MAP EXPLANATION

Karst Hydrogeomorphic Units

CRp — **Cedar River plain.** Gently rolling plain developed along the Cedar River and its tributaries. These streams begin to entrench into the bedrock as they cross this unit. Ground water flows to the Cedar River or its tributaries. Ground-water residence time at springs and wells ranges from mixed to recent. Vintage water likely flows from the Covered units and then mixes with recent waters from this unit.

DCp — **Deer Creek plain.** Gently to strongly rolling plain dissected by Deer Creek and Bear Creek. Many of the tributary valleys to these streams lack surface flow except after large runoff events. The western boundary of this unit is the point where Deer Creek and Bear Creek begin to entrench into the bedrock. At that point, the stream gradient steepens, and springs and sinkholes begin to occur. Ground water flows to springs along the streams. Dye tracing indicates rapid ground-water flow rates (miles/day) with a slower (miles/month) component.

LRp — **Le Roy plain.** Gently rolling plain bounded by higher elevation uplands. Surface runoff from these uplands flows onto this unit and disappears into stream sinks and sinkholes. In some areas of this unit, sinkholes are the dominant topographic feature. The western and northern boundaries of this unit are the points where the Upper Iowa and Little Iowa rivers begin to entrench into the bedrock. Ground water in this unit discharges from springs in the Upper Iowa and Little Iowa rivers. Dye traces from stream sinks and sinkholes to springs have shown both rapid ground-water flow (miles/day) and a slower (miles/month) component.

Op — **Ostrander plain.** The western extension of a gently rolling plain extending east into Fillmore County. This unit likely discharges ground water from springs in Fillmore County. Dye tracing in this unit in Fillmore County has shown rapid ground-water flow (miles/day) and a slower (miles/month) component.

SVp — **Spring Valley plain.** Gently rolling plain extending eastward into Fillmore County. This unit discharges ground water at springs along major streams.

LRu — **Le Roy upland.** Rolling upland bisected by the Little Iowa River. This unit is topographically higher than the Le Roy plain and discharges surface runoff onto it.

Lp — **Limestone plain.** Gently rolling plains underlain by limestone or dolostone. The streams crossing this unit are not entrenched into the bedrock. As a result, water may rapidly infiltrate through the soil, but the hydraulic gradient is not steep enough to form many sinkholes. Ground-water residence time is primarily recent with some areas of mixed water.

Cov — **Covered.** Rolling plains and uplands. Ground-water residence times range from mixed to vintage.

Map Symbols

Quarry

Stream sink

Spring—Color indicates tritium age of water
- **Recent**
- **Mixed**
- **Vintage**
- **Not sampled**

Uppermost Bedrock Well—Color indicates tritium age of water
- **Recent**
- **Mixed**
- **Vintage**

