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Hydrologic assessment of the Kickapoo Watershed, southwestern Wisconsin

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1998

Open-File Report 1998-08
81 p. + 1 black and white and 3 color plates

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Hydrologic Assessment of the Kickapoo Watershed, Southwestern Wisconsin

for:
Trout Unlimited Kickapoo Watershed Project
Home Rivers Initiative

Open - File Report 1998-08

by:

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Wisconsin Geological and Natural History Survey
and
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August 3, 1998

Executive Summary

Introduction

The Kickapoo River is a major tributary of the Wisconsin River in the Driftless Area of southwestern Wisconsin (figure 1). The Kickapoo watershed contains numerous coldwater streams with populations of brown and brook trout, and sport fishing is a growing industry in this area. Trout Unlimited's Kickapoo Watershed Project was undertaken to assist local land managers and citizens in protecting and restoring fish habitat by providing necessary resources and information. This study by the Wisconsin Geological and Natural History Survey (WGNHS) and University of Wisconsin Department of Geological Engineering (UW) focused on increasing our understanding of how the quality of fish habitat is controlled by physical factors such as stream temperature, groundwater flow into streams (baseflow), and stream channel form. The specific goals of this study were to (1) characterize the regional and local groundwater flow systems, spatial and temporal variations in baseflow and temperature, and the distribution and movement of fine sediment; (2) identify areas that are critical to stream habitat quality; and (3) develop quick and inexpensive assessment methods that can be used by land management agencies and local citizens to monitor the condition of the watershed

Methods

Our research focused on the watershed above La Farge (figure 2), with the most detailed work in the Warner and Morris Creek sub-basins (figures 3 and 4). We obtained hydrogeologic information by compiling and analyzing water well records on file at WGNHS, and by field mapping of bedrock geology. We measured stream baseflow, spring discharge, and the temperature and chemistry of streams and springs on several dates. Spring and stream discharges were standardized by comparing them to the discharge of the Kickapoo River at the La Farge gaging station (table 1), allowing analysis of flows at different locations and on different dates. A geographic information system (GIS) was developed to store this hydrogeologic information using the ARC/INFO software. To analyze the data, we developed a simple groundwater flow model using GFLOW, a two-dimensional, analytic element code for personal computers. The model provides information on how the watershed functions and predicts the effects of changing land use on streamflow. Stream channel form was studied by comparing field observations with analyses made from topographic maps, and we monitored the movement of fine sediment at one location in Warner Creek

Results and Conclusions

Although this study focused on the Kickapoo watershed above La Farge, our results should also apply to nearby watersheds with similar geology and topography. Throughout this part of the Driftless Area, the broad ridges are formed by the Oneota dolomite, and the valleys are cut into the underlying sandstone formations (figure 5). The valleys tend to have steep sides and flat bottoms, with up to 400 feet of relief This pronounced topography creates strong local groundwater flow systems, implying that most groundwater flowing into a stream originates from within its surface watershed (figure 6). This is supported by chemical sampling results that indicate groundwater discharging from springs is young, and therefore must have infiltrated the ground nearby (table 6 and 7).

The patterns of baseflow and spring locations are closely related to bedrock geology High baseflows per area tend to occur where streams cut through the St. Lawrence Formation and upper Tunnel City Group, and the Wonewoc Formation (figures 7,8 and 9; tables 2 and 3). Springs in the study area are most abundant in the St Lawrence Formation and upper Tunnel City Group (figure 5) Historical comparison of modern streamflow and springflow with data from 30 to 40 years ago does not provide a clear picture of how or if spring and stream discharges have increased during that period (tables 4 and 5).

Continuous monitoring shows that stream temperature fluctuates daily by as much as 10 degrees Celcius in summer, and less in winter (figure 10). Temperature differences from one location to another are closely related to patterns of groundwater discharge Areas with high baseflow per area tend to have the most stable water temperatures, being cooler in summer and warmer in winter (figure 11) Spring temperatures are fairly constant except where spring ponds exist, because these allow the air to significantly influence the water temperature.

The numerical groundwater model tests our conceptual understanding of how the groundwater flow system functions. It was calibrated using hydraulic information from water supply wells (table 8) and choosing reasonable values for model parameters (tables 9 and 10) that resulted in the best fit to observed water levels and streamflows. The model indicates that the deeply incised stream valleys divide the groundwater flow into local systems nearly coincident with the surface water basins (figures 12 and 13). The layered nature of the bedrock aquifer appears to separate local flow systems in the upper part of the aquifer from regional flow deeper in the aquifer

The groundwater model indicates that stream baseflow is sensitive to changes recharge rate, and therefore to changes in land use (figures 14 and 15) Geologic observations suggest that hillslopes are important recharge areas, and the groundwater model demonstrates that this is a reasonable possibility (figure 16). Springs form an important hydraulic connection between the aquifer and streams (figure 17), and streamflow is sensitive to the resistance of fine sediment in the streambed. The groundwater model indicates that removal of fine sediment from streambeds may increase baseflow locally, but the overall baseflow of any stream is likely to remain about the same

Recommendations

Construction of spring ponds should be discouraged until more information on how they affect stream temperature is available, because springs are critical to maintaining stream baseflow and temperature, especially in the St. Lawrence Formation and upper Tunnel City Group

Streamflow should also be protected by maintaining groundwater recharge. Wooded hillslopes are probably the most critical recharge areas, so development on the hillslopes should be discouraged. New developments in all areas should preserve recharge by spreading runoff from impervious areas such as roofs and driveways onto vegetated areas where it can infiltrate.

Efforts to control sources of sediment should be continued, and they should focus not only on streambanks but on barnyards, pastures, and cultivated fields as well. Although trees on streambanks can cause some bank erosion, streams should not be cleared of all large woody debris because it appears to have an important role in scouring the streambed and forming pools. In some headwater reaches with gradients steeper than about 0.015, pools may not be able to form without woody debris to initiate scouring.

Stream restoration projects should consider that stream reaches in different geologic settings will naturally have different temperature patterns. To restore a variety of habitats, stream reaches in a variety of geologic settings should be targeted.

Many important questions remain unanswered. The effect on fish communities of differences in temperature and baseflow should be assessed by sampling fish in areas with baseflow and temperature data. Collecting baseflow and temperature data in other watersheds would also be a useful test of ideas presented here. More information should also be gathered on how the volume of fine sediment stored in stream channels is changing, and on the role of woody debris in causing bank erosion and streambed scouring. The effects of stream channel shape and streambank vegetation on water temperature should be investigated and compared to the influence of groundwater discharge. Additional evaluation of focused recharge on hillslopes in the Kickapoo watershed would be a useful goal of future modeling efforts. Such evaluation would require more measurements of groundwater levels, especially near ridge crests, than are currently available

Acknowledgments

This work was funded by a grant from Trout Unlimited under the Home Rivers Initiative. Additional support was provided by the Wisconsin Geological and Natural History Survey. In particular we thank Mike Czechanski, Kate Barret and Kristin Harris for assisting with GIS development. John Attig provided valuable advice about local geology. Kate Barret, Bill Batten, Stan Nichols, Chris Kent, Vera Smith, and Alejandro Duissiant assisted with baseflow measurements. We thank Steve Born, Laura Hewitt and Al Anderson of Trout Unlimited for their support of the project.

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Introduction

Land management agencies are currently spending a great deal of effort to inventory natural resources such as stream fisheries. Many classification systems have been developed for the describing streams (eg. Montgomery and Buffington 1993, Rosgen 1984), and their application will provide an important database against which to evaluate future changes. However the relationships between the quality of habitats and the geologic and hydrologic processes that define them are commonly not well understood. This information is critical, because it determines how human activities and management decisions are likely to affect ecosystems in the future and what steps are necessary to restore degraded ecosystems.

This study investigates the physical controls on the coldwater fisheries of the Kickapoo watershed in southwestern Wisconsin, focusing on stream temperature, groundwater discharge to streams (baseflow), and stream channel morphology. It is widely accepted that water temperature is a critical control on the quality of coldwater fisheries, but detailed knowledge of what controls temperature throughout the watershed is lacking. Spatial patterns in baseflow may be an important control on temperature in coldwater fisheries, because groundwater temperatures are stable and average approximately 10 °C. Changes in adult trout populations in Black Earth Creek in Dane County, Wisconsin have been found to mirror fluctuations in streamflow (Field and Graczyk 1989), and the locations of different fish community types in Michigan appears to be related to groundwater discharge (Seelbach and Wiley 1997, Seelbach and others 1997).

Stream channel morphology has direct and indirect impacts on stream habitat. Water temperature is probably affected by the width to depth ratio of the channel, the stream gradient, and shading by riparian vegetation. The sediment making up the channel banks and bottom is important because it influences the shape of the channel, the erodability of its banks, and the availability of gravel spawning beds.

The goals of this study are to characterize the regional and local groundwater flow systems, spatial and temporal variations in stream flow and temperature, and the distribution and movement of fine sediment stored in the watershed. The identification of areas that are critical to maintaining high quality stream habitats is also a high priority. Finally, we hope to develop quick and inexpensive assessment methods that can be used by land management agencies and local citizens to monitor the condition of these watersheds.

Watershed Description

The Kickapoo River occupies a watershed of approximately 700 square miles in the unglaciated, or Driftless Area of southwestern Wisconsin (figure 1). This study focuses primarily on the 266-square-mile drainage area upstream of La Farge, Wisconsin (figure 2), with the most detailed work in the Warner and Morris Creek subwatersheds (figures 3 and 4). The landscape throughout the Kickapoo watershed is characterized by steep-sided valleys and broad, flat ridges, with several hundred feet of topographic relief.

The topography is controlled by the underlying bedrock, which consists of Paleozoic sandstone and dolomite layers that dip southwest by less than one degree (figure 5). The ridges are generally formed by the Oneota dolomite, although small remnants of St. Peter sandstone are scattered throughout the area and are most abundant in the western and southern parts of the watershed (V Smith, personal communication 1998). The stream valleys are cut into the underlying units, including the Jordan sandstone, siltstone and dolomite of the St. Lawrence Formation, Tunnel City sandstone, and Wonewoc sandstone. In general, the stream valleys become narrower and steeper toward the south because the bedrock dip places the more resistant Oneota and Jordan Formations closer to stream level in the southern parts of the watershed. This difference is apparent even over the relatively short distance between Morris and Warner Creeks.

Although the Pleistocene glaciers did not cover this area, wind blew silt from the glacial outwash plains of the Mississippi valley over the Driftless Area. The soils formed in these loess deposits are fertile but very susceptible to erosion. As a result, land use since European settlement of the area in the 1800's has had an enormous impact on stream habitats. Past agricultural practices caused large amounts of loess soil to be eroded from uplands and deposited in stream channels and floodplains. Much sediment is still stored in and near stream channels, forming eroding banks, filling pools, and burying spawning gravels. Sedimentation generally made streams wider and shallower (Johnson 1976), and this probably has decreased the stability of stream temperatures. Devegetation and the loss of organic topsoil led to a drastic decrease in the ability of the soil to absorb precipitation, creating flooding and erosion problems. Because less water infiltrated the soil to recharge the groundwater aquifer, stream flows dropped throughout the area. It is generally believe that improved land conservation practices have reduced soil erosion and increased the baseflows since the middle of this century, leading to the dramatic improvement that has been experienced by the fishery. Evidence that baseflows have increased since the 1960's has been found in a current study of Driftless Area streams (C. Kent, pers. com. 1997).

Methods

Geographic Information System

We built a geographic information system (GIS) to store, display and analyze data on topography, land cover, streams, hydrogeology, springs, temperature and water chemistry. The GIS covers only the drainage area above LaFarge, although it can be expanded in the future. It is constructed with the widely used software ARC/INFO. The GIS data layers include land surface topography at 1:24:000 scale, roads, perennial and intermittent streams, spring locations, and water well locations.

Analysis of Existing Hydrogeologic Data

Existing hydrogeologic information was compiled from water well records on file at the WGNHS, and from a survey of springs in the 1950's by the Wisconsin Conservation Department. We created a relational database created with the Paradox program to simplify analysis and future access to this information. Background information was also gained from an extensive review of previous studies in the Kickapoo watershed and by discussions with other WGNHS and University of Wisconsin researchers who have worked in the area.

Water well records generally include the well location, construction details, depth to bedrock, rock layers encountered, depth to water, and results of hydraulic tests. The driller's descriptions of rock units vary in quality, but in many cases the geologic formation encountered in the borehole can be inferred from the well record. The hydraulic testing information on the well records commonly includes the water level without pumping, a test pumping rate and duration, and the drawdown of the water level during the pumping test. From this information we estimated the transmissivities of different bedrock formations using the method of Bradbury and Rothschild (1994). A water table map (figure 6) was drawn based on water levels in the wells, and this indicates groundwater flow directions and the location of groundwater divides. These water table contours were digitized and imported to the GIS and groundwater model.

Springs are discharge points for the local groundwater flow system and tend to be important integrators of groundwater flow, temperature, chemistry. Spring surveys were conducted between 1956 and 1959 by the Wisconsin Conservation Department for Monroe, Vernon, Richland and Crawford Counties (McNurlin 1959, Wisconsin Conservation Department 1957, 1958 and 1959). These surveys contain the spring locations, surrounding land cover, and an estimate of the spring discharge. The accuracy of these discharge estimates is questionable, because only the Richland County survey contains any description of measurement methods. This states that a stick-float method was used, presumably to measure the velocity of the stream flowing from the spring, with the width and depth of the channel being used to calculate the discharge. Discharges of 5 to 10 gallons per minute were estimated rather than measured (Wisconsin Conservation Department 1958).

Geologic Mapping

We compared patterns in stream and spring flow with watershed geology to help distinguish natural variations in flow from those caused by human land use patterns. Because little geological information on the Kickapoo watershed has been published, the bedrock geology of numerous subwatersheds throughout the entire Kickapoo watershed was mapped by WGNHS and Smith (1998a,b). Geologic formations observed in natural outcrops and roadcuts were mapped onto 7.5 minute topographic quadrangle maps, and contacts between formations were drawn based on outcrop observations and landforms. Bedrock units mapped are the St. Peter, Oneota, Jordan, and St. Lawrence Formations, the Tunnel City Group, and the Wonewoc Formation (figure 5). Because the bedrock units are nearly horizontal, contacts between them were drawn in ARC/INFO based on the elevations of contacts mapped in the field (figures 7, 8 and 9).

Stream Baseflow Measurements

Stream baseflow measurements are simple and inexpensive, and a few measurements can be used to make relatively accurate estimates of baseflow parameters, such as the median, mean, and various quantiles, throughout the watershed based on some reasonable statistical assumptions (Potter 1996). The United States Geological Survey (USGS) measured baseflows at several sites in the Kickapoo watershed during low-flow studies in the 1960's and 1970's (Gebert 1978, Holmstrom 1979). In this study, we repeated baseflow measurements at several of the old USGS sites, allowing determination of trends over the past 30 years.

Stream baseflows were measured with hand-held pygmy current meters using the standard U.S. Geological Survey method (Buchanan and Somers 1969). Stream velocity was measured at approximately 20 or more positions along a channel cross section wherever possible Some small streams were too narrow for 20 velocity measurements, so the discharge estimates for small streams have greater uncertainty than those for larger streams To ensure that we measured baseflow and not runoff, streams were gaged when there had been little or no precipitation for several days, and when the USGS gage on the Kickapoo River at LaFarge showed no stormflow peak. Our gaging sites are named with a two letter abbreviation of the stream, and the approximate distance in miles above its mouth This convention was chosen because the mouths of the streams are easily identifiable locations, while the positions at which they originate are more difficult to locate and may even move seasonally.

To allow comparison of baseflows for basins of different sizes, we report baseflow per drainage area in cubic feet per second per square mile (csm) We used the surface drainage basin area because it is easy to determine from topographic maps and is likely to be very similar to the groundwater basin area in this hilly landscape. Underflow of groundwater into surface drainage basins can occur in the Driftless Area (Potter 1996), and that possibility is investigated in this study. Where multiple discharge measurements were made along a stream, we report incremental baseflows for each gaging site to show variations in baseflow within a basin Incremental flow is computed by subtracting the flow measured at the upstream site and dividing the remaining flow by the area below the upstream site

Baseflow at any site varies with time depending on the recent rainfall history. We remove this source of variability by standardizing discharge measurements by the discharge at the LaFarge gage (table 1). The underlying assumption is that when flow is high at the measurement site it is also high at the gage, and vice versa. This assumption is tested by making multiple measurements at most sites and evaluating the variability of flow at each site relative to the flow at the gage Standardized flows are the ratio of flow per area at the measurement site divided by the flow per area at the LaFarge gage.

In a reconnaissance survey on May 15, 1997 baseflows were measured at 18 sites above

LaFarge, with one to three measurements on each major Kickapoo tributary. Each subwatershed surveyed was approximately 10 to 20 square miles. Water at each site was screened in the field for temperature and electrical conductivity, and laboratory samples were collected for alkalinity, nitrates, chloride, pH and major ions. This survey included several repeats of USGS low-flow measurements.

Baseflow in the Morris and Warner Creek watersheds was studied in more detail with additional surveys in August and November 1997. Each survey was conducted over a period of two and a half days or less. Measurement locations were chosen based on the results of the May survey and observations local bedrock geology. A few of the USGS sites were also resurveyed in August and November.

Spring Measurements

Information on the age and source areas of spring water was obtained by field screening springs in the Warner Creek and West Fork watersheds for temperature and electrical conductivity. In addition, water samples from 8 springs were analyzed by a laboratory for major ions and tritium. Where possible, spring discharge was also measured with a bucket and stopwatch. At some springs with diffuse discharge, this was done in multiple locations and the results were summed to approximate the total discharge. Except where noted (tables 5 and 7), the accuracy of these discharge measurements is estimated to be 10%.

Historical changes in discharge were evaluated for three springs by comparing 1950's estimates by the Wisconsin Conservation Department to measurements made during this project. Field inspections of approximately 100 springs identified only 3 springs from the old surveys that could be gaged accurately with a bucket and stopwatch. Discharges were standardized by the La Farge gage with the same procedure as for the stream baseflow measurements. Our 1998 spring survey and the 1957 survey of spring 42294 were conducted during baseflow conditions, and these spring discharges were standardized by the mean daily flow at the gage on the day of the measurement However the hydrograph for the LaFarge gage indicates that the 1959 surveys of springs 12353 and 12441 were conducted during precipitation events, rather than during baseflow conditions. This introduces errors into the analysis, because some of the spring discharge observed then may have been stormflow. To correct for this as much as possible, the median daily flow for the summer of 1959 (June 15 to September 15) was taken as representative of baseflow conditions during that season and used to standardize these spring discharge estimates.

