Groundwater Issues in the Paleozoic Plateau

A Taste of Karst, a Modicum of Geology, and a Whole Lot of Scenery

Iowa Groundwater Association Field Trip Guidebook No. 1
Iowa Geological and Water Survey Guidebook Series No. 27

Dunning Spring, near Decorah in Winneshiek County, Iowa

September 29, 2008

In Conjunction with the 53rd Annual Midwest Ground Water Conference
Grand River Center, Dubuque, Iowa, September 30 – October 2, 2008

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September 2008

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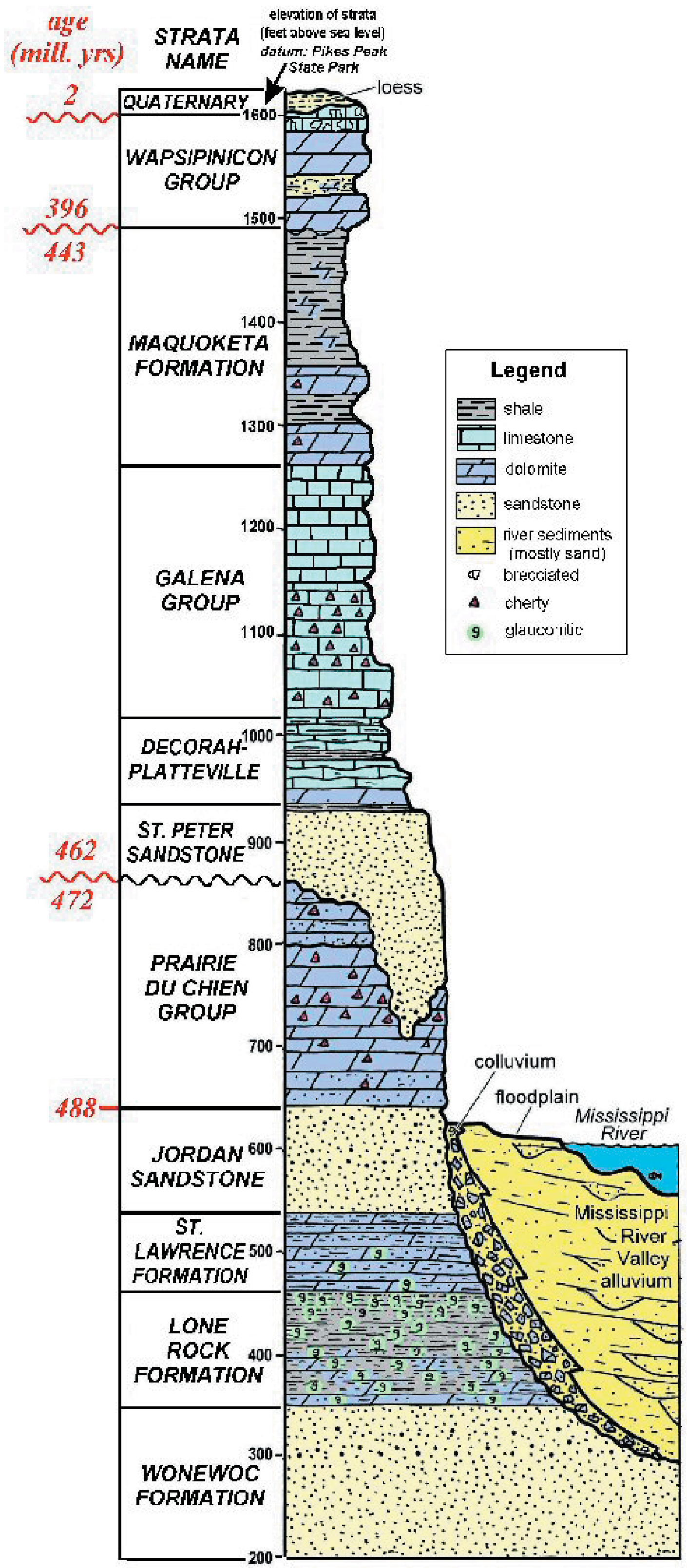

Figure 1. Generalized stratigraphic succession for northeast Iowa and the field trip area (from Hallberg et al., 1983).

INTRODUCTION

The Karst Landscape of Northeast Iowa

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A variety of geologic factors have produced the karst, shallow rock, high relief landscape of northeast Iowa. First, Paleozoic age carbonate (limestone and dolomite) rocks form the uppermost bedrock over much of the area. These carbonate strata are broken into various sized "blocks" by vertical fractures and roughly horizontal bedding planes. As groundwater circulates through these cracks, it slowly dissolves the rock away, creating wide fractures, pipes, voids, and caves. Second, erosion has removed much of the glacial deposits that once covered the landscape, leaving the carbonate rocks near the surface, typically within 25 feet and often within 10 feet. When rock that contains voids and openings is combined with a thin cover of soil, the soil may collapse into the rock openings producing sinkholes. Finally, the proximity of this area to the deeply cut Mississippi River Valley has resulted in steep, deep stream valleys.

These solutionally modified karst-carbonate rocks are excellent aquifers. They are capable of transmitting large quantities of groundwater at quite fast rates. However, the presence of sinkholes allows surface runoff and any associated contamination to directly enter these rock strata. When sinkholes or enlarged fractures occur in stream valleys and other drainage ways, entire streams may disappear into the rock. These streams are called "losing streams." In addition, "between the sinkholes," the thin soil cover provides much less filtration of percolating water than occurs elsewhere in the state. These factors make the aquifers, and water wells tapping them, very vulnerable to contamination and allow any contaminants that reach the aquifer to spread long distances very quickly – especially by groundwater standards.

Water – and any contaminants – enter karst-carbonate aquifers via sinkholes, losing streams, and by infiltration through the shallow soils in flat upland areas. The water travels through cracks and voids to the water table, below which all voids are water-filled. The groundwater then travels "down-flow" through the broken rocks to springs and seeps along the deeply cut stream valleys. These springs and seeps supply much of the stream flow in shallow rock areas. The carbonate aquifers are underlain by less transmissive rocks, called confining beds, which act as the "bottom seal" of the aquifer. Springs and seeps are most prominent where the contact between the aquifer and the underlying confining bed is exposed in valleys.

Figure 1 is a generalized stratigraphic column for northeast Iowa, showing the sequence of rocks that underlie the area. The unit called the Galena Limestone is the most karst-affected unit. In particular, most of the sinkholes and large springs in this area are formed in this unit. The unit called the Prairie du Chien Dolomite is another carbonate unit that exhibits voids and dissolved fractures, but few sinkholes. We will be referring to the rock column and geologic map throughout the trip to keep ourselves geographically and geologically located.

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Hallberg, G.R., Hoyer, B.E., Bettis, E.A., III, and Libra, R.D., 1983, Hydrogeology, water quality, and land management in the Big Spring Basin, Clayton County, Iowa: Iowa Geological Survey, Open-File Report 83-3, 191 p.

PALEOZOIC PLATEAU

What is the Paleozoic Plateau?

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Iowa has seven major landform regions, and Paleozoic Plateau is the name given to the distinctive, high-relief terrain in the northeastern part of the state (Figure 2). This field trip traverses through parts of Allamakee, Winneshiek, and Clayton counties and examines the unique topography, geology, and hydrology that set this region apart from the rest of Iowa. Watch for rugged terrain, steep escarpments, abundant rock outcrops, deep narrow valleys, springs, seeps, fast-flowing streams, and abundant woodlands as well as broad sweeping views across uniformly rolling summits. These unexpectedly scenic landscapes were dubbed "the Switzerland of Iowa" by Samuel Calvin, one of Iowa's best known 19th century geologists.

The key to this dramatic difference in the Iowa landscape is the dominance of shallow sedimentary bedrock at or near the land surface. Whereas glacial deposits of various kinds dominate other regions of the state, they are nearly absent here and more durable limestones and dolomites (carbonate rocks), sandstone, and shale units control the topography. These sedimentary strata, collectively referred to as Paleozoic in age, include fossiliferous rocks of Cambrian, Ordovician, Silurian, and Devonian age (Figure 3). Their layered sequences vary in resistance to erosion and, as a consequence, distinct geologic formations can be traced for miles across the landscape, mirroring the underlying bedrock units. Distinctive plateau surfaces are developed across the Hopkinton, Galena, and Prairie du Chien dolomites in particular. These carbonate units are marked along their edges by bold bluffs and escarpments, which produce an angular, stepped skyline all the way from the prominent (often wooded) bluff line along the Silurian Escarpment at the western border of the region eastward to the dramatic drop into the entrenched valley of the Mississippi River along the eastern margin of the region.

When observing limestone and dolomite outcrops, notice the prominent vertical fractures and crevices as well as the numerous horizontal bedding planes, recesses, and overhangs. These intersecting pathways, occurring at nearly right angles, are the primary avenues for infiltrating groundwater. The lime-rich strata are slowly soluble in the percolating waters. Through geologic time, this process has given rise to karst features such as sinkholes, "disappearing streams," caves, and springs as well as an explanation for the many sharply angled stream courses. These carbonate rocks also contain valuable groundwater resources for wells throughout the region. Thus, the karst topography characteristic of this region, with its inseparable surface water and groundwater interactions, results in a high vulnerability of this area to groundwater contamination problems.

Understanding the geologic and hydrologic systems at work across and beneath the Paleozoic Plateau region is important to meeting the challenges of landuse, water quality, water supply, recreation, and conservation issues in this part of Iowa.

Bedrock Geology of Northeast Iowa

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The bedrock formations of northeast Iowa are concealed, to varying degrees, by a cover of Quaternary deposits, but the majority of the area traversed by this field trip is within the portion of the state referred to by Prior (1991) as the "Paleozoic Plateau." This landform region is characterized by a thin mantle of Quaternary materials overlying early Paleozoic bedrock. Much of this area has traditionally been included within the so-called "Driftless Area," and although glacial deposits are largely absent across this area, the region is not truly "driftless," as scattered erosional outliers of glacial till are not-

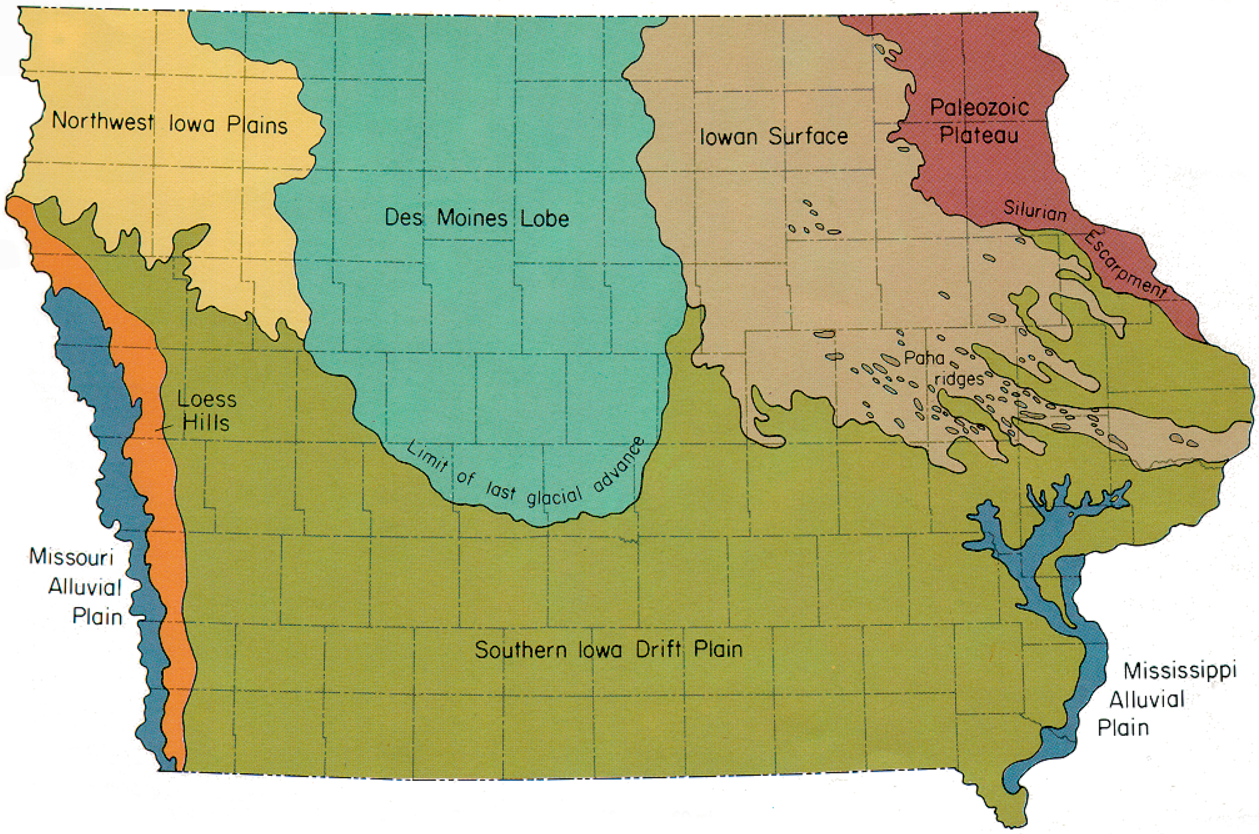

Figure 2. Landform regions of Iowa.

ed in more than a few places. All major streams within this area are incised into bedrock, and the bulk of the Quaternary deposits that conceal bedrock are upland loess deposits, valley wall colluvial deposits of mixed loess and bedrock, and alluvial sediments.

