STATE OF MINNESOTA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATERS

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COUNTY ATLAS SERIES
ATLAS C-8, PART B
Plate 9 — Springsheds

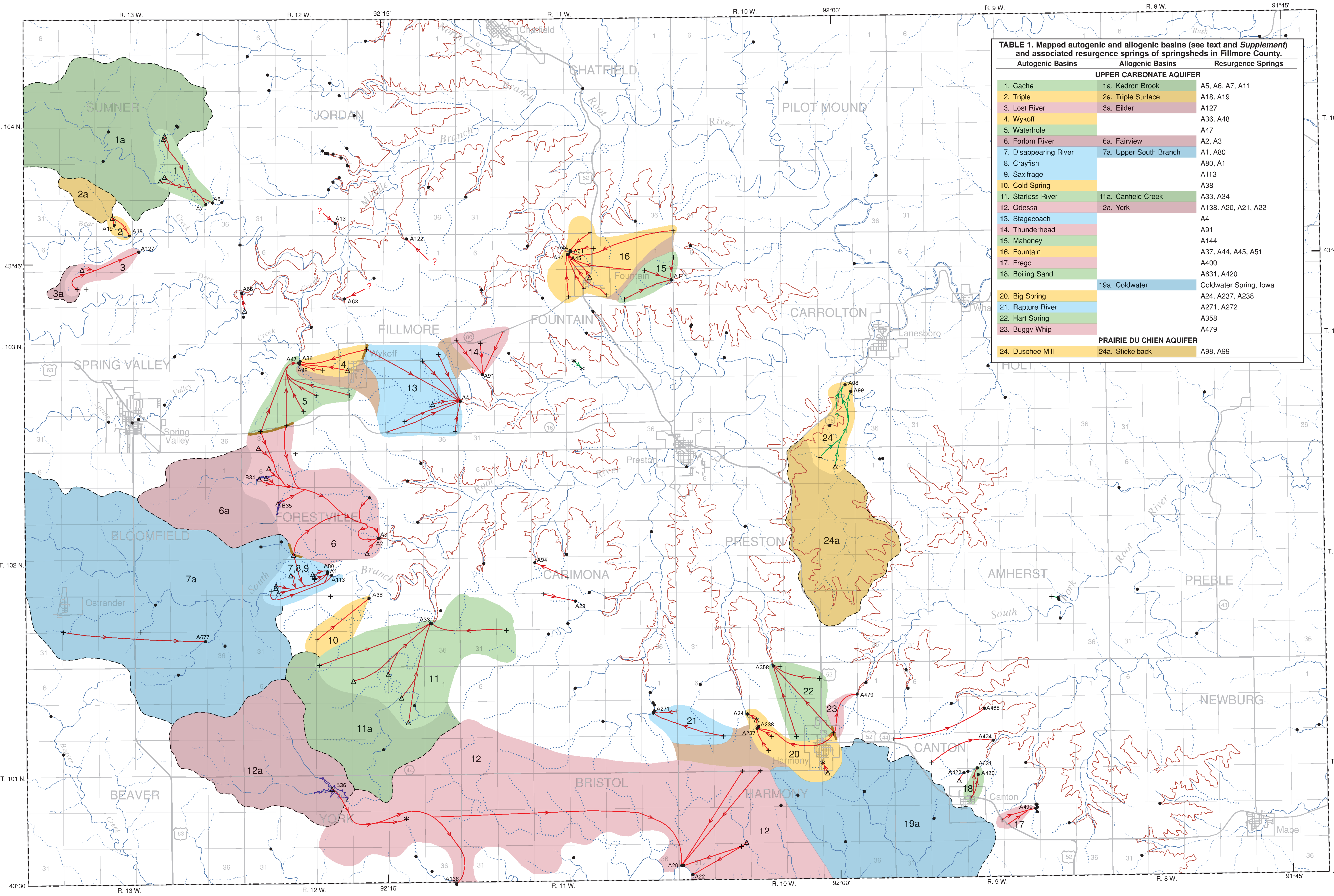

TABLE 1. Mapped autogenic and allogenic basins (see text and *Supplement*) and associated resurgence springs of springsheds in Fillmore County.