Groundwater Model

Purpose

The purpose of numerical groundwater flow modeling in the context of the Kickapoo Watershed Project is to test our conceptual understanding of the groundwater flow system, to help determine the geologic and hydrogeologic controls on the system, and to evaluate the sensitivity of the system to changes in various parameters, such as recharge rates and stream sediment properties. In this study, we develop a conceptual model of the groundwater flow system based on field observations, intuition, and experiences with groundwater flow systems in similar terrains. The conceptual model must explain major observational aspects of the groundwater system, in particular the elevation of the water table, the configuration of the water table, and groundwater discharges to streams and springs. Numerical modeling, which solves mathematical equations describing the hydraulics of groundwater flow, provides a rigorous test of this conceptual model by showing whether or not the conceptual model is consistent with the physical laws of groundwater flow, known boundary conditions, and parameter values. Given a set of boundary conditions and groundwater parameters, the numerical model should be able to replicate water levels, fluxes, and flow velocities observed in the field. The numerical model can then be used to evaluate the sensitivity of the system to future changes in these parameters.

Conceptual model

Our conceptual model of groundwater flow in the upper Kickapoo basin is as follows. Groundwater moves vertically and horizontally through an aquifer system composed of sandstones and dolomites ranging from the basal Mt Simon Formation up through the Oneota and St Peter Formations (figure 5) However, there are two groundwater flow systems in the area: a deep, regional system, occurring mostly in the Mt Simon Formation, and a shallow system occurring mostly in the Wonewoc and Tunnel City Formations. The shallow groundwater flow system in the upper Kickapoo basin discharges most baseflow to the Kickapoo River, its tributary streams, and local springs, seeps, and wetlands. The deeper, regional system extends far beyond the local study area and discharges to major regional rivers such as the Wisconsin and Mississippi The dividing line between the two systems probably varies from place to place, and is controlled both by hydraulics and stratigraphy Relatively thin but laterally extensive geologic units such as the shaley facies of the Eau Claire Formation and the Ironton Member of the Wonewoc Formation may help divide the regional from the local system.

In our conceptual model, all groundwater enters the shallow system as recharge from precipitation at the land surface, generally within the topographic extent of the Kickapoo watershed. The rugged topography of the incised tributary streams divides the groundwater flow system into groundwater basins analogous to, and nearly coincident with, surface water basins The water table map constructed for this project (figure 6) illustrates this concept, with shallow groundwater divides occurring between tributary valleys Consequently, groundwater flow paths are relatively short - rarely more than a mile or so in length Groundwater discharges to the tributary streams and to the main stem of the Kickapoo as baseflow, and also discharges to local springs and wetlands. Some groundwater moves downward to become part of the regional system.

Model Construction

The Kickapoo model uses the GFLOW analytic element code (Kelson and Haitjema 1995). Kelson and Haitjema (1995, page 1) briefly summarize the analytic element method:

> The analytic element method, developed in the 1980s by Otto Strack (Strack and Haitjema 1981) represents hydrologic features by "analytic elements", each of which has an analytic solution.....A model is constructed by arranging elements which describe the boundary conditions for groundwater flow in the domain of interest. For example, a stream which represents a boundary condition for groundwater flow may be represented as a network of line sink elements. The modeling program solves for the (a priori unknown) strength of each feature, e.g. the inflow or outflow rate of each line sink. Once the strengths of all elements are known, the head or groundwater discharge may be determined analytically at any point in the flow domain.

The geometry of the GFLOW model is based on geographic information assembled for this project in digital form. Important digital coverages included hydrography, a highway network, and a digital terrain model contain surface topography. The base information for the topographic coverage were USGS 1:24000 topographic maps having a contour interval of 20 ft. These geographic files were converted to the data exchange (*.dxf) format used in GAEP (Kelson and Haitjema 1995) a graphic preprocessor for the GFLOW model. Using GAEP, we constructed analytic elements (line sinks) to simulate most major surface water features in the upper Kickapoo basin. Each line sink is described by one analytical equation in the GFLOW code , and requires a length, a location, a hydraulic head, and a hydraulic resistance, where hydraulic resistance is defined as the thickness of a resistive layer (for example a stream bed) divided by its hydraulic conductivity. By linking a number of line sinks in series, the GFLOW model simulates a stream. The model requires shorter, more numerous line sinks in areas of most interest (called near-field areas) or in areas of steep topography. Areas of less interest (far-field areas) require less detail, and are simulated more coarsely. The GFLOW model then solves the groundwater and streamflow problems conjunctively, producing a solution that is valid for both groundwater flow and stream base flow.

Two characteristics of the analytic element modeling method make it ideal for simulating groundwater flow in the upper Kickapoo basin. First, the mathematical model domain is infinite in extent, making it possible to simulate the entire basin with a single model. Second, because it is an analytical method, the solution is independent of problem scale and is equally accurate for both small tributary streams and major hydrologic features. Accordingly, the GFLOW model constructed for this project is focused on the Warner Creek basin, but the model itself covers the entire upper Kickapoo basin (figure 12). All major tributaries are included in the model as line sinks. Far-field features, such as the Baraboo River to the east, and the LaCrosse River to the northwest, are also included, though in less detail. Regionally, the model extends west to the Mississippi River and south and east to the Wisconsin River (not shown on figure 12). Extending the model to such regional boundaries is considered good modeling practice even though these features have little influence on the near-field results.

Stream Morphology

Many Kickapoo tributaries were inspected by driving and walking along streams, observing habitat quality, depth of stored sediment, channel morphology, land use, riparian vegetation and bank stability. Sediment thickness and movement in one reach of Warner Creek were also monitored by WGNHS and Jeff Henrickson, aUniversity of Wisconsin-Madison undergraduate student. The study reach is in the Kickapoo Reserve, approximately 2 miles upstream of the Kickapoo River. Fine sediment depth was measured with a meter stick according to WDNR protocol (Simonson and others 1994), and scour chains were used to monitor erosion of the stream bed (Leopold and others 1992). These consisted of fine chains of beads secured to rocks buried in the sediment, with the chain pulled straight up through the sediment and draped over the bed. Scouring that eroded the bed also lowered the elevation of the chain, and subsequent deposition buried the chain, leaving a record of erosion and deposition.

We also tested the utility of a gradient-based stream classification scheme developed in the Pacific Northwest (Montgomery and Buffington 1993). Gradient is an important control on stream habitat (J. Lyons, pers. com. 1998) and sediment movement (Leopold and others 1992; Montgomery and Buffington 1993), and it can be measured using the GIS. Gradients are calculated for reaches of several streams and compared to observations of channel morphology, baseflow, temperature and fish populations Streams studied include Warner, Morris, Cook, and Endicott Creeks above La Farge, Seas Branch, and Pine Creek in Crawford County.

Results

Bedrock Hydrogeology

Field mapping identified bedrock units as young as the St Peter Formation and as old as the Wonewoc Formation in the study area. The Wonewoc Formation is exposed only in the lower parts of most subwatersheds above LaFarge (figures 6 and 7). Due to the southwest dip of the bedrock, the Wonewoc does not outcrop in most watersheds south and west of La Farge. Springs occur in many of the bedrock formations, but they are especially abundant in the St Lawrence Formation and in the upper part of the Tunnel City Group (figure 5) Many streams begin at springs in the St Lawrence Formation In other parts of the Kickapoo watershed, such as Seas Branch of the West Fork and Otter Creek in Crawford County, large springs occur at the contact between the Oneota dolomite and the Jordan sandstone, but no springs were observed that high in the stratigraphic section in the watersheds above LaFarge

Well records indicate that the sandstones of the Tunnel City, Wonewoc and Mount Simon Formations produce water for many of the wells in the area However below the ridges, where the water table is higher, wells commonly pump from the Jordan and St. Lawrence Formations. The water table map (figure 6) shows that the water table essentially mirrors the land surface topography, with groundwater divides between tributary streams. It also shows that the slope of the water table tends to be steeper in the south than in the north, which should lead to larger groundwater flow velocities in the south and may explain the higher baseflows there.

Groundwater Discharge

The stream gaging surveys detected differences in baseflow between and within subwatersheds (figures 7, 8 and 9; tables 2 and 3). The spatial pattern of high and low baseflow streams was consistent for each of our surveys and with the old USGS surveys (Gebert 1978, Holmstrom 1979). Comparison of baseflows with bedrock geology shows that the highest baseflows per area tend to occur in the lower parts of tributary valleys, where streams cut into the Wonewoc sandstone This may reflect the high transmissivity of the Wonewoc Formation, or it could simply be caused by the convergence of groundwater flow paths in the valleys The observation that streams with low baseflow per area, such as Poe and Jug Creeks (figure 8), tend to flow mostly above the Wonewoc Formation supports the hypothesis that these differences in baseflow are controlled by bedrock geology. The measured baseflow at the two Morris Creek sites in the Wonewoc Formation (MO-0.5 and MO-4.5) was quite different in August and November (figure 9). This is probably due to measurement error at MO-4.5, which is a difficult reach to gage accurately. This site has numerous cobbles and boulders on the bed, with somewhat turbulent flow, and our discharge measurement is probably only accurate to 2 or 3 cubic feet per second (cfs).

High baseflows also tend to occur near the spring-forming St. Lawrence Formation. In Morris and Warner Creeks, baseflow per area is lowest where the streams flow through the Tunnel City Formation (figures 9 and 10). In Warner Creek, baseflow per area increases upstream, reflecting the high spring discharge from the St. Lawrence Formation. This was not observed in Morris Creek, but baseflow measurements were not made near the St Lawrence Formation.

A comparison of stream flow and spring flows along Warner Branch, a tributary of Warner Creek (figure 3), indicates that at least half of the stream baseflow in that location is provided by discrete springs. Thus near the St. Lawrence Formation and upper Tunnel City Group, springs are a very important source of streamflow. Lower in the watersheds, diffuse groundwater flow becomes more important, because few springs are present in the Wonewoc Formation

Using the baseflow surveys of Warner and Morris Creeks, we can estimate the contribution of each bedrock formation to total streamflow at the mouths of these streams The Wonewoc Formation appears to contribute 44%, the Tunnel City Group 42%, and the St Lawrence Formation 14% These estimates are accurate to approximately 10%

Comparison of 1997 baseflows to 1960's and 1970's data indicates that, relative to the La Farge gage, the flow has increased in some watersheds and decreased in others (table 4). The northern watersheds (Morris Creek, Poe Creek and the Kickapoo River above Wilton) showed baseflow increases of 12% to 15%, while baseflows three southern watersheds (Brush, Billings and Warner Creeks) decreased by 7% to 17% relative to the La Farge gage The accuracy of these trends is questionable, because they are based on only one measurement during very low-flow periods in 1964 for Billings Creek and 1970 for Poe, Brush, Warner and Weister Creeks. It should also be noted that the pattern of low baseflow per area in the northern watersheds and higher baseflow per area in the southern watersheds was demonstrated by both the old USGS surveys and this study

Comparison of spring discharges measured in this study and the 1950's estimates (McNurlin 1959, Wisconsin Conservation Department 1957, 1958 and 1959) reveals no consistent trend (table 5) This can be attributed to the low number of springs that can be accurately gaged, the fact that some of the springs were not surveyed during baseflow conditions in the 1950's, and the questionable accuracy of the 1950's discharge estimates. Based on field observations and review of the 1950's spring surveys, it appears likely that most of the spring discharges reported are merely visual estimates rather than measurements

Stream Temperature

Spatial variations in the temperature of Warner and Morris Creeks (figure 11) correspond closely with the distribution of baseflow, indicating that stream temperature is controlled primarily by groundwater discharge Areas with high baseflow per area have more stable water temperatures, keeping them cooler in summer and warmer in winter. On a warm day in September, spring temperatures at the St. Lawrence Formation in the Warner Creek watershed were approximately 10 °C. The water temperature showed a large increase downstream in the Tunnel City Group, reaching a maximum of nearly 20 °C. Where Warner Creek cut into the Wonewoc Formation, the water temperature dropped by more than 1 °C The fairly constant water temperature through the Wonewoc Formation indicates that groundwater discharges from this sandstone. Although fewer temperature measurements were made in Morris Creek, areas with the highest baseflow per area also had the most stable water temperature.

A few temperature measurements at a spring pond in winter support the common concern that these ponds have a substantial affect on water temperature. On a day when the maximum air temperature was approximately 5 °C, the temperature at one Warner Creek springhead was 8 °C. This water flowed through a short channel to a pond, and the temperature at the pond outlet was only 4 °C.

Water Chemistry

Water samples from the tributaries surveyed in May 1997 (table 6) show little chemical variation. This is not surprising, because these samples were collected in the middle and lower reaches of the tributary watersheds, where water from different sources should be well mixed. The high conductivity and calcium and magnesium content of the water reflects travel through local dolomite and carbonate-cemented sandstone formations.

Springs sampled also had little variation in chemistry or temperature (table 7), and their chemistry is similar to that of the stream samples. The results of enriched tritium analyses for 8 springs are very similar and suggest that the water is relatively young, probably less than 30 years. This demonstrates that these springs are fed by nearby recharge areas.

Groundwater Model

Model parameters and calibration

GFLOW is a two-dimensional, steady-state code generally requiring single parameters for hydraulic conductivity, recharge, and aquifer thickness (although some variation in these parameters is possible using inhomogeneities as described later in this report). Initial values of these parameters were determined based on literature review and field observations, and were then varied during model calibration. Table 9 summarizes these global parameters. Groundwater model calibration consisted of varying initial model parameters through a series of model runs until the model reproduced measured hydraulic heads and stream base flows. Specific calibration objectives were to reproduce base flows measured at the mouth of Warner Creek and at the Kickapoo River at LaFarge while at the same time reproducing water levels observed in seven domestic wells in and around the Warner Creek subwatershed. It is unlikely that any model would reproduce all these flows and heads exactly because of errors in the field data and because the wells might respond to vertical variations in hydraulic head that our two-dimensional model cannot reproduce. The "best" model is one that reproduces all measurements with minimum error. For hydraulic heads, we used a root mean square (rms) statistic to assist with evaluating the fit of each calibration run.

The calibration process required over 70 model runs, during which recharge, aquifer thickness, hydraulic conductivity, and streambed leakance were varied within reasonable ranges. This process provided an opportunity to observe the model response to variations in parameters, and these responses help refine our conceptual model of the Kickapoo basin. Table 10 summarizes the parameters and results of key model runs. The response of the model to variations in each major parameters lead to the following observations:

Hydraulic conductivity and recharge rate Hydraulic conductivity and global recharge are co-dependent parameters in steady-state models because identical solutions (with respect to head) are possible across a broad range of hydraulic conductivities and recharge rates as long as the ratio between the two remains equal. However, the recharge rate also controls stream baseflow values. We found that a recharge rate of 10 in/yr gave acceptable results. This is slightly higher than the initial estimate of 8.6 in/yr, based on a water budget approach that assumed the annual recharge volume for the watershed equals the annual baseflow at the LaFarge gage. The recharge rate of 10 in/yr required a hydraulic conductivity of 1 ft/day for best head calibration. This hydraulic conductivity, while lower than the initial estimate of 5.9 ft/day obtained from 26 private wells in the Warner Creek basin, is reasonable for the upper part of the aquifer system which is dominated by the poorly-sorted sandstones of the Tunnel City Formation

Aquifer base. We initially assumed that the modeled aquifer would extend through the Mt Simon Formation to the Precambrian surface (an elevation of about 200 ft in the Kickapoo basin). However, the model was unstable using this base elevation, and would not reproduce either heads or base flows. Raising the base elevation to 500 ft produced a much more stable model. These results suggest that the divide between local and regional groundwater flow systems occurs at an elevation of about 500 ft.

Streambed resistance. For acceptable calibration the model required values of streambed resistance (thickness divided by hydraulic conductivity, having units of days) nearly two orders of magnitude higher than our initial estimates. Based on the amount of silt observed in local stream beds we assumed that these resistances might be large (about 2000 days). However, the model would not reproduce base flows acceptably until resistances were decreased to the range of 20-100 days. Large values of resistance severely restricted base flows and also caused nearby heads to be too high. The lower resistance is representative of silty sand (Freeze and Cherry 1979), which is consistent with the nature of pre-settlement stream valley sediment based on well records, field observations, and the experience of other researchers in this area (J Attig and J Knox, pers com 1997) We assume that heterogeneities and macropores in the stream beds provide pathways for groundwater to discharge in streams even in areas where the silt appears thick

Model results and interpretation

The calibrated model reproduces measured hydraulic heads and base flows very acceptably Figure 12 shows model results for the entire upper Kickapoo basin, while figure 13 shows results for the Warner Creek subwatershed The width of shading of the stream elements on figure 12 is proportional to baseflow calculated by the model, and the figure illustrates how baseflow increases down the length of the Kickapoo basin Figure 13 shows details of the modeled head distribution for Warner Creek, and includes points showing model fit at the seven domestic wells Comparison of these two figures to the measured water table map (figure 6) shows good agreement throughout the basin, and this agreement in turn supports our conceptual model of a shallow groundwater system divided into sub-basins by incised stream valleys

Sensitivity analyses

The calibrated model helps asses the sensitivity of the groundwater system to changes in parameters We evaluated the sensitivity of the Warner Creek basin to changes in recharge rate and to silt removal from a part of the streambed Small variations in recharge have a significant impact on water levels and stream flows in the Warner Creek basin We locally varied the recharge rate from 8 in/yr to 12 in/yr Figures 14 and 15 and table 10 summarize the results of these runs Increasing recharge from 10 in/yr to 12 in/yr causes water levels to rise nearly 25 ft beneath the ridges north and south of the creek, and causes baseflow to increase by about 4 cfs (figure 14) Decreasing recharge to 8 in/yr reduces water levels by over 25 ft, and reduces stream flow by about 4 cfs (figure 15)

We also evaluated the sensitivity of the model to an alternative areal distribution of recharge. It is likely that recharge in the Driftless Area of southwestern Wisconsin is focused on hillslopes. This idea is reasonable in the Kickapoo area, where low-hydraulic conductivity soils developed on loess and residuum cover the ridge crests and groundwater discharge occurs in the narrow valley bottoms. Using the digital elevation model developed for this project we delineated hillslope areas in the Warner Creek basin. Using the inhomogeneity elements available in the GFLOW code we modified the model to add recharge only on these hillslope areas, with no recharge in the valley bottoms or on the ridge crests. Recharge on the hill slopes was specified at 30 in/yr to account for runoff from the upper ridge crests. Recharge in areas of the model outside the Warner Creek subwatershed was maintained at 10 in/yr.