Figure 4 is an extract of the Bedrock Geology of Northeast Iowa map (Witzke, et al., 1998; Witzke, 1998) for the area of the field trip. It shows the major bedrock units, the field trip route, and significant towns along the route. Figure 1 illustrates the generalized stratigraphic sequence within all of northeast Iowa. Paleozoic strata across this region are deposits primarily of shallow marine origin that accumulated on slowly subsiding cratonic basins and shelves and along the margins of gentle positive arches. Depocenters and facies belts shifted through time in response to distant tectonic activity at continental margins and craton lithospheric adjustments from older Precambrian structures and basins (Bunker et al., 1985; Bunker et al., 1988; Witzke and Bunker, 1996). All Paleozoic strata of the region appear to be flat lying, but actually have a regional dip to the southwest that varies between 20 to 40 feet per mile. Along some local structures, strata attain slightly higher dips.

Cambrian

Cambrian strata are the oldest exposed rocks within the region, but these rocks will not be seen because they lie to the northeast of the trip route or are buried under thick alluvial deposits of the modern Mississippi River. The most notable of these units is the Jordan Sandstone, a friable, quartzose sandstone of sheet-like distribution approximately 100 feet thick. The Jordan forms the lower part of Cambrian-Ordovician aquifer system across eastern Iowa

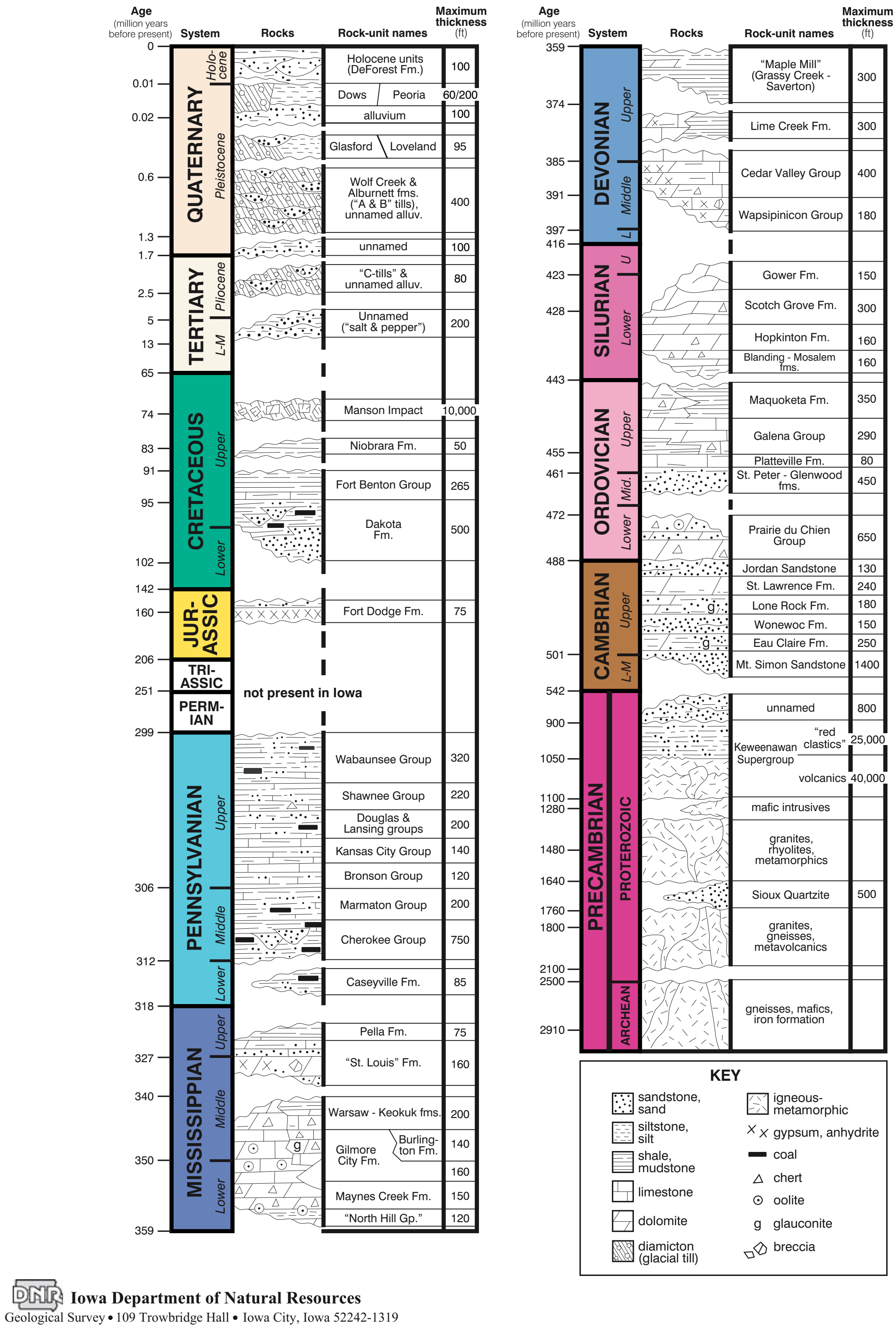

Figure 3. Stratigraphic column of Iowa.

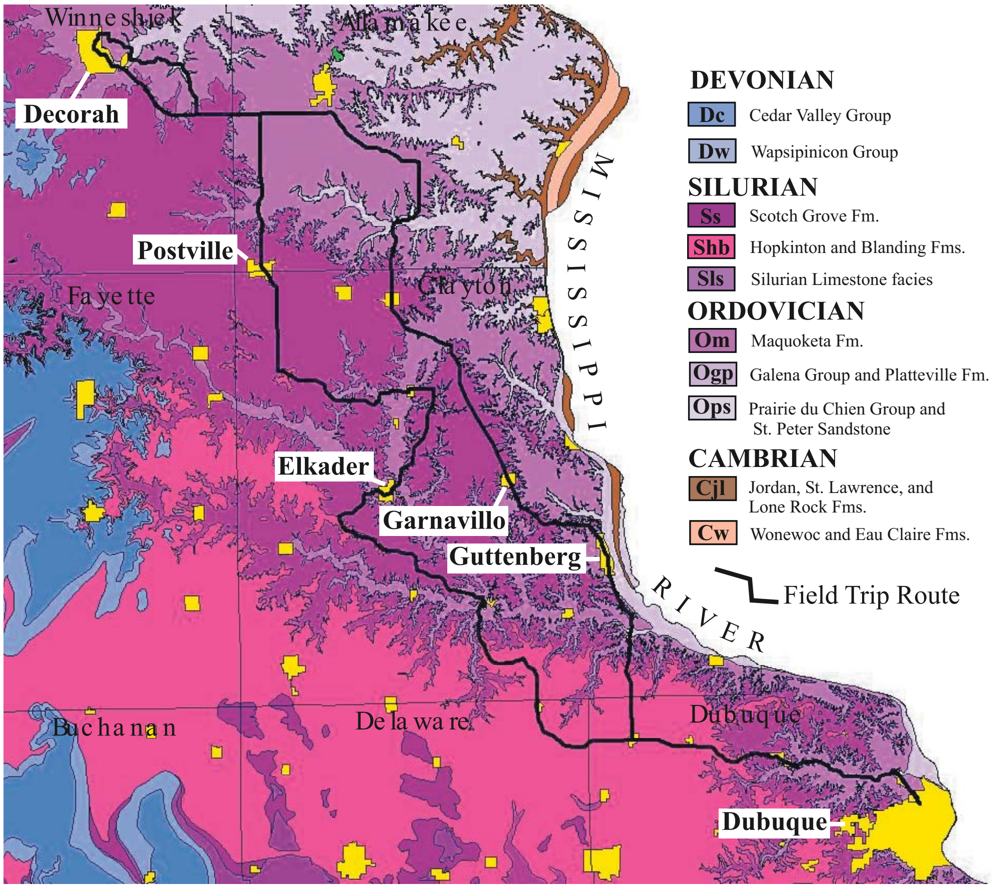

Figure 4. Bedrock geology of northeast Iowa with field trip route and selected towns (adapted from Witzke et al., 1998).

and surrounding states. Many communities and commercial entities draw their primary source of water from "Jordan" wells.

Ordovician

The Ordovician Prairie du Chien Group, above the Jordan, comprises the middle unit of the Cambrian-Ordovician aquifer. The Oneota Formation, the lower subdivision of the Prairie du Chien Group, is a dense to vuggy, cherty dolomite that averages 200 feet thick. It consists of numerous stacked cycles of shallow subtidal to peritidal carbonate rock. Some zones within the Oneota exhibit enhanced porosity of meter-scale vugs and pores which almost certainly contribute to water availability in many wells. Locally, the formation hosts small occurrences of Upper Mississippi Valley type lead mineralization. The Skakopee Formation, averaging 100 feet thick, is the upper division of the Prairie du Chien Group and lies disconformably on the Oneota. Its basal member, the quartzose New Richmond or Root Valley Sandstone, grades upward into the shallow-water carbonates of the Willow River Member which contains distinctive beds of oolites and stromatilites. The trip will pass a roadcut of large, meter-scale stromatolites, along Allamakee County Road X26 after crossing the Yellow River before Stop 2.

The uppermost unit of the Cambrian-Ordovician aquifer is the well-known St. Peter Sandstone, a friable, high-purity, fine- to medium-grained quartz sandstone that averages 50 feet in thickness. The St. Peter rests unconformably on older Ordovician and Cambrian strata across the upper Midwest and locally thick sequences of St. Peter, exceeding 250 feet in thickness, fill paleovalleys on this erosion surface. Community and commercial wells typically case-off the unit to prevent production of fine sand, however, many domestic wells in the region utilize the St. Peter as their primary aquifer. Although the trip will not stop at any St. Peter outcrop, the formation is visible in the valley wall of the Mississippi on the northwest side of Guttenberg, and again south of the crossing of the Yellow River along X26, and finally along Winneshiek County Road A52 east of Decorah. The St. Peter is currently mined along the Mississippi River at Clayton, Clayton County and shipped to the southern U.S. for use as a propping agent sand in the oilfields when hydraulic fractures need to be propped open.

The Glenwood Formation overlies the St. Peter everywhere and is an unusually thin, but highly distinctive green to gray, variably phosphatic and sandy, shale unit. It averages 4 to 8 feet thick and forms the lowermost division of an informal confining unit comprised of the Glenwood and the overlying Platteville and Decorah formations. In wet times small water seeps often form at the top of Glenwood outcrops. The Platteville Formation, a dense, fossiliferous dolomite and limestone formation, occurs above the Glenwood. It averages 30 to 50 feet in thickness, being thinner to the north, and is widely quarried for road stone.

The overlying Decorah Formation forms the upper and most effective division of this aquitard. The Decorah is included as the lowest statigraphic division of the Galena Group but is not considered part of the Galena aquifer. It is a sparsely to highly fossiliferous unit that averages 40 feet thick. It is shale-dominant to the north at Decorah, its type area, where it is known as the Decorah Shale but is limestone-dominant to the south near Guttenberg. The Decorah Shale aquitard is a major barrier to groundwater flow from the overlying Galena Group carbonates. Throughout the region, major groundwater springs issue from the base of the overlying Galena Group carbonates due to the presence of the Decorah Shale. The trip will not stop to see the Decorah Shale, but it can be viewed at a quarry in Decorah along the south side of State Highway 9 as the trip leaves Decorah.

The Galena Group is a resistant carbonate interval that is well displayed in the Ordovician outcrop of northeast Iowa. It forms prominent vertical outcrops along stream courses and stands well in roadcuts such as that at Stop 1. The bulk of the Galena Group is comprised in ascending order of three formations: the Dunleith, the Wise Lake, and the Dubuque. The Dunleith averages 135 feet thick, the Wise Lake 65 feet, and the Dubuque 35 feet, for a combined aquifer thickness of 235 feet that is remarkably consistent across the area. In the Dubuque area these formations are composed primarily of dolomite, but north of Dubuque County the sequence becomes dominated by limestone, and this is the area of karst that the Galena Group is so well known for. In general the Dunleith is variably cherty and chert is one characteristic that is used to divide the Dunleith from the overlying Wise Lake; the Dunleith is also fossiliferous and contains numerous thin shaly horizons. The Wise Lake is mostly chert-free, and often appears thick-bedded in exposures, a characteristic derived from the extensive bioturbated fabric that typifies the formation. The Dubuque is fossiliferous limestone with notable crinoid skeletal debris. It typically appears as thin to medium beds separated by thin beds of gray shale. All the units are jointed or fractured and karst-solutional features or activity is visible at nearly any exposure or quarry. Major joints have been widened by solutional activity and secondary carbonate deposits of flowstone are often commonly observed (Hallberg et al., 1983). The land surface above the Galena typically displays sinkhole topography to varying degrees, and some areas, such as near Stop 2 in southern Allamakee County, can be characterized as sinkhole plains. Stops 2, 3, 4, and 5 will all focus on the Galena Group aquifer and its karst characteristics.

