Identification and characterization of springs in west-central Wisconsin. [DNR-184] [between 2006 and 2009]

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Identification and Characterization of Springs in West-Central Wisconsin

by

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Acknowledgements

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1. Abstract

The objectives of this investigation were to locate springs within St. Croix County, to measure the discharge rate of each of these springs, and to estimate the recharge area for springs with discharge rates greater than or equal to 1.0 cubic foot per second (cfs). Eighty-seven springs were identified during this investigation, and 12 of these springs had a discharge rate greater than 1.0 cfs. Springs were found in each of the sedimentary rock groups younger than Precambrian age, but the Cambrian sandstone units had the greatest number of springs per unit area. Springs discharging at apparent interfaces between Cambrian rock units were especially common. A large number of springs were also found in the dolomitic Prairie du Chien Group, but since this unit is the uppermost bedrock for a large percentage of the county, the spring density was not especially high. The Prairie du Chien Group was significant for producing several of the larger springs, including the four springs with the highest discharge rates (≥ 2.0 cfs).

Conceptual models of groundwater flow were created to provide information about potential flowpaths to the springs located during this study. To accurately characterize groundwater flowpaths, methods such as dye tracing and monitoring networks of piezometers are necessary; these methods were beyond the scope of this investigation. Instead, analyses of water chemistry data and geological information were used to infer likely groundwater flow mechanisms. For the springs in St. Croix County, the literature review and some chemical data suggested that flow through fractures or dissolution channels was probable. However, other chemical analyses, especially age dating of the spring discharge, showed that a significant portion of the water discharging from springs probably flowed as percolation through porous media. Groundwater residence times ranged from 22 to 35 years, showing that at least part of the spring recharge flowed through porous media or along deeper flowpaths within bedrock units. Residence time estimates probably reflect a mixture of water discharging from deeper flowpaths (older water) and water flowing through unconsolidated sediments (younger water), so wells extracting groundwater from either bedrock or soil units are likely to affect spring discharge.

For each spring with a discharge rate greater than 1.0 cfs, an estimated recharge area was defined. The estimated recharge area was based upon an iterative process of infiltration modeling and flow path prediction using maps of groundwater elevation. Each recharge area defined using this method represents only the area needed for groundwater infiltration/recharge to approximately equal spring discharge. Most likely, some groundwater flows to the spring from an area outside the delineated recharge zone, but a more definitive recharge model could not be generated with the data currently available. Readers are encouraged to remember that the recharge areas shown in this report should be viewed as minimum areas needed to protect springs from groundwater withdrawal, and groundwater extraction outside the recharge area boundaries may still adversely affect springs.

2. Introduction

2.1 Purpose and Scope

Identification and characterization of springs are important for effective water management in many drainage basins. Springs may provide significant recharge to streams or lakes, sustain protected wetland or aquatic ecosystems, or serve as sources of public water supply. In some areas, recent population growth or economic development may pose a threat to springs. When local demands for water increase, additional water is often provided by extracting groundwater through high capacity wells. If a high capacity well is located within the recharge area of a spring, the discharge rate of the spring can be significantly reduced, sometimes resulting in surface water degradation. In recognition of this risk, the 2003 Wisconsin Act 310 (Groundwater Protection Act) directs the Wisconsin Department of Natural Resources (DNR) to review applications for high capacity wells and to assess the environmental impacts of these wells on springs with a discharge rate of 1 cubic foot per second (cfs) or more. Accurate assessment of the environmental impact of wells on springs is currently limited by insufficient information on the location and recharge area of many springs. The scarcity of information on springs is especially significant in areas with rapidly growing populations, such as St. Croix County. St. Croix County is located approximately 30 miles east of downtown Minneapolis-St. Paul along the St. Croix River in west-central Wisconsin (Figure 1), and the population in St. Croix County grew by 70% since 1970 and 12.7% between 2000 and 2003 (U.S. Census Bureau). State and county officials predict an additional 55% increase in population by the year 2020 (Kostka *et al.*, 2004). This rapid population growth has increased the demand for groundwater extraction in the area, and current hydrogeological information is needed to protect local groundwater resources such as springs.

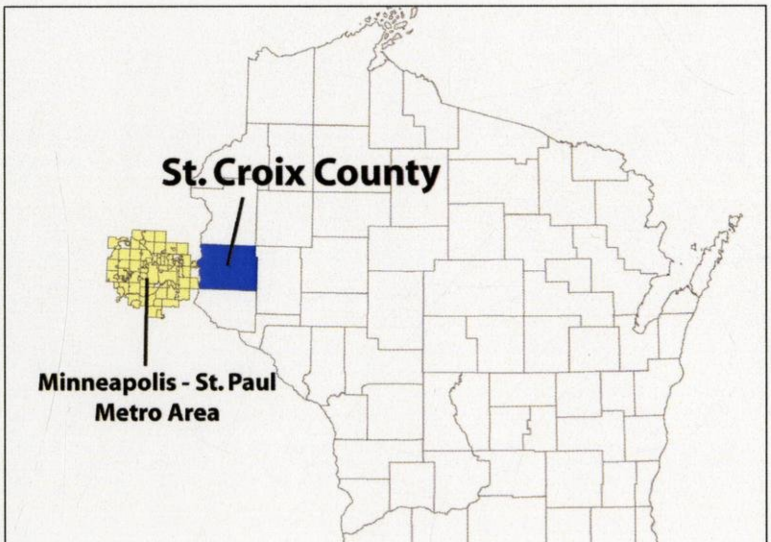

Figure 1: Location of St. Croix County, Wisconsin.

The main objectives of this investigation were to identify the locations of springs within St. Croix County, measure the discharge rates of these springs, and estimate the recharge area of the springs with a discharge of 1.0 cfs or greater. To accomplish these objectives, a field campaign to locate springs in St. Croix County was planned and implemented. For each spring located during this campaign, the discharge rate and basic water quality parameters were measured. For springs with high discharge rates, chemical data were acquired and recharge areas were estimated. The results of this investigation will provide DNR personnel and St. Croix County planning officials with a more complete understanding of the groundwater resources in this area and will aid in assessing the environmental impacts of groundwater withdrawal. This investigation also generated data that can be used as input into groundwater models for west-central Wisconsin, thereby facilitating predictive assessment of the impacts of high capacity wells on spring discharge and providing insight into spring recharge mechanisms.

2.2 Hydrogeologic setting

2.2.1. Geology

Groundwater flow in St. Croix County occurs primarily through unconsolidated surficial material and through Lower Paleozoic sedimentary rocks. Underlying these materials are low-permeability Precambrian crystalline and sedimentary rocks. The Precambrian units generally serve as aquitards and were not considered to serve as conduits for spring flow in this investigation, so the following summary focuses only on the younger geologic materials.

Overlying the Precambrian rocks are several Cambrian sandstone units (Figure 2). These units appear to have similar lithologic and hydrogeologic characteristics, being composed primarily of light grey, fine- to medium-grained or fine- to coarse-grained sand (Borman, 1976). Three of the Cambrian sandstone units were identified as the uppermost bedrock layer for springs located in this study. The oldest of these units is the Eau Claire Fm., which is a dolomitic sandstone with some shale and siltstone layers. The second unit is the Tunnel City Group, composed of sandstone and dolomitic sandstone, with some siltstone layers. The youngest unit is the Trempealeau Group, which has both sandstone and dolomite members with interbedded siltstone. The Cambrian sandstone units are the uppermost bedrock in approximately 20% of the county, mostly in the western portion of the county where faulting has uplifted these rocks and eroded away overlying sediments (Figure 3). These sandstones are continuous at greater depths over much of the county (excluding the northwestern corner) and are important aquifers for municipal water supplies.

Ordovician-age sedimentary rocks overlie the Cambrian sandstones. The most prevalent Ordovician rock in St. Croix County is the Prairie du Chien Group, which is the uppermost bedrock unit in about 50% of the county (Figure 3) and is composed of dolomite, with layers of sandstone and sandy dolomite. Karst features within the Prairie du Chien are well developed; caves, sinking streams, and sinkholes are common, and groundwater often flows through dissolution channels (Zhang and Kanivetsky, 1996; Kosta *et al.*, 2004; Cobb *et al.*, 2005). Since the Prairie du Chien covers a large portion of the county and is saturated over much of this area, this unit commonly serves as a water source for residential wells. The younger Ordovician unit, the Ancell Group, overlies the Prairie du Chien and is the uppermost bedrock unit for about 20% of the county. The Ancell Group is primarily composed of sandstone with an overlying shale unit. Both the Prairie du Chien and Ancell Groups dip westward and tend to thin to the northeast (Juckem *et al.*, 2005). Faults, mostly unmapped, are present in both the Ordovician and Cambrian bedrock and may strongly influence groundwater flow patterns.

System	Group	Formation	Principal Lithology
Lower Ordovician	Ancell	Glenwood	shale
		St. Peter	sandstone
	Prairie du Chien	Shakopee	dolomite & sandstone
		Oneota	dolomite
Cambrian	Trempealeau	Jordan	sandstone
		St. Lawrence	dolomite
	Tunnel City	Mazo-manie / Lone Rock	sandstone
	Elk Mound	Wonewoc	sandstone
		Eau Claire	shale & sandstone
		Mt. Simon	sandstone

Figure 2: Stratigraphic column of bedrock units in St. Croix County.

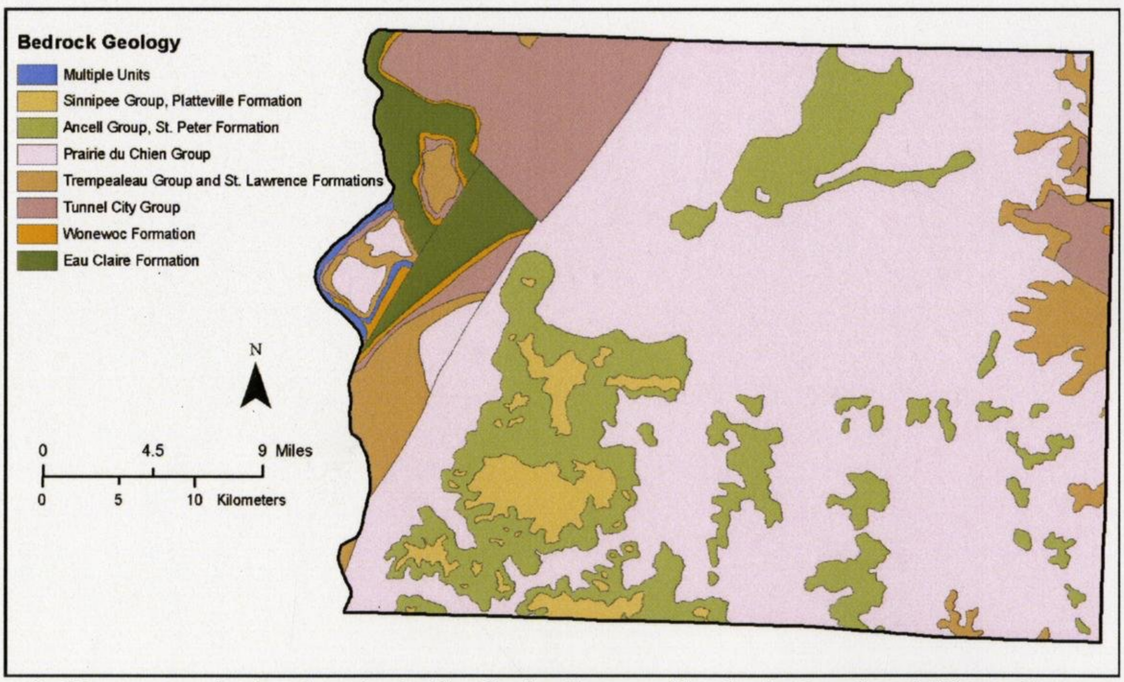

Figure 3: Uppermost bedrock units in St. Croix County (St. Croix Land and Water Conservation Dept., 2005).

The unconsolidated deposits overlying most of St. Croix County are predominantly of glacial origin, although alluvial sediments can be locally significant (Borman, 1976). Much of the eastern portion of the county is covered by ground moraine deposits ranging in grain size from clay to boulders and is characterized by a gently rolling plain. In the northwestern quarter of the county, end moraine deposits of unsorted sediment, again ranging in size from clay to boulders, are common; the topography in this area is rolling to hummocky, with many kettles and marshy areas. In the southwestern corner of the county, the soil is composed of outwash plain deposits consisting of stratified gravel, sand, silt, and clay. Kettles are also common in this area. The glacial and alluvial sand and gravel deposits are locally significant aquifers in about 25% of the county. The thickness of the unconsolidated deposits ranges from zero at bedrock outcrops (mostly on hillsides, along river valleys, or at roadcuts) to more than 450 ft (137 m) in sediment-filled bedrock valleys or along high end moraines (Borman, 1976). Most commonly, unconsolidated material ranges in thickness from 5 to 150 ft, (2 to 46 m) with deeper deposits in the western portion of the county.

Please note that the geology of St. Croix County is described in greater detail in several previous reports (Young and Hindal, 1973; Borman, 1976; Juckem *et al.*, 2005). The purpose of this description is to give a broad overview of the geology as it relates to groundwater flow and spring discharge; a detailed geologic description is beyond the scope of this report.

2.2.2. Groundwater Flow

Groundwater flow occurs primarily through the unconsolidated material and the underlying dolomite or sandstone bedrock units. Groundwater recharge is estimated as between 1 to 12 in (3 and 30 cm) per year and is derived from infiltrating precipitation (Borman, 1976). The depth to groundwater is greatest (more than 75 ft or 23 m) in areas of thick glacial deposits in the western part of the county and in some eastern areas underlain by the Prairie du Chien Group (Figure 4). The upper surface of saturation occurs in the unconsolidated sediment for about half the county, especially in the western portions of the county where glacial sediments are thickest. Groundwater flow directions generally mimic local surface topography, with a regional flow pattern trending towards the west. A map of the elevation of the groundwater surface is shown in Figure 5.

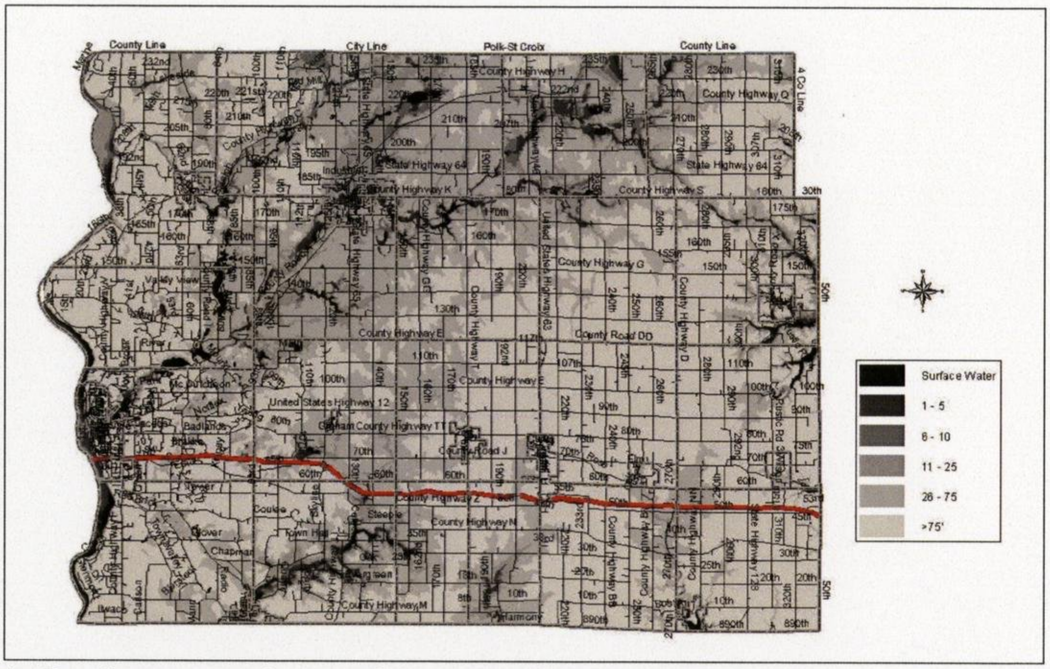

Figure 4: Depth to groundwater (ft) across St. Croix County (St. Croix Land and Water Conservation Dept., 2005). The depth to groundwater is greatest in areas of thick glacial deposits and in some areas where thinner unconsolidated deposits are underlain by the Prairie du Chien bedrock.

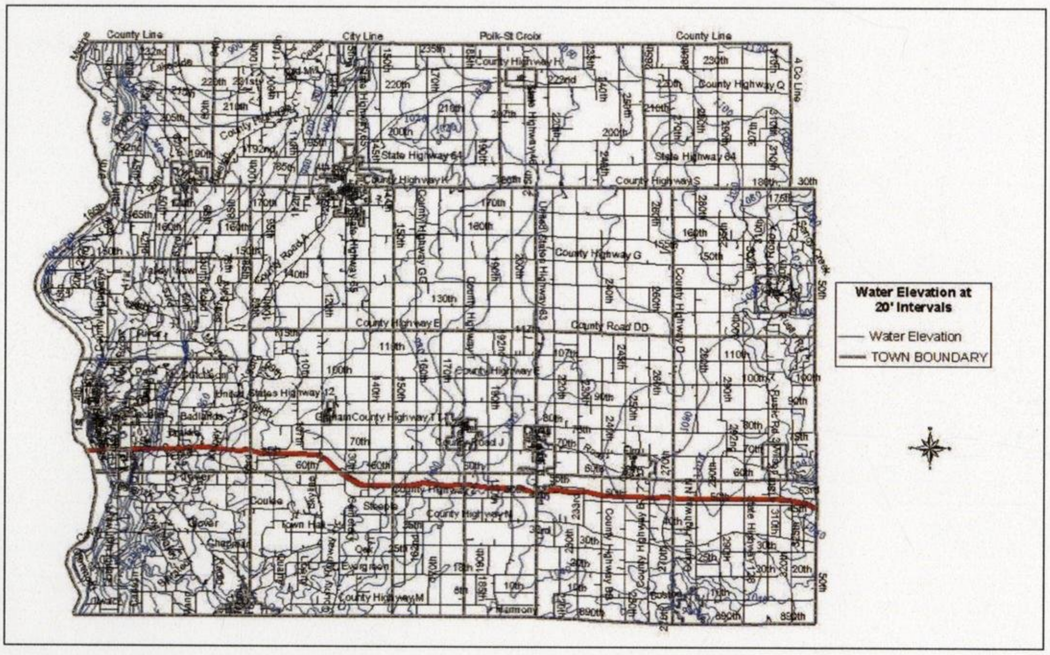

Figure 5: Elevation of the groundwater surface (ft above mean sea level) in St. Croix County (St. Croix Land and Water Conservation Dept., 2005). Flow directions vary locally, but the regional flow direction is to the west.

3. Methodology

3.1. Field methods and data collection

3.1.1 Determining spring locations

This investigation began with a field campaign to locate springs within St. Croix County. The original field plan utilized hydrogeological information such as maps of bedrock type, the potentiometric surface, soil thickness, etc. to identify the areas most likely to produce springs; these areas would then be investigated during the field campaign. After constructing a preliminary field plan, it became obvious that the areas likely to produce springs were too extensive to be investigated during the time available, so an alternative field plan that focused on locating specific springs within smaller areas was created. To create the alternative plan, the approximate locations of individual springs were determined by reviewing the published literature and by consulting with individuals knowledgeable of the area. The literature review included topographic maps, hydrogeological reports of the county, the county Plat book, and published maps such as the Wisconsin Gazetteer. In general, these sources contained little information on springs, and fewer than six possible spring locations were identified using these sources. The most useful document in the literature review was a report entitled *Spring Survey Analysis St. Croix County West Central Area* (WGNHS, 1960), which identified the approximate discharge rate and location of 38 springs to the nearest ¼ section. Of the 38 springs identified in this report, only 19 springs were flowing when the report was published, and our investigation attempted to locate only these active springs, beginning with the springs with the greatest discharge rates. Although the literature review was useful, consultations with individuals provided a much larger number of possible spring locations to investigate. Interviews with individuals at the St. Croix County DNR, the St. Croix Land and Water Conservation Office, and individual landowners provided approximate locations for many springs or suspected springs, allowing creation of a more implementable field plan.

3.1.2. Data Collection

For each spring located during the field campaign, a routine set of measurements were acquired. These measurements included pH, temperature, and electrical conductivity, which were obtained using standard field sampling equipment. Discharge was also measured for each spring. For larger springs, discharge was determined using a current meter and measurements of the spring's channel geometry. For smaller springs, the discharge was often too low to accurately measure the velocity using a current meter, so velocity was determined by measuring the time needed for a floating object to travel a known length of the channel. Some springs discharged into the bottom of larger streams; these springs were identified by active sand boils and low temperatures within a stream, but no accurate discharge measurements could be acquired. In addition to the previously listed measurements, the UTM coordinates, land use, and a brief description of the spring or directions to the spring were recorded. Digital photographs were also obtained for most springs. The measurements and description for each spring are given in Appendix II.

For the larger springs (those with discharge greater than ~0.3 cfs), selected chemical attributes of the discharge were analyzed. Samples were collected to measure the concentration of major ions (calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride) as well as nitrate, silica, arsenic, copper, iron, manganese, lead, phosphorous, and zinc. Samples were preserved using sulfuric and nitric acids and were processed at the Water and Environmental Analysis Lab at University of Wisconsin-Steven's Point. Chemical summaries for these samples are given in Appendix II.

For many of the largest springs (those with discharge greater than 0.5 cfs), the groundwater residence time (time since infiltration) was estimated using chlorofluorocarbon (CFC) age-dating techniques. Samples were collected in triplicate using the procedure recommended by the USGS (USGS, 2005) and were processed at the Tritium Laboratory at the University of Miami. Residence time estimates were made based upon CFC11, CFC12, and CFC113 concentrations.

3.2. Developing conceptual models for spring recharge

Understanding groundwater flow through the subsurface is necessary to ensure adequate protection of spring recharge areas. Unfortunately, determining the mechanisms and pathways of groundwater flow is difficult without using methods such as tracer tests or installing networks of wells to monitor the potentiometric surface. In this investigation, general conceptual models of groundwater flow for a large number of springs were developed using the data acquired as described above. The reader is encouraged to remember that the conceptual models described in Section 4.2 are based only upon the data acquired in this investigation and so do not include detailed information about the flow paths for each spring.

The first step in developing a conceptual model was to review the geological information available for each spring location. For each spring, the uppermost bedrock unit was identified, and the approximate soil thickness and depth to the water table were estimated. The bedrock unit was used to infer likely flow mechanisms; a spring discharging from a sandstone aquifer is more likely to be flowing through fractures or along the contact between units of different grain size, while a spring issuing from a dolomite layer is more likely to be flowing through dissolution channels. Springs located directly on a lithologic interface may be contact springs, flowing along an underlying lower-permeability rock unit. Springs discharging onto relatively flat topography with thick soil deposits might be depression springs, where groundwater flow occurs primarily as percolation through porous media. Most springs identified in this investigation occurred in areas where the groundwater surface was relatively shallow (less than 3 m or 10 ft), but some springs were found in areas where the estimated depth to groundwater was considerably greater, indicating that groundwater might be channelized in fractures or dissolution cavities as it flows towards the surface.

Chemical data were also analyzed to aid in the construction of conceptual models of groundwater flow by indicating the type of geologic material serving as an aquifer for each spring and to infer what type of groundwater flow (porous media or conduit flow) occurred. Data for springs discharging from different rock units were compared to determine if a characteristic chemical signature could be defined for groundwater discharging from a specific unit or whether there was a directional component to variations in groundwater chemistry across the county. Chemical data for each spring were also compared to the range values found by other researchers for different rock and sediment types (Lee and Fetter, 1994). This analysis was helpful if the uppermost rock unit consisted of multiple rock types (i.e. dolomite and sandstone) and the chemical signature could be used to indicate which rock type probably transmitted the majority of the spring discharge. Finally, Ca/Mg ratios were used to determine if flow through carbonate rocks was primarily through dolomite or limestone, and the calcite saturation index was calculated for each sample to determine whether the groundwater was in chemical equilibrium with the surrounding rock units. Groundwater that was not in chemical equilibrium was probably moving rapidly through the subsurface, perhaps via conduit flow.

For the largest springs, residence time data were used to determine the approximate age of the groundwater. If the water were very young, groundwater flow probably occurred at fairly high velocities through karst channels or fractures. Older groundwater ages imply flow through porous media or long periods of time in fractures or conduits. Since mixing of older and younger groundwater is probable, resulting in an intermediate residence time estimate, the measured groundwater ages cannot be considered definitive for all discharge from a spring, but residence time estimates can be used in conjunction with water chemistry and geologic data to infer information about groundwater flow mechanisms.

3.3 Estimating spring recharge areas

The spring recharge area is defined for this investigation as the area over which precipitation infiltrates into the ground, later to be discharged from the spring. One method of determining the extent of the spring recharge area is to divide the discharge rate (volume/time) by the infiltration or recharge rate (length/time). The accuracy of the resulting recharge area estimate is dependent upon the accuracy of the recharge rate, which can be difficult to determine over large areas. In this investigation, the Water Erosion Prediction Project (WEPP) model of soil infiltration and erosion (Flanagan and Nearing, 1995) was used to calculate the groundwater recharge rate after accounting for evapotranspiration and surface runoff. Input parameters for the WEPP model include the soil grain size distribution at different depths, soil permeability, topographic slope, vegetative cover, land use, and climate. Since the parameters affecting the recharge rate vary spatially, and since the estimated recharge area is partially a function of the recharge rate, calculating the recharge area was an iterative process. First, a likely recharge area was identified using a map of groundwater elevation (Figure 5) to determine groundwater flow directions in the vicinity of the spring and using an assumed infiltration rate to estimate the extent of the recharge area. Then, soil survey maps and tables (Langton, 1978) were used to identify the different soil types within the estimated recharge area and to obtain values for the soil characteristics used as input to the WEPP model. An example of an estimated recharge area superimposed on a soils map is shown in Figure 6. For each soil type within the estimated recharge area, the area covered by that soil was determined, and the WEPP model was run to determine the average groundwater recharge rate into that soil. Then, the recharge rate was multiplied by the area of that soil type to find total recharge into that soil. When the WEPP model had been used to calculate total recharge for each soil type within the estimated recharge area, the volume of recharge that infiltrated into all the soils was calculated and compared to the spring discharge. If the estimated recharge was not within 20% of the measured discharge, the estimated recharge area was modified to produce an area that seemed more likely provide a recharge similar to the measured discharge. Then, the WEPP modeling process was repeated using the soils in the revised recharge area. Thus, the delineation of recharge areas was an iterative process based upon groundwater elevation maps and infiltration modeling. Recharge areas were estimated for the springs with discharge greater than 1.0 cfs and for closely-spaced groups of springs whose combined discharge was greater than 1.0 cfs. When springs were closely spaced, the discharge was summed for all springs in a small area, and a single recharge area was estimated based upon the sum of the discharges for these springs.

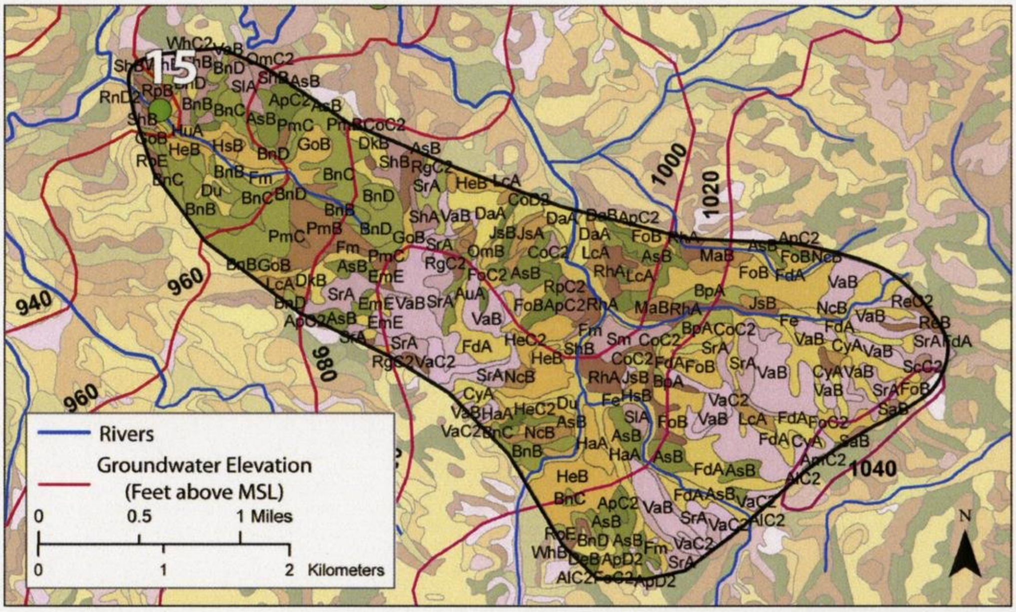

Figure 6: Estimated recharge area overlain on a soils map. The recharge for each soil type within the estimated recharge area was calculated using the WEPP model.

Groundwater residence time measurements obtained from CFC concentrations were used to ensure that the recharge areas estimated using WEPP were sufficiently large to contain the likely travel path of the water sampled for CFC concentrations. First, the average groundwater velocity (v) was calculated along the central flow path of the recharge area. To estimate the velocity, typical values for the hydraulic conductivity (K) and porosity (n) for the geologic unit in the spring recharge area were determined (Driscoll, 1986), and the groundwater gradient (dh/dx) was calculated from a map of the groundwater elevation. The velocity was then calculated as:

$$v = \frac{K}{n}\frac{dh}{dx}.$$

To estimate the length of the travel path from the infiltration point to the discharging spring, the average groundwater velocity was multiplied by the residence time. Since the water sampled in the residence time analysis may have infiltrated anywhere within the recharge area, the travel path estimated with this method should be considered as a minimum distance from the spring to the outer extent of the recharge boundary. The recharge area estimated using WEPP was inspected to ensure that some of the travel paths within the recharge area were longer than that estimated using the residence time analysis.

Estimation of the recharge area using the procedure described above will provide only the minimum area necessary to account for the spring discharge. First, the procedure assumes that all of the groundwater recharge within the estimated recharge area discharges through the spring. More probably, only part of the recharge that infiltrates in this area would flow to the spring, and the remainder would continue as groundwater flow or be discharged as a dilute source to surface water. Secondly, the procedure to estimate a flow path from residence time data uses typical (not measured) values of hydraulic conductivity and porosity and assumes porous media flow. If the aquifer contains high permeability zones or conduit flow, groundwater could be transported quickly from distances outside the estimated recharge area. Although the current hydrogeological data do not specify the locations of high permeability zones in this area, these zones are common in other formations of similar lithology. Finally, the map of groundwater elevations across the county lacked the detail necessary to determine flow paths everywhere in the recharge area. Thus, some error exists in the delineation of the recharge boundaries, and a more detailed map of groundwater elevations may change the boundary locations somewhat. These factors should be considered when reviewing the estimated recharge areas, and regulators should be aware that groundwater withdrawal outside the estimated recharge areas may still impact springs.

4. Results

Eighty-seven springs were found during this investigation. The location of each spring is shown on the map in Appendix I. Analysis of the data acquired at these springs began with a comparison of the measured parameters for springs discharging from each bedrock unit, where the bedrock unit is defined as the uppermost bedrock layer at the location of the spring. These comparisons, described in Section 4.1, provided information to aid in the development of conceptual models. The resulting conceptual models are discussed in Section 4.2. In Section 4.3, the estimated recharge areas derived from infiltration modeling and groundwater elevation maps are presented. Finally, a short analysis was performed to investigate correlations between groundwater parameters; the objective of this analysis was to determine if commonly measured water parameters could be used to indicate less easily determined parameters. These correlations are discussed in Section 4.4.

4.1. Comparison of spring parameters for different bedrock units

Several parameters were compared for springs discharging from different bedrock units. First, the "spring density" and discharge rates were examined with respect to bedrock unit (Section 4.1.1). Next, properties of the spring water such as residence time (Section 4.1.2) and temperature, pH, and electrical conductivity (Section 4.1.3) were investigated. Lastly, the chemical signatures for different springs were compared in Section 4.1.4.

4.1.1. Discharge

Eighty-seven springs were located during this investigation. Many of the springs (55%) were quite small, with a discharge rate of less than 0.1 cfs (Table 1). About one-fifth (22%) of the springs had intermediate discharge rates, between 0.1 cfs and 0.5 cfs. A similar number of springs (23%) were considered large (discharge greater than 0.5 cfs), but only 14% of springs exceeded the 1.0 cfs discharge rate currently required for legislative protection.

Formation	# of springs	# of springs with discharge <0.1 cfs	# of springs with discharge ≥0.1 cfs and <0.5 cfs	# of springs with discharge ≥0.5 cfs and <1.0 cfs	# of springs with discharge ≥1.0 cfs
St. Peter Formation	5	3	1	0	1
Prairie du Chien Group	26	15	4	2	5
Trempealeau Group	9	4	4	0	1
Tunnel City Group	12	4	3	3	2
Eau Claire Formation	17	7	5	3	2
Cambrian sandstone interfaces	18	15	2	0	1
Totals	**87**	**48**	**19**	**8**	**12**

Table 1: Number and discharge rate of springs found within each geologic unit.

In general, there was not an obvious correlation between the rate of spring discharge and bedrock geology for most units in St. Croix County, as seen in Table 1 and Figure 7. Most bedrock units had several small and a few intermediate or large springs. The most significant correlation between discharge rate and bedrock type was that the four largest springs (discharge rates between 2.0 and 3.5 cfs) occurred in the Prairie du Chien Group; springs in the other geologic units seldom exceed a discharge rate of 1.5 cfs. The notable exception to this observation occurred in the Tunnel City Group, where four closely-spaced springs had a combined discharge of 2.8 cfs, although the largest single discharge rate from any of these springs was 1.0 cfs.

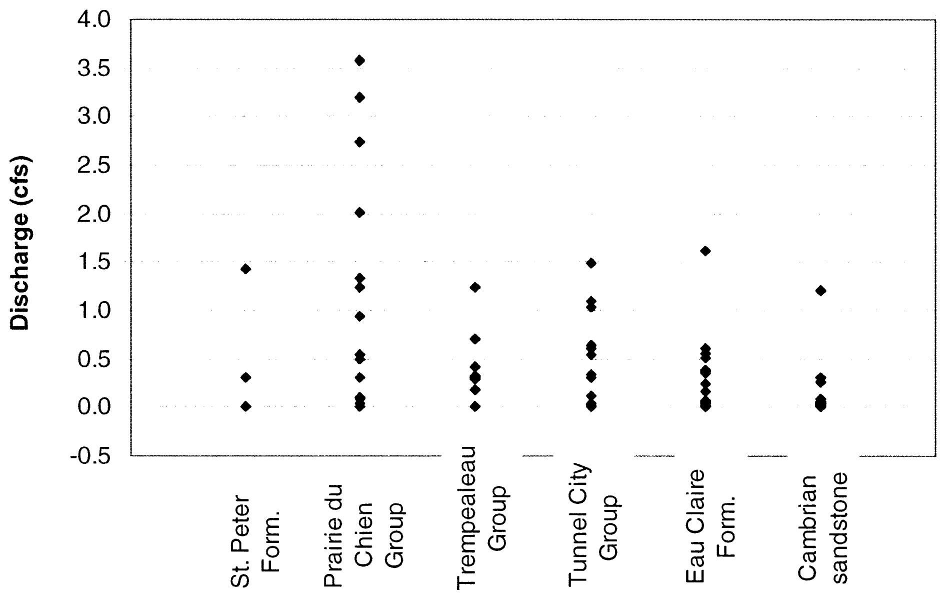

Figure 7: Discharge rates of springs for each geologic unit. The "Cambrian sandstone" classification refers to springs that appear to discharge at an interface between two Cambrian sandstone units.

