BOARD OF REGENTS

Governing Iowa's Public Universities

MEMORANDUM

December 20, 2023

The Honorable Kim Reynolds
State Capitol
1007 East Grand Ave.
Des Moines, IA 50319

Mr. Charlie Smithson
Secretary of the Senate
State Capitol Building
Des Moines IA 50319

Ms. Meghan Nelson
Chief Clerk of the House
State Capitol Building
Des Moines IA 50319

Re: State Geologist Annual Report

Dear Governor Reynolds and Members of the Iowa General Assembly:

Pursuant to the 2022 Iowa Code §456.7, 2022 House File 2463 §108; 2022 Iowa Acts Ch. 1032 §108, enclosed is the State Geologist Annual Report for 2022-2023.

If you have any questions or need more information, please don't hesitate to contact me.

Sincerely,

Mark J. Braun

\Box Sync\Board of Regents Shared\BF\Legislative\2024 session\Reports\

Attachments

cc: Legislative Liaisons
Legislative Log

IOWA

The IGS Geode

ACTIVITIES OF THE IOWA GEOLOGICAL SURVEY, 2022–23

IN THIS ISSUE:

USING GEOPHYSICS TO IMAGE IOWA'S LEVEES

SOURCE WATER DELINEATIONS FOR IOWA COMMUNITIES

THE IGS' GROUNDWATER LEVEL NETWORK

COMPLETED GEOLOGIC MAPPING IN SOUTHEASTERN IOWA

AND MORE. . .

The IGS Geode

Activities of the
Iowa Geological Survey
2022–23

ON THE COVER: Autumnal colors at Wildcat Den State Park, captured by Aneta Goska. The cliff face is sandstone of the Pennsylvanian Cherokee Group (deposited approximately 310 million years ago). Within the sandstone crossbedding is preserved and provides evidence for the flow direction in the ancient river systems that deposited these sediments.

THE IGS MISSION: To collect, reposit, and interpret geologic and hydrogeologic data; to conduct foundational research; and to provide Iowans with the knowledge needed to effectively manage our natural resources for long-term sustainability and economic development.

THE IGS VISION: To be a nationally recognized leader in geologic and hydrogeologic sciences, building upon our rich scientific heritage and serving Iowans through research, education, and outreach.

EDITORS:
Alyssa M. Bancroft and Rosemary Tiwari

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From the State Geologist

Another year has gone by way too quickly — does this sound familiar to folks? You can sometimes lose track of all the events and changes that have occurred over the course of a year unless you take the time to stop and reflect. For many, this occurs at the end of the year with the annual Christmas card exchange or summary post on Facebook, but our approach at the Iowa Geological Survey (IGS) is the publication of our annual report *The IGS Geode*. I believe you will see that the last year — marked by a number of important IGS milestones in terms of personnel, projects, and funding — was one of our best ever since our transition to the University of Iowa in 2014.

Personnel changes at the IGS this past year included hiring a hydrogeologist, a bedrock geologist, a geological technician, and a part-time GIS analyst. **Joseph (Joe) Honings** is our new hydrogeologist. Coming from a recently completed Ph.D. (Louisiana State University), Joe was able to seamlessly jump into new mapping initiatives using passive seismic geophysics to begin delineating the bedrock surface in Muscatine County (see *Geode* article herein). In August, **John (Jack) Malone** was hired away from a consulting job in Wyoming to work with Ryan Clark and Alyssa Bancroft on mapping the bedrock geology of Iowa and to assist with various critical mineral assessments. Both Joe and Jack left more exotic locations to return to their Midwestern roots and we are thankful that they have! Two years ago, **Valerie (Val) Diaz-Gibertini** began working with Matthew Streeter as a student employee in the IGS Sediment Laboratory and did such a great job in the lab and with field projects that we had no choice but to hire her full time as a geological technician. Val continues to help with laboratory and field work while expanding her duties to work with Rick Langel on various well and rock chip processing activities at our Oakdale facility. Lastly, we convinced GIS analyst **Calvin Wolter** to step out of full-time retirement from the Iowa DNR to join the IGS as a part-time employee. Calvin and I have a long history together and have collaborated on various projects through the years and I'm convinced that no one knows more about how to effectively use GIS for natural resources and watershed initiatives than he does. Calvin is currently working on using LiDAR to map streambank erosion in the state while providing GIS support on a variety of other IGS projects. We also said goodbye to one IGS Staff member, **Sophie Pierce** left our team this past January and was accepted into the graduate program in the Department of Earth and Environmental Sciences here at the University of Iowa. Sophie was instrumental in working on the INRC-funded multipurpose oxbow project and we finished our time together by publishing a research article on that work in the *Journal of the American Water Resources Association* (see Publications herein).

The IGS Team: (back row, left-to-right) Greg Brennan, Ryan Clark, Alyssa Bancroft; (middle, left-to-right) Jack Malone, Elliot Anderson, Rick Langel, Phil Kerr, Calvin Wolter, Tom Stoeffler; (front row, left-to-right) Jason Vogelgesang, Joe Honings, Rosemary Tiwari, Valerie Diaz-Gibertini, Stephanie Tassier-Surine, and Keith Schilling. Matthew Streeter was not present for this photograph.

In addition to personnel additions, the IGS crossed a major milestone for the State of Iowa with the installation of new groundwater monitoring wells. With funding, in part from the USGS National Ground-Water Monitoring Network (NGWMN) and from the IGS legislative appropriation, the IGS, led by **Rick Langel**, was able to install replacement bedrock wells in northwest and northeast Iowa, properly plug an old leaking well, and commit resources to installing a deep sand and gravel well in a buried channel aquifer in Muscatine County (see *Geode* article herein). Groundwater level monitoring is foundational for the State of Iowa, yet the initiative was never properly funded, and the work limped along for decades at a bare minimum. With the IGS' success in acquiring new projects, we were finally able to reallocate funds to begin updating the network to systematically track water level changes in response to drought and use, thus ensuring that Iowans have basic data on this most vital resource.

While the installation of groundwater monitoring wells is a huge "win" for the IGS (and Iowans!), I would be remiss not to highlight a few other outstanding examples of work accomplished by the IGS and highlighted in this year's *Geode*. In the evaluation of water resources, the IGS continues lead the way, including: mapping source water capture zones for local municipalities (Decorah source water project, **Greg Brennan**), helping with drought identification and monitoring (**Elliot Anderson**), and mapping the water quality benefits in a large reservoir (Red Rock, **Matthew Streeter** and **Tom Stoeffler**). The IGS continues to conduct foundational and important geologic mapping, as highlighted by completed bedrock and Quaternary mapping projects in southeast Iowa (**Ryan Clark** and **Stephanie Tassier-Surine**), new insights about the Iowa Erosion Surface (**Phil Kerr**), and ongoing efforts to map a deep bedrock channel in Muscatine County (**Joe Honings**, **Alyssa Bancroft**, and **Stephanie Tassier-Surine**). Lastly, we introduce new geophysical mapping of Iowa's flood control levees by **Jason Vogelgesang** that will certainly be highlighted in much greater detail next year — stay tuned!

As I seem to mention every year, the breadth of skills and the sheer number of interesting projects being tackled by our IGS Staff is remarkable. We utilize a rather shoe-string contribution from the state that accounts for only 35% of our operating expenses, and we leverage some of this base funding to acquire other grants and contracts. This past year, we did an outstanding job of acquiring new projects and that allowed us to free up funds to expand the groundwater monitoring network in our state. To me it is clear that the IGS has demonstrated an unmatched track record of excellence over the years, however the work that we do could be greatly enhanced for the benefit of all Iowans. Imagine what we could do if we received an increase in state appropriation. A legislative funding increase would allow the IGS to continue to focus on regional statewide initiatives helping to ensure that sustainable water, soil, and mineral resources are available for Iowa's future generations.

Keith Schilling

KEITH E. SCHILLING
State Geologist

Using Field-Based Geophysical Methods to Image Iowa's Levees

JASON VOGELGESANG

The Iowa Geological Survey (IGS) resides in the same institution (Iowa Institute of Hydrologic Research—Hydroscience and Engineering) as the Iowa Flood Center, and as such we are well aware of the risks that flooding poses to Iowans and their property. Levees and embankments have been built to prevent the overflow of river floods into surrounding infrastructure, and they serve a vital role in protecting Iowans from loss of life, livelihood, and economic setbacks. However, since 1988, flooding continues to impact each one of Iowa's 99 counties. The major flooding events of 1993 and 2008 come to mind as catastrophic, state-altering examples that cost billions of dollars in damages and lost economic opportunity. More recently (2019), significant and prolonged flooding along the Missouri and Mississippi rivers tested the integrity of Iowa's levee system. At least 30 levee failures flooded towns and highways in the Missouri River Valley south of Council Bluffs. The damage was estimated at $1.6 billion in Iowa, a state record.

Iowa has approximately 700 miles of levees protecting towns, agricultural land, and critical infrastructure. Assessing the stability of these levees is a vital component of ensuring these structures are resilient in anticipation of future flood events. Recently, the IGS began using field-based geophysics to image levees and delineate possible areas of weakness. Anomalies discovered by these geophysical surveys will help inform levee managers where vulnerabilities within the structure (such as porous materials, voids, or areas susceptible to underflow) might exist to help prevent the risk of failure. Although periodic visual inspections are conducted, geophysical methods can be used to scan levees for anomalies that cannot be detected by the naked eye.

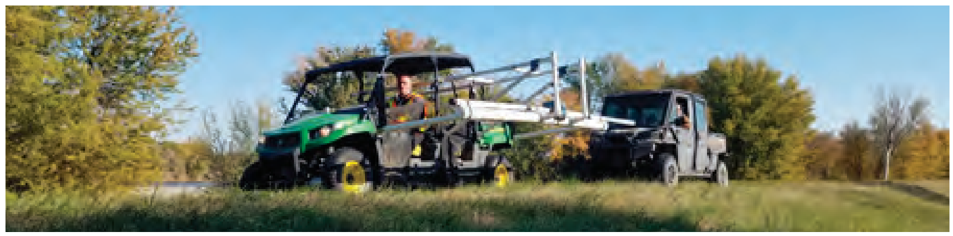

FIGURE 1.

In a new application of existing equipment, the IGS is using electromagnetic (EM) terrain conductivity imaging to assess the vulnerability of Iowa's levees. The EM equipment is mounted to a utility-terrain vehicle which is then driven along the top of the levee and along the toe slopes (**Figure 1**). This geophysical survey measures the conductivity of the geologic materials that the levee has been built from and also scans for anomalies up to a depth of 20 feet (**Figure 2**). In areas that are flagged 'anomalous' within the EM data, another geophysical survey, electrical resistivity (ER) tomography (**Figure 3**), can then be conducted to provide additional details. The results from ER surveys provide a cross-sectional view and more detailed information about the depth and extent of a potentially anomalous zone within the levee (**Figure 4**). To fully image a levee system (**Figure 5**), the IGS: 1) collects EM data along the top and toe slope of the levee; 2) conducts ER surveys in any areas flagged as 'anomalous'; and 3) creates a map depicting an(y) anomaly(ies) within the levee. The geophysical results and final map are then shared with the levee authority so they can determine what type of preventive action should be taken.

These procedures were developed when the IGS conducted a pilot study (2022) funded by the Iowa Department of Homeland Security and Emergency Management. Data was collected from two levee systems in southeast Iowa and this work demonstrated that the methodology can be used to accurately delineate vulnerable areas within a levee. Furthermore, these data are extremely valuable for assessing the appropriate measures to reduce and manage risks associated with a hazardous event caused by inadequate design, structural performance, or operational control of a given levee. These results were presented to the Iowa Legislature in early 2023, and discussions for conducting this geophysical work on levees statewide was begun. The Iowa Legislature subsequently passed an act which created a Levee Improvement Fund and established a new Office of Levee Safety (within the Department of Homeland Security and Emergency Management). A five-year state appropriation calls upon the IGS to assist with this statewide analysis to assess the condition of Iowa's levees — which span nearly 700 miles. Field work for this effort began earlier this autumn and several hundred miles of levees will be surveyed during each of the next five years.

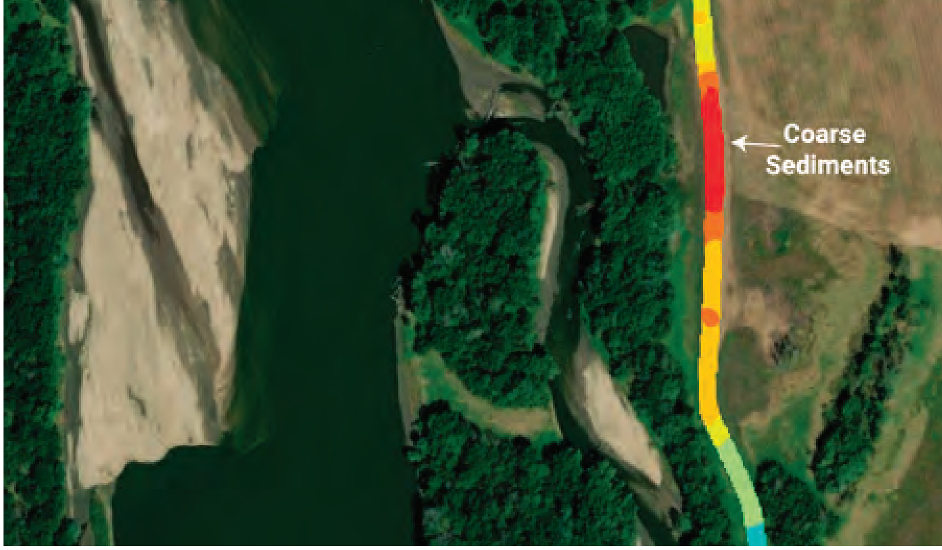

FIGURE 2.

FIGURE 3.

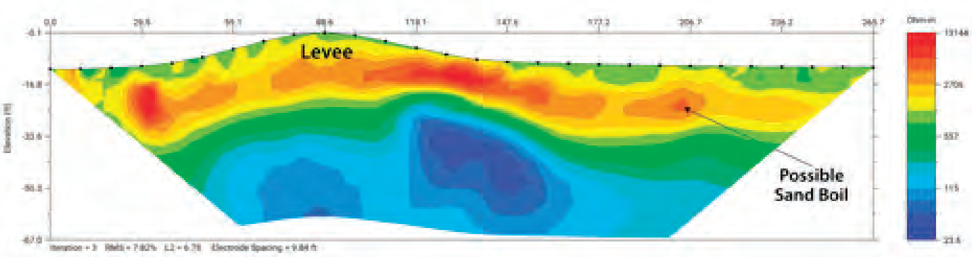

FIGURE 4.

