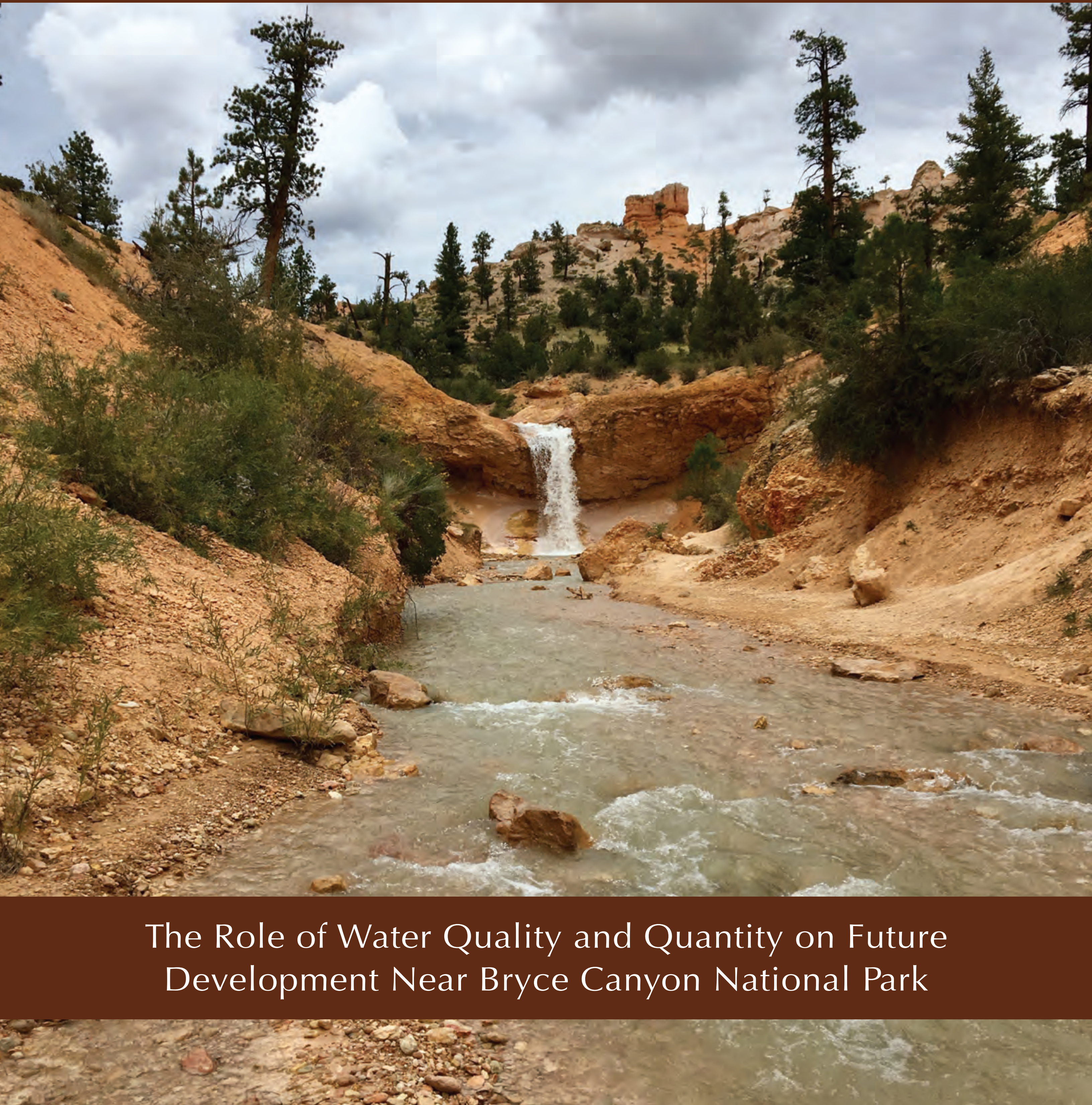
UTAH GEOLOGICAL SURVEY

SURVEY NOTES

Volume 53, Number 2 May 2021



The Role of Water Quality and Quantity on Future Development Near Bryce Canyon National Park

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Design | *John Good*
Cover | Tropic Ditch flowing over Water Canyon Falls through Bryce Canyon National Park. Photo by Trevor Schlossnagle.

Survey Notes is published three times yearly by the Utah Geological Survey, 1594 W. North Temple, Suite 3110, Salt Lake City, Utah 84116; (801) 537-3300. The UGS provides timely scientific information about Utah's geologic environment, resources, and hazards. The UGS is a division of the Department of Natural Resources. Single copies of *Survey Notes* are distributed free of charge within the United States and reproduction is encouraged with recognition of source. Copies are available at https://geology.utah.gov/map-pub/survey-notes/. ISSN 1061-7930 Printed on recycled paper

DIRECTOR'S PERSPECTIVE

by Bill Keach

I am not a fan of viewing today as "the new normal." For me, normal has always been a matter of facing what is in front of you and learning from the past, and there was a lot to learn in the past year. I wrote previously about the need to move our 18,000-pound block of *Utahraptor* fossils. We made the move in February 2020, literally weeks before the pandemic shut down much of what we do. In hindsight, the move was a blessing. With the block in its new isolated home, curation work has continued uninterrupted for the past year. In that time, the block has yielded many new fossil bones, including those of juvenile Utahraptors.