The Maquoketa Formation overlies the Galena Group. It is an Upper Ordovician aquitard characterized by shale and carbonate strata that exhibits considerable north-to-south facies variations within the outcrop belt of northeast Iowa

(Witzke et al., 1998). In Dubuque County, the Maquoketa is dominated by green-gray shale with subordinate interbeds of dolomite. The lower interval in this area includes a basal phosphorite and brown organic shale facies, locally with phosphatic dolomites. Significant sub-Silurian erosional relief on the Maquoketa shales is seen in this area. Northward in the outcrop belt the formation incorporates progressively more carbonate facies, where the Maquoketa can be readily subdivided into four constituent members, ascending: 1) Elgin (limestone/dolomite, variably cherty, shale interbeds, basal phosphorite); 2) Clermont (shale and argillaceous limestone/dolomite); 3) Fort Atkinson (fossiliferous limestone); and 4) Brainard (green-gray shale, dolomite interbeds in upper part). The alternation of resistant carbonates and easily eroded shale seen in the vertical progression of members produces a distinctive landscape within the Maquoketa exposure belt. The Maquoketa is capped by Silurian strata over much of eastern Iowa, but the Maquoketa is beveled northward in Winneshiek County beneath the Devonian (Witzke et al., 1998). Although a significant part of the trip will travel over the Maquoketa Formation there are few exposures. The Maquoketa and its shale-dominated nature forms an effective aquitard above the Galena Group and below the overlying Silurian and Devonian carbonates.

Silurian

Silurian strata along the field trip route are restricted to that of the Tete des Morts, Blanding, and Hopkinton formations. The Blanding Formation is a distinctive very cherty dolomite interval above the Tete des Morts dolomite. The Hopkinton Formation, the thickest Silurian formation in the trip area, is widely exposed in eastern Iowa, and everywhere is known to overlie the Blanding. The Hopkinton consists of variably fossiliferous dolomite of differing textures and is variably cherty. The aggregate thickness of these units is approximately 125 feet along the trip route. They comprise the bedrock that forms the prominent physiographic feature termed the "Niagaran" or Silurian Escarpment in eastern Iowa, and the trip will inspect the Blanding Formation at Stop 6 along the feather edge of the escarpment at "Chicken Ridge." Silurian dolomite strata of the escarpment host numerous sinkholes and related mechanical/solutional karst, and some groundwater springs do issue from Silurian strata along the foot of the escarpment.

Devonian

Devonian strata of the Wapsipinicon and Cedar Valley groups cap the bedrock sequence in the western counties of the field trip region. The Wapsipinicon Group, averaging 75 feet thick, lies unconformably above Silurian and Ordovician strata and rests as low as the middle portion of the Maquoketa Formation in Winneshiek County. It is comprised of a basal Spillville Formation composed of thick bedded dolomite and limestone, and an upper division, the Pinicon Ridge Formation, composed of laminated to brecciated limestone and shaly dolomite. The younger Cedar Valley Group attains thickness in excess of 100 feet and is dominated by laminated to fossiliferous, variably cherty limestone and dolomite.

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Quaternary History of the Paleozoic Plateau

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Introduction

On this Iowa Groundwater Association sponsored field trip, participants will travel to the most unique landform region of Iowa. The field trip area is almost entirely within the Paleozoic Plateau and includes stops in Winneshiek, Allamakee, and Clayton counties. Steep-sided cliffs, bluffs, deeply entrenched stream valleys, and karst features are characteristic of this markedly different physiographic region of northeast Iowa. In contrast to other parts of the state, where glacial cover dominates, the surficial character of this area is bedrock controlled. The Paleozoic Plateau is bordered by the Iowan Surface which comprises the western portion of Winneshiek County and the southernmost edge of Clayton County.

Paleozoic Plateau Landform Region

The Paleozoic Plateau region is characterized by an abundance of bedrock exposures, deep and narrow valleys, and limited glacial deposits. The steep slopes, bluffs, abundant rock outcrops, waterfalls, rapids, sinkholes, springs, and entrenched stream valleys form a unique physiographic setting. These characteristics combine to form an area of many diverse microclimates that support varied flora and fauna communities not represented elsewhere in the state. The boundaries of this landform region are defined along the southern and western margins with the change from a rugged, dissected, rock-controlled landscape to that of the gently rolling, lower relief landscapes of the Iowan Surface to the west and the Southern Iowa Drift Plain to the south. The Quaternary deposits of the Paleozoic Plateau are characterized by loess covered patches of isolated glacial till and alluvial materials.

The characteristic features of the Paleozoic Plateau are representative of deep dissection by streams through gently inclined Paleozoic rock units with varying resistance to erosion. These rocks range in age from 350 to 600 million years old and include formations from the Devonian, Silurian, Ordovician, and Cambrian. The rocks dip gently to the southwest, exposing progressively older Paleozoic rock units in the northeast corner of the state. The more resistant rock types (sandstones and carbonates) form cliffs and escarpments high on the landscape whereas the more easily weatherable shales have gentler slopes. This differential weathering creates a landscape reflecting the local bedrock. Topography is also controlled by extensive karst development in this area forming caves, sinkholes, springs, and subsurface caverns. The Mississippi River also influenced landscape development, and its tributary valleys contain well preserved terraces, older floodplain deposit remnants, and entrenched and hanging meanders. All of these features indicate the complexity of the alluvial history and river development associated with glacial melting and drainage diversions.

Early Studies of Northeastern Iowa – the "Driftless Area"

The landscape region of northeast Iowa was originally termed the "Driftless Area" due to the scarcity of glacial deposits and the belief that this area had never been glaciated. Later studies indicated this was not the case, and it was termed the Paleozoic Plateau (Prior, 1976). The first geological investigations of northeast Iowa were completed during the 1840s under the direction of David Dale Owen (in Calvin, 1894). In 1862, Whitney was the first to document a Driftless Area in Iowa, Wisconsin, Minnesota, and Illinois and produced a map depicting this region. Chamberlain (1883) and Chamberlain and Salisbury (1886) later used Whitney's designation in their mapping of the Driftless Area boundary in Iowa and noted a "pebbly border of earlier drift" in all except a few townships. Although the researchers recognized this drift as foreign material, they did not believe these materials had been deposited directly by the ice and thought they were possibly ice-rafted debris or the result of floodwaters.

Numerous studies and maps were published for this region by the Iowa Geological Survey from 1892 through the early 1900s. McGee (1891) and Calvin (1894, 1906) recognized upland glacial materials and granite boulders, but did not consider them to be "proper" drift. Other studies described glacial outwash materials and boulders of non-native origin, but they were not determined to be directly deposited by glaciers. Due to the lack of glacially deposited materials, the high relief, and the extensive bedrock exposures, all these investigations led to the conclusion that the northeastern region of Iowa had not been glaciated.

While working on a Master's thesis, A. J. Williams documented 80 patches of glacial drift in what had previously been called the Driftless Area. Due to the upland position of the drift and the differences between these materials and the Kansan drift to the west, he believed these deposits were Nebraskan in age. Prior to the completion of his Ph.D. in 1923 (Williams, 1923), a field conference was held, and at its completion researchers generally agreed that the drift east of the Kansan border was in fact deposited by a glacier and that the Kansan occurs both in the valleys and on the uplands. Kay and Apfel (1928) later published Williams' map showing the locations of upland drift in northeastern Iowa. From then on the area was mapped as Nebraskan and no truly driftless area was recognized in Iowa.

In 1966, Trowbridge published a summary of previous works and included additional data from his studies of the region. In all, Trowbridge documented more than 100 occurrences of glacial drift and determined that these materials are till and not outwash. Trowbridge's research further supported the idea that areas in northeast Iowa previously considered "driftless" by researchers had been glaciated.

The term Driftless Area came into being and was commonly used as a term to describe the region of high relief, heavily dissected, bedrock-controlled landscape of northeastern Iowa. However, the original area designated as the Driftless Area was much smaller than the region of rugged topography and associated flora and fauna commonly referred to by natural scientists. Therefore, it was incorporated into a much larger area than initially defined and termed the Paleozoic Plateau. Within this larger area, many remnants of glacial drift are identified, making the terminology "Driftless Area" incorrect. The term Paleozoic Plateau is a better description for this physiographic region and incorporates the much larger topographically and ecologically similar area referred to by natural scientists and biologists.

Quaternary Materials in the Paleozoic Plateau

The Paleozoic Plateau region was glaciated multiple times during the Pre-Illinoian between 2.2 million and 500,000 years ago. Based on work by Hallberg (1980a), it has been determined that two Pre-Illinoian till units are present, the Wolf Creek and the Alburnett formations. The younger Wolf Creek Formation cannot be directly dated in northeast Iowa, but based on other studies it is younger than 600 ka, and it is estimated to be about 500 ka indicating the last time glacial ice advanced into this area (Hallberg and Boellstorff, 1978; Lineback, 1979; Hallberg, 1980b). Stream erosion and hillslope development since the last glaciation has resulted in the removal of most of the glacial materials, except those high on the divides, and has produced the dissected landscape we see today (Hallberg et al., 1984).

More recent studies and drilling associated with mapping projects in the Upper Iowa River Watershed indicate that although glacial till is rarely recognized in outcrop, it is commonly found in drill core at upland locations. Review of existing drilling records shows the same pattern of till distribution. Most exposures at lower elevations and slopes near valleys are comprised of loess derived colluvium over bedrock. It is believed that a period of mass erosion occurred that removed till from slopes and left till on the uplands. Early researchers didn't have the benefit of drilling records and were limited to outcrops leading to the idea of a "Driftless Area." Glacial till thins toward the Mississippi River and is very limited in extent in Allamakee County. The majority of Winneshiek County has till in upland positions and increases in distribution to the west. The western third of the county is in the Iowan Surface landform region with loamy reworked glacial till at the surface and a thin mantle of eolian silt (loess) and sand.

Upland surfaces are mantled with 3 to 6 meters of Wisconsin age Peoria Formation loess which has been radiocarbon dated at 25.3 ± 0.65 ka (Hallberg et al., 1978). The end of loess deposition in Iowa is considered to be about 14 ka (Ruhe, 1969) and these materials often obscure the glacial deposits. On the primary stream divides, 4 to 6 meters of loess overlies well-drained paleosols developed on Pre-Illinoian tills. The paleosols are generally 1 to 2 meters thick, but locally may be up to 2 to 5 meters thick. These thicknesses and other features are typical of Late-Sangamon paleosols. Yarmouth-Sangamon paleosols are only locally preserved on the divides. The Late-Sangamon paleosol may extend to the Paleozoic bedrock surface (Hallberg et al., 1984).

Although many early studies suggested that the landform features of the Paleozoic Plateau are very old, more recent research indicates that the modern drainage system and dissected landscape of this region occurred during the Pleistocene. The oldest valley remnants are buried by Pre-Illinoian tills and may be middle to early Pleistocene in age, although the time of incision is not well constrained. Evidence is derived from studies of the upland stratigraphy and erosion, karst systems, fluvial and terrace deposits of the stream valleys, and the dating of speleothems.

Knox and Attig (1988) studied the Bridgeport terrace in the lower Wisconsin River valley, Wisconsin. Paleomagnetic dating of the Bridgeport terrace sediments indicate that they are older than 730 ka. The valley would have had to already be entrenched by this time, indicating a minimum age for these deposits. Therefore, they believe that the Mississippi River between northeast Iowa and southwestern Wisconsin was deeply entrenched by Pre-Illinoian time. Research summarized in Hallberg and others (1984) suggests that the Mississippi River and its tributaries are of middle Pleistocene age (500 ka). The major drainage lines were established by Late Sangamon time, however major stream incision probably began prior to the Illinoian (300 ka). The Upper Mississippi River valley likely originated as an ice-marginal stream during a Pre-Illinoian ice advance.

The relationship between karst deposits and Pre-Illinoian tills can also yield information regarding the landscape evolution of the Paleozoic Plateau area. Karst ages have been determined by radiometrically dating speleothems. Fifty speleothems in Minnesota and Iowa have been dated (Lively, 1983). A few dates range from 250 ka to greater than 350 ka, but the majority of the dates fall into three general groupings: 163-100 ka, 60-35 ka, and from 15 ka to present. Speleothem growth is episodic and partially controlled by climate, and dates provide minimum ages on major valley downcutting, which lowered the piezometric surface and allowed speleothem growth in vadose caves.

During the past 25 ka in the upper Mississippi River valley, there have been four major episodes of alluvial activity (Knox, 1996). The period between 25 ka and 14 ka was characterized by large quantities of bedload sediment being transported by a braided stream system. This aggradation has been related to outburst floods from glacial lakes and normal meltwater discharge from the Wisconsin glacier. An island braided channel system developed between 14 ka and 9 ka as large discharges from outlet failures of proglacial lakes and sustained low sediment flows caused major downcutting. Modern Holocene climate and vegetation systems developed from 9 ka to approximately 150 to 200 years before present. The upper Mississippi River returned to aggradation as Late Wisconsin age sediment in tributaries remobilized. Dominant processes during this period involved minor downcutting, channel migration, and the development of fluvial fans and deltas at the junction of tributaries. The fourth episode encompasses the time since European settlement when agricultural land use, channelization, and dam building have greatly impacted the upper Mississippi River.

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Karst and Cave Formation and Development on the Paleozoic Plateau

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In most carbonate rocks, there is relatively little intergranular porosity compared to sandstones. For this reason, most water movement through carbonates is along vertical fractures, or joints, and horizontal bedding planes. As water moves through these openings, it dissolves some of the confining rock, thus enlarging the openings and allowing greater flow. This diverts flow from smaller adjacent openings and concentrates flow in the larger conduits causing them to increase in diameter.