Autogenic Basins	Allogenic Basins	Resurgence Springs
UPPER CARBONATE AQUIFER		
1. Cache	1a. Kedron Brook	A5, A6, A7, A11
2. Triple	2a. Triple Surface	A18, A19
3. Lost River	3a. Etter	A127
4. Wykoff		A36, A48
5. Waterhole		A47
6. Forlorn River	6a. Fairview	A2, A3
7. Disappearing River	7a. Upper South Branch	A1, A80
8. Crayfish		A80, A1
9. Saxifrage		A113
10. Cold Spring		A38
11. Starless River	11a. Canfield Creek	A33, A34
12. Odessa	12a. York	A138, A20, A21, A22
13. Stagecoach		A4
14. Thunderhead		A91
15. Mahoney		A144
16. Fountain		A37, A44, A45, A51
17. Frego		A400
18. Boiling Sand		A631, A420
	19a. Coldwater	Coldwater Spring, Iowa
20. Big Spring		A24, A237, A238
21. Rapture River		A271, A272
22. Hart Spring		A358
23. Buggy Whip		A479
PRAIRIE DU CHIEN AQUIFER		
24. Duschee Mill	24a. Stickelback	A98, A99

Digital base modified from 1990 Census TIGER/Line Files of the U.S. Bureau of the Census (source scale 1:100,000); digital base annotation by the Minnesota Geological Survey.

Universal Transverse Mercator projection, grid zone 15, 1927 North American Datum. Vertical datum is mean sea level. Compiled 1994.

SCALE 1:100 000

1 0 1 2 3 4 5 6 MILES

1 0 1 2 3 4 5 6 KILOMETERS

Location Diagram

Partial funding for this project approved by the Minnesota Legislature M.L. 91, Ch. 254, Art. 1, Sec. 14, Subd. 4(f) and M.L. 93, Ch. 172, Sec. 14, Subd. 11(g) as recommended by the Legislative Commission on Minnesota Resources from the Minnesota Environment and Natural Resources Trust Fund. Base funding established by the 1989 Groundwater Protection Act, M.L. 89, c. 326, art. 10, sec. 1, subd. 6, item a. and b.

EXPLANATION

This springshed map was inspired by Quinlan and Ray's (1981) pioneering effort in Kentucky. Underground stream tracing is the main technique used to map connections between surface input points and karst springs. Kingston (1943) recorded the first fluorescent dye underground stream trace in Fillmore County. This map incorporates the results of previously published traces, unpublished traces by the authors over the past two decades, and about 80 new traces conducted from 1992 to 1995.

Underground stream tracing involves the introduction of a tracer, often a fluorescent dye, into a stream sink or sinkhole and the subsequent detection of that tracer in one or more springs. Mohring (1983), Mohring and Alexander (1986), and Alexander and Quinlan (1992) describe the techniques used to trace dye inputs in Fillmore County. Two complementary modes of dye tracing were used. Either the dyes were detected qualitatively with packets of charcoal that were placed in the springs for varying lengths of time and then analyzed, or the dyes were quantitatively analyzed in water samples collected directly from the springs. The use of a scanning spectrofluorophotometer during recent traces has allowed up to three fluorescent dyes to be used simultaneously.

Information and maps of the locations of underground rivers obtained from the cave-exploring community were also incorporated into this map. The distribution of sinkholes shown on Plate 8 was used in some cases to estimate the limits of springsheds.

A24 **Springs**—Resurgence springs of springsheds are identified by number and listed in Table 1. Only a few of the many other springs in the county are shown. See the Fillmore County Springs data base for additional information.

Sinkholes—Only those few sinkholes used as tracer input sites are shown. See the Fillmore County Sinkhole data base and Plate 8 for more locations and other information on sinkholes.

B36 **Blind valleys**—The outlines of the three largest blind valleys are identified by their stream sink numbers.

Stream sinks and sieves—Only stream sinks and sieves used as tracer input sites are shown. See the Fillmore County Stream Sink and Stream Sieve data base for additional information.

Water wells—Only water wells used as tracer sites are shown. See the County Well Index data base for Fillmore County for additional data.