Altering the recharge distribution causes significant changes in the water table configuration around Warner Creek (figure 16), with water levels reduced beneath the ridge crests and increased along the hill slopes. However, the overall fit of the model to the calibration criteria (table 10, run Warner83) is still reasonably good. Unfortunately there are not enough water level observation points beneath the ridge crests to fully evaluate this recharge distribution in the current model. However, the relatively successful model results suggest that hillslope recharge is a viable alternative conceptual model that should be evaluated more fully in the future.

A final sensitivity analysis (warner80, table 10) tested the effect of removing all sediment from a portion of Warner Branch (stream segment indicated by small circle on figure 13). One alternative management practice for improving flow in streams in the Kickapoo basin might be to reduce or remove the sediment in the stream bottoms. We “removed” stream sediment in several stream elements by setting their streambed resistance to zero. The result was an increase in baseflow of 0.8 cfs *for that stream segment*. However, the overall discharge of Warner Creek remained the same, suggesting that the increased stream flow for that segment resulted in decreased flow to other segments. Groundwater levels near the stream were essentially unchanged. This result suggests that artificial dredging of stream bottoms to remove sediment might locally increase baseflow, but might have little overall effect on the stream as a whole.

Particle tracking

One of the most powerful features of the GFLOW code is its ability to delineate groundwater streamlines using interactive particle tracking. Particle tracking simulates the advective movement of groundwater through the model in response to the hydraulic gradient. We used particle tracking to delineate the contributing area for groundwater in the Warner Creek subwatershed as well as the contributing area for a spring in the subwatershed.

Figure 17 shows the paths of particles traced backwards from Warner Creek to the water table in the surrounding basin. The collection of particle paths defines the groundwater basin contributing water to Warner Creek. The groundwater basin is slightly larger than the surface water basin. Using an effective porosity of 0.1, travel times from the edge of the basin to discharge at the stream range from about 100 to 200 years, while travel times from points inside the basin are as short as 5 or 10 years.

Figure 18 shows particles entering a simulated spring on upper Warner Creek. The contributing area for this spring extends both northeast and southwest from the creek.

Stream Morphology

Large volumes of fine sediment are stored in stream channels in the Kickapoo watershed. In many places pools have been filled with sediment, creating reaches without pools and with few riffles. It appears that substantial amounts of sediment are still being added to the streams from a variety of sources including unstable streambanks, runoff from agricultural lands in the valley bottoms, and hillside gullies. Each of these sources appears to be locally important, although detailed surveys would be necessary to accurately quantify their sediment contributions. The Wisconsin Department of Natural Resources priority watershed project (Strom 1994) also estimated that these three sources contribute comparable sediment volumes.

The stability of streambanks appears to be closely related to land use and vegetation in riparian areas Unstable streambanks tend to occur where riparian areas are intensively grazed or cultivated. Riparian areas that are less intensely grazed or are fenced off generally appear more stable. Pastures and cultivated fields appear to be as significant a sediment source as eroding streambanks Many of these areas have gullies that carry sediment directly to stream channels

Riparian vegetation clearly affects streambank stability. The dense roots of grass, such as reed canary, can make streambanks quite stable Many wooded reaches have actively eroding banks, although most of the instability seems to be caused by boxelder and black willow trees. Silver maple trees have extensive root systems that tend to prevent root throw when the tree falls fall, and the roots provide overhangs up to five or six feet wide along Warner Creek Another benefit trees is that the scouring caused by woody debris creates more abundant pools than occur in reaches with grass banks

Sediment monitoring results indicate that fine sediment is scoured from the stream bed by storms, but it is replaced by a similar volume of sediment from upstream. One summer 1997 storm scoured approximately 10 cm of fine sediment from the bed of Warner Creek, and all 5 of the scour chains there were lost, and presumably eroded away, in spring 1998 The total thickness of fine sediment measured at numerous cross sections in this location remained approximately constant, however

Field observations and computation of gradients for a number of stream reaches indicates that most of the perennial stream reaches in the watershed have pool-riffle channels with gradients between 0.01 and 0.005 This is consistent the findings of Montgomery and Buffington (1993) that pool-riffle channels form at gradients from 0.02 to 0.001. In steeper reaches near their headwaters, some streams such as Upper Seas Branch have few pools and may be considered plane bed channels. These reaches tend to have gradients between 0.015 and 0.02, which is again consistent with the conclusion of Montgomery and Buffington (1993) that plane bed channels can form at gradients steeper than 0.01 These observations appear to hold true regardless of the geologic unit through which the streams flow.

Discussion

The geologic control of springs, baseflow and temperature has important implications for fisheries management. Different streams/reaches have different potential/natural conditions- there's a natural variability in temperature (and flow). This probably benefits fish populations, because the optimum temperature for fish varies by species, age and activity (J. Lyons and D. Vetrano, pers. com. 1997). The goals of restoration projects should be compatible with the potential flow and temperature of a stream reach, given its geology.

Although groundwater discharge appears to be the primary control over stream temperature, channel morphology and vegetation may have important secondary effects. Other factors being equal, channels with low width to depth ratios should have the most stable water temperatures, since this minimizes contact with the air. Johnson (1976) has shown that many stream reaches in the Kickapoo watershed have widened substantially since European settlement. Although land use has improved, the natural adjustment of streams back to deeper, narrower channels will be very slow. This may be an important limitation on the potential to restore stream temperature.

The groundwater model is best used as a tool to demonstrate how streamflow is generated, and to predict the type of effects on streamflow that future changes in watershed conditions are likely to produce. The current model is not detailed enough to simulate with the flow of a particular stream great precision. However, the current model could be modified for detailed simulations of particular areas.

It is uncertain weather valley bottoms are recharge or discharge areas (R. Hunt, pers. com. 1998). Hillslopes likely to be important recharge areas because they are forested and tend to be composed of very course, permeable material (Attig, pers. com. 1998). The groundwater model shows that this is a viable hypothesis, but does not demonstrate this conclusively. In most places, the ridgetops seem unlikely to be important recharge areas because of the presence of thick clay soils. Exceptions may occur where the St. Peter sandstone occurs on ridges. Land use on the ridgetops is an important issue regardless of how much recharge occurs there, because runoff from the ridges can form gullies that quickly carry water and sediment to streams.

The watershed is currently experiencing an increase in single-family homes outside of village centers. Roofs and driveways increase impervious area and tend to reduce groundwater recharge and increase runoff. Because the groundwater model shows that reducing recharge rates will cause reductions in baseflows, it will be important to minimize runoff from these areas by designing them to disperse water onto vegetated areas where it can infiltrate. This can be done by requiring that downspouts from roofs drain onto vegetated areas, and with simple structures that spread out runoff from driveways and divert it onto vegetated areas. Most development is currently on the valley bottoms and ridgetops, which is fortunate if hillslopes are indeed the most important recharge areas. Future development on hillslopes should be discouraged.

Historical sediment causes several problems with stream habitat in the watershed. It buries spawning gravels, fills pools, and reduces overhead cover because it cannot be undercut without collapsing. Large volumes of this sediment are stored throughout the watershed, and it is not certain if the volume of this stored sediment is changing. Observations of sediment scouring in Warner Creek demonstrate that the sediment is transported frequently by snowmelt and summer rain events, but that sediment that is removed is replaced by sediment from upstream. This implies that if sediment sources are eliminated or substantially reduced, the streams will flush themselves of much of this stored sediment in a reasonably short time. Accurate estimates of the time required to transport this sediment out of the system would be difficult and expensive, and this would require installing gages for rainfall, streamflow and sediment movement in tributary watersheds.

Most of the Kickapoo tributaries have pool-riffle channels and gradients consistent with the range Montgomery and Buffington (1993) define for this channel type. Because there is not a large range of gradients in the watershed, a gradient-based classification system may be of limited use. However it is possible that variations in gradient within the pool-riffle range may have significant effects on sediment transport and channel form, and that possibility is worthy of future study. Application of the gradient-based classification system to the watershed does have a potentially important implication for headwater streams where brook trout are likely to be reintroduced. Some of these headwater reaches have plane-bed channels and may be too steep to form natural pools, limiting the quality of habitat they can provide. Large woody debris can force pools to form in these types of channels, and its removal can cause the channel to revert to a plane-bed morphology (Montgomery and Buffington 1993). Thus, large woody debris may be critical to maintaining and creating pools in steeper channels in the watershed. Pools and bars could also be forced by other flow obstructions (Montgomery and Buffington 1993).

Conclusions and Recommendations

Although this study focused on the Kickapoo watershed above La Farge, the results should be applicable to much of the Kickapoo watershed and other Driftless Area streams because they have similar geology and topography. The GIS developed for the study area can serve as a model for other watersheds, and it is already being expanded to cover other parts of the Kickapoo watershed. Data collected in this study and stored in the GIS include existing hydrogeologic information from water well records, bedrock geologic mapping results, and baseflow and spring survey results. The groundwater model uses different software, but can interface with the GIS. Analysis of this information suggests the following:

- The rugged land surface topography divides the groundwater flow system into local basins very similar to the surface water basins. Groundwater entering a stream comes from nearby source areas, rarely more than a mile or so away

- The importance of local recharge is also supported by chemical sampling results that indicate groundwater discharging from springs is young, and therefore must have infiltrated the ground nearby

- Bedrock geology is a major control on the pattern of baseflow and spring occurrence. High baseflow per area tends to occur where streams cut through the St. Lawrence Formation and upper Tunnel City Group, and the Wonewoc Formation. Springs in the study area are most abundant in the St Lawrence Formation and upper Tunnel City Group.

- The groundwater model indicates that the layered nature of the bedrock aquifer probably separates (at least partially) local flow systems in the upper part of the aquifer from regional flow deeper in the aquifer

- The groundwater model indicates that stream baseflow is sensitive to changes recharge rate, and therefore to changes in land use

- Geologic observations suggest that hillslopes are important recharge areas, and the groundwater model demonstrates that this is a reasonable possibility.

- The groundwater model indicates that removal of fine sediment from streambeds may increase baseflow locally, but the overall baseflow of any stream is likely to remain about the same

- Groundwater discharge is a major control on stream temperature. Stream reaches with the highest baseflow per drainage area tend to have the most stable temperatures

- The groundwater model, using the GFLOW code, is a useful interactive tool for explaining groundwater/surface water relationships in the Kickapoo watershed and for testing the impacts of potential management options.

These results can be used to guide management decisions in the watershed. Any policies that are instituted should be monitored for effectiveness and adjusted as new information is obtained. We recommend the following:

- Until more information on how spring ponds affect stream temperature is available, their construction should be discouraged. This is especially relevant in the St. Lawrence Formation and upper Tunnel City Group, where concentrations of springs produce a large proportion of stream baseflow.

- Maintaining groundwater recharge should be a high priority. Hillslopes are likely to be the most critical recharge areas, and their development should be discouraged. New developments in all areas should preserve recharge by spreading runoff from impervious areas such as roofs and driveways onto vegetated areas where it can infiltrate. Downspout from rooftop gutters should drain onto lawns rather than driveways, and driveway runoff can be spread onto vegetated areas with simple structures such as water bars.

- Efforts to control sources of sediment, such as those by WDNR, should be continued. It appears that large volumes of sediment are still being added to streams, and the habitat problems this creates are persisting. Pastures and cultivated fields in the valley bottoms appear to have a similar impact as eroding streambanks, and long-term efforts should focus on these areas as well.

- Streams should not be cleared of all large woody debris, because it appears to be important in causing scour and forming pools. In many reaches observed in this study, pools have been filled with fine sediment. Large woody debris may be especially important in headwater reaches with gradients steeper than about 0 015, where pools may not be able to form without debris to initiate scouring

- Stream restoration projects should consider that stream reaches in different geologic settings will naturally have different temperature patterns To restore a variety of habitats, stream reaches in a variety of geologic settings should be targeted

While this study has resulted in a much improved understanding of how the watershed functions, it has also raised many unanswered questions for future research The following issues are the most pressing:

- Fish should be sampled in areas with different temperature and baseflow patterns to determine the impact of these physical habitat differences on fish communities This is the subject of ongoing research by the authors and WDNR

- Baseflow and temperature should be surveyed in some West Fork and Lower Kickapoo streams where the geology is somewhat different than in our study area This will provide a test of ideas presented here and identify differences in the function of watersheds in these areas

- A more extensive study of the storage and movement of sediment in stream channels throughout the Kickapoo watershed would help determine if streams are flushing themselves of sediment, at what rate the volume of stored sediment is changing, and how effective management practices are at reducing sediment sources

- The effects of stream channel shape and streambank vegetation on water temperature should be investigated Such a study should also consider the effects of spring ponds and beaver ponds Although groundwater discharge may be the most important control over temperature, these other factors may also have important effects This information will be useful for decisions about the management of streambanks and springs.

- Research on the importance of woody debris in stream channels would be useful, because trees seem to create problems and benefits to fish habitat. Although wooded banks appear to be more susceptible to erosion, logs cause scouring and create pools. Different tree species also appear to have different effects on streambank stability.

- The groundwater model could easily be refined to provide greater resolution of baseflow and stream discharge on particular streams. Additional data required for this refinement includes detailed topographic surveys of stream elevations and improved estimates of streambed thickness and sediment hydraulic conductivity.

- Additional evaluation of focused recharge on hillslopes in the Kickapoo watershed would be a useful goal of future modeling efforts. Such evaluation would require more measurements of groundwater levels, especially near ridge crests, than are currently available.

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Table 1

Discharge Data for Kickapoo River at La Farge
U.S.G.S. Gaging Station # 05408000
Drainage Area 266 square miles

Date	Mean Daily Flow (cfs)	Discharge / Area (csm)
3/7/57	85	0.32
7/8/59	207	0.78
8/7/59	189	0.71
5/15/97	164	0.62
8/8/97	123	0.46
8/9/97	121	0.45
8/10/97	121	0.45
9/17/97	342	1.29
9/24/97	128	0.48
11/18/97	143	0.54
11/19/97	140	0.53
3/22/98	186	0.70

Abbreviations:
cfs = cubic feet per second
csm = cubic feet per second per square mile

Table 2
Baseflow Survey of Streams above La Farge
May 15, 1997

Stream	Station	Total Baseflow (cfs)	Incremental Baseflow (cfs)	Incremental Drainage Area (sq.mi.)	Incremental Baseflow / Area (csm)	Standardized Discharge / Area (csm)
Kickapoo R.	KI-98	20.5	14.9	24.9	0.60	0.97
Sleighton Cr.	SL-0.2	5.6	NA	9.8	0.57	0.92
Morris Cr.	MO-6.5	10.1	NA	19.9	0.51	0.83
Morris Cr.	MO-4.5	14.4	4.2	7.3	0.58	0.94
Morris Cr.	MO-0.5	24.2	9.8	13.1	0.75	1.22
Poe Cr.	PO-0.5	3.6	NA	9.5	0.38	0.62
Kickapoo R.	KI-91	36.8	12.6	17.7	0.72	1.16
Brush Cr.	BR-4.5	12.4	NA	19.5	0.64	1.03
Brush Cr.	BR-1.3	19.7	7.3	11.3	0.65	1.05
Cook Cr.	CO - 0.8	4.6	NA	8.3	0.56	0.91
Billings Cr.	BI-6.5	8.2	NA	11.5	0.71	1.15
Billings Cr.	BI-1.8	19.8	11.6	11.5	1.01	1.64
Cheyenne Cr.	CH-0	7.6	NA	11.2	0.68	1.10
Warner Cr.	WA-5.5	9.3	NA	15.3	0.61	0.99
Warner Cr.	WA-0	17.7	8.4	9.6	0.88	1.43
Jug Cr.	JU-0.5	2.9	NA	5.3	0.56	0.90
Weister Cr.	WE-1.5	12.7	NA	17.9	0.71	1.15
Otter Cr.	OT-0.5	6.5	NA	11.0	0.59	0.95

Notes
1. Incremental baseflow equals the flow measured at the gaging site minus flow at the next upstream site.
2. Standardized baseflow per area equals the flow per area at the measurement site divided by the flow per ar
   on that date at the La Farge gaging station.

