89-253

WATER FACT SHEET

U.S. GEOLOGICAL SURVEY, DEPARTMENT OF THE INTERIOR

FLOW OF GROUND WATER THROUGH FRACTURED CARBONATE ROCKS IN THE PRAIRIE DU CHIEN-JORDAN AQUIFER, SOUTHEASTERN MINNESOTA

Contamination of ground water from point and nonpoint sources (such as landfills, feedlots, agricultural chemicals applied to fields, and septic systems) is a recognized problem in the karst area of southeastern Minnesota. The migration of contaminants to and through the aquifers in the karst area is difficult to predict because of the complicated nature of the ground-water-flow system. Estimation of localized ground-water-flow directions on the basis of water-level measurements made in wells may be inaccurate because of the influence of bedrock fractures. The orientation and density of bedrock fractures and the relation of these features to localized ground-water flow is poorly understood in southeastern Minnesota.

The U.S. Geological Survey, in cooperation with the Minnesota Department of Natural Resources and the Legislative Commission on Minnesota Resources, began a study in October 1987 to improve the understanding of local ground-water flow through karst terrain in southeastern Minnesota. The objectives of the study are to (1) describe the orientations of systematic rock fractures and solution channels of the Prairie du Chien Group of Ordovician-age carbonate rocks in southeastern Minnesota, and, if possible, to define the principal and minor axes of these orientations and (2) evaluate the effect of fractures and solution channels in the Prairie du Chien Group on the local flow of ground water. The orientation of fractures was determined by field measurements and an interpretation of lineaments (linear terrain fractures) shown on aerial photographs. Local ground-water-flow patterns were investigated through analysis of base-flow seepage to selected stream reaches. The study area comprises Wabasha, Olmsted, Winona, Fillmore, and Houston Counties in the southeastern corner of Minnesota (fig. 1).

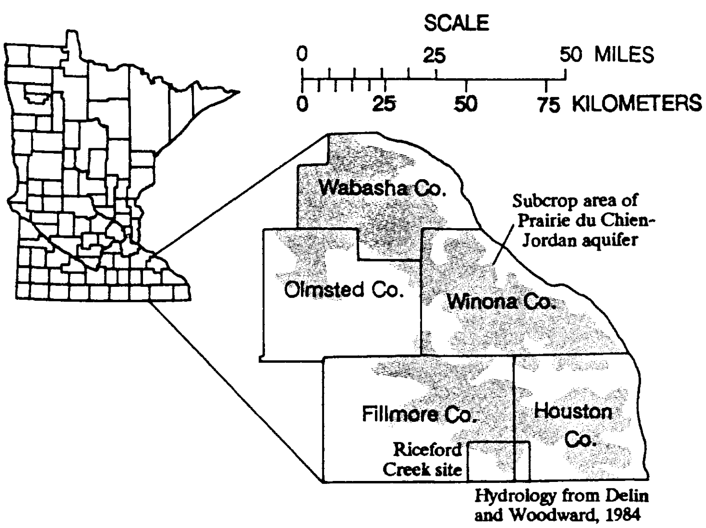

FIGURE 1.--Location of study area

The findings of the study may be useful to officials responsible for the development of programs and policies that address ground-water management issues in southeastern Minnesota. Knowledge of the ground-water-flow system is necessary for predicting the direction of contaminant movement and for estimating the time-of-travel for contaminants from known or potential sources of pollution to downgradient points of interest. This kind of information provides a basis for assessment of risks to human health or to vegetation and wildlife in affected surface waters, and a basis for the design of observation-well networks that may be needed for long-term evaluation of contaminated ground water.

WHAT ARE THE HYDROGEOLOGIC CHARACTERISTICS OF CARBONATE AQUIFERS IN THE KARST TERRAIN OF SOUTHEASTERN MINNESOTA?

A subdued karst topography has developed in southeastern Minnesota where carbonate rocks (limestone and dolomite) are close to land surface. These rocks are present in the Upper Carbonate aquifer (in the Devonian Cedar-Valley Limestone and Ordovician Dubuque Formation and Galena Dolomite) and Prairie du Chien-Jordan aquifers (in the Ordovician Prairie du Chien Group and the Cambrian Jordan Sandstone), the two principal carbonate aquifers in the region. Permeability in limestones and dolomites is mainly secondary--that is, permeability produced by fractures, which allow open-channel flow of ground water. Flow is very rapid where the openings are enlarged and interconnected by dissolution and/or solution weathering. The properties and distribution of the openings determine the hydrogeologic properties of the rocks. The storage coefficient and transmissivity--properties that indicate the capability of these rocks to store and transmit water--depend on the size, orientation, density, and degree of interconnection among the openings.

