the underlying bedrock. New Ulm till is an unconsolidated glacial drift, characterized by a matrix of sand, silt, and clay (Quade and Rongstad 1991). Large boulders, carried from Canada by glaciers, are mixed into the till with pebbles and cobbles (Quade and Rongstad 1991; Johnson 2004). The till ranges in thickness from 150 to 400 feet, except along the Minnesota River, where drift has been removed and the bedrock is exposed (Quade and Rongstad 1991). At Seven Mile Creek, the till is predominantly loam to clay loam soils (Antinoro 2003). The till generally yields little water over short time intervals, so recharge of bedrock and surficial aquifers is generally slow (Quade and Rongstad 1991; figure 7; figure 8).

The Jordan Formation is composed of highly permeable quartzose sandstone (Quade and Rongstad 1991). Groundwater flowing through the Jordan may improve stream water quality through natural attenuation (MPCA 2001). The Jordan sandstone is considered a single aquifer, because it is confined by the underlying, low-impermeable St. Lawrence Formation (Quade and Rongstad 1991; figure 8).

The rockiness of the streambed downstream (study site) indicates that the stream is flowing at a level very near or below the till-bedrock contact. Although there is some infiltrating groundwater from the till to the stream, the majority of the water probably originates from the Jordan (Lundy, personal contact). Farther upstream, the groundwater probably enters the stream from the till, as the creek is set higher in the landscape.

Surface Water – Groundwater Interactions

Typical groundwater evaluations have not considered the interactions with surface water because the area of the interface is generally small relative to the size of the groundwater system being studied (MPCA 2001). Remediation efforts in the past have been delayed or discredited because of a lack of understanding of these interactions. As we deplete our natural resources further with increasing land and water development, groundwater-surface water interactions are entering the scientific mainstream. It is crucial to understand this interaction, as groundwater and surface water are the two components of the hydrological system that humans use most (Winter 1998).

The relatively new scientific focus on these interactions is largely because of the effect they can have on the public. Residents of Long Lake, in Kalamazoo, Michigan, saw \$100,000 disappear in a useless attempt to pump water back into the lake during a

prolonged dry period (Rosenberry 2003; figure 9). The 2500 gal/min of groundwater that was being continuously pumped into Long Lake did nothing to raise lake levels, as the surface water immediately recharged the groundwater through the cone of depression left behind by the pumping (Rosenberry 2003).

Lake Belle Taine in Park Rapids, Minnesota experienced a wet period that caused high lake levels to swallow their docks and boathouses (figure 10; figure 11). The surface water could not send water to the groundwater fast enough during this wet period, because of an impermeable clay layer on the bottom of the lake (Rosenberry 2003).

Although it may be overlooked, groundwater discharge can make up a large percentage of total flow. A study completed by the United States Geologic Survey estimated the groundwater contribution of fifty-four streams in twenty-four regions of the United States, with at least two streams in each region (Winter 1998). Daily streamflow values measured over a thirty-year period (1961-1990) showed that groundwater discharge contributed to an average of 52% of streamflow for the 54 streams (Winter 1998).

When water quality studies evaluate the quality of surface water and provide reasons for its contamination, the focus is usually on other inputs (runoff, tributaries) rather than non-point sources like groundwater. However, 75% of superfund sites in the United States are within only a half-mile of surface water (Lundy 2003). If remediation efforts to improve surface water quality are too focused on point sources, they may be impeded due to the ongoing transport from contaminated groundwater.

Recently, numerous studies across the United States to determine the impacts that contaminated groundwater has on the quality of surface water have been carried out.

Government agencies such as the Minnesota Pollution Control Agency and the USGS, along with private companies, have completed case studies on contaminated groundwater discharge to surface water from the Florida Everglades to Minnesota (Lundy 2003; USGS 2004; CO Dept. of Public Health and Environment 2004).