A comparison of the number of springs in each bedrock unit to the area covered by that unit suggests that spring density is partially controlled by bedrock type (Figure 8). The greatest number (64%) of springs was found within Cambrian sandstone units (Trempealeau Group, Tunnel City Group, and Eau Claire Fm.) or between interfaces of these units. Cambrian sandstones are the uppermost bedrock unit for about 20% of the county's area, so the relative spring density in these rocks is quite high. Many springs (30% of total) were found within the Prairie du Chien Group, but this unit is the uppermost bedrock in approximately 50% of the county, so the spring density is not especially high. The Ordovician sandstone (St. Peter Fm.), which covers approximately 20% of the county, has a relatively low spring density (only 6% of were springs found in this unit), but several of the springs within the Prairie du Chien occurred near the interface between the Prairie du Chien and St. Peter units. These spring densities show that while springs may occur in any unit, bedrock type and interfaces between bedrock units might be used indicate areas where groundwater withdrawal is most likely to affect springs.

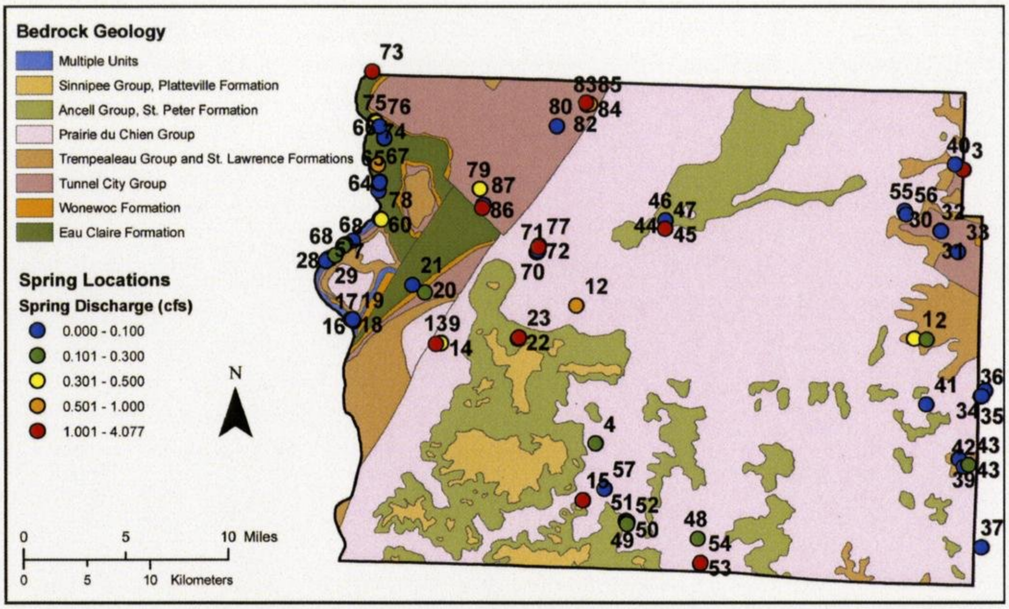

Figure 8: Spring locations and discharges overlain on a geologic map.

4.1.2. Groundwater residence time

The average residence time for all springs, irrespective of geologic unit, was 26 years, with a minimum of 22 years and a maximum of 35 years. The average residence time for the six springs discharging within the Prairie du Chien was 27 years, while the three springs discharging from the Eau Claire Fm. had an average residence time of 23 years (Figure 9). These residence times suggest that the groundwater recharging these springs must flow at least partially through porous media; flow entirely through well-developed karstic deposits or through large-aperture fractures would be expected to have a smaller residence time.

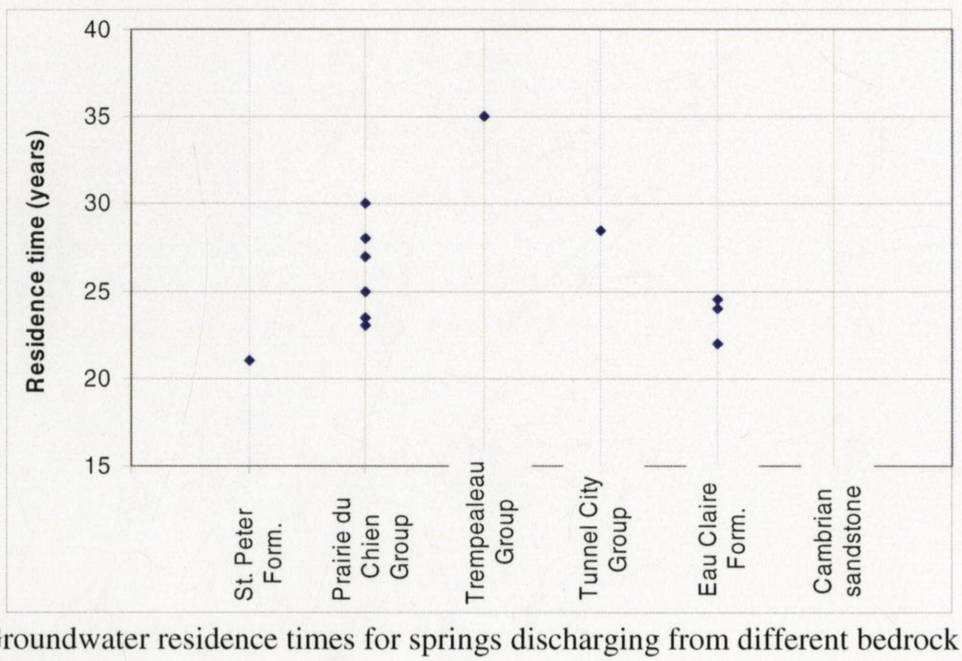

Figure 9: Groundwater residence times for springs discharging from different bedrock units.

4.1.3. Temperature, pH, and electrical conductivity

Commonly measured groundwater parameters, including temperature, pH, and electrical conductivity, were compared for springs discharging from different bedrock units. No clear correlation was observed between temperature (Figure 10) or pH (Figure 11) for different rock units. In general, springs discharging through the Cambrian sandstone units had slightly lower temperatures than those discharging from the Prairie du Chien dolomite. The exception to this observation occurred in a few springs discharging at bedrock interfaces in the Cambrian sandstones that had higher temperatures. Several of these springs discharged directly into surface water, so the measured temperatures may not be truly representative of the discharging springs.

Similarly to temperature, pH measurements did not appear to be strongly correlated to bedrock unit. The median pH values for springs discharging from the Eau Claire Fm. and from interfaces in the Cambrian sandstones were slightly higher than the pH of springs discharging from the Prairie du Chien, but the difference was probably not significant. Neither temperature nor pH could be considered strongly indicative of bedrock type.

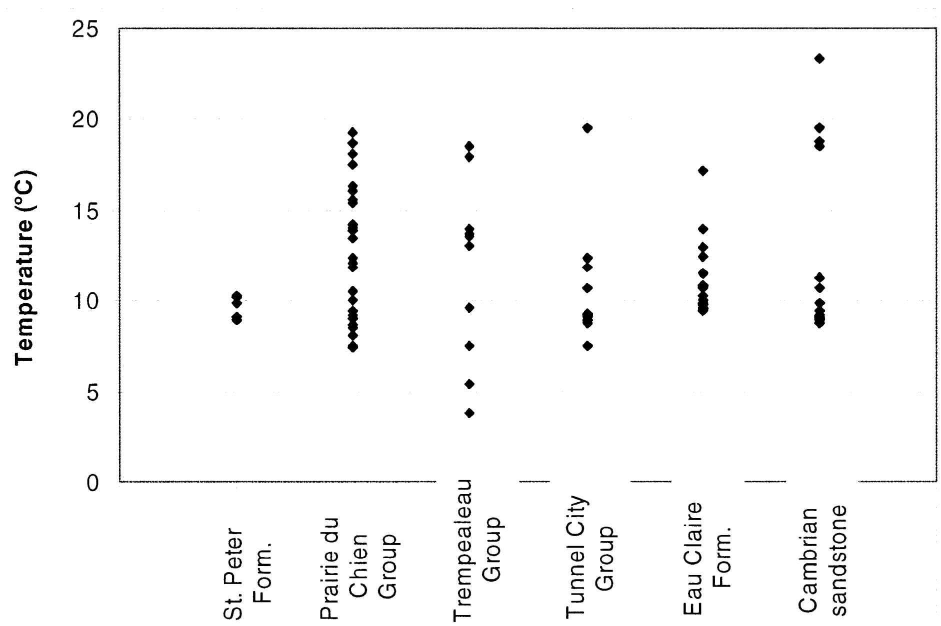

Figure 10: Temperature of springs discharging from different bedrock units. Temperature was not well correlated to bedrock unit in this investigation.

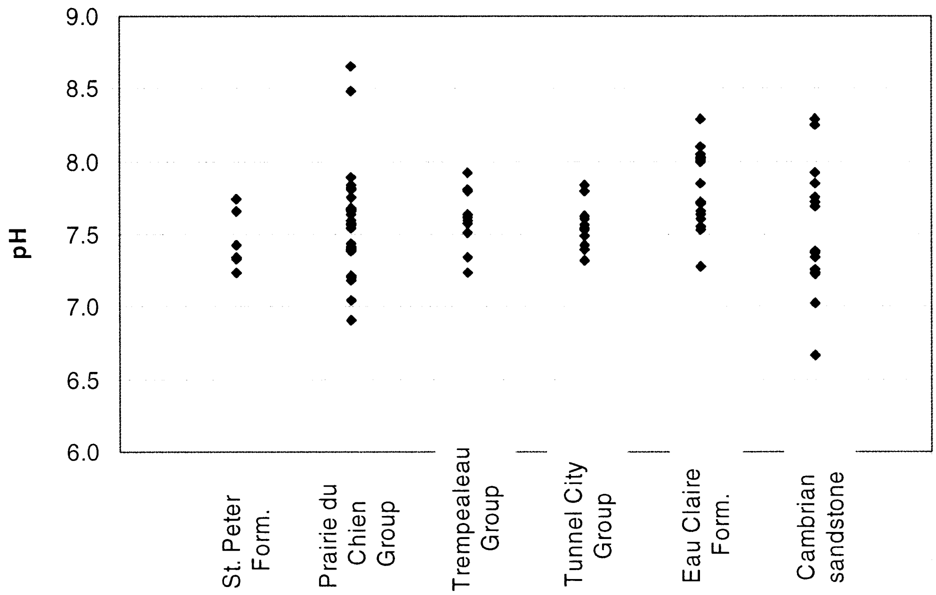

Figure 11: pH of springs discharging from different bedrock units. pH was not well correlated to bedrock unit in this investigation.

The electrical conductivity measurements acquired in this investigation were similar for most geologic units, but were somewhat more correlated to bedrock type than temperature or pH measurements. Although the range of electrical conductivity values within each unit partially or fully overlap with the range observed in other units, the springs discharging from the Eau Claire Fm. had a lower average electrical conductivity and less variability than springs in other units (Figure 12). Also, springs discharging along interfaces between Cambrian sandstone units showed a notably higher average electrical conductivity. The larger electrical conductivity values measured in these springs may indicate a higher proportion of percolation through porous media, with a relatively high rate of dissolution of the bedrock matrix, rather than flow through fractures or dissolution channels. Electrical conductivity values may also reflect changes in aquifer chemistry that influence the rate of bedrock dissolution.

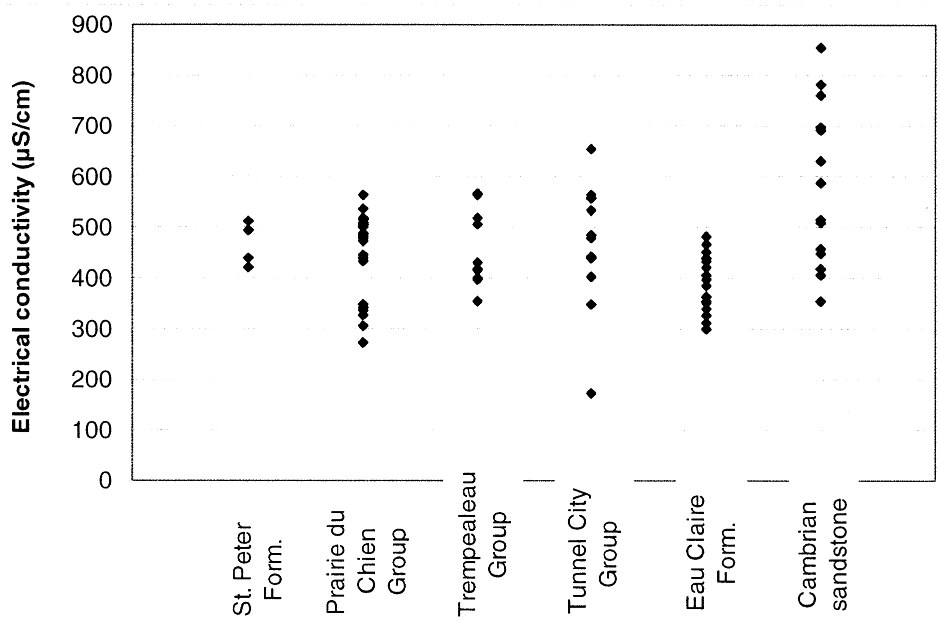

Figure 12: Electrical conductivity of springs discharging from different bedrock units. Electrical conductivity was on average lower for springs discharging from the Eau Claire Fm. and higher for springs discharging along interfaces of Cambrian sandstone units.

4.1.4. Chemical Analyses

Chemical analyses were performed to determine whether distinct chemical signatures existed for different geologic units and to infer information about groundwater flow through each unit. First, the accuracy of the chemical analyses was investigated (Section 4.1.4.1), then general analyses were performed to compare the chemical signatures of each unit (Section 4.1.4.2). These analyses showed a strong carbonate ionic signature for each of the geologic units, so carbonate chemical analyses were conducted to provide additional information (Section 4.1.4.3).

4.1.4.1. Accuracy of chemical analyses

The accuracy of the chemical results was investigated to ensure that the chemical analyses were valid. Accuracy was examined using the electrical balance method and through comparison with the electrical conductivity measurements collected in the field (Appelo and Postma, 2005). The electrical balance (EB) was calculated as:

$$EB,\% = \frac{\sum cations + \sum anions}{\sum cations - \sum anions} \times 100,$$

where cations and anions were inserted with the appropriate charge and were expressed as meq/L. If the EB was less than ±5%, the sample was considered accurate. For the data collected in St. Croix County, the EB ranged from 8% to 16%, with an average of 12%. This unexpectedly high error required explanation. Errors can be caused by long sample storage, laboratory error, or dissolution or precipitation of minerals during analysis; apparent error may also be caused by the presence of a cation or anion that contributes significantly to the electrical balance of the water but was not measured as part of the analysis (Fetter, 2001; Schwartz and Zhang, 2003; Bair and Lahm, 2006). The samples collected in this investigation were stored appropriately and analyzed promptly, so it seems likely that an ion was not being measured or was measured at less than its true concentration. Since the EB was always positive, an anion was probably missing or inaccurately measured. Analysis of the accuracy of the chemical data through comparison with the electrical conductivity also indicates a shortage of anions. In an accurate reporting of water chemistry, comparison with electrical conductivity (EC) measurements should show:

$$\Sigma \text{ anions (meq/L)} = \Sigma \text{ cations (meq/L)} \approx \text{EC}/100\ (\mu\text{S/cm}).$$

In this data set, the Σ cations (meq/L) is usually very similar to EC/100 (μS/cm), but the Σ anions (meq/L) is somewhat smaller, again suggesting an error in the anion measurement. These results are similar to those observed by Fritz (1994), whose study of charge balance errors in published journal articles showed that anions were under-measured more frequently than cations. Fritz suggests that this may be caused by bicarbonate measurements being analyzed in the laboratory rather than in the field, since carbonate ions may precipitate out of the water reserved for anion analysis, even when appropriate sampling and storage techniques are used. (Cations, which are preserved by acidifying the water, do not experience as much precipitation and thus are more accurately measured.) In this data set, the measured bicarbonate anion concentrations were not sufficient to balance the calcium and magnesium cation concentrations, suggesting that bicarbonate concentrations were under-measured. Thus, some inaccuracies exist in this data set, but the inaccuracies appear to cause the same bias for all samples, so comparison of the chemical signatures of different geologic units is probably valid.

4.1.4.2. General chemical analyses

The chemical data for all springs were compared to determine if springs discharging from different geologic units had different chemical signatures. Figure 13 shows a Piper diagram summarizing the ionic composition of each water sample. This figure shows that each of the springs sampled in this investigation had a groundwater chemistry that lies within the Mg-Ca-HCO_3 portion of the Piper diagram (in the upper left corner of the diamond), indicating flow through dolomitic rocks. Thus, the chemical signature of the groundwater discharging from springs was not indicative of the bedrock unit, since primarily sandstone units had the same signature as dolomite units. The chemical signature was useful for suggesting possible groundwater flow mechanisms; the similarity in chemical signatures for all rock units shows that even in sandstone units, groundwater may be dissolving dolomitic cement, and flow may be occurring partially through dissolution channels. Groundwater may also be flowing through deeper dolomitic units and then emerging from sandstone units as it approaches the surface, but the local geology and residence time data make this interpretation less likely.

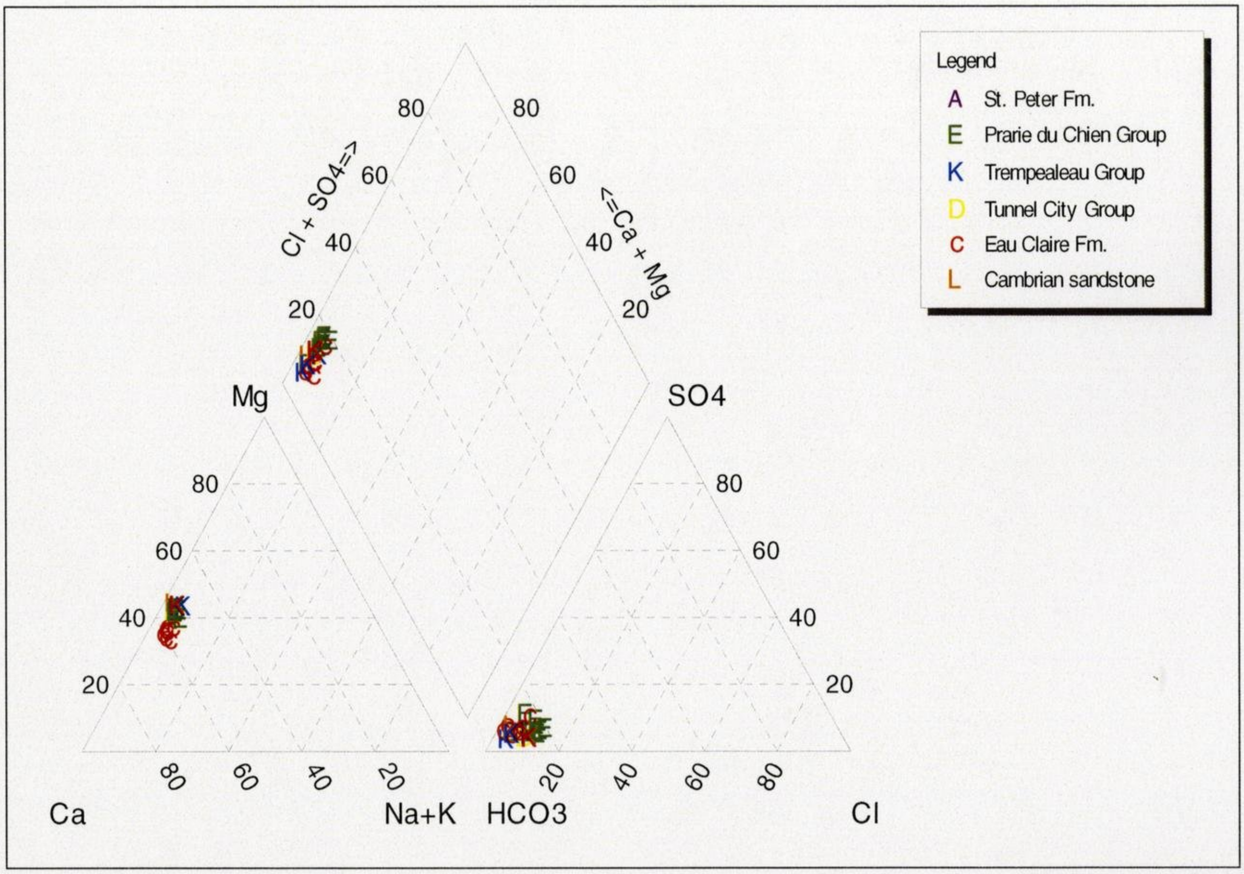

Figure 13: Piper diagram showing the chemical signature of spring water discharging from different bedrock units.

Stiff diagrams were used to visualize spatial variations in groundwater chemistry from discharging springs across St. Croix County. As seen in Figure 14, each of the stiff diagrams showed a characteristic carbonate/dolomitic shape, with a somewhat truncated left "wing" and a longer right (bicarbonate) "wing". The concentration of ions did not appear to be strongly dependent on bedrock type, since the size of the diagrams was similar for most bedrock units. The Eau Claire Fm. seemed to have the least variability in ionic concentrations of any bedrock unit, and the stiff diagrams showed intermediate ion concentrations for most springs in this unit. Springs in the Prairie du Chien Group tended to have somewhat higher ionic concentrations. Overall, variations in chemistry as a function of bedrock type were minor, and no clear pattern of groundwater chemical evolution was evident.

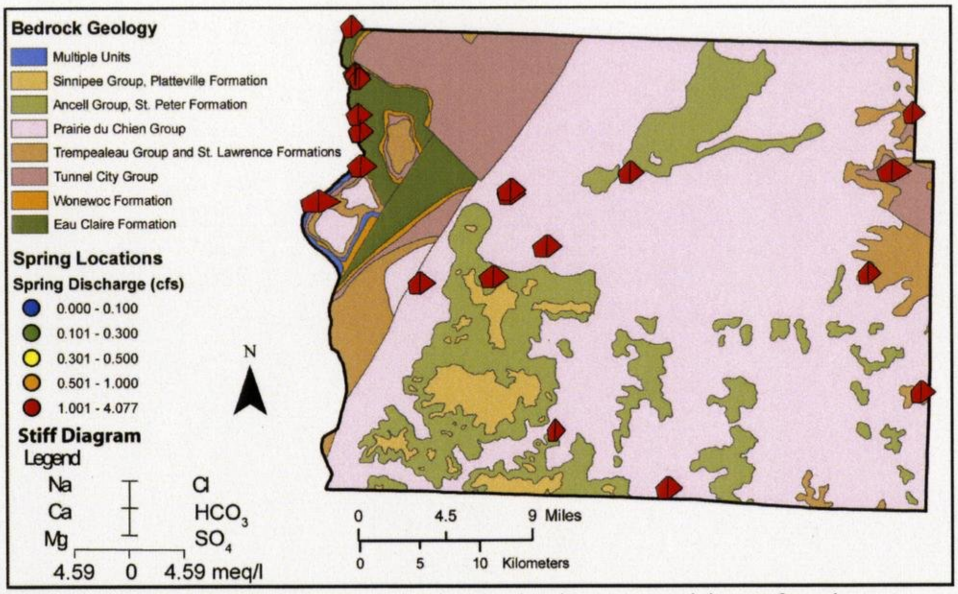

Figure 14: Stiff diagrams showing variations in the ionic composition of spring water across St. Croix County.

Although the chemical signatures of springs sampled in this investigation were dominated by carbonate ions, the silica concentration of each sample was also evaluated. Figure 15 shows that silica concentrations were relatively high in the St. Peter and Eau Claire Fms., which are both sandstone units. Average silica concentrations in the Prairie du Chien Group, composed primarily of dolomite, and in the adjacent Trempealeau Group, a sandstone and dolomite unit, were somewhat lower. Thus, silica concentrations may be weakly indicative of bedrock type, but the range of silica values observed in different units prevents silica from serving as an independent indicator of bedrock type.

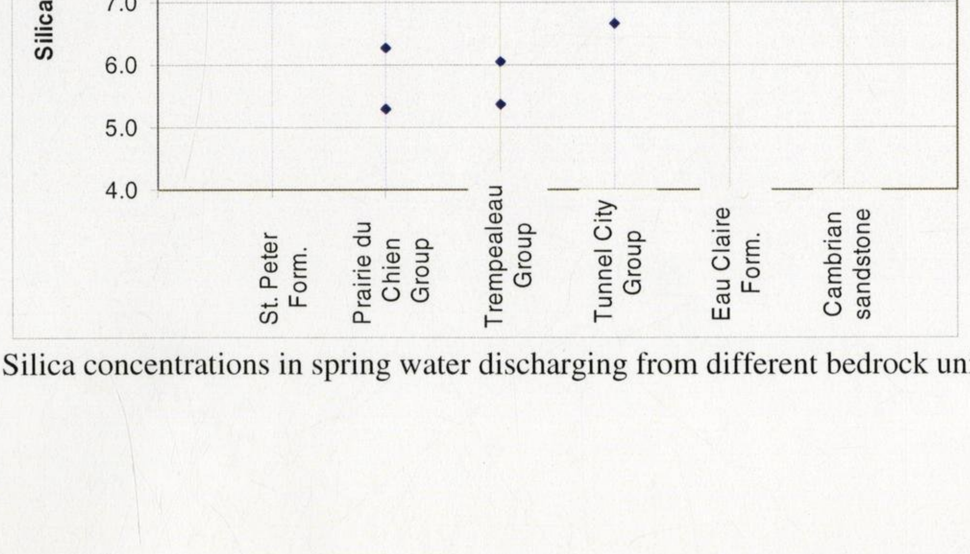

Figure 15: Silica concentrations in spring water discharging from different bedrock units.

The final general chemistry analysis was to investigate nitrate concentrations in different bedrock units, as shown in Figure 16. The highest nitrate concentrations occurred in the springs discharging above the Prairie du Chien Group, with the second highest concentrations in the St. Peter sandstone. Only one spring (located within the Prairie du Chien) showed a nitrate concentration in excess of the Wisconsin enforcement standard of 10 mg/L. The Eau Claire Fm. had the lowest nitrate concentrations, although all of the Cambrian sandstone units showed relatively low nitrates. As with the other chemical analyses, the range of nitrate concentrations overlapped for most geologic units, but nitrate concentration was better correlated to bedrock type than the previously discussed chemical parameters.

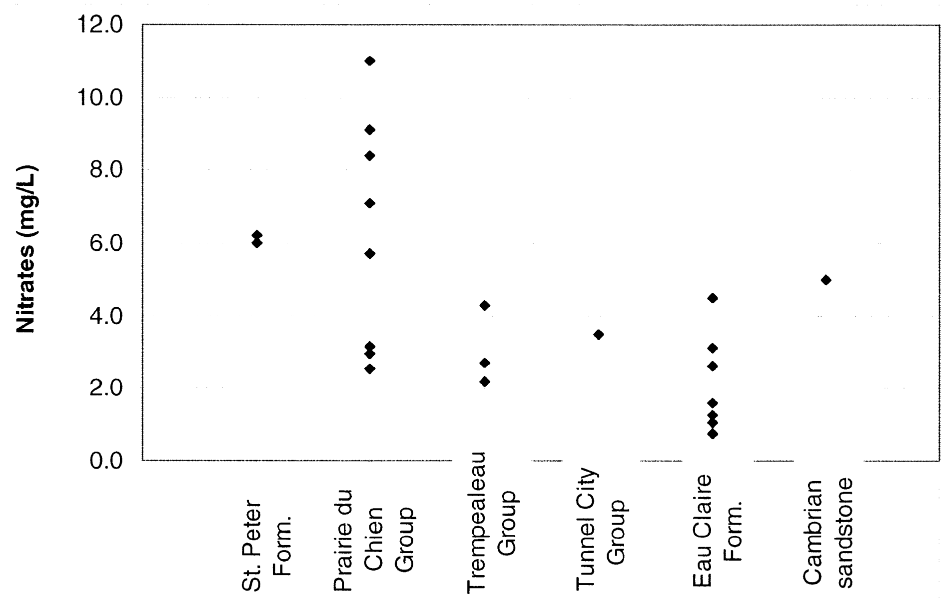

Figure 16: Nitrate concentrations in spring water discharging from different bedrock units.

4.1.4.3. Carbonate chemical analyses

Since the general chemical analyses indicated that bedrock units in St. Croix County all had carbonate characteristics, the carbonate signature was further investigated with two additional analyses. The first of these analyses was a comparison of the Ca/Mg ratio for different bedrock units. When Ca^{2+} and Mg^{2+} are expressed in molar concentrations, a Ca/Mg ratio of 1.0 to 1.5 indicates a dolomite aquifer, Ca/Mg of 6 to 8 indicates a limestone aquifer, and an intermediate Ca/Mg ratio indicates a mixed limestone/dolomite aquifer (White, 1999). As shown in Figure 17, water discharging from all of the bedrock units except the Eau Claire Fm. had Ca/Mg ratios that indicated dolomitic aquifers. In the Eau Claire Fm., the Ca/Mg ratio indicated a mixed limestone/dolomite aquifer. These results show that both the primarily carbonate units (such as the Prairie du Chien) and the clastic rocks with carbonate cements have undergone extensive dolomitization. Since dissolution occurs more slowly in dolomites than in limestones, conduit systems in dolomitic rocks are generally less well-developed, and dissolution will preferentially occur in limestones if they available (White, 1999). A slowly developing conduit system in the bedrock of St. Croix County could indicate that groundwater might flow partially through conduits, but might also be forced into porous media flow in some areas.

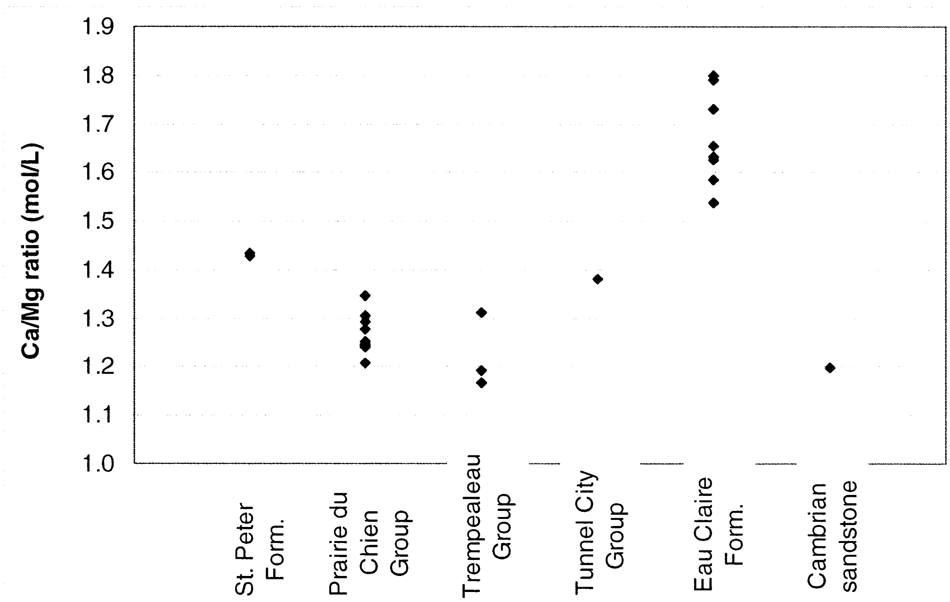

Figure 17: Ca/Mg ratios in spring water discharging from different bedrock units.

The second carbonate analysis was to compare the calcite saturation index (SI_c) for springs discharging from different bedrock units. The SI_c can be used to indicate the degree of equilibrium between the carbonate bedrock and groundwater, and it is defined as:

$$SI_c = \log \frac{\gamma_{Ca^{2+}}[Ca^{2+}]\gamma_{HCO_3^-}[HCO_3^-]K_2}{10^{-pH}K_c},$$

where γ_{Ca} is the activity coefficient for Ca^{2+}, γ_{HCO3} is the activity coefficient for HCO_3^-, $[Ca^{2+}]$ is the molal concentration of Ca^{2+}, $[HCO_3^-]$ is the molal concentration of HCO_3^-, and K_2 and K_c are temperature-dependent equilibrium constants for carbonate reactions (White, 1999). If the groundwater is exactly at equilibrium with the carbonate bedrock, SI_c will equal 0. If the water is undersaturated with respect to calcite, indicating a relatively short residence time, SI_c will be negative. Water that is supersaturated with respect to calcite will have a positive SI_c value, indicating that the water has been in contact with the bedrock for a longer time period. As shown in Figure 18, younger geologic units were generally undersaturated with respect to calcite, especially the Prairie du Chien Group, which may indicate relatively rapid groundwater flow through dissolution channels. A few springs within the Eau Claire Fm. and one spring that discharged at the interface between the Tunnel City and Eau Claire units were oversaturated with calcite, indicating that porous media percolation may be the primary flow mechanism for these springs. It should be noted that the SI_c values calculated here are probably somewhat lower than would be calculated in an error-free analysis, as the measured bicarbonate concentrations may be too low (Section 4.1.4.1). Although more accurate SI_c values may be slightly higher, minor changes to the calculated SI_c values are not anticipated to change the interpretation of the results provided here.

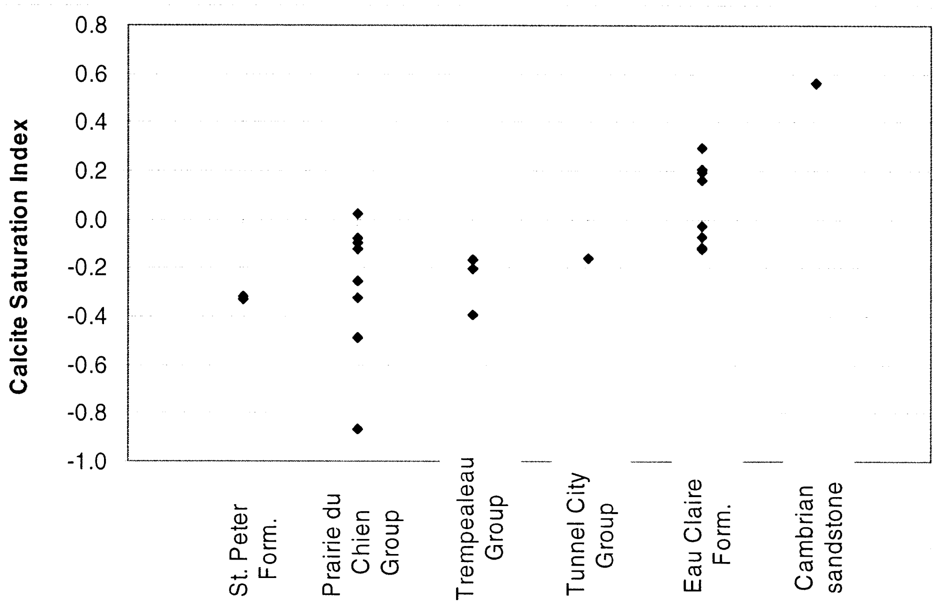

Figure 18: Calcite saturation index in spring water discharging from different bedrock units.