Table 3
Baseflow Surveys of Morris and Warner Creeks
August and November, 1997

Watershed	Station	Date Measured	Total Baseflow (cfs)	Incremental Baseflow (cfs)	Incremental Drainage Area (sq.mi.)	Incremental Baseflow / Area (csm)	Standardized Baseflow / Area	Conductivity (mS / cm)	Temperature (Celcius)		Time
									Water	Air	
Morris Cr.	MO - 10	8/9/97	1.3	1.3	5.25	0.24	0.54				
		11/19/97	1.2	1.2		0.23	0.43	0.43	1.1	0.1	03:00 PM
	MO - 6	8/9/97	4.9	3.7	14.25	0.26	0.57				
		11/19/97	5.4	4.2		0.29	0.56	0.485	1.2	0	03:59 PM
	SV - 2.5	8/9/97	0.62	0.62	3	0.21	0.46				
		11/19/97	Not Measured								
	SV - 1	8/9/97	2.6	1.9	3.4	0.57	1.25				
		11/19/97	Not Measured								
	MO - 4.5	8/9/97	8.0	3.1	6.5	0.47	1.03				
		11/19/97	12.7	7.3		1.12	2.13	0.521	1.4	-2.5	04:56 PM
	MO - 0.5	8/9/97	14.3	3.7	6.5	0.57	1.26				
		11/19/97	15.8	3.1	13.1	0.24	0.46	0.495	1.7	1.3	02:00 PM
Warner Cr.	WB - 4	8/8/97	0.15	0.15	0.3	0.50	1.07				
		11/18/97	0.11	0.11		0.37	0.68	0.398	6.8	5.8	10:25 AM
	WB - 3	8/8/97	1.0	0.9	2.5	0.34	0.74				
		11/18/97	1.2	1.1		0.44	0.81	0.451	3.5	3.2	12:40 PM
	WA - 8	8/9/97	2.1	2.1	3.9	0.53	1.16				
		11/18/97	2.2	2.2		0.56	1.05	0.521	4.3	0.4	01:37 PM
	WA - 5	8/8/97	7.4	4.3	10.25	0.42	0.91				
		11/18/97	7.3	3.9		0.38	0.71	0.505	3.1	1.2	02:21 PM
	WA - TR2	8/10/97	0.68	0.68	1.75	0.39	0.86				
		11/18/97	0.6	0.60		0.34	0.64	0.515	2.9	-0.5	03:48 PM
	WA - TR1	8/10/97	0.51	0.51	1.25	0.41	0.89				
		11/18/97	0.4	0.40		0.32	0.60	0.324	2.8	0	04:41 PM
	WA - 0	8/8/97	12.5	4.0	3.5	1.13	2.44				
		11/19/97	11.8	3.5		1.00	1.90	0.463	0.9	-2.2	08:58 AM

Table 4

Historic Changes in Stream Baseflow

Station	*1997 W.G.N.H.S. Data*						*U.S.G.S. Data*		Percent Change
	Date	Baseflow (csf)	Area (sq.mi.)	Baseflow per Area (csm)	Standardized Flow / Area **	Mean Standardized Flow / Area **	Years	Mean Standardized Flow / Area	
MO - 6.5	5/15/97	10.1	19.9	0.51	0.82	0.63	1972-75	0.56	12.15%
	8/9/97*	4.9	19.9	0.25	0.54				
	11/19/97*	5.4	19.9	0.27	0.52				
KI - 98	5/15/97	20.5	34.8	0.59	0.96	0.96	1970-75	0.83	15.23%
PO - 0.5	5/15/97	3.6	9.5	0.38	0.62	0.62	1970	0.54	14.28%
BI- 1.8	5/15/97	19.8	23	0.86	1.40	1.25	1964	1.35	-7.11%
	8/9/97	13.5	23	0.59	1.29				
	11/19/97	12.9	23	0.56	1.07				
BR - 1.3	5/15/97	19.7	30.8	0.64	1.04	0.91	1970	0.98	-7.21%
	8/9/97	13.2	30.8	0.43	0.94				
	11/19/97	12.3	30.8	0.40	0.76				
WA - 0	5/15/97	17.7	24.8	0.71	1.16	1.05	1970	1.27	-17.13%
	8/8/97	12.5	24.8	0.50	1.09				
	11/19/97	11.8	24.8	0.48	0.90				
WE - 1.5	5/15/97	12.7	17.9	0.71	1.15	1.15	1970	1.13	2.13%

<u>Notes</u>

* Measured one-half mile downstream of original location

** Standardized baseflow per area equals the flow per area at the measurement site divided by the flow per area on that date at the La Farge gaging station.

Table 5

Historic Changes in Spring Discharge

Spring	County	Watershed	WCD Survey Data			WGNHS Data				Percent Change
			Date	Discharge (cfs)	Standardized Discharge	Date	Discharge (cfs)	Measurement Accuracy	Standardized Discharge	
12353	Crawford	Otter Cr.	7/8/59	0.33	3.4E-03	3/22/98	0.84	20 %	4.5E-03	31%
12441	Crawford	Tainter Cr.	8/7/59	0.089	9.2E-04	3/22/98	0.018	5 %	9.7E-05	-89%
42294	Monroe	Endicott	3/7/57	0.089	1.0E-03	3/22/98	0.079	10 %	4.2E-04	-59%

Note

Spring discharges standardized by dividing them by the mean daily flow of the Kickapoo River at the La Farge gage for the date of measurement, except the 1959 estimates. These were not made during baseflow conditions, so they are standardized by the median daily flow for the summer of 1959 (June 15 - September 15).

Table 6

Water Quality of Streams above La Farge
May 15, 1997

		Field Measurements								Laboratory Analyses (parts per million)							
Stream	Station	Cond (mS / cm)	Time	Temperature (C)		NO3-N (ppm)	Cl (ppm)	Alk (mg CaCO3/L)	pH	P	K	Ca	Mg	S	Mn	Fe	Na
				Water	Air												
Kickapoo R.	KI - 98	0.347	12:53	8.3	NA	0.7	8.5	200	8.8	<0.217	<0.621	51.6	27.51	4.14	0.016	0.22	4.05
Sleighton Cr.	SL - 0.2	0.379	11:10	5.6	4.4	0.9	7.4	214.0	8.0	<0.217	0.78	51.19	27.52	3.45	0.005	0.14	3.34
Morris Cr.	MO - 6.5	0.398	15:42	9.4	10.0	1.1	9.2	207.0	8.8	<0.217	0.72	46.84	26.63	4.2	<0.003	0.19	6.28
Morris Cr.	MO - 4.5	0.386	17:10	9.4	9.4	1.2	11.9	207.0	9.1	<0.217	0.92	52.12	28.39	5.01	<0.003	0.19	8.63
Morris Cr.	MO - 0.5	0.393	18:12	8.9	8.9	0.6	8.0	221.0	8.4	<0.217	0.70	53.04	28.79	4.93	<0.003	0.22	5.54
Poe Cr.	PO - 0.5	0.454	14:05	8.3	8.9	0.6	5.5	228.0	8.8	<0.217	<0.621	61.69	31.39	5.03	<0.003	0.2	2.83
Kickapoo R.	KI - 91	0.440	12:00	8.0	NA	0.6	8.8	214	8.5	<0.217	0.64	54.93	28.77	4.58	0.014	0.24	4.33
Brush Cr.	BR - 4.5	0.446	14:00	9.3	NA	1.1	6.7	207	8.5	<0.217	<0.621	47.07	32.6	4.05	<0.003	0.09	3.03
Brush Cr.	BR - 1.3	0.457	13:20	8.6	NA	0.8	5.9	221	8.7	<0.217	<0.621	57.42	32.24	4.16	0.005	0.15	2.99
Cook Cr.	CO - 0.8	0.477	13:00	8.3	NA	0.9	4.3	250	8.5	<0.217	<0.621	64.37	33.45	4.48	<0.003	0.12	2.79
Billings Cr.	BI - 6.5	0.455	11:30	7.9	NA	1.2	3.4	228	8.3	<0.217	<0.621	54.79	31.27	3.7	<0.003	0.11	2.26
Billings Cr.	BI - 1.8	0.460	10:30	7.5	NA	0.7	4	228	8.2	<0.217	<0.621	61.12	31.45	4.27	<0.003	0.17	2.29
Cheyenne Cr.	CH - 0	0.495	14:40	8.5	NA	1	6.5	236	8.6	<0.217	<0.621	65.54	34.76	5.27	<0.003	0.13	3.36
Warner Cr.	WA - 5.5	0.405	16:30	9.0	NA	0.8	3.9	236	8.6	<0.217	<0.621	60.81	31.84	4.63	<0.003	0.11	2.51
Warner Cr.	WA - 0	0.337	15:06	5.0	NA	0.6	3.8	228	8.5	<0.217	<0.621	61.58	31.38	5.28	0.011	0.15	2.51
Jug Cr.	JU - 0.5	0.307	13:48	8.0	NA	0.7	1.6	228	8.2	<0.217	<0.621	61.05	30.53	4.93	<0.003	0.1	2.13
Weister Cr.	WE - 1.5	0.424	12:22	7.0	NA	0.7	4	228	8.4	<0.217	<0.621	61.29	31.64	4.59	<0.003	0.18	2.54
Otter Cr.	OT - 0.5	0.505	11:08	NA	NA	0.9	6.9	257	8.3	<0.217	<0.621	65.3	34.15	4.5	0.027	0.17	3.23

Abbreviations

Cond = electrical conductivity
NO3-N = Nitrate
Cl = Chloride
Alk = Alkalinity
P = phosphorus
K = potassium
Ca = calcium
Mg = magnesium
S = sulfur
Mn = manganese
Fe = iron
Na = sodium

Table 7
Discharge and Water Quality of Selected Springs in Vernon County

					Field Measurements			Laboratory Analyses												
Lab ID Number	Spring Number	Watershed	Geologic Formation	Date	Discharge (cfs)	Temp (Celcius)	Cond (mS / cm)	Enriched Tritium	NO3-N (ppm)	Cl (ppm)	Alk (mg CaCO3/L)	pH	P	K	Ca	Mg	S	Mn	Fe	Na
1	63039	Seas Branch	Base of Oneota	12/18/97	.040 *	9.0	0.437	13.0 +/- 0.9	5.78	10.8	186	7.9	0.27	<0.621	50.33	26.53	3.34	<0.003	<0.011	3.72
2	63300	West Fork	Tunnel City	12/18/97	0.0029	7.7	0.468	16.8 +/- 1.2	0.51	0.6	228	7.9	0.22	<0.621	56.90	31.6	5.58	<0.003	<0.011	1.16
3	63305	Warner Br.	Tunnel City	12/18/97	-	8.2	0.461	15.3 +/- 1.1	0.38	<0.1	300	7.6	0.24	1.17	73.49	38.67	11.38	<0.003	0.03	1.49
4	63145	Warner Br.	Tunnel City	9/17/97	0.073	-	-													
				12/18/97	0.056	8.0	0.469	12.4 +/- 0.9	0.25	<0.1	243	7.7	0.24	<0.621	58.88	30.81	7.25	<0.003	<0.011	1.20
5	63301	Warner Br.	Tunnel City	9/24/97	0.03 **	10.7	0.35													
				12/18/97	-	9.6	0.491	12.5 +/- 0.9	2.1	3.4	286	7.6	0.25	<0.621	72.34	38.38	6.78	<0.003	<0.011	2.41
6	63302	Warner Br.	Tunnel City	9/24/97	0.024	9.4	0.494													
				12/18/97	-	8.9	0.326	12.4 +/- 0.9	1.19	1.1	250	7.6	0.26	<0.621	62.66	32.91	5.42	0.116	0.02	1.62
7	63312	Warner Br.	St. Lawrence	12/18/97	-	8.3	0.515	15.9 +/- 1.2	1.98	1.7	257	7.7	0.24	<0.621	64.80	34.18	3.68	<0.003	<0.011	1.41
8	63307	Warner Br.	St. Lawrence	9/24/97	0.051	9.4	0.31													
				12/18/97	-	8.8	0.387	14.2 +/- 1.0	1.57	2.3	236	7.7	0.27	<0.621	58.22	29.07	3.90	<0.003	<0.011	1.98
								16.2 +/- 1.2												
N/A	63304	Warner Br.	Tunnel City	9/24/97	0.00059	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A	63306	Warner Br.	Tunnel City	9/24/97	0.023	12.1	0.523	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A	63308	Warner Br.	St. Lawrence	9/24/97	0.028	8.9	0.268	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A	63309	Warner Br.	Tunnel City	9/24/97	0.022	10.2	0.249	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A	63310	Warner Br.	St. Lawrence	9/24/97	N/A	12.2	0.402	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
N/A	63311	Warner Br.	St. Lawrence	9/24/97	0.033	9.8	0.361	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Abbreviations

Cond = electrical conductivity
NO3-N = Nitrate
Cl = Chloride
Alk = Alkalinity
P = phosphorus
K = potassium
Ca = calcium
Mg = magnesium
S = sulfur
Mn = manganese
Fe = iron
Na = sodium

Notes

* Measured only flow discharging from pipe at roadside, which is a small percentage of total spring discharge. No estimate of total discharge could be made.

** Measured approximately 1/3 of total flow (0.0092 cfs). This estimate accurate only to about 30%.

Table 8

Bedrock Formation Hydraulic Properties

Bedrock Formation	Database Code	Mean K (ft/s)	Mean T (sq ft/s)	Number of Wells
Cambrian, undifferentiated	3000	2.04E-05	1.73E-03	1
Jordan Fm.	3210	1.38E-04	4.32E-03	3
St. Lawrence Fm.	3300	2.15E-05	1.29E-03	1
Trempealeau & Tunnel City Gps.	3380	1.28E-05	9.39E-04	2
Tunnel City Gp.	3400	5.96E-05	3.33E-03	9
Tunnel City & Elk Mound Gps.	3490	5.66E-05	2.32E-03	4
Elk Mound. Gp.	3500	5.85E-06	7.60E-04	1
Wonewoc Fm.	3600	5.83E-05	3.43E-03	4
Mt. Simon Fm.	3800	2.94E-04	2.06E-02	1
Weighted Average		**6.84E-05**	**3.55E-03**	26

Notes

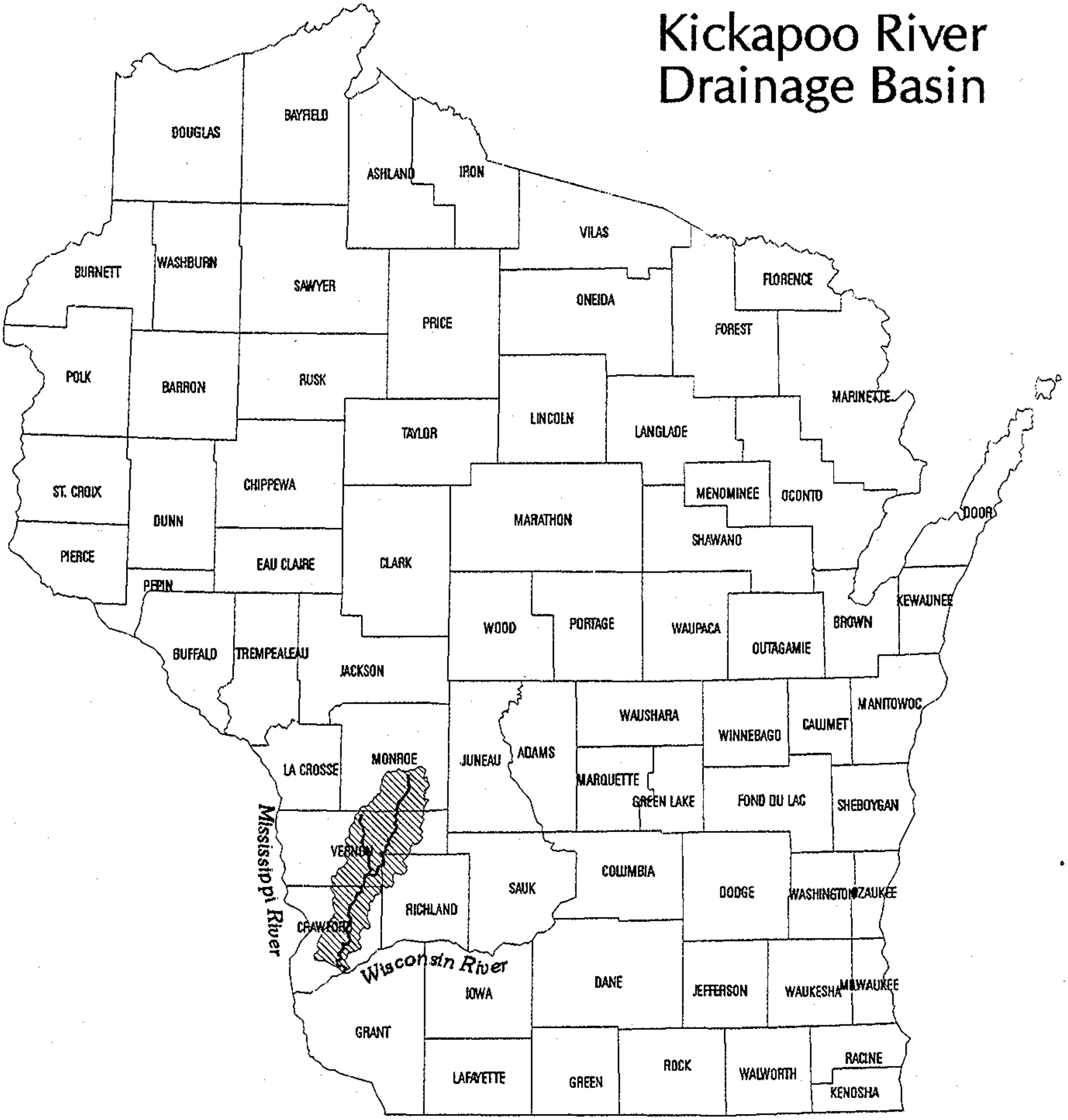
1. Database code identifies formation in Paradox well construction report database.
2. K = hydraulic conductivity.
3. T = transmissivity (= K x aquifer thickness)
4. The average properties are weighted by the number of wells in each formation.