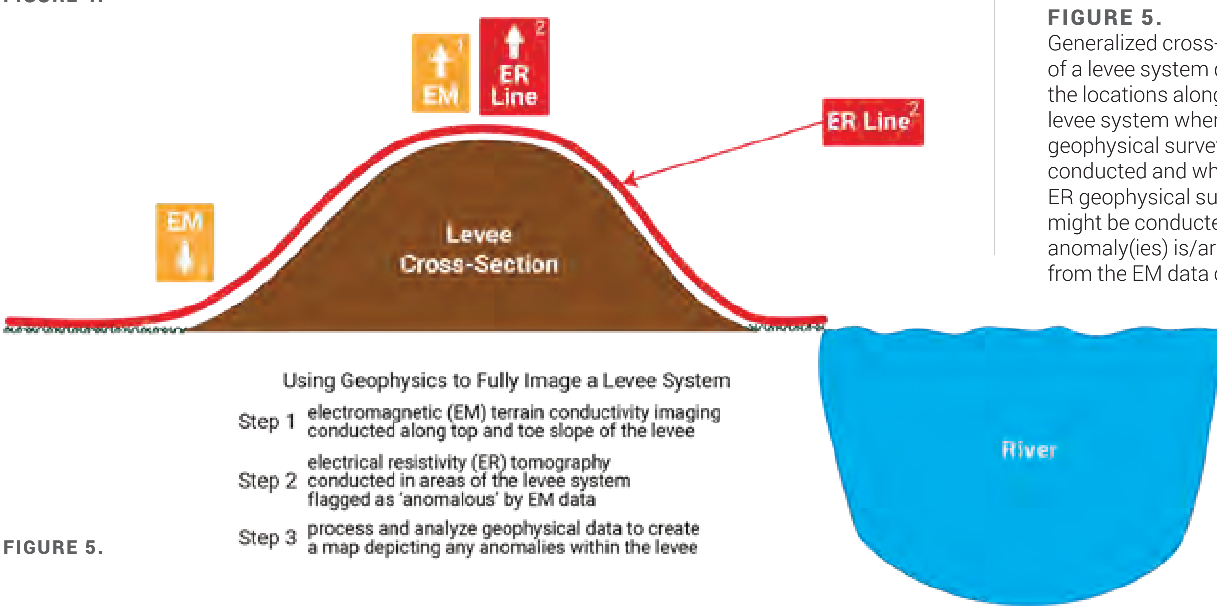

FIGURE 5.

FIGURE 1.
Conducting an electromagnetic (EM) terrain conductivity survey along the top of a levee.

FIGURE 2.
An interpretation of levee characteristics from electromagnetic (EM) terrain conductivity geophysical data.

FIGURE 3.
Collecting electrical resistivity (ER) tomography data along the top of a levee to better constrain anomalous areas within the system.

FIGURE 4.
An interpretation of levee characteristics from electrical resistivity (ER) geophysical data delineating a potential area of weakness (in this case a possible sand boil) within the levee structure.

FIGURE 5.
Generalized cross-section of a levee system depicting the locations along the levee system where EM geophysical surveys are conducted and where ER geophysical surveys might be conducted if an(y) anomaly(ies) is/are flagged from the EM data collected.

Sediments and Nutrients in Red Rock Reservoir, Iowa

MATTHEW T. STREETER AND THOMAS V. STOEFFLER

Eroded soil sediments and aqueous nutrients like nitrate-nitrogen (NO_3-N) and phosphorus exported from agricultural regions continue to degrade rivers and streams at local, regional, and continental scales. Impairments from sediment and nutrients include filling of reservoirs and ponds, nutrient enrichment in local streams and lakes, and development of hypoxic (dead) zones in regional water bodies, including the Gulf of Mexico. Concentrations of NO_3-N above the U.S. Maximum Contaminant Level of 10 mg/L also threaten drinking water supplies. Many Midwestern states have adopted strategies to reduce nutrient export and best management practices that enhance nutrient processing while minimizing loss of crop production are highly desired.

River deltas are ecologically critical components of the landscape and provide habitat for plants, wildlife, and millions of people. Furthermore, these landforms store vast quantities of eroded nutrient-rich sediment and play a significant role in water quality management through nutrient cycling and storage. In Iowa, there are nearly 4,000 state-regulated reservoirs of varying scale that have been created for ecological management and water use. This includes more than 20 major reservoirs that hold at least 6.2 million m^3 of water. While not all of these reservoirs are fed by major rivers, sedimentation resulting in delta formation occurs at varying rates in all of them. However, characterization of the sediments residing in these deltas and assessment of their ability to process and store nutrients has not been completed until now.

In 2022, the Iowa Geological Survey (team includes Keith Schilling, Matthew Streeter, Thomas Stoeffler, Elliot Anderson, and Valerie Diaz-Gibertini) began a study of Lake Red Rock Reservoir in Marion County, Iowa with a focus on the geomorphological characteristics of the sediment residing in the lower Des Moines River delta where the river enters the lake (**Figure 1**). The team assessed sediment and nutrient storage and the potential impact that this delta environment may have on other ecologically important facets such as water quality (**Figure 2**). The IGS is conducting research to quantify the degree to which NO_3-N reductions may be occurring with varying levels of delta inundation. In addition, the IGS team is conducting monthly water quality surveys using boat transects and high-resolution water quality measurements in the study area.

At the onset of the project, Schilling and Anderson led an effort to quantify how much NO_3-N is typically reduced in Lake Red Rock in any given year. Utilizing rare long-term upstream and downstream NO_3-N monitoring records extending back in time 42 years and combining these data with estimates from tributary inputs, Red Rock Reservoir was found to remove an average of 7,379 Mg NO_3-N per year, representing 12.4% of the NO_3-N inputs to the reservoir.

Detailed soil sampling in the delta was subsequently conducted to characterize the delta sediments. Overall, we found that the approximately 30-year-old lower delta is storing up to 60% of the contributing watershed's eroded sediment and total carbon, with total sediment depths of approximately 9 m across the 755-ha area. We further identified two major geomorphic landscape positions within the lower delta that we termed the distributary

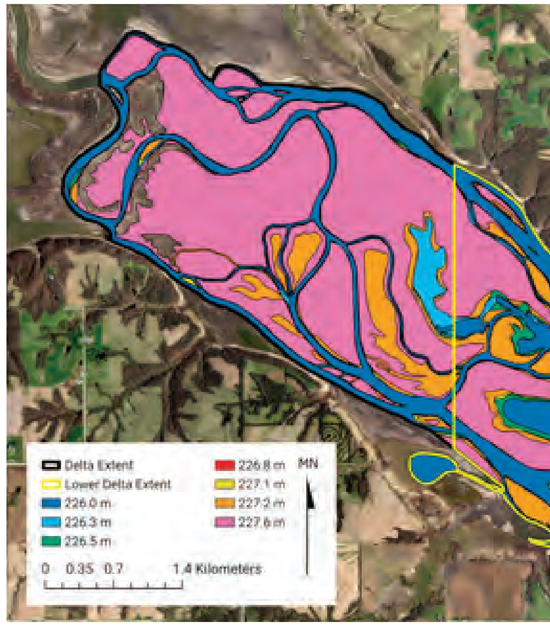

FIGURE 3.

channels and delta plains. The silt-dominated delta is regularly inundated when lake pool elevations change. The emergent vegetation becomes a zone of critical importance for waterbird habitat and nutrient processing (**Figure 3**).

With assistance from Todd Gosselink (Iowa DNR), we have utilized an IIHR-developed, boat-mounted, water quality monitoring system to map spatial patterns of NO_3-N concentrations in the lower delta. This mobile system collects real-time water quality data, including NO_3-N concentration, water temperature, specific conductance, pH, and dissolved oxygen, as the boat travels through the delta region. Each measurement is timestamped and geo-located, producing a "heat map" of water quality measurements along the designated route (**Figure 4**). This route has been repeated

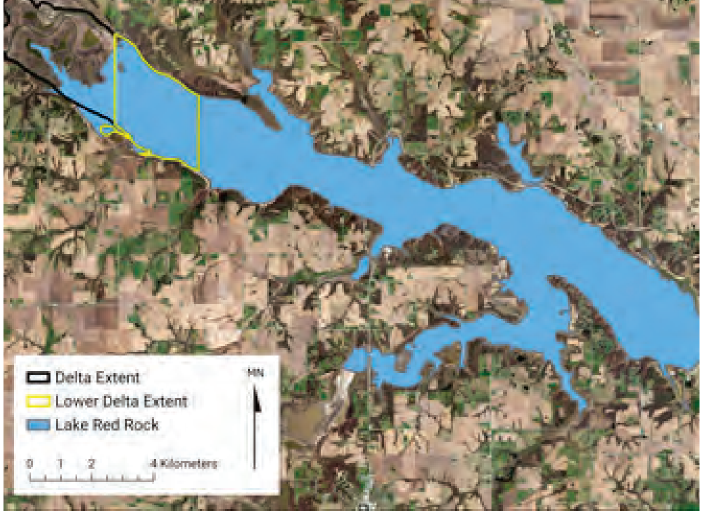

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FIGURE 2.

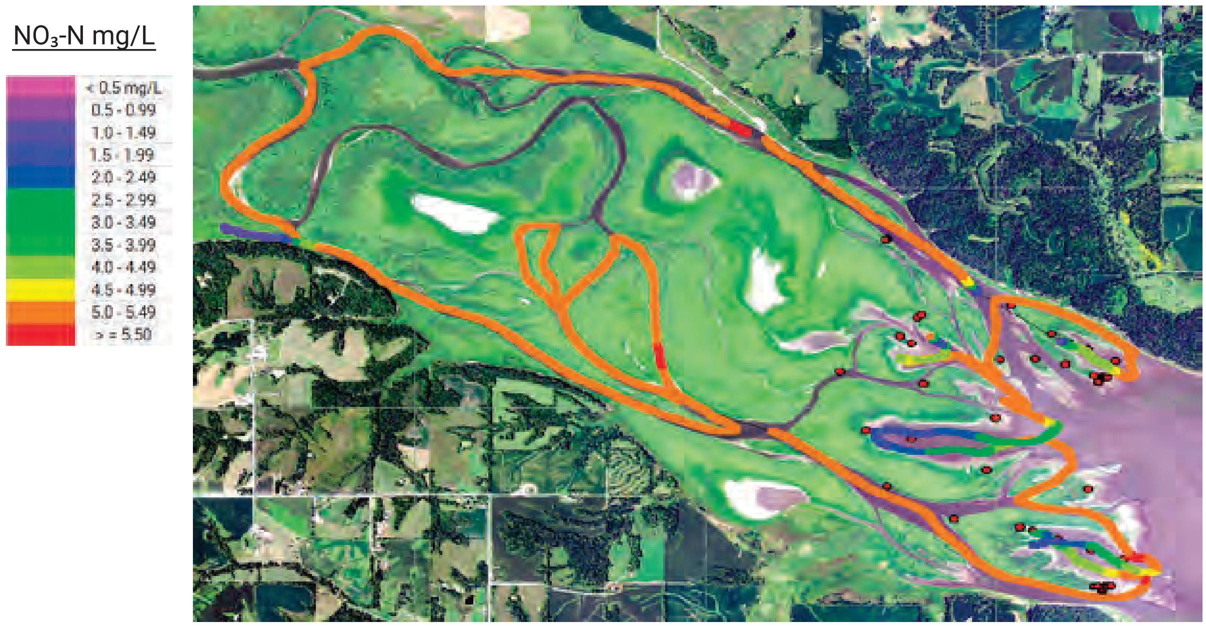


FIGURE 4.

monthly, allowing for comparison of data across varying weather and flow conditions and delta inundation/reservoir pool levels.

With collaboration from Dr. Tom Isenhart and student Jennifer Merryman from Iowa State University, N-loss rates in the lower delta sediments were determined from laboratory assays. By combining this laboratory data with satellite imagery, we developed a rating curve to quantify the amount of NO_3-N lost with various amounts of land area inundation within the delta. Results indicated that raising pool elevations to inundate more of the lower delta would result in greater N losses, ranging from 2 to 377 Mg per year. Potential N loss of 102 Mg could be achieved by increasing pool stage by 0.5 m which would be equivalent to installing nearly 650 edge-of-field practices (like bioreactors) in the watershed.

Although flood-control reservoirs are designed primarily for flood protection, manipulating reservoirs to achieve longer water retention times, particularly during periods of high NO_3-N concentrations and loads, could be a strategy to alleviate impairments at downstream water suppliers and help state and federal agencies meet NO_3-N reduction goals. The IGS will continue conducting boat surveys through the 2024 field season. Additionally, the IGS is exploring soil development and surface/groundwater interactions within the Red Rock Reservoir delta. This data will help inform local, state, and federal partners about the potential water quality benefits associated with pool level management within the reservoir.

FIGURE 1.
Red Rock Reservoir and its associated delta in Marion County, Iowa.

FIGURE 2.
The IGS team sampling sediments in the lower portion of the Red Rock Reservoir delta (from left: Matthew Streeter, Tom Stoeffler, and Keith Schilling).

FIGURE 3.
Inundation contour map of the Red Rock Reservoir delta developed by the IGS.

FIGURE 4.
Example of boat survey water quality data points. The high-frequency data collection allows for the creation of a map depicting variations in NO_3-N concentrations throughout the Red Rock Reservoir delta.

Using Streamflow to Identify Iowa's Droughts

ELLIOT S. ANDERSON

Drought has been on the minds of most Iowans over the last several years. Iowa has experienced consecutive years of limited rainfall, and at the time of this publication, every part of the state is experiencing some form of drought warning. The effects of drought materialize through several hydrologic processes, each of which negatively impacts Iowa's environment and/or economy. Common examples are reduced rainfall, drier soils, and lower groundwater tables. Drought conditions are typically identified by monitoring these hydrologic parameters and comparing them against historical values to determine how wet or dry the environment in a region currently is.

Another process that is strongly correlated with drought is streamflow. During droughts, Iowa experiences extended periods of low flow in many of its major rivers. The United States Geological Survey (USGS) operates over 130 gauges that continuously monitor streamflow; many have daily flow records extending back several decades. Researchers at the IGS have devised a new method that utilizes this extensive repository of USGS streamflow data to characterize Iowa's drought conditions. A new metric, the standardized streamflow index (SSI), is now calculated weekly to describe the relative dryness of Iowa's streams.