4.2. Conceptual models of spring recharge

4.2.1. St. Peter Formation

Five springs identified during this investigation discharged from areas where the St. Peter sandstone (part of the Ancell Group) was the uppermost bedrock unit. Only one of these springs had a discharge rate greater than 1.0 cfs. As with the other springs tested in this study, ionic concentrations indicated a dolomitic origin to water discharging from this unit. This chemical composition is probably due to dissolution of dolomitic cement within a silica matrix, as the chemical analyses also showed relatively high concentrations of silica. Several analyses suggest that groundwater flows through the St. Peter sandstone relatively quickly: 1) the residence time of the single sample acquired from this unit was 22 years, 2) nitrate concentrations were relatively high, suggesting rapid infiltration of surface water, and 3) the water was undersaturated with respect to calcite, indicating that the groundwater had not been in contact with the carbonate cement long enough to reach equilibrium. The residence time was sufficiently long that flow through porous media is indicated, probably during and soon after infiltration. Then, if the hydraulic conductivity of the bedrock matrix is sufficiently high, flow may continue to move through the matrix before being discharged. However, it also seems probable that flow becomes channelized into bedrock fractures at some point after infiltration and then moves relatively quickly through the subsurface.

4.2.2. Prairie du Chien Group

During this investigation, more springs were identified in the Prairie du Chien than in any other single bedrock unit. 30% of all springs and 42% of springs with a discharge rate greater than 1.0 cfs were found within this unit. The Prairie du Chien did not have an especially high density of springs, but it was significant for producing the greatest number of large springs.

The Prairie du Chien is composed of dolomite and dolomitic sandstone, so conduit flow through dissolution channels is a probable flow mechanism for groundwater transport, especially for some of the springs with larger discharge rates. Several of the analyses discussed in Section 4.1 supported this conclusion. First, the ionic chemical signature was dolomitic, as expected from the geologic description found in the literature. Secondly, most springs within the Prairie du Chien were undersaturated with respect to calcite, indicating that the water moved through the unit fairly quickly, before chemical equilibrium could be established. This rapid movement suggests conduit flow rather than percolation through porous media. Thirdly, nitrate concentrations were high in several of the Prairie du Chien springs, again suggesting that relatively young water had infiltrated rapidly into this unit. Despite these indications of conduit flow, the results of other analyses suggested that percolation through porous media might also be an important groundwater flow mechanism in the Prairie du Chien. Several springs had high silica concentrations, indicating significant contact with a sandy matrix, and residence times ranged from 23 to 30 years. These are unlikely characteristics for groundwater transported solely through well-developed dissolution channels. Therefore, a realistic conceptual model of groundwater flow through the Prairie du Chien probably includes porous media percolation that is channelized into conduits within the bedrock unit and/or flow through poorly developed conduits. The heterogeneity of the Prairie du Chien Group and the influence of overlying soil layers must also be recognized; some springs may be supplied primarily by conduit flow, while others may be supported primarily by percolation. To reliably determine flow mechanisms, each spring must be tested individually using methods such as dye tracing, but the long residence times observed in this investigation indicate that such an analysis may be difficult.

4.2.3. Cambrian sandstones

The Cambrian sandstones (Trempealeau Group, Tunnel City Group, and Eau Claire Fm.) had the highest spring density of the bedrock units investigated in this study. 64% of all springs and 50% of springs with a discharge rate greater than 1.0 cfs were found within these units. The geology of the Cambrian sandstone units is similar, and it is reasonable to expect similar flow mechanisms for these units. However, analysis of the measured parameters showed that different flow mechanisms may be dominant in each unit.

The Trempealeau and Tunnel City Groups both had relatively low silica concentrations and were undersaturated with respect to calcite, indicating that flow may occur relatively rapidly through fractures or dissolution conduits. However, the residence time measurements (one residence time measurement was available for each of these units) indicated a relatively long travel time of 28 to 35 years. Thus, rapid flow only through fractures or conduits was unlikely. The lower silica and calcite concentrations might indicate either that less cement exists between clastic particles in these units or that the cement may be less prone to dissolution than in other units. Both of these units had intermediate to low Ca/Mg ratios, suggesting that the carbonate cement would not dissolve as easily as in units with higher Ca/Mg values. Therefore, a conceptual model of flow through these units should include percolation through unconsolidated sediments as the initial mode of infiltration, then percolation through porous bedrock, but perhaps with less dissolution of cement. Within the bedrock, flow along the top of interbedded siltstone layers or along the top of the fining-upward sequences common in these units is especially likely. Flow may also occur along the top of or through dissolution channels within the dolomite layer in the Trempealeau group.

The Eau Claire Fm. is lithologically similar to the other Cambrian sandstone units, but the results of the analyses performed using water from this unit were somewhat different. The residence times were relatively young (22 to 25 years), but the concentrations of silica were high. Also, the chemistry of the springs sampled showed that the water ranged from slightly undersaturated to moderately oversaturated with respect to calcite. Thus, the silica and calcite saturation indicated percolation through a porous media, while the residence time could be appropriate for either porous media or a combination of porous media and fracture/conduit flow. The Eau Claire Fm. was also unique in having the highest Ca/Mg values of any unit in this investigation; the Ca/Mg values indicated a mixed limestone/dolomite cement in this unit. The higher proportion of calcite in the cement of this unit may help to explain the previous results. Since calcite dissolves more easily than dolomite, the cement may dissolve relatively easily, increasing the calcite saturation. The dissolution of cement may cause part of the matrix to erode, increasing the silica concentrations. Finally, the dissolution channels produced in this process may increase groundwater velocity, resulting in lower residence times. A conceptual model for flow through the Eau Claire Fm. should include some flow through porous media, with possible capture by dissolution-enlarged fractures or small dissolution channels within the sandy matrix. These channels may be especially common above low-permeability layers such as the interbedded shale within this unit.

A large number of springs (21% of total) were found where an interface between different Cambrian sandstone units was indicated on the bedrock map. Since the area where these interfaces occur is relatively small, the spring density was quite high. Many of these springs were found where several rock units were exposed (Tunnel City, Wonewoc, and Eau Claire), and it was not always clear which rock unit served as the source of the spring. Thus, it was difficult to conclusively identify the units acting as aquitards or as higher permeability zones. Most likely, since all of these units have similar lithology, flow is restricted by low-permeability layers within individual units as much as by interfaces between sandstone units. It is also important to note that many of the springs found at "interfaces" between geologic units are located in river valleys or along a fault, so it is not clear whether the springs are due to flow along an interface above a lower-permeability unit, seepage from exposed rock faces, or flow along fault zones. Thus, bedrock interfaces should be considered likely locations for springs, but the large number of springs found at bedrock "interfaces" in this study may also reflect flow through individual units that emerges at outcrops where multiple units are present.

4.3. Delineation of recharge areas

Recharge areas were drawn for each spring or closely-spaced group of springs with discharge greater than 1.0 cfs, as described in Section 3.3. The recharge areas ranged in size from 1.0 to 5.1 mi^2 (2.6 to 13.2 km^2), as shown in Table 2, and the entire area covered by the estimated recharge areas was 37.2 mi^2 (96.3 km^2), or about 5% of the area of St. Croix County. The locations of the recharge areas for the entire county are shown on Figure 19, and more detailed maps of the recharge area for each spring are given in Appendix III. As discussed in Section 3.3, the delineated recharge areas are likely only the minimum areas from which springs receive groundwater flow, and significant groundwater withdrawal beyond the boundaries shown in Figure 18 may still affect nearby springs. It should also be noted that the infiltration rate, a critical parameter for estimating the recharge area, is partially dependent upon land use. If the land use changes significantly in the future, especially with continued urban development, the recharge areas may change as well.

Spring number	Measured discharge (cfs)	Modeled recharge (cfs)	Difference between measured and modeled discharge (%)	Estimated recharge area (mi^2)	Estimated recharge area (km^2)
3	1.2	1.3	8	1.9	4.9
9 and 14	1.8	1.9	6	1.9	5.0
12	0.93	1.1	18	1.7	4.3
15	2.7	3.1	15	4.7	12.2
23	1.4	1.4	0	2.1	5.4
30	1.5	1.7	13	2.4	6.1
47	1.2	1.4	17	2.5	6.4
54	3.4	3.7	9	5.1	13.2
60 and 78	1.0	1.0	0	1.0	2.6
63	4.1	4.0	-2	6.4	16.5
69 and 70	2.6	2.6	0	3.6	9.4
82 through 85	2.8	3.1	11	3.2	8.4
86	1.2	1.1	-8	1.6	4.2

Table 2: Results from infiltration/reached modeling and comparison to spring discharge rates. Due to uncertainties inherent in the modeling procedure and possible error in the discharge measurements, a maximum difference of 20% between the modeled recharge and measured discharge was deemed acceptable.

Since one of the main objectives of this investigation was to estimate the recharge areas of large springs to allow assessment of the environmental impacts of proposed high capacity wells, it was interesting to note the number of high capacity wells already located within the estimated recharge areas, as shown in Figure 20. Of the 13 estimated recharge areas delineated in this study, 6 currently contain high capacity wells. The impact of these wells on the current spring conditions, as measured in this investigation, is uncertain.

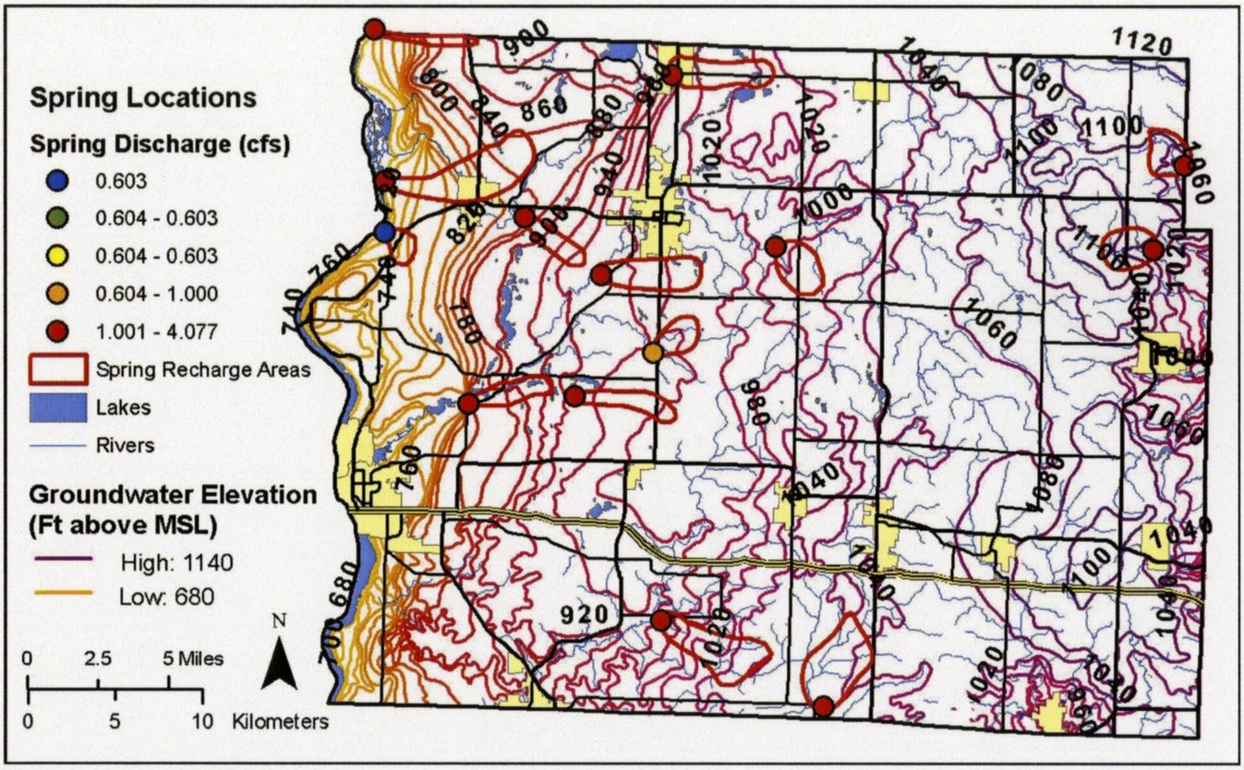

Figure 19: Estimated recharge areas for springs with discharge greater than 1.0 cfs.

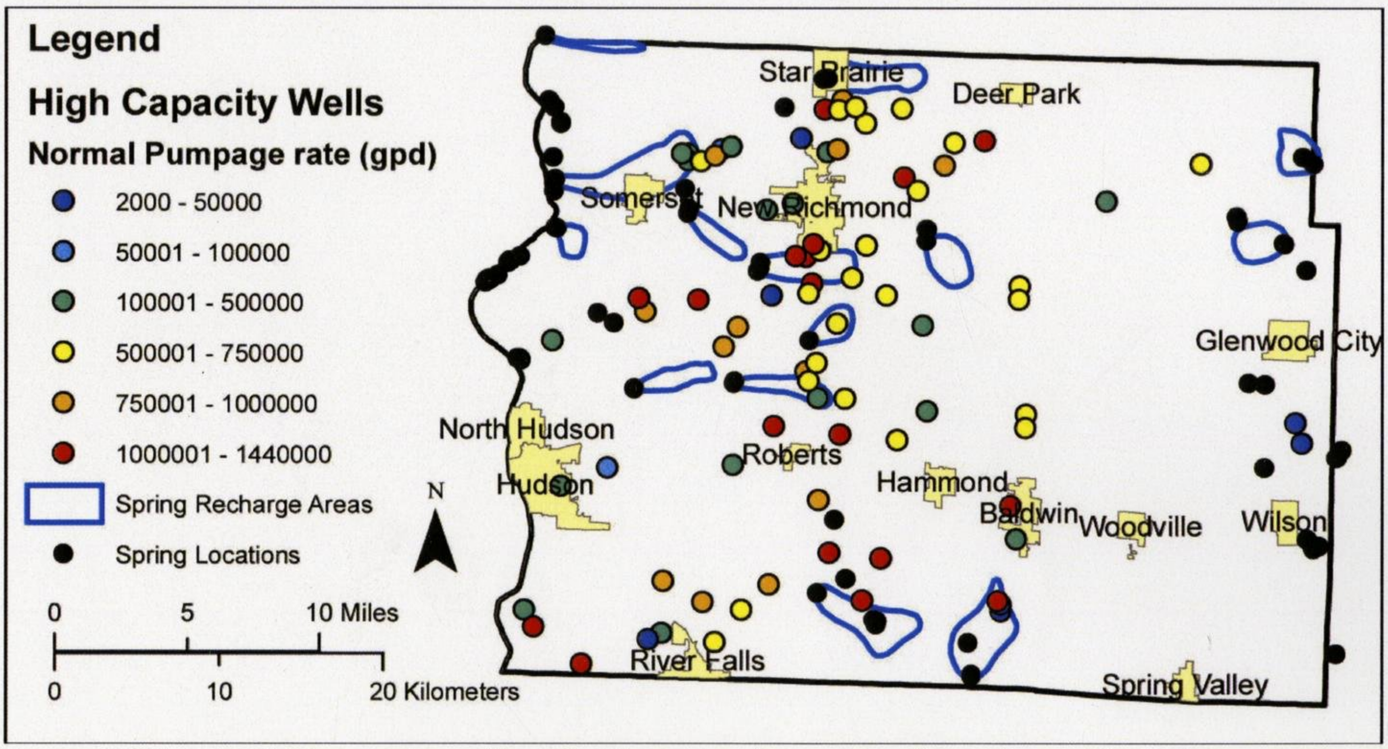

Figure 20: Existing high capacity wells and estimated recharge areas for springs with discharge greater than 1.0 cfs. Data for well locations and pumping rates were provided by the Wisconsin DNR.

4.4. Correlations for common groundwater parameters

The measurements collected and analyses performed during this investigation provided an opportunity to compare groundwater parameters. These parameters were compared to determine if commonly measured water parameters could be used to indicate less easily determined parameters. First, nitrate (an ion common to Wisconsin groundwater and with a relatively low cost for analysis) was compared to residence time measurements for different samples to determine if nitrate could be used to indicate groundwater age. Previous studies (Lindsey *et al.*, 2003; Osenbruck *et al.*, 2006) have found that nitrate concentrations may be related to groundwater residence time in some aquifers. Figure 21 shows that in this investigation, nitrate concentrations were not well correlated to residence time, although the highest nitrate concentrations did occur in relatively young groundwater samples. Secondly, nitrate concentrations were compared to electrical conductivity measurements obtained in the field to determine whether easily collected field measurements could be used to predict nitrate concentrations. Although the resulting correlation (Figure 22) was insufficient to accurately estimate nitrate concentration, there is a discernable trend of increasing nitrate concentrations as electrical conductivity increases.

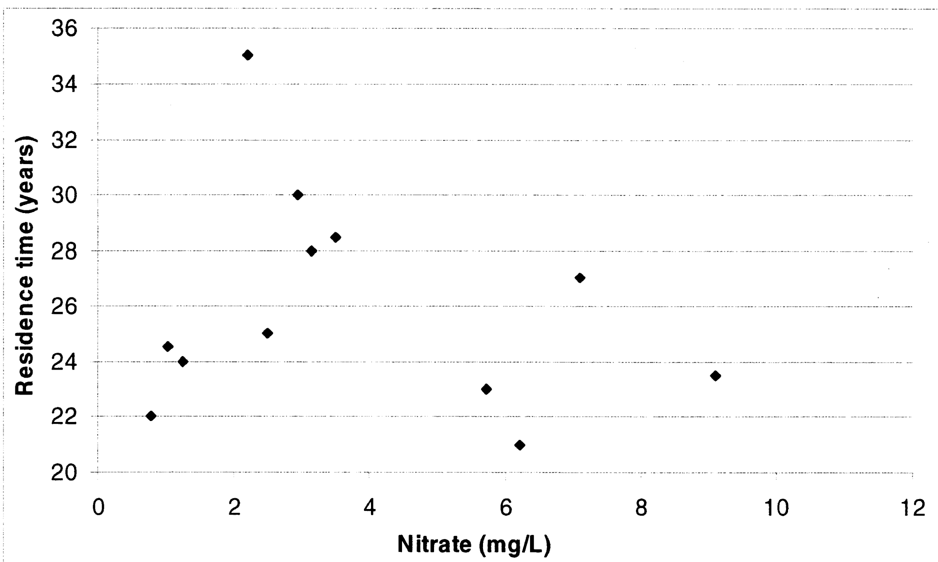

Figure 21: Nitrate concentrations and residence time estimates for spring water in St. Croix County.

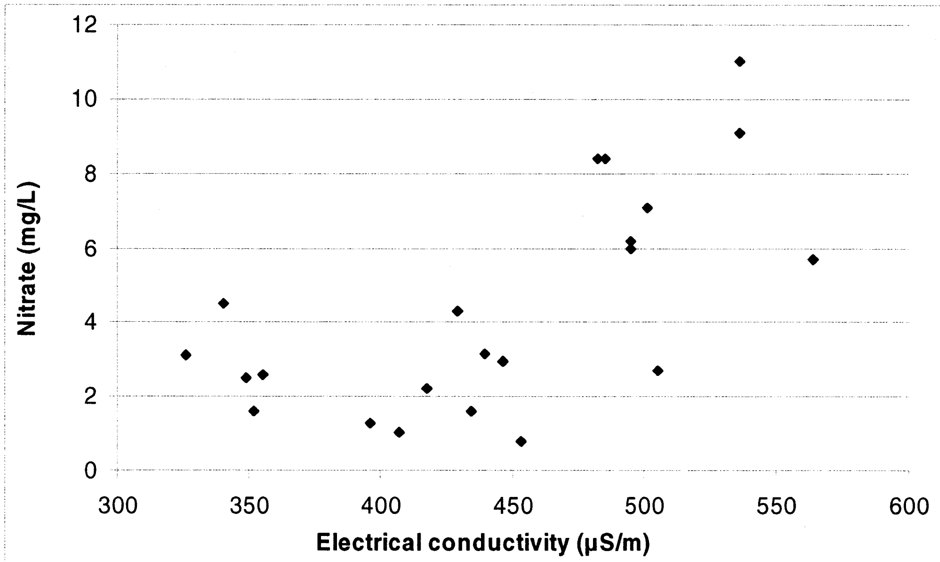

Figure 22: Electrical conductivity and nitrate concentrations for spring water in St. Croix County.

The final correlation investigated was a comparison between the calcite saturation index (SI_c) and residence time. If groundwater passes through formations of similar chemical composition, longer travel times are expected to result in larger SI_c values. Although each geologic unit within St. Croix County had a dolomitic ionic signature, the SI_c values were not well correlated to residence time (Figure 23). Presumably, differences in the ease of dissolution of the cement or bedrock matrix, as reflected by the Ca/Mg ratios, affect the SI_c values as much as the residence time of the groundwater.

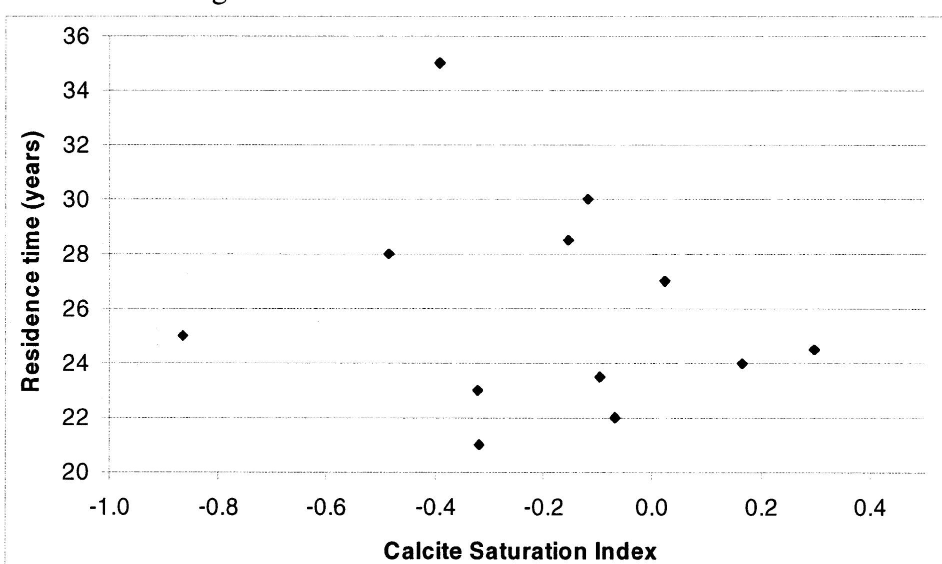

Figure 23: Calcite saturation index does not appear to correlate well to residence time for spring water in St. Croix County.

5. Conclusions

Eighty-seven springs were identified during this investigation, showing that the hydrogeology of west-central Wisconsin is favorable for spring formation. Although the larger springs in St. Croix County were probably located during this investigation, there are almost certainly a large number of smaller springs undocumented by this or other surveys. The duration of this study was insufficient to investigate every possible spring in the field plan, and conversations with local landowners often revealed springs not included in the field plan. Additional field work similar to that described here would indubitably identify more springs, although the discharge rates of these springs are probably low, so the cost effectiveness of such a survey is questionable.

One of the main motivations for finding springs and protecting spring recharge areas is that springs often feed cold-water streams, which are important trout habitat. For this investigation, a "spring" was defined as a small area on the land surface where groundwater discharge was apparent. It should be recognized that much of the recharge to cold-water streams enters as more diffuse flow, although the flow mechanisms are probably similar to those producing springs. Thus, limiting groundwater withdrawal within the recharge area of large springs will aid in the protection of cold-water streams, but will not eliminate threats to surface water quantity due to groundwater extraction. Also, flow from springs with discharge rates less than 1.0 cfs may still be significant for sustaining cold-water creeks; in this study, 34% of the total volume of discharge measured came from springs with discharge less than 1.0 cfs. However, a large portion of the volume discharged (66%) came from a relatively small number (12) of springs with discharge greater than or equal to 1.0 cfs, so limiting groundwater withdrawal within the recharge areas of large springs may be the most practical method of protecting discrete discharges of groundwater.

To protect a spring recharge area from excessive groundwater extraction, a conceptual model of groundwater flow to the spring is required. Methods such as dye tracing are needed to definitely determine the boundaries of a spring recharge area, but analyses of water chemistry and local hydrogeology can provide some insight into groundwater flow mechanisms. For the springs in St. Croix County, the literature review and some chemical data suggested that flow through fractures or dissolution channels was probable. However, other chemical analyses, especially age dating of the spring discharge, showed that percolation through porous media was likely. Groundwater residence times ranged from 22 to 35 years, showing that at least part of the recharge flowed through porous media or along deeper flowpaths within bedrock units. Residence time estimates probably reflect a mixture of water discharging from deeper flowpaths (older water) and water flowing through unconsolidated sediments (younger water), so wells extracting groundwater from either unit are likely to affect spring discharge. It should also be noted that residence times for springs are sometimes biased towards older groundwater during drier years (when a higher percentage of discharge comes from deeper units), so the residence time measurements may change somewhat in years of significantly different precipitation.

The conceptual models of flow through most geologic units in St. Croix County include a mixture of flow through porous media and through fractures or dissolution conduits. The scope of this project did not allow the investigators to determine definitively which flow mechanism was dominant for each spring. Conduit springs often have large variations in discharge, temperature, and chemical concentrations throughout a year, while springs fed by matrix-dominated flow are typically more stable (Shuster and White, 1972). For this investigation, springs were usually sampled only once, so seasonal variations in discharge and chemical properties are probable.

Finally, the reader should be aware that the method used in this investigation to estimate the recharge areas for springs provides only the area needed to balance groundwater infiltration/recharge with spring discharge. More probably, recharge to a spring flows from an area larger than the area estimated using this method. Thus, groundwater extraction outside of the boundaries of the recharge areas shown in Appendix III may still adversely affect springs.

6. References

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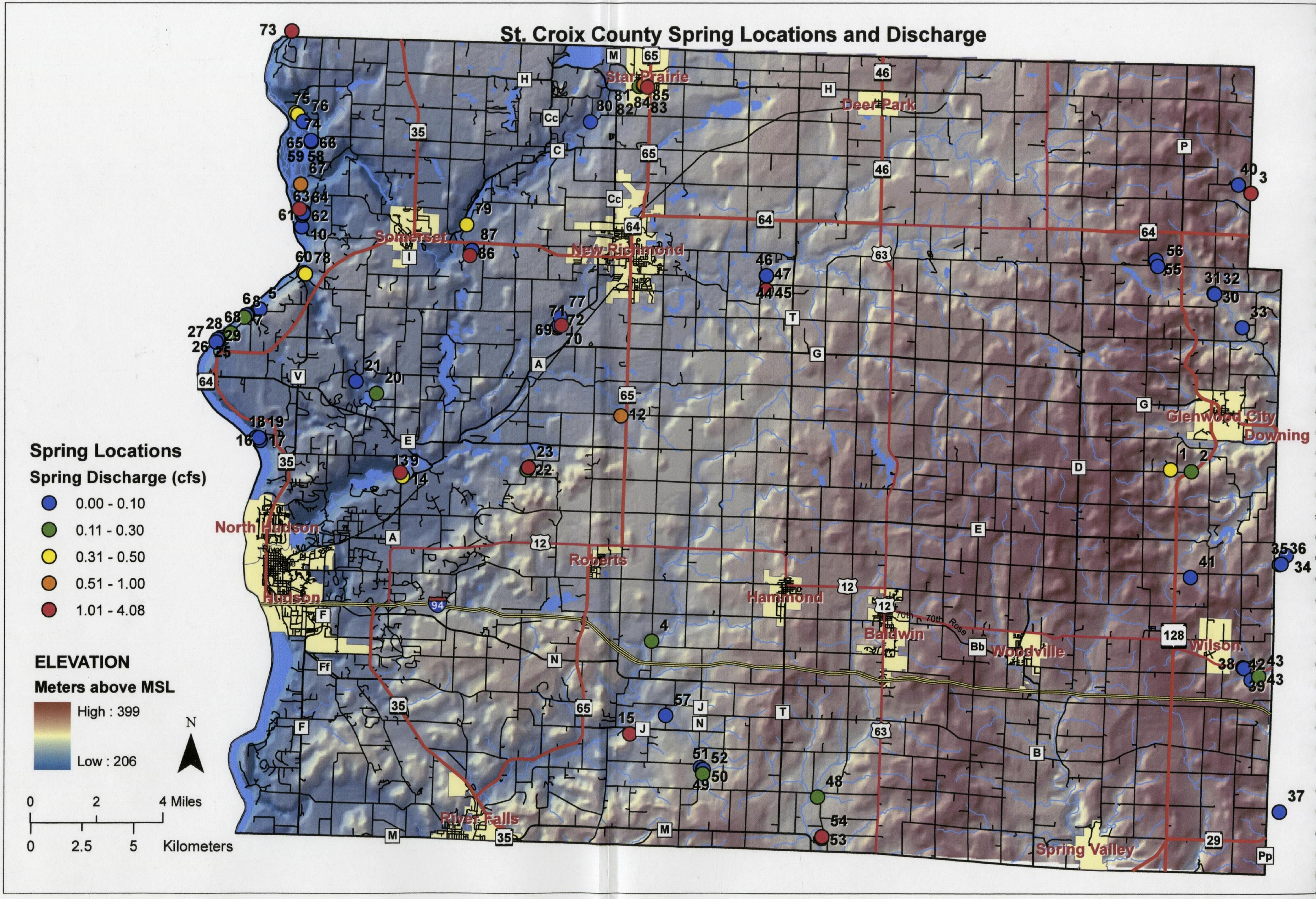
Appendix I:

Map of spring locations and discharges in St. Croix County


St. Croix County Spring Locations and Discharge
Spring Locations
Spring Discharge (cfs)
0.00 - 0.10
0.11 - 0.30
0.31 - 0.50
0.51 - 1.00
1.01 - 4.08
ELEVATION
Meters above MSL
High : 399
Low : 206
N
0 2 4 Miles
0 2.5 5 Kilometers
Star Prairie
Deer Park
Somerset
New Richmond
Glenwood City
Downing
North Hudson
Roberts
Hudson
Hammond
Baldwin
Woodville
Wilson
River Falls
Spring Valley

Appendix II:

Measured parameters and spring descriptions

Spring Survey, St. Croix County, Wisconsin

Sample ID	1	Land Use	Pasture
Sample Date	7/18/2005		
7.5 Minute Quadrangle	Glenwood City	Uppermost bedrock unit at discharge point	Trempealeau Group
Northing	562922		
Easting	4986935		
Discharge (cfs)	0.319	Approximate soil thickness (ft)	0-50
Temperature (°C)	18.6		
Conductivity (μS/cm)	397	Estimated recharge area (mi^2)	0.619
pH	7.24		

Description:

Spring is accessible from 300th street, just off Cnty Rd DD. Spring is ~2 m in diameter and is located to the west of an oblong pond.

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.

Spring Survey, St. Croix County, Wisconsin

Sample ID	1
Sample Date	1/18/2006
7.5 Minute Quadrangle	Glenwood City
Northing	4986935
Easting	562922
Discharge (cfs)	0.290
Temperature (°C)	3.8
Conductivity (μS/cm)	429
pH	7.81

Land Use	Pasture
Uppermost bedrock unit at discharge point	Trempealeau Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.563

Sum of anions (meq/L)	3.11
Sum of cations (meq/L)	3.98
Electrical balance (%)	+12.36
Residence time (years)	

Total dissolved solids (mg/L)	259.06
Total hardness (mg/L $CaCO_3$)	190.53
Alkalinity (mg/L $CaCO_3$)	131.23
Ca/Mg (mol/L)	1.19
Calcite saturation index	4.21

Concentration (mg/L)

Na	3.30	Cl	11.00	As	<0.003	P	0.018
K	1.20	SO_4	5.78	Cu	<0.001	Pb	<0.002
Ca	41.50	NO_2+NO_3	4.3	Fe	0.083	Si	5.37
Mg	21.10	HCO_3	160.00	Mn	0.034	Zn	<0.002

Description:

Spring is accessible from 300th street, just off Cnty Rd DD. Spring is ~2 m in diameter and is located to the west of an oblong pond.

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.

Spring Survey, St. Croix County, Wisconsin

Sample ID	2	Land Use	Wooded
Sample Date	7/18/2005		
7.5 Minute Quadrangle	Glenwood City	Uppermost bedrock unit at discharge point	Trempealeau Group
Northing	4986881		
Easting	563923		
Discharge (cfs)	0.300	Approximate soil thickness (ft)	0-50
Temperature (°C)	13.1		
Conductivity (µS/cm)	517	Estimated recharge area (mi^2)	0.582
pH	7.34		

Description:

Spring is located directly behind house, just north of the intersection of Hwy 128 and County DD. The spring is 2 m in diameter and has a sandy bottom with many small sand boils. (Address: 1202 Hwy 128, town of Glenwood)

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.

Spring Survey, St. Croix County, Wisconsin

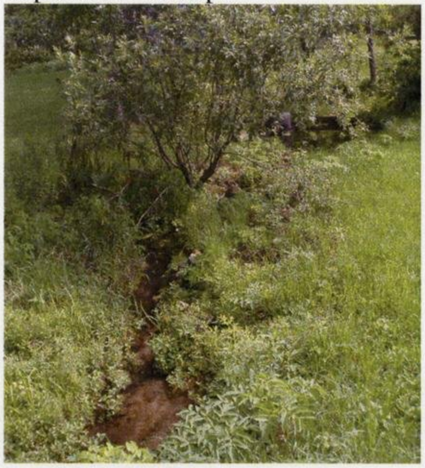
Sample ID	3
Sample Date	7/21/2005
7.5 Minute Quadrangle	Graytown
Northing	5000444
Easting	566325
Discharge (cfs)	1.229
Temperature (°C)	13.6
Conductivity (μS/cm)	354
pH	7.6

Land Use	Yard
Uppermost bedrock unit at discharge point	Trempealeau Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.9

Description:

The spring is located on the county line between St. Croix and Dunn Counties at E111 1290th Ave. The area around the spring is well maintained. The spring emerges into a pool, in the front yard of the house, with a sandy bottom and numerous sand boils. The pool is approximately 2 m in diameter and 30 cm deep. There is a concrete cylinder within the spring pool.

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.



Spring Survey, St. Croix County, Wisconsin

Sample ID	3	Land Use	Yard
Sample Date	1/18/2006		
7.5 Minute Quadrangle	Graytown	Uppermost bedrock unit at discharge point	Trempealeau Group
Northing	5000444		
Easting	566325		
Discharge (cfs)	0.700	Approximate soil thickness (ft)	0-50
Temperature (ºC)	7.5		
Conductivity (μS/cm)	417	Estimated recharge area (mi^2)	1.9
pH	7.51		

Sum of anions (meq/L)	2.86	Total dissolved solids (mg/L)	248.54
Sum of cations (meq/L)	3.62	Total hardness (mg/L $CaCO_3$)	173.35
Electrical balance (%)	+11.71	Alkalinity (mg/L $CaCO_3$)	131.23
Residence time (years)		Ca/Mg (mol/L)	1.31
		Calcite saturation index	4.56

Concentration (mg/L)

Na	3.10	Cl	4.00	As	<0.003	P	0.02
K	0.80	SO_4	4.74	Cu	<0.001	Pb	<0.002
Ca	39.40	NO_2+NO_3	2.2	Fe	0.006	Si	8.03
Mg	18.20	HCO_3	160.00	Mn	<0.001	Zn	<0.002

Description:

The spring is located on the county line between St. Croix and Dunn Counties at E111 1290th Ave. The area around the spring is well maintained. The spring emerges into a pool, in the front yard of the house, with a sandy bottom and numerous sand boils. The pool is approximately 2 m in diameter and 30 cm deep. There is a concrete cylinder within the spring pool.