Fracture Patterns

Fractures in the bedrock strata of southeastern Minnesota, particularly in the carbonate rock formations, are extensive. Gentle folding of the bedrock strata may have controlled development of some regional fractures. Topographic features commonly are expressions of the surfaces of fractures, which are called joints. Mossler and Book (1984) report that the orientation of stream valleys in Winona County indicate the direction of joints. Erosional patterns in stream valleys of Olmsted County suggest dominant northwest-southeast and northeast-southwest jointing patterns and less prominent north-south patterns (Olsen, 1988). Mohring and Alexander (1986) report that the alignment of springs, sinkholes, and caves in the Galena and Dubuque Formations reflects major joint trends.

Ground-Water-Flow Patterns

Ground water in the Upper Carbonate aquifer regionally flows toward the periphery of the aquifer and locally flows into streams and bedrock valleys (Delin and Woodward, 1984). The hydraulic gradient in this aquifer generally is greatest near areas of ground-water seepage to streams. Regional ground-water flow in the Prairie du Chien-Jordan aquifer generally is to the south and east in much of Fillmore and Houston Counties and in the southern parts of Olmsted and Winona Counties (Delin and Woodward, 1984). Regional flow in the northern parts of Olmsted and Winona Counties and in all of Wabasha County generally is toward the major river systems, such as the Mississippi River. The influence of stream valleys on ground-water flow is evident in Olmsted County, where stream channels separate and receive water from localized ground-water-flow systems. These local flow systems are more numerous in the Upper Carbonate aquifer than in the Prairie du Chien-Jordan aquifer because the dendritic pattern of streams that have eroded into the Upper Carbonate aquifer is more extensive.

HOW WERE DATA COLLECTED?

Lineaments (linear features at least 1 mile in length) and fracture traces (natural linear features less than 1 mile in length) were mapped on a regional basis from 1:80,000-scale black and white aerial photographs (Lattman, 1958). Stereoscopic examination of the photographs enabled topographic features to be easily identified. Most of the lineaments and fracture traces mapped from the photographs are straight segments of the bottoms of stream valleys. These range in size from very small ephemeral stream channels to major rivers. Well-defined drainage paths down the sides of stream valleys also appeared as fracture traces. Approximately 10 percent of the mapped fracture traces were identified as tonal features related to vegetation patterns and soil color. Field measurements of the orientation of fractures were made from rock exposures in quarries, along roads, and in stream valleys. Pit quarries provided the best source of data because of the full 360-degree exposure of the bedrock surfaces.

Measurement of Ground-Water Seepage

Ground-water seepage to selected streams was evaluated by current-meter measurements of downstream gains or losses of streamflow and by an experimental approach based on radon activity in streams. The activity of radon in ground water ranges from two to four orders of magnitude greater than the activity in surface water; therefore, ground-water seepage to streams generally increases the in-stream radon activity. The calculation of the volume of ground-water seepage on the basis of radon activity uses a mass-balance equation that assumes insignificant loss of radon to the atmosphere between two measuring points (Lee and Hollyday, 1987). The current-meter measurements provided a basis to assess the reliability of the radon method. The discharge measurements and radon-activity data were collected during the low-flow conditions of late summer 1988 along straight reaches of eight streams that flow across on the Prairie du Chien Group. A discussion of the preliminary results of the interpretation of these data for a reach of Riceford Creek follows.

WHAT IS THE RELATION OF FRACTURE ORIENTATIONS AND GROUND-WATER SEEPAGE ALONG RICEFORD CREEK?