The IGS' approach divided Iowa into five distinct drought regions (**Figure 1**). Similar to landform regions (Prior, 1991), the defined drought regions share similar soils, geology, topography, and hydrology and would be expected to behave similarly during a drought. Data from these regions provide details at a greater spatial resolution and can be used to place drought severity within its proper historical context. The boundaries of the five drought regions have been aligned with Iowa's county boundaries to match local political boundaries.

USGS gauges within each drought region were selected to represent the region's overall hydrology. Gauges were chosen based on several criteria, including having a sufficiently large (>150 km^2) watershed area, lying completely within a drought region, containing 40+ years of continuous flow data, and having minimal overlap in tributary areas. Six to 12 gauges per drought region were ultimately chosen to represent the regional hydrology.

Daily water yields are calculated at each selected gauge. Water yields are determined by dividing a gauge's measured streamflow by its tributary area, thus enabling more consistent hydrologic comparisons by accounting for watershed size. The average of each region's daily water yields is then calculated to produce an overall regional value (e.g., Drought Region 3 in **Figure 2**).

The last step in calculating the SSI for Iowa's five drought regions involves placing the regional yield within its proper historical context. More rain typically falls in the spring and summer, so flow values in those months also tend to be higher. Flows considered dry in June may be wetter than average in the winter months. Additionally, since drought is a slow-moving phenomenon, the SSI takes the regional yield for the past 30 days and compares it to the yields observed on that same day of the year. Hence, the SSI describes the relative dryness observed in a region's streamflow over the past 30 days when accounting for seasonal variations. More specifically, it is the number of standard deviations a regional water yield is from its historical mean. Negative SSI values represent drier-than-average periods, while positive SSI values are indicative of wetter-than-average periods.

The SSI has been calculated for each drought region, and these records span from 1960 to the present (e.g., Drought Region 3 in **Figure 3**), thereby providing long-term records of Iowa's hydrologic history. In consultation with the Iowa Department of Natural Resources, the SSI methodology has been incorporated into Iowa's statewide drought plan, and these data are disseminated weekly to provide updates on regional flow patterns. IGS researchers have also constructed a similar version of the SSI that describes flows from the previous 365 days. Both metrics help categorize the region's drought intensity—normal, watch, warning, or emergency. Drought mitigation will remain a vital area of focus in the coming years, and we will be partnering with the Iowa Institute of Hydrologic Research — Hydroscience and Engineering to construct a web platform that can effectively communicate the SSI and other drought-related parameters to Iowans. The IGS will continue to play an important role in identifying droughts and their intensity for the benefit of Iowa's citizens.

Footnote: *The IGS partnered with the Iowa Department of Natural Resources (IDNR) and Iowa Department of Agriculture and Land Stewardship (IDALS) in preparing Iowa's Drought Plan and developing the regional drought index and standardized streamflow index (SSI) methodology.*

CITATION

Prior, J.C., 1991. "Landforms of Iowa," *University of Iowa Press*, 154 p.

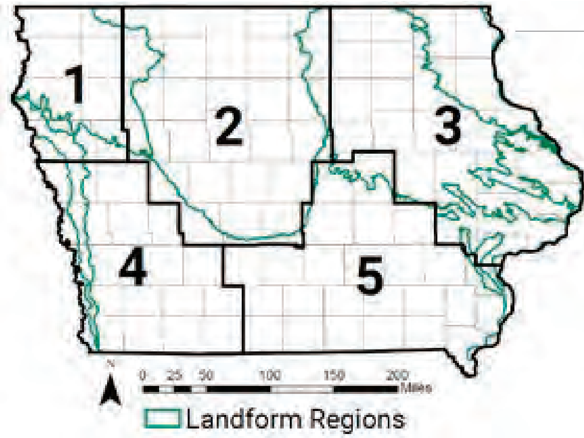
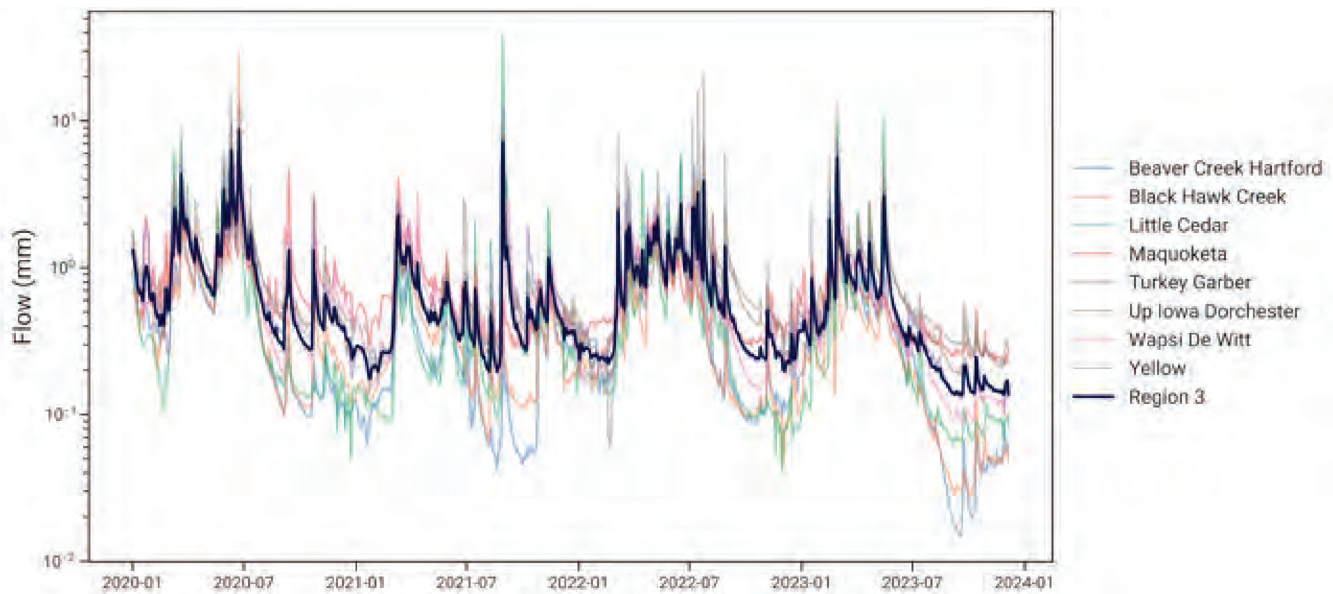


FIGURE 1.



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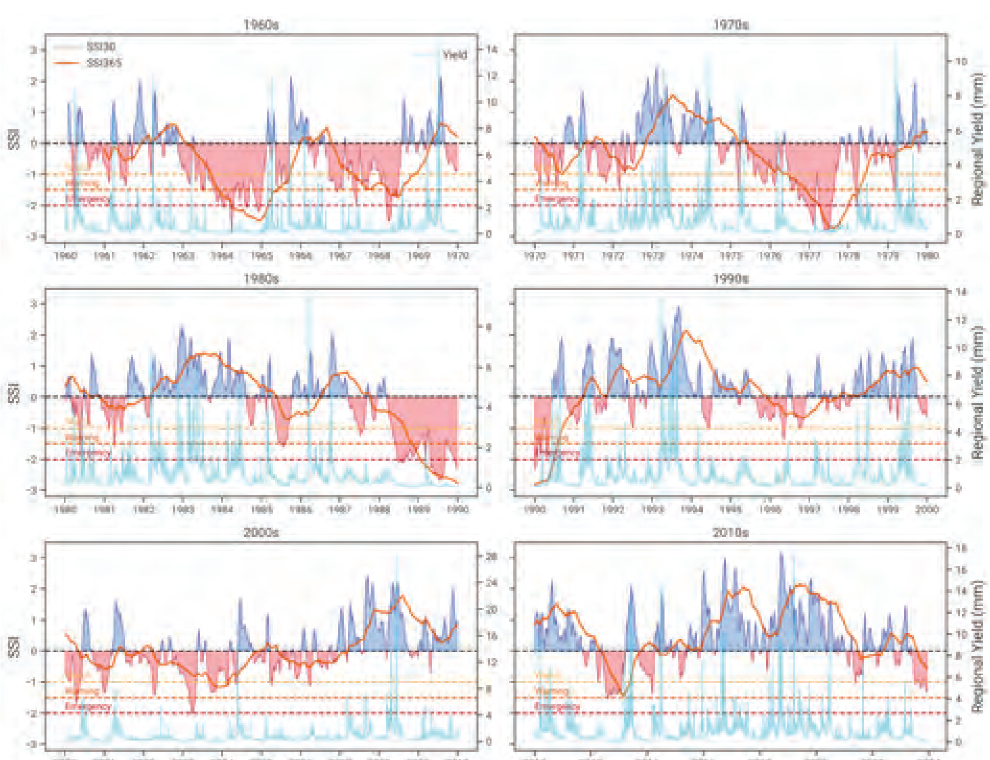

FIGURE 3.

FIGURE 1.
The five drought regions of Iowa with the landform regions (blue lines) of Prior (1991) depicted.

FIGURE 2.
The streamflow yields in the 2010s for Drought Region 3.

FIGURE 3.
The historical (decadal) standardized streamflow index (SSI) values for Drought Region 3. Daily regional yields are displayed on the secondary axis.

Source Water Delineations by the IGS Enhances Groundwater Protection and Planning for Communities

GREG J. BRENNAN

The Iowa Geological Survey (IGS) assisted the City of Decorah with source water protection planning by delineating a Well Head Protection Area (WHPA) around their well field based on actual hydrogeologic conditions, operating parameters, and groundwater modeling. A WHPA is the surface and subsurface area surrounding a well through which contaminants are reasonably likely to move toward and reach such a well.

Decorah is supplied by six production wells drilled 60 to 80 feet deep into fine- to coarse-grained sediments of the Upper Iowa River Alluvial Aquifer (**Figure 1**). Field characterization of this aquifer consisted of drilling and soils testing, geophysical surveys, and production well pumping tests. The initial step was the installation of monitoring wells for use as water level measuring points. Soil and water level data were then used to assess the grain size distribution of the alluvial deposits and the groundwater flow patterns and interconnection of the river–groundwater systems.

Geophysical surveys, using electrical resistivity (ER) tomography, were conducted along the river to map the variation in subsurface electrical current flow. More permeable aquifer materials (i.e., sands and gravels) are typically characterized by higher resistance values (warmer colors in **Figure 2**). For each line, fifty-six electrodes were deployed at an in-line spacing of 20 feet to form a 1,120-foot traverse, along which high-resolution subsurface current data was collected (**Figure 2**).

When a pumping well is located near a river the water it produces is initially derived from groundwater stored in the aquifer. However, as pumping continues the influence of drawdown spreads laterally to intersect the riverbank, inducing leakage of river water into the aquifer. This 'pumping induced recharge' often makes up a portion of the production in wells located adjacent to a river (**Figure 3**).

Two pumping tests were performed to calculate the parameters that quantify groundwater flow in the aquifer and to define the river's contribution to well yield. The aquifer parameters were then used to construct a groundwater flow model for the area. The model was calibrated by systematically varying input parameters (e.g., hydraulic conductivity, recharge) until the match between the observed measurements at eleven measuring points and the model-simulated predictions was considered good. The calibration curve and statistics were very good with an absolute residual mean value of 0.12 feet (the average magnitude of the residuals).

The calibrated model was first used to establish a WHPA by using reverse particle tracking. This process involves placing hypothetical particles at each well and tracking their path lines in the reverse (upgradient) flow direction to their sources. Since each of these hypothetical particles begin at a given well, the group of path lines defines the overall capture

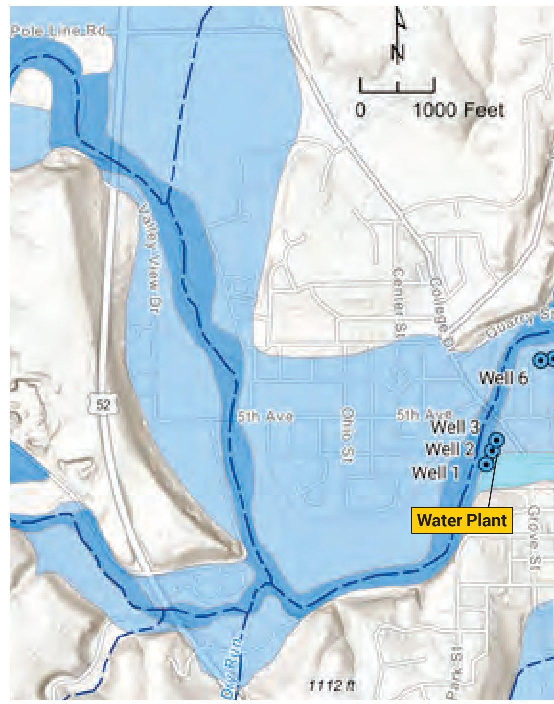

FIGURE 1.

FIGURE 3. Diagram depicting pumping induced recharge within a production well adjacent to a river.

FIGURE 4. Proposed Well Head Protection Area (WHPA) for the City of Decorah.

zone and, hence, the overall WHPA for the well fields. The calibrated model was also used to estimate the induced recharge component of production through water balance calculations. Specifically, the termination of flow path lines at the river indicates that the river is a recharge boundary and that well production does consist of induced recharge water. Under the simulated conditions, induced recharge water from the Upper Iowa River at Wells 1, 2, and 3 comprised 20% of the total pumped volume, while at Wells 5, 6, and 7 it comprised 13% of the total pumped volume. The remaining production was derived from groundwater in aquifer storage.

The proposed WHPA was drawn to encompass both the groundwater capture zones and the ground elevation features that contribute surface water runoff to the capture area. The capture zone was then simplified by using real-world features, streets, to represent the WHPA (**Figure 4**). The use of streets aids land use planning decisions because the area can easily be written into local zoning or ordinances and be marked by beneficial signage, all of which would provide concrete visuals and raise community awareness about this vulnerable source water area.

Overall, the WHPA delineated by the IGS was much smaller than those previously defined (only 15% as large) for the City of Decorah. This improved WHPA delineation will allow the city to focus limited resources to a smaller area to achieve their drinking water protection goals and it will also provide incentive for continued planning efforts. Source water delineations by the IGS can greatly enhance groundwater protection and planning efforts for Iowa communities. Please contact the IGS for more information if you are interested in these services.