Table 9. Summary of model parameters

Model parameter	Initial Estimate	Calibration Value	Range Tested	Comments
hydraulic conductivity, ft/d	5.9	1	0.5 - 20	higher values require too much recharge
aquifer base, ft above msl	200	500	0 - 800	model unstable if >500
recharge, in/yr	8.6	10	1 - 15	range of 8 - 10 is feasible
streambed thickness, ft	20	5 (with some variation)	0 - 30	relatively insensitive
stream resistance, days	1000	20 (with some variation)	0 - 10000	streams not sensitive if > 200

Table 10. Summary of major model runs and calibration data

Run	Objective	RMS Error, ft	Minimum Error, ft	Maximum Error, ft	Warner Cr. Flow, cfs	Kickapoo Flow, cfs
field data	calibration targets	0	+/- 20	+/- 20	17	169
Warner79	"best" calibration	20.5	-9.0	+36.6	22.4	184.0
Warner80	remove stream sediment	20.2	-9.0	+35.2	22.4	184.0
Warner81	increase recharge to 12 in/yr	26.0	+10.6	+42.6	26.2	190.4
Warner82	decrease recharge to 8 in/yr	23.9	-30.8	+30.6	18.5	177.7
Warner83	simulate hillslope recharge	23.8	-25.6	+40.2	19.6	177.5



Location of Kickapoo River Drainage Basin

Figure 1

Drainage Basins above La Farge, WI

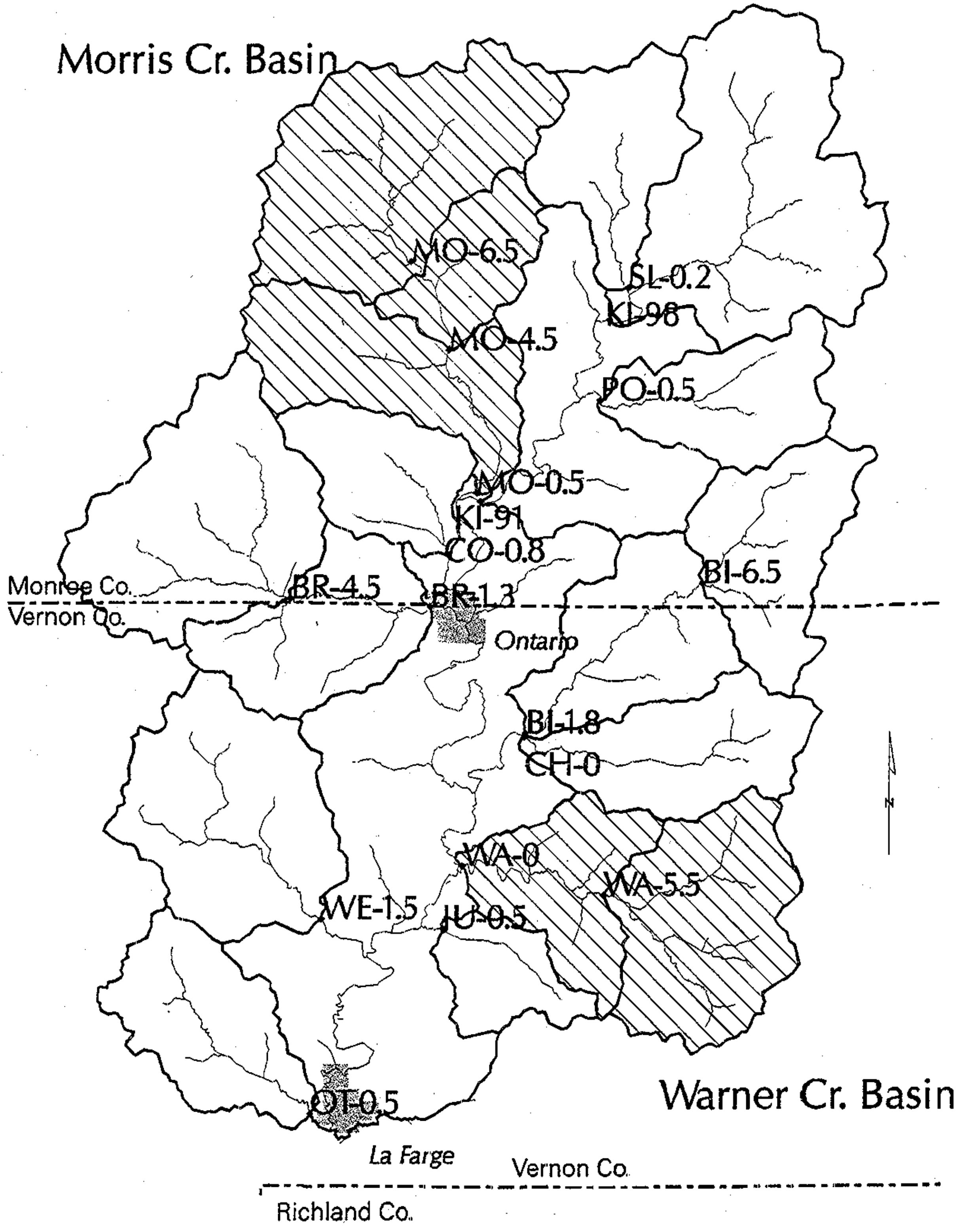
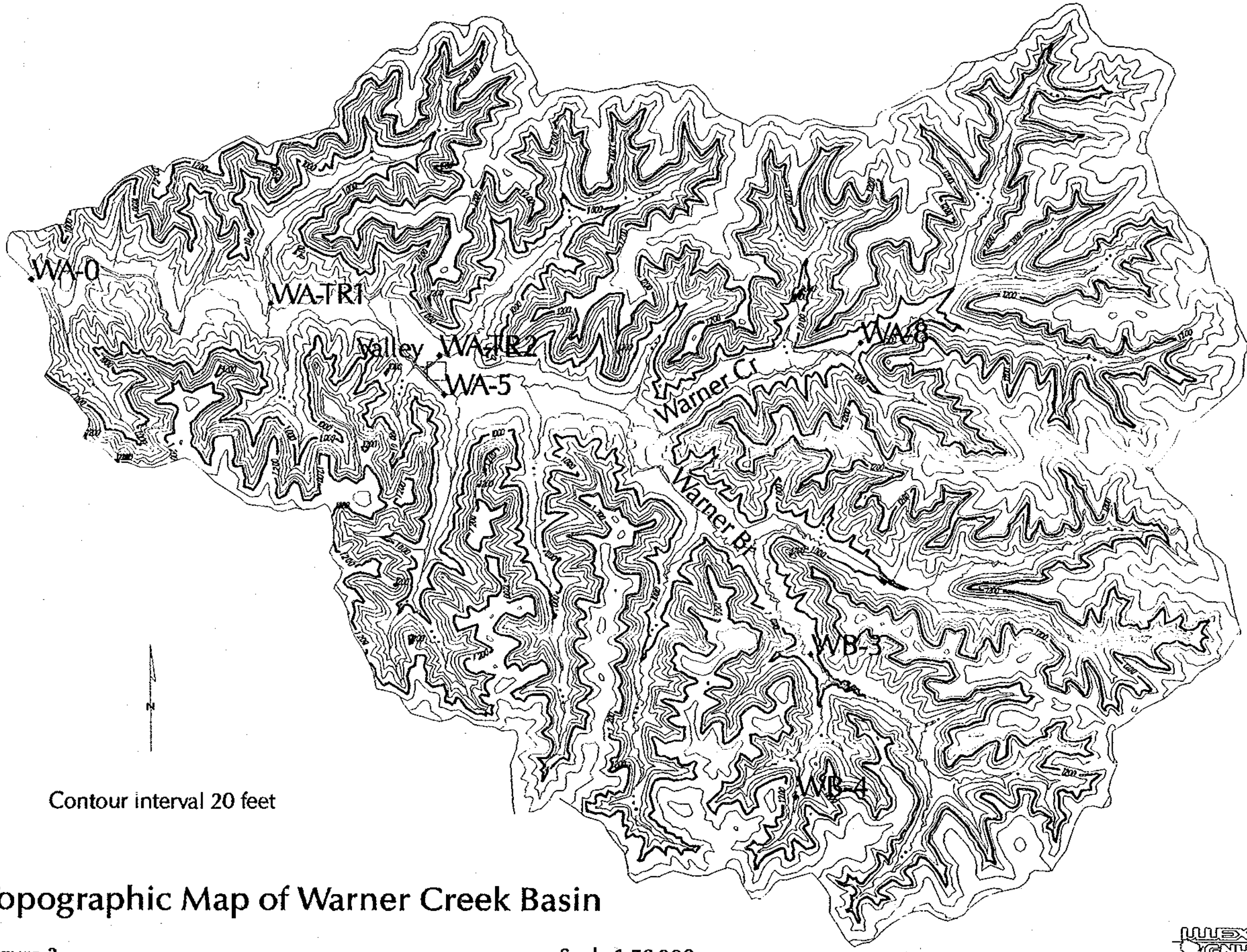


Figure 2

Scale 1:200,000



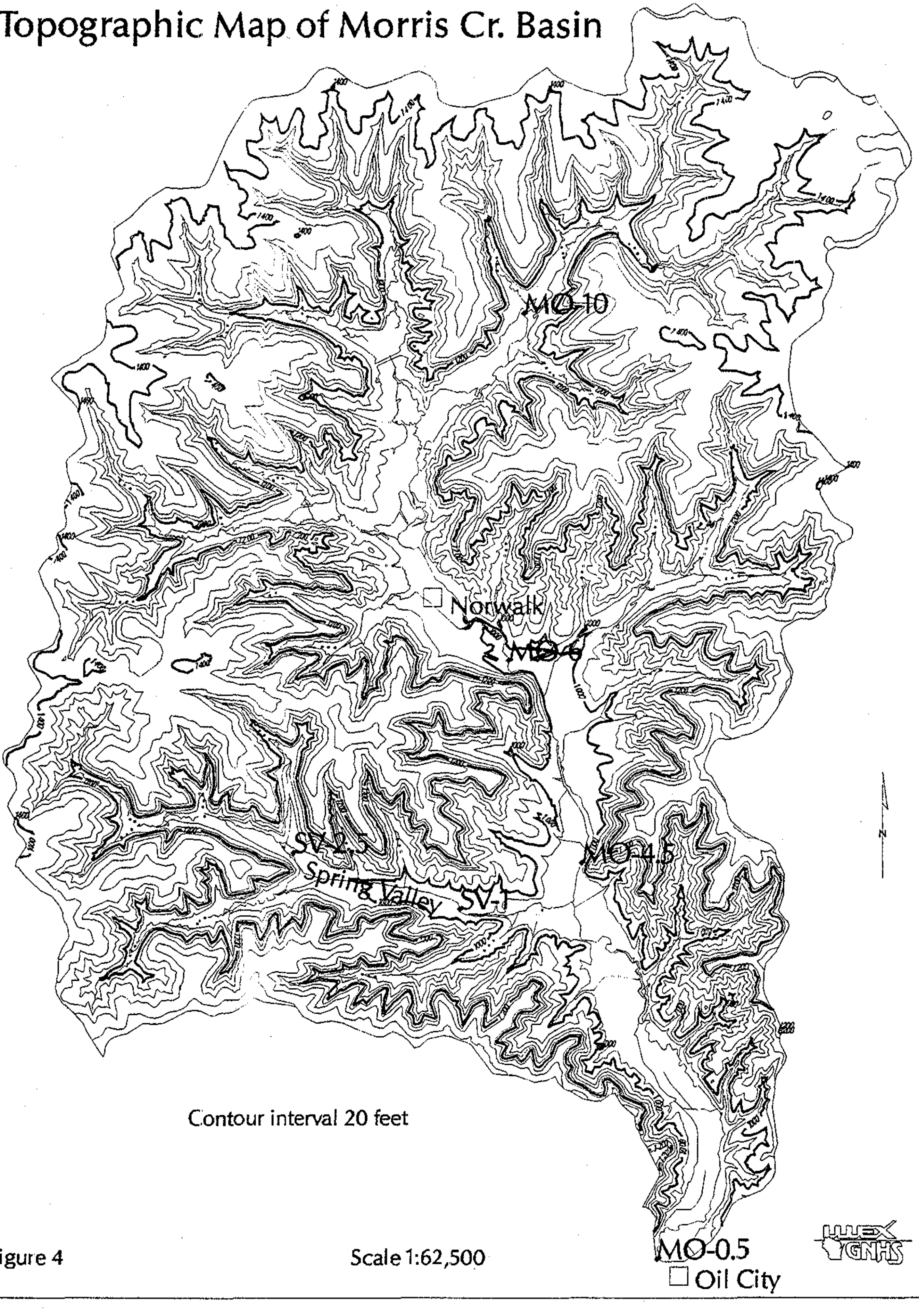
Topographic Map of Warner Creek Basin

Figure 3

Scale 1:50,000

WGNHS

Topographic Map of Morris Cr. Basin



Contour interval 20 feet

Figure 4

Scale 1:62,500

WGNHS

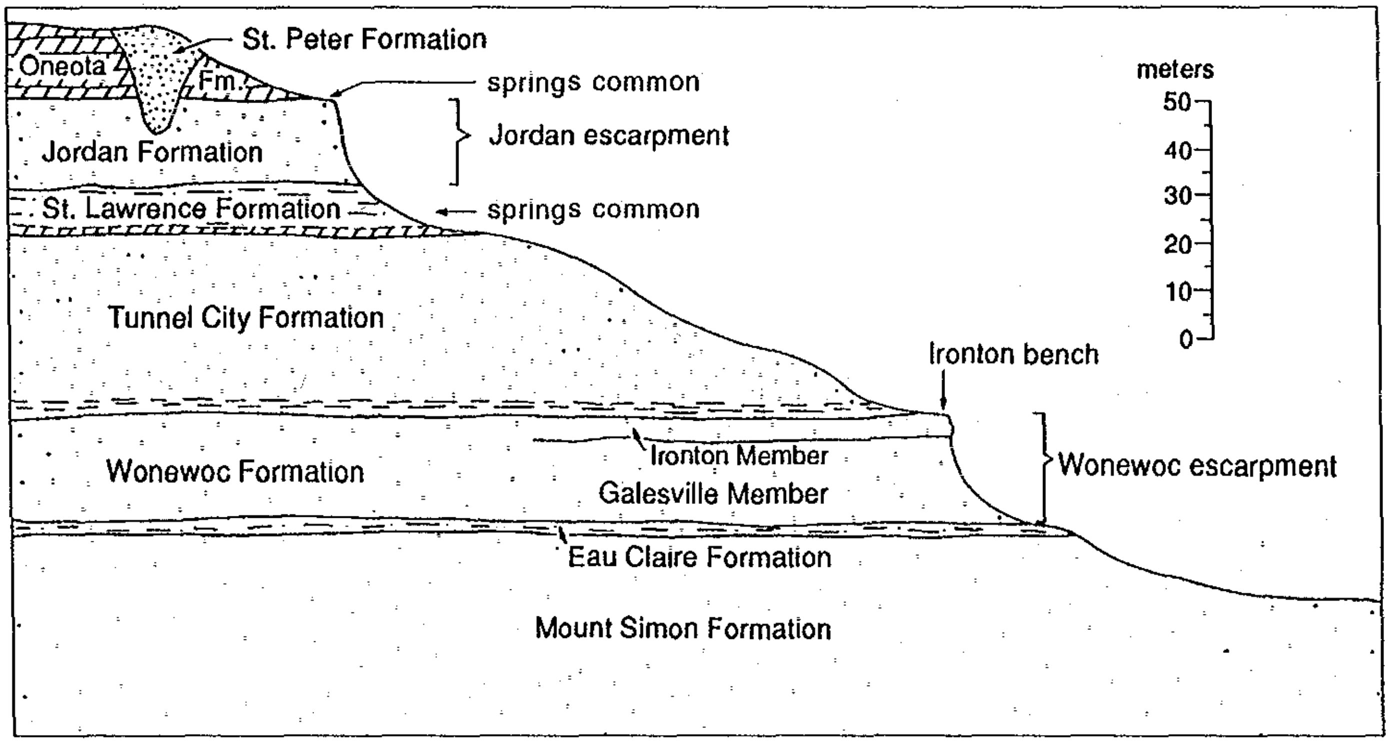


Figure 5. Topographic profile across Paleozoic bedrock formations in the Kickapoo watershed (after Clayton and Attig 1990).

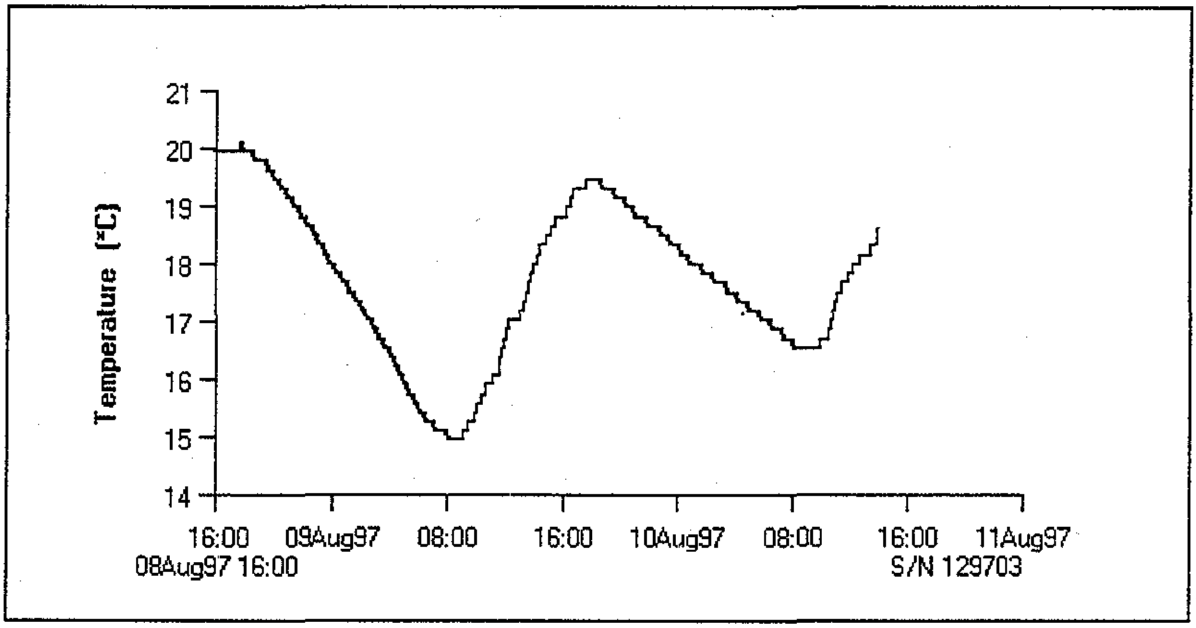


Figure 10a. Continuous temperature data for Warner Creek, at station WA - 2.2, for August 1997.

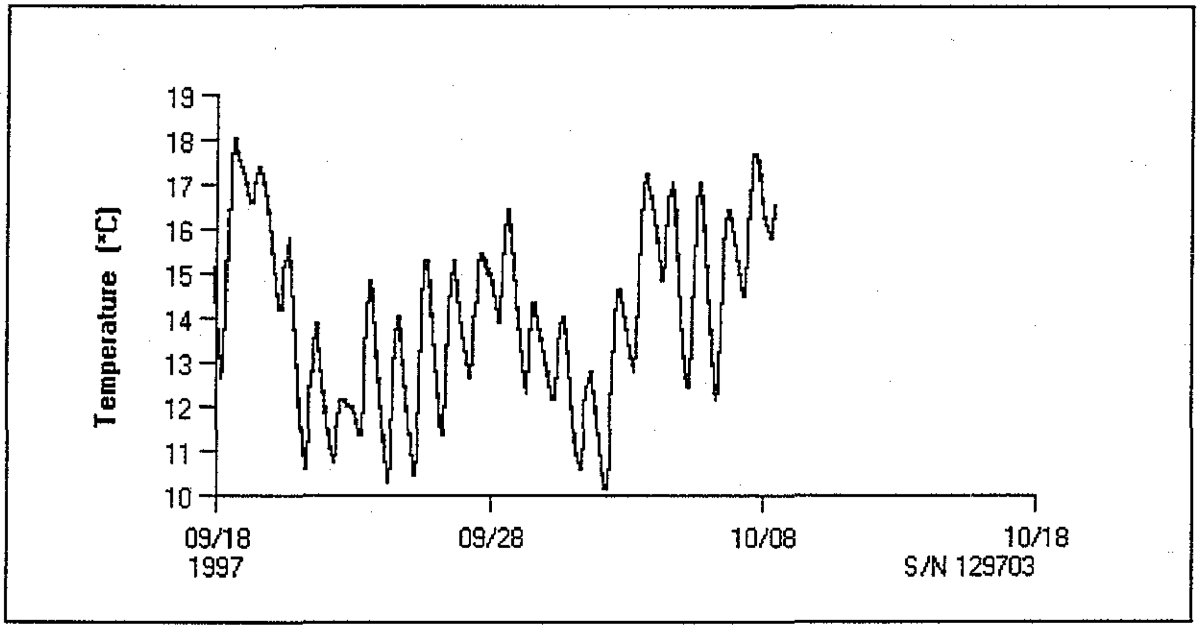


Figure 10b. Continuous temperature data for Warner Creek, at station WA - 2.2, for September and October 1997.