The overall direction of groundwater flow in carbonate rocks is down-head in response to hydrostatic pressure, as it is in a more hydrologically, more isotropic rock such as sandstone. In carbonates however, flow is concentrated along fractures and bedding planes, zones of high hydraulic conductivity or water movement. Thus, solutional conduit and cavern development in Iowa occurs along those fracture trends which best facilitate down-head movement (Bounk 1983a, 1983b)

The presently active and easily discernible karst landforms were not the first to develop in what is now the Paleozoic Plateau. Prior to the Pleistocene, other episodes of karstification occurred in carbonate rocks in this area. Most of this older karst was destroyed by erosion prior to and during the advance of Pleistocene glaciers into this area. The present northeast Iowa karst system began to develop after retreat of Pre-Illinoian glaciers from the area approximately 500,000 years ago (Hallberg, 1980). At that time, glacial deposits covered much of the landscape, and relief was subtle compared to that in the area today. Groundwater levels would have been fairly high and water flow was down head along horizontal bedding planes and vertical fractures. As time progressed, groundwater dissolved portions of the rock along these zones of high hydraulic conductivity and elliptical-shaped conduits began to develop. These first conduits developed while completely water filled under phreatic conditions. Sometime before 30,000 years ago, entrenchment of the Mississippi River and its major tributary valleys lowered the level of groundwater far below the land surface of upland areas. As the level of the groundwater dropped, conduits closer to the land surface became partly air-filled and cavern formation continued under vadose conditions. Under these conditions, water in a conduit is analogous to a surface stream and it dissolves and mechanically erodes the floor of the conduit, forming a canyon-like vadose trench below the elliptical phreatic tube. Many spectacular cave formations, such as stalactites and stalagmites, form under vadose conditions as dripstone and flowstone accumulate because of the high carbonate content of the water. Where a vertical conduit enlarged near the surface and the mantle of glacial or alluvial deposits collapsed, sinkholes developed. Occasionally, a surface drainageway was intercepted by a large sinkhole and a blind valley developed. When valleys intercepted conduits at the groundwater level, springs formed. As vadose processes operated in the aerated zone, conduit enlargement continued in the phreatic zone. These processes continue to operate today, increasing the secondary porosity of the carbonate rocks and allowing for faster groundwater flow through these aquifers.

Water in a sinking stream or entering a sinkhole also carries sediment into the conduit system. As conduits are abandoned, they may become partly or entirely filled with sediment. Many of these plugged passages, remnants of earlier cavern systems, are known from explored sections of northeast Iowa caves. In addition, large blocks occasionally fall from the roof and

Cold Water Cave, in northeastern Iowa, is shown in both photos. This cave contains spectacular speleothems, including stalactites, stalagmites, bacon rind (shown in photo below), soda straws, and flowstone.

sides of caverns forming “breakdown.” Some passages become blocked with breakdown and are abandoned. In some instances breakdown, plus the downcutting of a surface stream into a cavern, will result in destruction of the cavern and formation of a steep-sided valley at the surface. Indicators of former cave systems which have since been destroyed include: 1) large blocks of breakdown on the valley floor; 2) natural bridges formed from small, uncollapsed sections of the original cavern; and 3) tufa, which is deposited at or near springs, and is highly porous due to the presence of plant material (generally moss) incorporated at the time of deposit.

Mechanical Karst Formation and Development in Iowa

Another type of karst, mechanical karst, develops in massive carbonate units which overlie shale. In this instance, the carbonate/shale contact is lubricated by groundwater, and blocks of the overlying carbonates slide downslope on the overlying shale. Often the base of the moving rock rotates outward, forming a roofed cave. Slumping of overlying unconsolidated material results in the development of sinkholes which form in parallel alignment to the nearby bluffline. This type of sinkhole usually occurs within a few hundred feet of the bluffline (Hansel, 1976).

Distribution of Karst in Northeast Iowa

Karst development includes several types of landforms which result from solution and mechanical movement of the carbonate rocks and from collapse of overlying, unconsolidated deposits into solutional and mechanically induced openings. These landforms are not uniformly distributed across northeast Iowa. Instead, they are concentrated where lithologic, hydrologic, and geomorphic conditions have promoted their development and preservation.

Figure 5 shows the general distribution of karst features in northeastern Iowa. Two major areas of concentration are readily apparent: the outcrop area of the Ordovician-age Galena Group, and a zone extending roughly northwest to southeast along the leading edge of Silurian-age strata in northern Dubuque, southwestern Clayton, and northeastern Fayette counties.

Solutional karst dominates the Galena outcrop area. Sinkholes are abundant in portions of this area, with more then 1,800 recorded in a single township (Ludlow) in southwestern Allamakee County (Hallberg and Hoyer, 1982). Sinkholes in northeast Iowa range from about two meters in diameter and one-half meter deep to large depressions one hundred meters in diameter and in excess of ten meters deep. Blind valleys are also common in this area where high sinkhole concentrations are found. Several caves are known in the Galena outcrop area. These range from a minimum of a few meters to a maximum known length of over 28 kilometers. Generally, the larger caves contain streams and are said to be hydrologically active. The streams in these caves emerge at the surface as springs. Springs issuing from the Galena vary in average discharge from less than three liters a minute to over 75,000 liters a minute, although the majority occur at the low end of the spectrum. A single spring can also show wide fluctuations in discharge throughout the year. An estimated 100-fold increase in flow can occur following a heavy rain or spring snowmelt.

Occasional examples of mechanical karst also are found in the Galena outcrop area. These usually are restricted to escarpments along major valleys draining the area. Some of these mechanical karst features are shaped so as to trap cold winter air and hold it far into the warmer spring and summer months. Water descending into these areas during the spring freezes and forms ice, from which the term, “ice cave” is derived. Prior to widespread use of refrigeration, several ice caves, such as Decorah Ice Cave, were used by local inhabitants for cold storage.

Karst along the Silurian Escarpment is dominantly mechanical in origin (Hansel, 1976). Here, Silurian strata are underlain by the Ordovician-age Maquoketa Shale. Water percolating through the Silurian carbonates is perched at the contact with the underlying shale. This lubricating action coupled with high relief along the escarpment induces downslope movement of the Silurian rocks and development of mechanical karst. Some solutional karst is also developed in this area, but the known caves and other solution features are smaller than those formed in the Galena outcrop area.

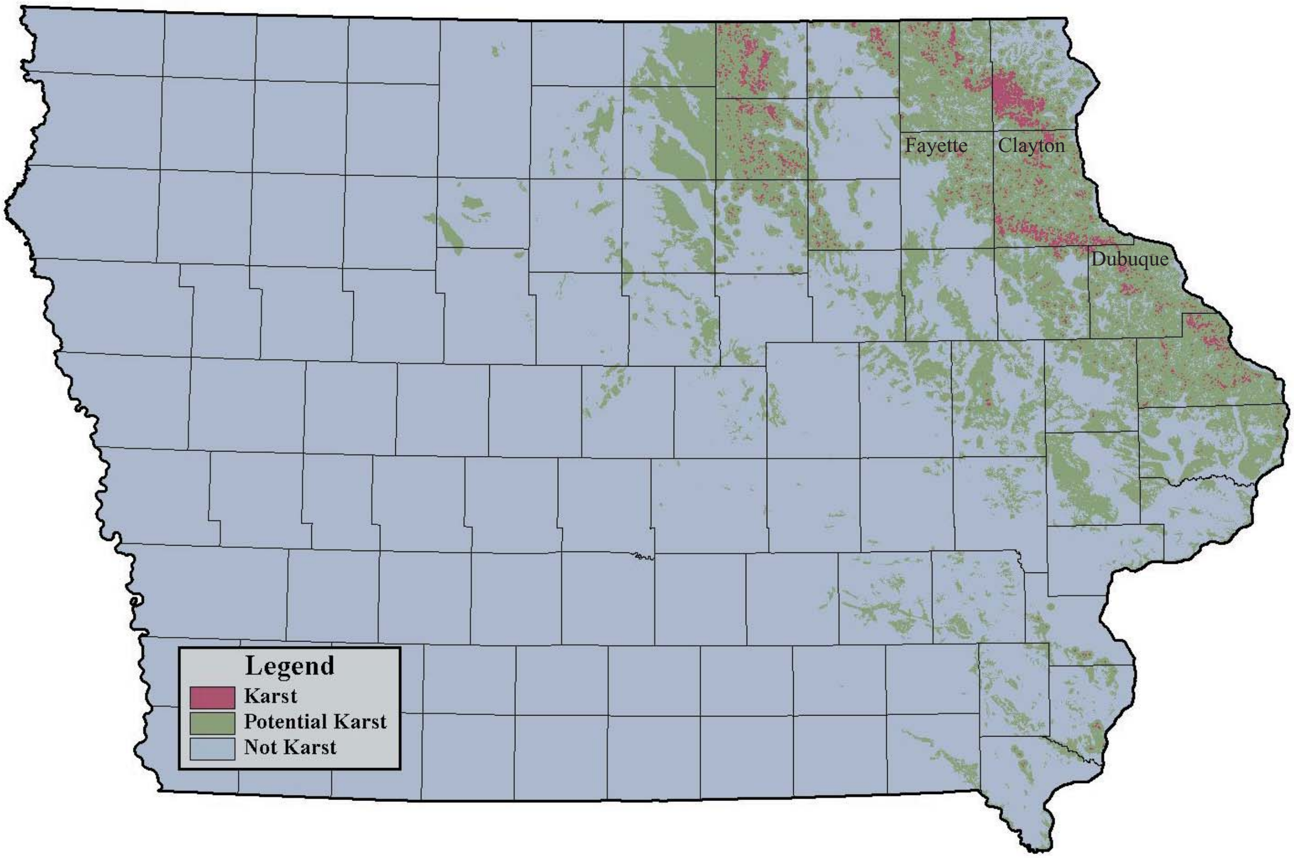

Figure 5. Areas in Iowa with varying levels of karst development and potential.

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LIVING WITH KARST

Sources of Bacteria in Karst

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The Upper Iowa River and its watershed are valuable natural and economic resources located in extreme northeast Iowa and southeast Minnesota. The Upper Iowa River watershed is a 1,005-square-mile watershed recognized by the U.S. Environmental Protection Agency and the State of Iowa as a priority watershed for water quality protection. This river system is heavily utilized for swimming, tubing, and canoeing. The river has a variety of water quality issues. Some reaches of the river were placed on Iowa's Impaired Waters List in 2004. Concentrations of the indicator bacteria *E. coli* exceeded state standards for body contact in recreational waters. Efforts to lower bacteria levels need information on the source(s) of the bacteria. In the Upper Iowa Watershed, this involves knowing where the water sources are. The presence of sinkholes and losing streams, which may contribute bacteria-laden runoff to the complex groundwater system, complicates the question of where the bacterial sources are located. Further, in all our watersheds, there are questions as to the biological sources of bacteria. Are they from human waste, livestock manure, or wildlife?

Tourism and Agriculture

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Northeast Iowa communities balance the economics of agriculture and tourism every day. On one side of the scale is a strong agricultural community with a rich heritage that includes hundreds of small livestock and dairy producers managing hay and pasture on steep, highly erodible slopes. On the other side of the scale is a burgeoning recreation and tourism industry that capitalizes on the beautiful and unique features found in the rolling hills of northeast Iowa and the coldwater fisheries and streams that flow through them. The marriage of these two industries creates a balanced, diverse economy, but it also creates an environment for conflict when one industry tries to dominate the resources or when shifts in one industry negatively impact the other.

Trout Fishing

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Trout fishing is a major economic force in northeast Iowa. It is estimated that angler expenditures for all Iowa coldwater trout fisheries total $13.9 million per year. The American Sportfishing Association's report "Sportfishing in America" indicated the retail sales related to all fishing in Iowa was $356 million and total economic output from these sales was $728 million.

All of Iowa's 105 trout streams are located in 10 counties in the northeastern part of the state. Trout have a water temperature requirement that restricts their distribution in Iowa. In general, trout cannot survive in water greater than 75 degrees. Most Iowa waters will reach maximum summer water temperature of greater than 80 degrees. The only waters that stay cold enough during the summer to support trout are the spring-fed streams that drain from the karst topography of northeast Iowa.

A coldwater trout stream is a very complex natural system. The quality of the stream is affected by the underground aquifer that forms the spring flow, the surface watershed that drains into the stream, the land use immediately along the stream, and the physical characteristics in the

Livestock is one of the many potential sources of *E. coli* bacteria in Iowa streams.

stream itself. High-quality trout streams result from successful partnerships between private landowners and conservation agencies in the management of these natural resources.

During rainfall events, sinkhole-driven water source can be contaminated by heavy silt loads and high concentrations of nitrogen gas. These runoff events cause severe fish mortality and health problems, and fish production and efficiency are greatly impacted. Problems with fish health are still directly related to runoff events and necessitate costly treatments to minimize disease outbreaks. It is apparent that additional improvements in the watershed will have a positive impact on fish health.

Landfills – Solid Waste in Karst

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The Iowa Department of Natural Resources regulates landfills through the solid waste program. Landfills are tracked from the initial site selection through approval of the engineer's site plans, construction of base works, day-to-day operations, final closure, and the 30-year post-closure monitoring and maintenance.

The DNR's Solid Waste Section gives initial site approval, approves plans, and monitors reports that the landfill operators and responsible officials are required to submit. The reports include water monitoring, gas monitoring, and engineer inspections.

The DNR's Field Office located in Manchester inspects the site on a periodic basis for compliance with the solid waste regulations and to offer operator assistance. The Field Office also maintains a working relationship with the landfill personnel so they are aware that assistance from the DNR is available. The Field Office also works closely with the Solid Waste Section to insure that any concerns noted in any of the reports are properly addressed.