Contaminants

This study focuses on two contaminants, chloride and nitrate. Polluted groundwater may hold a number of different contaminants, such as phosphorus, pathogens, and arsenic, but chloride and nitrate were used in this study because they are two of the most important pollutants in determining the role of groundwater in surface water contamination, as effective tracers and strong indicators of anthropogenic pollutants.

Chloride, commonly found in soil and rocks is a halogen occurring primarily from halite brines (MPCA 1999). Human activity may apply chloride to the surface through fertilizers, road salt, human and animal waste, and industrial applications. Chloride that exists in higher concentrations in shallow groundwater is a useful indicator of anthropogenic sources (MPCA 1999). The MPCA's statewide baseline study of contaminants found chloride concentrations in groundwater in Nicollet County to be generally less than 25 mg/l (MPCA 2001). Chloride was sampled in this investigation because it moves well with groundwater and is an excellent tracer of contaminant sources (MPCA 1999).

Nitrate is found naturally in groundwater at concentrations of less than 1 mg/l, but it is most commonly added to groundwater through the use of agricultural fertilizers

(MPCA 1998). Nutrients such as nitrogen are important to the survival of lake and river ecosystems, but because it is one of the limiting nutrients (and phosphorus), an excess of nitrate can have profound impacts. Increased levels of the nutrient can cause eutrophication, or excessive algal (phytoplankton) production.

High concentrations of nitrate in drinking water can result in serious illness or death. Nitrate is especially dangerous in infants, where the body converts nitrate to nitrite, which interferes with the oxygen carrying capacity of the bloodstream (MPCA 1998). Long-term exposure to nitrate can also result in hemorrhaging of the spleen (MPCA 1998). The drinking water standard for nitrate is 10mg/l (MPCA 1998). The MPCA's baseline study found Nicollet County to average groundwater nitrate concentrations of less than 5 mg/l (MPCA 2001).

METHODS

Before samples were collected, I determined general areas of strong groundwater discharge to surface water, by referring to the St. Peter wellhead protection model (figure 12). At discharge zones, groundwater has an upward vertical gradient, and is discharging to the surface water. At recharge zones, surface water is recharging the groundwater due to the downward vertical gradient. Near the sites estimated by the wellhead protection groundwater flow model, vertical gradient measurements between the surface water and groundwater were taken to determine the exact zones of discharge.

Vertical gradient contrast measurements were taken using a six-foot long steel probe with a 10-inch retractable screen and drive point (figure 13; figure 14; figure 15). With the probe in the sediment near the land-stream interface, the screen was exposed,



Figure 1: Seven Mile Creek is located in Nicollet County, Minnesota.