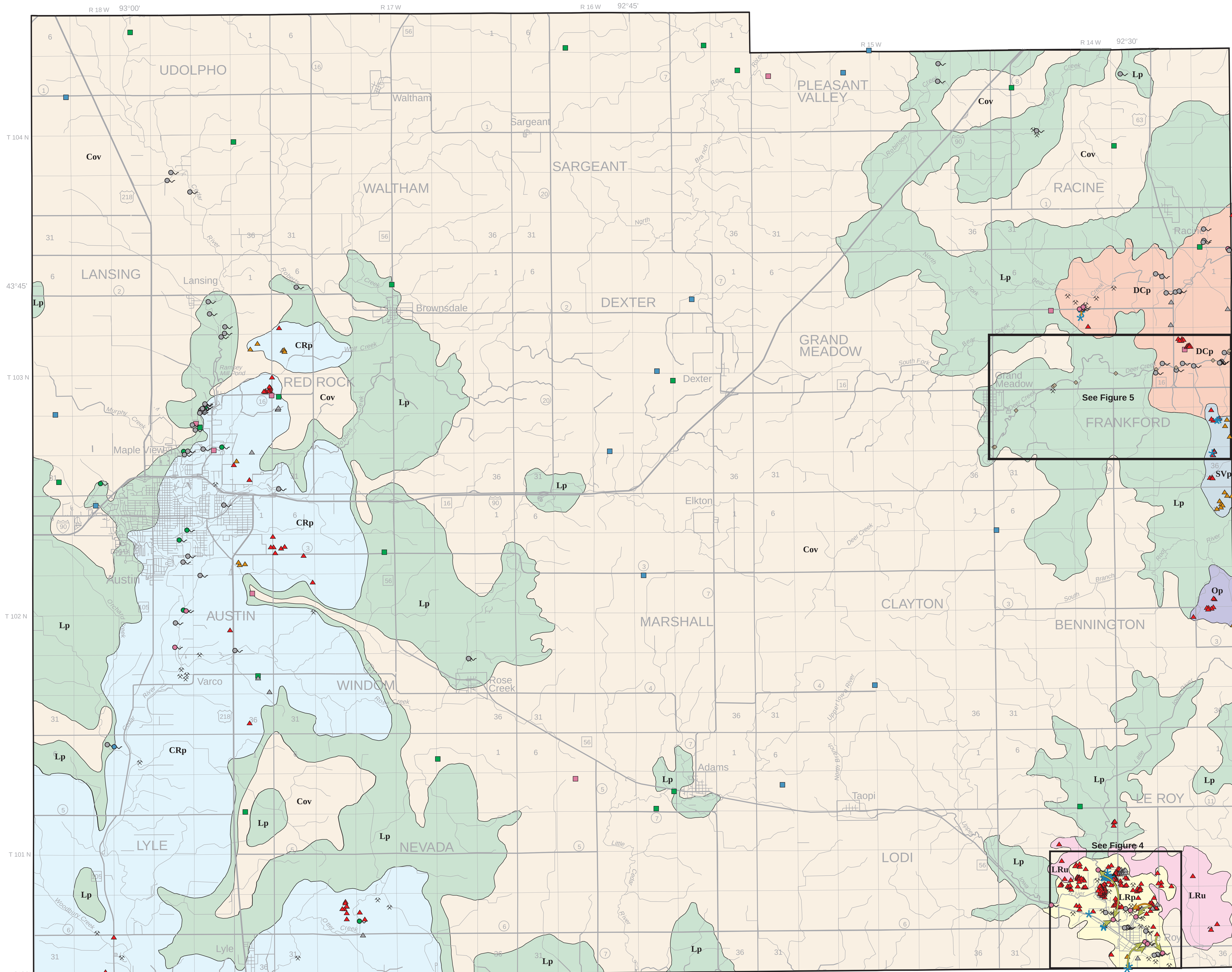
Dye Trace
- **Natural gradient**
- **Forced—Quarry pumping-induced gradient**

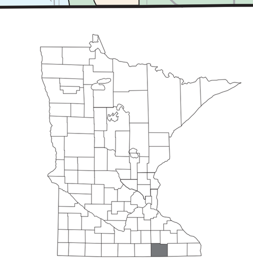
Sinkhole*
- **Verified**
- **Unverified**
- **Filled**
- **Sinkhole mapped in Iowa**

*Verified sinkholes have been field checked by one or more authors of this plate. Unverified sinkholes were mapped based on information from soil survey and topographic maps, aerial photographs, or county government staff. Filled sinkholes have been altered by human activity; their locations were provided by local government staff, county residents, or field observation. The locations of sinkholes mapped in Iowa were provided by the Iowa Geological Survey Bureau.

TABLE 1. Hydromorphic and hydrogeologic characteristics of karst hydrogeomorphic units

Hydromorphic and Hydrogeologic Characteristics	Karst Hydrogeomorphic Units							
	Shallow Karst Units						Limestone plain	Covered
	Cedar River plain	Deer Creek plain	Le Roy plain	Ostrander plain	Spring Valley plain	Le Roy upland		
Depth to bedrock (feet)	0–75	0–50	0–25	0–50	0–50	0–50	0–75	greater than 50–75
Karst feature	sinkholes, springs, solution voids, quarries	sinkholes, stream sinks, springs, solution voids, quarries	stream sinks, sinkholes, springs, solution voids, quarries	sinkholes	sinkholes, stream sinks	sinkholes, solution voids, quarries	sinkholes, solution voids, quarries	no surface features, but subsurface cavities and blowing wells
Primary bedrock unit	Bassett Member	Spillville Formation	Lithograph City Formation	Bassett Member, Spillville Formation	Spillville Formation	Lithograph City Formation, Coralville Formation	Coralville Formation, Bassett Member, Spillville Formation	Coralville Formation, Bassett Member, Spillville Formation
Percentage of county	11	2	less than 1	less than 1	2	less than 1	20	65




LOCATION DIAGRAM

SCALE 1:100 000

1 0 1 2 3 4 5 MILES

1 0 1 2 3 4 5 6 7 8 KILOMETERS

WARNING: This map provides an overview of the distribution of karst features, as interpreted from 1:100,000-scale geologic map information.
THIS MAP SHOULD NOT BE THE BASIS FOR EVALUATION OF SPECIFIC SITES.