Although not a stop on this trip, the Winneshiek County landfill lies within a few miles of some of the most karst-affected areas in the state. How can a landfill be in such a setting? Relatively subtle changes in the underlying geology occur in the landfill area. Here, more slowly permeable shale and shaley carbonate rocks of the Maquoketa Formation overlie the Galena Limestone. The Maquoketa rocks are less prone to fracturing and karst formation, although the lowermost part of the formation does exhibit some sinkholes. Also, there is a somewhat greater thickness of glacial deposits. Taken together, these deposits provide suitable materials for the landfill cells.

The Winneshiek County Sanitary Landfill is a regional landfill serving the counties of Winneshiek, Howard, and Clayton, the municipality of Postville, and Fillmore County in Minnesota. The population served by the Winneshiek County Sanitary Landfill is approximately 63,000.

It is estimated that the remaining life of this landfill is 11 years (2019). When the landfill is closed the Winneshiek County Area Solid Waste Agency is required to monitor and maintain the site for the following 30 years. The items that will be monitored include methane gas production, settlement, groundwater, storm water runoff, leachate, fencing, vegetation, building maintenance, and erosion. Closure and post-closure costs at this site are included in the tipping fee that the current landfill customers are paying.

Groundwater monitoring is required at all Municipal Solid Waste Landfills. Monitoring wells are placed and designed based on the "hydrogeologic investigation" that was done for each landfill. A range of parameters are measured depending upon well position and site history. In 2004, a review of annual monitoring reports from landfills was conducted by the DNR-Solid Waste and Geological Survey staff. At that time, there were 14 monitoring wells in use at the Winneshiek landfill. Wells monitor both the "top of the water table" within the unconsolidated deposits, and groundwater from the underlying bedrock. Two locations on Trout River are also monitored, as the stream passes close to the landfill and loses water into the Galena Limestone downstream to the north. While some monitoring wells have detected indications of landfill leachate in the shallow geologic materials, concentrations have not been significantly above background, and no upward trends were visually identified in the monitoring data. The review included a recommendation for better monitoring of the deeper zones, given the relatively vulnerable nature of the underlying aquifers. Stream sampling has shown minor contamination in Trout River. The landfill operates a leachate control/recirculation system which is likely helping to limit leachate movement.

Trout River is a small coldwater stream that originates 2 miles south of the Winneshiek County landfill. As the stream flows north toward its confluence with the Upper Iowa River, it is adjacent to the east edge of the landfill site. Downstream of the landfill Trout River is a losing stream and goes completely dry in one segment during most summers. This stream has been stocked with four-inch fingerling brook trout yearly since 2000. Brook trout are the trout that are native to Iowa and the trout species that is the most intolerant of warm water temperatures and pollution. These trout have survived and flourished in the section of Trout River on the landfill property. Recent fishery surveys have shown good numbers of brook trout present with fish up to 14 inches in length. In the case of the Winneshiek County Landfill, a managed brook trout stream and a landfill are compatible uses for the same piece of property.

Wastewater and Water Quality

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Iowa has a little over 1,500 facilities covered under individual "National Pollutant Discharge Elimination System" (NPDES) permits. Of those, about 800 are municipal facilities, 365 are industrial facilities, 280 are semi-public facilities (such as mobile home parks), and there are about 80 other miscellaneous facilities with permits (water treatment plants, land application facilities, and industrial stormwater). In addition, there are three stormwater general permits that cover a total of more than 6,000 active sites, and one general permit for over 400 rock and sand-and-gravel mining operations.

The Department of Natural Resources regulates wastewater facilities through the National Pollution Discharge Elimination System (NPDES) permitting and inspection process. Plans for wastewater plants, beginning with site location separation distances, were submitted to the department and separation distances were verified in the field. The final plans were reviewed and approved by DNR engineers prior to construction. Plants will be monitored by the owners, who will operate the plant and submit periodic reports to the department. The plant will also be monitored by the DNR's Field Office in Manchester which will conduct periodic inspections of the plant, monitor the receiving streams, and respond to concerns from the public.

Animal Feeding Operations in Karst

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Within the outcrop belt of the Galena Limestone, the Allamakee County Soil Survey shows more than 1,000 sinkholes in one 36-square-mile township, or about one mapped sinkhole every 20 acres. The sinkholes here aren't all mapped; in places the soil survey stopped trying to map individual sinkholes and created a soil mapping unit that is described as containing "sinkholes too numerous to map."

Senate File 2293 banned confinement structures within 1,000 feet of "known" sinkholes. Much of the soil mapping was carried out 20 or more years ago. DNR's Geological and Water Survey, the Northeast Iowa RC&D, and other partners are mapping sinkholes in the area to improve and update our knowledge of their locations and characteristics.

In Ludlow Township, Allamakee County, and adjacent areas, over 75% of the land is within 1,000 feet of known sinkholes. Sinkholes are present within 200 feet of certain farm's animal feeding operation (AFO) structures.

The Prairie du Chien dolomite forms an important statewide aquifer. Wells as far southwest as the Des Moines area are drilled into the Prairie du Chien and the underlying Jordan Sandstone, where these rocks lie more than 1,500 feet below the surface. The Prairie du Chien typically exhibits solutionally enlarged openings, but rarely sinkholes. The number of Prairie du Chien sinkholes mapped by the county soil survey are miniscule compared to those mapped on the Galena Limestone. However, subsurface voids do occur in the Prairie du Chien, even though there are no sinkholes to help indicate their presence. Unanticipated voids found to be present affect manure operators in this area.

Forestry Planting – Alternative Land Use

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Iowa Department of Natural Resources

The wood products industry in northeast Iowa is booming. The region's climate and great soils combine to produce some of the highest quality fine hardwoods in the world. Buyers travel from all over to northeast Iowa because we are viewed as growing some of the best quality black walnut anywhere. In a recent timber harvest in Delaware County, a 2.5 acre stand of red oak, white oak, and black walnut sold for $29,200. The 140-year-old trees were quite large, but were otherwise of typical quality for the area. The stand went virtually unmanaged from the time squirrels planted the seeds. The stand averaged $83.43 of net return per acre per year with very small input costs including no property taxes.

The water quality benefits from timber production are obvious when compared with row crop production. Storm runoff is minimal with most of the rain being intercepted by the forest canopy and absorbed in the soil. Pollution from pesticides and nutrients is a tiny fraction of that from row crop production. Woodlands also provide clean air, wildlife habitat, carbon storage, and recreation. Timber production in northeast Iowa is a terrific conservation alternative. Policy makers and natural resource agencies should promote timber production on our most highly erodible farm ground.

Pasture-based Dairies – Alternative Land Use

James Ranum
Natural Resources Conservation Service

A pasture-based dairy will have around one acre of intensively managed pasture per cow. They may have another half-acre of hay where they take one or two cuttings, then graze. They may purchase their stored feed, creating a market for other producers. These well managed pastures will be a dense sward which practically eliminates soil erosion and greatly reduces surface runoff. On a 10% slope, a 3-inch rain in 90 minutes will only have 10% runoff vs. 50% to 60% for cropland or overgrazed pastures. The reduced runoff decreases the chance of nutrients and pesticides reaching sinkholes. Another water quality advantage is the reduced amount of fertilizers and pesticides applied to the land. A 100-cow dairy would have 100 acres of pasture receiving 0 to 100 lbs/acre of nitrogen and minimal phosphorus compared to row crop that would be heavily fertilized. Pesticides are only spot applied as needed, as opposed to broadcast applications for cropland. Another advantage can be the reduced amount of manure storage needed. Seasonal systems can have the cows on pasture from seven to twelve months spreading their own manure. Cropland can be converted to long-term pasture for less than $100 per acre making this system the most cost effective method of erosion control.

The local community receives considerable economic benefits from dairies, and new operations should be a priority. Grass-based systems are a viable entry avenue for beginning farmers. Two hundred acres could support a 100-cow dairy. Low costs and labor efficiency are the keys to success. An efficient milking parlor is essential and should be considered as a cost shareable practice in the same manner as a manure storage structure.

GROUNDWATER RESOURCES

An Overview of Water Use Permitting in Iowa

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In order to obtain and use groundwater in Iowa, state law requires a water allocation permit. This is required by municipalities, industries, agricultural and golf course irrigators, farms, agribusinesses, and any other user of over 25,000 gallons of water per day. These permits are required under Iowa laws that originated during the droughts of the 1950s. The stated purpose of the law is to "...assure that the water resources of the state be put to beneficial use to the fullest extent possible, that the waste or unreasonable use, or unreasonable methods of use of water be prevented, and that the conservation and protection of water resources be required with the view to their reasonable and beneficial use of the people."

The law requires permitting the use of all water in quantities over 25,000 gallons per day. It applies to the use of water from streams and reservoirs, gravel pits, quarries, and other sources. The injection of water into the ground, for disposal of water used in heat pumps, or for other purposes, is also regulated, but in practice, this is done by EPA.

The term of these permits is 10 years; in some circumstances, they are issued for a shorter period.

Authority/Mission

The authority for regulating water allocation arises from the mission the State has to protect public health and welfare. The use of water by one person can affect other nearby water users and the general public. Iowa's water allocation program attempts to sort through various competing uses, by doing the following:

1. An administrative procedure to resolve water use conflicts.
2. A permitting program to ensure consistency in decisions on the use of water.
3. Provisions for public involvement in issuing water allocation permits and in general establishing water-use policies.

All waters, surface and groundwater, are "public waters and public wealth" of Iowa citizens. Iowa statute provides an allocation system based on the concept of "beneficial use." The key points are:

1. Water resources are to be put to beneficial use to the fullest extent of which they're capable.
2. Waste, unreasonable use, and unreasonable methods of water use are prevented.
3. Water conservation is expected.
4. Established average minimum instream flows are protected.

Usual Procedures

Application for a water use permit is made on a 6-page form supplied by the Iowa DNR, last updated in 2005 and available on our web-site. The completed forms must be accompanied by a $25 fee and a map showing the location of the proposed well must be returned to the DNR. The location of the land upon which the water is to be used must also be shown on the map. The applicant should include a description of the exact manner in which they intend to use the water for which a permit is requested.

When DNR receives an application, it is initially screened to determine whether there is sufficient information provided to process the application. In the case of groundwater, the Iowa Administrative Code requires that available hydrogeological information be reviewed to determine what, if any, further information the applicant must provide. The IAC specifically states that additional information, over and above that requested by the application form, may be required. The application is not complete without this additional information; the applicant must supply it in order to obtain the water-use permit.

If DNR is unable to identify the aquifer from which withdrawals are proposed, the applicant is required to assist in determining this. They're further required to provide information that will assist DNR to predict the effects of the withdrawals upon the aquifer and upon neighboring water supplies. DNR may require a survey of surrounding wells (usually within 1-2 mile radius), to determine the probability of serious well interference problems.

Water-quality data, if available, though not specifically mentioned in the rules, is helpful in determining the aquifer that is being tapped. It should be supplied by the applicant if it is available and may be requested by DNR. In practice, DNR relies heavily on the expertise of the Iowa

Geological and Water Survey (IGWS) in Iowa City to evaluate data in ambiguous cases.

Test drilling may be required, and if done, the well logs must be submitted to IGWS in Iowa City. Yield tests may be needed, and even controlled aquifer tests using the formal Theis method are on occasion necessary. These are done under the supervision of a registered well driller or a licensed professional engineer. DNR may require monitoring well installation for the aquifer test.

For wells in a karst-type hydrogeologic setting, special procedures are suggested. Where possible, the Department will ask the applicant to conduct some form of hydrogeologic mapping. Hydrogeologic mapping has a high degree of accuracy and produces an easily defensible wellhead protection area. This method maps physical flow boundaries using a combination of geologic, geomorphic, and geophysical methods. To determine the appropriate flow boundaries, studies of the aquifer are undertaken to identify varying rock characteristics, the extent and thickness of unconfined aquifers, groundwater drainage divides, and groundwater and surface water basin delineation.

This method can be used to delineate wellhead protection aquifers whose flow boundaries are close to the surface, such as glacial and alluvial aquifers and those aquifers exhibiting different physical properties in different directions, such as fractured bedrock and karst. This delineation technique requires technical expertise in the geological sciences. Hydrogeologic mapping may prove expensive if sufficient hydrogeologic data does not exist and field investigations are necessary. New karst wells will, however, require hydrogeologic mapping with associated field verification before a final permit is issued.

After all the necessary supporting information is received, a summary report of the application is written containing recommendations to award or deny the permit. It describes the hydrogeologic context of the proposed withdrawal, the anticipated effects of the proposed withdrawals of groundwater, and indicates whether verified well interference has been found. The reasons for the inclusion of non-standard permit conditions are indicated in the summary report.

Community water tower in Colesburg, Iowa.

Upon completion of the summary report, DNR publishes a notice of its intent to award a permit. The Iowa Administrative Code allows 20 days for the public to request a copy of the summary report and to submit comments. The comment period may be extended for cause.

At the end of the notice period, DNR considers all comments and if necessary revises the summary report. The initial decision is then issued, as either a Water Use Permit or a disapproval of the application. Complete disapprovals are very rare. In many cases, though, special conditions are included in the permit. In others, the rates of withdrawal, and the total annual amount of withdrawals, may be reduced from the rates and amounts requested to facilitate wise and beneficial use of the water resource. Copies of the initial decision are mailed to the applicant, all who provided comments, and any others who request a copy.