Cummingsville Formation - Decorah Shale contact—This contact (see Plate 2, Bedrock Geology) separates the karst systems formed in the upper carbonate aquifer in the west and south parts of the county from those in the Prairie du Chien aquifer in the north and east parts of the county. Many of the resurgence springs of springsheds in the upper carbonate aquifer occur where surface valleys cross this contact.

Upper Carbonate Aquifer / *Prairie du Chien Aquifer* **Ground water flow paths**—The lines show **diagrammatically** the flow paths and directions of mapped underground rivers. Most lines connect the input and exit points of positive traces. The lines do not necessarily show the actual locations of the conduits. Flow paths queried at their upstream ends show diagrammatically the flow of mapped, but as yet untraced underground rivers. The flow path queried at its upstream end in SH24 is deduced from quantitative tracer results.

Perennial stream—Streams and rivers that flow throughout the year.

Intermittent stream—Watercourses that flow only for short times after large runoff events.

Sinking stream—Reaches of surface watercourses which sometimes lose water to underground drainage. Sinking reaches may be dry when the surface watercourse upstream or downstream of the sinking reach is flowing. Some reaches have been field verified, others are based on stratigraphic interpretations.

1 *Autogenic* — The **autogenic** portion (see text) of springsheds. See Table 1 for names and associated resurgence springs. Two or more traces to the same resurgence spring were generally required to define a mapped autogenic basin. Several isolated trace lines are shown but were not included in mapped springsheds.

1a *Allogenic* — The **allogenic** portion of springsheds. Allogenic springsheds drain into adjacent autogenic basins with the same number. The autogenic springshed to which the Coldwater springshed (SH19a) drains is in Iowa.

Autogenic interbasin areas—Karst area between mapped autogenic springsheds where further tracing is needed to define the boundaries. Water sinking in these areas may flow to any or all adjacent springsheds.

Unmapped areas—Most of the areas outside mapped springsheds are parts of unmapped springsheds; many areas have not yet been traced.

Springshed boundaries

No line — Uncertain boundaries enclose areas where several traces have drained to a specific resurgence spring. Boundaries may change significantly following further studies.

Boundaries of allogenic springsheds defined by surface topography. Additional data may show drainage to resurgence springs other than those indicated.

Boundaries defined by traces to resurgence springs of two or more autogenic springsheds. Defines adjacent basins under flow conditions at the time of the traces.

SPRINGSHEDS

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INTRODUCTION

This plate illustrates the interaction of surface drainage and shallow karst ground waters and shows the subsurface flow connections that feed some of Fillmore County's springs. Background information on Fillmore County's karst landscape and karst processes is given in the Introduction and Karst Processes sections of the Sinkholes and Sinkhole Probability plate (Plate 8) and is further discussed in the section on karst in the accompanying *Text Supplement to the Geologic Atlas of Fillmore County (Supplement)*. A more detailed discussion of karst can be found in Ford and Williams (1989) and White (1988).

Subsurface drainage with scant standing or flowing surface water is characteristic of karst areas. Much of Fillmore County has little natural surface water and smaller surface watercourses have flowing water for only a few hours after a major rainstorm or sudden thaw. In karst areas, any rainfall not lost to evapotranspiration quickly sinks underground via infiltration through the soil, runoff into stream sinks and sieves (see below), sinkholes (see Plate 8), and joints or solution openings on exposed bedrock surfaces. Once in the subsurface, karst ground waters can flow rapidly through complex conduit systems that behave much like an underground piping system. Ground water in the conduits can resurge (return to the surface) in springs that can be miles from the source. The figures in the *Supplement* section on karst illustrate these features of ground-water flow in karst areas.

STREAM SINKS AND STREAM SIEVES

Stream sinks and stream sieves are places where water in surface streams passes from the surface to underground drainage systems (Ford and Williams, 1989). Stream sinks are well-defined points of water loss, such as a surface stream draining into a sinkhole. Stream sinks range in size from cave entrances into which entire rivers can flow to narrow cracks in bedrock streambeds. In contrast, stream sieves are poorly defined reaches of streams where the water sinks; stream sieves may extend for hundreds of feet along a sediment-covered streambed. Each stream sink or sieve can accept up to a maximum flow of water which varies for each sink or sieve. If the surface stream contains more than that maximum, part of the flow will sink while the remaining flow will continue downstream where it may stay on the surface or sink at other stream sinks and sieves. The flow of water into a stream sink or sieve can change if debris either clogs or washes out of them.