In front of us, there is new focus on what some might call the "Grand Challenges of Utah": water availability and quality, increased exposure to natural hazards, energy and minerals availability, and air quality. Utah's new Governor has placed an emphasis on improving the lives of the citizens in our state. Facing the Grand Challenges is part of the process. The UGS is uniquely poised to assist in defining the path forward. Let's look briefly at each of the Grand Challenges.

Water Availability and Quality – UGS teams evaluate and quantify water budgets in areas of rapid growth, providing local communities with the information needed to make sound decisions to manage potential impacts. They also compile wetlands classification maps for Utah, particularly those areas being impacted by urban growth. The lead article in this issue of *Survey Notes* looks at water quality in the Bryce Canyon area.

Exposure to Natural Hazards – Last year's magnitude 5.7 earthquake in the Salt Lake Valley was a reminder that we are not immune to natural hazards. We need to better prepare for all types of natural hazards, including landslides, rockfalls, and yes, earthquakes. At the UGS, we map and identify potential geologic hazards in the state, with a particular emphasis on areas that have large and growing populations. This information is shared with the public through our *Utah Geologic Hazards Portal*.

Energy and Minerals Availability – Critical minerals are essential in the development of renewable energy, solar in particular. In the past year, governmental agencies and the private sector have contacted the UGS regarding the availability of critical minerals in Utah. Currently, most of the critical minerals used in the manufacture of "clean energy" devices come from outside the U.S. The UGS is providing insight on how and where to find the critical mineral resources that exist in Utah.

Geothermal energy is another resource in Utah that we may not hear much about. However, Utah has two facilities generating electricity from geothermal resources and we are experiencing an increased interest in finding and developing more. In the future we will see more.

Air Quality – Utah has seen improvements in our air quality; however, much remains to be done. Over the last few years, researchers from the University of Utah and Brigham Young University worked together to better understand where the particulates in our air come from. Surprisingly, many come from wind-caused soil erosion in the west desert and the Bonneville Salt Flats. As the climate becomes warmer and drier, we will need to better understand the mechanisms that contribute particulates to the atmosphere; this is the work of geologists.

Of course, there are other "Grand Challenges." These are a few that the UGS is working on to improve the lives of those who live in Utah.

The Role of Water Quality and Quantity on Future Development Near Bryce Canyon National Park

by Janae Wallace and Trevor Schlossnagle

Bryce Canyon National Park (BCNP) and its environs host spectacular variegated pink, orange, and white-colored cliffs of the Claron Formation that attract millions of visitors every year. BCNP was designated as a national monument in 1923 and became a national park five years later. The rural area surrounding BCNP was settled by Mormon pioneers in the 1850s and in 2007, nearby Bryce Canyon City was established. Visitation to BCNP and the surrounding area is growing. For example, approximately 1.7 million people visited the park in 2015 compared to 2.7 million people in 2018. This increase in visitors has put a strain on the current water supply wells and wastewater disposal systems in the area. Bryce Canyon City gets its water from public supply wells and has its own sewage lagoons, whereas the surrounding community of scattered residents, campgrounds, and larger hotel developments use individual wells for water and septic tanks for waste disposal. Potential future development, groundwater resources development, and the threat of future drought in southwestern Utah prompted our study of groundwater quality and quantity for BCNP and Bryce Canyon City.

Groundwater resources in the area include an aquifer in alluvial sediments filling the valleys, an aquifer in rocks of the Tertiary-age Claron Formation, and bedrock aquifers in older Cretaceous-age strata. Aquifers in the valley fill and Claron Formation feed springs, seeps, and waterfalls in BCNP and supply water to wells used by the park and the local community. Snowmelt and headwater springs that issue from the Claron Formation and local alluvial deposits also feed the East Fork Sevier River, which originates south of Emery Valley and is an important source of irrigation water in nearby Tropic Valley. The East Fork Sevier River flows through Emery Valley from southwest to northeast and continues northeast through Johns Valley. The hand-dug Tropic Ditch taps into the East Fork Sevier River and transports water east through Water Canyon toward Tropic Valley from April until October. Understanding the interactions between the groundwater aquifers and surface water (seeps, springs, and the East Fork Sevier River) in Johns and Emery Valleys is a key goal of this study.