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.

Spring Survey, St. Croix County, Wisconsin

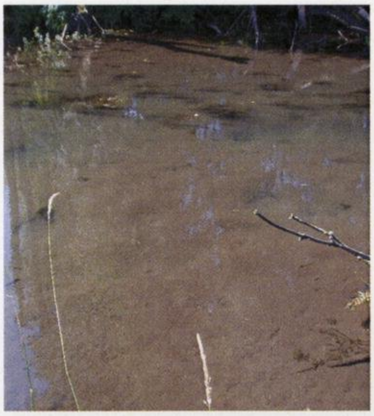
Sample ID	4
Sample Date	7/22/2005
7.5 Minute Quadrangle	Roberts
Northing	4977470
Easting	538082
Discharge (cfs)	0.300
Temperature (ºC)	14.1
Conductivity (µS/cm)	508
pH	7.54

Land Use	Wooded (Public Fishery Area)
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.582

Description:

The spring is Located in the Kinnickinnic River Public Fishery Area on 140th St. The spring is visible from the bridge. The spring is feeding the Kinnickinnic River from the bottom through multiple seepage holes. Discharge estimated as 0.3 cfs based on visual observation of stream; the actual discharge could not be measured, since the spring discharged directly into the stream.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.



Spring Survey, St. Croix County, Wisconsin

Sample ID	5	Land Use	Boy Scout Camp
Sample Date	7/26/2005		
7.5 Minute Quadrangle	Stillwater	Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Northing	4993045		
Easting	518418		
Discharge (cfs)	0.036	Approximate soil thickness (ft)	0-50
Temperature (ºC)	9.9		
Conductivity (μS/cm)	459	Estimated recharge area (mi^2)	0.070
pH	7.72		

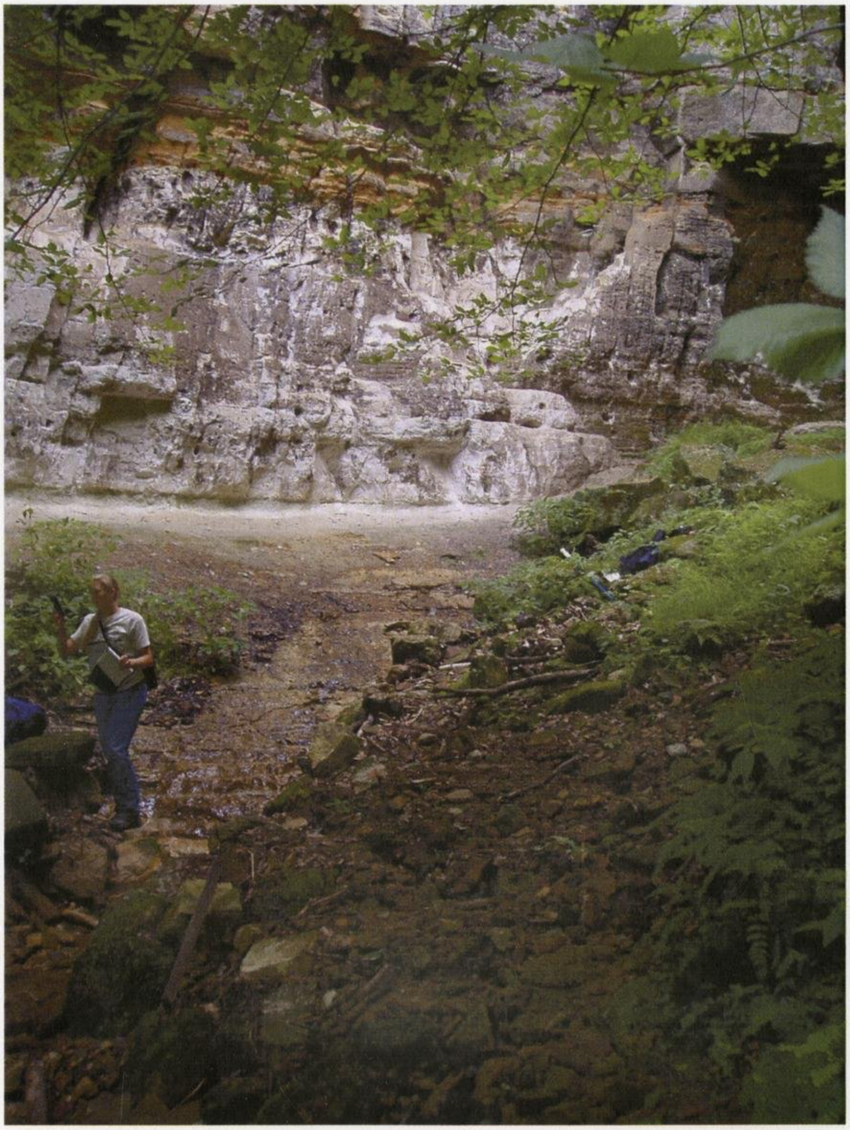
Description:

Spring is located at the end of Chapel trail, off the main trail from the parking lot on Fred Anderson Boy Scout Camp property. Spring is emerging between 2 layers of rock. The lower unit is medium grained, friable, oxidized sandstone. The upper unit is similar and is a very creamy, white, friable sandstone. Some layers have a blue-green tint. The measured discharge is approximate.

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones

Spring Survey, St. Croix County, Wisconsin

Sample ID	5	Land Use	Boy Scout Camp
Sample Date	7/26/2005		
7.5 Minute Quadrangle	Stillwater	Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Northing	4993045		
Easting	518418		
Discharge (cfs)	0.036	Approximate soil thickness (ft)	0-50
Temperature (°C)	9.9		
Conductivity (µS/cm)	459	Estimated recharge area (mi^2)	0.070
pH	7.72		



Spring Survey, St. Croix County, Wisconsin

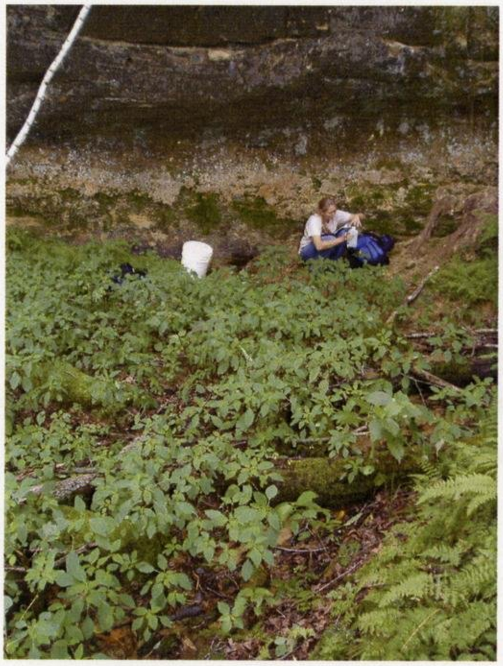
Sample ID	6
Sample Date	7/26/2005
7.5 Minute Quadrangle	Stillwater
Northing	4992758
Easting	517832
Discharge (cfs)	0.002
Temperature (ºC)	9.9
Conductivity (µS/cm)	760
pH	7.24

Land Use	Boy Scout Camp
Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.003

Description:

Walked down to the St. Croix River from a break in the fence off of the main trail on Fred Anderson Boy Scout Camp property, and then walked along the St. Croix River. The spring is emerging from a rock wall. The discharge is low and creates a small pond (maximum depth ~ 3 cm.).

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones



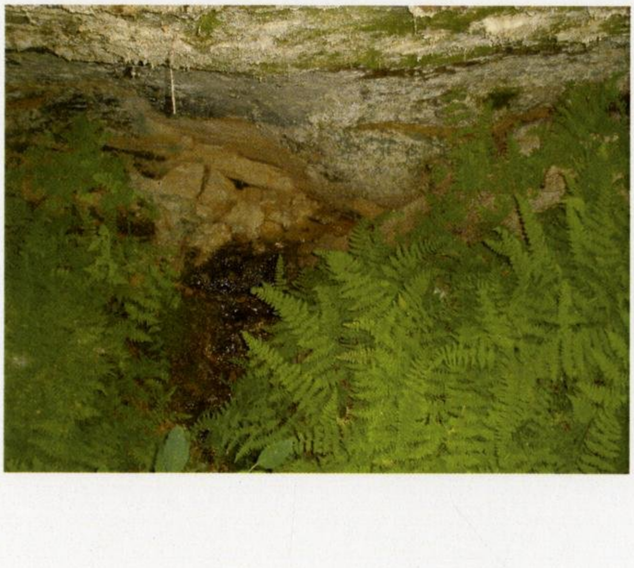
Spring Survey, St. Croix County, Wisconsin

Sample ID	7	Land Use	Boy Scout Camp
Sample Date	7/26/2005		
7.5 Minute Quadrangle	Stillwater	Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Northing	4992736		
Easting	517767		
Discharge (cfs)	0.002	Approximate soil thickness (ft)	0-50
Temperature (ºC)	9.2		
Conductivity (μS/cm)	783	Estimated recharge area (mi^2)	0.003
pH	6.67		

Description:

Walked down to the St. Croix River from a break in the fence off of the main trail on Fred Anderson Boy Scout Camp property, and then walked along St. Croix River away from the Boy Scout camp. There is a lot of vegetation surrounding this spring. (Note: this spring is located ~50 m from spring #6)

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones



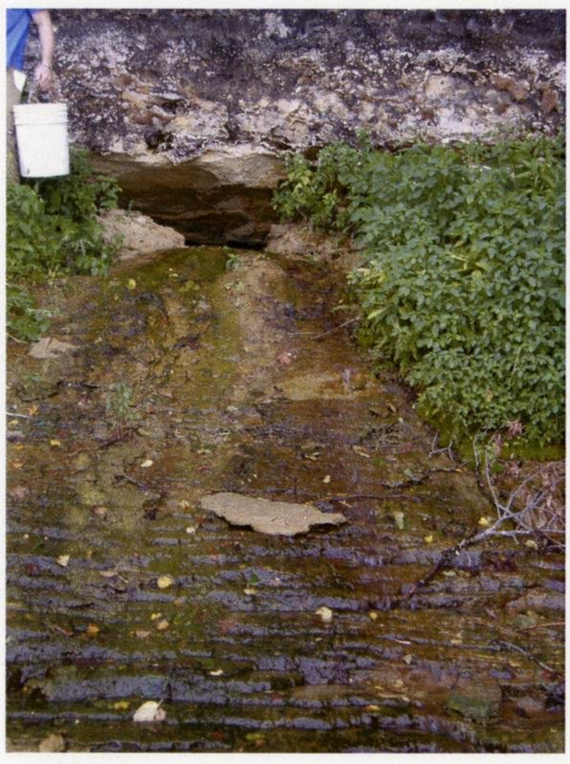
Spring Survey, St. Croix County, Wisconsin

Sample ID	8	Land Use	Boy Scout Camp
Sample Date	7/26/2005		
7.5 Minute Quadrangle	Stillwater	Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Northing	4992629		
Easting	517668		
Discharge (cfs)	0.300	Approximate soil thickness (ft)	0-50
Temperature (°C)	9.4		
Conductivity (μS/cm)	631	Estimated recharge area (mi^2)	0.582
pH	7.02		

Description:

Walked down to the St. Croix River from a break in the fence off of the main trail on Fred Anderson Boy Scout Camp property, and then walked along the St. Croix River. The spring is emerging from a rock wall. There is no vegetation surrounding this spring. There is a vertical opening (~75 cm in diameter) producing a 50 cm wide flow. The water from the spring flows over the bedrock to the St. Croix River, which is less than 10 m away. The discharge was estimated as 0.3 cfs based on visual observation of stream; the spring geometry made accurate discharge measurements difficult.

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones



Spring Survey, St. Croix County, Wisconsin

Sample ID	9
Sample Date	7/26/2005
7.5 Minute Quadrangle	Somerset South
Northing	4985212
Easting	525625
Discharge (cfs)	1.332
Temperature (ºC)	10.0
Conductivity (µS/cm)	439
pH	7.18

Land Use	Willow River State Park
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.9 (combined with spring 14)

Description:

Spring located on Willow River State Park property. To access the spring, follow the trail from the roadside parking lot down the hill. Spring is located under the foot bridge, on the side of the river with the scenic overlook. Area is highly vegetated with many moss covered rocks. The stream produced by the spring is flowing in the opposite direction of the river.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	9
Sample Date	11/12/2005
7.5 Minute Quadrangle	Somerset South
Northing	4985212
Easting	525625
Discharge (cfs)	1.332
Temperature (°C)	10.0
Conductivity (µS/cm)	4.39
pH	7.18

Land Use	Willow River State Park
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.9 (combined with spring 14)

Sum of anions (meq/L)	3.60
Sum of cations (meq/L)	4.6
Electrical balance (%)	+12.16
Residence time (years)	28

Total dissolved solids (mg/L)	306.75
Total hardness (mg/L $CaCO_3$)	219.65
Alkalinity (mg/L $CaCO_3$)	160.76
Ca/Mg (mol/L)	1.21
Calcite saturation index	4.21

Concentration (mg/L)

Na	4.10	Cl	6.00	As	<0.003	P	0.026
K	1.20	SO_4	8.73	Cu	<0.001	Pb	<0.002
Ca	48.13	NO_2+NO_3	3.14	Fe	0.004	Si	7.63
Mg	24.15	HCO_3	196.00	Mn	0.00058	Zn	<0.002

Description:

Spring located on Willow River State Park property. To access the spring, follow the trail from the roadside parking lot down the hill. Spring is located under the foot bridge, on the side of the river with the scenic overlook. Area is highly vegetated with many moss covered rocks. The stream produced by the spring is flowing in the opposite direction of the river.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	10
Sample Date	7/27/2005
7.5 Minute Quadrangle	Somerset North
Northing	4997106
Easting	520307
Discharge (cfs)	0.018
Temperature (ºC)	10.8
Conductivity (µS/cm)	299
pH	7.28

Land Use	Scenic Riverway
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.035

Description:

From Hwy 35, go west on 180th Ave. Turn right into a gated driveway after crossing railroad tracks. The land is now owned by the DNR, but the spring was used by the property owner over 20 yrs ago. The spring discharges from a pipe into the pond.

The unconsolidated material overlying the Eau Claire Formation at this spring is relatively shallow, but thicker soil layers are found over much of the recharge area for this spring. Much of the recharge to this spring probably occurs as percolation through this unconsolidated material, but the recharge may be channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation as flow approaches the discharge point.

Spring Survey, St. Croix County, Wisconsin

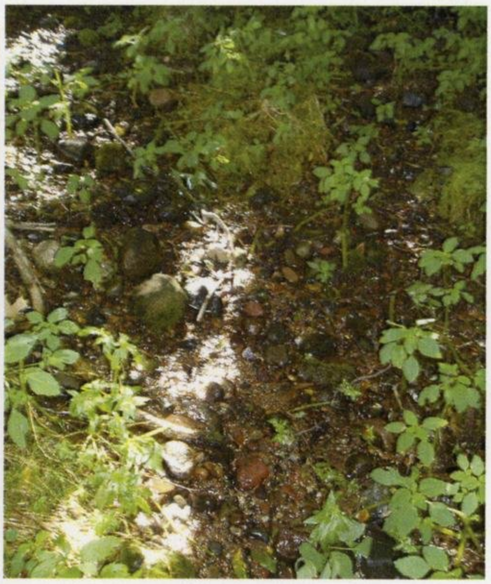
Sample ID	11
Sample Date	7/27/2005
7.5 Minute Quadrangle	Somerset North
Northing	4997670
Easting	520309
Discharge (cfs)	0.010
Temperature (°C)	10.3
Conductivity (µS/cm)	439
pH	7.72

Land Use	Scenic Riverway
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.019

Description:

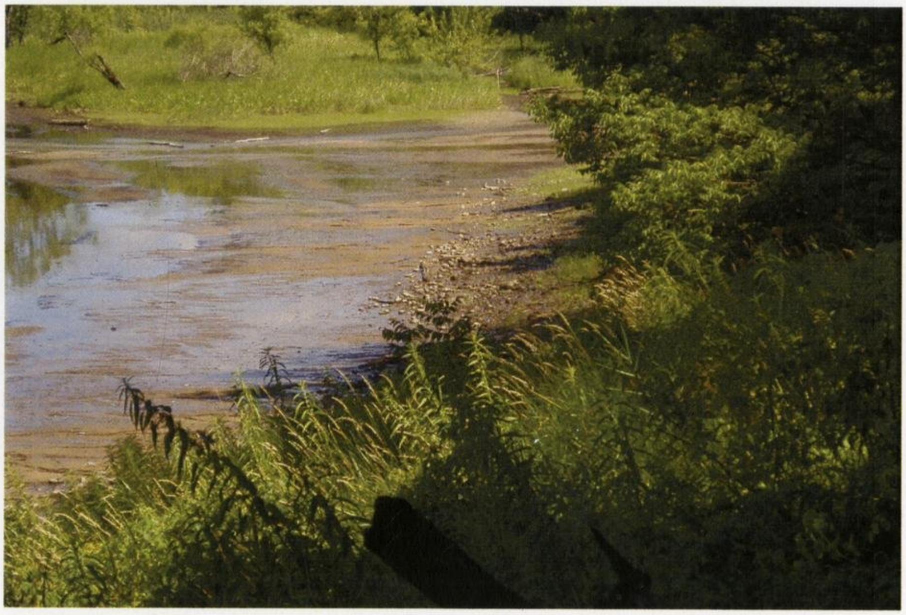
From Hwy 35, go west on 180th Ave. Turn right into a gated driveway after crossing railroad tracks. These springs are located on DNR property. To access these springs, drive down the driveway to some cabins, then follow an ~ 8 ft wide path to the area where multiple springs are flowing (path goes through the woods toward the river). These springs are hillside seepage that flows directly into the river. Considerable sediment was floating in the water discharged by the springs.

The unconsolidated material overlying the Eau Claire Formation at this spring is relatively shallow, but thicker soil layers are found over much of the recharge area for this spring. Much of the recharge to this spring probably occurs as percolation through this unconsolidated material, but the recharge may be channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation as flow approaches the discharge point.



Spring Survey, St. Croix County, Wisconsin

Sample ID	11	Land Use	Scenic Riverway
Sample Date	7/27/2005		
7.5 Minute Quadrangle	Somerset North	Uppermost bedrock unit at discharge point	Eau Claire Formation
Northing	4997670		
Easting	520309		
Discharge (cfs)	0.010	Approximate soil thickness (ft)	0-50
Temperature (ºC)	10.3		
Conductivity (µS/cm)	439	Estimated recharge area (mi^2)	0.019
pH	7.72		



Spring Survey, St. Croix County, Wisconsin

Sample ID	12	Land Use	Private Land
Sample Date	7/27/2005		
7.5 Minute Quadrangle	New Richmond South	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4988550		
Easting	536160		
Discharge (cfs)	0.934	Approximate soil thickness (ft)	0-50
Temperature (ºC)	9.4		
Conductivity (µS/cm)	536	Estimated recharge area (mi^2)	1.7
pH	7.60		

Sum of anions (meq/L)	3.99	Total dissolved solids (mg/L)	342.54
Sum of cations (meq/L)	5.53	Total hardness (mg/L $CaCO_3$)	263.24
Electrical balance (%)	+16.21	Alkalinity (mg/L $CaCO_3$)	157.47
Residence time (years)	23	Ca/Mg (mol/L)	1.29
		Calcite saturation index	4.68

Concentration (mg/L)

Na	5.70	Cl	16.50	As	<0.003	P	0.033
K	0.90	SO_4	11.40	Cu	<0.001	Pb	<0.002
Ca	59.40	NO_2+NO_3	11	Fe	0.001	Si	8.85
Mg	27.90	HCO_3	192.00	Mn	<0.001	Zn	<0.002

Description:

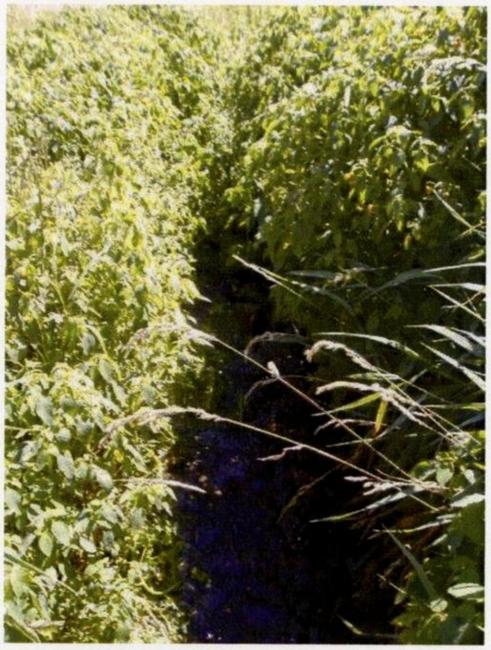
From Hwy 65, go west on 130th Ave. Property owner is Herman Keller.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	12
Sample Date	7/27/2005
7.5 Minute Quadrangle	New Richmond South
Northing	4988550
Easting	536160
Discharge (cfs)	0.934
Temperature (°C)	9.4
Conductivity (µS/cm)	536
pH	7.60

Land Use	Private Land
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.7



Spring Survey, St. Croix County, Wisconsin

Sample ID	12
Sample Date	11/12/2005
7.5 Minute Quadrangle	New Richmond South
Northing	4988550
Easting	536160
Discharge (cfs)	0.934
Temperature (°C)	9.4
Conductivity (μS/cm)	536
pH	7.60

Land Use	Private Land
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.7

Sum of anions (meq/L)	3.91
Sum of cations (meq/L)	5.36
Electrical balance (%)	+15.67
Residence time (years)	23

Total dissolved solids (mg/L)	335.85
Total hardness (mg/L $CaCO_3$)	255.46
Alkalinity (mg/L $CaCO_3$)	154.19
Ca/Mg (mol/L)	1.28
Calcite saturation index	4.56

Concentration (mg/L)

Na	5.20	Cl	12.50	As	<0.003	P	0.03
K	1.00	SO_4	17.14	Cu	0.001	Pb	<0.002
Ca	57.34	NO_2+NO_3	9.1	Fe	0.01	Si	9.13
Mg	27.26	HCO_3	188.00	Mn	0.00112	Zn	<0.002

Description:

From Hwy 65, go west on 130th Ave. Property owner is Herman Keller.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

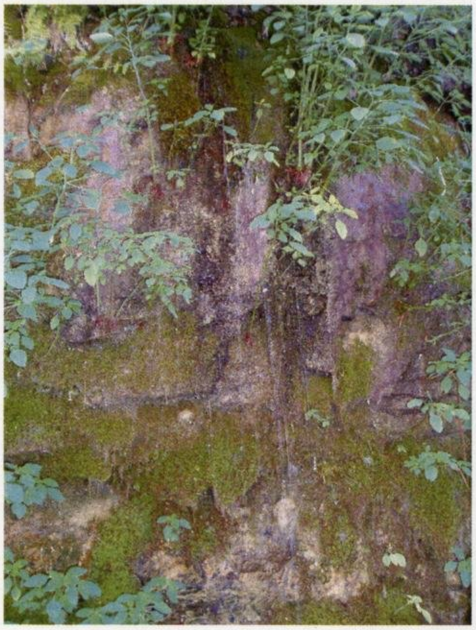
Spring Survey, St. Croix County, Wisconsin

Sample ID	13	Land Use	Willow River State Park
Sample Date	7/27/2005		
7.5 Minute Quadrangle	Somerset South	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4985227		
Easting	525640		
Discharge (cfs)	0.002	Approximate soil thickness (ft)	0-50
Temperature (°C)	11.9		
Conductivity (µS/cm)	502	Estimated recharge area (mi^2)	0.003
pH	7.66		

Description:

The spring is located on Willow River State Park property. To access the spring, follow the trail down the hill from the roadside parking lot. Many springs are located in the rock walls on the south bank of the Willow River Falls (free-flowing seepage from rock walls).

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.



Spring Survey, St. Croix County, Wisconsin

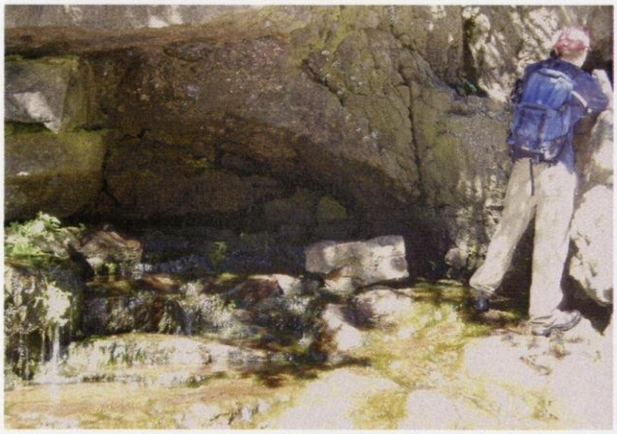
Sample ID	14
Sample Date	7/27/2005
7.5 Minute Quadrangle	Somerset South
Northing	4985204
Easting	525642
Discharge (cfs)	0.500
Temperature (°C)	10.6
Conductivity (µS/cm)	446
pH	7.57

Land Use	Willow River State Park
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.9 (combined with spring 9)

Description:

The spring is located on Willow River State Park property. To access the spring, follow the trail down the hill from the roadside parking lot. The spring is on the north side of the Willow River, east of the foot bridge; and emerges from between rock layers.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.



Spring Survey, St. Croix County, Wisconsin

Sample ID	14	Land Use	Willow River State Park
Sample Date	11/12/2005	Uppermost bedrock unit at discharge point	Prairie du Chien Group
7.5 Minute Quadrangle	Somerset South	Approximate soil thickness (ft)	0-50
Northing	4985204	Estimated recharge area (mi^2)	1.9 (combined with spring 9)
Easting	525642		
Discharge (cfs)	0.500		
Temperature (°C)	10.6		
Conductivity (μS/cm)	446		
pH	7.57		

Sum of anions (meq/L)	3.45	Total dissolved solids (mg/L)	295.12
Sum of cations (meq/L)	4.44	Total hardness (mg/L $CaCO_3$)	213.26
Electrical balance (%)	+12.54	Alkalinity (mg/L $CaCO_3$)	154.19
Residence time (years)	30	Ca/Mg (mol/L)	1.24
		Calcite saturation index	4.60

Concentration (mg/L)

Na	3.50	Cl	5.00	As	<0.003	P	0.012
K	1.00	SO_4	9.17	Cu	<0.001	Pb	<0.002
Ca	47.27	NO_2+NO_3	2.94	Fe	0.002	Si	7.55
Mg	23.12	HCO_3	188.00	Mn	<0.00005	Zn	<0.002

Description:

The spring is located on Willow River State Park property. To access the spring, follow the trail down the hill from the roadside parking lot. The spring is on the north side of the Willow River, east of the foot bridge; and emerges from between rock layers.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

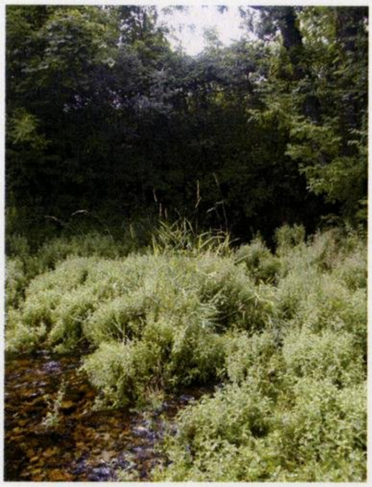
Spring Survey, St. Croix County, Wisconsin

Sample ID	15	Land Use	Recreation Area
Sample Date	7/28/2005		
7.5 Minute Quadrangle	Roberts	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4973135		
Easting	537195		
Discharge (cfs)	2.736	Approximate soil thickness (ft)	0-50
Temperature (ºC)	9.0		
Conductivity (µS/cm)	307	Estimated recharge area (mi^2)	4.7
pH	7.20		

Description:

To access the spring, take Hwy 65 to Cnty Rd J, and then turn right onto a private drive (fire # 1361,1363,1365). There is a small parking lot on the right hand side of the drive. Follow the path on public land (township owned), over a small bridge. When you get to the first bird house, go down into the woods (immediately after crossing a small bridge). The spring has eroded a channel ~1.5 m deep near the spring, and the spring emerges from some rocks at the mouth of the channel. The spring is within ~200 m of the parking lot.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.



Spring Survey, St. Croix County, Wisconsin

Sample ID	15
Sample Date	1/29/2006
7.5 Minute Quadrangle	Roberts
Northing	4973135
Easting	537195
Discharge (cfs)	
Temperature (°C)	8.1
Conductivity (μS/cm)	349
pH	7.22

Land Use	Recreation Area
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	4.7

Sum of anions (meq/L)	2.55
Sum of cations (meq/L)	3.02
Electrical balance (%)	+8.39
Residence time (years)	25

Total dissolved solids (mg/L)	200.47
Total hardness (mg/L $CaCO_3$)	142.34
Alkalinity (mg/L $CaCO_3$)	104.98
Ca/Mg (mol/L)	1.24
Calcite saturation index	4.01

Concentration (mg/L)

Na	3.10	Cl	5.00	As	<0.003	P	0.026
K	1.40	SO_4	13.43	Cu	0.001	Pb	<0.002
Ca	31.60	NO_2+NO_3	2.5	Fe	0.007	Si	5.29
Mg	15.40	HCO_3	128.00	Mn	0.0002	Zn	0.005

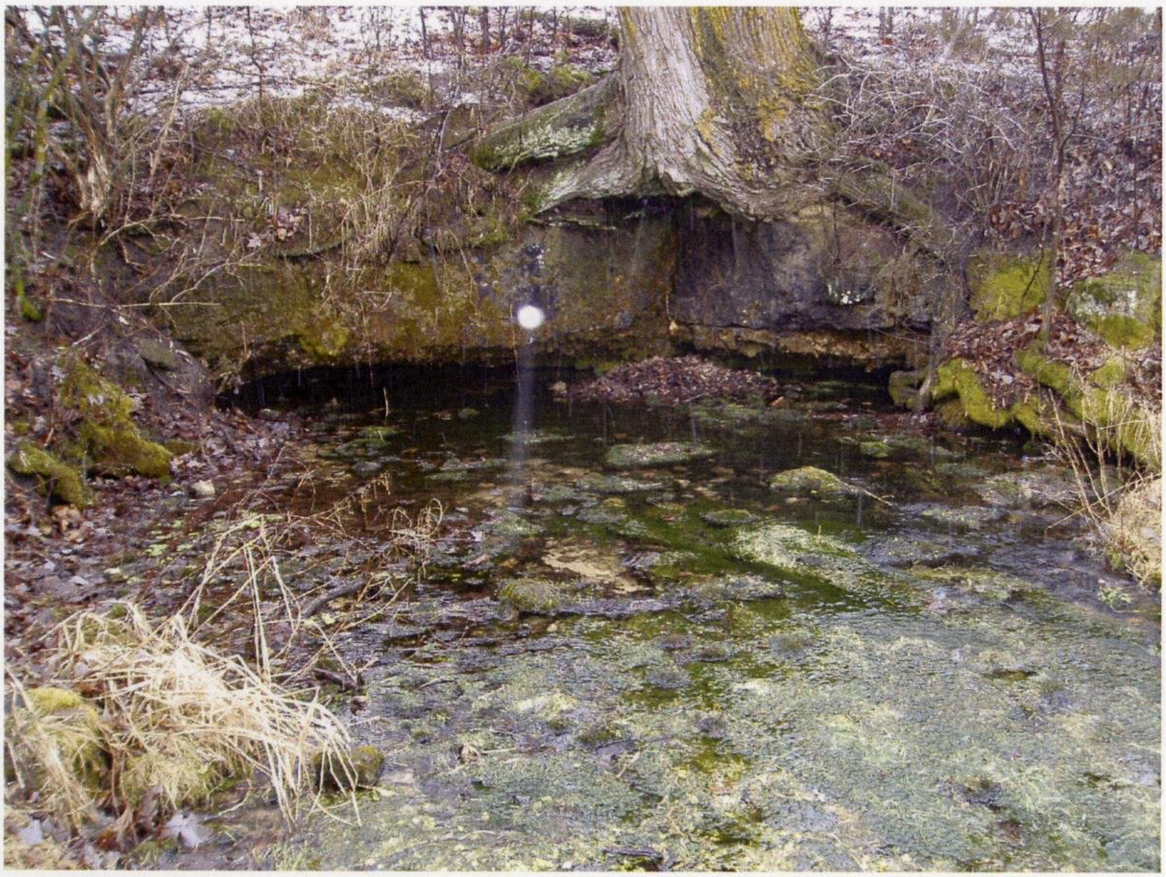
Description:

To access the spring, take Hwy 65 to Cnty Rd J, and then turn right onto a private drive (fire # 1361,1363,1365). There is a small parking lot on the right hand side of the drive. Follow the path on public land (township owned), over a small bridge. When you get to the first bird house, go down into the woods (immediately after crossing a small bridge). The spring has eroded a channel ~1.5 m deep near the spring, and the spring emerges from some rocks at the mouth of the channel. The spring is within ~200 m of the parking lot.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	15	Land Use	Recreation Area
Sample Date	1/29/2006		
7.5 Minute Quadrangle	Roberts	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4973135		
Easting	537195		
Discharge (cfs)		Approximate soil thickness (ft)	0-50
Temperature (ºC)	8.1		
Conductivity (µS/cm)	349	Estimated recharge area (mi^2)	4.7
pH	7.22		



Spring Survey, St. Croix County, Wisconsin

Sample ID	15	Land Use	Recreation Area
Sample Date	2/26/2006		
7.5 Minute Quadrangle	Roberts	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4973135		
Easting	537195		
Discharge (cfs)	2.730	Approximate soil thickness (ft)	0-50
Temperature (°C)	8.5		
Conductivity (µS/cm)	335	Estimated recharge area (mi^2)	4.7
pH	7.05		

Description:

To access the spring, take Hwy 65 to Cnty Rd J, and then turn right onto a private drive (fire # 1361,1363,1365). There is a small parking lot on the right hand side of the drive. Follow the path on public land (township owned), over a small bridge. When you get to the first bird house, go down into the woods (immediately after crossing a small bridge). The spring has eroded a channel ~1.5 m deep near the spring, and the spring emerges from some rocks at the mouth of the channel. The spring is within ~200 m of the parking lot.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	16	Land Use	River Edge
Sample Date	8/2/2005		
7.5 Minute Quadrangle	Stillwater	Uppermost bedrock unit at discharge point	Wonewoc Formation- Eau Claire Formation
Northing	4986733		
Easting	518677		
Discharge (cfs)	0.080	Approximate soil thickness (ft)	>100
Temperature (ºC)	10.7		
Conductivity (µS/cm)	450	Estimated recharge area (mi^2)	0.155
pH	7.23		

Description:

Approach spring from River Crest private road off of Hwy 35, north of Hudson (before Houlton). When the road curves to the right, park on the side of the road and follow the dirt/grass trail that continues straight. This path leads to the river. The spring discharges near the St. Croix River. Flow has been channelized into a pipe.

Relatively thick layers of unconsolidated material overlie the Cambrian sandstone bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

Sample ID	17
Sample Date	8/2/2005
7.5 Minute Quadrangle	Stillwater
Northing	4986699
Easting	518669
Discharge (cfs)	0.051
Temperature (ºC)	23.3
Conductivity (µS/cm)	508
pH	7.26

Land Use	River Edge
Uppermost bedrock unit at discharge point	Wonewoc Formation- Eau Claire Formation
Approximate soil thickness (ft)	>100
Estimated recharge area (mi^2)	0.099

Description:

Approach spring from River Crest private road off of Hwy 35, north of Hudson (before Houlton). When the road curves to the right, park on the side of the road and follow the dirt/grass trail that continues straight. This path leads to the river. A small spring comes out of the side of the hill near the trail. The temperature is probably influenced by stagnant surface water near the spring.