Digital base map composite:
Roads and county boundaries—Minnesota Department of Transportation GIS Statewide Base Map (source scale 1:24,000)
Hydrologic features—U.S. Geological Survey Digital Line Graphs (source scale 1:100,000)
Digital base map annotation—Minnesota Geological Survey.

Project data compiled from 1997 to 2001 at the scale of 1:100,000. Universal Transverse Mercator projection, grid zone 15, 1983 North American datum. Vertical datum is mean sea level.

GIS data and metadata available through the DNR Waters website: http://www.dnr.state.mn.us/waters

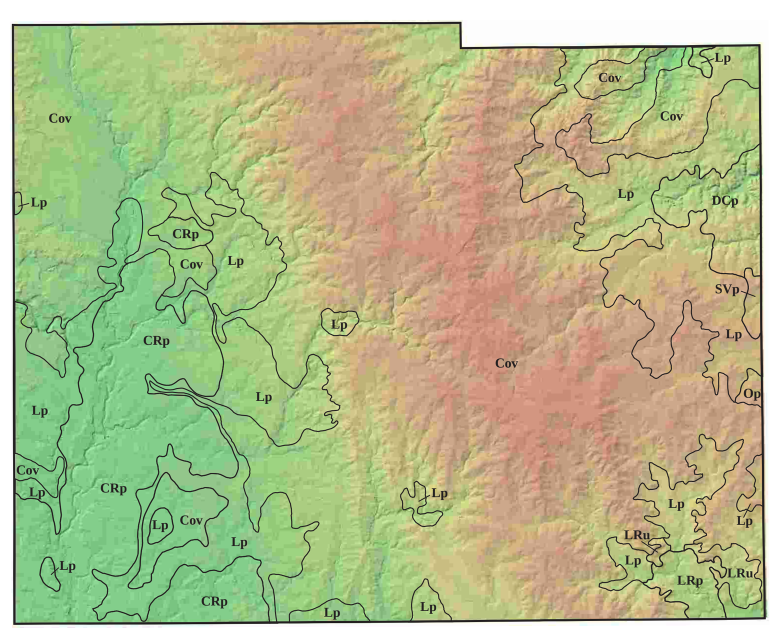


FIGURE 1. *Karst units on an exaggerated shaded relief base map. The relatively smooth surface of the plains units is particularly visible in the Cedar River and Le Roy units. The dissected nature of the Deer Creek unit is clearly evident. A prominent range of hills in the east-central part of the county is part of the area in the Covered unit. Descriptions of karst map units and abbreviations are given in the map explanation above.*

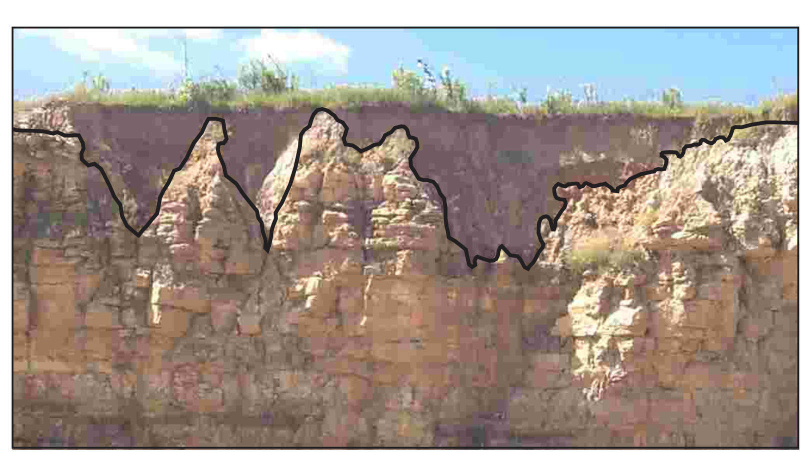


FIGURE 2. *The carbonate bedrock under Mower County has been altered by solution processes. This has produced features in the subsurface that are often exposed during quarry operations. This photograph shows the uneven bedrock surface (solid line) resulting from differential weathering of the bedrock surface. Photograph by Jeff Green.*