→ **THE FULL REPORT CAN BE FOUND ON THE IGS PUBLICATIONS PAGE: DRINKING WATER PROTECTION IN DECORAH, IOWA (WATER RESOURCES INVESTIGATION REPORT 19).**

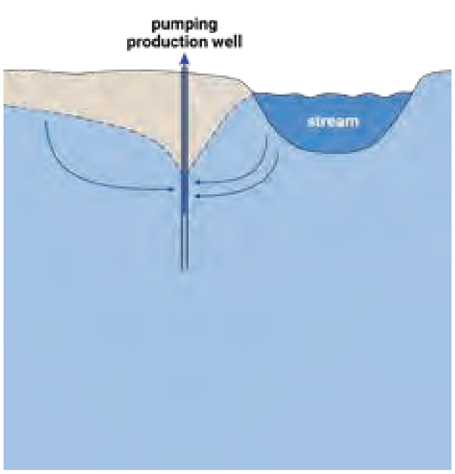

FIGURE 3.

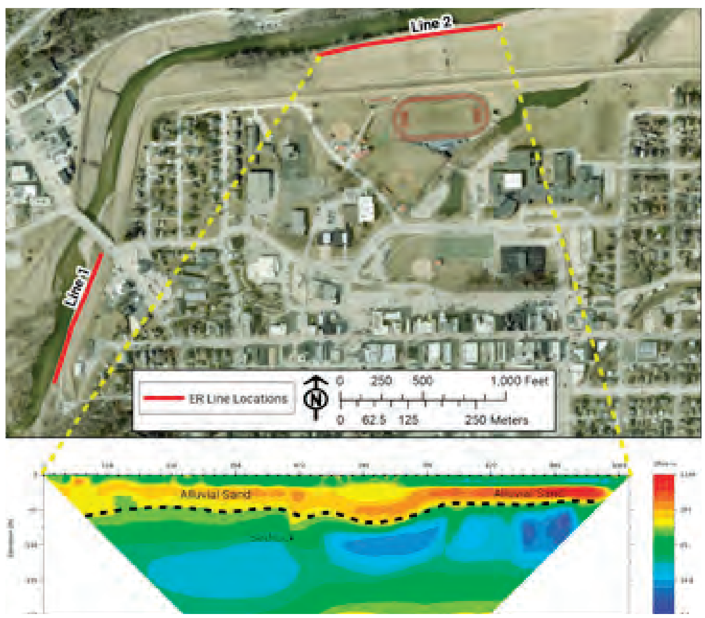

FIGURE 2.

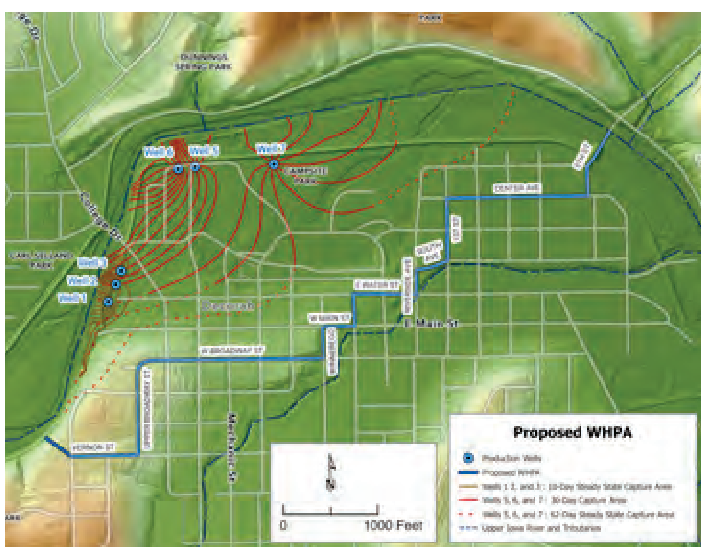

FIGURE 4.

FIGURE 1. Location map showing the Upper Iowa River Alluvial Aquifer as well as the Water Plant and municipal production wells supplying water to Decorah, Iowa.

FIGURE 2. The electrical resistivity (ER) tomography data collected along geophysical survey Line #2 showing the sand and gravel aquifer (warmer colors) relative to fine-grained sediments or bedrock (colder colors).

The Great Melting of Eastern Iowa

PHIL KERR

The formation of the unique terrain of the Iowan Erosion Surface (IES) in eastern Iowa has been a source of debate for more than a century. Not only is the terrain of this landform region subdued in comparison with areas to the south and northeast, but it is also missing the loess and paleosol (old, buried soil) found in those regions. Although the topography of the IES is very similar to the till plain of the Des Moines Lobe (DML) to the west, the IES was not covered by ice during the most recent glaciation — as such, erosion during the last glacial episode is not responsible for the development of this landform region. Interestingly, the biggest contrast between these two regions are their drainage networks and valley shape. The IES lacks the closed depressions and prairie potholes found on the DML till plain. Instead, the IES has a well-established drainage network, and many tributary valleys on the IES are usually much broader than those found in the surrounding areas. Recent geologic mapping projects have clarified one of the major geomorphic processes responsible for this unique landscape: *permafrost*.

Over the last 50,000 years the climate of Iowa has undergone major shifts, one of the biggest began approximately 29,000 years ago when orbital parameters caused a reduction in the amount of sunlight reaching North America during the summer months. The most significant effect was the growth of continental ice in Canada as well as a drop in average summer temperatures in Iowa, potentially up to 20°F cooler than today. Around 26,000 years ago, eastern Iowa was put into a periglacial regime where the yearly overall average temperature dropped below 0°F and the ground was permanently frozen — hence the 'perma' in permafrost. However, the uppermost soil horizons freeze and thaw yearly and are referred to as the 'active layer'. The presence of ice wedge casts, patterned ground, and thermokarst activity are lines of evidence that this landform region was a *periglacial landscape* during the last glacial episode.

Rain and snow would have fallen on the IES during this interval providing moisture for the sediments. When water freezes it increases in volume (or expands) by approximately 9% and can exert extreme pressure within the sediment (or bedrock) around the ice. Ask anyone who has accidentally left a can of pop in the freezer! The force of water freezing in the ground can radiate in any direction and can create gaps in the sediment. Large pockets or even layers of pure ice can form in permafrost. When vertical cracks on the land surface develop in a periglacial region, ice wedges may form. Water from either rain or snow melt will flow into the void space that is created. If the water is not rapidly absorbed into the surrounding sediment, it can freeze in shape of the crack and wedge it farther apart, expanding the fracture. Once the ice melts, water may again fill the void space, and this repeated process will continue to widen the crack. Sediments ranging in size from fine sand to coarse gravel may also fall into the fracture and help hold the space open. This freeze-thaw process, combined with sporadic sediment infilling, may occur repeatedly for potentially hundreds or thousands of years. After the permafrost finally melts, the sediments in the fracture still remain (**Figure 1**) thus forming a cast of the ice wedge! These ice wedge casts are actually part of a larger polygonal network which has a pattern similar to mud (or desiccation) cracks. The sediment in the ice wedges often dry out faster than the surrounding material and this contrast can be seen in aerial photographs as *patterned ground*. Although ice wedge casts and patterned ground indicate that permafrost was present in the IES, these two processes alone cannot explain the eroded landscape, however *thermokarsting* can. Thermokarsting is the process of rapidly melting a periglacial landscape which can result in the creation of a unique topography. **Figure 2** is a sequence of conceptual block models illustrating the evolution of the eastern Iowa landscape over five intervals. When ice-rich permafrost melts, the water-laden sediment loses the strength that the ice had provided and becomes unstable. Two primary types of thermokarsting occurred across the IES landform region: retrogressive thaw slumping and active layer detachment. Retrogressive thaw slumps developed when the sides of permafrosted channels or valleys began to thaw. What was once a stable frozen slope was transformed into a muddy debris flow when thawed. The initial collapse formed an amphitheater-shaped slump in the valley wall. This fresh surface then exposed more frozen ground to warmer summer air, creating a positive feedback loop, which caused further destabilization. The resulting scarp could cut back into the landscape hundreds to thousands of feet from the original channel wall and erosion continued until a stable slope was reached. On the hillslopes, active layer detachment occurred when water from a gradual melting or a large rain event pooled between the active layer and impermeable permafrost. The layer of water destabilized the sediment in the active layer on these slopes creating debris flows. Ultimately, the colluviated sediment from these mass wasting events filled the downslope valleys that had been reshaped by retrogressive

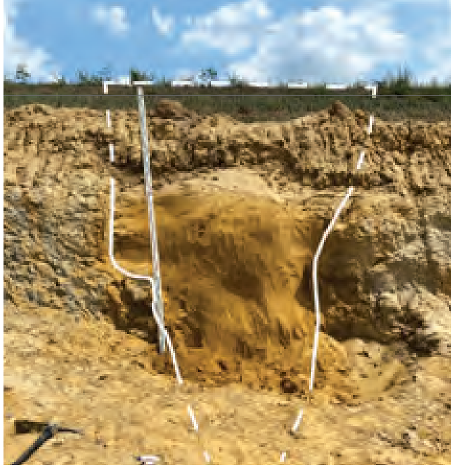

FIGURE 1.

thaw slumps. In heavily eroded areas the resultant hummocky topography is called 'thermokarst badlands'. The large-scale flattening of the IES landscape was caused by the net movement of upland sediment downslope, which filled in the valleys.

Although the features of the IES are particularly interesting for a glacial geomorphologist, this landscape can provide further insight into modern-day processes as well. The IES is a good analog for the stability of modern periglacial landscapes. Studying how permafrost destabilized and evolved during the end of the last glacial episode (as climate was warming) can inform our understanding of the rate of permafrost failure and erosion that is occurring in Arctic regions like northern Alaska and Canada today.

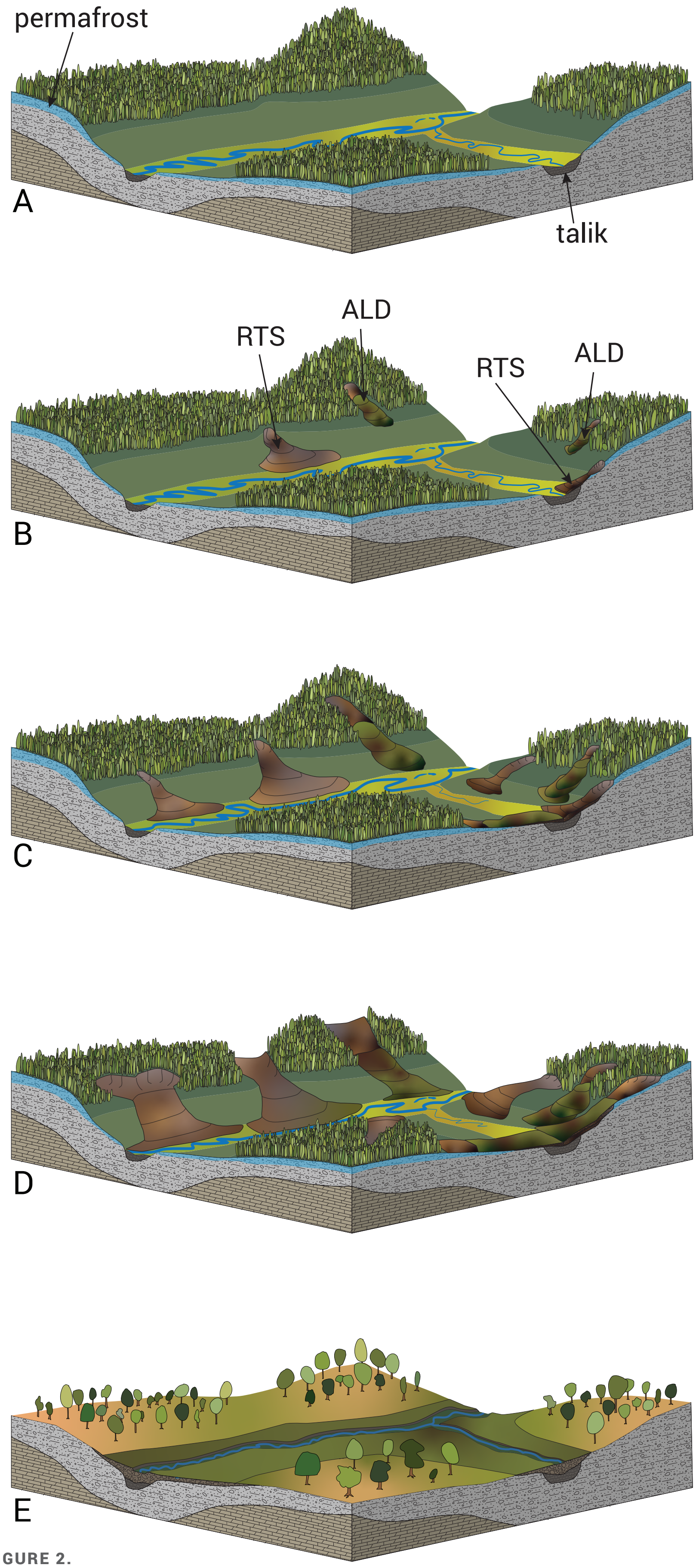

FIGURE 2.

FIGURE 1
A photograph of a wedge cast from the Wendling Garrison Quarry (Benton County, Iowa). This wedge was at the summit of the paleolandscape and is now filled with fine-grained sand.

FIGURE 2
These block models illustrate some of the erosive processes responsible for creating the topography of the Iowan Erosion Surface (IES) landform region. **Block A** represents the initial onset of permafrost, however, some areas, called taliks, were not frozen. **Block B** shows the onset of thermokarst erosion driven by such processes as retrogressive thaw slumps (RTS) and active layer detachments (ALD). Over time, this succession of individual mass wasting events exposes and erodes farther back into the landscape, as displayed in **Block C**. The continuation of erosion eventually causes the sediment from subsequent debris flows to fill the paleovalleys and block drainages, as depicted in **Block D**. The modern landscape, shown in **Block E**, has a more subdued topography and the modern channel is incising into sediment derived from the uplands.

The IGS' Groundwater Level Network

RICHARD J. LANGEL

Groundwater is a critical resource, heavily depended upon by approximately 75% of Iowans for their drinking water. Increased demands by agriculture, industries, and municipalities have raised concerns about the future availability of groundwater. Long-term data, therefore, are crucial for successfully managing Iowa's water resources.

Beginning in 1982, the IGS and United States Geological Survey (USGS) collaboratively operated a Groundwater Level Network in Iowa to provide a historical record of the water level changes in the state's aquifers. At its peak this network had more than 200 wells, however budget restrictions caused monitoring to be suspended at many wells in 2004 and monitoring was then suspended at the remaining wells in 2007.