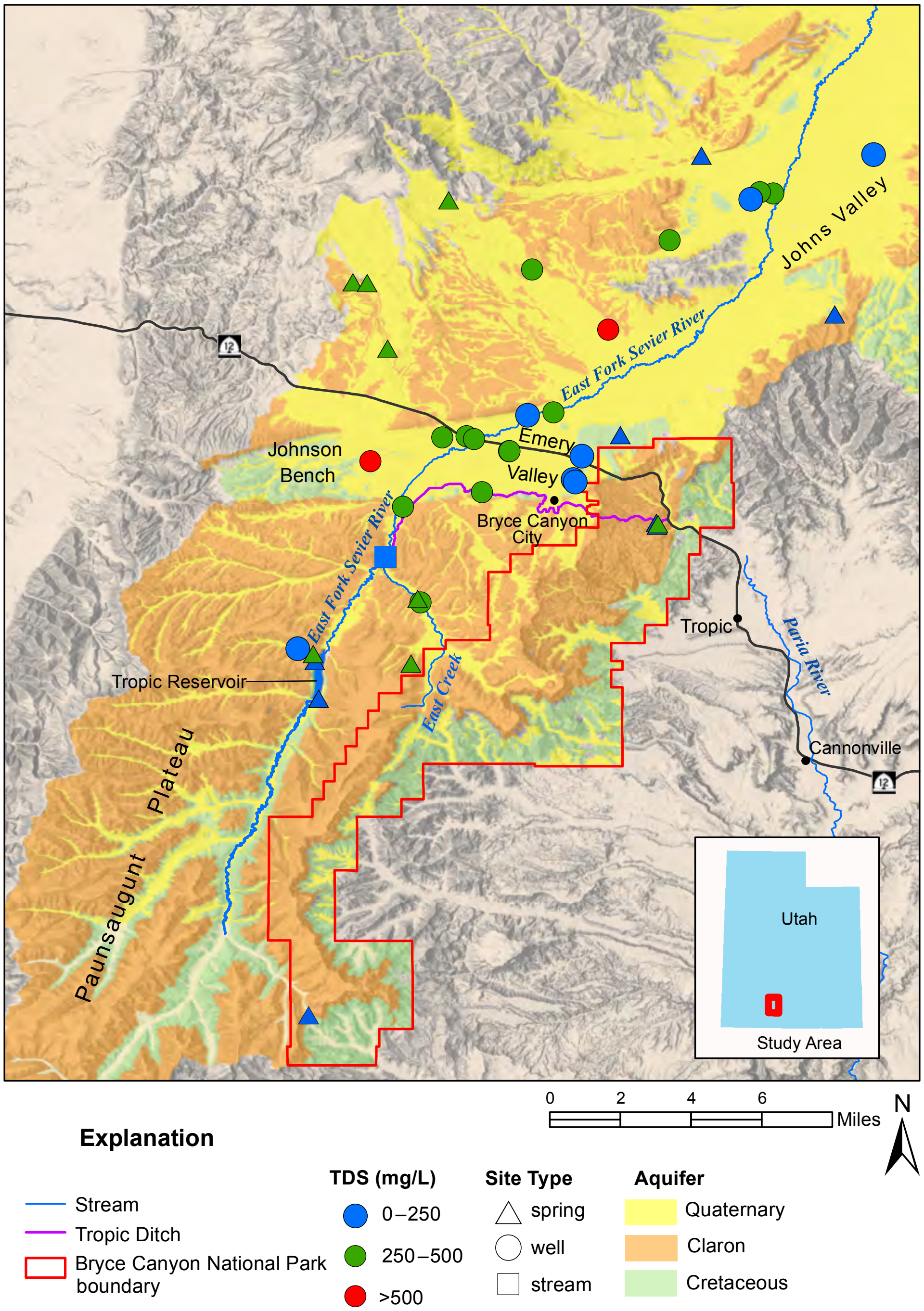
Capturing spring flow and collecting water samples of a spring at the headwaters of the East Fork Sevier River.

To shed light on the groundwater–surface-water relationship, we measured flow in streams and canals, including the Tropic Ditch, and measured water levels in wells to generate a map that shows contours of water-level elevations used to help understand groundwater flow in the valley. We collected geochemistry and stable isotope data from wells, springs, and streams in the area to characterize water quality and to determine how groundwater and surface water interact. We used the radiogenic isotope data to determine how long the water has been in the groundwater system.