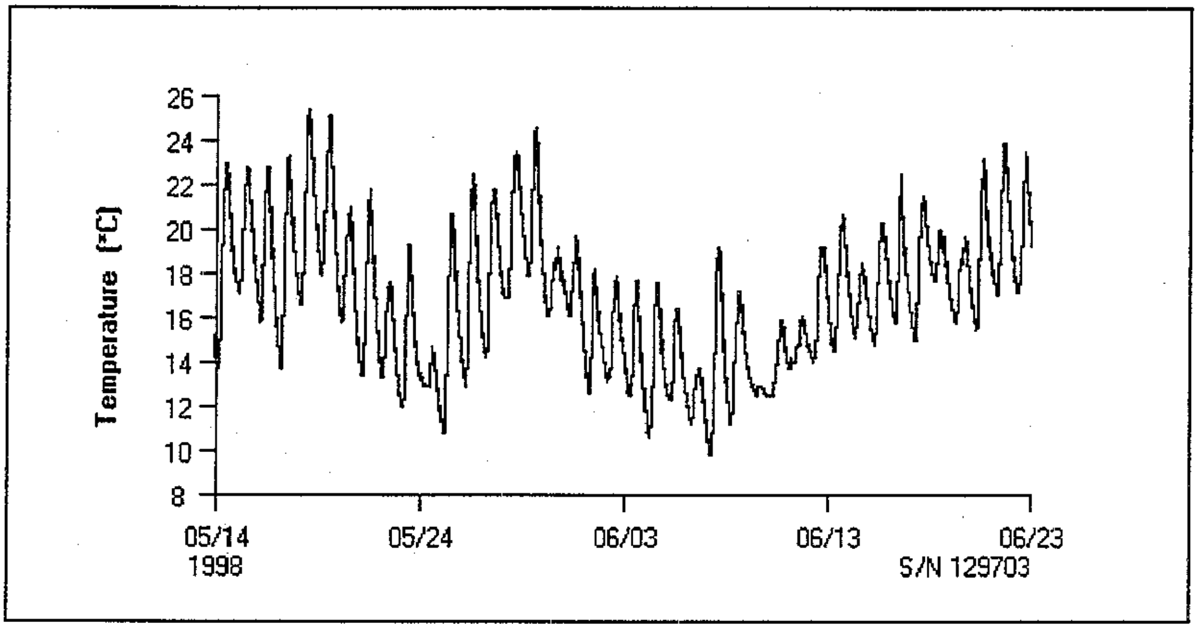


Figure 10c. Continuous temperature data for Morris Creek, at station MO - 4.5, for May and June 1998.

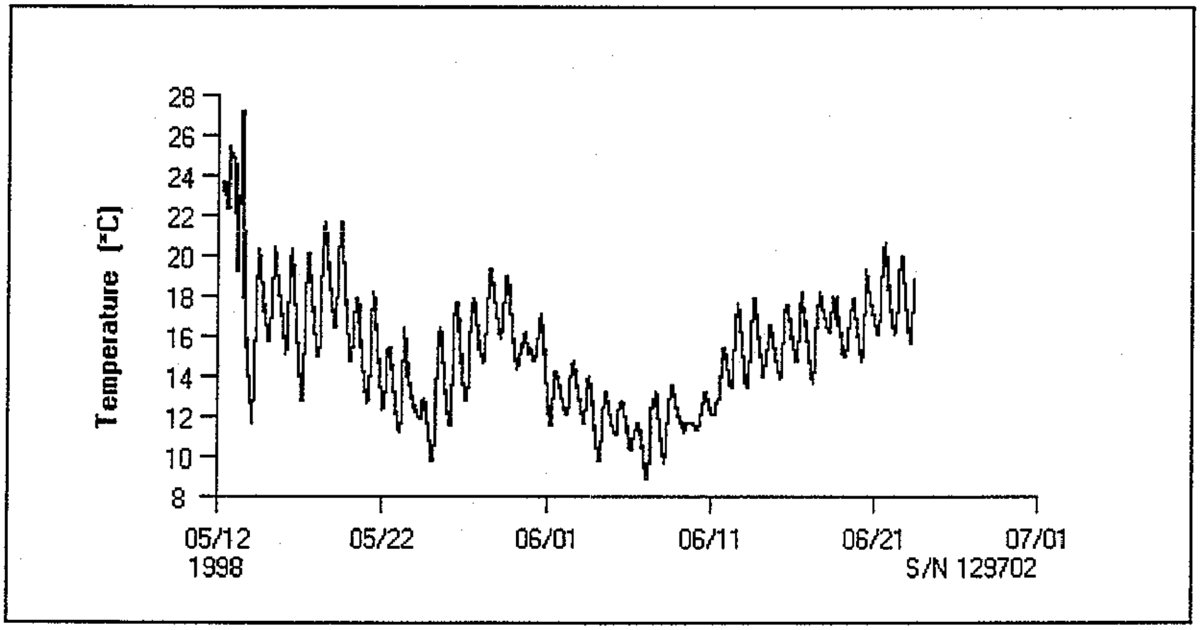
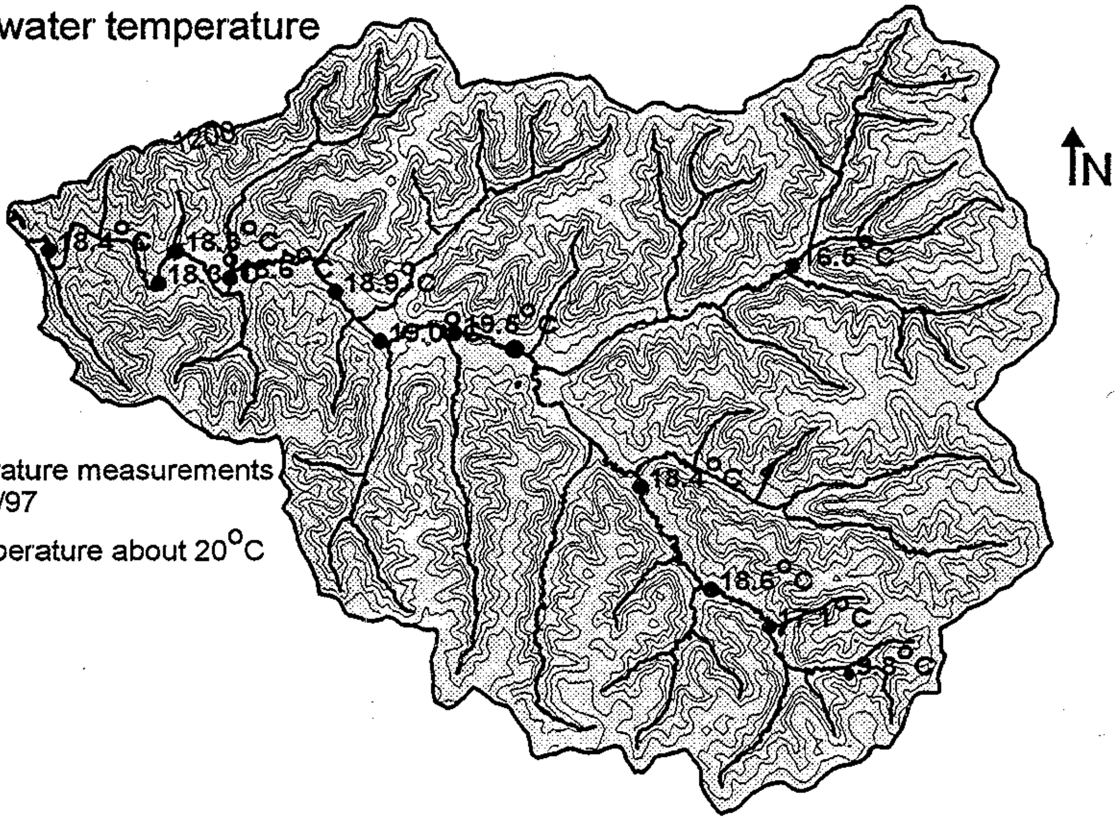


Figure 10d. Continuous temperature data for Morris Creek, at station MO - 10, for May and June 1998

Warner Creek Basin- water temperature

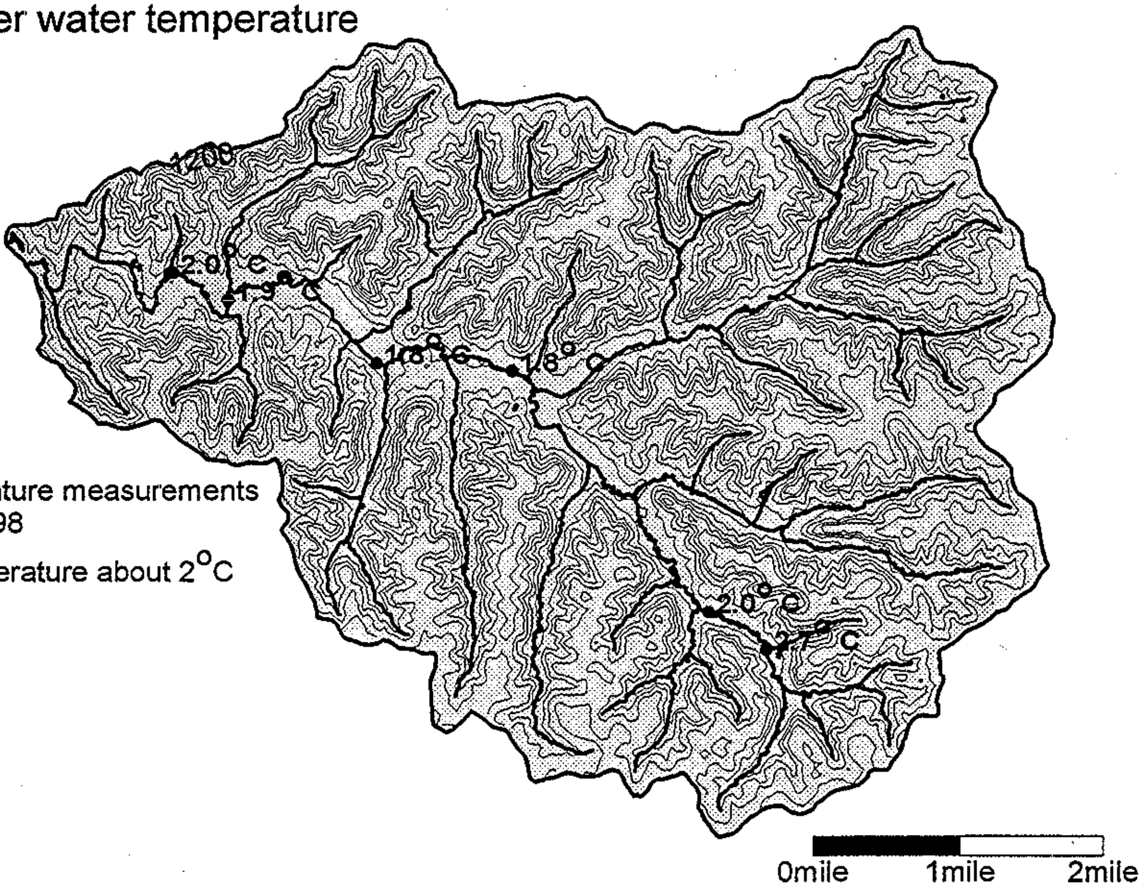
Fall water temperature



Temperature measurements on 10/8/97

Air temperature about 20°C

Winter water temperature



Temperature measurements on 1/30/98

Air temperature about 2°C

Figure 11. Surface water temperatures in the Warner Creek basin

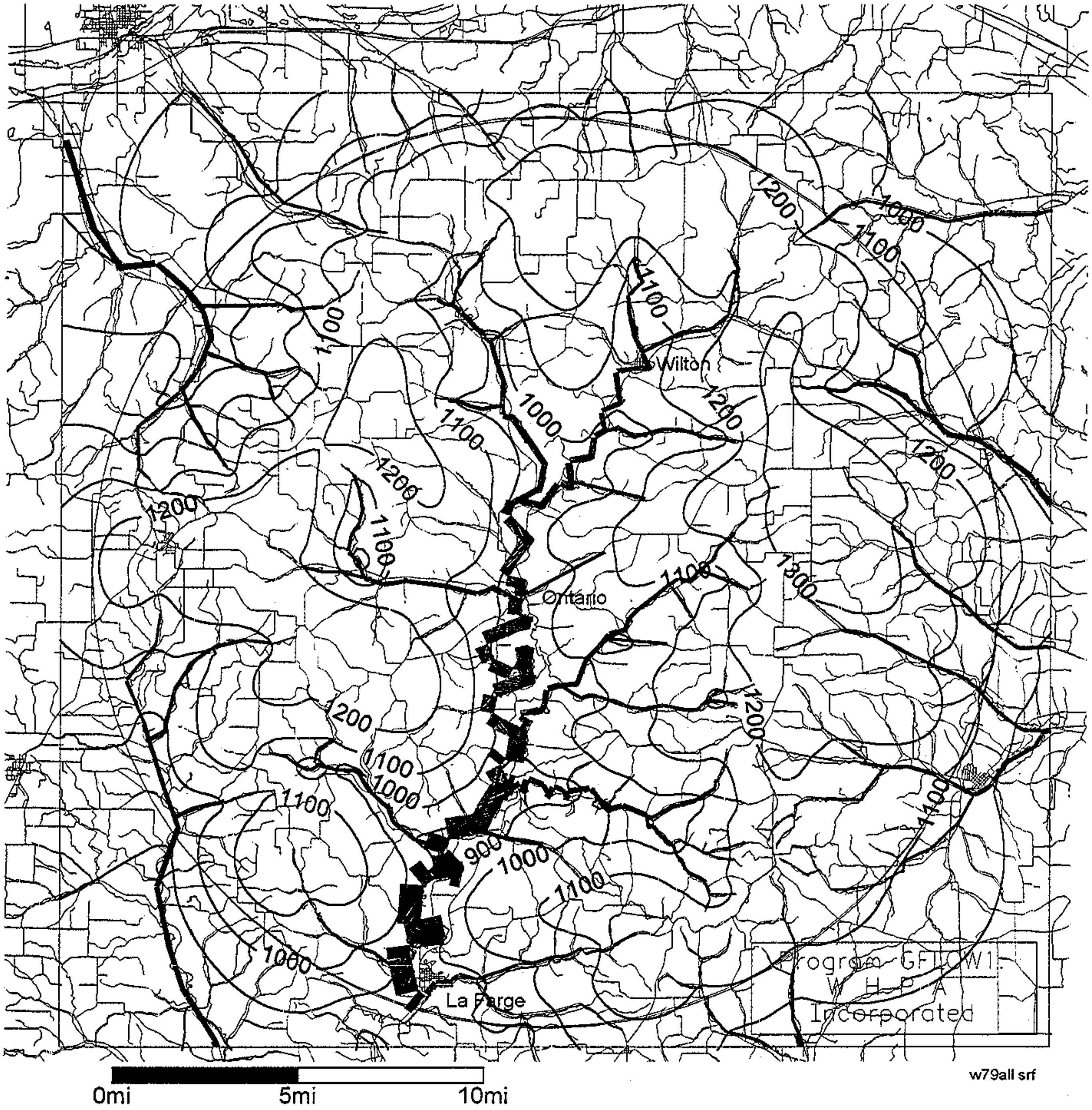


Figure 12. GFLOW model layout, showing calibrated water level contours. Width of stream elements is proportional to model-calculated baseflow.

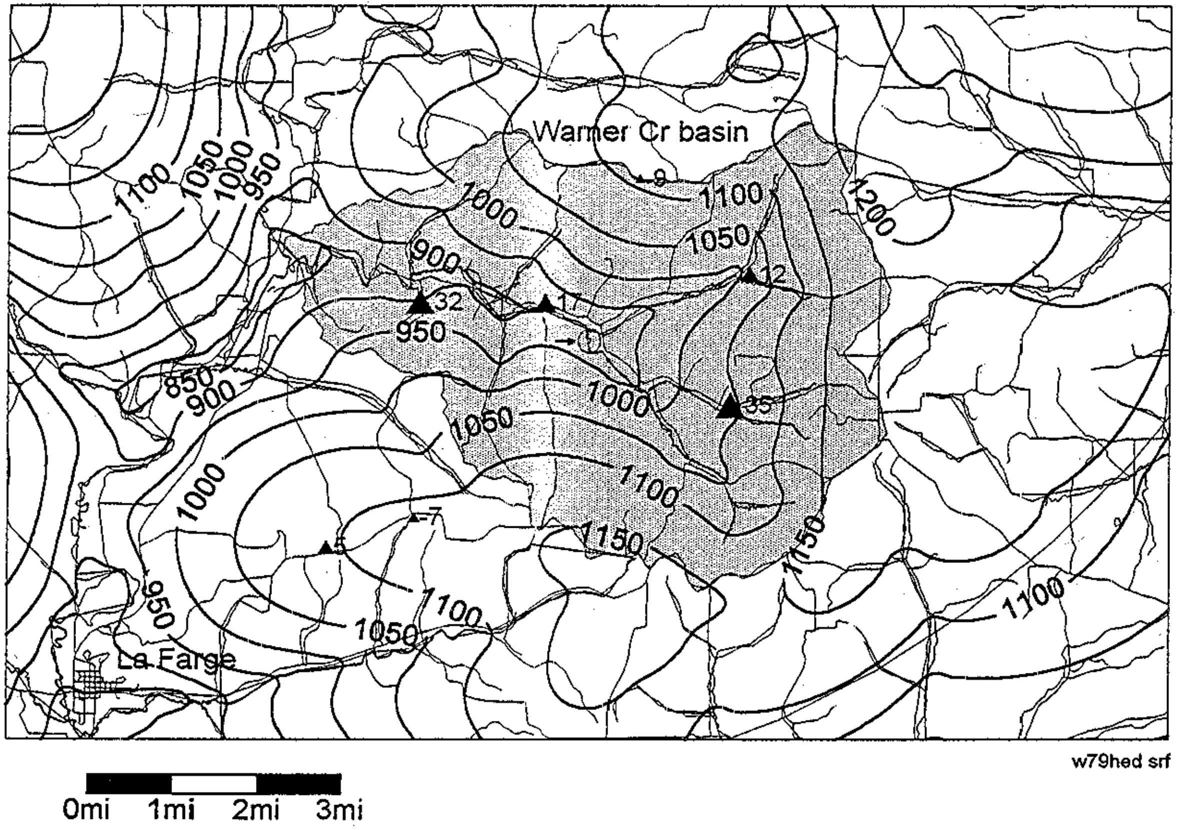


Figure 13. Calibrated water-level configuration in the Warner Creek basin. Triangles show locations of wells used for calibration, and numbers indicate calibration error in feet. Small circle indicates location of stream resistance test described in text.