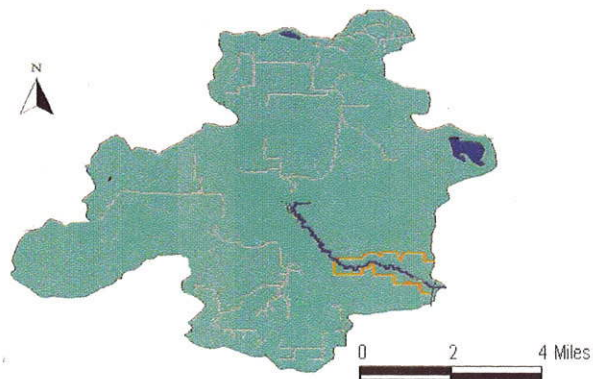
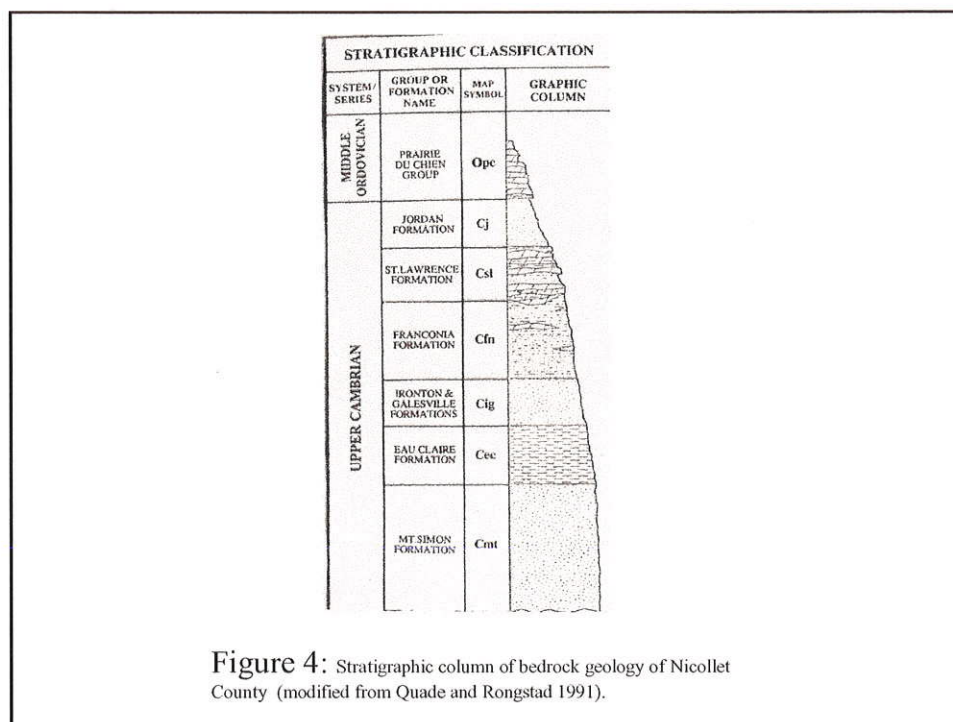
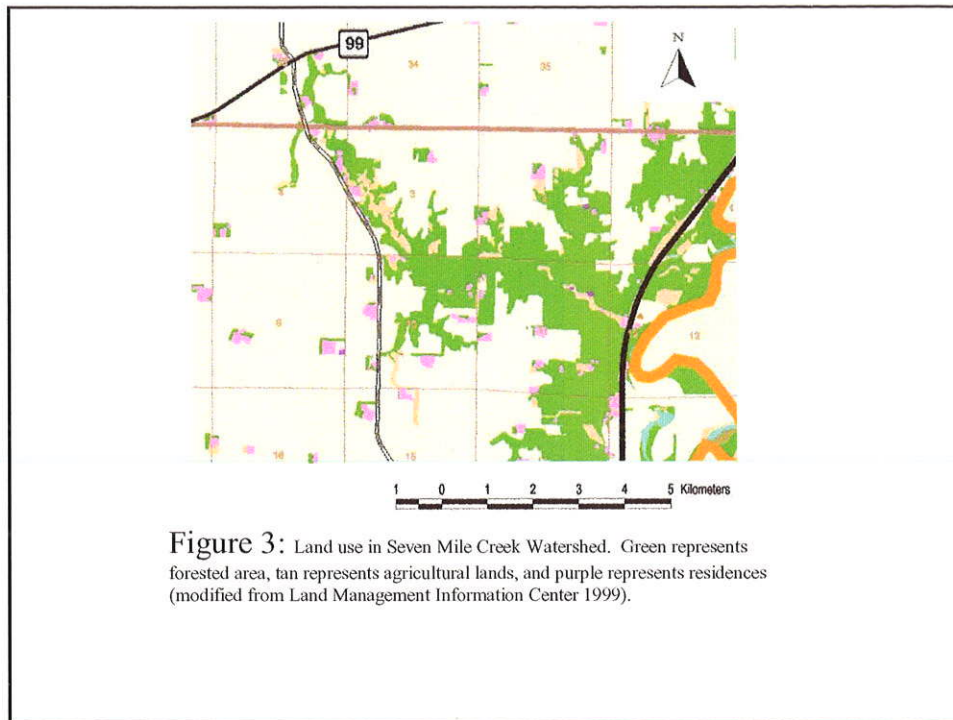


Figure 2: Seven Mile Creek Watershed. Orange line is park boundary (modified from Antinoro 2003).