FIELD TRIP STOPS

(See inside back cover for map of Field Trip Stops.)

STOP 1.

Guttenberg scenic overlooks

There are two Mississippi River scenic overlooks at Guttenberg: south and north. The south overlook, while stratigraphically important, will be bypassed on this trip because the focus of this trip is karst-related issues. Besides which, we're on a tight schedule!

South overlook

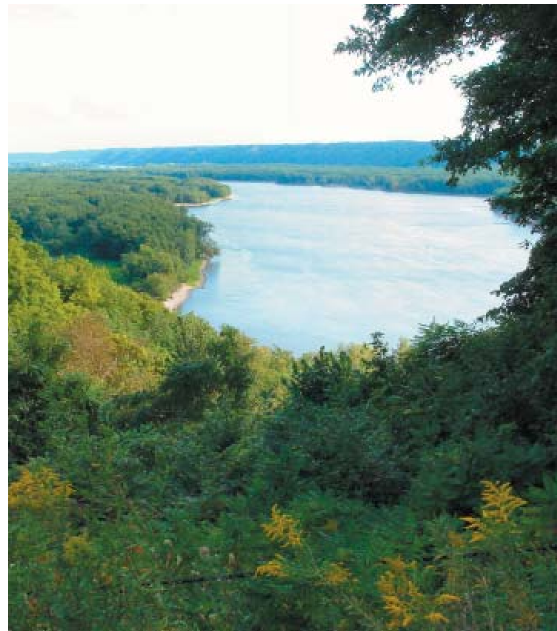
from Delgado, David J., ed., Ordovician Galena Group of the Upper Mississippi Valley – Deposition, Diagenesis, and Paleoecology, Guidebook for the 13th Annual Field Conference September 30 – October 2, 1983, Great Lakes Section Society of Economic Paleontologists and Mineralogists, Stop 3, p. R16 – R27.

"This magnificent road cut, constructed in 1975, is the most nearly complete exposure of the Galena Group. Parts of the Decorah and Dubuque formations, and the entire Dunleith and Wise Lake formations are exposed without break, with road level access to the Dunleith and lower Wise Lake. Upper Wise Lake and Dubuque strata must be reached with ladders but can be examined by intrepid sedimentologists with sufficient motivation. This cut illustrates most of the characteristics and sedimentological problems associated with the Galena Group."

North overlook

Paul VanDorpe
Iowa Department of Natural Resources
Iowa Geological and Water Survey

While enjoying the colorful view of islands, sloughs, and Mississippi River vehicular traffic, keep in mind that you're looking at the top of about 350 feet of alluvium. That amount of down-cutting, below the river level you see before you, is approximately the same as the distance from the river level to where we're standing, perhaps a bit more. That's a lot of missing rock! Accompanying down-cutting are changes in base level, which, of course, affected solutional karst and cave development across the Paleozoic Plateau. So enjoy the view of the mighty "Ole Man River," 'cause he's had a profound influence on what you're going to see today.



Scenic overlook of the Mississippi River at Guttenberg.

Additional information about this area:

Sinkhole Development

Bob Libra
Iowa Department of Natural Resources
Iowa Geological and Water Survey

Percolating soil water is typically acidic and therefore can dissolve carbonate rocks such as limestone. When near surface fractures and cracks are dissolved into larger voids, the overlying glacial soils may no longer have the strength to bridge the void and will slowly begin to slump downward. The process of dissolving out voids takes thousands to tens of thousands of years. The failure of surface soils over the void is a much shorter process. It can occur over months to years, or it can occur instantaneously. Figure 1-1 is a schematic depiction of sinkhole

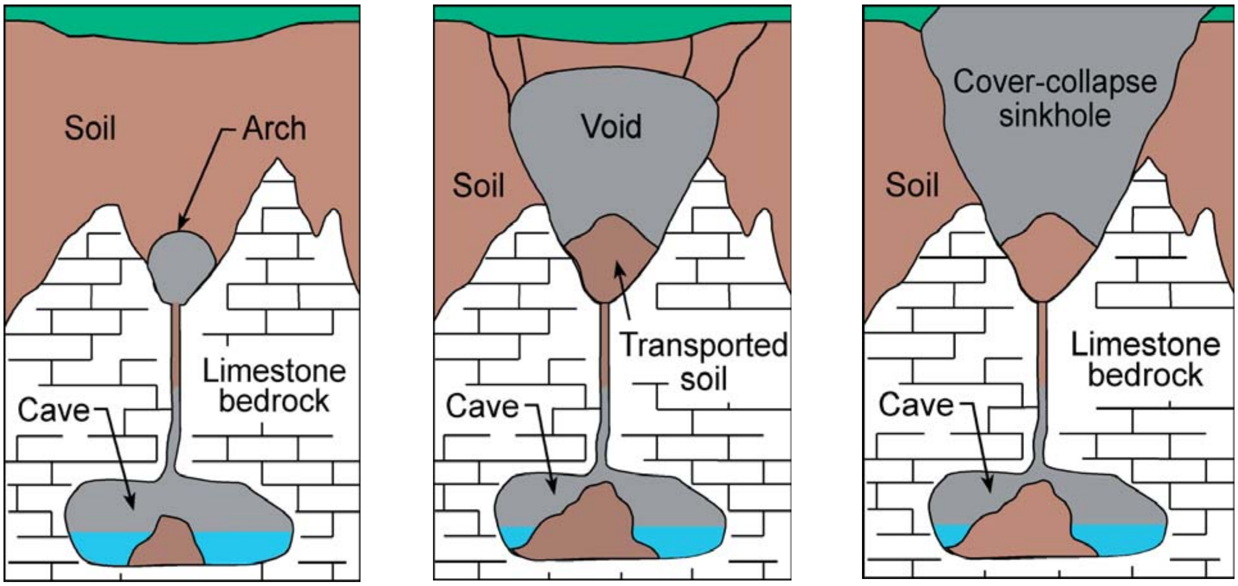


Figure 1-1. Diagram showing steps in sinkhole formation.

formation. Saturated glacial soils will collapse into voids more readily than dry soils. They can flow and ooze into relatively small openings. For this reason, seepage from earthen structures such as lagoons and farm ponds may accelerate collapse, as the seepage keeps the underlying soils permanently saturated. This was the unfortunate case of the Garnavillo sewage lagoon in Clayton County in the early 1980s.

The Garnavillo lagoon system was built as a passive three-cell system, a design easy for the small community to maintain and operate. The lagoon cell shown in Figure 1-2 was built into a hillside, with the floor of the lagoon cut to within 5 feet of the Galena Limestone. As the lagoon system was approaching completion, stormwater was directed into this cell to test the seal of the liner, filling the cell to roughly a 1-2 foot depth. This occurred on a Friday afternoon. By Monday morning, a sinkhole had formed and the lagoon was dry (Figures 1-2 and 1-3). Over the coming months, a line of small depressions formed in the cell. Ultimately, this cell and a second were abandoned. The third cell, which overlies a thicker cover of glacial materials, was converted to an aerated system. This was a less simple design than the city had planned on, but it was a retrofit that would work.

In the more typical setting in the countryside, when a sinkhole forms, it becomes the new low spot on the ground. Runoff will flow downhill into the sinkhole, and typically cause headward erosion and the establishment of a drainage way leading to the sink. Eventually the sinkhole may form its own watershed. Other sinkholes form in streams beds and are referred to more commonly as stream sinks or just as a losing stream point. These sinkholes come with their own watershed.

Since sinkholes take surface drainage, they receive inputs of sediment as well. Often, they will become "plugged" with sediment, and have no obvious opening. However, since they will continue to receive drainage, they will often plug and unplug repeatedly. This can happen on time-scales of months, years, or decades. Sinkholes have been known to "form" and expose decades-old farm equipment that was dumped in a former sinkhole, at that location, in the past.

Along with sediment, sinkholes may receive runoff containing relatively high levels of herbicides, phosphorus, bacteria, ammonia nitrogen, and organic matter. This water is delivered into

Figure 1-2. City of Garnavillo lagoon after sinkhole failure.

Figure 1-3. Close-up of sinkhole at City of Garnavillo lagoon.

the groundwater system with little or no filtration and may travel quickly through the fractured and karsted rocks. The water may impact wells or recharge the coldwater streams found in the valleys below.

As suggested above, sinkholes are far too convenient locations for waste disposal. Trash, old equipment, white goods, cars, and pesticide cans have been disposed of in sinkholes in the past. While this practice is no longer as common as it used to be, some dumping still occurs. The Groundwater Protection Act of 1987 provided funds for a number of sinkhole cleanups. As you can imagine, removing large quantities of trash and old equipment, mixed with sediment and rock, is not an easy or inexpensive task.

STOP 2.

Allamakee County Park near Rossville

The Rossville County Park is located on the drainage divide between the Yellow River to the south and Paint Creek to the north. State Highway 76 follows the divide southeast to the Mississippi River, a distance of roughly 10 miles. The valleys of Paint Creek and the Yellow River are cut through the Galena Limestone and into the St. Peter Sandstone and older rocks. But on the divide, Galena Limestone is present much of the way to the Mississippi River, and sinkholes are very common in the Rossville area (see Figure 2-1). We will view and enter a prominent sinkhole in the wooded part of the park, and see several depressions in the ground where sinkholes appear to be forming…or re-forming.

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Thank You.

Additional information about this area:

Glenwood Cave

Michael Bounk
Iowa Department of Natural Resources
Iowa Geological and Water Survey

Glenwood Cave is developed near the base of the Dunleith Fm. of Ordovician age. The entrance at the end of the box canyon is a wet weather overflow. Figure 2-2 is an incomplete map of Glenwood Cave (Iowa Grotto, 1992) overlain on the USGS 7.5' quadrangle.

During dry weather, this entrance leads downward about 10' to water level. This wet passage can be followed for about 1,600 feet to a "T" intersection with a stream that flows from left to right. This stream sumps (goes completely under water) about 30 ft. to the right of the "T." It is believed to resurge at a spring located in the valley to the north of here, on the west side of the north-south road. To the left of the "T," the

Figure 2-1. Color infrared photo of the Rossville area showing sinkholes (yellow circles).

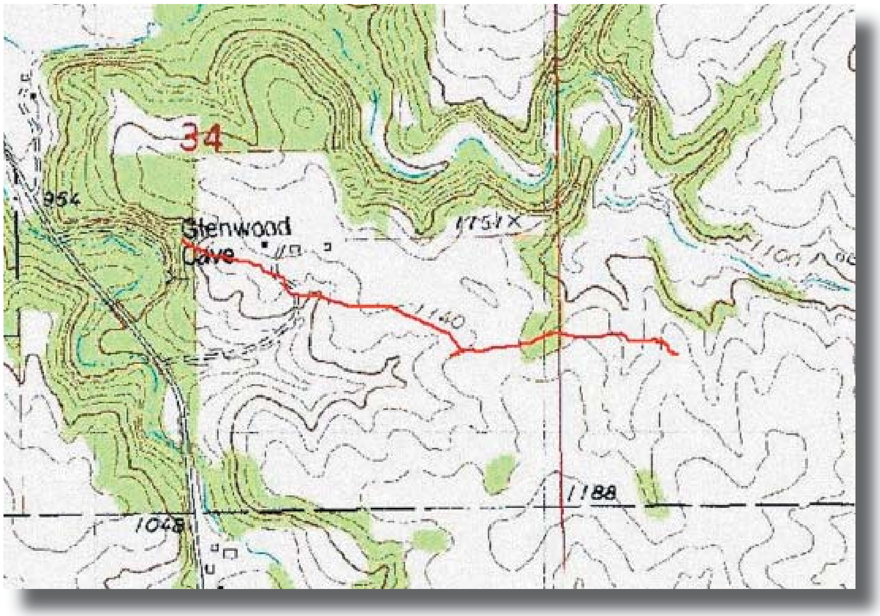


Figure 2-2. Mapped extent (in red) of Glenwood Cave.

passage continues for about 1,100 ft. to where the stream comes out of an un-enterable slot. A short distance before this, there is a flowstone climb up to an upper level. Total passage length for this cave is estimated to be about 1 mile. At one time the passage at the end of which the entrance is located extended at least to the end of the box canyon. It has since retreated due to headward collapse of the canyon. The collapsed rock prevents the stream from flowing out here except during higher water levels.

WARNING: This entrance and several hundred feet of passage can be sumped for months at a time; therefore, it should only be entered, beyond the beginning of the water, during dry conditions, when rain is not expected, and in the company of experienced wetsuit cavers. A full wetsuit is required.

This cave was shown as a commercial cave during the summers from 1931-1935. The tour was by boat and cost 25 cents a person. The boats which held a guide and two passengers were poled by the guide. Illumination was by flashlight (Hedges, 1974).

Glenwood Spring and Cave is an easily accessible example of the several known stream caves which can or could be entered through their springs. Other springs, in the Galena Group, which are known or believed to be fed by solutional caves, include Dunning Spring in Decorah, and Big Spring near Elkader. These and other springs and related solutional conduits are important components in the hydrology of the Galena Group in its outcrop area in northeast Iowa. Understanding the factors controlling the development of this karst is important in protecting this source of water from contamination by both point source and nonpoint sources of pollution.

This karst is also important as the site of deposition of speleothems. The oxygen isotope and carbon 14 analyses of sufficient stalagmites can provide us with a chronology of the mean annual temperature, of the area where the cave is located, through time.