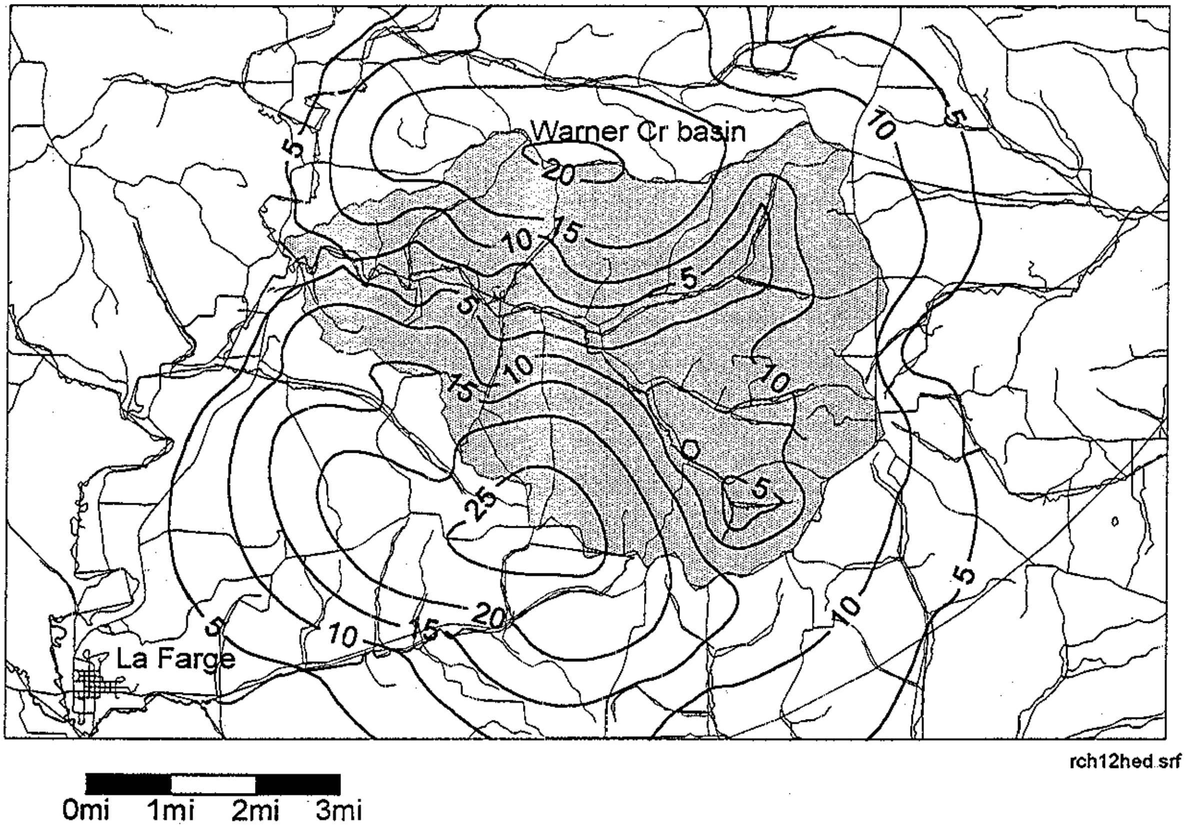


Figure 14. Change in hydraulic head (ft) caused by increasing recharge in the Warner Creek basin from 10 in/yr to 12 in/yr.

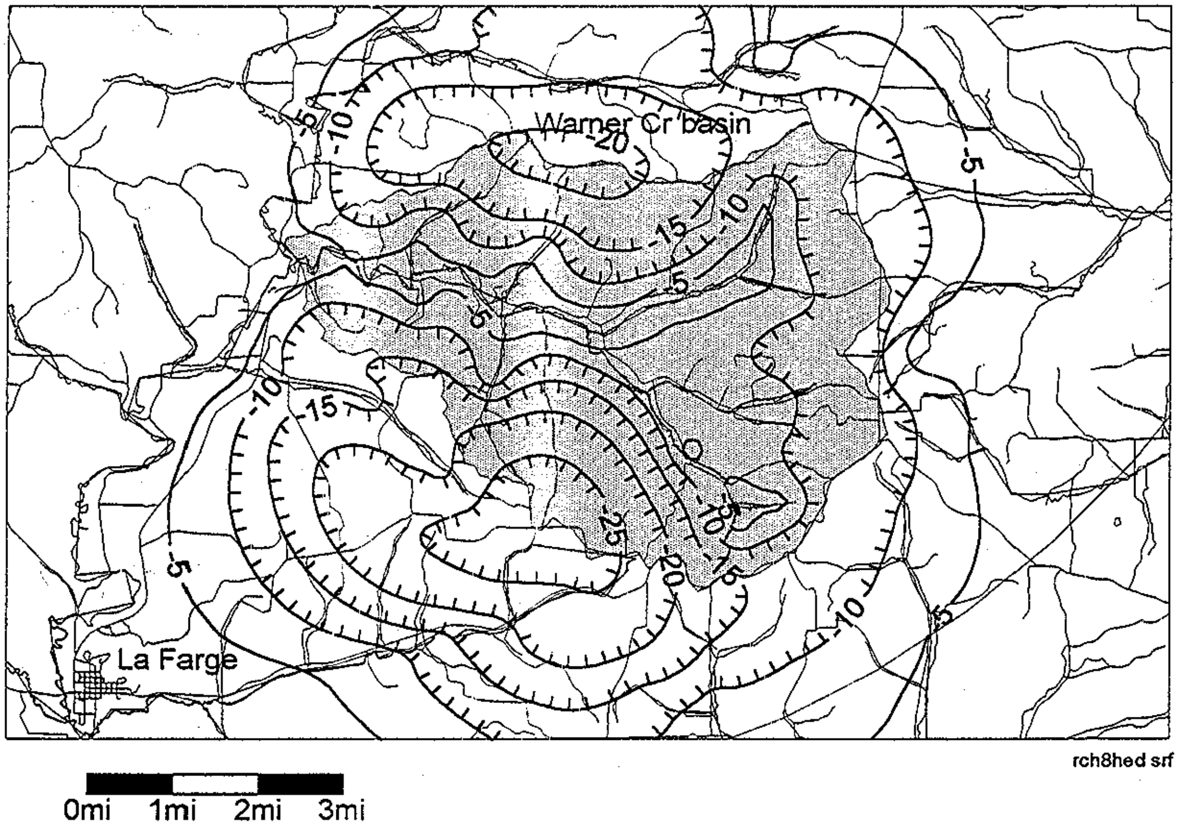


Figure 15. Change in hydraulic head (ft) caused by decreasing recharge in the Warner Creek basin from 10 in/yr to 8 in/yr.

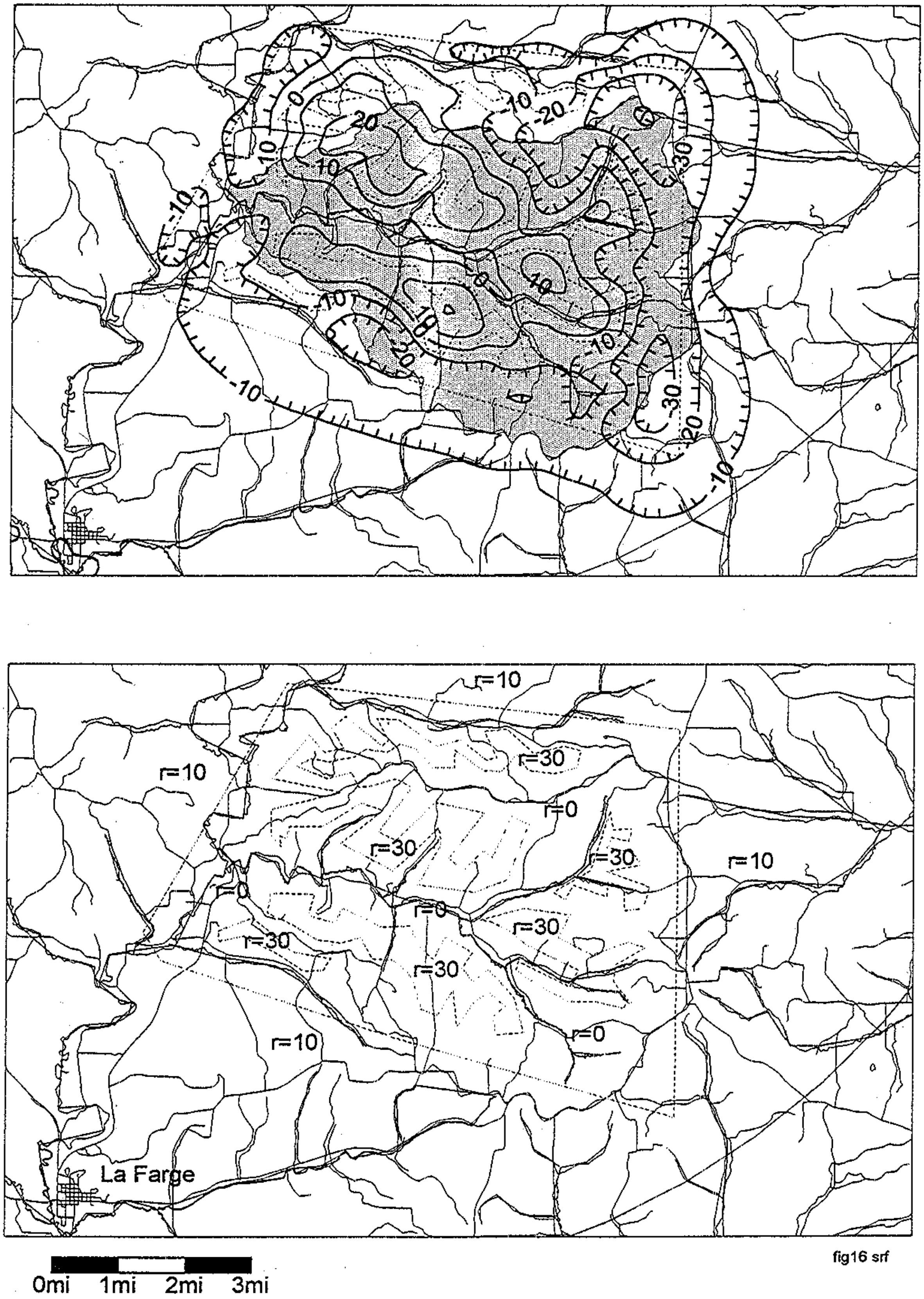


Figure 16. Effects of hillslope recharge. Top: Change in modeled water levels caused by insertion of recharge along hillslopes. Bottom: Locations of recharge elements and corresponding recharge rates of 0, 10, and 30 in/yr.

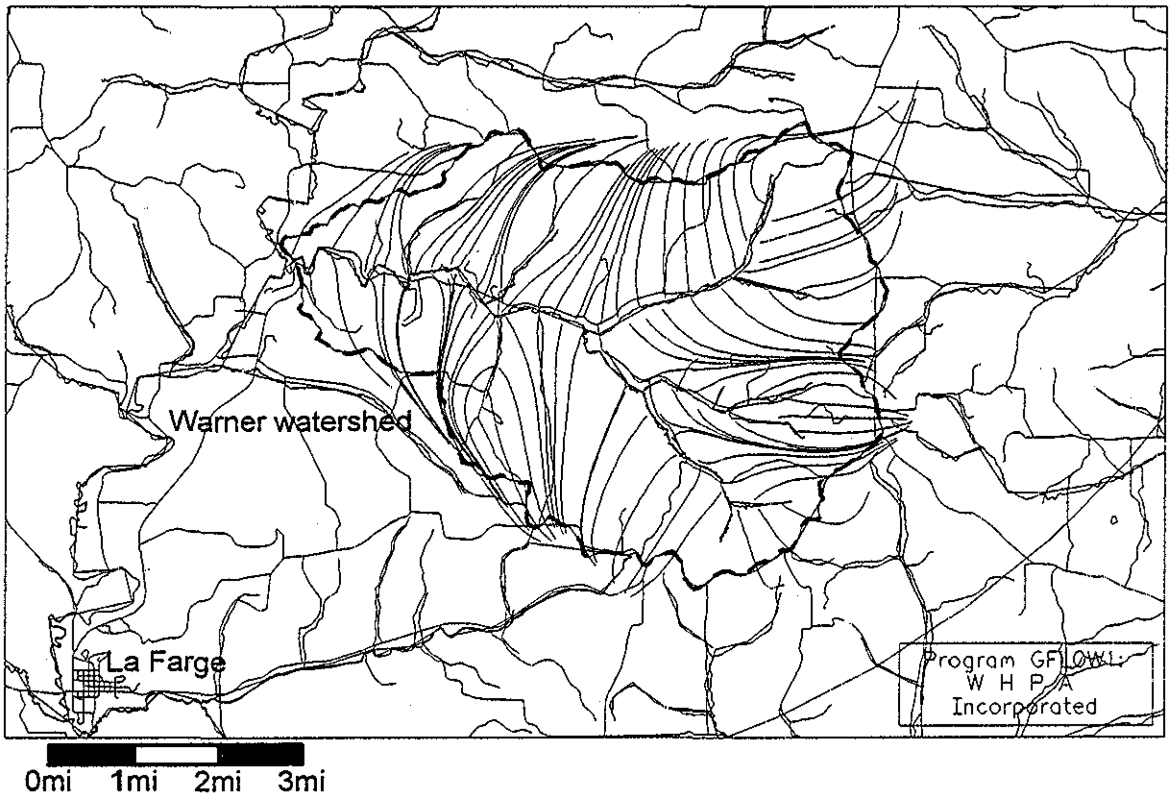


Figure 17. Particle paths generated for the Warner Creek basin.

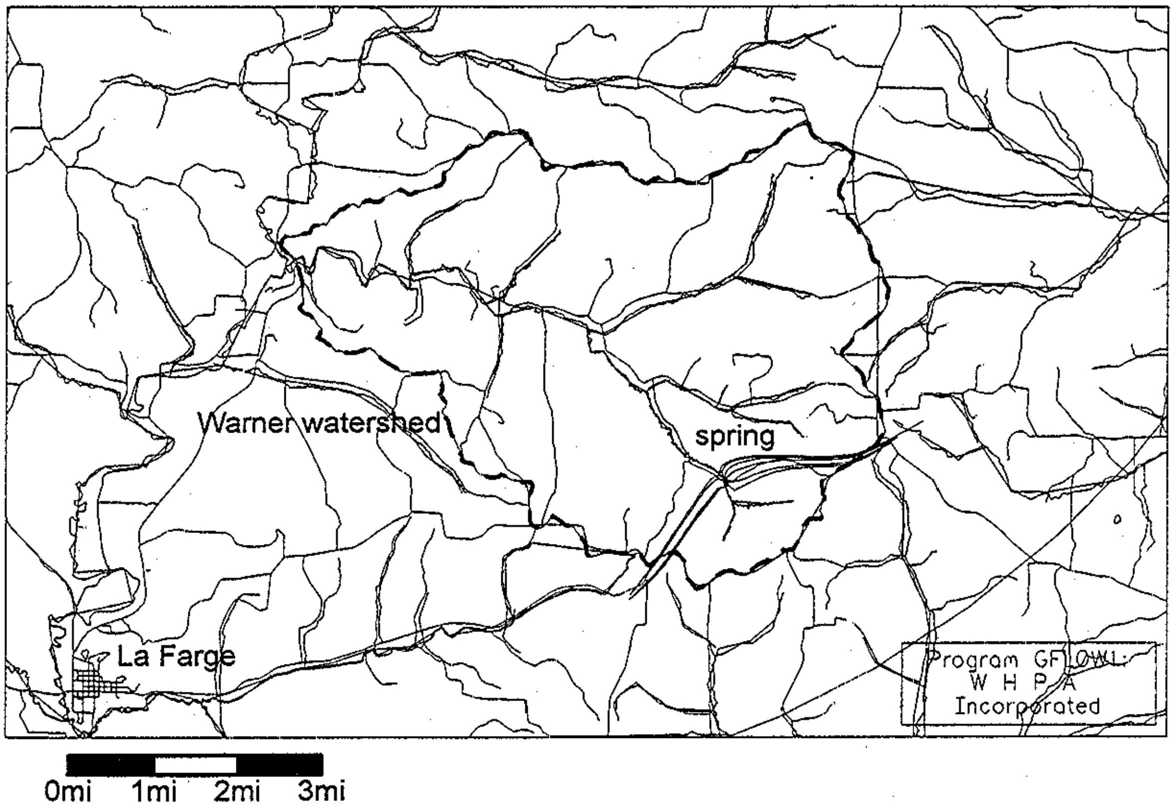


Figure 18. Particle paths outlining the area contributing to a spring in the Warner Creek basin.

Appendix A
Baseflow Measurement Site Locations

BI-1.8
Billings Creek in Wildcat Mountain State Park. Approximately 100 feet downstream from Highway 33, near intersection with County F. Access from Highway 33 bridge.

