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Keck Geology Consortium: Projects 2009-2010
Short Contributions – WISCONSIN

THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN

Project Faculty: ***SUSAN K. SWANSON***: Beloit College
MAUREEN A. MULDOON: University of Wisconsin – Oshkosh

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HANNAH DOHERTY: Mount Holyoke College
Research Advisor: Al Werner

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ELIZABETH FORBES: Whitman College
Research Advisor: Kirsten Nicolaysen

A COMPARISON OF TECHNIQUES FOR DETERMINING SPRING SOURCE AREAS: CRAWFORD COUNTY, WISCONSIN

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Research Advisor: Terry Lahm

WATER GEOCHEMISTRY OF TUFA-DEPOSITING SPRINGS IN THE DRIFTLESS AREA, WISCONSIN

MARY LIANG: Franklin and Marshall College
Research Advisor: Dorothy Merritts

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ETHAN MAMER: Beloit College
Research Advisor: Susan Swanson

TEMPERATURE PROFILE MODELING OF A SMALL SPRING-FED STREAM

MILES REED: DePauw University
Research Advisor: Tim Cope

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

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A COMPARISON OF TECHNIQUES FOR DETERMINING SPRING SOURCE AREAS: CRAWFORD COUNTY, WISCONSIN

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INTRODUCTION

Bedrock geology in Crawford County Wisconsin consists of Cambrian sandstones, with intermittent dolomite and shale. Areas of higher elevation consist of Ordovician sandstones, limestone, dolomite, and shale (Mudrey et al., 2007). Geologic units determined to be involved in the spring site were identified through the inspection of the study site and knowledge of the geology of the area. These units likely correlate with the Tunnel City Group in this part of Wisconsin, also correlated with the Franconia Formation in other areas, and St. Lawrence Formation.

The study area is located about three miles east of Gays Mills in the Driftless Area of Wisconsin, meaning that the area remained ice free during the Pleistocene glaciations. Information from domestic well logs indicate a geology with limestone ridge tops north of the spring site and some sandstone/shale ridge tops to the south of the study area. Shallow groundwater flow would most likely come from the higher elevations within the area surrounding the springs. Cross sections drawn from the domestic well logs produce uniform parallel bedrock layers of limestone, sandstone, and shale. For purposes of modeling the sandstone layer around the source area is labeled the contributing aquifer, and a layer of intermittent shale forms the base of the aquifer. The state of Wisconsin relies heavily on the use of groundwater sources, whether for domestic use, industry, agriculture, or for energy production. A little more than half of the water supply for all sectors, excluding hydroelectric power, comes from groundwater sources (Buchwald, 2005). Endangered and threatened species as well as popular trout populations also rely heavily on the groundwater spring habitat. Springs are important hydrological resources and in order to protect and manage the water quality and quantity, the source area must be defined in sufficient detail (Kreye et al., 1996).

The purpose of this study is to use a number of techniques to calculate the source areas of two springs, a northeast (NE) and southwest (SW) spring, in Crawford County, Wisconsin. A number of different techniques have been developed in order to calculate source areas for springs. These techniques include: arbitrary technique, topography, geology, water balance, water table contours, water chemistry, spring discharge hydrographs, and tracers (Kreye et al., 1996). Arbitrary technique would require drawing an area around the spring and determining it as the source area with no other detail needed. Topography technique requires the use of the local topography to better predict the source area based on land contours and the fact that groundwater flows from higher hydraulic head to lower hydraulic head. Geology of the area would give better information on the source of the groundwater based on the information of local aquifers. The water balance technique produces a maximum source area based on the calculated recharge rate of the area and the measured spring discharge to calculate the source area. The water chemistry of an area relates the chemistry of the aquifer to the groundwater chemistry to locate the source due to the relationship between the chemical compositions. Spring discharge hydrographs relate discharge to time, and similar to the water balance equation, hydrographs can be used to calculate the amount of area needed to produce the amount of discharge in a given time. Tracers, while expensive, trace the flow of the groundwater from infiltration to discharge and give an accurate source area.

Determining which technique to use requires knowing the amount of time given to finish the project, the availability of resources, and the amount of detail needed for each technique. For our study area, field data and existing information suggest that the techniques that work best on shallow local flow systems, which is assumed for the study area based on topography and geology, are appropriate (Kreye et al., 1996). The methods used in this study are topography, water table contours, the water balance equation, and groundwater flow modeling.