Seepage runs consist of measuring flow at multiple points along streams and canals to determine where water seeps from the stream into the ground or from the ground into the stream. The difference between flow at the upstream and downstream ends of a stream reach is assumed to be due to seepage. During most irrigation seasons, the entirety of the East Fork Sevier River is diverted into the Tropic Ditch, which for about a century has transported water through Water Canyon within BCNP to irrigate crops in the nearby town of Tropic. The Tropic Ditch is unusual in that it transports water across a major hydrographic boundary. Unimpeded, the East Fork Sevier River flows toward Sevier Lake, a terminal lake within the Great Basin to the west. However, water flowing in the Tropic Ditch ends up in the Paria River drainage, which flows southeastward to the Colorado River and ultimately the Gulf of California. During one of the seepage runs after the heavy snowpack of winter 2019, we measured over half the total flow of the East Fork Sevier River continuing past the Tropic Ditch diversion point during irrigation season. By the time the East Fork Sevier River reached the downstream boundary of the study area, 75 percent of its flow was lost to groundwater, recharging the valley-fill aquifer.

Water levels were measured in wells across four seasons from 2018 to 2020. Winter snowpack was far below average in 2018, far above average in 2019, and average in 2020. The heavy 2019 snowpack, followed by a normal snowpack in 2020, resulted in increased water levels in many valley-fill aquifer wells. Over half the valley-fill wells had water-level increases of at least 10 feet. Water levels in wells completed in bedrock aquifers were less variable than wells completed in valley fill, with some water levels declining and others rising during different seasons and years, weather independent. Water-level increases in valley-fill wells after heavier winter snowpack indicates the valley-fill aquifer is more sensitive to precipitation via surface water runoff and direct infiltration than the bedrock aquifers.

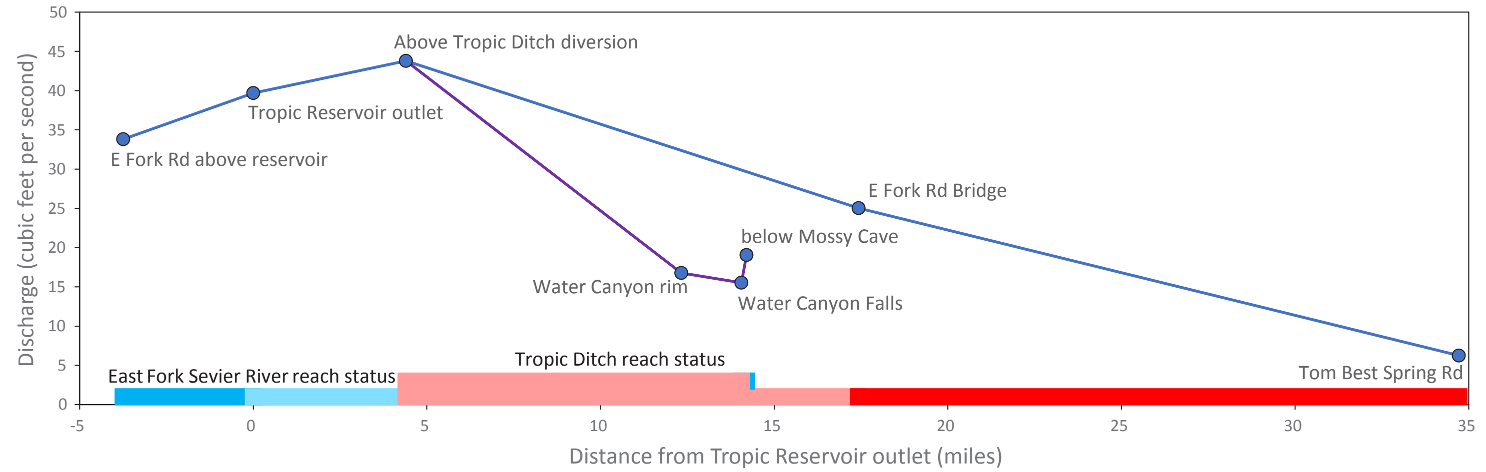
The UGS evaluated water quality in streams, wells, and springs in 2018 and 2019. Sample collection focused on characterizing the valley-wide major solute chemistry and measuring nitrate concentrations. Major solute chemistry is characterized as calciummagnesium bicarbonate type. Overall water quality, defined here as the amount of total dissolved solids (TDS), is excellent in the valley-fill and Claron Formation aquifers and is classified as Pristine (less than 500 milligrams per liter [mg/L] TDS) based on the Utah Division of Water Quality Board's groundwater quality classification scheme. Water from the older Cretaceous sandstone aquifers underlying the valley fill has slightly higher TDS and is considered Drinking Water quality (between 500 and 3,000 mg/L TDS). With continued population growth and installation of septic tank soil-absorption systems in new developments, the potential for nitrate contamination will increase. The UGS modeled the impact of septic tanks on groundwater and recommended that advanced large underground wastewater disposal systems be utilized instead of individual septic tank systems to limit the increase in mean nitrate concentration above the current valley-wide background nitrate concentration of 0.35 mg/L.



Location map of the Bryce Canyon National Park and Johns and Emery Valleys area, showing aquifer outcrops, sampling locations, and total-dissolved-solids concentrations for wells, springs, and streams, including the East Fork Sevier River.