The IGS began a new Groundwater Level Network in 2010, which currently consists of 48 dedicated monitoring wells (**Figure 1**) that are completed in most of the major bedrock aquifers in Iowa. These wells provide a historical record of groundwater levels, and these data are important for evaluating the sustainability of Iowa's bedrock aquifers. Many of the wells have long-term historical records because they were part of the earlier IGS/USGS groundwater level network. However, most aquifers lack a sufficient number of wells to properly evaluate the spatial and temporal patterns in their groundwater levels.

Nonetheless, data from the IGS' Groundwater Level Network is being used to better assess Iowa's aquifers and the state's groundwater resources. In northwest Iowa, groundwater levels are declining in the Dakota Aquifer. In eastern Iowa, data from the water level network is being used to calibrate groundwater models that show aquifer drawdowns in the Silurian Aquifer near municipal pumping centers. Interestingly, Iowa water level data were also used in a recent *New York Times* article (August 2023) that documented the decline in groundwater levels nationally.

The oldest wells in the IGS Groundwater Level Network were constructed in the early 1970s, most were constructed by the mid-1980s, and unfortunately some of these wells are being lost as they age. Each year any existing problems with the wells are documented, including borehole collapse. The IGS, with assistance from Iowa-certified well contractors, has begun addressing problem wells within the network during the last year.

Most notably, many wells in the Dakota Aquifer no longer have an acceptable connection to the aquifer, which compromises data integrity. A Dakota well, near Moville, had two large holes in the surface casing and an obstruction roughly 70 feet below the surface. Attempts to remove the obstruction failed and the IGS could not determine how the obstruction might impact the use of this well in its groundwater level network. Thus, the only option to guarantee that quality data is being collected in the area was to replace the well.

With funding assistance from the USGS National Ground-Water Monitoring Network (NGWMN) Program, the IGS drilled its first new bedrock monitoring well in 20 years. With permission from Woodbury County Conservation, the IGS installed a 300-foot-deep Dakota well (**Figure 2**) in Midway Park, just three miles northeast of Moville. Once water levels between the old and new wells are correlated, the IGS will be able to confidently continue to evaluate the Dakota Aquifer in the area for the long-term.

In other instances, data collection is hindered due to an insufficient well diameter (five wells are less than 1.0-inch and eleven wells are 1.5-inch). Small well diameter severely limits the types of equipment that can be used and the tests that can be run within the well to assess aquifer conditions. Two such wells were being used to monitor the Devonian Aquifer in Mitchell County, and each of these wells has now been replaced with a 7.0-inch-diameter well (**Figure 3**). These larger-diameter wells will allow the IGS to monitor two zones within the aquifer and test aquifer characteristics in ways that were not previously possible.

Many of the older wells in the IGS' Groundwater Level Network are located in roadside ditches, which makes them

vulnerable to vehicle or mowing accidents. Damaged wells may allow water and chemicals from the ditches in which they reside to enter the local aquifer(s) with potential impacts to nearby private wells. In Spring 2023, two wells in the network (monitoring the Devonian and Silurian aquifers near Hiawatha) were damaged beyond repair after an unidentified accident (**Figure 4**). The IGS was proactive and immediately plugged both of these damaged wells to protect the aquifers. Unfortunately, this particular site does not offer the appropriate parameters necessary for installation of replacement wells, but more suitable areas nearby are being evaluated. Although losing the long-term records from these sites does hamper the ability to evaluate the Devonian and Silurian aquifers, the protection of Iowa's aquifers will always be the utmost priority.

In the past year, the IGS has taken its first steps in more than a decade to begin to modernize its aging Groundwater Level Network. The continual upkeep and expansion of this network — to fully evaluate all of Iowa's aquifers — will require a substantial investment and likely many years of effort. However, the cost will be worthwhile if it helps Iowans to successfully manage our state's groundwater resources for future generations.

→ **ARTICLE IN THE *NEW YORK TIMES*: "AMERICA IS USING UP ITS GROUNDWATER LIKE THERE'S NO TOMORROW"**

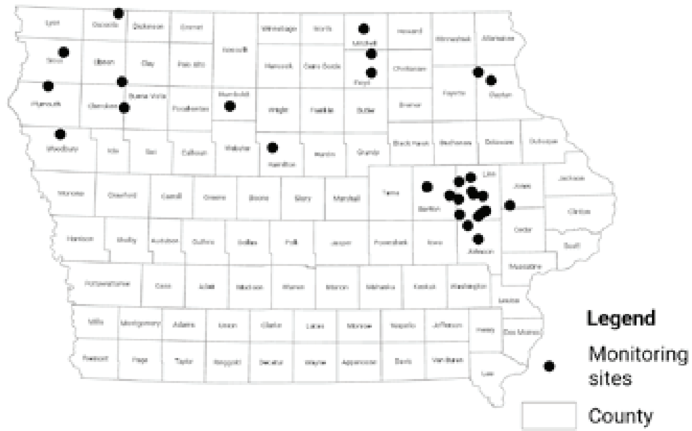

FIGURE 1.

FIGURE 3.

FIGURE 2.

FIGURE 4.

FIGURE 1.
Map of IGS groundwater monitoring sites.

FIGURE 2.
The new well installed at Midway Park (Woodbury County) to replace an existing, but compromised, old well. This new well will allow the IGS to continue monitoring the Dakota Aquifer.

FIGURE 3.
Construction of a new well in Mitchell County which will allow the IGS to continue to monitor the Devonian Aquifer.

FIGURE 4.
Damage to an existing well in the network that was discovered by IGS Staff. This well was subsequently plugged by the IGS to protect the local Silurian Aquifer.

Geologic Mapping in Southeast Iowa

STEPHANIE A. TASSIER-SURINE AND RYAN J. CLARK

The mission of the Iowa Geological Survey (IGS) is to provide Iowans with the knowledge needed to effectively manage our state's natural resources for long-term sustainability and economic development. Mapping the geology of Iowa is integral to fulfilling that mission. The IGS takes an iterative approach to mapping, once an area has been thoroughly studied and mapped, the IGS then sets its sights on another area requiring attention. After decades have passed, allowing for new insights and analytical techniques (and for some areas, the invention of automobiles and GPS), an area may find itself in the crosshairs of IGS geologic mappers once again. For example, the north-central Iowa counties of Worth, Cerro Gordo, Mitchell, and Floyd were last mapped at the county scale around 1902. IGS geologists spent the better part of a decade mapping this four-county area before relocating to southeastern Iowa where the last county scale bedrock maps were published more than 120 years ago (1893). The shift from north-central to southeastern Iowa was guided by the IGS' State Mapping Advisory Committee (SMAC), which consists of approximately two dozen people representing state agencies, local governments, industry, and academia. Since the floods of 2008, the primary focus of mapping efforts shifted to watersheds, specifically the Cedar River Basin, and it was determined that the Skunk River Watershed in southeast Iowa required further scrutiny too. Addressing current issues related to groundwater quantity and quality, flood mitigation, and aggregate resource protection in areas undergoing rapid development are of interest to many stakeholders and are central to the purpose of the U.S. Geological Survey STATEMAP Program.

The IGS began its mapping initiative in southeast Iowa in 2017. Over the subsequent six years, time was devoted to combing through old data, collecting new data, and synthesizing the findings to produce 10 bedrock and 10 surficial geologic maps at the quadrangle scale (1:24,000). The culmination of this work has resulted in the creation of new 1:100,000 scale bedrock and surficial geologic maps of Lee (2022) and Des Moines (2023) counties (**Figures 1 and 2**).

BEDROCK MAPPING

Of utmost importance with any geologic mapping enterprise in Iowa is the accuracy of the location of subsurface data. During the southeast mapping effort, drilling records from over 3,800 water wells were reviewed for accuracy, with 62% being correctly located. Almost all of these records include paper logs provided by the driller that indicated the depth of the well, description of materials, and most importantly the depth at which bedrock was encountered. Approximately half of these wells had chip samples that were logged to provide detailed lithologic information. Where well data was sparse, the IGS used a Tromino® horizontal-to-vertical spectral ratio (HVSR) passive seismic unit to collect 206 new depth-to-bedrock data points. The final component in assembling the bedrock mapping dataset was the description of 175 bedrock exposures that were identified during field work activities (**Figures 3 and 4**). After compilation of these data, the elevation of the bedrock surface was drawn using 25-foot contour intervals. The resulting bedrock elevation map is a significant

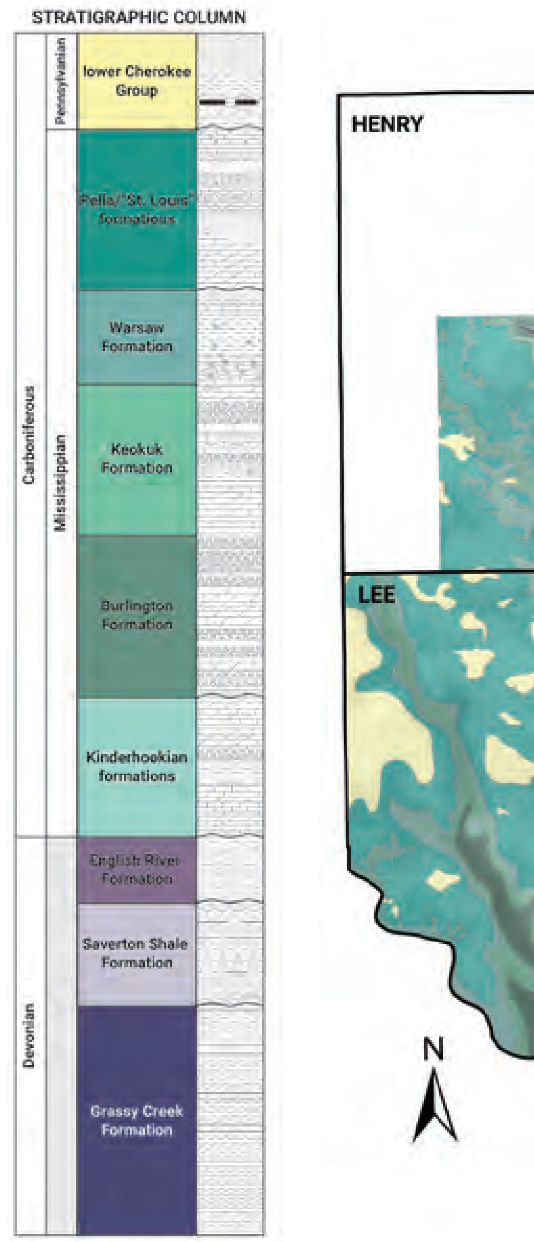

FIGURE 1.

improvement over the previous statewide map that was drawn with 50-foot contour intervals. Once the bedrock elevation map was completed, the bedrock geologic mapping units were drawn to show the distribution of formations that comprise the bedrock surface of southeastern Iowa (**Figure 1**).

The geologic complexity of the tristate area of Iowa, Illinois, and Missouri has been recognized for decades, as this region is the "type" area for the Mississippian Subsystem in North America. Recent advances in technology and new data have allowed for significant revision of key bedrock stratigraphic units bracketing the boundary between the Devonian and Carboniferous systems for worldwide application. One key question that vexed Midcontinent geologists over the years is whether the basal Mississippian "McCraney" Formation in Iowa is correlative with the type section of this unit in Illinois.

Geologic Mapping in Southeast Iowa continues on page 18.

FIGURE 1.
Compilation of bedrock geologic maps created during recent mapping in southeast Iowa.

FIGURE 2.
Compilation of surficial geologic maps created during recent mapping in southeast Iowa.

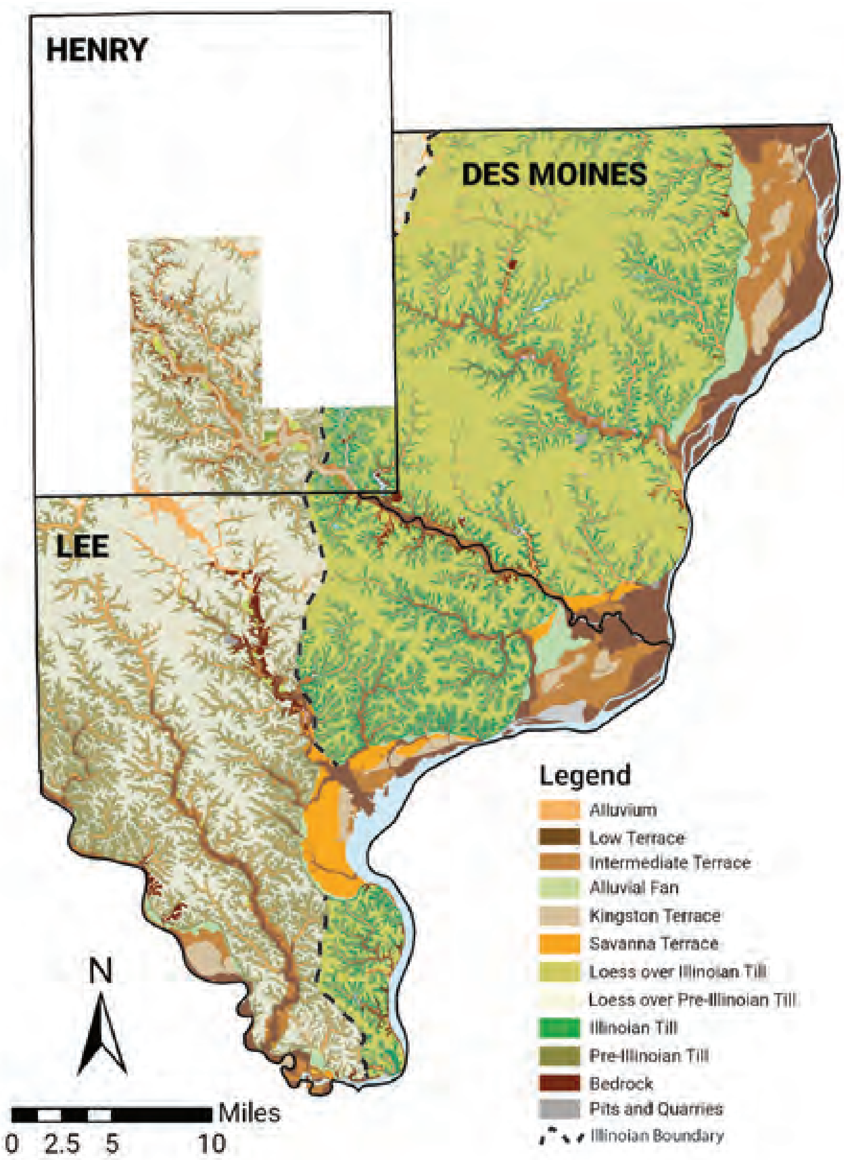

FIGURE 2.