Fillmore County contains many sinking streams. One large sinking stream is the South Branch of the Root River. Near the entrance to Mystery Cave No. 1 (see Plate 8), the river begins to disappear into a series of discrete stream sinks and diffuse stream sieves. During periods of low and intermediate stream flow, the entire river sinks underground and flows through at least four separate underground river systems. Tracer studies (see Explanation) show that the water resurges in three springs along the South Branch and two springs where Forestville Creek begins.

Although stream sinks and sieves can occur at any point where the water table is below the streambed, most of them are concentrated in four settings controlled by the bedrock geology. The sinks of the South Branch of the Root River pass water downward through the underlying Dubuque Formation into enlarged joints in the Stewartville Formation. Other major sinks occur where the rock underlying the streambed changes from the Dubuque Formation to the Stewartville Formation. Many sinks occur where water passes through the St. Peter Sandstone into the upper part of the underlying Shakopee Formation. Water that emerges from springs at the boundary between the Cummingsville Formation and the Decorah Shale often flows on the surface over the relatively impermeable rocks of the Decorah-Platteville-Glenwood confining unit. Where the water reaches the eroded edge of the confining unit, the water sinks into the St. Peter Sandstone. Several sinks occur where water passes through the New Richmond Sandstone member of the Shakopee Formation beneath a streambed into the underlying Oneota Dolomite.

Stream valleys are eroded as water flows in them, but when a stream sink or sieve develops, water is directed underground. While the valley continues to erode upstream of the sink, erosion downstream of a sink slows or stops, creating a closed or "blind" valley. Blind valleys have closed topographic contours with no surface water outflow. York blind valley (B36) in springshed (hereafter SH) 12a is the largest blind valley in Fillmore County. Fairview blind valley (B34) and Lefever blind valley (B35) in SH6 are the second and third largest blind valleys. These blind valleys accept the entire flow of their streams in all but the largest runoff events.

UNDERGROUND RIVERS

In contrast to sand or sandstone aquifers, karst aquifers often contain underground rivers. Several of Fillmore County's underground rivers have been mapped by cave explorers, and others have been documented by tracer studies. Underground rivers are largely inaccessible except where they flow through a cave, such as near Harmony where an underground river flows through Niagara Cave. Figure 5 in the karst section of the *Supplement* illustrates in cross section three of Fillmore County's underground rivers.

Underground rivers resemble surface rivers in map view. Small conduits gather water from sinkholes, stream sinks, stream sieves, and water that infiltrates through the soil into the fractured bedrock. The small conduits combine downstream into larger conduits, and most return to the surface in springs. Conduits partially filled with water are similar to surface streams. Conduits completely filled with water behave more like pipes. Water in both conduit types can travel as fast as several miles per day. The subsurface drainage systems formed by the conduits often bear little resemblance to surface drainage basins. The underground rivers can flow under surface watercourses and surface drainage divides. For example, the longest trace shown in SH12 documented that water travels more than 10 miles underground, crossing under one major surface divide and several smaller drainageways.

Near the headwaters of underground rivers, water entering sinkholes and stream sinks may be divided between two or more subsurface basins. The subsurface flow in these areas is mixed with the ground water in the different basins. In the mid-regions of the underground drainage systems conduit flow converges to underground rivers. In these regions, underground pools and riffles provide the only mixing, and the waters are diluted by flow converging from side conduits. At their downstream ends, conduit systems can diverge to several springs. Moth and Grabau springs (A2 and A3, respectively), resurgence springs for SH6, are the headwaters of Forestville Creek in Forestville State Park. These springs flow from opposite sides of a valley, but dye tracing has demonstrated that both springs are fed from a single conduit system.

The underground flow systems in karst basins can transfer or "pirate" water between surface basins. York blind valley (B36) in SH12a pirates the flow from 10 square miles of the Canfield Creek surface watershed, which would otherwise flow into the South Branch of the Root River. The subsurface flow system then diverts the water 10 miles underground to Odessa spring (A20) along the Upper Iowa River.