METHODS

TOPOGRAPHIC MAP AND WATER TABLE CONTOUR MAP

The spring locations were plotted on a topographic map and surface watersheds above these locations were determined by drawing the surface water divides to define the source area for the springs. The size of these spring source areas was determined using an image processing software known as ImageJ (2008) to calculate the surface area of the watershed based on topographic contours. The shape of source areas were described using maximum length and width of areas.

A water table contour map was drawn on a topographic map of the study area based on known water level elevations. These water level elevations were from the contact between elevation and surface water intersection on the topographic map and measured water table levels in domestic wells. The assumption was made that the water table followed the topographic contours of the area with a more subdued gradient. A similar method as that used with the topographic map technique was employed to calculate the source area of the springs and shape characteristics.

WATER BALANCE

The source area of springs can also be estimated using a water budget or water balance analysis. The necessary data includes spring discharge data collected from the field measurements and precipitation data collected from the National Climatic Data Center for Gays Mills, Wisconsin. In addition, an estimate of the recharge rate and sources area of the springs were determined by using equations 1 and 2 below.

Recharge Rate = Precipitation - Evapotranspiration - Runoff Equation 1

Source Area of Spring = Spring Discharge / Recharge Rate * (1/Porosity) Equation 2

The following assumptions were made to complete this water balance calculation. First the runoff in the source area is assumed to be negligible due to the high amount of vegetation in the area. Some runoff likely does occur during large storm events, thus this method is an underestimation of spring source areas. Second, the evapotranspiration rate was estimated based on regional measurements to be 75% of precipitation values (Hindall and Borman, 1974). Third, the average porosity of the source area was assumed to be 20%.

GFLOW

A groundwater flow model was created using the GFLOW program by Haitjema et al. (2007). Base maps from the USGS digitized topographic map database were imported into GFLOW. GPS points of the springs were also entered for a more accurate location of the site. Hydrography levels were then inserted by locating elevation contour intersections with water levels on the topographic map from West Fork Knapp Creek. Stream segments surrounding the site were used as boundaries for the model. GFLOW simulates streams as line-sink functions. Hydraulic heads for the line-sinks in GFLOW were correlated with the hydrography levels of the water table. Spring discharge measurements and well hydraulic heads from domestic wells were represented as test points to use for model calibration. Domestic well log data for the area were used to estimate the general geology of the area in order to model heterogeneities within the aquifer.

A common layer of shale of the Tunnel City Group

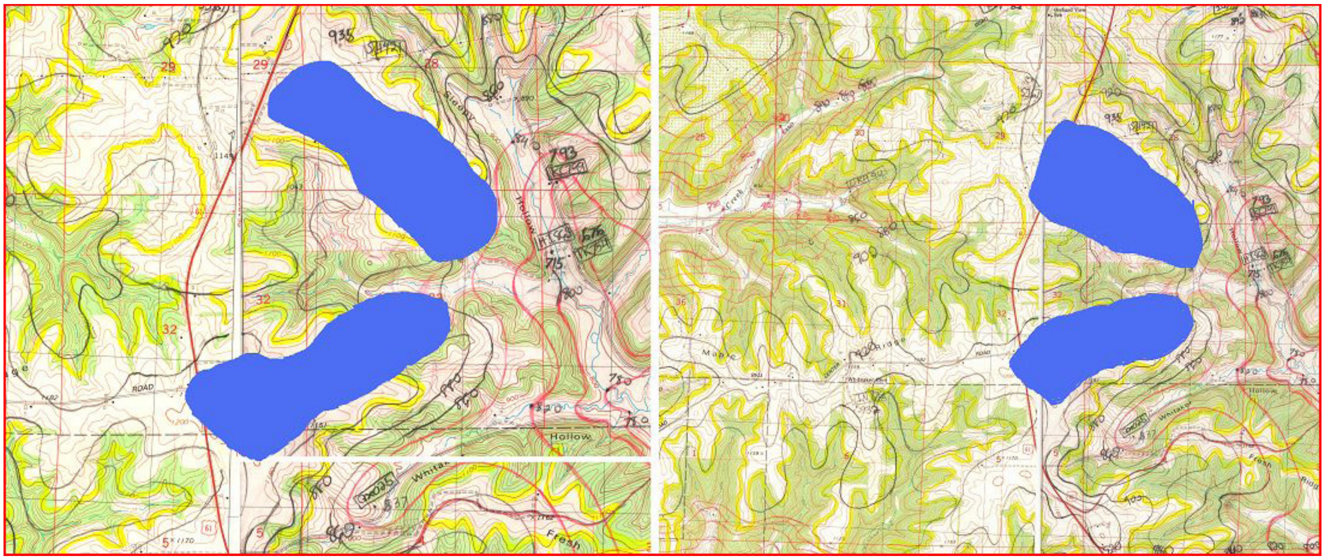

Figure 1. Results of topographic and water table contour techniques. Topographic source areas on the left, water table contour source areas on the right. Source areas outlined in blue.