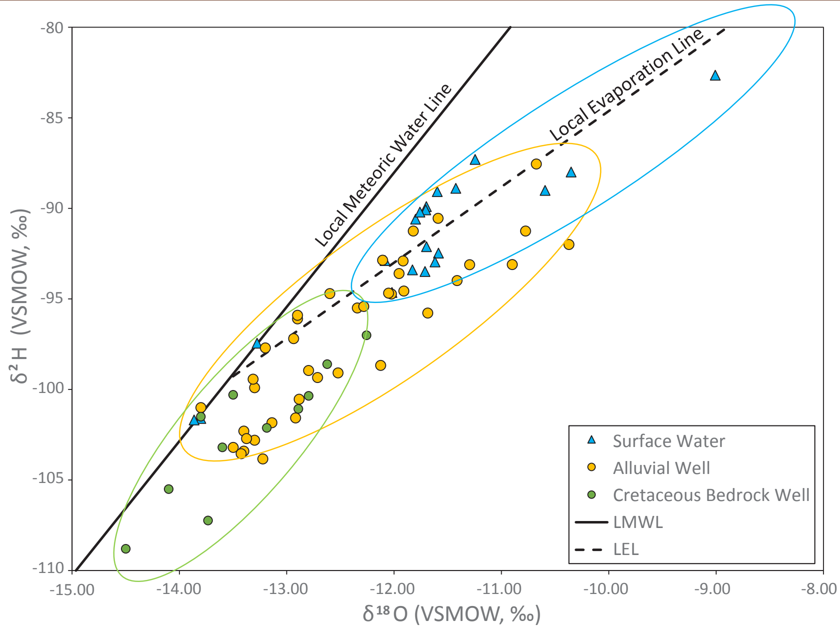
The water quality samples collected in 2018 and 2019 were also analyzed for stable and radiogenic isotopes. Stable isotope composition of hydrogen and oxygen in water molecules can be used to determine the source and timing of recharge of groundwater and how surface water and groundwater interact. Our results show an evaporative signal in the alluvial aquifer, as well as a considerable overlap between the isotopic signature of surface water and the valley-fill aquifer, suggesting shallow recharge from streams. Conversely, the isotopic signature of water from the Cretaceous aquifer shows little evidence of evaporation or connection to surface water. We applied radiometric dating using carbon and tritium (an isotope of hydrogen) to water samples from wells and springs in the study area to obtain a semi-quantitative residence time, or age, of groundwater. Most samples from the valley-fill aquifer and Claron Formation contained tritium in quantities indicating that groundwater is modern, recharged after about 1950. Samples from the underlying Cretaceous-age bedrock aquifer were much older, with radiocarbon ages ranging from approximately 5,000 to 9,000 years before present. The water supply for BCNP and Bryce Canyon City is modern groundwater from the valley-fill aquifer. The widespread presence of modern groundwater in the valley-fill and Claron Formation aquifers suggests these aquifers are actively recharged and thus sensitive to snowpack levels and climate change, as well as susceptible to surface-based contamination sources.

Water quality, quantity, and the potential for water-quality degradation are critical elements that may determine the extent and nature of future development in Johns and Emery Valleys in the vicinity of Bryce Canyon National Park. Our data show a connection between surface water and groundwater in the valley-fill aquifer based on shared geochemical characteristics, isotopic tracer signatures, increases in water levels in wells in direct response to heavy precipitation seasons, and seepage run measurements showing streams with distinct gaining and losing reaches. Because of the potential increase in growth from tourism-related development, an increased demand on drinking water warrants continued research that will assist land-use planning and resource management to preserve local water resources. Over the next two years, the UGS will continue to study the interaction between groundwater and surface water in the study area by constraining recharge and discharge to develop a water budget.



Graph showing discharge of East Fork Sevier River (blue line) and Tropic Ditch (purple line) from spring 2019 seepage run, along with gaining and losing reach status. Reach status: red = losing, light red = losing within measurement error, blue = gaining, light blue = gaining within measurement error.

UGS employee sampling a well for solute chemistry, nitrate, and radiogenic isotopes.



Hydrogen isotope ratios versus oxygen isotope ratios for surface water and groundwater samples in the Bryce Canyon and Johns and Emery Valleys area. Local precipitation plots along the local meteoric water line (LMWL). Evaporation causes samples to plot on the local evaporation line (LEL). Evaporation increases with distance from the LMWL along the LEL. Surface water and alluvial groundwater samples overlap along the LEL, whereas bedrock groundwater samples remain closer to their original recharge composition.