Relatively thick layers of unconsolidated material overlie the Cambrian sandstone bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

Sample ID	18	Land Use	River Edge
Sample Date	8/2/2005		
7.5 Minute Quadrangle	Stillwater	Uppermost bedrock unit at discharge point	Wonewoc Formation- Eau Claire Formation
Northing	4986827		
Easting	518477		
Discharge (cfs)	0.010	Approximate soil thickness (ft)	>100
Temperature (°C)			
Conductivity (μS/cm)		Estimated recharge area (mi²)	0.019
pH			

Description:

Approach spring from River Crest private road off of Hwy 35, north of Hudson (before Houlton). When the road curves to the right, park on the side of the road and follow the dirt/grass trail that continues straight. This path leads to the river. This spring is a muddy seep near the river bank. Rivulets were observed coming from bank, but the small size of the spring and lots of sediment in the water made accurate measurements difficult.

Relatively thick layers of unconsolidated material overlie the Cambrian sandstone bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

Sample ID	19
Sample Date	8/2/2005
7.5 Minute Quadrangle	Stillwater
Northing	4986820
Easting	518604
Discharge (cfs)	0.018
Temperature (°C)	9.1
Conductivity (µS/cm)	417
pH	7.69

Land Use	River Edge
Uppermost bedrock unit at discharge point	Wonewoc Formation- Eau Claire Formation
Approximate soil thickness (ft)	>100
Estimated recharge area (mi^2)	0.035

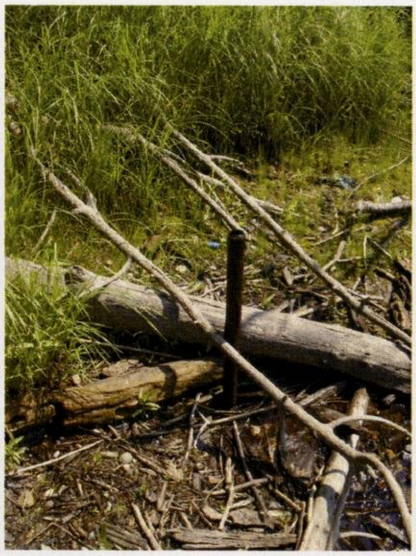
Description:

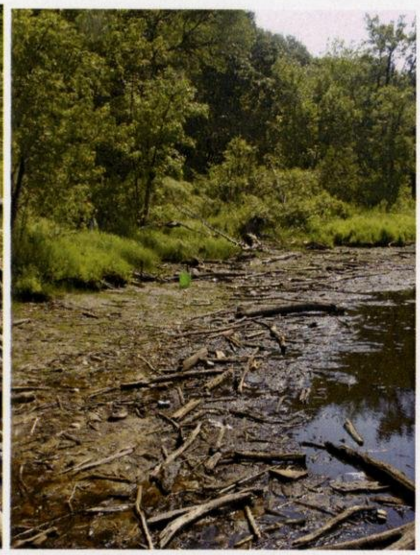
Approach spring from River Crest private road off of Hwy 35, north of Hudson (before Houlton). When the road curves to the right, park on the side of the road and follow the dirt/grass trail that continues straight. This path leads to the river. The spring is located in a backwater area of the St. Croix River and is surrounded by dense vegetation. Several springs discharge from vertical pipes in this area. Some pipes did not have discharge when the spring was found, but may flow at other times. The sampled spring discharged from a vertical pipe that extended a few centimeters above the land surface.

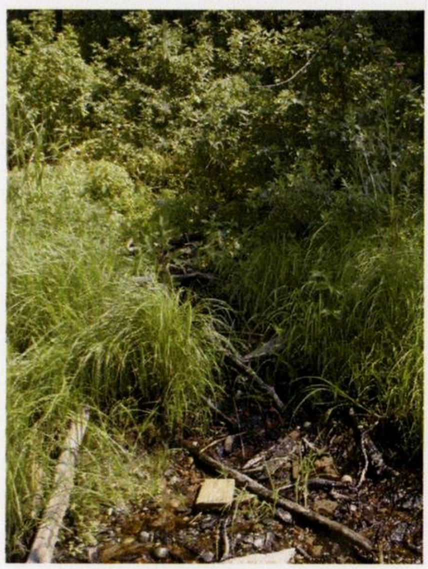
Relatively thick layers of unconsolidated material overlie the Cambrian sandstone bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

Sample ID	19	Land Use	River Edge
Sample Date	8/2/2005		
7.5 Minute Quadrangle	Stillwater	Uppermost bedrock unit at discharge point	Wonewoc Formation- Eau Claire Formation
Northing	4986820		
Easting	518604		
Discharge (cfs)	0.018	Approximate soil thickness (ft)	>100
Temperature (°C)	9.1		
Conductivity (μS/cm)	417	Estimated recharge area (mi^2)	0.035
pH	7.69		







Spring Survey, St. Croix County, Wisconsin

Sample ID	20
Sample Date	8/2/2005
7.5 Minute Quadrangle	Stillwater
Northing	4989184
Easting	524232
Discharge (cfs)	0.300
Temperature (°C)	
Conductivity (µS/cm)	
pH	

Land Use	Recreation Area
Uppermost bedrock unit at discharge point	Trempealeau Group
Approximate soil thickness (ft)	250-300
Estimated recharge area (mi^2)	0.582

Description:

Springs discharge at the bottom of Perch Lake. No springs were visible, but several people familiar with the lake spoke of feeling very cold areas in the midst of warm water at the lake bottom and of feeling water upwelling from the lake bottom, suggesting spring discharge into the lake. No perennial surface drainage enters or leaves the lake. No measurements were collected at this site since we could not directly access the springs.

Relatively thick layers of unconsolidated material overlie the Trempealeau Group bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material.

Spring Survey, St. Croix County, Wisconsin

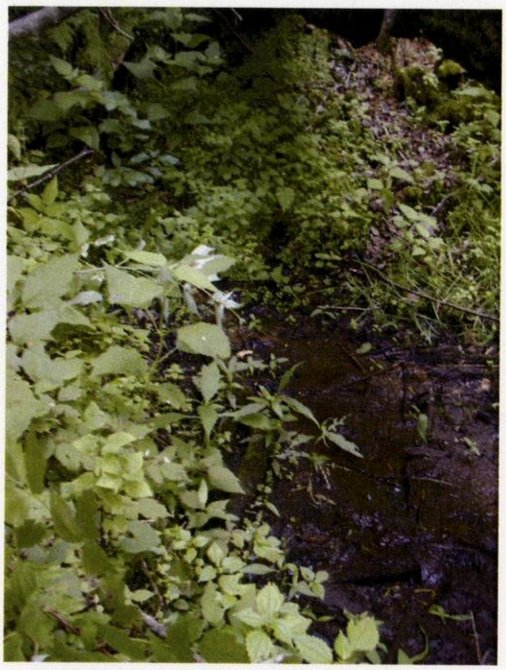
Sample ID	21
Sample Date	8/2/2005
7.5 Minute Quadrangle	Somerset South
Northing	4989731
Easting	523227
Discharge (cfs)	0.010
Temperature (ºC)	
Conductivity (μS/cm)	
pH	

Land Use	Pasture
Uppermost bedrock unit at discharge point	Tunnel City Group
Approximate soil thickness (ft)	300-350
Estimated recharge area (mi^2)	0.019

Description:

Intermittent spring located in ravine on farmer's land on Perch Lake Road off of Cnty Rd. E. The discharge was too low and the water was too muddy to take reliable measurements. Land owner is Lloyd Waldroff.

Relatively thick layers of unconsolidated material overlie the Tunnel City bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.



Spring Survey, St. Croix County, Wisconsin

Sample ID	22	Land Use	DNR Property
Sample Date	8/3/2005		
7.5 Minute Quadrangle	New Richmond South	Uppermost bedrock unit at discharge point	St. Peter Formation
Northing	4985756		
Easting	531658		
Discharge (cfs)	0.300	Approximate soil thickness (ft)	0-50
Temperature (°C)	8.9		
Conductivity (µS/cm)	512	Estimated recharge area (mi^2)	0.582
pH	7.34		

Description:

Hennessey Spring. Spring is discharging into the bottom of a creek and is located on the downstream side of a driveway, near the bank closest to the house. Discharge estimated as 0.3 cfs based on visual observation of stream, but the actual discharge could not be measured since discharge occurred within a stream.

The unconsolidated material overlying the St. Peter Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the St. Peter Formation.

Spring Survey, St. Croix County, Wisconsin

Sample ID	23
Sample Date	8/3/2005
7.5 Minute Quadrangle	New Richmond South
Northing	4985874
Easting	531720
Discharge (cfs)	1.428
Temperature (°C)	9.1
Conductivity (μS/cm)	495
pH	7.33

Land Use	DNR Property
Uppermost bedrock unit at discharge point	St. Peter Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	2.1

Sum of anions (meq/L)	3.86
Sum of cations (meq/L)	5.20
Electrical balance (%)	+14.82
Residence time (years)	21

Total dissolved solids (mg/L)	333.83
Total hardness (mg/L $CaCO_3$)	247.98
Alkalinity (mg/L $CaCO_3$)	164.04
Ca/Mg (mol/L)	1.43
Calcite saturation index	4.20

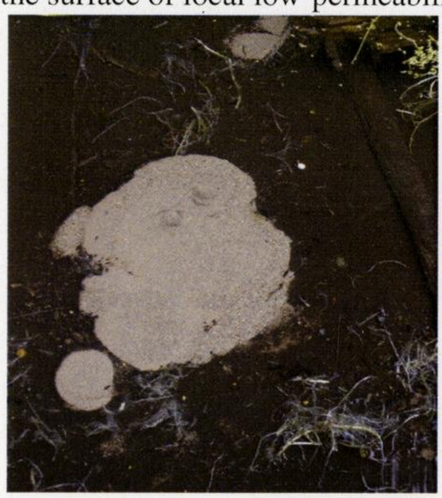
Concentration (mg/L)

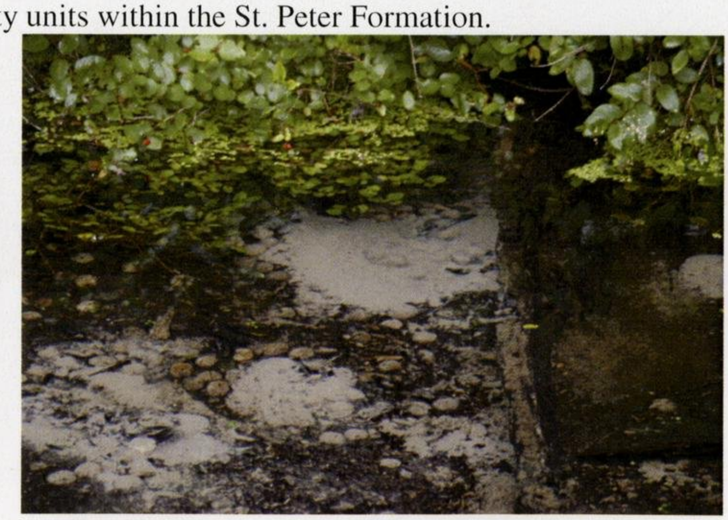
Na	4.80	Cl	10.00	As	<0.003	P	0.04
K	1.20	SO_4	10.57	Cu	0.002	Pb	<0.002
Ca	58.40	NO_2+NO_3	6.00	Fe	0.011	Si	9.00
Mg	24.80	HCO_3	200.00	Mn	0.001	Zn	0.005

Description:

Hennessey Spring. Approximately six separate areas with vigorous bubbling are found at the head of stream; numerous smaller bubbling areas are nearby. Spring is located on the upstream side of driveway. The owner has a trail through the trees leading to the spring.

The unconsolidated material overlying the St. Peter Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the St. Peter Formation.





Spring Survey, St. Croix County, Wisconsin

Sample ID	23
Sample Date	11/12/2005
7.5 Minute Quadrangle	New Richmond South
Northing	4985874
Easting	531720
Discharge (cfs)	1.428
Temperature (°C)	9.1
Conductivity (μS/cm)	495
pH	7.33

Land Use	DNR Property
Uppermost bedrock unit at discharge point	St. Peter Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	2.1

Sum of anions (meq/L)	3.86
Sum of cations (meq/L)	5.34
Electrical balance (%)	+15.99
Residence time (years)	21

Total dissolved solids (mg/L)	337.24
Total hardness (mg/L $CaCO_3$)	254.83
Alkalinity (mg/L $CaCO_3$)	164.04
Ca/Mg (mol/L)	1.44
Calcite saturation index	4.29

Concentration (mg/L)

Na	4.70	Cl	9.50	As	<0.003	P	0.039
K	1.40	SO_4	11.50	Cu	0.002	Pb	<0.002
Ca	60.14	NO_2+NO_3	6.20	Fe	0.002	Si	9.17
Mg	25.41	HCO_3	200.00	Mn	0.00008	Zn	<0.002

Description:

Hennessey Spring. Approximately six separate areas with vigorous bubbling are found at the head of stream; numerous smaller bubbling areas are nearby. Spring is located on the upstream side of driveway. The owner has a trail through the trees leading to the spring.

The unconsolidated material overlying the St. Peter Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the St. Peter Formation.

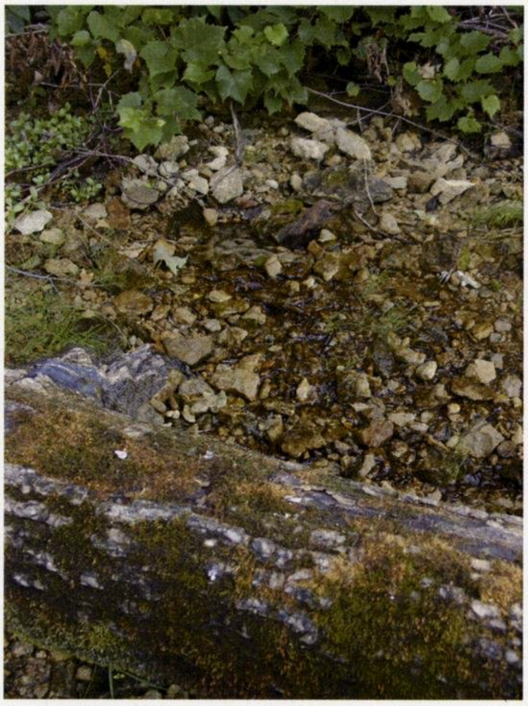
Spring Survey, St. Croix County, Wisconsin

Sample ID	24	Land Use	River Edge
Sample Date	8/3/2005		
7.5 Minute Quadrangle	Stillwater	Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Northing	4991570		
Easting	516530		
Discharge (cfs)	0.030	Approximate soil thickness (ft)	0-50
Temperature (°C)	8.8		
Conductivity (µS/cm)	515	Estimated recharge area (mi^2)	0.058
pH	7.38		

Description:

The spring is accessible from 1481 Pine Tree Lane by following the steps that go down to the river. The spring discharges from a vertical outlet above the river bank. Rocks have been placed around the spring mouth. The discharge is estimated as between 0.01 cfs and 0.05 cfs. (Note: When the river is high this spring would be hidden beneath river water.)

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones



Spring Survey, St. Croix County, Wisconsin

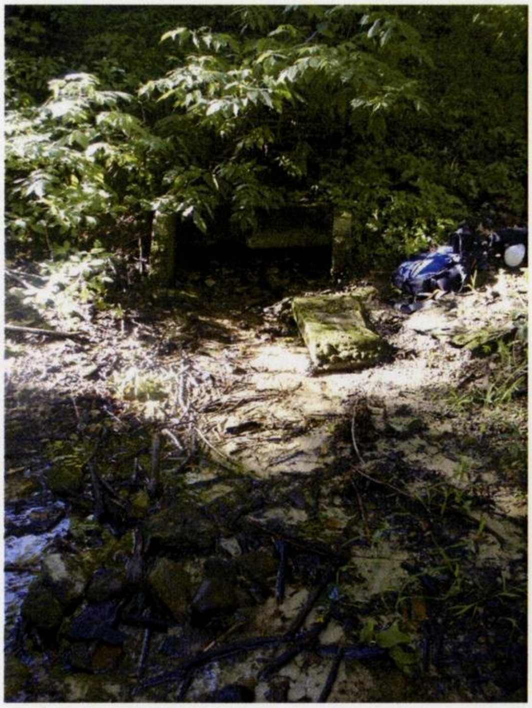
Sample ID	25
Sample Date	8/4/2005
7.5 Minute Quadrangle	Stillwater
Northing	4991555
Easting	516646
Discharge (cfs)	0.057
Temperature (°C)	9.0
Conductivity (μS/cm)	515
pH	7.37

Land Use	River Edge
Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.111

Description:

The spring is located in the backyard of the property at 1480 Pine Tree Lane. The spring is surrounded by large concrete blocks and used to be hooked up to a pipe. Presently, the water from the spring trickles down to the St. Croix River and is surrounded by typical spring vegetation. Sandstone bedrock is exposed as the bottom for most of the spring.

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones



Spring Survey, St. Croix County, Wisconsin

Sample ID	26
Sample Date	8/4/2005
7.5 Minute Quadrangle	Stillwater
Northing	4991598
Easting	516570
Discharge (cfs)	
Temperature (°C)	
Conductivity (µS/cm)	
pH	

Land Use	River Edge
Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	

Description:

There is evidence of an inactive spring (erosional patterns and mud).

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones

Spring Survey, St. Croix County, Wisconsin

Sample ID	27	Land Use	River Edge
Sample Date	8/4/2005		
7.5 Minute Quadrangle	Stillwater	Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Northing	4991539		
Easting	516471		
Discharge (cfs)	0.030	Approximate soil thickness (ft)	0-50
Temperature (°C)	18.8		
Conductivity (µS/cm)	588	Estimated recharge area (mi^2)	0.058
pH	8.29		

Description:

This spring discharges from bedrock and flows into the St. Croix River. The spring is most easily observed while walking along river and looking up at the bank. Accurate estimates of discharge were difficult to acquire, so discharge is estimated as between 0.01 cfs and 0.05 cfs.

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones

Spring Survey, St. Croix County, Wisconsin

Sample ID	28	Land Use	River Edge
Sample Date	8/4/2005		
7.5 Minute Quadrangle	Stillwater	Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Northing	4991500		
Easting	516424		
Discharge (cfs)	0.030	Approximate soil thickness (ft)	0-50
Temperature (ºC)	18.5		
Conductivity (µS/cm)	514	Estimated recharge area (mi^2)	0.058
pH	8.25		

Description:

The spring originates from bedrock in banks above the St. Croix River. We did not climb to the spring, so discharge was estimated as between 0.01 cfs and 0.05 cfs. The water temperature measured at the base of the bank may not be representative of the water discharging from the bedrock above.

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones

Spring Survey, St. Croix County, Wisconsin

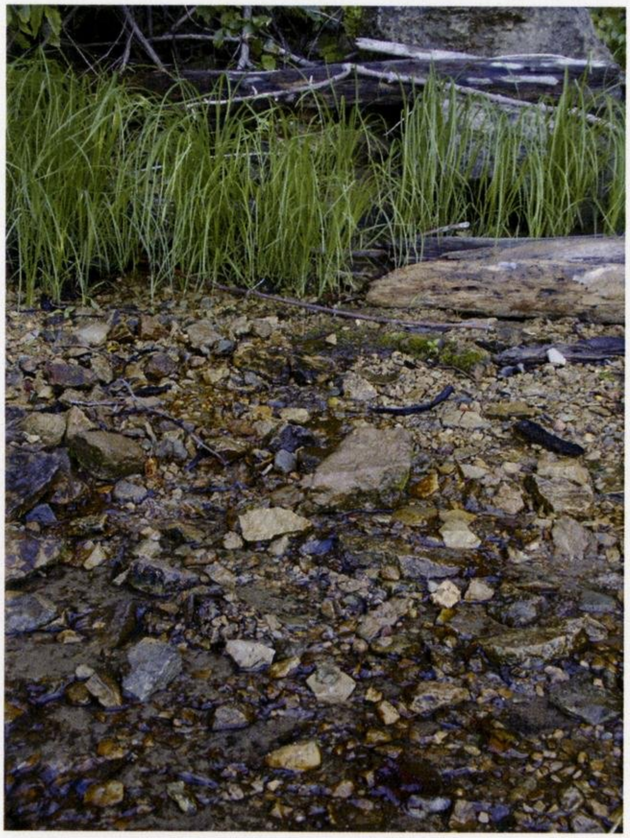
Sample ID	29
Sample Date	8/4/2005
7.5 Minute Quadrangle	Stillwater
Northing	4991374
Easting	516339
Discharge (cfs)	0.030
Temperature (°C)	9.1
Conductivity (µS/cm)	690
pH	7.38

Land Use	River Edge
Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.058

Description:

This spring emerges as seepage from a rocky beach near the river's edge. It is located by a private dock. The discharge was estimated as between 0.01 cfs and 0.05 cfs.

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones



Spring Survey, St. Croix County, Wisconsin

Sample ID	30
Sample Date	8/11/2005
7.5 Minute Quadrangle	Glenwood City
Northing	4995541
Easting	564703
Discharge (cfs)	1.490
Temperature (°C)	8.9
Conductivity (μS/cm)	557
pH	7.43

Land Use	Wooded
Uppermost bedrock unit at discharge point	Tunnel City Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	2.4

Description:

Spring located 10 m west of 310th St. on the north side of the bridge. (Spring may also be accessed by a trail ~100 m north of the bridge that leads directly to the spring.) The spring is obvious, approximately 1 to 2 m wide, and was bubbling slightly. Sand boils were observed at the discharge point. The spring was discharging from a sandstone hill and feeds Sandy Creek.

The unconsolidated material overlying the Tunnel City Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Tunnel City Group.

Spring Survey, St. Croix County, Wisconsin

Sample ID	30
Sample Date	1/18/2006
7.5 Minute Quadrangle	Glenwood City
Northing	4995541
Easting	564703
Discharge (cfs)	1.100
Temperature (°C)	7.5
Conductivity (µS/cm)	656
pH	7.39

Land Use	Wooded
Uppermost bedrock unit at discharge point	Tunnel City Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	2.4

Sum of anions (meq/L)	4.62
Sum of cations (meq/L)	5.73
Electrical balance (%)	+10.69
Residence time (years)	28

Total dissolved solids (mg/L)	381.68
Total hardness (mg/L $CaCO_3$)	273.48
Alkalinity (mg/L $CaCO_3$)	200.12
Ca/Mg (mol/L)	1.38
Calcite saturation index	4.39

Concentration (mg/L)

Na	4.90	Cl	14.00	As	<0.003	P	0.025
K	1.80	SO_4	8.72	Cu	<0.001	Pb	<0.002
Ca	63.50	NO_2+NO_3	3.50	Fe	0.008	Si	6.66
Mg	27.90	HCO_3	244.00	Mn	<0.001	Zn	<0.002

Description:

Spring located 10 m west of 310th St. on the north side of the bridge. (Spring may also be accessed by a trail ~100 m north of the bridge that leads directly to the spring.) The spring is obvious, approximately 1 to 2 m wide, and was bubbling slightly. Sand boils were observed at the discharge point. The spring was discharging from a sandstone hill and feeds Sandy Creek

The unconsolidated material overlying the Tunnel City Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Tunnel City Group.

Spring Survey, St. Croix County, Wisconsin

Sample ID	31
Sample Date	8/11/2005
7.5 Minute Quadrangle	Glenwood City
Northing	4995541
Easting	564703
Discharge (cfs)	0.300
Temperature (ºC)	8.8
Conductivity (µS/cm)	564
pH	7.63

Land Use	Wooded
Uppermost bedrock unit at discharge point	Tunnel City Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.582

Description:

This is a small spring located about 3 m west of a larger spring (spring #30). The larger spring is located 10 m west of 310th St. on the north side of the 310th St. bridge. The spring is discharging from the bank/wall. Sand boils were observed in the sandy spring bed. The discharge was estimated as 0.3 cfs based on visual observation of the spring, but the actual discharge could not be measured accurately.

The unconsolidated material overlying the Tunnel City Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Tunnel City Group.

Spring Survey, St. Croix County, Wisconsin

Sample ID	32
Sample Date	8/11/2005
7.5 Minute Quadrangle	Glenwood City
Northing	4995506
Easting	564740
Discharge (cfs)	0.011
Temperature (ºC)	10.7
Conductivity (µS/cm)	532
pH	7.54

Land Use	Wooded
Uppermost bedrock unit at discharge point	Tunnel City Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.021

Description:

Spring emerges as a trickle between rocks. The spring is located directly under the bridge on the northern side.

The unconsolidated material overlying the Tunnel City Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Tunnel City Group.

Spring Survey, St. Croix County, Wisconsin

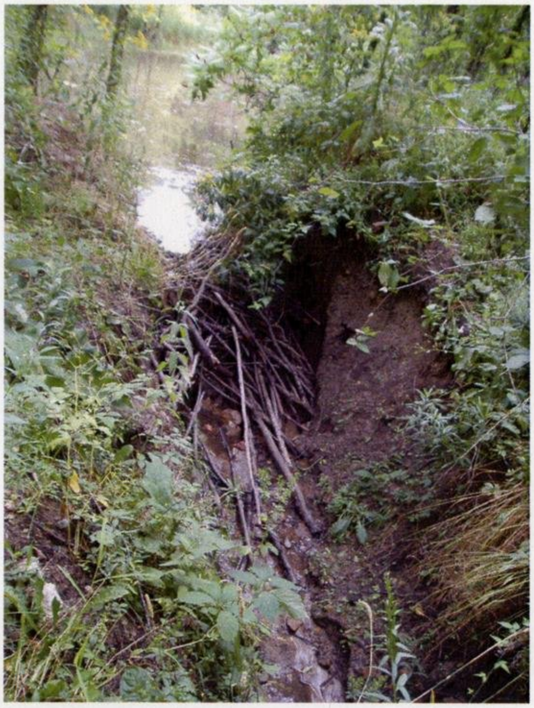
Sample ID	33
Sample Date	8/11/2005
7.5 Minute Quadrangle	Glenwood City
Northing	4993932
Easting	566135
Discharge (cfs)	0.014
Temperature (°C)	19.5
Conductivity (μS/cm)	172
pH	7.32

Land Use	Wooded
Uppermost bedrock unit at discharge point	Tunnel City Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.028

Description:

Spring is located off of Hwy X directly across from Sandy Creek Rd. (at corner). Address is 1650 Glenwood Twp.

The unconsolidated material overlying the Tunnel City Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Tunnel City Group.



Spring Survey, St. Croix County, Wisconsin

Sample ID	34	Land Use	Pasture
Sample Date	8/10/2005		
7.5 Minute Quadrangle	Wilson (Dunn Co.)	Uppermost bedrock unit at discharge point	Tunnel City Group – Eau Claire Formation
Northing	4982993		
Easting	568685		
Discharge (cfs)	0.033	Approximate soil thickness (ft)	0-50
Temperature (ºC)	19.5		
Conductivity (µS/cm)	855	Estimated recharge area (mi^2)	0.063
pH	7.34		

Description:

Spring is located at 8733-8735 N Stanton in Dunn Co. Follow the creek that veers right around the house and through a pasture. The spring is located immediately before a refuse pile.

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones

Spring Survey, St. Croix County, Wisconsin

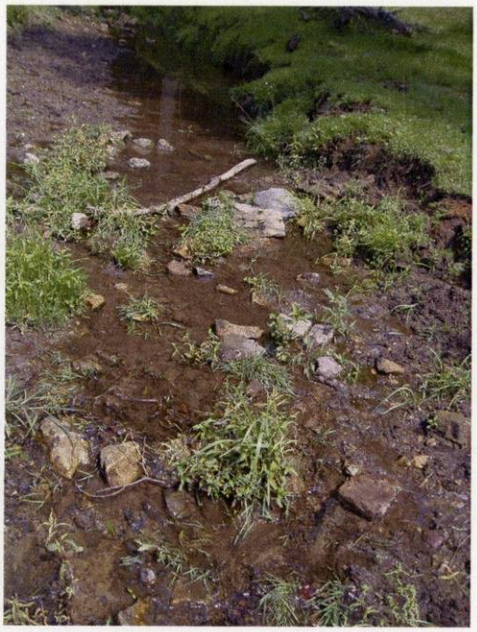
Sample ID	35
Sample Date	8/10/2005
7.5 Minute Quadrangle	Wilson (Dunn Co.)
Northing	4982540
Easting	568368
Discharge (cfs)	0.300
Temperature (ºC)	16.1
Conductivity (µS/cm)	518
pH	7.68

Land Use	Pasture/Wooded
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.582

Description:

Spring located at 8733-8735 N Stanton in Dunn Co. Follow the creek that veers left around the house and into the woods. The streambed appears to have abundant spring activity. The discharge was estimated as 0.3 cfs based on visual observation of stream, but the actual spring discharge could not be measured.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.



Spring Survey, St. Croix County, Wisconsin

Sample ID	36
Sample Date	8/10/2005
7.5 Minute Quadrangle	Wilson (Dunn Co.)
Northing	4982562
Easting	568459
Discharge (cfs)	0.010
Temperature (ºC)	14.2
Conductivity (µS/cm)	501
pH	7.67

Land Use	Pasture/Wooded
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.019

Description:

Spring located at 8733-8735 N Stanton in Dunn Co. Follow the creek that veers left around the house and into the woods. The spring discharges from the creek bank. Bubbles were also observed in the creek bed.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	37	Land Use	Pasture
Sample Date	8/9/2005		
7.5 Minute Quadrangle	Wilson (Dunn Co.)	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4970572		
Easting	568834		
Discharge (cfs)	0.009	Approximate soil thickness (ft)	0-50
Temperature (°C)	16.3		
Conductivity (µS/cm)	342	Estimated recharge area (mi^2)	0.017
pH	7.89		

Description:

Spring is the head of Gilbert Creek at Lucass N5666 off of 50th St. The spring is located on a horse ranch. The owner says the discharge is much greater in other seasons.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

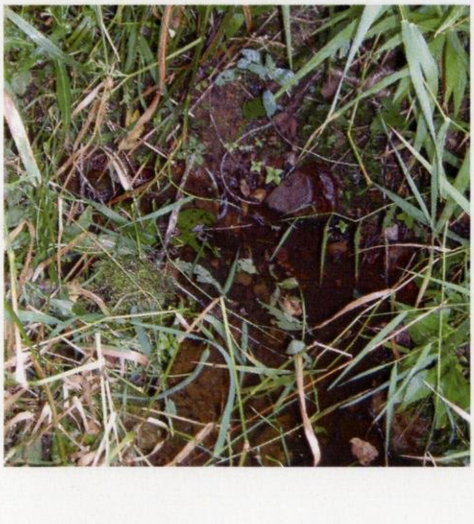
Sample ID	38
Sample Date	8/9/2005
7.5 Minute Quadrangle	Wilson
Northing	4977493
Easting	566786
Discharge (cfs)	0.009
Temperature (ºC)	13.7
Conductivity (µS/cm)	568
pH	7.64

Land Use	Wooded
Uppermost bedrock unit at discharge point	Trempealeau Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.017

Description:

To access the spring, follow Wilson Creek westward and follow the north-branching tributary.

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.



Spring Survey, St. Croix County, Wisconsin

Sample ID	39
Sample Date	8/9/2005
7.5 Minute Quadrangle	Wilson
Northing	4977445
Easting	566836
Discharge (cfs)	0.010
Temperature (°C)	14.0
Conductivity (µS/cm)	563
pH	7.92

Land Use	Wooded
Uppermost bedrock unit at discharge point	Trempealeau Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.019

Description:

To access the spring, follow Wilson Creek westward and follow the north-branching tributary. The spring discharges from the stream bank; bubbles were observed emerging from the spring. The discharge was difficult to measure accurately since the spring discharged below/at the water level of the creek, so the discharge was estimated as approximately 0.01 cfs.

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.

Spring Survey, St. Croix County, Wisconsin

Sample ID	40	Land Use	Wooded
Sample Date	8/2/2005		
7.5 Minute Quadrangle	Graytown	Uppermost bedrock unit at discharge point	Trempealeau Group
Northing	5000616		
Easting	565694		
Discharge (cfs)	0.010	Approximate soil thickness (ft)	0-50
Temperature (ºC)	17.9		
Conductivity (µS/cm)	401	Estimated recharge area (mi^2)	0.019
pH	7.57		

Description:

Spring is located off of 307th St. To access the spring, cross the bridge and then follow the creek upstream to the east until you reach a rock wall overhang.

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.

Spring Survey, St. Croix County, Wisconsin

Sample ID	41	Land Use	Pasture
Sample Date	8/10/2005		
7.5 Minute Quadrangle	Wilson	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4981756		
Easting	564077		
Discharge (cfs)		Approximate soil thickness (ft)	0-50
Temperature (°C)			
Conductivity (µS/cm)		Estimated recharge area (mi^2)	
pH			

Description:

This spring was dry when we visited it, but there are signs that the spring seasonally flows into the nearby pond. A well is located directly north of the pond.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	42	Land Use	Wooded
Sample Date	8/9/2005		
7.5 Minute Quadrangle	Wilson	Uppermost bedrock unit at discharge point	Trempealeau Group
Northing	4976904		
Easting	567216		
Discharge (cfs)		Approximate soil thickness (ft)	0-50
Temperature (°C)			
Conductivity (µS/cm)		Estimated recharge area (mi^2)	
pH			

Description:

This spring was dry when we visited it on 8-9-2005, but we observed it flowing at a rate of ~ 0.05 cfs in June 2005. The property owners report that it usually flows continuously and that they had not observed it dry previously. The spring had typical spring vegetation including abundant watercress.

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.

Spring Survey, St. Croix County, Wisconsin

Sample ID	43	Land Use	Wooded
Sample Date	8/9/2005		
7.5 Minute Quadrangle	Wilson	Uppermost bedrock unit at discharge point	Trempealeau Group
Northing	4977084		
Easting	567568		
Discharge (cfs)	0.413	Approximate soil thickness (ft)	0-50
Temperature (°C)	9.6		
Conductivity (μS/cm)	416	Estimated recharge area (mi^2)	0.801
pH	7.80		

Description:

To access this spring, follow the path leading from the road. The path will cross some small streams and then continue through the forest. Where the path makes a 90 degree turn, continue straight, with a pasture on the left and woods on the right, following a fence line. The spring is located in the swampy area in the woods on the right, 30-50 m from the pasture. The spring is covered in water cress but was flowing well. The measured discharge is probably less than the actual discharge due to difficulties in measuring the entire area over which discharge occurred.

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.