BI-6.5
Billings Creek in Monroe County, near Vernon County line. Approximately 100 feet downstream from County Z bridge, near intersections with Eureka Drive and 24th Drive. Below confluence with small tributary. Access from County Z bridge.

BR-1.3
Brush Creek at the western edge of Ontario, at the Monroe and Vernon County line. Approximately 20 feet upstream of Highway 33 bridge. Access from bridge.

BR-4.5
Brush Creek approximately 3 miles west of Ontario. Approximately 75 feet upstream of 16th Court bridge. Access from bridge.

CH-0
Cheyenne Creek in Wildcat Mountain State Park, approximately 350 feet upstream from confluence with Billings Creek. Access by walking southwest across state park land from the Highway 33 bridge over Billings Creek.

CO-0.8
Cook Creek at Niagra Road. Immediately upstream of bridge.

JU-0.5
Jug Creek on the Kickapoo Reserve. Approximately 240 feet upstream of the Highway 131 bridge, and 50 feet upstream of large willow tree.

KI-91
Kickapoo River at Oil City. At downstream edge of Highway 131 bridge.

KI-98
Kickapoo River at the south side of Wilton. Approximately 50 feet downstream of Highway 131 bridge, on right-of-way.

MO-0.5
Morris Creek at Oil City, at County T bridge approximately 1/4 mile from Highway 131. Measured 10 feet upstream or 50 feet downstream of bridge, depending on conditions. Access from bridge.

MO-4.5
Morris Creek near intersection of County T and F. Approximately 150 feet upstream of County T bridge, just above large pool and below fence. On right-of-way. Access from north side of bridge.

MO-6
Morris Creek just south of Norwalk. Approximately 15 feet upstream of County T and Highway 71 bridge, near meat packaging plant. On right-of-way. Access from bridge

MO-6.5
Morris Creek in Norwalk. Approximately 15 feet upstream of bridge on Elroy-Sparta Bike Trail near sewage treatment plant. Thick silt and rip rap make this site difficult to gage. Switched to MO-6 location after May 1997 survey

MO-10
Morris Creek headwaters, on Monroe County land off Kennel Road (listed as Dover Avenue on some maps). From parking circle at end of road, walk a few hundred feet east to stream. Measure approximately 20 feet below confluence with small tributary.

SV-1
Spring Valley Creek approximately 1 mile above confluence with Morris Creek. On Dennis Hubbard's farm (the westernmost of two). South-flowing reach with abundant emergent vegetation.

SV-2.5
Spring Valley Creek headwaters, approximately 2.5 miles above Morris Creek. Two feet upstream of culvert below Edgewood Avenue, just south of Duke Road.

OT-0.5
Otter Creek at La Farge. Approximately 170 feet downstream of first Highway 82 bridge west of La Farge. Access from bridge.

PO-0.5
Poe Creek at second County Z bridge east of Highway 131. County Z is east-west here. Approximately 20 feet downstream of bridge.

SL-0.2
Sleighton Creek at Wilton. Approximately 20 feet downstream of Elroy-Sparta Bike Trail bridge, about 1/4 mile east of County M. Access from trail.

WA-0
Warner Creek mouth, on Kickapoo Reserve. Approximately 50 feet downstream of County P bridge

WA-5
Warner Creek at Valley. Approximately 100 feet downstream of Valley Avenue bridge, south of County P. Access from Mr. Vern Nelson's driveway.

WA-5.5
Warner Creek at Valley. Approximately 120 feet downstream of Union Avenue bridge, on Mr. Robert McCoy's farm. Switch to WA-5 location after May 1997 survey.

WA-8
Upper Warner Creek on County P, approximately 2.5 miles east of Valley and 1 mile west of Fish Hollow Road. Approximately 10 feet downstream of County P bridge

WB-3
Warner Branch on Twin Ash Road. Approximately 100 feet upstream of barnyard on Mrs. Edith Marshall's farm.

WB-4
Warner Branch headwaters on Twin Ash Road. Approximately 10 feet upstream of culvert at road crossing 1 mile north of Maple Road and 1 mile south of Morning Star Road.

WA-TR1
Warner Creek tributary on Kickapoo Reserve just east of Scratch Road. Access from Scratch Road and measure above confluence with Warner Creek.

WA-TR2
Warner Creek tributary at Valley. Approximately 5 feet downstream of culvert below County P, just west of Valley Avenue.

WE-1.5
Weister Creek at Potts Corners. On Kickapoo Reserve approximately 200 feet upstream of County P bridge.

Appendix B
Laboratory Analytical Reports

University of Wisconsin–Madison/Extension

Soil & Plant Analysis Laboratory
Soil Science Department
5711 Mineral Point Road
Madison, Wisconsin 53705-4453
Phone (608) 262-4364
FAX (608) 263-3327

College of Agricultural and Life Sciences

KB → STEVE

June 12, 1997
Acct. No. 514
Lab No. S932

TO:	Ken Bradbury Wis. GNHS 3817 Mineral Point Road U. of W., Madison CAMPUS
FROM:	Soil & Plant Analysis Lab Sherry M. Combs, Director
SUBJECT:	Results of analyses on 18 solution samples.

Please find enclosed results of analyses on 18 solution samples submitted May 22, 1997.

If you have any questions concerning these analyses, please feel free to contact us.

Enclosure(s)

SC/ss

S932 KEN BRADBURY

UWEX SOIL AND PLANT ANALYSIS LAB
5711 MINERAL POINT ROAD
MADISON WI 53705

DATE OF ANALYSIS: 6 / 2 / 97

(RESULTS REPORTED ON 'AS RECEIVED' BASIS)

	PPM											
SAMPLE	P	K	CA	MG	S	ZN	B	MN	FE	CU	AL	NA
1	< 0.217	0.78	51.19	27.52	3.45	< 0.010	< 0.029	0.005	0.14	< 0.025	< 0.352	3.34
2	< 0.217	< 0.621	65.30	34.15	4.50	0.02	< 0.029	0.027	0.17	< 0.025	< 0.352	3.23
3	< 0.217	0.72	46.84	26.63	4.20	< 0.010	< 0.029	< 0.003	0.19	< 0.025	< 0.352	6.28
4	< 0.217	0.92	52.12	28.39	5.01	< 0.010	< 0.029	< 0.003	0.19	< 0.025	< 0.352	8.63
5	< 0.217	0.70	53.04	28.79	4.93	< 0.010	< 0.029	< 0.003	0.22	< 0.025	< 0.352	3.34
6	< 0.217	< 0.621	61.69	31.39	5.03	< 0.010	< 0.029	< 0.003	0.20	< 0.025	< 0.352	2.83
7	< 0.217	< 0.621	51.60	27.51	4.14	< 0.010	< 0.029	0.016	0.22	< 0.025	< 0.352	4.05
8	< 0.217	< 0.621	61.58	31.38	5.28	< 0.010	< 0.029	0.011	0.15	< 0.025	< 0.352	2.51
9	< 0.217	< 0.621	47.07	32.60	4.05	< 0.010	< 0.029	< 0.003	0.09	< 0.025	< 0.352	3.03
10	< 0.217	< 0.621	57.42	32.24	4.16	< 0.010	< 0.029	0.005	0.15	< 0.025	< 0.352	2.99
11	< 0.217	< 0.621	54.79	31.27	3.70	< 0.010	< 0.029	< 0.003	0.11	< 0.025	< 0.352	2.26
12	< 0.217	< 0.621	61.12	31.45	4.27	< 0.010	< 0.029	< 0.003	0.17	< 0.025	< 0.352	2.29
13	< 0.217	< 0.621	65.54	34.76	5.27	< 0.010	< 0.029	< 0.003	0.13	< 0.025	< 0.352	3.36
14	< 0.217	0.64	54.93	28.77	4.58	< 0.010	< 0.029	0.014	0.24	< 0.025	< 0.352	4.33
15	< 0.217	< 0.621	64.37	33.45	4.48	< 0.010	< 0.029	< 0.003	0.12	< 0.025	< 0.352	2.79
16	< 0.217	< 0.621	61.29	31.64	4.59	< 0.010	< 0.029	< 0.003	0.18	< 0.025	< 0.352	2.54
17	< 0.217	< 0.621	60.81	31.84	4.63	< 0.010	< 0.029	< 0.003	0.11	< 0.025	< 0.352	2.51
18	< 0.217	< 0.621	61.05	30.53	4.93	< 0.010	< 0.029	< 0.003	0.10	< 0.025	< 0.352	2.13

5932 KEN BRADBURY

UWEX SOIL AND PLANT ANALYSIS LAB
5711 MINERAL POINT ROAD
MADISON WI 53705

KB —> STEVE

DATE OF ANALYSIS: 6 / 2 / 97

(RESULTS REPORTED ON 'AS RECEIVED' BASIS)

	PPM											
SAMPLE	P	K	CA	MG	S	ZN	B	MN	FE	CU	AL	NA
1	< 0.217	0.78	51.19	27.52	3.45	< 0.010	< 0.029	0.005	0.14	< 0.025	< 0.352	3.34
2	< 0.217	< 0.621	65.30	34.15	4.50	0.02	< 0.029	0.027	0.17	< 0.025	< 0.352	3.23
3	< 0.217	0.72	46.84	26.63	4.20	< 0.010	< 0.029	< 0.003	0.19	< 0.025	< 0.352	6.28
4	< 0.217	0.92	52.12	28.39	5.01	< 0.010	< 0.029	< 0.003	0.19	< 0.025	< 0.352	8.63
5	< 0.217	0.70	53.04	28.79	4.93	< 0.010	< 0.029	< 0.003	0.22	< 0.025	< 0.352	5.54
6	< 0.217	< 0.621	61.69	31.39	5.03	< 0.010	< 0.029	< 0.003	0.20	< 0.025	< 0.352	2.83
7	< 0.217	< 0.621	51.60	27.31	4.14	< 0.010	< 0.029	0.016	0.22	< 0.025	< 0.352	4.05
8	< 0.217	< 0.621	61.58	31.38	5.28	< 0.010	< 0.029	0.011	0.15	< 0.025	< 0.352	2.51
9	< 0.217	< 0.621	47.07	32.60	4.05	< 0.010	< 0.029	< 0.003	0.09	< 0.025	< 0.352	3.03
10	< 0.217	< 0.621	57.42	32.24	4.16	< 0.010	< 0.029	0.005	0.15	< 0.025	< 0.352	2.99
11	< 0.217	< 0.621	54.79	31.27	3.70	< 0.010	< 0.029	< 0.003	0.11	< 0.025	< 0.352	2.26
12	< 0.217	< 0.621	61.12	31.45	4.27	< 0.010	< 0.029	< 0.003	0.17	< 0.025	< 0.352	2.29
13	< 0.217	< 0.621	65.54	34.76	5.27	< 0.010	< 0.029	< 0.003	0.13	< 0.025	< 0.352	3.36
14	< 0.217	0.64	54.93	28.77	4.58	< 0.010	< 0.029	0.014	0.24	< 0.025	< 0.352	4.33
15	< 0.217	< 0.621	64.37	33.45	4.48	< 0.010	< 0.029	< 0.003	0.12	< 0.025	< 0.352	2.79
16	< 0.217	< 0.621	61.29	31.64	4.59	< 0.010	< 0.029	< 0.003	0.18	< 0.025	< 0.352	2.54
17	< 0.217	< 0.621	60.81	31.84	4.63	< 0.010	< 0.029	< 0.003	0.11	< 0.025	< 0.352	2.51
18	< 0.217	< 0.621	61.05	30.53	4.93	< 0.010	< 0.029	< 0.003	0.10	< 0.025	< 0.352	2.13

SOIL & PLANT ANALYSIS LABORATORY
5711 MINERAL POINT ROAD
MADISON, WI 53705

KEN BRADBURY
WIS. GNHS

LAB # S 932
ACCT # 514

DATE OF ANALYSIS 6/11/97

(RESULTS REPORTED ON "AS RECEIVED" BASIS)

SAMPLE ID	NO3-N (ppm)	Cl (ppm)	Alkalinity (mg CaCO3/L)	pH
1	0.9	7.4	214	8.0
2	0.9	6.9	257	8.3
3	1.1	9.2	207	8.8
4	1.2	11.9	207	9.1
5	0.6	8.0	221	8.4
6	0.6	5.5	228	8.8
7	0.7	8.5	200	8.8
8	0.6	3.8	228	8.5
9	1.1	6.7	207	8.5
10	0.8	5.9	221	8.7
11	1.2	3.4	228	8.3
12	0.7	4.0	228	8.2
13	1.0	6.5	236	8.6
14	0.6	8.8	214	8.5
15	0.9	4.3	250	8.5
16	0.7	4.0	228	8.4
17	0.8	3.9	236	8.6
18	0.7	1.6	228	8.2

Sampling Locations on May 15, 1997

Laboratory ID	Sampling Location
1	SL - 0.2
2	OT - 0.5
3	MO - 6.5
4	MO - 4.5
5	MO - 0.5
6	PO - 0.5
7	KI - 98
8	WA - 0
9	BR - 4.5
10	BR - 1.3
11	BI - 6.5
12	BI - 1.8
13	CH - 0
14	KI - 91
15	CO - 0.8
16	WE - 1.5
17	WA - 1.5
18	JU - 0.5

University of Wisconsin–Madison/Extension

Soil & Plant Analysis Laboratory
Soil Science Department
5711 Mineral Point Road
Madison, Wisconsin 53705-4453
Phone (608) 262-4364
FAX (608) 263-3327

College of Agricultural and Life Sciences

January 14, 1998
Acct. No. **514**
Lab No. **S1631**

Kickapoo Springs Project

TO: Ken Bradbury
Wis. GNHS
3817 Mineral Point Road
U. of W., Madison
CAMPUS

FROM: Soil & Plant Analysis Lab
Sherry M. Combs, Director

SUBJECT: Results of analyses on 8 solution samples.

Please find enclosed results of analyses on 8 solution samples submitted December 22, 1997.

If you have any questions concerning these analyses, please feel free to contact us.

Enclosure(s)

SC/ss

SOIL & PLANT ANALYSIS LABORATORY
5711 MINERAL POINT ROAD
MADISON, WI 53705

KEN BRADBURY
WIS. GNHS

LAB # **S 1631**
ACCT # **514**

DATE OF ANALYSIS **1/13/98**

(RESULTS REPORTED ON "AS RECEIVED" BASIS)

SAMPLE ID	NO3-N (ppm)	Cl (ppm)	pH	Alkalinity (mg CaCO3/L)
Kickapoo Springs Project				
1	5.78	10.8	7.9	186
2	0.51	0.6	7.9	228
3	0.38	<0.1	7.6	300
4	0.25	<0.1	7.7	243
5	2.10	3.4	7.6	286
6	1.19	1.1	7.6	250
7	1.98	1.7	7.7	257
8	1.57	2.3	7.7	236

S1631 KEN BRADBURY-WGNHS

UWEX SOIL AND PLANT ANALYSIS LAB
5711 MINERAL POINT ROAD
MADISON WI 53705

KICKAPOO SPRINGS PROJECT

DATE OF ANALYSIS: 1 / 5 / 98

(RESULTS REPORTED ON 'AS RECEIVED' BASIS)

	PPM											
SAMPLE	P	K	CA	MG	S	ZN	B	MN	FE	CU	AL	NA
1	0.27	< 0.621	50.33	26.53	3.34	< 0.010	< 0.029	< 0.003	< 0.011	< 0.025	< 0.352	3.72
2	0.22	< 0.621	56.90	31.60	5.58	< 0.010	< 0.029	< 0.003	< 0.011	< 0.025	< 0.352	1.16
3	0.24	1.17	73.49	38.67	11.38	< 0.010	< 0.029	< 0.003	0.03	< 0.025	< 0.352	1.49
4	0.24	< 0.621	58.88	30.81	7.25	< 0.010	< 0.029	< 0.003	< 0.011	< 0.025	< 0.352	1.20
5	0.25	< 0.621	72.34	38.38	6.78	< 0.010	< 0.029	< 0.003	< 0.011	< 0.025	< 0.352	2.41
6	0.26	< 0.621	62.66	32.91	5.42	< 0.010	< 0.029	0.116	0.02	< 0.025	< 0.352	1.62
7	0.24	< 0.621	64.80	34.18	3.68	< 0.010	< 0.029	< 0.003	< 0.011	< 0.025	< 0.352	1.41
8	0.27	< 0.621	58.22	29.07	3.90	< 0.010	< 0.029	< 0.003	< 0.011	< 0.025	< 0.352	1.98

University of Waterloo

Waterloo Ontario Canada
N2L 3G1

Faculty of Science
Department of Earth Sciences
519/885-1211

Telex: 069-55259
Fax: 519/746-7484

Environmental Isotope Lab
April 21, 1998

Mr. Steve Gaffield
Wisconsin Geological and
Natural History Survey
3817 Mineral Point Road
Madison, Wisconsin
USA 53705

Dear Steve:

Enclosed please find the results of the testing done on the samples you submitted to our lab recently. I hope you are happy with them. As storage_space here is scarce, we can keep these samples for two months (i.e. until June 21, 1998), after which time we will throw them out unless you have called with other instructions.

A bill for these services will arrive shortly.

Thank you for sending your samples to our lab.

Yours truly

Mary Ellen

Mary Ellen Patton

uw@40.celebrate
UNIVERSITY OF WATERLOO
1957⇨1997

EIL Homepage: http://www science.uwaterloo.ca/~rkhmskrk
Environmental Isotope Laboratory
EIL

```
Condensed Data output for File ISO#-  980073      Gaffield/WGNHS          98/02/17     LOCATION 5 - D

          LAB#         Sample        18Osmow   2H        3H          EH3          13C  18Opdb   34S  18Oso4


          90653 Sample 1                                         13.0 +/- 0.9

          90654 Sample 2                                         16.8 +/- 1.2

          90655 Sample 3                                         15.3 +/- 1.1

          90656 Sample 4                                         12.4 +/- 0.9

          90657 Sample 5                                         12.5 +/- 0.9

          90658 Sample 6                                         12.4 +/- 0.9

          90659 Sample 7                                         15.9 +/- 1.2

          90660 Sample 8                                         14.2 +/- 1.0
                                                                 16.2 +/- 1.2
```

Sampling Locations on December 18, 1997

Laboratory ID	Spring Number
1	63039
2	63300
3	63305
4	63145
5	63301
6	63302
7	63312
8	63307