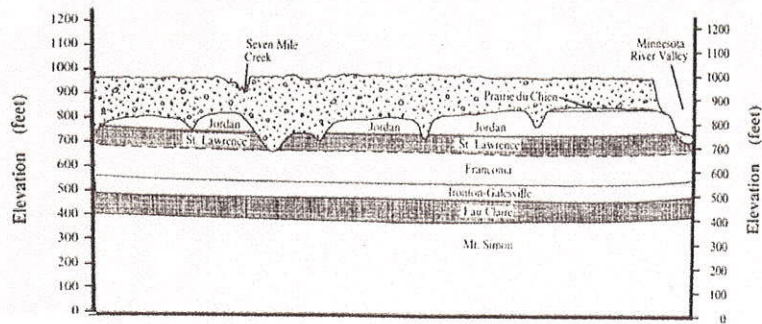


Figure 5: Cross-section across part of Nicollet County, crossing Seven Mile Creek upstream. Downstream, there are areas where the Jordan is present in outcroppings (modified from Quade and Rondstad 1991).



Figure 6: The retreat of the Des Moines Lobe caused Glacial Lake Agassiz to form. River Warren, the lake's only drainage route, carved the Minnesota River Valley over 10,000 years ago (taken from the Minnesota Historical Society 2001).

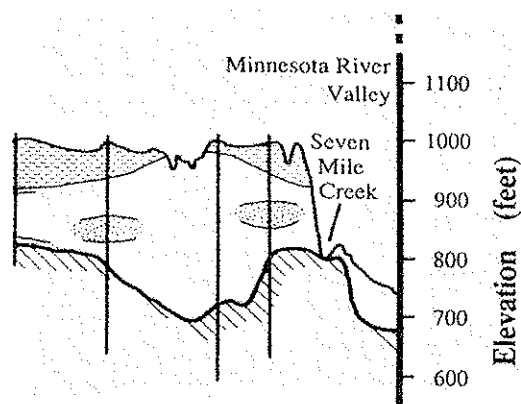


Figure 7: The uppermost drift zone of the till is composed of clay and silty clay. The lower zone is composed of clay, silt, sand, and gravel, containing lenses of permeable sand and gravel deposits. The glacial till generally yields little water over short time intervals, thus recharge is slow (modified from Quade and Rongstad 1991).

DESCRIPTION OF AQUIFERS		
AQUIFER SYSTEM	AQUIFER	AQUIFER CHARACTERISTICS
PRAIRIE DU CHIEN - JORDAN AQUIFERS	PRAIRIE DU CHIEN DOLOMITE	Limited to erosional remnants in southeastern part of the county.
	JORDAN SANDSTONE	Highly permeable quartzose sandstone; has direct hydrogeologic contact with surficial glacial deposits. Used primarily as a source for domestic wells that require moderate water supplies.
CONFINING LAYER	ST. LAWRENCE DOLOMITE & SILTSTONE	Rocks of low permeability; act as confining bed at the base of the Jordan sandstone.

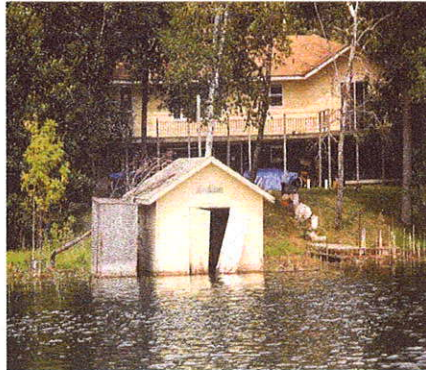
Figure 8: Highly permeable Jordan sandstone is considered a separate aquifer due to the underlying, low permeable St. Lawrence Formation (modified from Quade and Rongstad 1991).



Date Reported: 8/24/2000, walking in the former lakebed from the direction of Long Lake. He is standing approximately half way between the current shoreline and the former shoreline.

3-6-DD

Figure 9: An attempt to bring lake levels back up at Long Lake in Kalamazoo, Michigan, was unsuccessful due to immediate groundwater recharge from the surface water (taken from Rosenberry 2003).