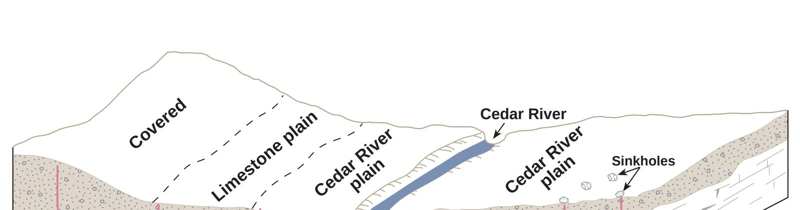


FIGURE 3. *Diagrammatic depiction of the Cedar River plain unit and adjacent units. West of the Cedar River, vintage ground water from the Covered karst unit mixes with recent water under the Limestone plain and the Cedar River plain units.*

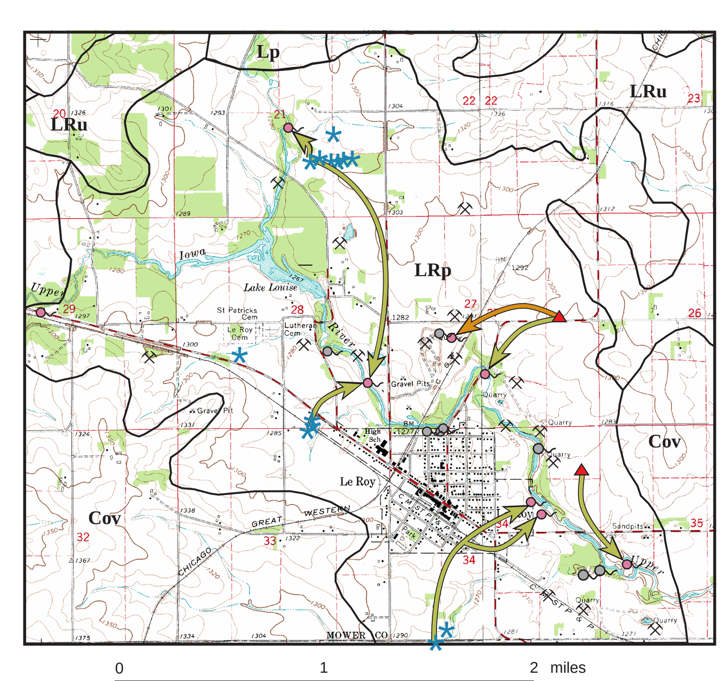


FIGURE 4. *Results of dye tracing in the Le Roy plain. Map symbols are defined in map explanation above.*

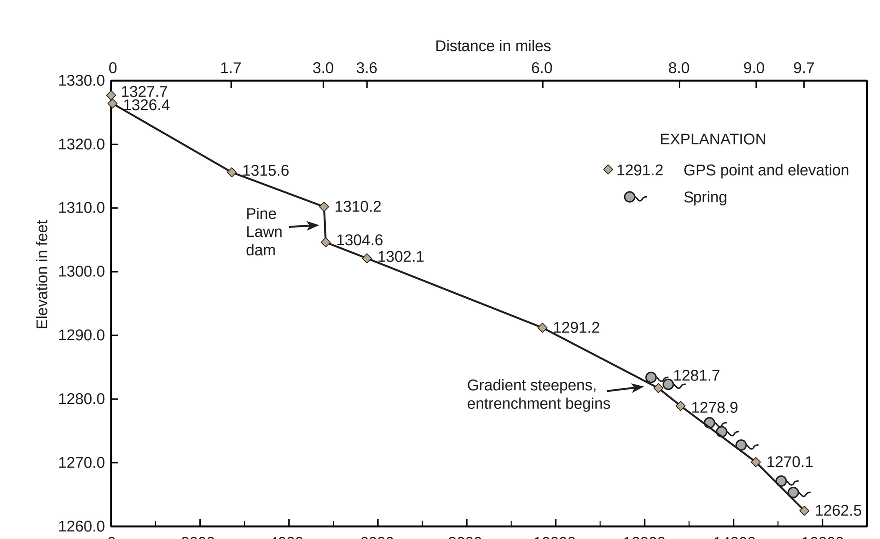


FIGURE 5. *Surface-water profile of Deer Creek. Springs and sinkholes begin to occur where the gradient steepens and the stream begins to cut into the bedrock. Water surface points were surveyed with a high-accuracy global positioning system (GPS) in autumn 2001.*