Method (NE spring)	Source Area (ft^2)	Source Area Shape
Topographic Map	68,200,000	Maximum Width: 1,080 ft Maximum Length: 5,040 ft
Water Table Contour Map	88,700,000	Maximum Width: 2,020 ft Maximum Length: 7,000 ft
Water Balance	18,000,000	Cannot be determined
GFLOW	13,000,000	Maximum Width: 10 ft Maximum Length: 8,000 ft

Method (SW spring)	Source Area	Source Area Shape
Topographic Map	56,800,000	Maximum Width: 2000 ft Maximum Length: 5,060 ft
Water Table Contour Map	88,000,000	Maximum Width: 2,080 ft Maximum Length: 5,060 ft
Water Balance	78,000,000	Cannot be determined
GFLOW	26,000,000	Maximum Width: 20 ft Maximum Length: 10,500 ft

Table 1. Outline of results from all techniques. Results compare source area sizes as well as the shape of the source areas.

was observed in the field and found in most all of the well logs examined, so it was determined to be the base for the groundwater flow model. The thickness of the aquifer was determined from a series of geologic cross sections of the domestic well log data. The presence of a sandstone layer of the Tunnel City Group is the source aquifer for the springs of interest. Hydraulic conductivity values used in the model are from regional data found in Runkel at al. (2003). The data in the model were used to analytically calculate water table contour lines for groundwater flow based on the input information (Haitjema et al., 2007). The model-computed contour lines and discharge values were compared to measured values during a calibration process.

RESULTS

TOPOGRAPHIC MAP AND WATER TABLE CONTOUR MAP

The spring source area results from the topographic map technique are seen in Table 1 and shapes of these areas are shown in Figure 1. Also shown in Table 1 and Figure 1 are the spring source areas based on the water table contour method. The water table contours were determined using surface water elevation levels and water elevations from local domestic wells in the same aquifer. The shape of the source areas are different based on the water table contours since additional hydraulic information about the aquifer is used to inform the determined source area.

WATER BALANCE

The results of the water balance calculations are seen in Table 1 and show ranges in calculated source areas between 14 and 18.7 million ft^2 for the NE spring. The SW spring values range from 68.8 to 78 million ft^2 for the source area. The assumption is made that the infiltration in the source area upgradient of the spring flows directly into the ground

NE Spring					
Sample Date	Gay's Mills Precipitation (feet/month)	Estimated Evapotranspiration (ft/month)	Estimated Recharge Rate (ft/month)**	Spring Discharge (ft^3/month)	Calculated Source Area (ft^2)***
31-Jul	0.257	0.193	0.064	241,000	18,770,000
18-Jul	0.257	0.193	0.064	182,000	14,000,000
SW Spring					
Sample Date	Precipitation (feet/month)	Estimated Evapotranspiration (ft/month)	Estimated Recharge Rate (ft/month)**	Spring Discharge (ft^3/month)	Calculated Source Area (ft^2)***
21-Jul	0.257	0.193	0.064	884,000	68,880,000
22-Jul	0.257	0.193	0.064	884,000	68,880,000
31-Jul	0.257	0.193	0.064	937,000	73,000,000
1-Aug	0.257	0.193	0.064	1,000,000	78,000,000

** Assumes negligible runoff in source area

*** Assume 20% porosity, therefore source area will be 5 times larger than if no porous media considered

Table 2. Results of water balance calculations.

and then discharges to the spring. The large areas needed to produce the amount of spring discharge assume local flow only. Unfortunately, no defined shape of the area is possible to calculate with the water balance calculation so no comparison of shape can be made with the other methods.