Figures 10 & 11: A wet period caused lake levels at Lake Belle Taine in Park Rapids, Minnesota, to rise, as a low permeable clay layer on the bottom of lake contributed to slow groundwater recharge from surface water (taken from Rosenberry 2003).



Figure 12: Before field work was completed, zones of strong groundwater discharge were estimated using the St. Peter wellhead protection groundwater flow model (taken from Walsh 2003).

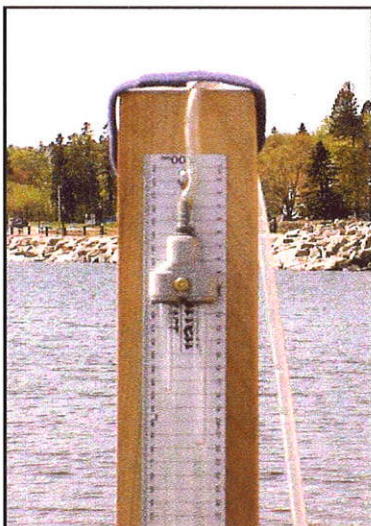


Figure 14: The drive point and 10 inch retractable screen at the end of a six foot long steel probe used for computing the vertical gradient (taken from Lundy 2003).

Figure 13: Zones of groundwater recharge and discharge were determined by computing the vertical gradient. Relative head differences between surface water and groundwater were determined using the tool pictured in figures 13, 14, and 15. Vertical gradient = relative head difference/depth of the exposed screen. Upward gradients (positive) are groundwater discharge zones, and downward gradients are recharge zones (taken from Lundy 2003).



Figure 15: Vertical gradient device. The six foot long steel probe is inserted into the sediment, where the 10-inch retractable screen (figure 14) is exposed. Applying the same vacuum, groundwater and surface water are pumped simultaneously into tubes attached to the measuring stick shown in figure 13. Relative head differences are computed by recording the difference of the water levels in the groundwater tube and the surface water tube. Vertical gradient = head difference/depth of the exposed screen (taken from Lundy 2003).

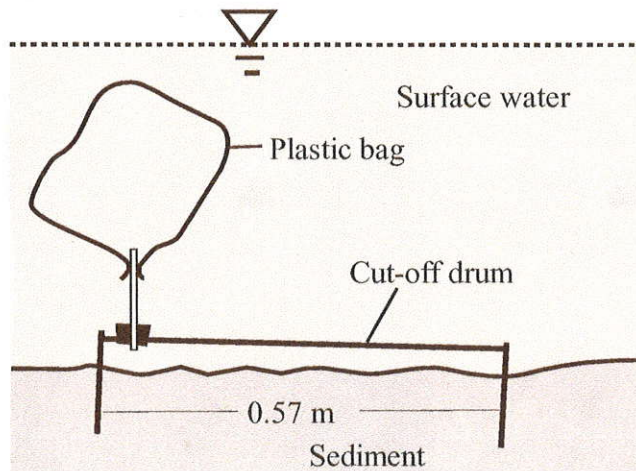


Figure 16: Basic design of seepage meters used in the field. The volume of water change in the collection bag divided by the time elapsed is the seepage rate. Positive seepage rates are groundwater discharge zones, and negative seepage rates are groundwater recharge zones (taken from Lee 1977).

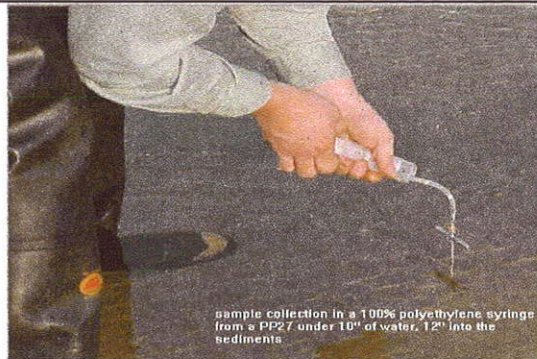


Figure 17: Groundwater samples were taken using narrow steel probes pushed into the sediment. A syringe was used to draw the water (taken from Lundy 2003).