ABOUT THE AUTHORS

Janae Wallace is a Utah licensed professional geologist and Senior Scientist for the Utah Geological Survey. She received her B.S. in geology from the University of Utah in Salt Lake City and M.S. in geology from Northern Arizona University in Flagstaff. She has been employed with the UGS in the Groundwater and Wetlands Program since 1996. Her principal duties include groundwater-quality projects, with an emphasis on petitioning and classifying aquifers across the state, elevated nitrate concentrations in rural valleys, septic-tank density recommendation maps, environmental tracer analysis, pesticide sensitivity and vulnerability maps, and water well-cuttings' analysis. Current projects include characterizing the hydrogeology of the Bryce Canyon area and monitoring hydrologic changes in the Montezuma watershed in southeast Utah.

Trevor Schlossnagle is a hydrogeologist in the Groundwater and Wetlands Program. Since joining the UGS in 2018, Trevor's work has focused on applying geochemistry to groundwater issues, including water budgets, aquifer characterization, and small- to large-scale watershed restoration projects.

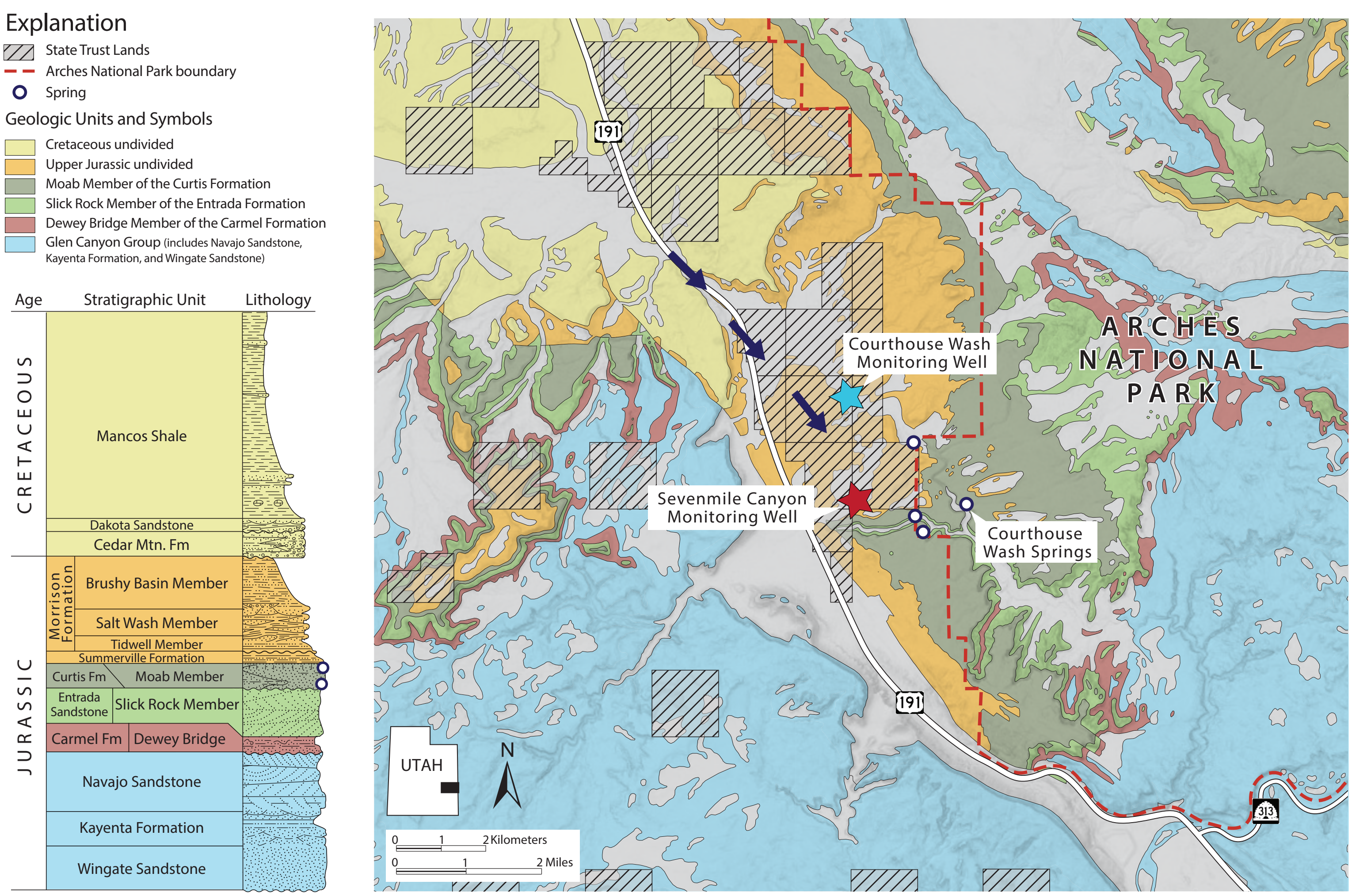
Groundwater Monitoring Well Installation at Sevenmile Canyon Near Arches National Park

by Stefan M. Kirby and J. Lucy Jordan

Overview

Groundwater in the Courthouse Wash area supports important springs in Arches National Park and provides domestic and irrigation water via wells that penetrate the Entrada or Navajo aquifers in adjacent areas outside of the park. A potential increase in future groundwater withdrawal from existing and new wells outside Arches could interfere with spring flow in the park. Springs in Arches issue from the Moab Member of the Curtis Formation, which is considered the upper part of the regional Entrada aquifer system. The Entrada aquifer is separated from the underlying Navajo aquifer by the potentially impermeable Dewey Bridge Member of the Carmel Formation; however, the presence, thickness, and permeability of the Dewey Bridge Member in the immediate project area is uncertain.