Spring Survey, St. Croix County, Wisconsin

Sample ID	43
Sample Date	1/29/2006
7.5 Minute Quadrangle	Wilson
Northing	4977084
Easting	567568
Discharge (cfs)	0.184
Temperature (°C)	5.4
Conductivity (µS/cm)	505
pH	7.62

Land Use	Wooded
Uppermost bedrock unit at discharge point	Trempealeau Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.357

Sum of anions (meq/L)	3.56
Sum of cations (meq/L)	4.20
Electrical balance (%)	+8.27
Residence time (years)	

Total dissolved solids (mg/L)	289.94
Total hardness (mg/L $CaCO_3$)	197.15
Alkalinity (mg/L $CaCO_3$)	150.91
Ca/Mg (mol/L)	1.17
Calcite saturation index	4.76

Concentration (mg/L)

Na	5.30	Cl	12.00	As	<0.003	P	0.025
K	1.00	SO_4	8.11	Cu	0.005	Pb	<0.002
Ca	42.50	NO_2+NO_3	2.70	Fe	0.056	Si	6.05
Mg	22.10	HCO_3	184.00	Mn	0.0126	Zn	0.022

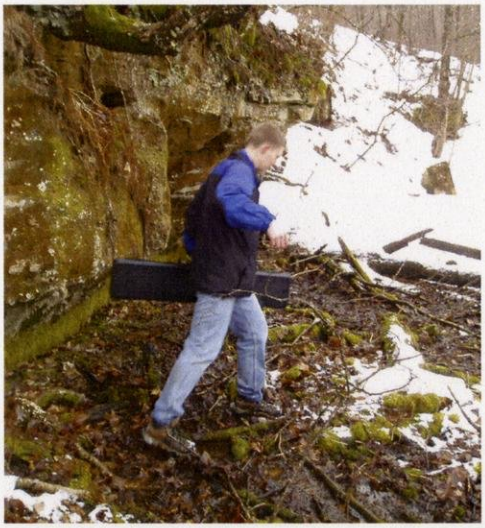
Description:

To access this spring, follow the path leading from the road. The path will cross some small streams and then continue through the forest. Where the path makes a 90 degree turn, continue straight, with a pasture on the left and woods on the right, following a fence line. The spring is located in the swampy area in the woods on the right, 30-50 m from the pasture. The spring is covered in water cress but was flowing well. The measured discharge is probably less than the actual discharge due to difficulties in measuring the entire area over which discharge occurred.

The unconsolidated material overlying the Trempealeau Group at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Trempealeau Group.

Spring Survey, St. Croix County, Wisconsin

Sample ID	43	Land Use	Wooded
Sample Date	1/29/2006		
7.5 Minute Quadrangle	Wilson	Uppermost bedrock unit at discharge point	Trempealeau Group
Northing	4977084		
Easting	567568		
Discharge (cfs)	0.184	Approximate soil thickness (ft)	0-50
Temperature (ºC)	5.4		
Conductivity (μS/cm)	505	Estimated recharge area (mi^2)	0.357
pH	7.62		



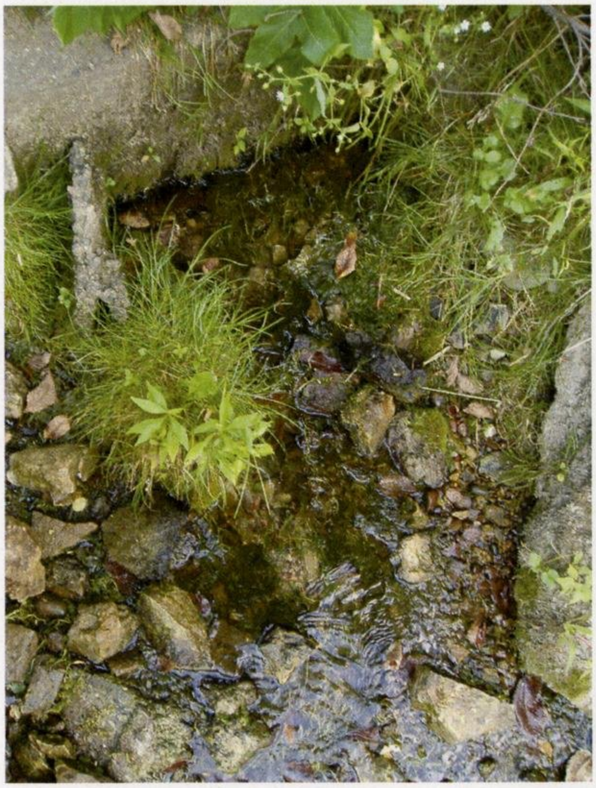
Spring Survey, St. Croix County, Wisconsin

Sample ID	44	Land Use	River Edge
Sample Date	8/16/2005		
7.5 Minute Quadrangle	Jewett	Uppermost bedrock unit at discharge point	St. Peter Formation
Northing	4995587		
Easting	542959		
Discharge (cfs)	0.013	Approximate soil thickness (ft)	0-50
Temperature (°C)	9.9		
Conductivity (µS/cm)	439	Estimated recharge area (mi^2)	0.025
pH	7.43		

Description:

Spring is located at 1747 Erin Prairie at "Willow Run", directly behind a house on the bank of the Willow River. Spring discharges from a concrete slab. The spring appears to have been developed at one time. The discharge was difficult to measure accurately, so the given discharge is an estimate.

The unconsolidated material overlying the St. Peter Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the St. Peter Formation.



Spring Survey, St. Croix County, Wisconsin

Sample ID	45	Land Use	River Edge
Sample Date	8/16/2005		
7.5 Minute Quadrangle	Jewett	Uppermost bedrock unit at discharge point	St. Peter Formation
Northing	4995582		
Easting	542968		
Discharge (cfs)	0.002	Approximate soil thickness (ft)	0-50
Temperature (°C)	10.3		
Conductivity (µS/cm)	420	Estimated recharge area (mi^2)	0.004
pH	7.74		

Description:

Spring is located at 1747 Erin Prairie at "Willow Run", directly behind a house on the bank of the Willow River. The spring discharges directly from the bank, but there are also sand boils where the spring meets the river. The spring is located underneath a bench placed by the land owner.

The unconsolidated material overlying the St. Peter Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the St. Peter Formation.

Spring Survey, St. Croix County, Wisconsin

Sample ID	46	Land Use	River Edge
Sample Date	8/16/2005		
7.5 Minute Quadrangle	Jewett	Uppermost bedrock unit at discharge point	St. Peter Formation
Northing	4995588		
Easting	542973		
Discharge (cfs)	0.011	Approximate soil thickness (ft)	0-50
Temperature (°C)	10.2		
Conductivity (µS/cm)	440	Estimated recharge area (mi^2)	0.021
pH	7.66		

Description:

Spring is located at 1747 Erin Prairie at "Willow Run", directly behind a house on the bank of the Willow River. Spring discharges directly from bank into a very rocky area.

The unconsolidated material overlying the St. Peter Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the St. Peter Formation.

Spring Survey, St. Croix County, Wisconsin

Sample ID	47
Sample Date	1/18/2006
7.5 Minute Quadrangle	Jewett
Northing	4994904
Easting	542977
Discharge (cfs)	1.240
Temperature (°C)	7.5
Conductivity (µS/cm)	501
pH	7.81

Land Use	Marshy(Grassy Wetland)/Forest
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	2.5

Sum of anions (meq/L)	3.50
Sum of cations (meq/L)	4.60
Electrical balance (%)	+13.54
Residence time (years)	27

Total dissolved solids (mg/L)	298.39
Total hardness (mg/L $CaCO_3$)	218.72
Alkalinity (mg/L $CaCO_3$)	144.35
Ca/Mg (mol/L)	1.24
Calcite saturation index	4.62

Concentration (mg/L)

Na	4.40	Cl	12.00	As	<0.003	P	0.04
K	1.30	SO_4	9.07	Cu	0.003	Pb	<0.002
Ca	48.50	NO_2+NO_3	7.10	Fe	0.01	Si	8.12
Mg	23.70	HCO_3	176.00	Mn	<0.001	Zn	0.025

Description:

Spring is located between 1729 and 1715 on 170 Ave. The spring is on the south (upstream) side of the bridge on 170th Ave, approximately 20 m from the road. Spring is ~ 1-2 m wide and about 10 cm deep. It is in the SE branch upstream from the culvert. The spring was bubbling (sometimes audibly) and is surrounded by typical spring vegetation.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	48	Land Use	River Edge
Sample Date	8/17/2005		
7.5 Minute Quadrangle	Baldwin West	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4970227		
Easting	546418		
Discharge (cfs)	0.300	Approximate soil thickness (ft)	0-50
Temperature (°C)	17.5		
Conductivity (µS/cm)	484	Estimated recharge area (mi^2)	0.582
pH	7.82		

Description:

The spring is located along the Rush River just north of Centerville. The spring discharges into the stream bed; sand boils and vigorous bubbling were observed. The discharge was estimated as 0.3 cfs based on visual observation of the spring, but could not be measured independently of the stream flow.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	49
Sample Date	8/17/2005
7.5 Minute Quadrangle	Baldwin West
Northing	4971663
Easting	540667
Discharge (cfs)	0.037
Temperature (ºC)	18.1
Conductivity (μS/cm)	342
pH	7.84

Land Use	(DNR) Pasture/Locally Wooded
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.072

Description:

From the east side of the bridge on Cnty Rd. W, follow the creek upstream. The spring discharges directly out of the left bank (when facing upstream) into the river. The spring bed is sandy to gravelly.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	50	Land Use	(DNR) Pasture/Locally Wooded
Sample Date	8/17/2005		
7.5 Minute Quadrangle	Baldwin West	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4971584		
Easting	540784		
Discharge (cfs)	0.008	Approximate soil thickness (ft)	0-50
Temperature (°C)	13.9		
Conductivity (µS/cm)	434	Estimated recharge area (mi^2)	0.016
pH	7.56		

Description:

From the east side of the bridge on Cnty Rd. W, follow the creek upstream. There are two small springs located approximately 2m apart. Both springs discharge from the bank through mud and trickle down to the creek. Discharge is steady but low and was difficult to measure accurately.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	51	Land Use	(DNR) Pasture/Locally Wooded
Sample Date	8/17/2005		
7.5 Minute Quadrangle	Baldwin West	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	540815		
Easting	4971567		
Discharge (cfs)	0.010	Approximate soil thickness (ft)	0-50
Temperature (°C)			
Conductivity (µS/cm)		Estimated recharge area (mi^2)	0.019
pH			

Description:

From the east side of the bridge on Cnty Rd. W, follow the creek upstream. Although the spring discharge at the time of measurement was low, the spring mouth had a fairly wide channel, suggesting that discharge may be much greater at different times.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	52	Land Use	(DNR) Pasture/Locally Wooded
Sample Date	8/17/2005		
7.5 Minute Quadrangle	Baldwin West	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4971362		
Easting	540786		
Discharge (cfs)	0.100	Approximate soil thickness (ft)	0-50
Temperature (°C)	18.7		
Conductivity (µS/cm)	337	Estimated recharge area (mi^2)	0.582
pH	7.64		

Description:

From the east side of the bridge on Cnty Rd. W, follow the creek upstream, and then follow the tributary branching to the right. The spring has a gravelly bed, but discharge flows over gravel into mud. Numerous other inlets flowing into the stream suggest that this is a spring seepage area, although we did not attempt to identify all the seepage as springs. Discharge was estimated as 0.1 cfs based on visual observation of stream, but accurate measurements of the discharge were difficult.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	53
Sample Date	8/18/2005
7.5 Minute Quadrangle	Martell
Northing	4968445
Easting	546694
Discharge (cfs)	0.010
Temperature (ºC)	13.5
Conductivity (μS/cm)	479
pH	7.42

Land Use	Pasture
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.019

Description:

Spring is located behind 50 Rush River north of Centerville. Follow the Rush River north from Y at bridge. The spring discharges through a pool (flow enters the pool from a generally swampy area) and then joins the feeder stream discharging into the Rush River.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	54
Sample Date	8/18/2005
7.5 Minute Quadrangle	Martell
Northing	4968525
Easting	546708
Discharge (cfs)	3.200
Temperature (°C)	10.1
Conductivity (µS/cm)	472
pH	7.75

Land Use	Pasture
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	5.1

Description:

Spring is located behind 50 Rush River north of Centerville. Follow the creek behind the house north (upstream) past live electric fences. The headwaters of the creek are a swampy region with many fingering seepage sources. The creek bottom consists of sand and gravel. Discharge was measured at the bridge (UTMs 546711, 4968470).

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	54
Sample Date	1/29/2006
7.5 Minute Quadrangle	Martell
Northing	4968525
Easting	546708
Discharge (cfs)	3.580
Temperature (ºC)	7.4
Conductivity (µS/cm)	564
pH	7.44

Land Use	Pasture
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	5.1

Sum of anions (meq/L)	3.84
Sum of cations (meq/L)	4.63
Electrical balance (%)	+9.29
Residence time (years)	23

Total dissolved solids (mg/L)	312.08
Total hardness (mg/L $CaCO_3$)	214.54
Alkalinity (mg/L $CaCO_3$)	150.91
Ca/Mg (mol/L)	1.35
Calcite saturation index	4.38

Concentration (mg/L)

Na	6.70	Cl	17.50	As	<0.003	P	0.04
K	1.70	SO_4	12.35	Cu	0.001	Pb	<0.002
Ca	49.30	NO_2+NO_3	5.70	Fe	0.038	Si	6.27
Mg	22.20	HCO_3	184.00	Mn	0.0055	Zn	<0.001

Description:

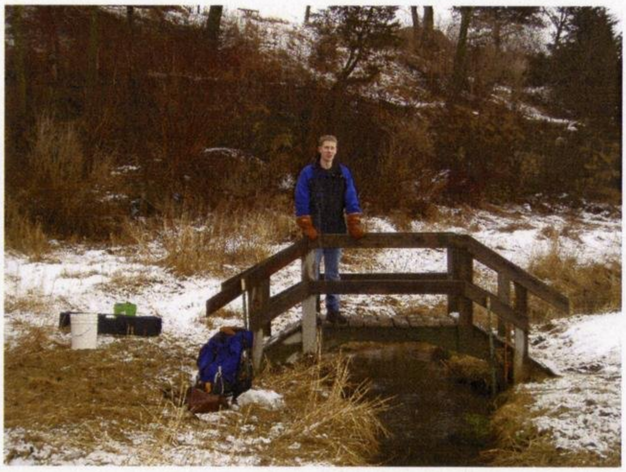
Spring is located behind 50 Rush River north of Centerville. Follow the creek behind the house north (upstream) past live electric fences. The headwaters of the creek are a swampy region with many fingering seepage sources. The creek bottom consists of sand and gravel. Discharge was measured at the bridge (UTMs 546711, 4968470).

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

Spring Survey, St. Croix County, Wisconsin

Sample ID	54
Sample Date	1/29/2006
7.5 Minute Quadrangle	Martell
Northing	4968525
Easting	546708
Discharge (cfs)	3.580
Temperature (°C)	7.4
Conductivity (μS/cm)	564
pH	7.44

Land Use	Pasture
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	5.1



Spring Survey, St. Croix County, Wisconsin

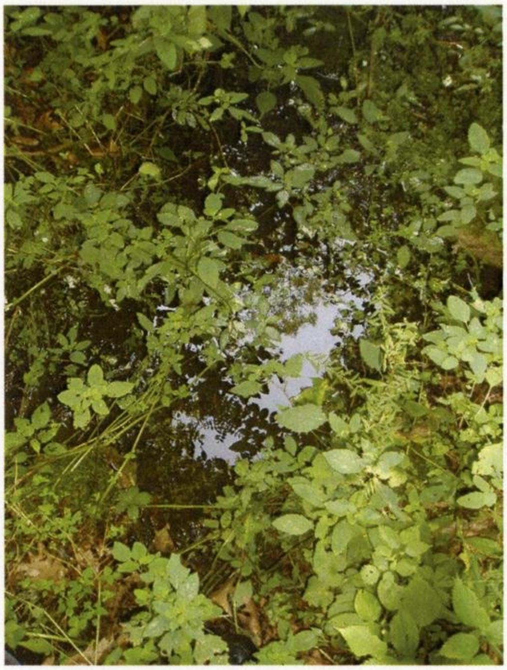
Sample ID	55
Sample Date	8/16/2005
7.5 Minute Quadrangle	Graytown
Northing	4997034
Easting	561835
Discharge (cfs)	0.010
Temperature (°C)	15.4
Conductivity (µS/cm)	326
pH	6.91

Land Use	Wooded
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.019

Description:

Spring is located at #2930, town of Forest, at the Forest Ridge Hunt Club. A stream enters the pond from the north; follow the stream north (upstream) to access the spring.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.



Spring Survey, St. Croix County, Wisconsin

Sample ID	56
Sample Date	8/16/2005
7.5 Minute Quadrangle	Glenwood City
Northing	4996755
Easting	561938
Discharge (cfs)	0.008
Temperature (ºC)	12.1
Conductivity (µS/cm)	272
pH	7.68

Land Use	Wooded
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.016

Description:

Spring is located at #2930, town of Forest, at the Forest Ridge Hunt Club. Behind the pond, follow the stream to the north, then continue upstream and follow a small tributary that veers to the right. Note: there are most likely other springs in this area.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.

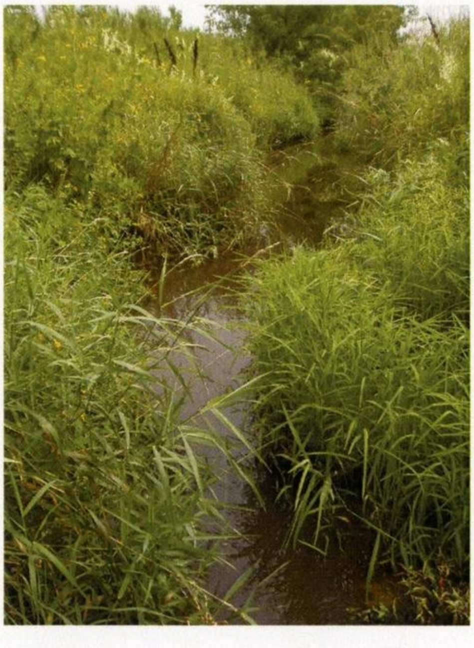
Spring Survey, St. Croix County, Wisconsin

Sample ID	57	Land Use	Pasture
Sample Date	8/19/2005		
7.5 Minute Quadrangle	Roberts	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4974110		
Easting	538889		
Discharge (cfs)	0.030	Approximate soil thickness (ft)	0-50
Temperature (°C)	19.3		
Conductivity (µS/cm)	445	Estimated recharge area (mi^2)	0.058
pH	8.65		

Description:

Follow Parker Creek upstream from bridge on Pleasant Ave, then follow the tributary that veers north. Spring discharges into a somewhat stagnant "pond". There is a progression of less and less stagnant ponds until the creek forms. Discharge estimated as between 0.01 cfs and 0.05 cfs.

The unconsolidated material overlying the Prairie du Chien at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the flow is likely channeled into dissolution conduits as the recharge enters the Prairie du Chien bedrock.



Spring Survey, St. Croix County, Wisconsin

Sample ID	58
Sample Date	8/29/2005
7.5 Minute Quadrangle	Somerset North
Northing	5001237
Easting	520603
Discharge (cfs)	0.158
Temperature (ºC)	10.0
Conductivity (µS/cm)	311
pH	7.28

Land Use	River Edge
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.307

Description:

To access the spring (located in Section 20 of Somerset Township), take Hwy 35 N to Cnty Rd I. Turn north on Cnty Rd I, then left onto 210th Ave. Go down the private drive at the bend in the road. The spring is located on the bank of the St. Croix River. There are multiple springs discharging in the same area. David Grimsrud is the property owner (2095 40th St., private drive on 210th Ave., driveway furthest to the south). Phone: 247-5168.

The unconsolidated material overlying the Eau Claire Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation.

Spring Survey, St. Croix County, Wisconsin

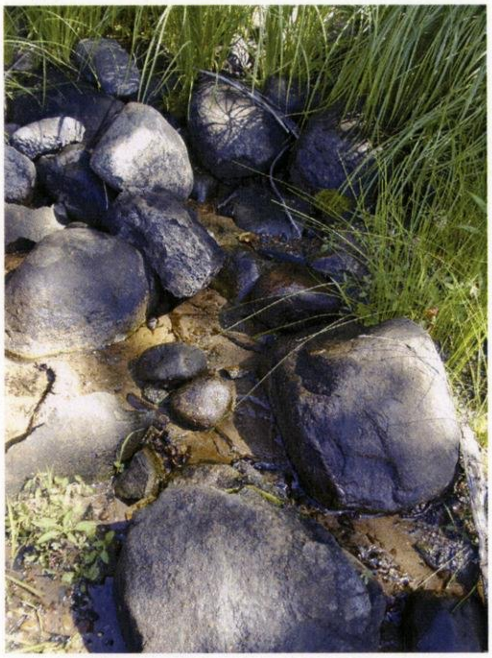
Sample ID	59
Sample Date	8/29/2005
7.5 Minute Quadrangle	Somerset North
Northing	5001241
Easting	520602
Discharge (cfs)	0.030
Temperature (°C)	9.9
Conductivity (µS/cm)	364
pH	7.64

Land Use	River Edge
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.058

Description:

To access the spring (located in Section 20 of Somerset Township), take Hwy 35 N to Cnty Rd I. Turn north on Cnty Rd I, then left onto 210th Ave. Go down the private drive at the bend in the road. The spring is located on the bank of the St. Croix River. There are multiple springs discharging in the same area. David Grimsrud is the property owner (2095 40th St., private drive on 210th Ave., driveway furthest to the south). Phone: 247-5168. Discharge estimated as between 0.01 and 0.05 cfs. (Note: spring located about 5 m from spring #58)

The unconsolidated material overlying the Eau Claire Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation.



Spring Survey, St. Croix County, Wisconsin

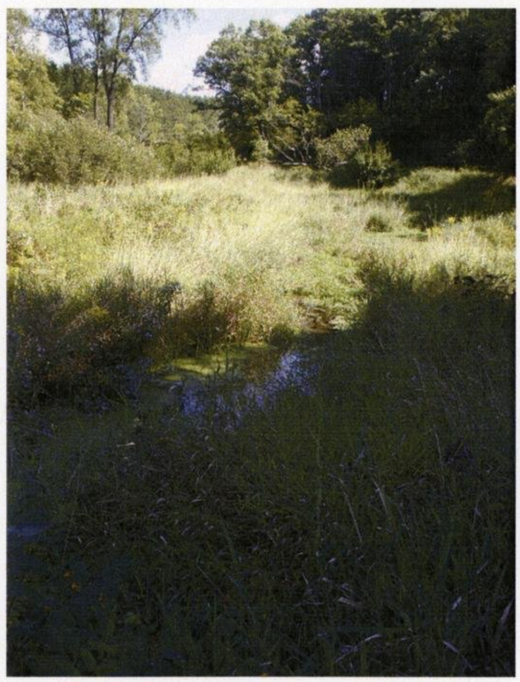
Sample ID	60
Sample Date	8/29/2005
7.5 Minute Quadrangle	Somerset South
Northing	4994883
Easting	520493
Discharge (cfs)	0.603
Temperature (°C)	12.5
Conductivity (µS/cm)	453
pH	7.53

Land Use	Trout Ponds/Wood Lot
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.0 (combined with spring 78)

Description:

Multiple springs are located in this area, and all of the springs discharge from the ground at about the same elevation. The vegetation was not especially dense around the springs. To access the springs, follow Hwy 35/64 N, then left onto 172nd, left onto 38th, and right to 165th. Springs are located near 280 165th Ave., and the property owner is Karl Neameier, phone: 549-6608.

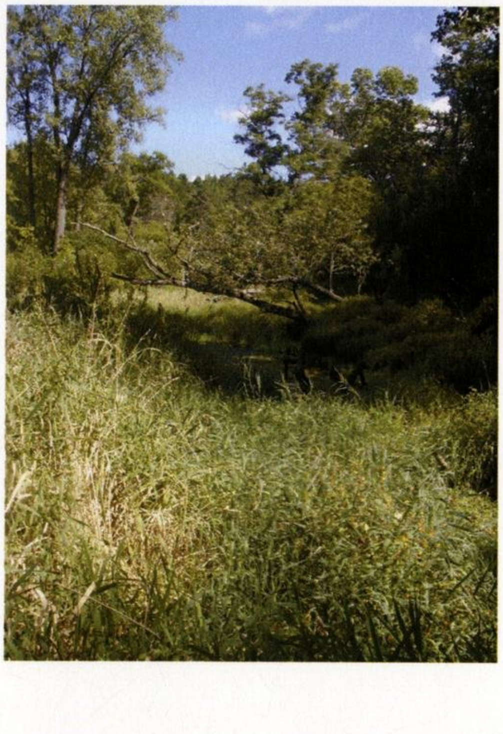
The unconsolidated material overlying the Eau Claire Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation.



Spring Survey, St. Croix County, Wisconsin

Sample ID	60
Sample Date	8/29/2005
7.5 Minute Quadrangle	Somerset South
Northing	4994883
Easting	520493
Discharge (cfs)	0.603
Temperature (ºC)	12.5
Conductivity (µS/cm)	453
pH	7.53

Land Use	Trout Ponds/Wood Lot
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.0 (combined with spring 78)



Spring Survey, St. Croix County, Wisconsin

Sample ID	60
Sample Date	11/12/2005
7.5 Minute Quadrangle	Somerset South
Northing	4994883
Easting	520493
Discharge (cfs)	0.603
Temperature (°C)	12.5
Conductivity (µS/cm)	453
pH	7.53

Land Use	Trout Ponds/Wood Lot
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.0 (combined with spring 78)

Sum of anions (meq/L)	4.05
Sum of cations (meq/L)	4.86
Electrical balance (%)	+8.99
Residence time (years)	22

Total dissolved solids (mg/L)	337.93
Total hardness (mg/L $CaCO_3$)	226.16
Alkalinity (mg/L $CaCO_3$)	167.32
Ca/Mg (mol/L)	1.54
Calcite saturation index	4.56

Concentration (mg/L)

Na	6.40	Cl	10.00	As	<0.003	P	0.065
K	1.30	SO_4	20.11	Cu	0.001	Pb	<0.002
Ca	54.89	NO_2+NO_3	0.77	Fe	0.674	Si	8.79
Mg	21.63	HCO_3	204.00	Mn	0.49572	Zn	0.006

Description:

Multiple springs are located in this area, and all of the springs discharge from the ground at about the same elevation. The vegetation was not especially dense around the springs. To access the springs, follow Hwy 35/64 N, then left onto 172nd, left onto 38th, and right to 165th. Springs are located near 280 165th Ave., and the property owner is Karl Neameier, phone: 549-6608.

The unconsolidated material overlying the Eau Claire Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation.

Spring Survey, St. Croix County, Wisconsin

Sample ID	61
Sample Date	8/30/2005
7.5 Minute Quadrangle	Somerset North
Northing	4997742
Easting	520341
Discharge (cfs)	0.239
Temperature (°C)	9.4
Conductivity (µS/cm)	434
pH	8.01

Land Use	National Park Scenic Riverway
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.464

Description:

Spring is located along the St. Croix River bank on National Park land. The entire riverbank is wet from discharging springs, but most springs were too shallow to measure discharge. All of the springs discharged at approximately the same elevation, where the river bank steepens.

The unconsolidated material overlying the Eau Claire Formation at this spring is relatively shallow, but thicker soil layers are found over much of the recharge area for this spring. Much of the recharge to this spring probably occurs as percolation through this unconsolidated material, but the recharge may be channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation as flow approaches the discharge point.

Spring Survey, St. Croix County, Wisconsin

Sample ID	61	Land Use	National Park Scenic Riverway
Sample Date	8/30/2005		
7.5 Minute Quadrangle	Somerset North	Uppermost bedrock unit at discharge point	Eau Claire Formation
Northing	4997742		
Easting	520341		
Discharge (cfs)	0.239	Approximate soil thickness (ft)	0-50
Temperature (°C)	9.4		
Conductivity (μS/cm)	434	Estimated recharge area (mi^2)	0.464
pH	8.01		

Spring Survey, St. Croix County, Wisconsin

Sample ID	61	Land Use	National Park Scenic Riverway
Sample Date	11/12/2005	Uppermost bedrock unit at discharge point	Eau Claire Formation
7.5 Minute Quadrangle	Somerset North		
Northing	4997742		
Easting	520341		
Discharge (cfs)	0.239	Approximate soil thickness (ft)	0-50
Temperature (°C)	9.4		
Conductivity (µS/cm)	434	Estimated recharge area (mi^2)	0.464
pH	8.01		

Sum of anions (meq/L)	3.14	Total dissolved solids (mg/L)	277.53
Sum of cations (meq/L)	4.01	Total hardness (mg/L $CaCO_3$)	190.30
Electrical balance (%)	+12.05	Alkalinity (mg/L $CaCO_3$)	141.07
Residence time (years)		Ca/Mg (mol/L)	1.63
		Calcite saturation index	4.97

Concentration (mg/L)

Na	3.90	Cl	3.50	As	<0.003	P	0.057
K	1.00	SO_4	9.86	Cu	0.001	Pb	<0.002
Ca	47.18	NO_2+NO_3	1.6	Fe	0.023	Si	10.38
Mg	17.60	HCO_3	172.00	Mn	0.04262	Zn	<0.002

Description:

Spring is located along the St. Croix River bank on National Park land. The entire riverbank is wet from discharging springs, but most springs were too shallow to measure discharge. All of the springs discharged at approximately the same elevation, where the river bank steepens.

The unconsolidated material overlying the Eau Claire Formation at this spring is relatively shallow, but thicker soil layers are found over much of the recharge area for this spring. Much of the recharge to this spring probably occurs as percolation through this unconsolidated material, but the recharge may be channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation as flow approaches the discharge point.

Spring Survey, St. Croix County, Wisconsin

Sample ID	62
Sample Date	8/30/2005
7.5 Minute Quadrangle	Somerset North
Northing	4997743
Easting	520341
Discharge (cfs)	0.069
Temperature (°C)	9.5
Conductivity (µS/cm)	466
pH	8.05

Land Use	National Park Scenic Riverway
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.134

Description:

Spring is located along the St. Croix River bank on National Park land.

The unconsolidated material overlying the Eau Claire Formation at this spring is relatively shallow, but thicker soil layers are found over much of the recharge area for this spring. Much of the recharge to this spring probably occurs as percolation through this unconsolidated material, but the recharge may be channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation as flow approaches the discharge point.

Spring Survey, St. Croix County, Wisconsin

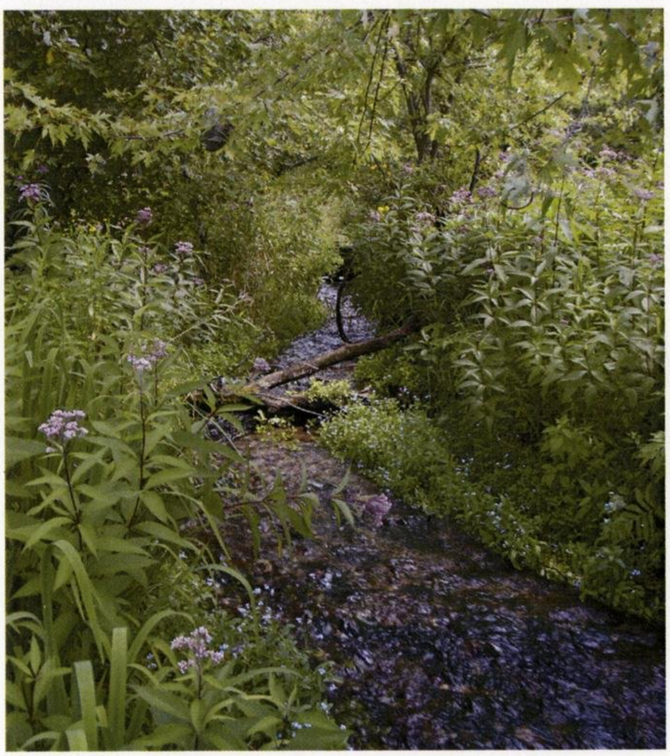
Sample ID	63
Sample Date	8/30/2005
7.5 Minute Quadrangle	Somerset North
Northing	4997825
Easting	520371
Discharge (cfs)	4.077
Temperature (°C)	10.9
Conductivity (µS/cm)	407
pH	8.02

Land Use	National Park Scenic Riverway
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	6.4

Description:

Spring is located along the St. Croix River bank on National Park land. We could not find exact source of the spring, since we could not penetrate the dense vegetation. The spring's large discharge channel is visible from the river bank.

The unconsolidated material overlying the Eau Claire Formation at this spring is relatively shallow, but thicker soil layers are found over much of the recharge area for this spring. Much of the recharge to this spring probably occurs as percolation through this unconsolidated material, but the recharge may be channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation as flow approaches the discharge point.



Spring Survey, St. Croix County, Wisconsin

Sample ID	63
Sample Date	8/30/2005
7.5 Minute Quadrangle	Somerset North
Northing	4997825
Easting	520371
Discharge (cfs)	4.077
Temperature (ºC)	10.9
Conductivity (µS/cm)	407
pH	8.02

Land Use	National Park Scenic Riverway
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	6.4

Spring Survey, St. Croix County, Wisconsin

Sample ID	63
Sample Date	11/12/2005
7.5 Minute Quadrangle	Somerset North
Northing	4997825
Easting	520371
Discharge (cfs)	4.077
Temperature (°C)	10.9
Conductivity (µS/cm)	407
pH	8.02

Land Use	National Park Scenic Riverway
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	6.4

Sum of anions (meq/L)	3.14
Sum of cations (meq/L)	4.01
Electrical balance (%)	+12.26
Residence time (years)	24.5

Total dissolved solids (mg/L)	274.85
Total hardness (mg/L $CaCO_3$)	191.44
Alkalinity (mg/L $CaCO_3$)	141.07
Ca/Mg (mol/L)	1.58
Calcite saturation index	5.05

Concentration (mg/L)

Na	3.60	Cl	2.50	As	<0.003	P	0.044
K	1.00	SO_4	11.18	Cu	0.003	Pb	<0.002
Ca	46.99	NO_2+NO_3	1.03	Fe	0.004	Si	9.25
Mg	17.99	HCO_3	172.00	Mn	0.0003	Zn	<0.002

Description:

Spring is located along the St. Croix River bank on National Park land. We could not find exact source of the spring, since we could not penetrate the dense vegetation. The spring's large discharge channel is visible from the river bank.

The unconsolidated material overlying the Eau Claire Formation at this spring is relatively shallow, but thicker soil layers are found over much of the recharge area for this spring. Much of the recharge to this spring probably occurs as percolation through this unconsolidated material, but the recharge may be channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation as flow approaches the discharge point.

Spring Survey, St. Croix County, Wisconsin

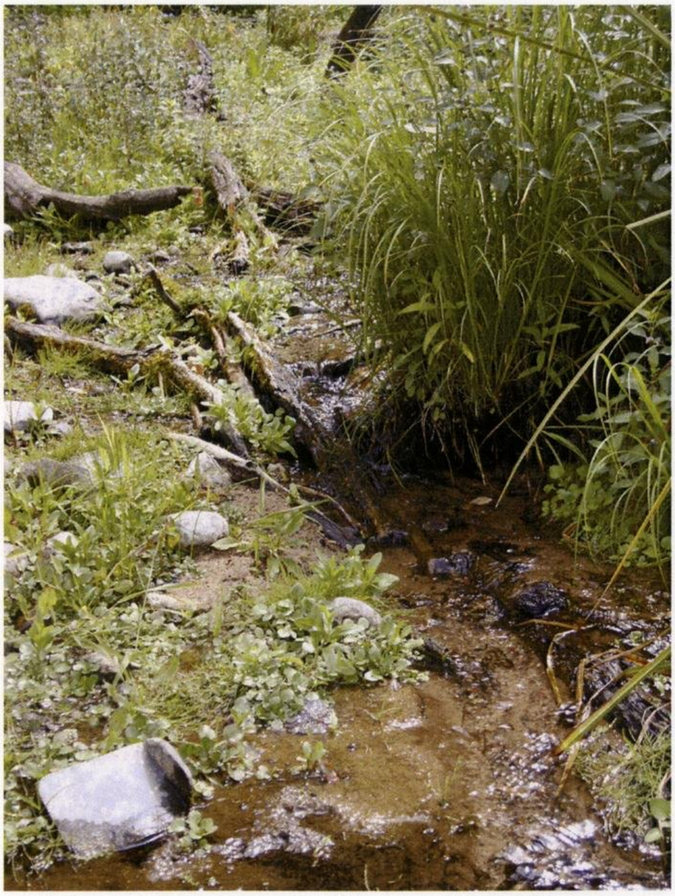
Sample ID	64
Sample Date	8/30/2005
7.5 Minute Quadrangle	Somerset North
Northing	4997778
Easting	520346
Discharge (cfs)	0.059
Temperature (°C)	10.7
Conductivity (µS/cm)	482
pH	8.10

Land Use	National Park Scenic Riverway
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.114

Description:

Spring is located along the St. Croix River bank on National Park land.