Figure 18: Drive point of a push point probe. Quarter for scale (taken from Lundy 2003).

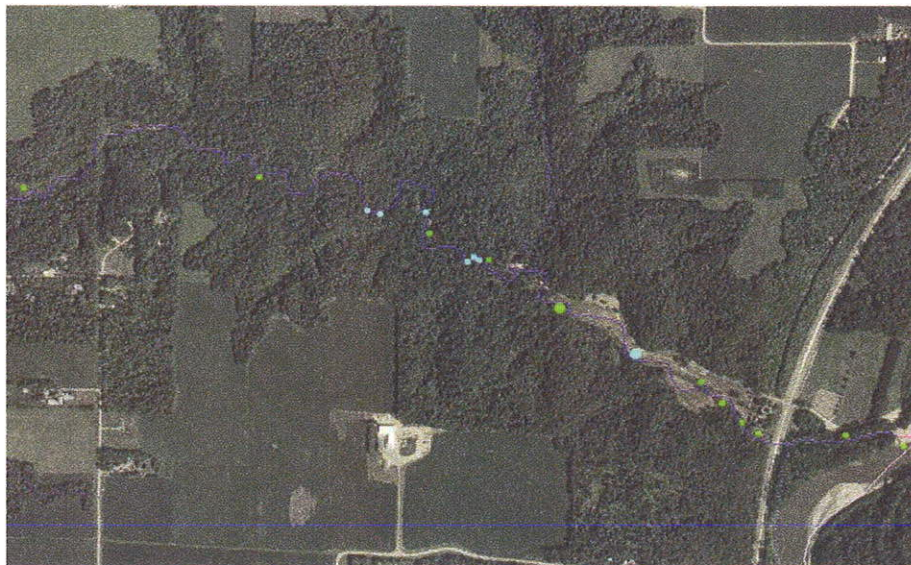


Figure 19: Sites where samples were taken of surface water and groundwater. Green dots represent samples taken at groundwater discharge zones, and light blue dots represent those taken at recharge zones. The two large dots represent locations where seepage measurements were taken.



Figure 20: Sites where relative head differences were measured in order to compute vertical gradients. Red dots represent upward gradients (groundwater discharge), and yellow dots represent downward gradients (recharge).

Concentration ranges	Pore Water	Pore Water	Surface Water	Surface Water
	Nitrate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Chloride (mg/l)
Upward Gradient	.0025 - 4.9	8.7 - 21.0	4.2 - 19.0	15.0 - 23.0
Mean	1.71	17.97	9.733	20
Downward Gradient	6.0 - 18.0	23.0 - 41.0	8.0 - 18.0	17.0 - 31.0
Mean	8.82	27.4	11.43	27.33

Table 1: Nitrate and chloride concentration ranges for surface water and groundwater at discharge and recharge zones.

Seepage Measurements						
Measurement/Calculation	units	BNC 3 (trial 1)	Trial 2	Trout pool (trial 1)	Trial 2	Trial 3
head difference	cm	-1.9	-1.9	0.3	0.3	0.3
depth	cm	28	28	21	21	21
hydraulic gradient	NA	-0.068	-0.068	0.014	0.014	0.014
beginning volume	mL	1300	1300	1290	1290	1310
ending volume	mL	70	130	1360	1520	1820
elapsed time	min	29	15	23	69	133
seepage rate	cm/day	-33	-61	2	3	3
Hydraulic conductivity (Kv)	cm/day	0.0057	0.0105	0.00194	0.00213	0.00245
Hydraulic gradient		Head difference/depth of measurement				
Seepage rate		Change in volume/ (time * area)				
Kv		Seepage rate/gradient				

Table 2: Seepage measurements taken from sites shown in figure 19. The trout pool was an upward gradient (discharge) site, while BNC 3 was a groundwater recharge zone.