SPRINGS

Fillmore County has many springs and seeps. Springs and seeps are points where the water table and the land surface intersect, and ground water discharges to surface water. The locations of more than 850 springs are known, but the total number is likely closer to 2000. Springs range in size from small seeps producing less than a gallon per minute (gpm), to Odessa spring (A20), Fillmore County's largest spring; its flow is estimated to vary from 20,000 to 90,000 gpm.

Springs were important in the development of Fillmore County. Early settlers used springs for water supply and cooling purposes as can be seen by the many spring houses still standing in the county. Other uses included milling, municipal and railroad water supply, and fish hatcheries. The springs' critical role for trout habitat led to Thaddeus Surber's (1924) pioneering work. In 1918 and 1920 he walked nearly 1000 miles of streams in the Root River basin conducting an inventory of springs and assessing stream characteristics for trout stocking. Surber noted and discussed two fundamentally different types of limestone springs; those springs where flow and water quality changes occur within hours after recharge events and those springs which change at a slower rate. He concluded that springs that respond quickly were fed directly by surface water from sinkholes. Surber also noted the dramatic decreases in spring flow which had occurred as a result of the changes in land cover wrought by settlement.

Surber's study of Fillmore County springs has been continued by later workers. Johnson and others (1949) noted the continuing decrease in spring volumes throughout the Root River basin. Department of Natural Resources staff continue to monitor spring flow in Fillmore County. Dye tracing studies by Mohring (1983) and Mohring and Alexander (1986) defined the springsheds feeding some of Fillmore County's springs. Mohring's work was continued by private cave explorer groups, the Minnesota Speleological Survey, and University of Minnesota researchers.

There are many types of springs in Fillmore County, differing in flow, water source, and other characteristics. Springs in the county vary greatly in flow. During dry periods some large springs may stop flowing while others continue to flow steadily. Some springs are fed by karst aquifers while other springs are fed by non-karst aquifers. Ground water in karst regions moves readily between karst and non-karst aquifers. The aquifer from which a spring emerges may not be the same aquifer where most of the water's chemical and physical characteristics were established. As Surber (1924) noted, two different types of karst springs exist: Springs in which flow, chemistry, and physical characteristics change slowly and springs where flow and other properties respond rapidly to recharge events. Flow of the latter, "conduit springs" (Shuster and White, 1971), is from recharge directly into sinkholes or stream sinks; flow then moves rapidly underground to the spring. The resurgence springs of springsheds (see Table 1) are conduit springs. Understanding karst spring behavior is complicated because all possible combinations of the two types of springs exist.

The ground water emerging from karst springs can be shown by tracer studies to have been on the surface a few hours or weeks earlier. Therefore, most springs in Fillmore County show surface contaminants including nitrate, pesticides, and bacteria. The water quality in conduit springs can undergo complex changes in the hours and days following major recharge events (Ford and Williams, 1989). The concentration of surface contaminants can change by factors of 2 to 10. Grow's (1986) study of the Forlorn River Springshed (SH6) found major short-term (hours to days) water-quality changes as well as longer-term (months to years) changes. The longer-term changes reflect periods that are wetter or dryer than average. The water quality in Fillmore County karst springs is so degraded that use of the springs as domestic water supplies has been largely abandoned.

SPRINGSHEDS

A springshed includes both the surface area and subsurface rock and sediment that contribute water to a spring. In non-karst landscapes the surface and subsurface spring-water sources generally coincide. In karst springsheds, however, the surface and subsurface sources need not coincide.

An autogenic basin includes both the land surface and the subsurface karst drainage system. Water falling on the surface drains into sinkholes or infiltrates directly downward to the subsurface drainage system. Where two or more springs drain a given sinkhole area, the boundaries of the autogenic basins supplying each spring meet at divides that often do not correspond to surface divides. The positions of these divides may change as ground water levels rise or fall. Where enough information exists to delineate such autogenic basins, they are shown on the springshed map. A few autogenic interbasin areas, located between traces going in different directions, are shown on the map. They show where further tracing is needed to define the boundaries between known autogenic springsheds.