GFLOW

The contours modeled in GFLOW are based on the inserted hydraulic head values. Precipitation data used from the water balance technique was also used to inform the recharge rate to the shallow aquifer. Local geological data were used to alter the model to best represent accurate field conditions in terms of the heterogeneous nature of the aquifer system. Exact geological information for the source area of the springs is not known but interpolated from the available geological information and geologic well log data from the area. Based on this information, the aquifer may vary in thickness from 5 to 200 feet with possible conductivity of 0.1 to 85 ft/day (Runkel et al., 2003). Precipitation is also an estimate because exact data for the location is not known. The source area was determined by using trace particles to the springs.

All values used for the calibration assuming a homogeneous aquifer did not lead to an optimal calibration of the well hydraulic heads. For further calibration, a heterogenous hydraulic conductivity model was designed by altering the hydraulic conductivity in areas with different bedrock types. Looking at domestic well records and topographic map, ridge tops within the source area were composed of a dolomite/limestone bedrock while valleys were more likely composed of a deeper sandstone aquifer with no over lying dolomite/limestone layer.

Values for hydraulic conductivity for the limestone layer range from 0.1-46 ft/day (Runkel et al., 2003). Heterogeneity of the model showed better calibration for the domestic well hydraulic heads but poorer calibration for the measured spring discharge. Calibration results from the GFLOW model produced a model that had conditions set at thickness of the aquifer of 145 feet and hydraulic conductivity of 6 ft/day. These numbers were chosen because they produced the best calibration as well as having values resembling actual values that may be present in the field. Limited field data did not allow for exact values for these parameters to be determined so estimates had to be made of what values could be physically possible, and from these values the ones that were believed to most closely resemble reality were chosen.

DISCUSSION AND CONCLUSION

The topographic map method of determining the source area for the springs is easily determined using the land elevation contours, allowing for some interpretation for contours. The water table contour method results in a similar representation of

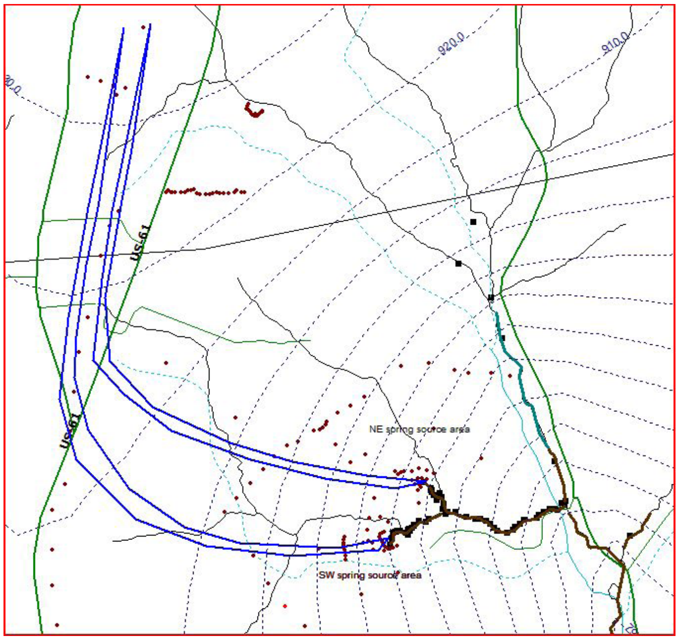

Figure 2. GFLOW model results with estimated source areas delineated in blue

the source area and source area shape with added hydraulic information. The water balance method results in large source areas based on the assumptions necessary to complete the calculations. An underestimation of the source area using the water balance calculation occurs because runoff is not taken into account. The resulting source area would be larger because of the decrease in overall recharge to the aquifer that supplies the springs.

The results are based on the most accurate information available for each technique. The GFLOW program is able to produce an accurate groundwater model based on details of the study area. The GFLOW model however needed the most amount of information about the geologic and hydrogeologic setting which was not available at the nescessary level of detail for the site. The level of detail that is needed to produce spring source areas similar to the topographic, water table contour, or water balance techniques may not be available for use in the GFLOW model. If the source area of the springs were more geologically simple, GFLOW would be able to produce a more accurate source area model for the springs, but a three dimensionsal representation of the area is needed for a most accurate source area calculation. The source areas appear to be topographically controlled, therefore a significant amount of detailed information about the hydraulic conductivity of the aquifer would be needed to produce an accurate groundwater flow model, which is not available. Areas with fairly simple geology can use the topographic or water table contour techniques to produce an easy, faily accuarate predicition of spring source areas.

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