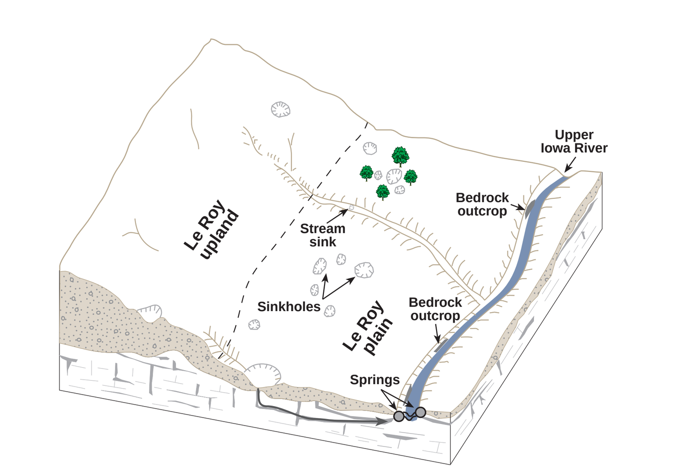


FIGURE 6. *Diagrammatic view of the Le Roy plain and Le Roy upland units. During precipitation events, runoff from the Le Roy upland flows to the Le Roy plain where it disappears into stream sinks and sinkholes and resurfaces at springs on the Upper Iowa River.*

KARST HYDROGEOMORPHIC UNITS

By

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INTRODUCTION

Mower County lies above bedrock susceptible to solution, which is the basis of karst. Traditionally, karst was viewed as a landscape that was delineated based on the presence or absence of diagnostic features such as caves and sinkholes. Recent research draws on the importance of a systems approach to produce a definition based on universal characteristics: “The karst system is an integrated mass-transfer system in soluble rocks with a permeability structure dominated by conduits dissolved from the rock and organized to facilitate the circulation of fluid” (Klimchouk and Ford, 2000). Klimchouk and Ford (2000) also address the implications of this definition for hydrogeology, in which the system has “a specific kind of fluid circulation capable of self-development and self-organization”. By focusing on both the surface and subsurface systems, rather than the presence or absence of sinkholes, this definition addresses the difference between karst and porous media aquifers and their overlying landscapes. In shallow systems, water carrying out the process of solution is routed through landforms quickly into the subsurface, where it contributes to the function of an integrated drainage system.

This plate provides a map that portrays the karst as a system with water and material moving through it. The system consists of karst hydrogeomorphic units, each with distinctive characteristics. The result is a plate that has integrated relevant geologic and hydrologic information into a comprehensive presentation that identifies located karst features and provides an interpretation of the karst flow systems (Table 1). Figure 1 displays the units on a shaded relief map of the county.

The method of developing the map involved delineating hydrogeomorphic units as discrete three-dimensional bodies in which solution of the bedrock has resulted in the integration of surface water and ground water at various time scales. These karst hydrogeomorphic units were delineated based on bedrock type; depth to bedrock; topography; surface and subsurface hydrology; spring chemistry; and the distribution, landscape position, and type of surface and subsurface karst features. Water and material enter these units, move through the carbonate bedrock, and discharge into either streams or lower bedrock aquifers. As a result, this map not only shows the known karst features but also relates that information to landscape morphology, depth to bedrock, bedrock geology, and ground-water age.

MAPPING KARST FEATURES

Mower County is underlain by a thick sequence of sedimentary rocks. Across the county, the first rocks encountered are limestone or dolostone (carbonate rocks). These rocks, which are susceptible to solution, form the framework for the county’s karst. The primary formations are all Middle Devonian: the Lithograph City, Coralville, Hinkle and Eagle Center of the Little Cedar, and the Spillville (Plate 2, Part A). As precipitation percolates through the soil, it reacts with carbon dioxide to form carbonic acid. This weak acid dissolves the carbonate bedrock to produce a system of solution-enlarged fractures and joints that are visible at quarries and road cuts (Green and Alexander, 2000). Where there is a relatively thin layer (less than 75 feet thick) of unconsolidated material (cover) above the bedrock, surface karst features such as sinkholes and stream sinks begin to appear. The primary source for the depth to bedrock information was Plate 5 in Part A. Where the depth to bedrock was greater than 75 feet, no surface karst features were found. The Covered karst unit was delineated based on a depth to bedrock greater than 50–75 feet.