References

Hedges, 1974, Intercom, vol. 10, issue 1, National Speleological Society Convention Guidebook, p. 117.

Iowa Grotto, 1992, Iowa Cave Map Book, vol. 1, p. 142.

STOP 3.

Skyline Quarry – The View from Inside an Aquifer

Bob Libra and Robert M. McKay
Iowa Department of Natural Resources
Iowa Geological and Water Survey

STOP! If you are not wearing a hard hat, you must remain on the bus.

Skyline Quarry is owned and operated by Bruening Rock Products, Inc. of Decorah. The quarry floor is about 102 feet above the top of the underlying Decorah Shale; about 70 feet of Galena limestone is mined here. The quarry section is essentially in the middle of the 235-foot thick limestone portion of the Galena Group. The lower 35 feet of the section is within the upper part of the Dunleith Formation. It is composed of dense limestone with mudstone to packstone depositional textures and contains numerous chert nodule horizons. Distinctive multimillimeter-thick, dark-colored surfaces, referred to as hardgrounds or corrosion surfaces, are common. These are features formed on the seafloor during times of sediment starvation and possible water chemistry change. The overlying Wise Lake Formation comprises the upper half of the quarry section. It contains minor chert in the lower few feet but is mostly chert-free, tends to be thicker bedded, and has a well developed bioturbated depositional fabric. The upper 10 feet of Wise Lake is considered suitable for concrete aggregate.

As you enter the quarry, you are in essence "stepping into" the Galena aquifer. Visible in the quarry walls are nearly vertical fractures and nearly horizontal bedding planes that have been solutionally enlarged to varying degrees (Figure 3-1). These are the pathways that groundwater flows through. The rock "matrix" itself has little permeability and transmits little groundwater. As the groundwater is forced to flow through only a small percentage of the rock, it moves relatively fast. Where large, open, cavernous conduits are present, dye traces have shown flow rates ranging from miles per hour following rainstorms to thousands of feet per day during dry periods. The larger voids act as drains for the aquifer, and groundwater within smaller openings and fractures follows the path of least resistance, moving towards the larger voids. Geologists spend much time explaining that groundwater isn't contained in underground rivers. However, in karst aquifers the underground river analogy isn't that far off; major conduits are like the main stem of a river, and the smaller voids and fractures are like a three-dimensional web of tributaries. This is in contrast to sand, gravel, and sandstone aquifers, where groundwater movement is more uniform throughout the aquifer and much slower as it works its way between the individual sand and gravel particles.

At the top of the quarry walls, only a thin cover of unconsolidated soils is present. Beneath this thin soil mantle, fractures widen (Figure 3-2). This is the result of void formation near the top of the bedrock, a common occurrence in karst that marks the first steps towards sinkhole formation. A larger sinkhole is also exposed in cross-section by the quarry walls (Figure 3-3). The combination of a thin soil cover that offers limited filtration and protection from any contamination in downward-percolating soil water, sinkholes which capture surface runoff and direct it into the aquifer, and essentially no removal of contaminants from the fast moving groundwater in the fractures results in common water-quality problems in the Galena aquifer. As this aquifer supplies much of the "baseflow" for area streams, any contamination is delivered to the streams as well.

Long-term groundwater monitoring has been conducted at Big Spring, which drains a 100-square-mile area underlain by the Galena Limestone in Clayton County. On average over 15,000 gallons per minute of groundwater discharges from Big Spring to the Turkey River. For comparison, this is a little over one-half of the average amount of water produced by the Des Moines Water Works. Land use in Big Spring's "groundwater-shed" is essentially all agricultural. Typically, 45-50% of the land is in corn production and 35-40% is used to raise alfalfa. Small dairy and hog operations are common. Concentrations of nitrate-N at Big Spring commonly are near the 10 mg/L U.S. EPA drinking water standard. Low levels of atrazine (0.1 to 1.0 ug/L) are typically present, along with 200 to 300 ug/L of phosphorus. Fecal bacteria levels are commonly in the hundreds to thousands of colonies/100 ml. Concentrations of phosphorus, bacteria, and herbicides are generally 1-2 orders of magnitude greater following major rainfall events. These data point out the vulnerability to contamination of this productive karst aquifer.

Additional information about this area:

Decorah Ice Cave

George E. Knudson and James Hedges
Luther College, Decorah, Iowa

The Ice Cave at Decorah, Iowa, is the largest known glacière in North America east of the Black Hills and the subject of much international speculation. A satisfactory theory for ice formation in late spring is that cold air circulates freely through the cave in winter, cooling the rocks to below freezing. Warmed air ascends through fissures in the roof. Thick layers of ice occur after a thaw of the bluff surface above. Since the mouth of the cave is higher than the ice chamber, cold air is trapped in the interior in the summer allowing ice to persist until August or September.

Figure 3-1. Skyline Quarry. Note vertical and horizontal fractures.

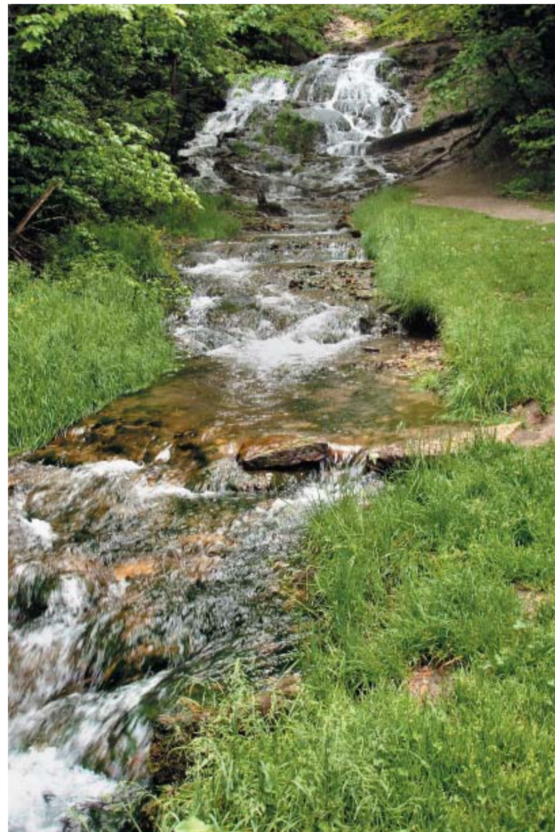
Figure 3-2. Skyline Quarry. Note widening of vertical fracture below soil horizon.

Figure 3-3. Skyline Quarry. Note sinkhole in cross section.

STOP 4. LUNCH

Dunning Spring Park – The Bottom of an Aquifer

Dunning Spring issues from near the base of the Galena aquifer. The much less permeable Decorah Shale - the confining bed "floor" for the aquifer - is near the land surface, forcing the water to discharge from the wall of the Upper Iowa River Valley. The result is the picturesque falls. The groundwater issuing from the spring is flowing through an open, cavernous conduit, formed by the solutional enlargement of fractures. Solutionally modified fractures and cracks are the most common characteristic of karst. The water from this (and most larger springs in the area) maintains a fairly constant temperature of about 45 degrees F most of the year. Exceptions occur after snowmelt or heavy rains when colder or warmer water rapidly enters the aquifer via sinkholes and losing streams. About 50 feet below our feet is the contact between the Decorah confining bed and the underlying St. Peter Sandstone.



Dunning Spring near Decorah in Winneshiek County, Iowa.

Additional information about the area between Stops 4 and 5:

Losing Streams

Bob Libra
Iowa Department of Natural Resources
Iowa Geological and Water Survey

Losing streams are defined by Iowa Code:

> "Losing streams" means streams which lose 30 percent or more of their flow during the seven-day, ten-year low stream flow periods to cracks and crevices of rock formations, sand and gravel deposits, or sinkholes in the streambed.

An additional part of the Code addresses losing streams this way:

> The *Escherichia coli (E. coli)* content of water which enters a sinkhole or losing stream segment, regardless of the water body's designated use, shall not exceed a Geometric Mean value of 126 organisms/100 ml or a sample maximum value of 235 organisms/100 ml. No new wastewater discharges will be allowed on watercourses which directly or indirectly enter sinkholes or losing stream segments.

Iowa streams, whether losing or not, commonly exceed these bacteria levels. At present, new discharges to losing streams are not allowed, regardless of the level of treatment. Streams that lose water to fractured rocks and sinkholes are typically considered greater environmental and public health threats than those that lose water to sand and gravel aquifers, in that the lost surface drainage moves much faster and farther in fractured rock, and can appear in hard-to-predict places. The fractured rock situations also offers little or no filtration of contaminants.

Losing streams are not uncommon in northeast Iowa and other parts of the state that are underlain by shallow permeable bedrock. Some streams lose water into their underlying sand and gravel deposits, even when no shallow rock or karst is involved. Losing streams are complex to characterize, as the losing aspect may vary seasonally, and the locations where water goes into the ground often changes through the year with flow conditions. Efforts to map losing stream reaches, sinkholes, and springs are underway in northeast Iowa, including detailed geologic mapping to further our ability to predict where such features are most likely to occur.

The Yellow River in this area provides a larger example of a losing stream. The Yellow River heads on the slowly permeable Maquoketa Formation, and as its valley cuts into the karstic Galena Limestone, the river loses water into the rock. In the drier parts of most years, the Yellow River has no flow as it crosses the Galena Limestone, although it is fed by an 80-square-mile watershed. Further downstream, the valley cuts into the Decorah Shale "floor" below the Galena. Where this occurs, numerous springs discharge groundwater into the Yellow River, and its flow from that point on downstream is typically perennial.

Hecker Creek is a tributary of the Yellow River. The creek heads near Postville and joins the Yellow about 3 miles north. The uppermost part of the watershed is underlain by bedrock of the relatively slowly permeable Maquoketa Formation, and a relatively thick cover of glacial deposits. As the stream flows north, its valley cuts into the underlying karstic Galena Limestone. Where the stream runs over the fractured Galena bedrock, it "loses water" into the rock. During relatively dry conditions, the entire flow disappears into the rock.

Postville straddles the drainage divide between the Yellow and Turkey rivers. Postville is underlain by 40 to 100 feet of unconsolidated glacial materials which rest on the Maquoketa Formation. The karst-forming Galena Limestone is nowhere to be seen, and in fact lies about 200 feet deep. Between Postville and the Yellow River, Hecker Creek cuts downward towards the upward-sloping Galena Limestone. Where the two meet, the creek begins to lose water.

STOP 5.

Roberts Creek Sinkhole

Gary Siegwarth, Fisheries Bureau
Iowa Department of Natural Resources

The Roberts Creek sinkhole, located 2 miles west of Farmersburg, can be a highly visible example of a losing stream. During low flows, the direct opening allows the entire streamflow to cascade and disappear into the opening (Figure 5-1). For several consecutive years this sink caused nearly four miles of Roberts Creek to go completely dry. During higher flows, the sink becomes submerged and is barely visible. The original 1856 land survey map for Clayton County documents Roberts Creek ending abruptly and labeled as "Sink" in Section 15 on the accompanying map (Figure 5-2). More recent maps showed Roberts Creek connected to Poney Creek with no mention of the losing portion. The current sinkhole opening is located in Section 14, several miles downstream from the originally documented opening.

In 2005, a dye-trace was conducted that confirmed the direct connection of Roberts Creek to Big Spring. The sinkhole is 5.8 straight line miles ("as the crow flies") from Big Spring and it took nearly 3 days for the dye to be detected at the spring during low flows. However, flow bypass manipulations that temporarily diverted flows around the opening during this same low-flow period were detected in flow changes at the spring within several hours. The Roberts Creek connection is also the suspected origin of numerous non-trout fish species that show up in raceways at the trout hatchery.

Roberts Creek is currently listed as an impaired stream due to excessive nutrients that plague the stream. Due to the connection of this impaired stream to the Big Spring aquifer, there are water quality concerns at Big Spring because of the associated use of the spring for rearing trout. The direct connection of Roberts Creek is

Figure 5-1. Roberts Creek sinkhole. Note the large visible sinkhole that is taking the entire flow of Roberts Creek.