The unconsolidated material overlying the Eau Claire Formation at this spring is relatively shallow, but thicker soil layers are found over much of the recharge area for this spring. Much of the recharge to this spring probably occurs as percolation through this unconsolidated material, but the recharge may be channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation as flow approaches the discharge point.



Spring Survey, St. Croix County, Wisconsin

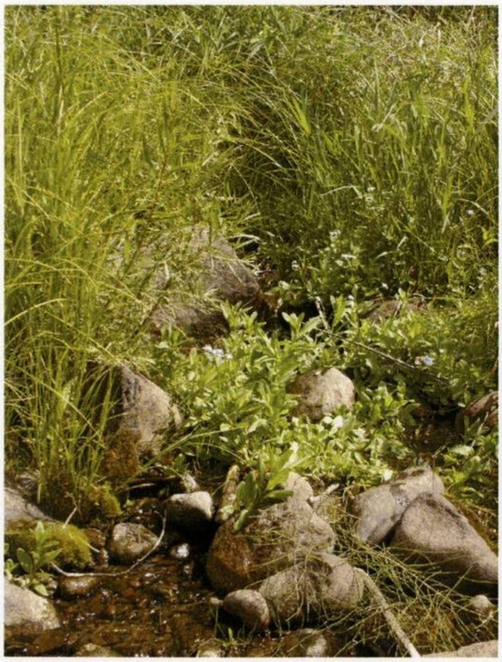
Sample ID	65
Sample Date	8/30/2005
7.5 Minute Quadrangle	Somerset North
Northing	5001262
Easting	520598
Discharge (cfs)	0.030
Temperature (°C)	11.6
Conductivity (μS/cm)	385
pH	7.55

Land Use	River Edge/Wood Lot
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.058

Description:

Spring is located on a river bend accessed from David Grimsrud's property, 2095 40th St. (private drive off of 210th Ave). The discharge was estimated as between 0.01 cfs and 0.05 cfs.

The unconsolidated material overlying the Eau Claire Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation.



Spring Survey, St. Croix County, Wisconsin

Sample ID	66	Land Use	River Edge/Wood Lot
Sample Date	8/30/2005		
7.5 Minute Quadrangle	Somerset North	Uppermost bedrock unit at discharge point	Eau Claire Formation
Northing	5001300		
Easting	520595		
Discharge (cfs)	0.030	Approximate soil thickness (ft)	0-50
Temperature (ºC)	14.0		
Conductivity (µS/cm)	422	Estimated recharge area (mi^2)	0.058
pH	8.03		

Description:

A small spring is located on the St. Croix River bank. It can be accessed from David Grimsrud's property, 2095 40th St. (private drive off of 210th Ave). The discharge estimated as between 0.01 cfs and 0.05 cfs. (Note: debris was floating in the water when measurements were collected.)

The unconsolidated material overlying the Eau Claire Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation.

Spring Survey, St. Croix County, Wisconsin

Sample ID	67
Sample Date	8/31/2005
7.5 Minute Quadrangle	Somerset North
Northing	4999172
Easting	520172
Discharge (cfs)	0.562
Temperature (°C)	10.0
Conductivity (μS/cm)	396
pH	7.85

Land Use	Wood Lot
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.090

Description:

Spring is located at 1962 Apple River Lane. (Neil Cosgrove is the property owner) A path behind the garage leads to the spring. We were unable to locate the exact spring head due to the thick vegetation.

The unconsolidated material overlying the Eau Claire Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation.

Spring Survey, St. Croix County, Wisconsin

Sample ID	67
Sample Date	11/12/2005
7.5 Minute Quadrangle	Somerset North
Northing	4999172
Easting	520172
Discharge (cfs)	0.562
Temperature (°C)	10.0
Conductivity (μS/cm)	396
pH	7.85

Land Use	Wood Lot
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.090

Sum of anions (meq/L)	3.22
Sum of cations (meq/L)	4.16
Electrical balance (%)	+12.76
Residence time (years)	24

Total dissolved solids (mg/L)	284.77
Total hardness (mg/L $CaCO_3$)	198.36
Alkalinity (mg/L $CaCO_3$)	147.63
Ca/Mg (mol/L)	1.63
Calcite saturation index	4.88

Concentration (mg/L)

Na	3.80	Cl	2.00	As	<0.003	P	0.039
K	1.00	SO_4	9.35	Cu	<0.001	Pb	<0.002
Ca	49.25	NO_2+NO_3	1.26	Fe	0.015	Si	9.87
Mg	18.30	HCO_3	180.00	Mn	0.0078	Zn	<0.002

Description:

Spring is located at 1962 Apple River Lane. (Neil Cosgrove is the property owner) A path behind the garage leads to the spring. We were unable to locate the exact spring head due to the thick vegetation.

The unconsolidated material overlying the Eau Claire Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation.

Spring Survey, St. Croix County, Wisconsin

Sample ID	68	Land Use	Wooded
Sample Date	8/31/2005		
7.5 Minute Quadrangle	Somerset South	Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Northing	4991844		
Easting	517052		
Discharge (cfs)	0.254	Approximate soil thickness (ft)	0-50
Temperature (ºC)	11.3		
Conductivity (µS/cm)	697	Estimated recharge area (mi^2)	0.493
pH	7.92		

Description:

Spring is located on Twin Springs Road. To access the spring, take Hwy 35 N to Anderson Scout Camp Rd., then take Twin Springs Rd. Spring is located 50 m from the left side of road, just before township signs about a boat launch.

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones

Spring Survey, St. Croix County, Wisconsin

Sample ID	68
Sample Date	11/12/2005
7.5 Minute Quadrangle	Somerset South
Northing	4991844
Easting	517052
Discharge (cfs)	0.254
Temperature (°C)	11.3
Conductivity (µS/cm)	697
pH	7.92

Land Use	Wooded
Uppermost bedrock unit at discharge point	Tunnel City Group-Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	0.493

Sum of anions (meq/L)	5.23
Sum of cations (meq/L)	6.97
Electrical balance (%)	+14.23
Residence time (years)	

Total dissolved solids (mg/L)	443.56
Total hardness (mg/L $CaCO_3$)	338.56
Alkalinity (mg/L $CaCO_3$)	229.65
Ca/Mg (mol/L)	1.20
Calcite saturation index	4.95

Concentration (mg/L)

Na	3.70	Cl	6.50	As	<0.003	P	0.018
K	1.50	SO_4	18.95	Cu	<0.001	Pb	<0.002
Ca	73.88	NO_2+NO_3	5.00	Fe	0.011	Si	8.29
Mg	37.41	HCO_3	280.00	Mn	0.00409	Zn	<0.002

Description:

Spring is located on Twin Springs Road. To access the spring, take Hwy 35 N to Anderson Scout Camp Rd., then take Twin Springs Rd. Spring is located 50 m from the left side of road, just before township signs about a boat launch.

The unconsolidated material overlying the Cambrian sandstones at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Cambrian sandstones

Spring Survey, St. Croix County, Wisconsin

Sample ID	69
Sample Date	7/5/2006
7.5 Minute Quadrangle	New Richmond South
Northing	4992880
Easting	533008
Discharge (cfs)	2.010
Temperature (°C)	8.7
Conductivity (µS/cm)	482.00
pH	7.39

Land Use	Pasture on Eastern Side, Woods on Western Side
Uppermost bedrock unit at discharge point	Prairie du Chien Group
Approximate soil thickness (ft)	50-100
Estimated recharge area (mi^2)	3.6 (combined with spring 70)

Sum of anions (meq/L)	3.9
Sum of cations (meq/L)	5.19
Electrical balance (%)	+14.17
Residence time (years)	

Total dissolved solids (mg/L)	333.08
Total hardness (mg/L $CaCO_3$)	246.67
Alkalinity (mg/L $CaCO_3$)	157.47
Ca/Mg (mol/L)	1.30
Calcite saturation index	-0.254

Concentration (mg/L)

Na	4.6	Cl	16.00	As	<0.003	P	0.034
K	1.2	SO_4	9.55	Cu	0.002	Pb	<0.002
Ca	55.90	NO_2+NO_3	8.4	Fe	0.024	Si	9.677
Mg	26.00	HCO_3	192.00	Mn	0.005	Zn	0.002

Description:

Anderson Spring. The spring is located at the end of the driveway (less than ~100 m behind barn/house) at 1570 Cnty Rd A. The spring discharges across a fairly wide area that is well marked with many sand boils that were actively bubbling. The spring flows north into the Willow River. The spring discharge area is partially built up with boulders and has a sandy streambed.

The depth to bedrock map indicates that the unconsolidated material in this area is relatively deep, but inspection of the spring area shows several large boulders and large quantities of smaller stones, indicating that the bedrock may be relatively shallow at this site. This spring is not located along a river bank, so these boulders were probably not transported by floods. Rather, it is possible that the depth to bedrock map is inaccurate in this area. Groundwater discharging from this spring probably infiltrated in unconsolidated material well upgradient of the spring and then flowed through dissolution channels in the Prairie du Chien. The dissolution channels do not reach the surface, so groundwater may be flowing up through unconsolidated sediments above the Prairie du Chien before discharging at the surface.

Spring Survey, St. Croix County, Wisconsin

Sample ID	69	Land Use	Pasture on Eastern Side, Woods on Western Side
Sample Date	7/5/2006		
7.5 Minute Quadrangle	New Richmond South	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4992880		
Easting	533008		
Discharge (cfs)	2.010	Approximate soil thickness (ft)	50-100
Temperature (ºC)	8.7		
Conductivity (µS/cm)	482.00	Estimated recharge area (mi^2)	3.6 (combined with spring 70)
pH	7.39		

Spring Survey, St. Croix County, Wisconsin

Sample ID	70	Land Use	Pasture on Eastern Side, Woods on Western Side
Sample Date	7/5/2006		
7.5 Minute Quadrangle	New Richmond South	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4992694		
Easting	532871		
Discharge (cfs)	0.550	Approximate soil thickness (ft)	50-100
Temperature (°C)	9.2		
Conductivity (μS/cm)		Estimated recharge area (mi^2)	3.6 (combined with spring 69)
pH	7.38		

Description:

Three springs discharge from bank; the measured discharge is for all three springs combined. One spring is slightly further back in rushes, the other two springs discharge from a wooded area on the bank. All three springs are at the end of a backwater slough south of Anderson spring. (Access these springs by following slough from Anderson Spring (spring # 69), still in sight of barn/house). Streambed is sand with some silt built up; there are many friable sandstone boulders (20 cm to 60 cm in diameter) nearby.

The depth to bedrock map indicates that the unconsolidated material in this area is relatively deep, but inspection of the spring area shows several large boulders and large quantities of smaller stones, indicating that the bedrock may be relatively shallow at this site. This spring is not located along a river bank, so these boulders were probably not transported by floods. Rather, it is possible that the depth to bedrock map is inaccurate in this area. Groundwater discharging from this spring probably infiltrated in unconsolidated material well upgradient of the spring, and then flowed through dissolution channels in the Prairie du Chien. The dissolution channels do not reach the surface, so groundwater may be flowing up through unconsolidated sediments above the Prairie du Chien before discharging at the surface.

Spring Survey, St. Croix County, Wisconsin

Sample ID	71	Land Use	Pasture on Eastern Side, Woods on Western Side
Sample Date	7/5/2006		
7.5 Minute Quadrangle	New Richmond South	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4992741		
Easting	532946		
Discharge (cfs)	0.030	Approximate soil thickness (ft)	50-100
Temperature (°C)	9.2		
Conductivity (µS/cm)		Estimated recharge area (mi^2)	0.058
pH	7.40		

Description:

Small spring discharging from bank, with sand boils and numerous other small springs nearby (not measured). This spring is located at the end of a backwater slough south of Anderson spring. (Access this spring by following slough from Anderson Spring (spring # 69), still in sight of barn/house). Streambed is sand with some silt built up; there are many friable sandstone boulders (20 cm to 60 cm diameter) nearby. Discharge estimated as between 0.01cfs and 0.05 cfs.

The depth to bedrock map indicates that the unconsolidated material in this area is relatively deep, but inspection of the spring area shows several large boulders and large quantities of smaller stones, indicating that the bedrock may be relatively shallow at this site. This spring is not located along a river bank, so these boulders were probably not transported by floods. Rather, it is possible that the depth to bedrock map is inaccurate in this area. Groundwater discharging from this spring probably infiltrated in unconsolidated material well upgradient of the spring, and then flowed through dissolution channels in the Prairie du Chien. The dissolution channels do not reach the surface, so groundwater may be flowing up through unconsolidated sediments above the Prairie du Chien before discharging at the surface.

Spring Survey, St. Croix County, Wisconsin

Sample ID	72	Land Use	Pasture on Eastern Side, Woods on Western Side
Sample Date	7/5/2006		
7.5 Minute Quadrangle	New Richmond South	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4992824		
Easting	532960		
Discharge (cfs)	0.010	Approximate soil thickness (ft)	50-100
Temperature (°C)	12.4		
Conductivity (μS/cm)		Estimated recharge area (mi^2)	0.019
pH	7.59		

Description:

Vigorously boiling sand in backwater slough south of Anderson spring. The discharge could not be measured accurately since the spring discharged at the bottom of the streambed; the given discharge is estimated. The streambed is silty except around sand boils, where it is sandy. This spring is located within a backwater slough south of Anderson spring. (Access this spring by following slough from Anderson Spring (spring # 69), still in sight of barn/house)

The depth to bedrock map indicates that the unconsolidated material in this area is relatively deep, but inspection of the spring area shows several large boulders and large quantities of smaller stones, indicating that the bedrock may be relatively shallow at this site. This spring is not located along a river bank, so these boulders were probably not transported by floods. Rather, it is possible that the depth to bedrock map is inaccurate in this area. Groundwater discharging from this spring probably infiltrated in unconsolidated material well upgradient of the spring, and then flowed through dissolution channels in the Prairie du Chien. The dissolution channels do not reach the surface, so groundwater may be flowing up through unconsolidated sediments above the Prairie du Chien before discharging at the surface.

Spring Survey, St. Croix County, Wisconsin

Sample ID	73	Land Use	Undeveloped Shoreline/Woods
Sample Date	7/21/2006		
7.5 Minute Quadrangle	Marine on St. Croix	Uppermost bedrock unit at discharge point	Eau Claire Formation
Northing	5006544		
Easting	519451		
Discharge (cfs)	1.620	Approximate soil thickness (ft)	0-50
Temperature (°C)	9.6		
Conductivity (µS/cm)	340	Estimated recharge area (mi^2)	3.143
pH	8.00		

Sum of anions (meq/L)	2.86	Total dissolved solids (mg/L)	252.85
Sum of cations (meq/L)	3.73	Total hardness (mg/L $CaCO_3$)	176.54
Electrical balance (%)	+13.11	Alkalinity (mg/L $CaCO_3$)	121.39
Residence time (years)		Ca/Mg (mol/L)	1.73
		Calcite saturation index	0.196

Concentration (mg/L)

Na	3.20	Cl	6.50	As	0.004	P	0.027
K	1.30	SO_4	9.45	Cu	<0.001	Pb	<0.002
Ca	44.80	NO_2+NO_3	4.50	Fe	0.012	Si	9.677
Mg	15.70	HCO_3	148.00	Mn	<0.001	Zn	<0.002

Description:

There are several springs discharging over about 100 meters of shoreline, but data were collected for only the largest of these springs. This spring is located about 1/2 mile north of Marine on St. Croix, MN along the St. Croix River, across from the southern-most point of a large island. The spring discharges next to a dock structure.

The unconsolidated material overlying the Eau Claire Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation.

Spring Survey, St. Croix County, Wisconsin

Sample ID	73	Land Use	Undeveloped Shoreline/Woods
Sample Date	7/21/2006		
7.5 Minute Quadrangle	Marine on St. Croix	Uppermost bedrock unit at discharge point	Eau Claire Formation
Northing	5006544		
Easting	519451		
Discharge (cfs)	1.620	Approximate soil thickness (ft)	0-50
Temperature (°C)	9.6		
Conductivity (µS/cm)	340	Estimated recharge area (mi^2)	3.143
pH	8.00		

Spring Survey, St. Croix County, Wisconsin

Sample ID	74
Sample Date	7/21/2006
7.5 Minute Quadrangle	Somerset North
Northing	5002603
Easting	519800
Discharge (cfs)	0.390
Temperature (°C)	9.8
Conductivity (µS/cm)	355
pH	7.71

Land Use	Backyard/River Edge
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	50-100
Estimated recharge area (mi^2)	.757

Sum of anions (meq/L)	3.09
Sum of cations (meq/L)	3.98
Electrical balance (%)	+12.56
Residence time (years)	

Total dissolved solids (mg/L)	269.26
Total hardness (mg/L $CaCO_3$)	186.09
Alkalinity (mg/L $CaCO_3$)	134.51
Ca/Mg (mol/L)	1.79
Calcite saturation index	-0.026

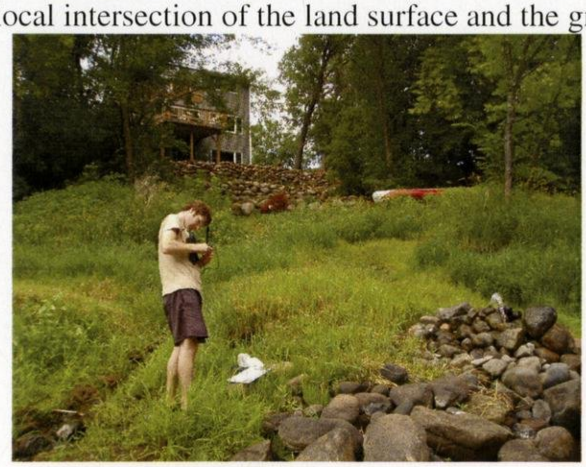
Concentration (mg/L)

Na	4.60	Cl	7.00	As	0.003	P	0.021
K	1.04	SO_4	8.14	Cu	<0.001	Pb	<0.002
Ca	47.80	NO_2+NO_3	2.60	Fe	<0.001	Si	8.742
Mg	16.20	HCO_3	164.00	Mn	0.003	Zn	<0.002

Description:

The spring is located in the backyard of Somerset Township fire number 331 along the edge of the St. Croix River. Several springs are flowing into the river, and large sand boils were observed along the shore. There is a pipe discharging here as well, which may be a developed spring, but the origin of the water discharging through the pipe is unknown.

Relatively thick layers of unconsolidated material overlie the Eau Claire Formation bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.



Spring Survey, St. Croix County, Wisconsin

Sample ID	75
Sample Date	7/21/2006
7.5 Minute Quadrangle	Somerset North
Northing	5002531
Easting	219913
Discharge (cfs)	0.370
Temperature (°C)	10.1
Conductivity (µS/cm)	352
pH	7.61

Land Use	Backyard/Undeveloped Shoreline
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	50-100
Estimated recharge area (mi^2)	0.718

Sum of anions (meq/L)	3.14
Sum of cations (meq/L)	3.91
Electrical balance (%)	+10.94
Residence time (years)	

Total dissolved solids (mg/L)	271.64
Total hardness (mg/L $CaCO_3$)	179.87
Alkalinity (mg/L $CaCO_3$)	141.07
Ca/Mg (mol/L)	1.80
Calcite saturation index	-0.118

Concentration (mg/L)

Na	5.90	Cl	5.50	As	<0.003	P	0.020
K	1.60	SO_4	7.00	Cu	<0.001	Pb	<0.002
Ca	46.30	NO_2+NO_3	1.60	Fe	0.030	Si	8.041
Mg	15.60	HCO_3	172.00	Mn	0.004	Zn	<0.002

Description:

The spring is located about 200 m downstream from fire number 331 Somerset Township. There are several small springs surrounding a large dock and discharging into river.

Relatively thick layers of unconsolidated material overlie the Eau Claire Formation bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

Sample ID	76
Sample Date	7/21/2006
7.5 Minute Quadrangle	Somerset North
Northing	5002204
Easting	520184
Discharge (cfs)	0.511
Temperature (°C)	13.0
Conductivity (µS/cm)	326
pH	7.66

Land Use	Undeveloped Shoreline
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	50-100
Estimated recharge area (mi^2)	0.991

Sum of anions (meq/L)	2.77
Sum of cations (meq/L)	3.59
Electrical balance (%)	+12.88
Residence time (years)	

Total dissolved solids (mg/L)	245.43
Total hardness (mg/L $CaCO_3$)	168.31
Alkalinity (mg/L $CaCO_3$)	121.39
Ca/Mg (mol/L)	1.65
Calcite saturation index	-0.122

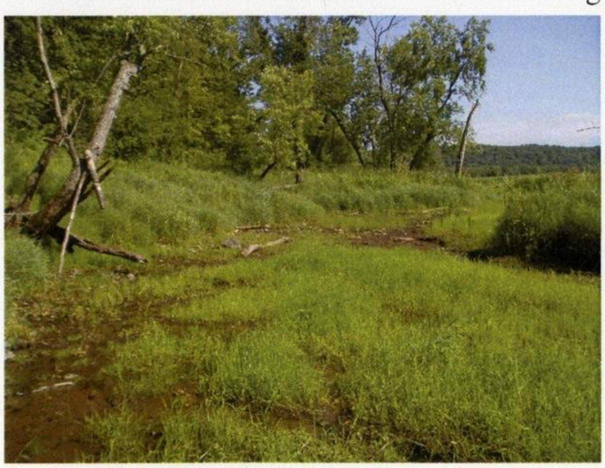
Concentration (mg/L)

Na	3.70	Cl	5.00	As	<0.003	P	0.032
K	1.20	SO_4	7.82	Cu	<0.001	Pb	<0.002
Ca	42.0	NO_2+NO_3	3.10	Fe	0.167	Si	9.490
Mg	15.40	HCO_3	148.00	Mn	0.020	Zn	<0.002

Description:

There is about 100 m of seepage with several outlets into the St. Croix River however there is no one head. The spring is located at the northeastern corner of Rice Lake at St. Croix River inlet.

Relatively thick layers of unconsolidated material overlie the Eau Claire Formation bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.



Spring Survey, St. Croix County, Wisconsin

Sample ID	77	Land Use	Wooded
Sample Date	7/30/2006		
7.5 Minute Quadrangle	New Richmond South	Uppermost bedrock unit at discharge point	Prairie du Chien Group
Northing	4993204		
Easting	533015		
Discharge (cfs)	0.090	Approximate soil thickness (ft)	50-100
Temperature (°C)	15.6		
Conductivity (µS/cm)	485	Estimated recharge area (mi^2)	0.175
pH	8.48		

Sum of anions (meq/L)	3.90
Sum of cations (meq/L)	5.27
Electrical balance (%)	+14.93
Residence time (years)	

Total dissolved solids (mg/L)	333.80
Total hardness (mg/L $CaCO_3$)	249.38
Alkalinity (mg/L $CaCO_3$)	157.47
Ca/Mg (mol/L)	1.25
Calcite saturation index	0.939

Concentration (mg/L)

Na	4.60	Cl	15.00	As	<0.003	P	0.054
K	1.10	SO_4	10.58	Cu	<0.001	Pb	<0.002
Ca	55.50	NO_2+NO_3	8.40	Fe	0.102	Si	9.771
Mg	26.90	HCO_3	192.00	Mn	0.011	Zn	<0.002

Description:

The spring is located about 200 m upstream of Anderson Springs on the Willow River. Follow the shallow creek that enters the Willow River upstream for ~100 m until it becomes a swampy pond. Data were acquired where the creek leaves the pond. Very small sand boils were present in the mudflat along the length of the creek, and the entire bank appeared to be seeping. There is an old barbed wire fence on the southern side of the creek.

Relatively thick layers of unconsolidated material overlie the Prairie du Chien Group bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

Sample ID	78
Sample Date	8/3/2006
7.5 Minute Quadrangle	Somerset South
Northing	4994832
Easting	520577
Discharge (cfs)	0.350
Temperature (ºC)	17.2
Conductivity (µS/cm)	396
pH	8.29

Land Use	Backyard
Uppermost bedrock unit at discharge point	Eau Claire Formation
Approximate soil thickness (ft)	0-50
Estimated recharge area (mi^2)	1.0 (combined with spring 60)

Description:

Take 165th Ave to driveway Y-intersection, then veer right on blacktop road at blacktop/gravel intersection. A spring-fed pond is located on the property of Somerset township fire # 322. The pond owner said that the pond is spring-fed and was used to stock trout; no streams flow into or out of the pond. Measurements were acquired on seepage emerging near the base of the dam, but the temperature measurements are probably inaccurate due to the residence time within the pond.

The unconsolidated material overlying the Eau Claire Formation at this site is relatively shallow. Recharge probably infiltrates through this soil layer as percolation through porous media, but the recharge is likely channeled into dissolution-enlarged fractures or may flow along the surface of local low-permeability units within the Eau Claire Formation.

Spring Survey, St. Croix County, Wisconsin

Sample ID	79
Sample Date	8/3/2006
7.5 Minute Quadrangle	Somerset North
Northing	4997520
Easting	528277
Discharge (cfs)	0.330
Temperature (°C)	12.4
Conductivity (µS/cm)	350
pH	7.84

Land Use	Woods
Uppermost bedrock unit at discharge point	Tunnel City Group
Approximate soil thickness (ft)	50-100
Estimated recharge area (mi^2)	0.640

Description:

The spring is located on Xcel Riverdale Hydro Substation Dam property. The spring discharges into a pond, and discharge from this pond flows into the Apple River. The pond is located about 20 m west of the Xcel access road, just below the entrance to the gate on the east side of the Apple River.

Relatively thick layers of unconsolidated material overlie the Tunnel City Group bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

Sample ID	80	Land Use	Woods
Sample Date	8/3/2006		
7.5 Minute Quadrangle	New Richmond North	Uppermost bedrock unit at discharge point	Tunnel City Group
Northing	5002724		
Easting	534118		
Discharge (cfs)	0.040	Approximate soil thickness (ft)	>100
Temperature (°C)	11.9		
Conductivity (µS/cm)	403	Estimated recharge area (mi^2)	0.078
pH	7.8		

Description:

To access this spring, go right at the split in the dirt road just before a gravel pit. Continue down the road for about 300 - 500 m. The spring is on the right side of the dirt road, about 20 m from the road. Small seepage was observed on the northern end of a long, narrow pond.

Relatively thick layers of unconsolidated material overlie the Tunnel City Group bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

Sample ID	81	Land Use	Star Prairie Trout Farm
Sample Date	8/7/2006		
7.5 Minute Quadrangle	New Richmond North	Uppermost bedrock unit at discharge point	Tunnel City Group
Northing	5004540		
Easting	536450		
Discharge (cfs)	0.110	Approximate soil thickness (ft)	>100
Temperature (ºC)	9.3		
Conductivity (µS/cm)	484	Estimated recharge area (mi^2)	0.213
pH	7.49		

Description:

This is the western-most spring discharging into the trout ponds on this property. This spring is located about 4 m north of Cnty Rd H. Large sand boils were observed in a 1 m diameter pond. Discharge from the pond is channelized into a pipe that carries the water ~100 m north to trout ponds. Discharge measurements were taken at the pipe outlet into a trout holding tank, 1 m west of the hatchery building.

Relatively thick layers of unconsolidated material overlie the Tunnel City Group bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

Sample ID	82
Sample Date	8/7/2006
7.5 Minute Quadrangle	New Richmond North
Northing	5004559
Easting	536649
Discharge (cfs)	0.600
Temperature (°C)	9.1
Conductivity (µS/cm)	480
pH	7.56

Land Use	Star Prairie Trout Farm
Uppermost bedrock unit at discharge point	Tunnel City Group
Approximate soil thickness (ft)	>100
Estimated recharge area (mi^2)	3.2 (combined with springs 83,84, and 85)

Description:

Spring fed commercial trout pond/fishery located ~40 m east of driveway and about 3 m north of road. The spring discharges along the base of a stone wall into the pond. The water then flows from the pond through a horizontal pipe. Near the end of the pipe, an upward-turning elbow joint causes the water to flow vertically upward and the water discharges from the pipe. The discharge exiting the pipe could not be measured accurately as the water flowed down the sides of the pipe and could not be channeled. The discharge was estimated based upon visual comparison with discharge from other springs at the site. (Pond number 1)

Relatively thick layers of unconsolidated material overlie the Tunnel City Group bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

Sample ID	83	Land Use	Star Prairie Trout Farm
Sample Date	8/7/2006		
7.5 Minute Quadrangle	New Richmond North	Uppermost bedrock unit at discharge point	Tunnel City Group
Northing	5004571		
Easting	536665		
Discharge (cfs)	1.030	Approximate soil thickness (ft)	>100
Temperature (°C)	9.1		
Conductivity (µS/cm)	443	Estimated recharge area (mi^2)	3.2 (combined with springs 82, 84, and 85)
pH	7.61		

Description:

Spring fed trout pond located ~45 m east of driveway and about 3 m north of road. (Pond number 2)

Relatively thick layers of unconsolidated material overlie the Tunnel City Group bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Spring Survey, St. Croix County, Wisconsin

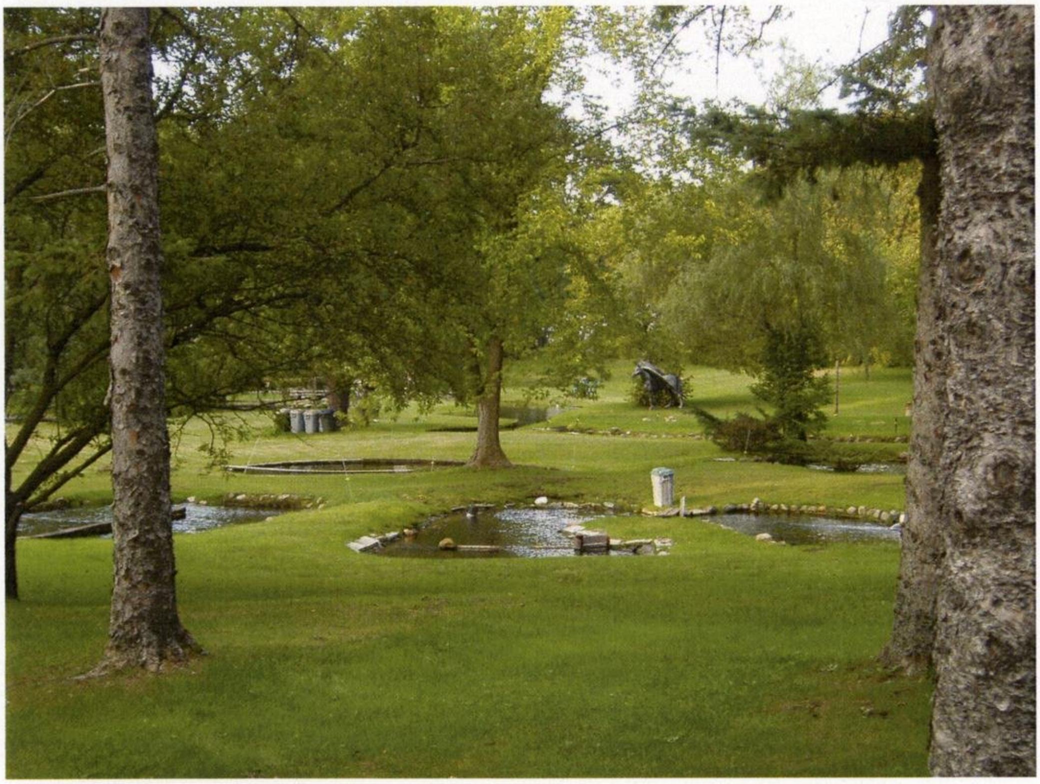
Sample ID	84
Sample Date	8/7/2006
7.5 Minute Quadrangle	New Richmond North
Northing	5004581
Easting	536675
Discharge (cfs)	0.540
Temperature (°C)	9.2
Conductivity (μS/cm)	443
pH	7.56

Land Use	Star Prairie Trout Farm
Uppermost bedrock unit at discharge point	Tunnel City Group
Approximate soil thickness (ft)	>100
Estimated recharge area (mi^2)	3.2 (combined with springs 82, 83, and 85)

Description:

Spring fed trout pond located ~50 m east of driveway and about 3 m north of road. (Pond number 3)

Relatively thick layers of unconsolidated material overlie the Tunnel City Group bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.



Spring Survey, St. Croix County, Wisconsin

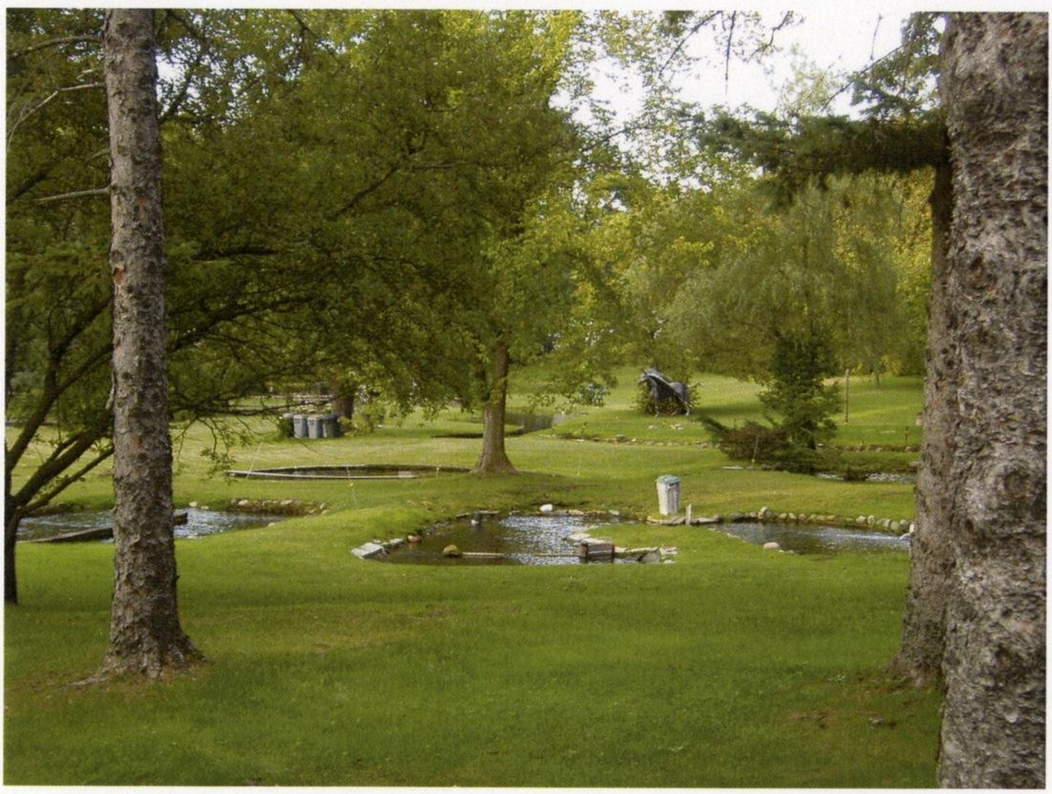
Sample ID	85
Sample Date	8/7/2006
7.5 Minute Quadrangle	New Richmond North
Northing	5004592
Easting	536673
Discharge (cfs)	0.640
Temperature (°C)	9.2
Conductivity (μS/cm)	440
pH	7.53

Land Use	Star Prairie Trout Farm
Uppermost bedrock unit at discharge point	Tunnel City Group
Approximate soil thickness (ft)	>100
Estimated recharge area (mi^2)	3.2 (combined with springs 82, 83, and 84)

Description:

Spring fed trout pond located ~55 m east of driveway and about 3 m north of road. (Pond number 4)

Relatively thick layers of unconsolidated material overlie the Tunnel City Group bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.