In 2012, the Utah Geological Survey, in partnership with the Utah School and Institutional Trust Lands Administration, Utah Division of Water Rights, and National Park Service (NPS), installed a dual-completion monitoring well in Courthouse Wash, northwest of Arches National Park. This well verified the impermeable and confining nature of the Dewey Bridge Member. In 2019, the NPS requested another dual-completion monitoring well to be located southwest of the existing well and closer to important springs located in the park. The primary goal of this new well is to determine the nature of groundwater flow and potential interconnection of the Entrada and Navajo aquifers upgradient of important springs in Sevenmile Canyon within Arches. Additionally, the new well will help (1) define the potentiometric surface and geochemical character of groundwater in the Entrada and Navajo aquifers, (2) monitor long-term groundwater levels in the Entrada and Navajo aquifers in the area, (3) determine the vertical gradients and degree of interconnection between the Entrada and Navajo aquifers, and (4) determine hydrologic and geochemical properties of these aquifers. Like the 2012 Courthouse Wash well, the new Sevenmile Canyon well is completed with two nested independent piezometers, one screened to the Navajo Sandstone and the other screened to the Entrada Formation. The general design of the new well follows that of the 2012 well (report available at https://ugspub.nr.utah.gov/publications/open_file_reports/ofr-606.pdf). The dual completion allows for independent measuring of water levels, geochemistry, and aquifer characteristics in the two aquifers. This information will be used by decision makers to protect downgradient springs in Arches National Park and allow for responsible water development outside of the park.



Sevenmile Canyon overview map and stratigraphic column. General direction of groundwater flow is shown by blue arrows (geology from UGS Map 180 [Doelling, 2002]).

Drilling Summary and Preliminary Results

The new well was drilled using a downhole hammer with conventional circulation over fourteen days beginning August 14, 2020, by the U.S. Geological Survey (USGS) Research Drilling service. Water was injected with compressed air to lift rock cuttings, except through the upper 225 feet of the borehole where only air was used as the circulation fluid. The upper 40 feet of strata consists of maroon and gray siltstone and gray limestone of the Tidwell Member of the Jurassic-age Morrison Formation. The Summerville Formation, red-brown and brown-gray fine- to medium-grained sandstone, is logged from 40 to 60 feet deep. At 60 feet there is an abrupt lithologic change to well-sorted, fine- to medium-grained white sandstone of the Moab Member of the Middle Jurassic-age Curtis Formation. The cuttings were damp from 187 to 193 feet at the base of this unit, possibly indicating a zone of perched groundwater on top of the underlying Slick Rock Member of the Entrada Formation. Two important springs discharge from this contact in Sevenmile Canyon about a mile east of the drill site, suggesting that perched zones at the base of the Moab Member may be regionally common.

Drilling progressed quickly through 329 feet of the Slick Rock Member of the Middle Jurassic-age Entrada Formation. The driller began injecting water with the air to facilitate cuttings removal at 227 feet. Drilling and water injection was halted about every 60 feet to test for water entering the borehole. Results indicate that the Entrada aquifer does not yield water to the borehole very quickly, and the water that is produced has moderate water quality with a 2,500 microsiemens per centimeter (µS/cm) electrical conductivity. Below the Slick Rock Member, the borehole penetrates 143 feet of the Dewey Bridge Member of the Carmel Formation. In the Courthouse Wash monitoring well, this confining unit creates tens of feet of groundwater level difference between wells completed in the Entrada aquifer above and Navajo aquifer below. The lithology of the Dewey Bridge Member in the Sevenmile Canyon borehole consists of dark red-brown and bleached white, silty, very fine grained sandstone and mudstone and lesser Slick Rock-like orange sandstone. The contact with the Lower Jurassic-age Navajo Sandstone at 665 feet depth was obvious in both the lithology change to light tan and gray medium-grained, well-sorted sandstone completely lacking fine-grained sediment and a sharp increase in water production from the borehole. By about 60 feet into the Navajo aquifer, the borehole produced at least 50 gallons per minute of fresh water. The electrical conductivity of the water in the Navajo was 500 to 600 µS/cm, much better quality than the Entrada above.