To begin to delineate the other karst units, various karst diagnostic features were mapped, including sinkholes, stream sinks, springs, and quarries. Sinkholes are the most abundant and visible surface karst feature in the county. More than 300 have been located across the county in various forms, ranging from steep-sided funnels to broad, shallow bowls (Green and Alexander, 2000). The funnel sinkholes are generally as deep or deeper than they are wide. The shallow bowls, in the most extreme examples, measure from 30 to 60 times as wide as they are deep. These two karst features are end members of a continuum, examples of which can be found in the various karst units in the county. The different forms of sinkholes occur on the landscape together; everywhere that the shallow bowls are found, there are examples of funnel sinkholes that have catastrophically collapsed. Many of the county’s sinkholes have been filled in the past; some appear on this plate based on location information supplied by local residents.

Stream sinks are another important diagnostic karst feature. They are a point at which a surface stream sinks into the ground (Monroe, 1970). In Mower County, their forms range from cracks in streambeds to broad, shallow sinkhole bowls in streambeds. In every case, they were observed to have surface streams sinking into them; in some instances, they were also mapped as sinkholes. Stream sinks serve as direct recharge points for the ground-water system. Their presence indicates rapid conduit flow in the bedrock, and dye tracing has demonstrated their connection to large springs.

For this mapping effort, limestone quarries were included as a diagnostic karst feature. Quarries are only present in the county where limestone is accessible for mining. Observations in quarries confirmed the presence of small karst features, including solution pits and solutionally enlarged bedding planes (Figure 2). These features provide evidence of the solution of the bedrock and, in areas where there may be few or no sinkholes, demonstrate the usefulness of quarries for delineating karst units.

KARST HYDROLOGY

The study of the hydrology of the Mower County karst system involved spring mapping, measuring ground-water residence time of spring and well water samples based on tritium concentrations, dye tracing (ground-water time of travel studies), and potentiometric surface mapping.

Springs are the most obvious expression of the karst ground-water system. As part of the atlas mapping effort, nearly 100 springs were inventoried across the county. Field observations indicate that many other springs have not been mapped.

Ground-water residence time (age) was determined by sampling for tritium and by analyzing the water’s cation and anion concentrations. Tritium, a radioactive isotope of hydrogen (^3H), occurs naturally in water; atmospheric nuclear bomb testing from 1953 to 1964 increased the concentration to the point where elevated tritium levels indicate water recharged after 1953 (Alexander and Alexander, 1989). Water with approximately 10 or more tritium units (TU) was judged to be “recent”. Water with less than 1 TU was “vintage” or recharged before 1953; water between these values was judged to be a mixture of vintage and recent waters. The water chemistry sampling also included nitrate-nitrogen (NO_3-N). All previous work has shown that water with high concentrations of nitrate (above 10 parts per million) only occurs with elevated tritium concentrations.

Fourteen springs were sampled for tritium and water chemistry. Although there are many ways to classify springs (Ford and Williams, 1989), the spring’s residence time (relative age of the water) and water chemistry proved valuable in the classification of karst hydrogeomorphic units. These data show that in the Cedar River plain (Figure 3), the springs are discharging either mixed or recent water. The mixed water is likely the result of vintage water from the Covered unit moving to the Cedar River and mixing with recent water from the Cedar River plain.

Staff from DNR Waters, Mower County, and the Minnesota Pollution Control Agency took water samples from wells across the county to characterize aquifer chemistry and aquifer interactions (see Plates 7 and 8). A subset of those data, wells that were finished in the uppermost bedrock aquifer, was derived to delineate karst units. In Iowa, the ground-water residence time was greatly influenced by the depth to bedrock (Libra and others, 1984). Where there was more than 50 feet of cover, the ground water was vintage; where there was less than 50 feet of cover, the ground water was recent and commonly had elevated nitrate levels. In Mower County, the same general pattern was found. In those areas with less than 50 feet of cover, the ground water was recent. In those areas with 50 to 75 feet of cover, the water was recent or mixed. If the depth of cover over the bedrock exceeded 75 feet, the samples were primarily vintage with a few samples in the mixed category.