Spring Survey, St. Croix County, Wisconsin

Sample ID	86
Sample Date	8/9/2006
7.5 Minute Quadrangle	Somerset South
Northing	4996040
Easting	528493
Discharge (cfs)	1.210
Temperature (°C)	9.2
Conductivity (µS/cm)	405
pH	7.75

Land Use	Backyard/Woods
Uppermost bedrock unit at discharge point	Fault (Tunnel City Group/Eau Claire Formation)
Approximate soil thickness (ft)	>100
Estimated recharge area (mi^2)	1.6

Description:

Levesque Spring. Multiple springs are discharging from the side of a southwest-facing hill about 300 m northwest of the house and pond. According to the landowner, the springs are tapped with about 8-10 pipes driven 18 ft down into side of the hill. The pipes flow down to the pond near the house. The discharge measurements were acquired ~30 m west of the driveway near the pond at the outlet pipe.

This spring occurs along a fault separating the Eau Claire Fm. and the Tunnel City Group. Flow probably occurs through the Tunnel City Group until the fault zone is encountered; flow may then be forced upward along the interface between rock units. Although the unconsolidated material in the vicinity of the spring is relatively thick, the spring discharges from the side of a hill where the soil layer may be less significant.

Spring Survey, St. Croix County, Wisconsin

Sample ID	86	Land Use	Backyard/Woods
Sample Date	8/9/2006		
7.5 Minute Quadrangle	Somerset South	Uppermost bedrock unit at discharge point	Fault (Tunnel City Group/Eau Claire Formation)
Northing	4996040		
Easting	528493		
Discharge (cfs)	1.210	Approximate soil thickness (ft)	>100
Temperature (°C)	9.2		
Conductivity (µS/cm)	405	Estimated recharge area (mi^2)	1.6
pH	7.75		

Spring Survey, St. Croix County, Wisconsin

Sample ID	87	Land Use	Woods
Sample Date	8/9/2006		
7.5 Minute Quadrangle	Somerset South	Uppermost bedrock unit at discharge point	Tunnel City Group
Northing	4996281		
Easting	528592		
Discharge (cfs)	0.020	Approximate soil thickness (ft)	>100
Temperature (ºC)	8.9		
Conductivity (µS/cm)	356	Estimated recharge area (mi^2)	0.039
pH	7.85		

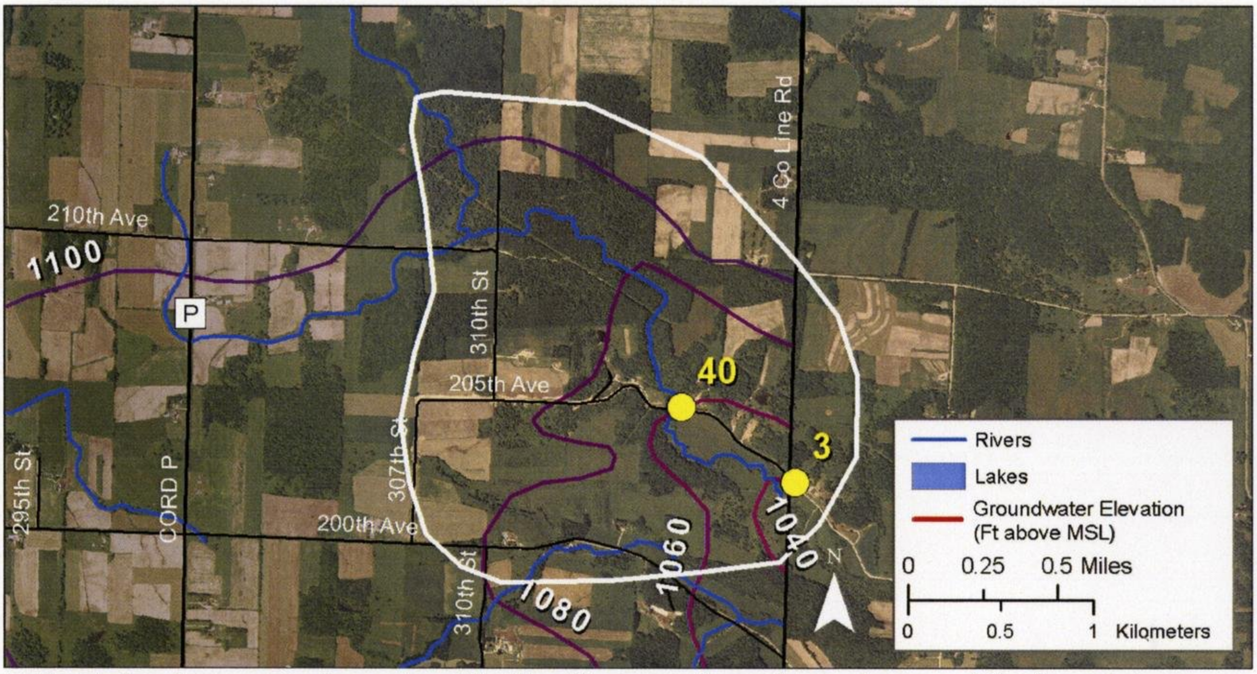
Description:

There is a small spring is located about 10 m west of the split in the dead end road on the way to Levesque spring. The spring is discharging on the side of the road ~1.5 m below road level. Small sand boils were observed.

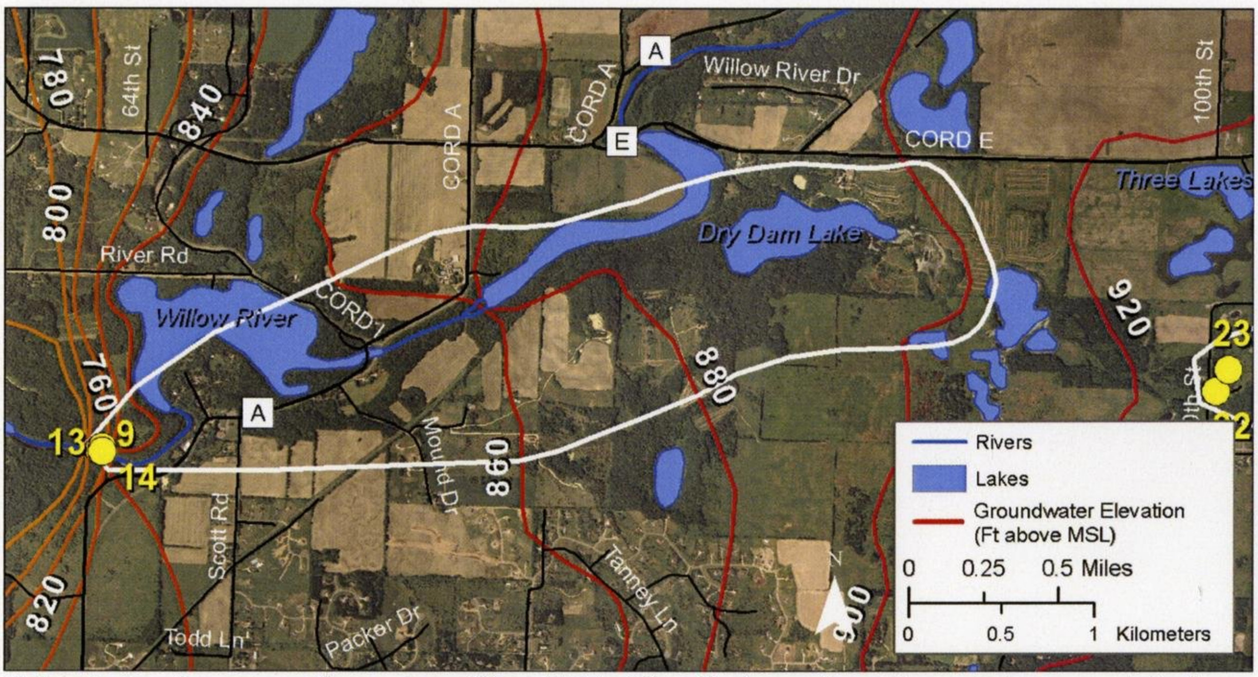
Relatively thick layers of unconsolidated material overlie the Tunnel City bedrock at this site. Since the upper surface of saturation is significantly above the rock-soil interface, the conceptual model of groundwater flow for this spring must include significant percolation through unconsolidated material. This spring may be a depression spring caused by a local intersection of the land surface and the groundwater table.

Appendix III:

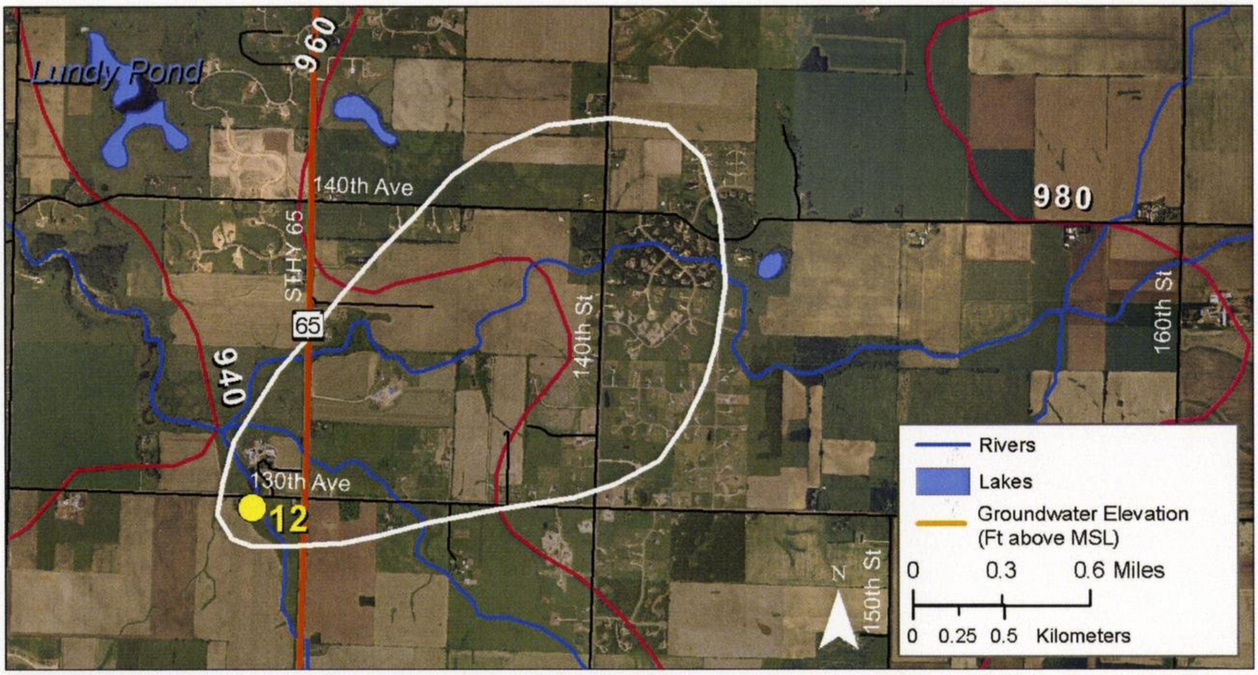
Estimated recharge areas for springs with discharge rates ≥ 1.0 cfs



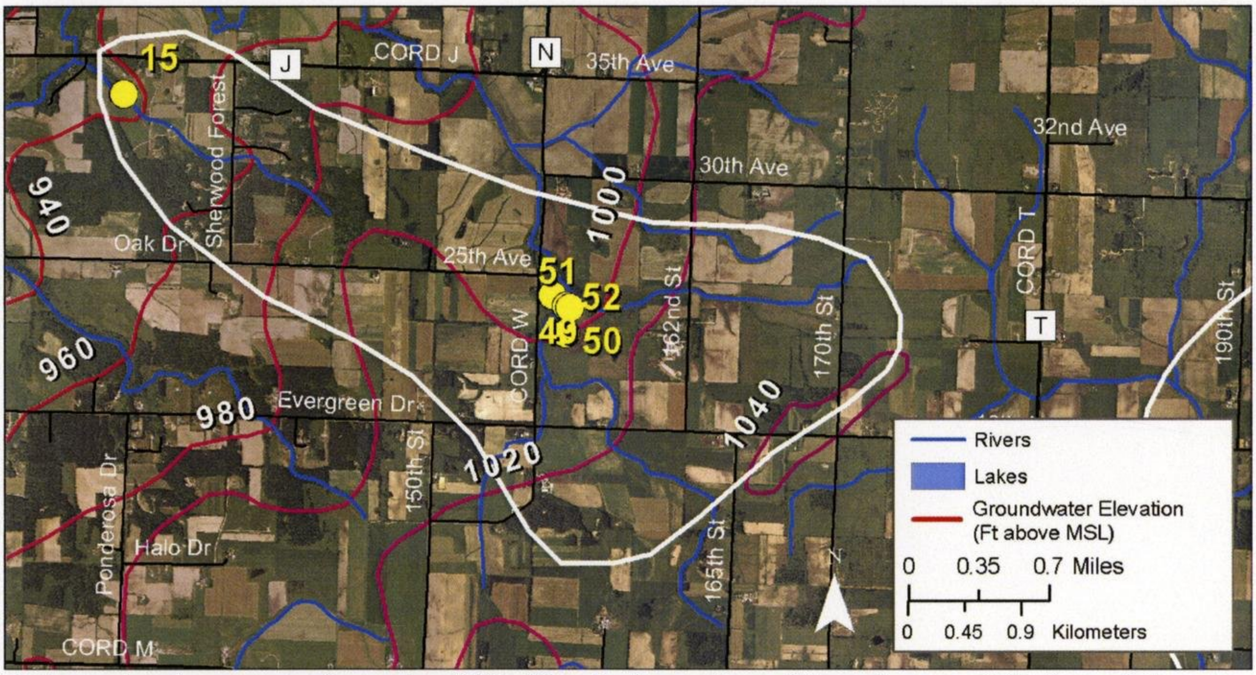
Estimated recharge area for spring #3. The discharge from this spring was 1.2 cfs, and the estimated recharge area was 1.9 mi^2.



Estimated recharge area for springs #9 and #14. The discharge from these springs was 1.8 cfs, and the estimated recharge area was 1.9 mi^2.

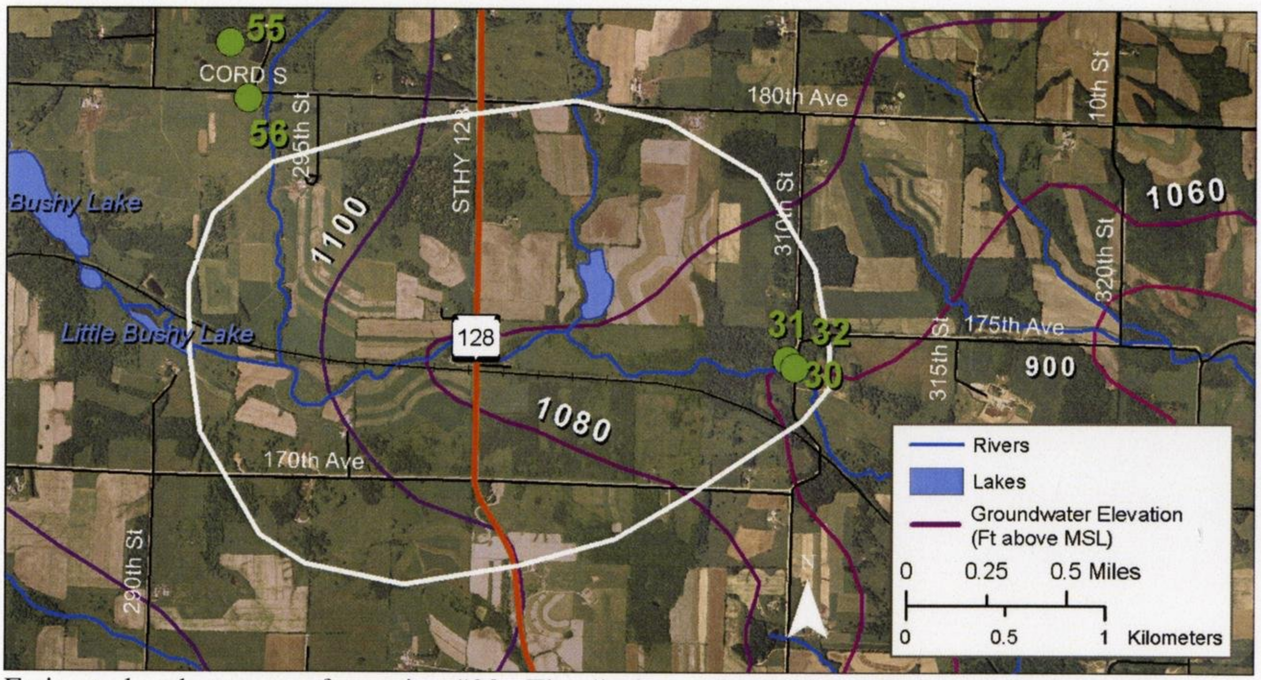


Estimated recharge area for spring #12. The discharge from this spring was 0.93 cfs, and the estimated recharge area was 1.7 mi^2.

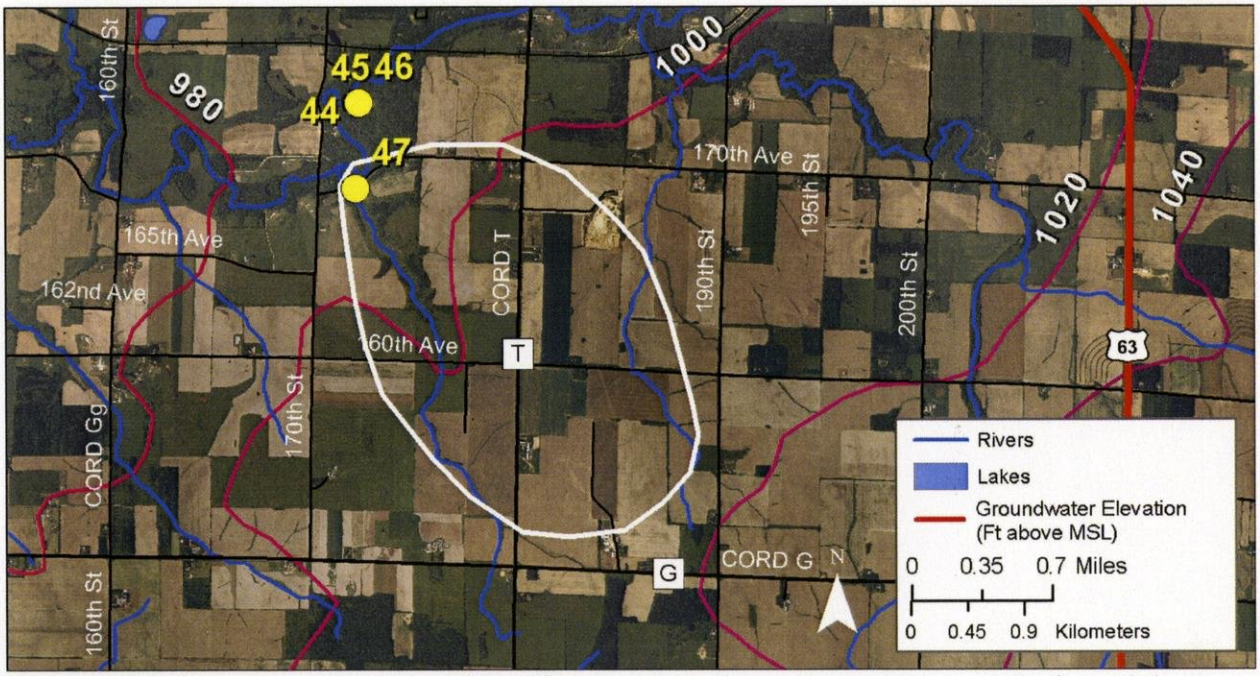


Estimated recharge area for spring #15. The discharge from this spring was 2.7 cfs, and the estimated recharge area was 4.7 mi^2.

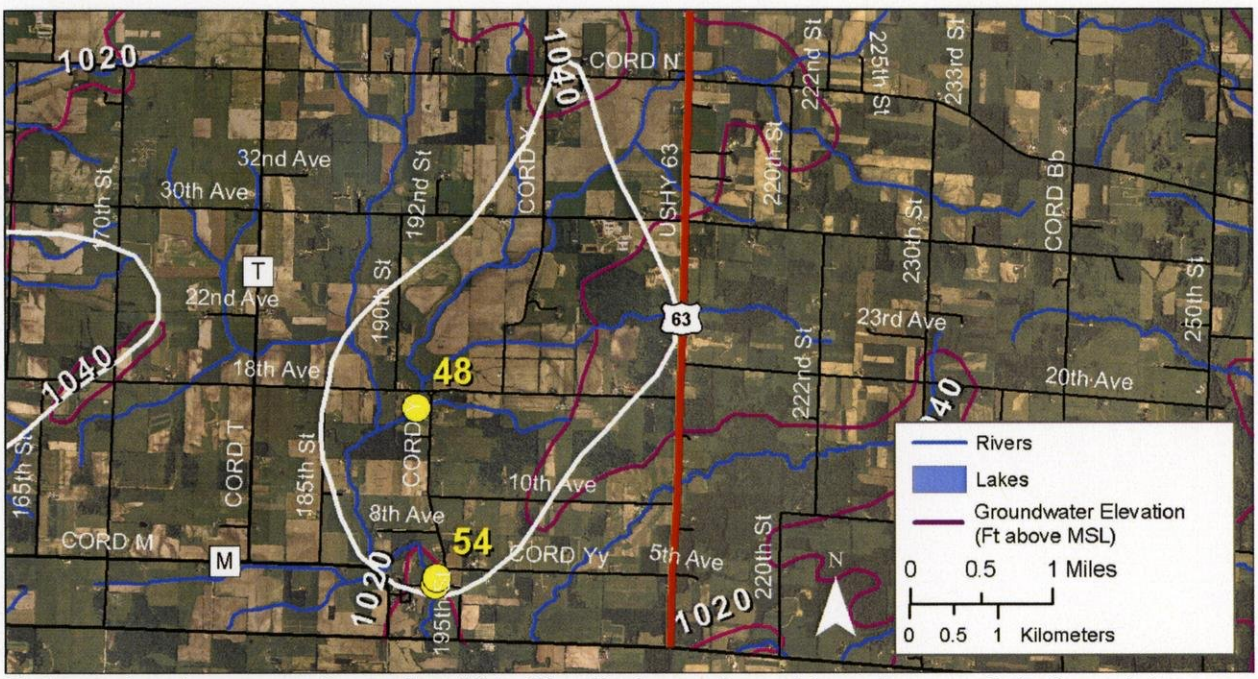
Estimated recharge area for spring #23. The discharge from this spring was 1.4 cfs, and the estimated recharge area was 2.1 mi^2.



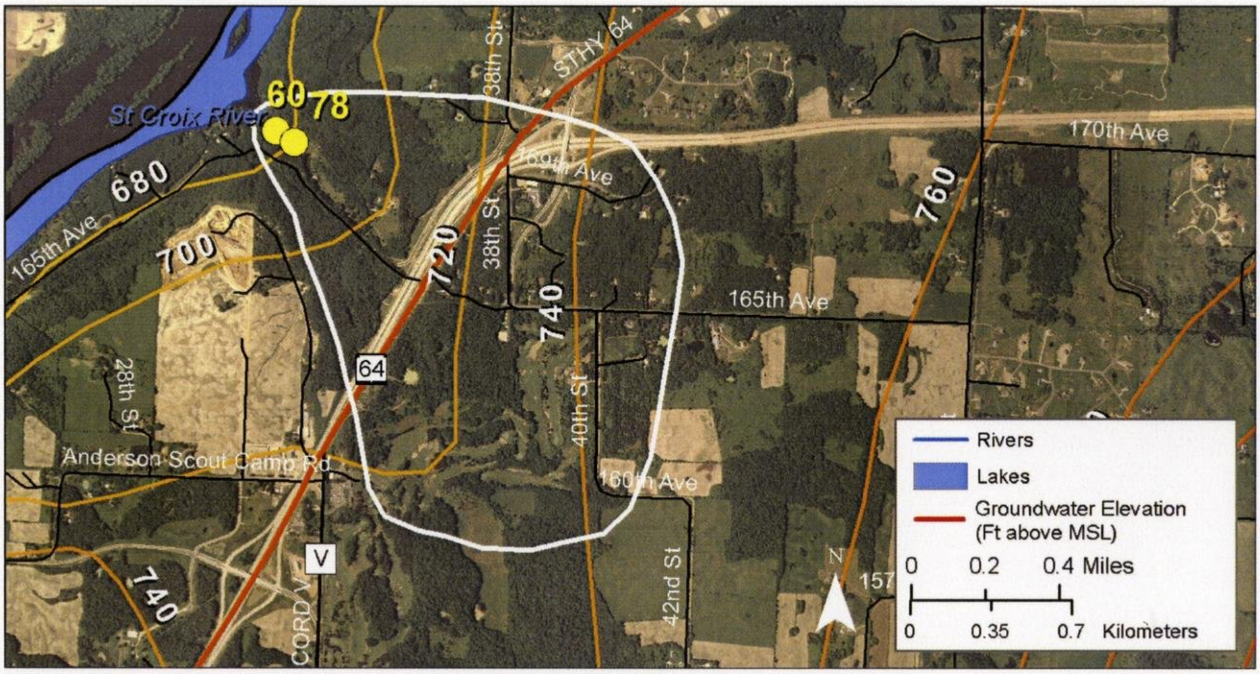
Estimated recharge area for spring #30. The discharge from this spring was 1.5 cfs, and the estimated recharge area was 2.4 mi^2.



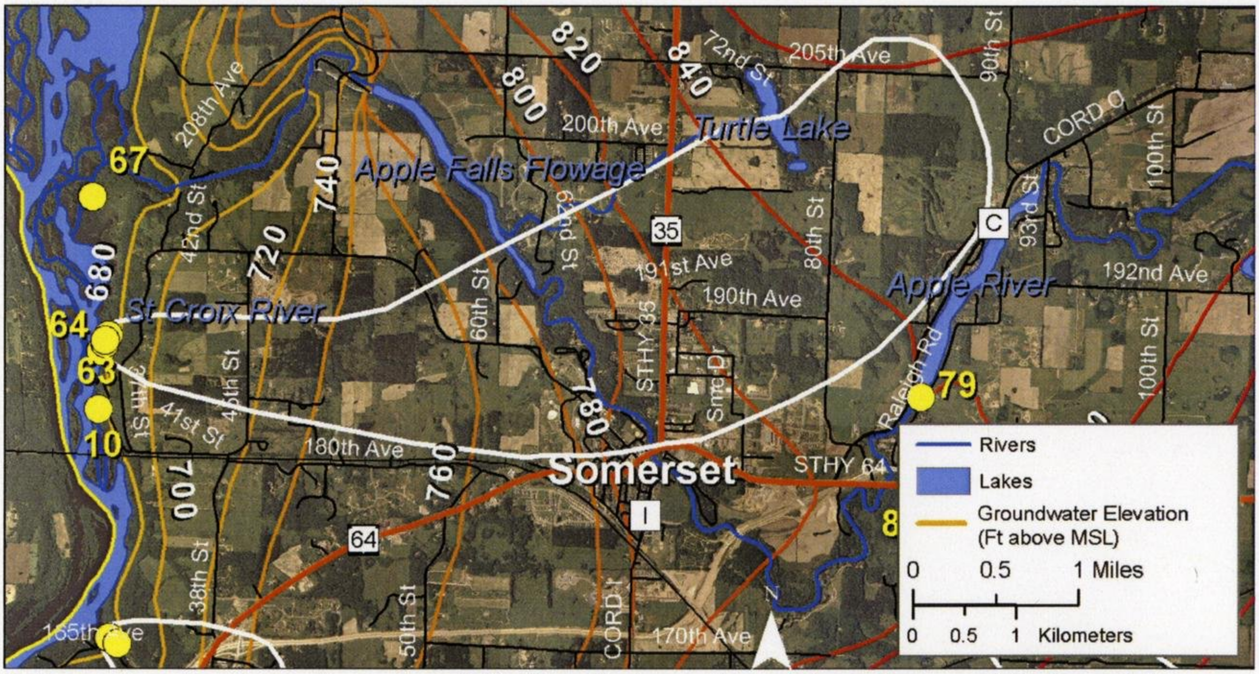
Estimated recharge area for spring #47. The discharge from this spring was 1.2 cfs, and the estimated recharge area was 2.5 mi^2.



Estimated recharge area for spring #54. The discharge from this spring was 3.4 cfs, and the estimated recharge area was 5.1 mi^2.

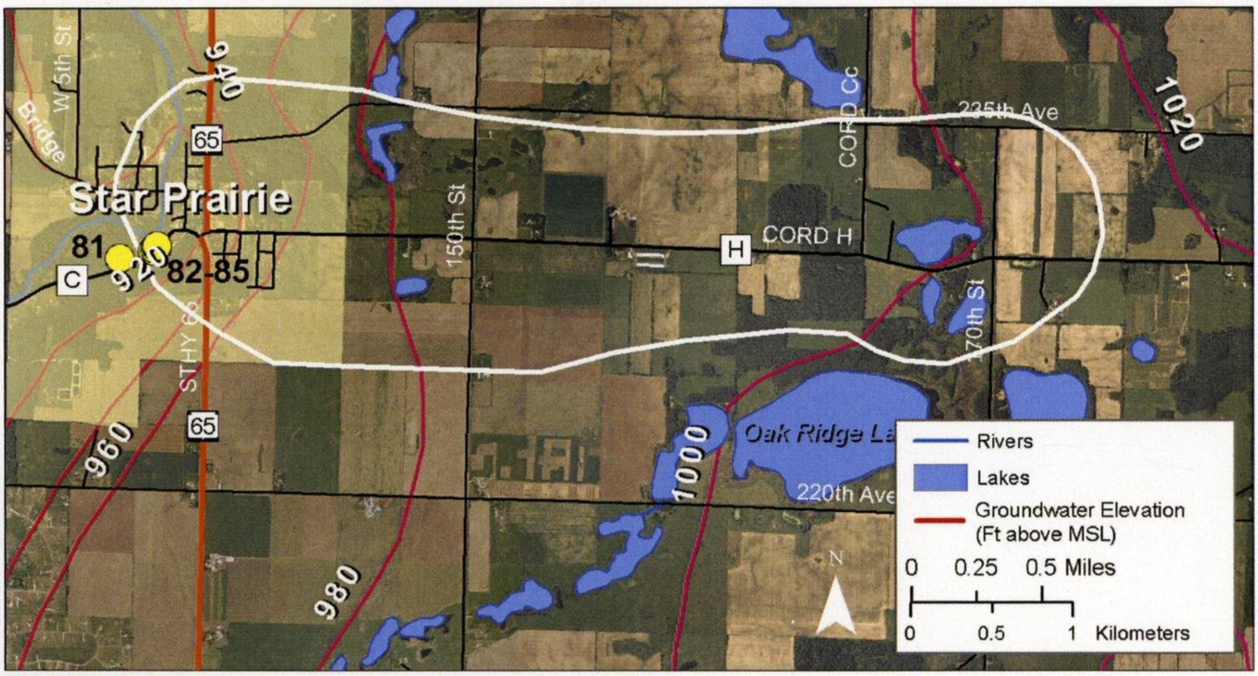


Estimated recharge area for spring #60 and #78. The discharge from these springs was 1.0 cfs, and the estimated recharge area was 1.0 mi^2.

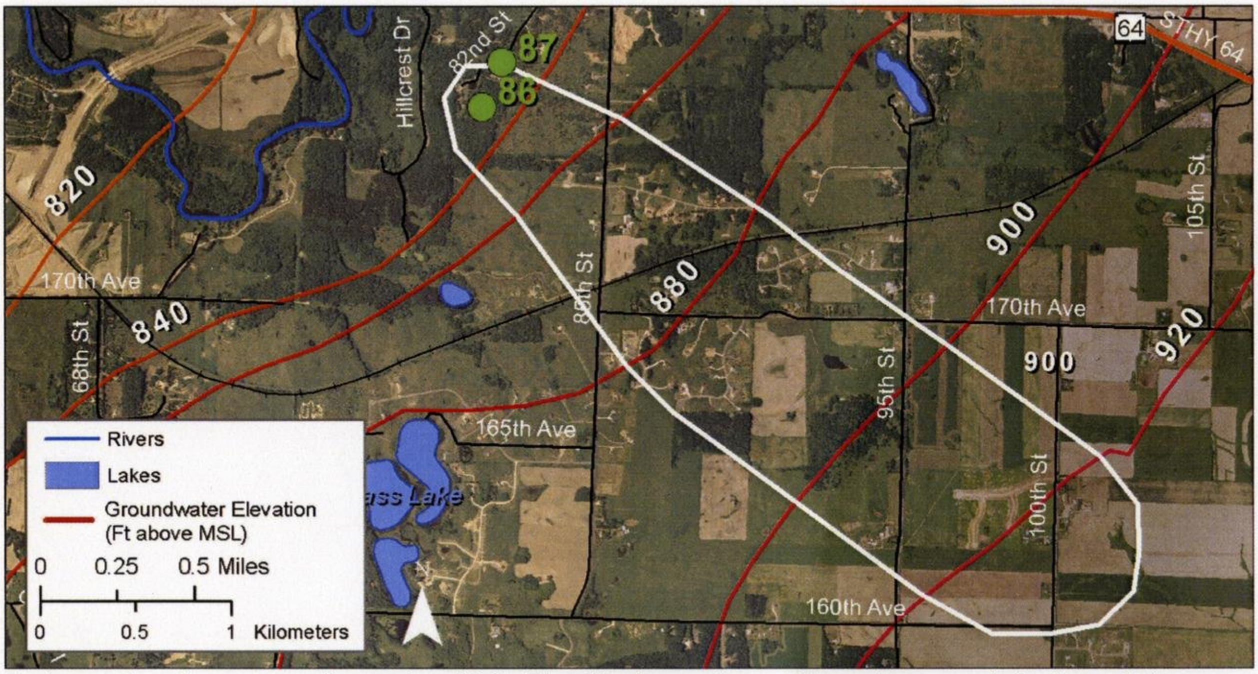


Estimated recharge area for spring #63. The discharge from this spring was 4.1 cfs, and the estimated recharge area was 6.4 mi^2.

Estimated recharge area for spring #69 and #70. The discharge from this spring was 2.6 cfs, and the estimated recharge area was 3.6 mi^2.



Estimated recharge area for spring #82-#85. The discharge from these springs was 2.8 cfs, and the estimated recharge area was 3.2 mi^2.



Estimated recharge area for spring #86. The discharge from this spring was 1.2 cfs, and the estimated recharge area was 1.6 mi^2.