Geologic Mapping in Southeast Iowa continues from page 17.

In conjunction with IGS mapping efforts, University of Iowa (UI) Department of Earth and Environmental Sciences (EES) undergraduate and graduate students used chronostratigraphic proxies (e.g., carbonate carbon [$\delta^{13}C_{carb}$] isotopes and conodont biostratigraphy) to help unravel the problem. Rock cores in Lee and Des Moines counties, available within the IGS repository, and exposures at Starr's Cave Park and Preserve and Crapo Park in Des Moines County were sampled and analyzed. Results from several EES thesis projects indicate that the "McCraney" Formation in southeastern Iowa is not correlative with its type section in Illinois, but is instead correlative with the Louisiana Formation in Missouri and Illinois (Cramer, 2019; Stolfus et al., 2020; Heath et al., 2021; Braun et al., 2023). The Louisiana Formation is currently assigned to the uppermost Devonian System; however the International Subcommission on Devonian Stratigraphy (SDS) is currently revising the position of the Devonian-Carboniferous Boundary, which would potentially elevate this lithostratigraphic unit to the lowermost position of the Mississippian Subsystem. This collaboration between the IGS and the UI-EES, to better understand the Devonian-Carboniferous succession in its type area of North America, is helping to revise the regional stratigraphy of this systemic boundary.

SURFICIAL MAPPING

The last comprehensive study of Quaternary stratigraphy in southeastern Iowa was conducted by IGS geologist George Hallberg in 1980. At that time, a lithostratigraphic framework (defining units based on their physical properties, including their mineralogy) was established for the Pre-Wisconsin glacial advances. A component of the study focused on the Illinoian till in southeast Iowa. Data suggest that between 190,000-130,000 years ago the Illinoian glacier advanced approximately 25 miles into Iowa from the northeast, and the associated till was classified as the Kellerville Member of the Glasford Formation (as identified in Illinois — Willman and Frye, 1970). Due to a source area that differs from most older till deposits, the clast component of the Illinoian till is distinctive from the Pre-Illinoian deposits in that coal fragments (**Figure 5**) and sandstone and shale clasts are more common. Mapping in Lee and Des Moines counties presented an opportunity to reinvestigate the Illinoian till and further characterize the glacial stratigraphy (**Figure 2**). Since drilling for the original study by Hallberg did not extend to the southern border of Iowa, new drilling data in the two counties (including 55 drill cores totaling 1,735 feet) identified the position of the terminal moraine of the Illinoian glacial advance farther south (closer to Keokuk) than what had been proposed in the original study. This was based on the descriptions of the new core and aided by LiDAR imagery for Illinois.

LiDAR and hillslope data have been valuable tools for mapping terraces in the Mississippi River Alluvial Plain (MRAP). Bettis and others (US Army Corps of Engineers Report, 1996) mapped a series of Wisconsin-age terraces in the MRAP. This mapping effort in the southeast not only confirmed the presence of these terraces but was able to further refine their boundaries. The Kingston Terrace (14,000-12,000 years ago) and the older Savanna Terrace (17,000-14,000 years ago) sit well above the elevation of the modern valley and are associated with outwash related to the development of the Mississippi River. An additional terrace level, interpreted as correlative with the older "St. Charles Group", was also identified at higher elevations in tributary valleys.

Overall, as demonstrated by the IGS' recent work in southeast Iowa, mapping not only helps refine and advance previous geologic understanding of an area, especially when new data is collected and new techniques are used, but it also provides essential subsurface information to Iowans to help them make informed decisions.

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FIGURE 3.

FIGURE 4.

FIGURE 5.

FIGURE 3.
Bedrock exposure near Starr's Cave in Des Moines County, Iowa (Emeritus IGS Geologist Brian Witzke is in the foreground). The Devonian English River Formation is at the base of the outcrop, overlain by the Mississippian Louisana Formation (formerly "McCraney" Formation), Prospect Hill Formation (gray in color), and Starr's Cave Member of the Wassonville Formation.

FIGURE 4.
Bedrock exposure of the Mississippian Warsaw Formation (overlain by the basal "St. Louis" Formation at the very top of the outcrop) in Lee County, Iowa.

FIGURE 5.
Coal fragment in Illinoian till (approximately 0.25-inch diameter).

Delineating Buried Bedrock Valley Aquifers Using Passive Seismic Geophysics

BY JOSEPH (JOE) P. HONINGS, ALYSSA M. BANCROFT, AND STEPHANIE A. TASSIER-SURINE

You may have visited Wildcat Den State Park in Muscatine County and noted the bedrock outcrops incised by streams — now imagine a similar topography, but on a somewhat larger scale. Envision the low-elevation areas being filled in with glacial sediments (sands, gravels, tills) deposited by the advance and retreat of continental ice sheets. Not only would these sediments completely mask the relief of the previous landscape, but they would also create very productive and desirable unconsolidated aquifers. These deposits are referred to as buried bedrock valley aquifers, and repeated episodes of Quaternary glaciation have left Iowans with potentially large, although poorly understood, reservoirs of groundwater resources. The Iowa Geological Survey (IGS) is currently investigating a buried bedrock valley in east-central Iowa, historically referred to as the Cleona Channel, with a focus on Muscatine County (**Figure 1**).

The bedrock surface of the Cleona Channel is not well-defined and its elevation can vary considerably over short distances. To delineate the dimensions of the this buried bedrock valley and characterize the unconsolidated Quaternary succession filling it, additional work is necessary. Although the IGS' GeoSam database contains more than 1,200 drilling records for Muscatine County, less than half of these actually penetrate the bedrock surface. The first step for constraining the geometry of the Cleona Channel is to 'fill in' these depth-to-bedrock data gaps. Horizontal-to-vertical spectral ratio (HVSR) passive seismic geophysical data (collected with a Tromino®) is a relatively quick, inexpensive, and non-invasive method for accomplishing this.

There are natural vibrations within the Earth which resonate differently due to contrasts in density between unconsolidated Quaternary sediments and the underlying (consolidated) bedrock. Very simply, the Tromino® is a tromograph that measures the longitudinal, transverse, and vertical components of these natural vibrations relative to the orientation of the instrument (**Figure 2**). The impedance contrast between the unconsolidated sediments overlying the bedrock (ultimately, the maximum ratio of the horizontal [longitudinal and transverse] spectra to the vertical spectra) can then be used to determine the depth to the bedrock surface (**Figure 3**).

With the assistance of a National Science Foundation (NSF) Grant* as well as U.S. Geological Survey STATEMAP funding, the IGS was able to hire University of Iowa (UI) Department of Earth and Environmental Sciences (EES) students as interns over the summer. It was with the help of these UI-EES student interns that the IGS was able to acquire more than 300 passive seismic data points in Muscatine County and the surrounding area to begin to help constrain the geometry of the Cleona Channel (**Figure 1**). The IGS is now using these data to design complementary geophysical surveys (specifically, electrical resistivity [ER]) and identify key locations for rotosonic borings. This initiative is ongoing and will require the collective expertise of all of the IGS Staff.

*_Iowa Environmental Internship Pathways Program, National Science Foundation (NSF) Improving Undergraduate STEM Education (IUSE), Award # 2119888 — received by University of Iowa Department of Earth and Environmental Sciences faculty (Bradley D. Cramer, Kate E. Tierney, Jessica R. Meyer, Benjamin J. Swanson) and IGS Geologist Stephanie A. Tassier-Surine_

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ACKNOWLEDGEMENTS

The IGS would like to thank Cameron Parrelly, Nathan Platt, Rachel Walenceus, Avery Norman, and Justyn Wyatt (University of Iowa Department of Earth and Environmental Sciences students) for all of their help collecting and processing passive seismic data during the Spring and Summer of 2023. These data are integral to the IGS' ongoing study of the Cleona Channel in Muscatine County.

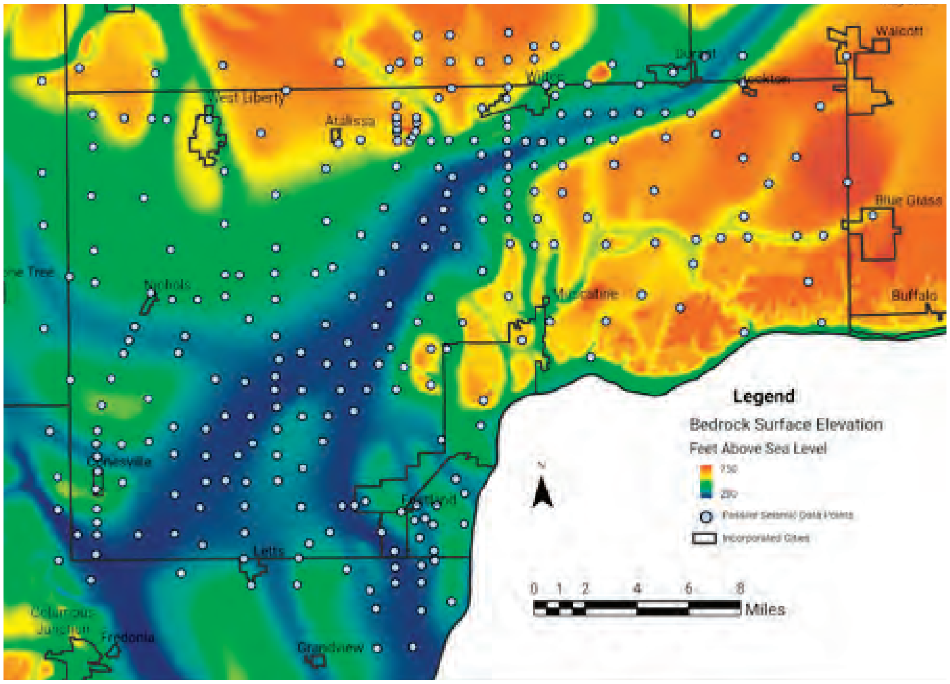


FIGURE 1.

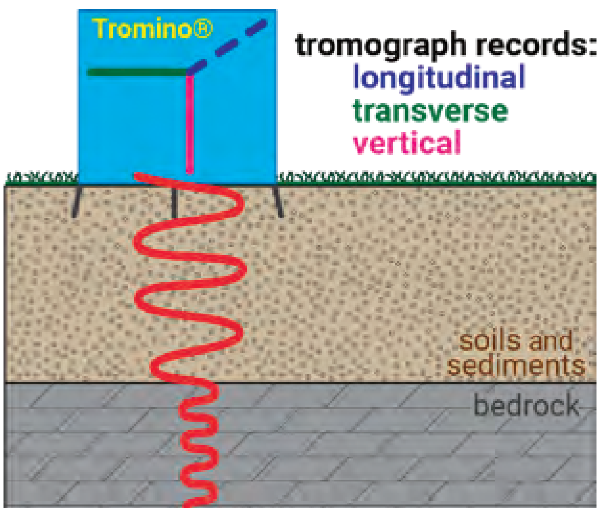


FIGURE 2.

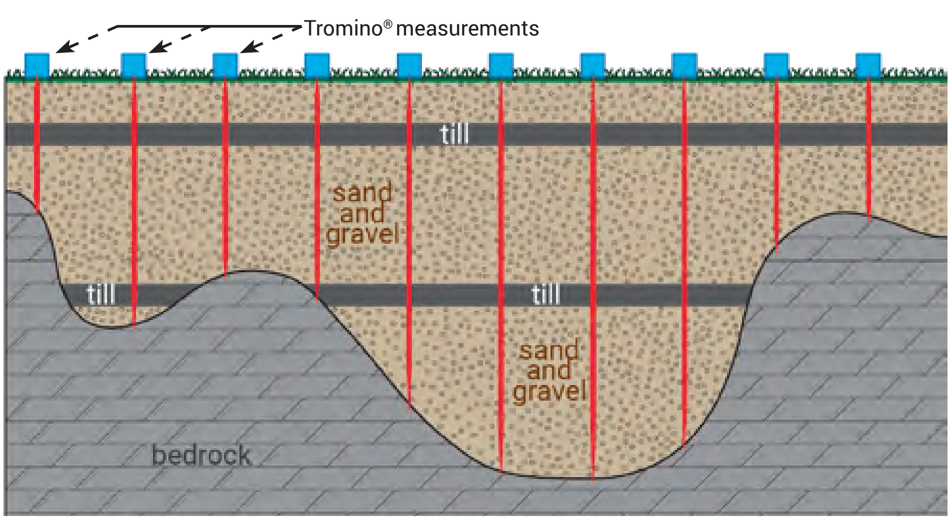


FIGURE 3.

FIGURE 1.
Map of the Muscatine County area of east-central Iowa. The color ramp represents areas of shallow (red/orange) to deeper (blue) bedrock topography, note the southwest-northeast trend of the Cleona Channel. The dots are locations where passive seismic (Tromino®) data have been collected

FIGURE 2.
Conceptual diagram (not to scale) of a tromograph (Tromino®) collecting data. Spikes secure the tromograph in the soil surface and record the longitudinal, transverse, and vertical components of vibrations in the subsurface. The natural vibrations (waves [red line]) within the Earth resonate within the unconsolidated soils and sediments and are amplified by waves moving upward from the consolidated bedrock beneath. The frequency of this resonance is related to the shear wave velocity and from this data the depth to bedrock can be calculated at a given locality.

FIGURE 3.
Conceptual cross-section (not to scale) of a buried bedrock valley filled with glacial deposits (sand, gravel, till). The sands and gravels represent buried bedrock valley aquifers, whereas the glacial tills compartmentalize the system. The blue boxes and corresponding red lines represent locations where passive seismic (Tromino®) measurements are taken and the data is then used to calculate the depth to bedrock at those localities to help constrain the geometry of the buried bedrock valley.

Wildcat Den State Park

ALYSSA M. BANCROFT, PHIL KERR, AND JACK MALONE

Iowa's state parks are some of the most beautiful and peaceful places to visit and reconnect with nature — Wildcat Den is no exception (**Figure 1**). Dedicated in 1935, Wildcat Den State Park encompasses 417 acres along Pine Creek in rural Muscatine County in southeastern Iowa. The park is located one mile north of the Mississippi River, approximately twelve miles northeast of the City of Muscatine. The rugged, rocky terrain and scenic sandstone cliffs are all accessible via a well-maintained trail system.