The rose diagrams in figure 2 schematically display lineament-direction data mapped from aerial photographs and fracture orientations measured in a quarry in the Prairie du Chien Group. The lineaments are postulated to be indirect expressions of joints. Data collected from an area along Riceford Creek provide some support for this hypothesis. The orientation of the principal axis of the lineaments compares within 30 degrees of the principal axis of joint-fracture measurements. The rose diagrams indicate that the principal orientation of the lineaments is slightly south of west to slightly north of east, and the principal orientation of joint fractures is southwest to northeast. Other strong orientations of the lineaments are northwest to southeast and slightly east of north to slightly west of south. These data suggest that lineaments may be a rough approximation of regional joint patterns.

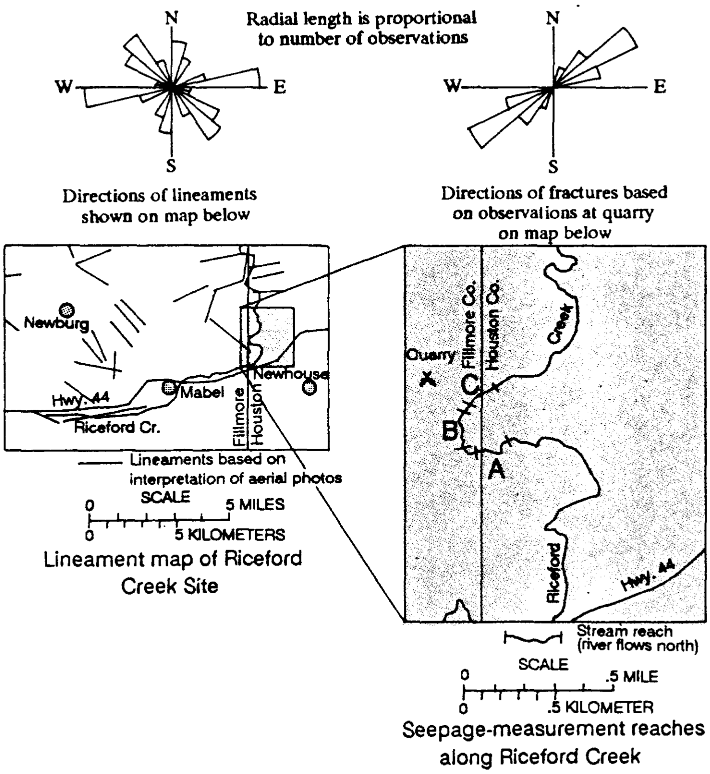

FIGURE 2.--Lineaments, fractures, and ground-water seepage along Riceford Creek

Seepage rates along reaches of Riceford Creek vary with orientation of the stream reach. Streamflow along the reaches of Riceford Creek shown in figure 2 ranged from 1.38 to 2.52 cubic feet per second as measured by a current meter on August 31, 1988. Reach B, which flows 5 degrees west of north, received the highest rate of ground-water inflow per linear foot of stream channel. Reaches A and C, which flow 15 degrees south of west and 45 degrees north of east respectively, received less than half of the maximum inflow rate. The radon-activity measurements were in close agreement to the current meter results for reaches A and B but were considerably different for reach C. The high seepage indicated for reach C by the radon activity was likely due to measurement error. Contamination of the radon sampling cell used at the downstream point of stream reach C probably occurred because of insufficient flushing of radon gas from the cell prior to its use.

Seepage reach	Seepage rate determined by: (cubic feet per second per 100 feet stream channel)	
	Current meter	Radon activity
A	0.023	0.016
B	.080	.095
C	.036	.274

The Prairie du Chien Group of rocks forms a valley wall along the southern, western, and northern sides of reaches A, B, and C, respectively. The opposite side of the creek is a level alluvial plain. The stream is likely to be in good hydraulic connection with the bedrock because the streambed consists of 2 to 3 feet of muck that is in contact with the bedrock. Most of the seepage is assumed to enter the stream from the bedrock.

The orientation of stream reach B appears to be perpendicular or nearly perpendicular to the axis of the principal set of fractures as defined by the lineament mapping and rose diagrams produced from field measurements. Assuming that transmissivity (and, therefore, the volume of ground-water flow) is greatest along the direction of the principal set of fractures, the amount of ground water that discharges to streams would be expected to be greatest along reaches of streams that are at right angles to the principal set of fractures. The relation of fracture orientation to seepage along Riceford Creek is consistent with this model. The approach used to analyze the fracture orientation and seepage data in the Riceford Creek area will be applied to the remainder of the study area.

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