In the Le Roy plain, Deer Creek plain, and Ostrander plain karst units, fluorescent dyes were used to trace ground-water flow directions and determine time of travel. For the Ostrander unit, the traces were performed in adjoining Fillmore County. This method is a fundamental tool for investigating shallow karst systems (American Society for Testing and Materials, 2001). Fluorescent dyes are poured into sinkholes or stream sinks, and then the surrounding springs are monitored to detect the dye. These traces all had rapid ground-water flow rates (miles/day) along with a slower (miles/month) component. The traces at Le Roy are shown on Figure 4. Springs that had dye discharge from them were also labeled as having recent water.

Potentiometric surface mapping to show flow direction was based on measurements of water levels in wells across the county. DNR staff, which conducted this work in 1993 and 1999, measured wells that were cased down to a single aquifer. A subset of those data, water levels from wells that were finished in the uppermost bedrock aquifer, was used to map the karst units. These data indicated that ground water in the units flows toward the major streams and rivers in the county.

KARST UNIT DELINEATION

The information about karst geology, features, hydrology, and springs previously described was combined to delineate a series of discrete karst units across Mower County. Water and material enter this karst system, move through the carbonate bedrock, and discharge into streams or lower bedrock aquifers (Green and others, 2002). This has resulted in the integration of the county’s ground and surface waters at a variety of time scales. In the shallow bedrock units, that time scale is hours to months. In the covered karst units, the scale is decades to centuries.

While the field mapping and hydrologic investigations were done with conventional methods, the overlay and presentation of data points was done using geographic information system software. Using this technology allowed presentation of the county’s karst in various ways. Many different overlays of the karst elements were combined to better understand the karst system. Ultimately, it was the overlays of the karst features, hydrologic information, and depth to bedrock mapping over the shaded relief base map that allowed delineation of the individual karst hydrogeomorphic units.

A critical factor for determining the boundary between the shallow karst units (Cedar River, Deer Creek, Le Roy, Ostrander, Spring Valley) and the Limestone plain unit was stream entrenchment. In the shallow units, their major streams are entrenched or have begun to entrench into the bedrock. Streams in the Limestone plain unit are not entrenched. When the streams entrench, their gradient steepens, springs become much more common, and sinkholes occur on the surrounding landscape (Figure 5).

Another factor for classifying karst units is their landscape morphology. This refers to the unit’s form. Plains are relatively low-relief areas that are characterized as gently to strongly rolling. Uplands have greater relief and typically are a series of rolling hills. Of the plain units, the Deer Creek plain has the most relief.

The map units show the hydrologic and geomorphic relationships between the units. In the shallow karst units, water sinks into the sinkholes and stream sinks. Large quantities of water also infiltrate through the thin drift into the bedrock. There is turbulent water flow through the bedrock in conduits and fractures, and then the water discharges from springs to streams and rivers (Figure 6). The mapped units integrate these surface and subsurface features to depict flow systems. Water movement in them was verified by dye tracing and potentiometric surface mapping. In the Limestone plain unit, water moves into it from infiltration through the thin drift into the bedrock. Movement of water through the drift also occurs in the Covered karst units but at a much longer time scale.

CONCLUSION

The goal of this mapping was to allow map users not only to view the location of mapped surface karst features but also to show how they fit into the karst flow system. Karst is not defined simply by the presence or absence of sinkholes but by the flow dynamics in the karsted bedrock. In the shallow units, where turbulent flow dominates, ground water flows rapidly to springs through subsurface voids, conduits, and fractures. Water flowing in those features is both highly vulnerable to human activities and a factor that needs to be considered for water and land resource management. By looking at the whole karst system, rather than pieces of it, a more comprehensive view can be obtained. By defining the karst on this basis, the citizens of the county will be able to appropriately use and protect their karst water resources.

ACKNOWLEDGMENTS

This project was a cooperative effort between the Minnesota Department of Natural Resources, the University of Minnesota Department of Geology and Geophysics, and Mower County. It would have been impossible to complete without assistance from county and other local government staff. Robert Libra of the Iowa Geological Survey provided valuable insights into the nature of the karst in this area. Donal Daly of the Geological Survey of Ireland and Joseph Ray of the Kentucky Division of Water gave very useful insights and advice.

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