The oldest bedrock outcrops in the park are found along the creek banks. These units are fossiliferous limestones and dolostones of the Cedar Valley Group and were deposited during the Devonian (approximately 375 million years ago) when the region was covered by shallow tropical seas. There is a significant depositional gap (unconformity) in the geologic record within this park, as these Devonian strata are overlain by much younger Pennsylvanian shales, sandstones, and some coals. These Pennsylvanian strata were deposited nearly 65 million years later in a deltaic environment that was greatly influenced by fluctuating sea levels. The park's most remarkable features are its picturesque cliffs which are formed from the sandstones of the Cherokee Group. These fine-grained rocks record multiple episodes of erosion, transportation, and deposition within an ancient river system. Crossbedding preserved in these sandstones (**Figure 2**) indicate that these rivers were flowing from the newly formed Appalachian Mountains across modern-day Michigan, Indiana, and Illinois. Some areas of the cliffs seem to be decorated with reddish-brown swirls, rings, and bands called Liesegang rings or bands. These features were created by the chemical precipitation of iron oxides from mineralized groundwater that flowed through these sandstones after deposition.

More recently, this area has been covered by glaciers numerous times during the Quaternary, approximately 160,000-130,000 years ago during the Illinoian Episode. The ice sheets deposited glacial sediments and altered the drainage networks. After ice retreated, the Mississippi River flowed from Clinton, Iowa to St. Louis, Missouri through Peoria, Illinois. During the last glacial episode, the Wisconsinan, ice advanced southwest out of Lake Michigan which blocked the Mississippi River and formed glacial Lake Milan. When this glacial lake burst around 24,500 years ago, it flowed to the southwest and carved out a new valley. This diversion affected Wildcat Den by increasing the rate of incision of Pine Creek, exposing the ancient river deposits of the Cherokee Group. The most prominent of these sandstone formations have been given whimsical names, such as Devil's Punchbowl, Fat Man's Squeeze, and Steamboat Rock.

Wildcat Den is also home to two sites on the National Register of Historic Places: the restored Pine Creek Grist Mill (built in 1848, **Figure 3**) and the Pine Mill Bridge (constructed in 1878). So not only can visitors looking to connect with nature marvel at the rich geologic history of this particular state park, but they can also gain a unique perspective on life in rural Iowa during the 19th Century.

A more comprehensive synopsis of *The Natural History of Wildcat Den State Park* has been captured in the 1997 "Geological Society of Iowa, Guidebook 64" — a PDF version can be downloaded from the IGS Publications website.

All photographs included in this article were taken by Aneta Goska — she has captured the autumnal colors of Wildcat Den State Park.

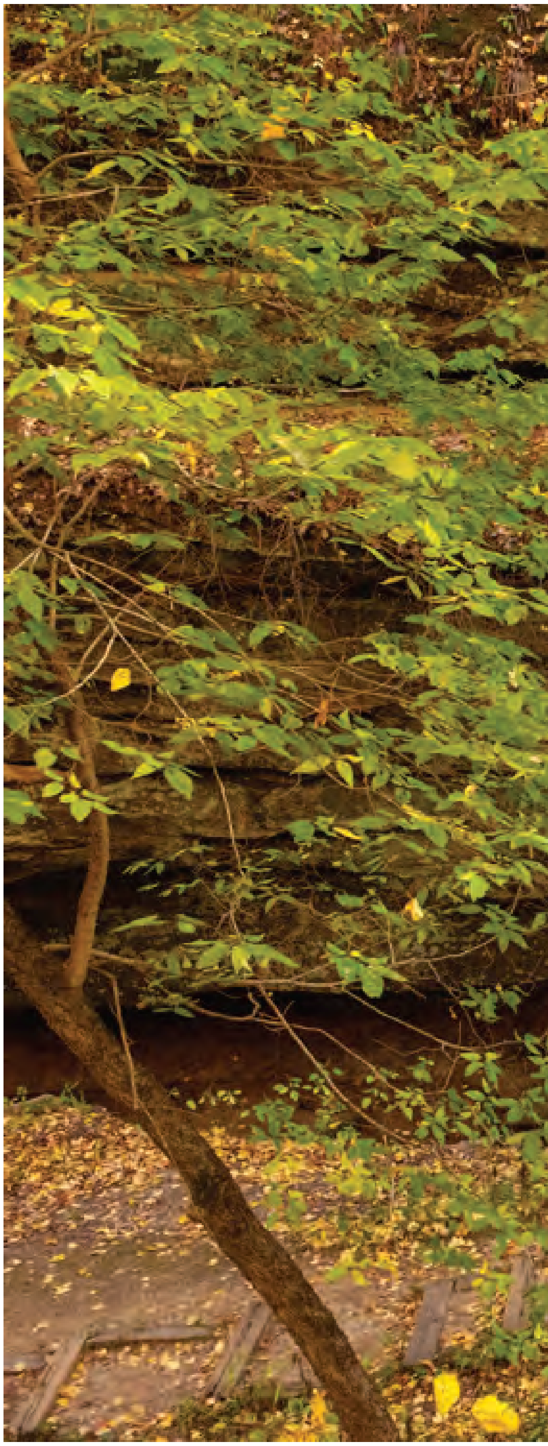


FIGURE 1.

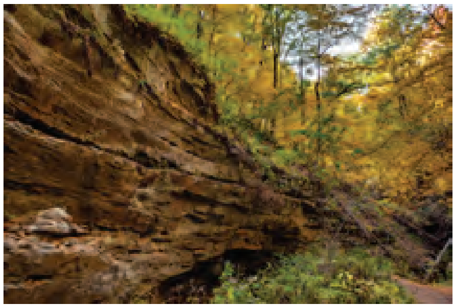


FIGURE 2.


FIGURE 3.

FIGURES 1 AND 2:
Note the crossbedding preserved in the Pennsylvanian sandstones of the Cherokee Group, exposed in the picturesque cliffs at Wildcat Den State Park.

FIGURE 3:
The Pine Creek Grist Mill, built in 1848, is one of two sites on the National Register of Historic Places at Wildcat Den State Park in Muscatine County, Iowa.

IGS Publications from Summer 2022 — Summer 2023

Anderson, E.S., 2022. "An Investigation of Iowa's Riverine Phosphorus Loads and Statewide Phosphorus Budget," Doctoral Dissertation, The University of Iowa.

Bancroft, A.M., **R.J. Clark**, and **P. Kerr**, 2023. Bedrock Geologic Map of the Atalissa 7.5' Quadrangle, Muscatine and Cedar Counties, Iowa: Iowa Geological Survey, Open File Map OFM-23-4, 1:24,000 scale map sheet.

Bancroft, A.M., **P. Kerr**, and **R.J. Clark**, 2023. Bedrock Elevation and Quaternary Thickness Maps of the Atalissa 7.5' Quadrangle, Muscatine and Cedar Counties, Iowa: Iowa Geological Survey, Open File Map OFM-23-5, 1:24,000 scale map sheet.

Beck, W., T. Isenhart, P. Moore, **K.E Schilling**, R.C. Schultz, K. Cole, and M.D. Tomer, 2022. "Fine-Grained Sediment and Phosphorus Storage in a Suspended-Load-Dominated, Alluvial Channel," *Journal of the ASABE*, 65(5):1149-1162.

Brennan, G.J. and **J.A. Vogelgesang**, 2023. "Drinking Water Protection in Decorah, Iowa," Iowa Geological Survey, Water Resources Investigation WRI-19, 39 p.

Clark, R.J., **S.A. Tassier-Surine**, **P. Kerr**, and **A.M. Bancroft**, 2023. Bedrock Geologic Map of Des Moines County, Iowa: Iowa Geological Survey, Open File Map OFM-23-1, 1:100,000 scale map sheet.

Clark, R.J. and **P. Kerr**, 2023. Bedrock Elevation and Quaternary Thickness Maps of Des Moines County, Iowa: Iowa Geological Survey, Open File Map OFM-23-3, 1:100,000 scale map sheet.

Kerr, P., **S.A. Tassier-Surine**, and **A.M. Bancroft**, 2023. Surficial Geologic Map of the Muscatine NW 7.5' Quadrangle, Muscatine County, Iowa: Iowa Geological Survey, Open File Map OFM-23-6, 1:24,000 scale map sheet.

Oborny, S.C., B.D. Cramer, C.E. Brett, and **A.M. Bancroft**, 2022. "Chronostratigraphic Correlation of the Upper Silurian Salina Group for the Michigan and Appalachian Basins Through Coupled ($\delta^{13}C_{carb}$) Chemostratigraphy and Subsurface Geophysical Analyses," *Geosphere*, 18(6):1910-1925.

Pierce, S.M. and **K.E. Schilling**, 2023. "Nutrient Retention in Tile-Fed and Non-Tile Reconstructed Oxbows in North Central Iowa," *Journal of the American Water Resources Association*, 00(0):1-16.

Schilling, K.E., **E.S. Anderson**, **M.T. Streeter**, and C. Theiling, 2023. "Long-Term Nitrate-Nitrogen Reductions in a Large Flood Control Reservoir," *Journal of Hydrology*, 620(B):129533.

Schilling, K.E., J. Mount, K.M. Suttles, E.L. McLellan, P.W. Gassman, M.J. White, and J.G. Arnold, 2023. "An Approach for Prioritizing Natural Infrastructure Practices to Mitigate Flood and Nitrate Risks in the Mississippi-Atchafalaya River Basin," *Land*, 12(2):276.

Schilling, K.E., **M.T. Streeter**, C.S. Jones, and P.J. Jacobson, 2023. "Dissolved Inorganic and Organic Carbon Export from Tile-Drained Midwestern Agricultural Systems," *Science of the Total Environment*, 883:163607.

Schilling, K.E., **C.F. Wolter**, J.A. Palmer, W.J. Beck, F.F. Williams, P.L. Moore, and T.M. Isenhart, 2023. "An Assessment of Streambank Erosion Rates in Iowa," *Environments*, 10(5):84.

Schmitz, E.V., C.L. Just, **K.E. Schilling**, **M.T. Streeter**, and T.E. Mattes, 2023. "Reconnaissance of Oxygenic Denitrifiers in Agriculturally Impacted Soils," *mSphere*, 8(3):e00571-22.

Stolfus, B.M., L.J. Allman, S.A. Young, M. Calner, E.R. Hartke, S.C. Oborny, **A.M. Bancroft**, and B.D. Cramer, 2023. "Expansion of Reducing Marine Environments During the Ireviken Biogeochemical Event: Evidence from the Altajme Core, Gotland, Sweden," *Paleoceonography and Paleoclimatology*, 38(2):e2022PA004484.

Streeter, M.T., **K.E. Schilling**, C.S. Jones, and M. St. Clair, 2023. "Effects of Cattle Manure and Soil Parent Material on Shallow Groundwater Quality," *Agrosystems, Geosciences, and Environment*, 6(3):e20380-12.

Tassier-Surine, S.A., **R.J. Clark**, **P. Kerr**, and A.M. Bancroft, 2023. Surficial Geologic Map of Des Moines County, Iowa: Iowa Geological Survey, Open File Map OFM-23-2, 1:100,000 scale map sheet.

Zhang, J., X. Liang, Y.-K. Zhang, X. Chen, E. Ma., and **K.E. Schilling**, 2022. "Groundwater Responses to Recharge and Flood in Riparian Zones of Layered Aquifers: An Analytical Model," *Journal of Hydrology*, 614(B):128547.

Sadie Richter, University of Iowa (UI) Department of Earth and Environmental Sciences (EES) undergraduate student and IGS intern, presenting a poster of work she did with IGS Geologist Phil Kerr on the Quaternary succession in Iowa at the 21st International Union for Quaternary Research (INQUA) Conference in Rome, Italy.

IGS Presentations from Summer 2022 — Summer 2023

**IGS Student Intern Presentation*

Anderson, E.S., "Investigating Iowa's Riverine Phosphorus Loads and Statewide Phosphorus Budget," Science Team Meeting at the Iowa Nutrient Research Center (INRC), Virtual Presentation, June 6, 2022.

Anderson, E.S., "Event-Based Phosphorus Sampling in Iowa," Prairie Lakes Conference, Okoboji, Iowa, August 8, 2022.

Schilling, K.E., "Oxbows and Drainageways as New Tile Drainage Edge-of-Field Practice Opportunities," International Drainage Symposium, Des Moines, Iowa, September 1, 2022.

Streeter, M.T., "Evaluating the Effectiveness of Stacked Practices: Utilizing Modified Blind Inlets at Terrace Sites for N and P Load Reductions," International Drainage Symposium, Des Moines, Iowa, September 1, 2022.

Schilling, K.E., "Potential for Enhancing Nutrient Reductions in Iowa's Roadside Ditches," Iowa Roadside Conference, Okoboji, Iowa, September 9, 2022.

Streeter, M.T. and **K.E. Schilling**, "In-Field and Edge-of-Field Opportunities for Nutrient Reduction at a Community College," Kirkwood Community College Lunch and Learn, Cedar Rapids, Iowa, September 15, 2022.

Kerr, P., **S.A. Tassier-Surine**, and **K.E. Schilling**, "Outside of the (Quadrangle) Box: Surficial Mapping of a HUC 12 Watershed to Enhance Societal Relevancy," Geologic Mapping Forum Online, Virtual Presentation, September 29, 2022.

Anderson, E.S., "Monitoring Phosphorus and Turbidity During High Flows," Iowa Water Conference, Dubuque, Iowa, September 29, 2022.

Streeter, M.T., "Forest Soil Genesis and Geomorphology," Iowa State University Forestry Field Day, Yellow River State Forest, October 6, 2022.

***Schopen, E.** and **P. Kerr**, "Using Remote Sensing to Identify Stabilized Late Wisconsin Sand Dunes in Eastern Iowa," Geological Society of America Annual Meeting, Denver, Colorado, October 9, 2022.

Kerr, P., "On the Long-Term Behavior of the Laurentide Ice Sheet Using Newly Identified Pre-Illinoian (> MIS 6) Margins," Geological Society of America Annual Meeting, Denver, Colorado, October 11, 2022.

Kerr, P. and **S.A. Tassier-Surine**, "The Status of MIS 3 Tills in Iowa, USA," Geological Society of America Annual Meeting, Denver, Colorado, October 11, 2022.