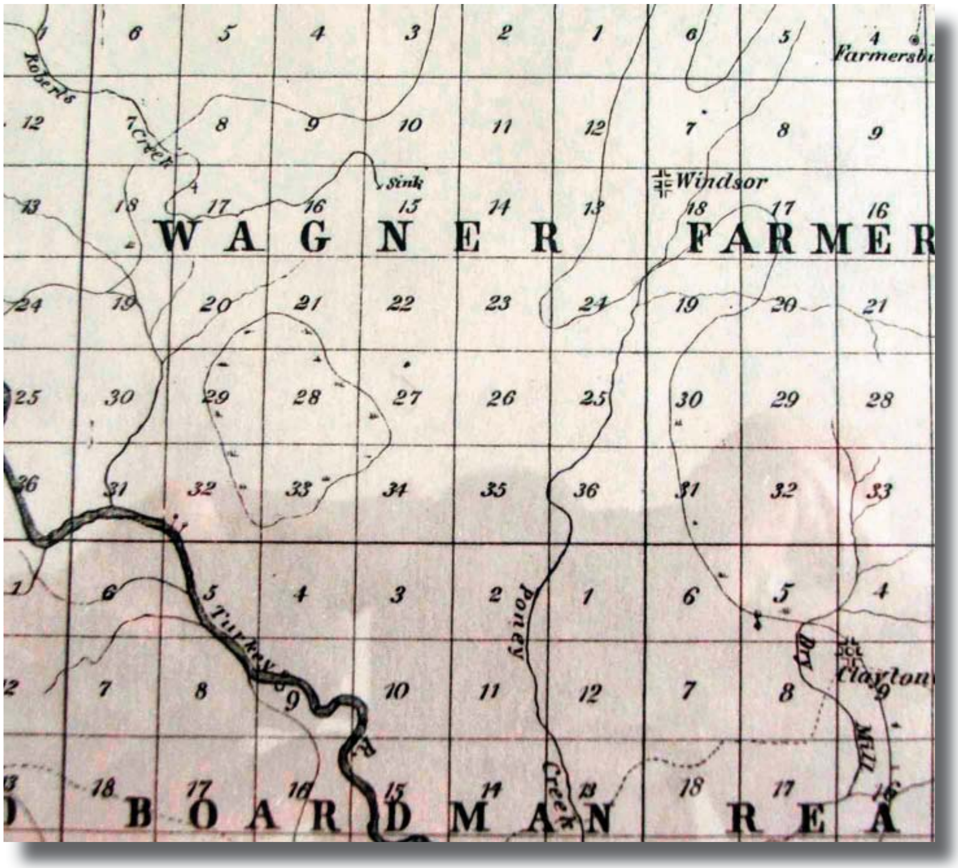


Figure 5-2. This original 1856 Land Survey Map shows an early documentation of the Roberts Creek Sink in northwest corner of Section 15, Wagner Township in Clayton County.

suspected to be causing excessive nutrient (as well as other unknown chemicals and contaminants) and sediment deposition problems at the hatchery during annual snowmelt and other high water events. There is also concern about the consequences of other "emerging contaminants" entering the Big Spring aquifer. Until these water quality concerns can be corrected, there is consideration of a plan to temporarily divert or partially block the known flow of Roberts Creek into the sinkhole.

Additional information about this area:

Results from the Big Spring Basin Water Quality Monitoring and Demonstration Projects

Robert D. Rowden, Huaibao Liu,
and Robert D. Libra
Iowa Geological and Water Survey,
Iowa Department of Natural Resources

Agricultural practices, hydrology, and water quality of the 267 km^2 Big Spring groundwater drainage basin in Clayton County, Iowa, have been monitored since 1981. Landuse is agricultural, dominated by corn and alfalfa production, along with numerous small livestock operations; nitrate-nitrogen (-N) and herbicides are the resulting contaminants in groundwater and surface water (Figure 5-3). The Ordovician Galena Group carbonate rocks comprise the main aquifer in the basin. Recharge to this shallow, moderately karsted aquifer is dominated by infiltration, augmented by sinkhole-captured runoff. Groundwater is discharged to the surface at Big Spring, where the quantity and quality of the discharge are monitored.

Monitoring has shown a three-fold increase in groundwater nitrate-N concentrations from the 1960s to the early 1980s, following a similar increase in nitrogen fertilizer applications. The nitrate-N discharged from the basin by groundwater and surface water typically is equivalent to over one-third of the nitrogen fertilizer applied, with larger losses and greater concentrations occurring during wetter years. Atrazine is present in the groundwater year round, however, contaminant concentrations in the groundwater respond directly to recharge events, and the unique chemical signatures of infiltration versus runoff recharge are detectable in the discharge from Big Spring.

Education and demonstration efforts have decreased pesticide use and have reduced nitrogen fertilizer application rates by one-third since 1981, while crop yields have been maintained. Relating declines in nitrogen and pesticide inputs to nitrate and pesticide concentrations at Big Spring is problematic. Annual recharge, as inferred by discharge from Big Spring, has varied five-fold during the monitoring period, overshadowing any water quality improvements resulting from incrementally decreased inputs.

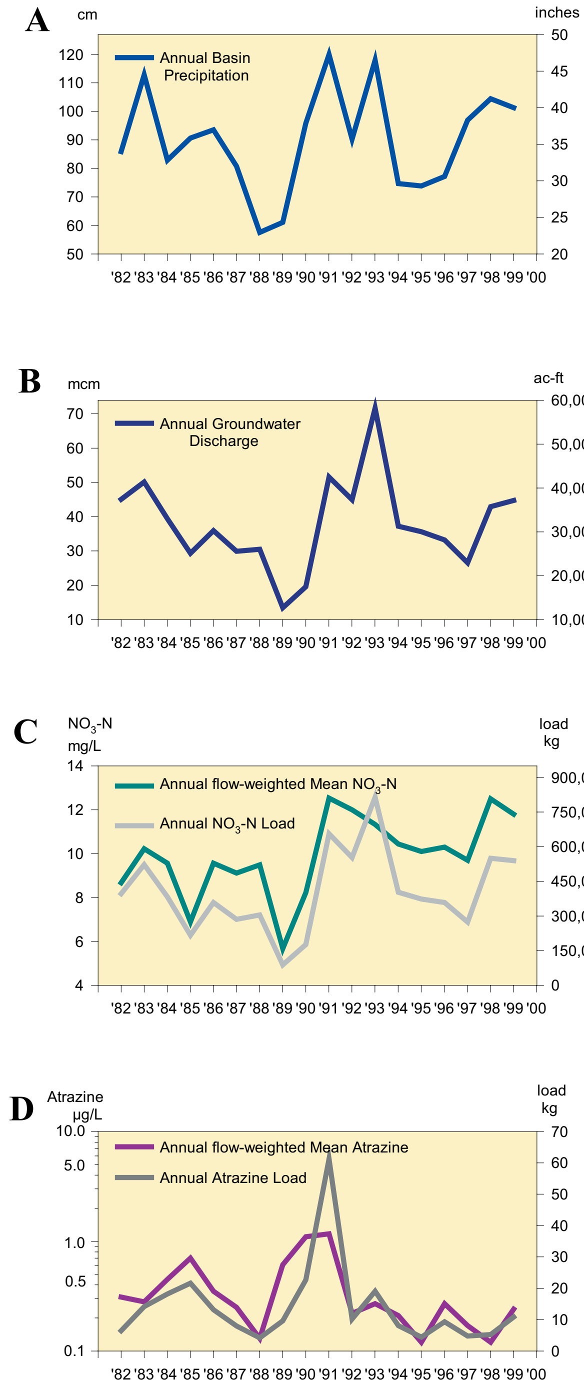


Figure 5-3. Summary of annual **A** – basin precipitation, **B** – groundwater discharge, **C** – flow-weighted mean nitrate-N concentrations and nitrogen loads, and **D** – flow-weighted mean atrazine concentrations and loads from Big Spring groundwater, water years 1982-1999.

STOP 6.

Chicken Ridge

Michael Bounk
Iowa Geological and Water Survey
Iowa Department of Natural Resources

This portion of the Silurian (Niagaran) escarpment affords spectacular views of the Turkey River valley to the north and the Volga River valley to the south. Much of the Niagaran escarpment in Iowa is characterized by a mechanical karst, the result of slippage and rotation of blocks of Silurian carbonates on the underlying Maquoketa Formation Brainard Shale. Possibly, solutional karst once was developed along the entire escarpment in conjunction with stream incision. As the caverns were destroyed by headward erosion, mechanical karst developed which diverted surface water rapidly downward to the Brainard Shale, thus preventing additional solutional karst. Thus, the present-day escarpment has little solutional karst of any size.

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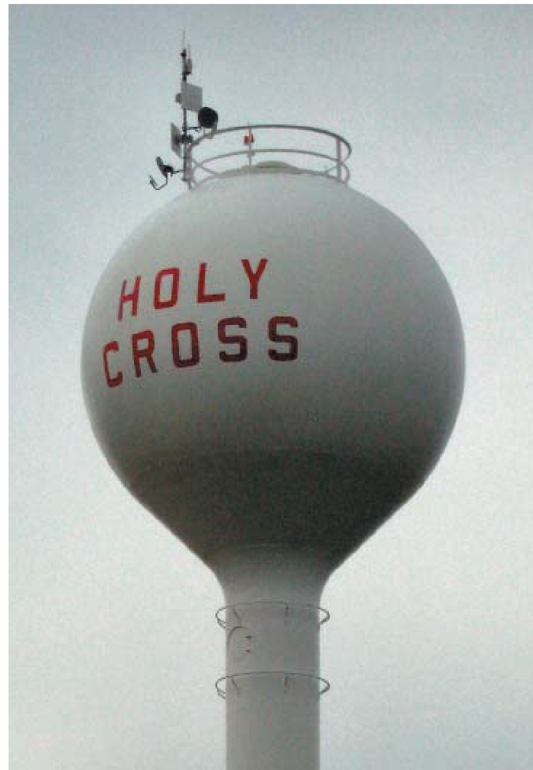
Additional information about this area:

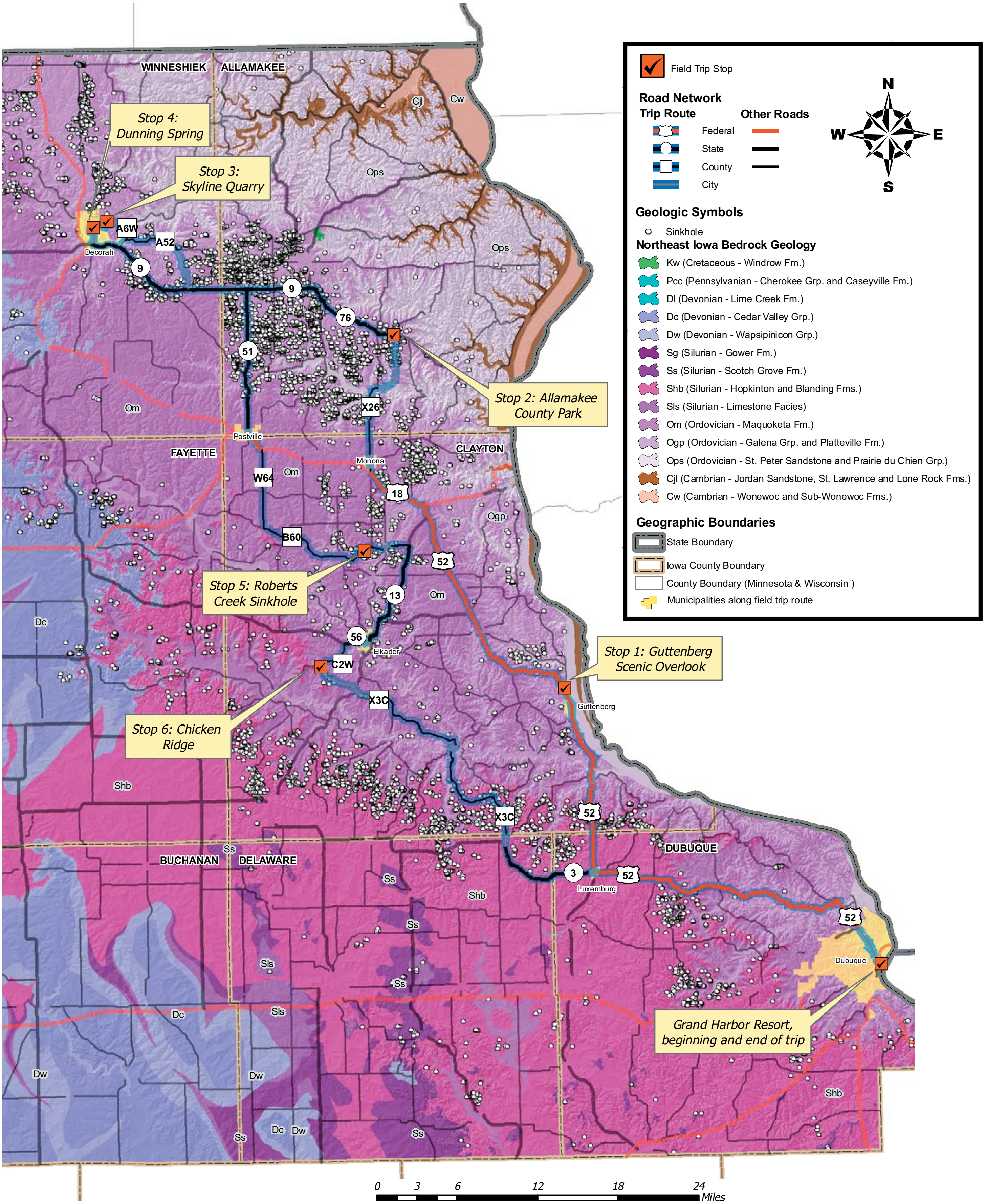
Drinking Water

Paul VanDorpe
Iowa Geological and Water Survey
Iowa Department of Natural Resources

Drinking water for northeast Iowa citizens is derived from Paleozoic aquifers: Devonian/Silurian; Ordovician above the St. Peter (i.e., Galena Group and, locally, Maquoketa Formation); Cambrian-Ordovician (Jordan) (i.e., St. Peter Sandstone, Prairie du Chein Group, Jordan Sandstone); and the Dresbach (i.e., Wenowoc Formation, Eau Clare Formation, and the Mt. Simon Sandstone). Alluvial, glacial drift, and buried-channel aquifers are available mostly southwest of the Paleozoic Plateau. There are no public water supplies that rely on surface water in this region.



Groundwater supplies are so prolific that some communities do not have municipal water supplies (e.g., Luxemburg, population 246). Other small communities readily rely upon Paleozoic Plateau bedrock aquifers for their drinking water (e.g., Holy Cross, population 339).



Map of Field Trip Stops

(Field trip route outlined in blue.)

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