Stream sinks that drain surface or allogenic watersheds also contribute flow to karst springs. Allogenic watersheds overlie relatively impermeable materials which retain runoff on the surface until the water can move into the subsurface. The upstream boundaries of allogenic basins are surface divides and can be identified from topographic maps. Allogenic basins that provide runoff to stream sinks and sieves associated with mapped autogenic basins are shown on the springshed map. Several of the autogenic streamsheds have no mapped allogenic springsheds.

The *Supplement* discusses further how springsheds operate. Figure 5 in the karst section shows the relationship between allogenic and autogenic springsheds in cross section. Underground stream tracing from stream sinks and sinkholes to resurgent springs has identified seven allogenic and 22 autogenic springsheds in the upper carbonate aquifer, and one allogenic and one autogenic springshed in the Prairie du Chien aquifer. Many springsheds remain to be mapped throughout much of Fillmore County. Many years of additional traces and mapping will be required to refine the existing springsheds and to delineate all of Fillmore County's karst springsheds.

SPRINGSHEDS AND WATER-RESOURCE PROTECTION

Ground-water contamination is a major concern in Fillmore County's karst areas, as it is in many karst areas of the world. Stream sinks, stream sieves, and sinkholes are direct connections between surface runoff and the underlying ground-water resources. Karst systems bypass water-purifying processes in the soil zone and conduct surface water directly (sometimes within minutes) into the underlying aquifers. As a result, any contaminants in surface waters are introduced directly into ground water. Water in near-surface karst aquifers generally shows evidence of surface contaminants and the Minnesota Well Code does not permit wells to be developed in such aquifers (Minn. Rules Part 4725.3050 and 4725.3650). However, many older wells continue to pump water from near-surface karst aquifers in Fillmore County. Over a long period of time, water from these near-surface aquifers will recharge deeper aquifers, potentially transferring contaminants to them.

In hours to days, karst conduits can transport contaminated water many miles and return it to the surface at springs. Water flowing from springs is used extensively for livestock watering and fisheries. Springs are also an important part of Fillmore County's tourism industry. Contaminants introduced into a sinking stream or sinkhole can pollute springs and surface streams many miles away. The speed and distance that contaminants can move underground is a major challenge for environmental protection in karst areas.

This springshed map was designed to help manage, limit, and remediate damage from future accidental releases of contaminants in Fillmore County. The springshed map shows the directions that a contaminant will move in the mapped springsheds if it flows into a sinkhole or stream sink or infiltrates through the soil to the water table. This information can be used to predict the direction contaminants will move, notify affected populations, identify monitoring sites and allow protective measures at appropriate springs. The map can also be used to assure others that their water resources are not likely to be contaminated by a spill incident.

This springshed map can be used in designing monitoring programs for spills or leakage from storage tanks, landfills, drainfields, and waste and storage lagoons. In karst regions, monitoring wells appropriate for sandstone or similar aquifers yield incomplete or erroneous information about the spread of pollutants (Quinlan and Ewers, 1985). The ground-water flow in karst areas is via conduits and the probability that a monitoring well will intersect a conduit carrying polluted water is small. Collecting water samples at resurgence springs shown by traces to drain the pollution site is a critical component of an adequate monitoring program in karst areas (Quinlan and Ewers, 1985). This map shows the resurgence springs that must be included in a monitoring program in the event of a spill in a mapped springshed. For example, in the case of a spill in the York surface basin (SH12a) that flows to York blind valley (B36), the spring at which to establish a monitoring program is Odessa (A20) 10 miles away. In karst areas not included in the springsheds shown on this map (see Plate 8), tracing will be required prior to designing a sound monitoring program.

The information on this map is also valuable for watershed management. Because springshed boundaries can be very different from surface drainage divides, watershed plans should take into account all of the landscape which contributes water to the subsurface watershed. For example, Canfield Big Spring (A33) is the headwater spring for the perennial portion of Canfield Creek and the resurgence of SH11. Efforts to improve water quality in Canfield Creek will need to recognize that upstream portions of the Canfield Creek surface basin actually belong to a different springshed and do not contribute flow to Canfield Big Spring. However, sinkholes east of Canfield Big Spring, in a different surface basin, are contributing flow to it. This kind of relationship makes water resources management in karst areas especially challenging.

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GEOLOGIC ATLAS OF FILLMORE COUNTY, MINNESOTA