Clark, R.J., "Using HVSR "Passive Seismic" Geophysical Mapping Techniques to Enhance Bedrock Topography," Iowa Groundwater Association, Newton, Iowa, November 9, 2022.

Vogelgesang, J., "Introduction to Near-Surface Geophysical Field Methods," University of Iowa Earth and Environmental Sciences Guest Lecture, Iowa City, Iowa, December 6, 2022.

Tassier-Surine, S.A., "Benefits of Geologic Mapping in Iowa," Iowa County Engineers Association, December 15, 2022.

Schilling, K.E., "Floodplains and Conservation Opportunities," Iowa Learning Farms Conservation Webinar Series, Virtual Presentation, January 4, 2023.

Streeter, M.T., "Evaluating the Effectiveness of Stacked Practices — Can Modified Blind Inlets at Terrace Sites Reduce N and P Loads?" Iowa Learning Farms Conservation Webinar Series, Virtual Presentation, January 19, 2023.

Schilling, K.E., "Drought and the Development of Iowa's Drought Plan," Iowa Water Well Association, Des Moines, Iowa, January 26, 2023.

Schilling, K.E., "Hydrogeology of Iowa," National Ground Water Association (NGWA) Hydrogeology of States Webinar Series, Virtual Presentation, January 31, 2023.

Clark, R.J., "The Future of Carbon Sequestration in Iowa," Iowa Legislature — Environmental Protection Committee, Des Moines, Iowa, February 1, 2023.

Streeter, M.T., **K.E. Schilling**, **E.S. Anderson**, and **T.V. Stoeffler,** "Sediments and Nutrients at Red Rock Reservoir, Iowa," U.S. Army Corps of Engineers Project Update Meeting, Knoxville, Iowa, February 8, 2023.

Schilling, K.E. and **E.S. Anderson**, "Potential for Natural Infrastructure to Reduce Flood and Nitrate Risks in the Mississippi River Basin," Department of Earth and Environmental Sciences Seminar, University of Iowa, Iowa City, Iowa, February 10, 2023.

Clark, R.J., "The Potential for Geologic Carbon Sequestration in Iowa," Department of Earth and Environmental Sciences Seminar, University of Iowa, Iowa City, Iowa, February 17, 2023.

Clark, R.J., "What's in a Map? A Behind the Scenes Look at the Bedrock Geologic Map of Lee County, Iowa," Cedar Valley Rocks and Minerals Society, Cedar Rapids, Iowa, February 21, 2023.

Schilling, K.E., "Following the Water: Roadside Ditches and Oxbows as Nutrient Reduction Opportunities," Iowa Nutrient Research Center (INRC) Highlight Presentation, Iowa State University, Ames, Iowa, March 8, 2023.

Streeter, M.T., "Evaluating the Effectiveness of Stacked Practices: Utilizing Modified Blind Inlets at Terrace Sites for N and P Load Reductions," Iowa Nutrient Research Center (INRC) Highlight Presentation, Iowa State University, Ames, Iowa, March 8, 2023.

Clark, R.J., "The Potential for Geologic Carbon Sequestration in Iowa," Public Health Conference of Iowa, Ames, Iowa, March 28, 2023.

Kerr, P., "The Glacial History of Storm Lake," Storm Lake 150th Celebration (Sanford Museum and Planetarium, Buena Vista University, and Buena Vista County Historical Society), Storm Lake, Iowa, April 15, 2023.

Vogelgesang, J., "Adventures in Geophysics: How the Iowa Geological Survey Uses Geophysics to Image Beneath the Ground," Cedar Valley Rocks and Minerals Society, Hiawatha, Iowa, April 18, 2023.

Schilling, K.E., "Groundwater Monitoring in Floodplains: How Floodplains Function to Process Water and Nutrients in Agricultural Watersheds," Invited Seminar Presentation, U.S. Geological Survey (USGS) Upper Midwest Environmental Sciences Center, Lacrosse, Wisconsin, May 17, 2023.

Schilling, K.E., "State Geological Surveys and Managed Aquifer Recharge," National Academies of Sciences, Engineering and Medicine, Virtual Presentation, June 7, 2023.

Brennan, G.J., "Drinking Water Protection," City of Decorah, Iowa, Public Meeting, June 27, 2023.

Streeter, M.T., "In-Field and Edge-of-Field Opportunities for Nutrient Reduction at a Community College," Iowa Learning Farms Conservation Webinar Series, Virtual Presentation, June 28, 2023.

Kerr, P., "The Current State of Glacial Stratigraphy form the Gelasian to Chibanian stages in the Midwest United States," 4th International Congress on Stratigraphy (STRATI), Lille, France, July 11, 2023.

Kerr, P., "Loess, Sand, Wind and Ice: A Midwestern United States Late Wisconsin (MIS 2) polygenetic Landscape and the Formation of Paha," 21st International Union for Quaternary Research (XXI INQUA), Rome, Italy, July 18, 2023.

*__Richter, S__. and **Kerr, P.**, "Evidence for an Illinoian (MIS 6) Aged 3,500 km^2 Proglacial Lake in the Midwestern United States," 21st International Union for Quaternary Research (XXI INQUA), Rome, Italy, July 18, 2023.

Kerr, P., "Insights into the Long-Term Behavior of North American Ice Sheets from Newly Identified Middle Pleistocene Margins," 21st International Union for Quaternary Research (XXI INQUA), Rome, Italy, July 19, 2023.

Selected FY23 IGS Projects

A Vision Toward a More Resilient Iowa Great Lakes: Keith E. Schilling: Iowa Department of Natural Resources (IDNR)

Advanced Modeling of Soil Erosion, Sediment Delivery, and Nutrient Export from Iowa Watersheds: Matthew T. Streeter: Iowa Nutrient Research Center (INRC)

Critical Minerals in Coaly Strata of the Cherokee-Forest City Basin: Ryan J. Clark: U.S. Department of Energy (DOE)

Desktop Evaluation of Timber and Lafayette Ridge: Greg J. Brennan: Ames Construction

Desktop Study of the Mississippian Aquifer at Rosebud Farms: Greg J. Brennan: City of Iowa Falls

Developing Design Criteria to Test a New Saturated Waterway Conservation Practice: Keith E. Schilling: Iowa Nutrient Research Center (INRC)

#DiverseCornBelt: Resilient Intensification through Diversity in Midwestern Agriculture: Keith E. Schilling: U.S. Department of Agriculture (USDA)

Drinking Water Protection: Greg J. Brennan: Iowa Water Quality Consulting

Earth Mapping Resources Initiative (Earth MRI): Cooperative Agreement for Geochemical Reconnaissance: Critical Minerals in Pennsylvanian Black Shales of the US Midcontinent: Alyssa M. Bancroft: U.S. Geological Survey (USGS)

Evaluating a Two-Stage Roadside Ditch Design to Improve Environmental Performance: Keith E. Schilling: Iowa Department of Transportation (IDOT)

Evaluating the Effectiveness of Stacked Practices: Utilizing Modified Blind Inlets at Terrace Sites for N and P Load Reductions: Matthew T. Streeter: Iowa Nutrient Research Center (INRC)

Evaluating the Nutrient Reduction Benefits of Farm Ponds: Keith E. Schilling: Iowa Nutrient Research Center (INRC)

Evaluating the Relation of Total Phosphorus to Turbidity During High Flow Events to Improve Quantification of Phosphorus Export from Iowa Rivers: Keith E. Schilling: Iowa Nutrient Research Center (INRC)

Geophysical and Geologic Services Near the Chemplex Facility, Camanche, Iowa: Ryan J. Clark: GHD Engineering, Architecture, and Construction Services

Geophysical Reconnaissance, Iowa River Alluvial Aquifer: Greg J. Brennan: City of Iowa City

Illinois Basin Carbon Ore, Rare Earth, and Critical Minerals (CORE-CM) Initiative: Ryan J. Clark: U.S. Department of Energy (DOE)

Iowa Environmental Internship Pathways Program: Stephanie A. Tassier-Surine: National Science Foundation (NSF) Improving Undergraduate STEM Education (IUSE)

National Geological and Geophysical Data Preservation Program (NGGDPP) — Data Preservation and Critical Minerals Activities in Iowa 2022-2023: Richard J. Langel: U.S. Geological Survey (USGS)

National Ground-Water Monitoring Network (NGWMN) — Revitalization of the IGS' Cretaceous Well Network: Phase 1: Richard J. Langel: U.S. Geological Survey (USGS)

Levee Imaging: A Pilot Assessment: Jason Vogelgesang: Iowa Department of Homeland Security and Emergency Management (HSEMD)

Nitrate Reduction via Reservoir Water Level Management in Central Iowa: Keith E. Schilling: U.S. Army Corps of Engineers (DOD)

Permitting Assistance for Jordan Well: Greg J. Brennan: Ottumwa Water Works

Polk County Science Advisory Committee: Elliot S. Anderson: Polk County, Iowa

Regional Initiative to Accelerate CCUS Deployment in Midwestern and Northeastern USA: Ryan J. Clark: U.S. Department of Energy (DOE), Midwest Regional Carbon Initiative (MRCI)

Soil and Plant Health Analysis: Matthew T. Streeter: Perimeter Solutions LP

STATEMAP FY2022 — Geologic Mapping in Iowa: Including Projects in Muscatine, Des Moines, and Black Hawk Counties: Stephanie A. Tassier-Surine: U.S. Geological Survey (USGS)

Financials

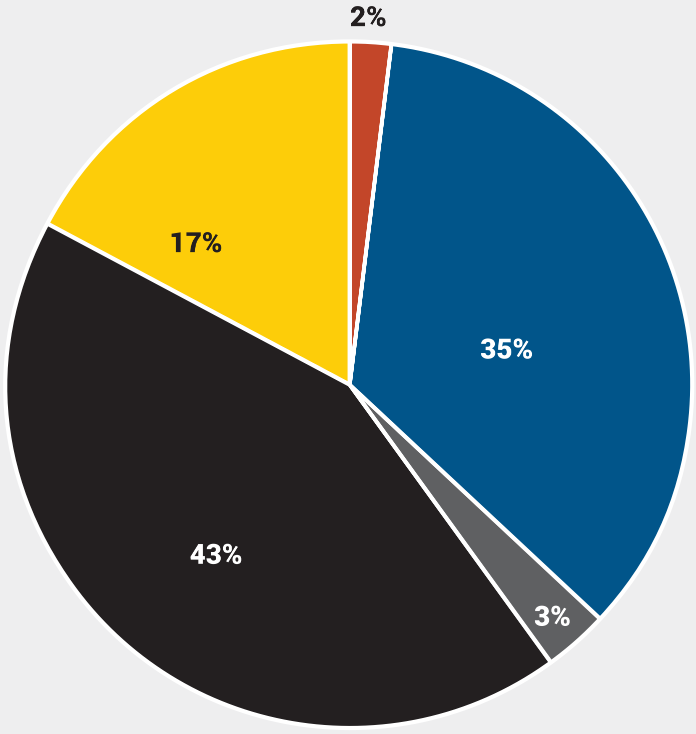
Funding for the Iowa Geological Survey (IGS) is provided through a combination of sources. A state appropriation provides approximately 35% of our annual operating budget, and while the amount has remained constant over the last few years it is declining as a percentage of our overall budget. The IGS leverages this base funding to obtain support for a diverse portfolio of projects from a variety of funding sources. In 2022–2023, these funding sources included local municipalities, state agencies, the U.S. Geological Survey (USGS), the Iowa Department of Transportation (Iowa DOT), and the Iowa Nutrient Research Center (INRC), among others. It is quite noteworthy that the entire 2022–2023 operating budget for the IGS was funded by these diverse sources.

The University of Iowa (UI) Department of Earth and Environmental Sciences (EES) continues to allow the IGS to leverage a portion of its own state appropriation to secure additional funding from the USGS — and we sincerely appreciate the collaboration and support of the UI-EES!

The IGS will always continue to seek external funding. However, an increase in our annual state appropriation would allow the Survey to leverage even more when applying for this outside support — meaning that the state's return on its investment in the IGS would also increase as would the benefits for Iowans. Ultimately, an increase to our annual state appropriation would ensure that the IGS can continue to focus on regional statewide initiatives and provide science-based information to support the decision-making necessary for effectively managing Iowa's natural resources for long-term sustainability and economic development. As always, the IGS is more than willing to collaborate with existing and new clients on exciting, impactful projects.

FY 2022 $1,983,265

- **Municipal** City Water Projects (2%)
- **State Appropriation** (35%)
- **INRC** Iowa Nutrient Research Center (3%)
- **Federal Agencies** U.S. Geological Survey, Natural Resources Conservation Service, Environmental Protection Agency, US Department of Energy (43%)
- **Other** Non-Government Contracts, Iowa DNR, Iowa DOT, Iowa Department of Agriculture and Land Stewardship (17%)



FY2019	FY2020	FY2021	FY2022	FY2023
$1,633,533	$1,596,525	$1,807,632	$1,715,862	$1,983,265

IGS Geologists Then and Now

Although the basic tenets of geologic study are still the foundation upon which we stand, the tools that are employed as we test our working hypotheses have evolved significantly! Please have a look at some of the articles featured in this year's *Geode* to see how IGS Staff are addressing Iowa's geologic questions today.

TOP PHOTO.
Bedrock Geologic Fieldwork in the late 19th Century and early 20th Century — a geologist studying an outcrop of the Upper Ordovician lower Maquoketa Formation (at Graf) in Dubuque County, Iowa. Photograph from the University of Iowa Digital Library — Calvin Geological Photographs.

MIDDLE LEFT PHOTO.
Bedrock Geologic Fieldwork in the early 21st Century — IGS Bedrock Geologist Ryan Clark, contemplating the Upper Ordovician basal Maquoketa phosphorite at Graf, Iowa (Dubuque County). Photograph taken by IGS Bedrock Geologist Jack Malone.

BOTTOM LEFT PHOTO.
Surficial Geologic Fieldwork in the late 19th Century and early 20th Century — a geologist studying Illinoian till capped by loess in Muscatine County, Iowa (note the nesting burrows of birds in the loess at the top of the section). Photograph from the University of Iowa Digital Library — Calvin Geological Photographs.

BOTTOM RIGHT PHOTO.
Surficial Geologic Fieldwork in the early 21st Century — IGS Quaternary Geologist, Phil Kerr, pondering the Sangamon Geosol formed in sand and gravel which is capped by Peoria Loess at Wendling's Moscow Quarry in Muscatine County, Iowa. Photograph taken by UI-EES undergraduate student Sadie Richter.