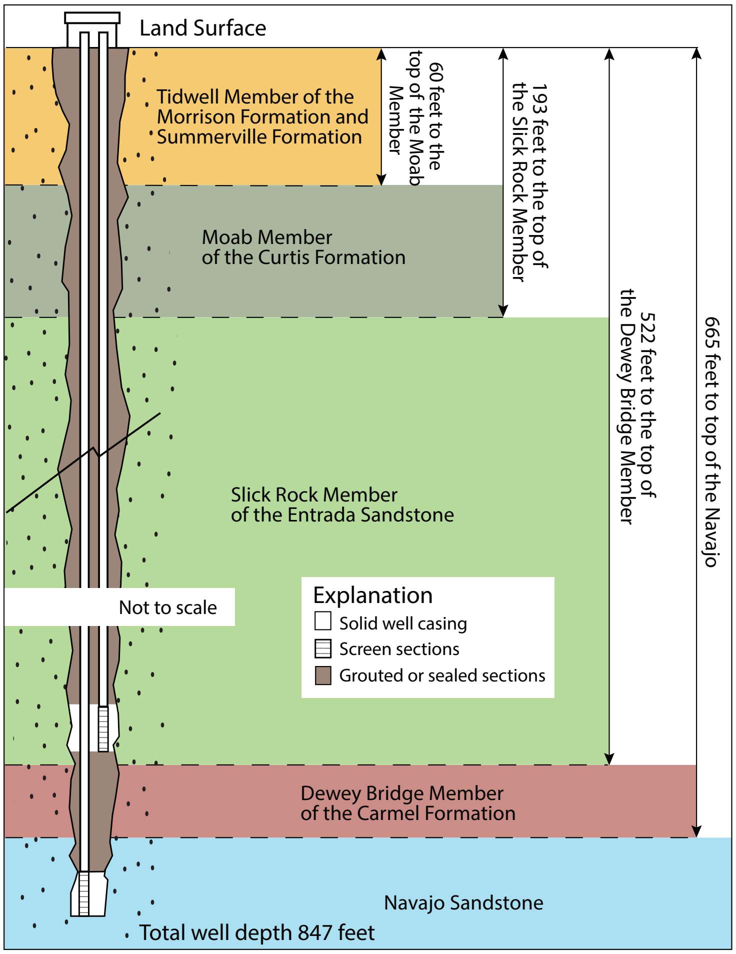
The dual-completion well constructed in the borehole consists of one string of 2-inch-diameter PVC having a 40-foot screen open to the Navajo aquifer and another PVC string and 40-foot screen open to the Entrada aquifer. The well annulus was filled with grout adjacent to the Dewey Bridge confining unit to assure a watertight seal between the two well completions. The wells were developed by air lifting water from the wells. Water levels in the wells are currently logged hourly using pressure transducers. The Entrada completion took some days to recover from drilling. The water level in the Entrada completion is approximately 215 feet below surface level, or 4,290 feet elevation, and reflects unconfined conditions. The Navajo aquifer is under confined conditions and has a water level of approximately 271 feet below surface, or 4,234 feet elevation. Water level reached static more quickly in the Navajo well than in the Entrada well. The 50-plus-foot difference in head between the aquifers is strong evidence that the Dewey Bridge Member is a good confining unit.

Groundwater discharge while drilling in the Navajo aquifer.

Sevenmile Canyon monitoring well drill site. View to the southeast. The Windows Section of Arches National Park is in the background.

Summary

Groundwater in the Courthouse Wash area supports both culinary and irrigation uses and also supplies springs and streamflow in adjoining areas of Arches National Park. To ensure future availability of groundwater to all uses it is important to constrain the relationship between the important aquifers and monitor long-term trends in water levels. The successful installation of the Sevenmile Canyon monitoring well provides important background data for both the Entrada and Navajo aquifers and allows long-term monitoring of water levels that are relevant to continued shared use of these important resources.



Well completion diagram for the Sevenmile Canyon well.

Teacher's Corner

EARTH SCIENCE WEEK

Launched by the American Geosciences Institute (AGI) in 1998, Earth Science Week is an international event highlighting the vital role earth sciences play in society's use of natural resources and interaction with the environment.

Last year due to the COVID-19 pandemic, on-site activities for Earth Science Week 2020 at the UGS were canceled. Instead, the UGS created a self-guided virtual experience into earth science topics where teachers, parents, students, and the public can learn about the Earth and its processes. You can view this information on our website at https://geology.utah.gov/2020-earth-science-week/.

In 2021 the UGS plans once again to host this popular annual event with hands-on activities that are particularly suited for the 4th and 5th grades, where earth science concepts are taught as outlined in the Utah Science Core Curriculum standards. Earth Science Week activities take place at the Utah Core Research Center in Salt Lake City and include panning for "gold," identifying rocks and minerals, experimenting with erosion and deposition on a stream table, examining dinosaur bones and other fossils, and new for this year, learning about earthquakes.

For more information, please visit our web page at https://geology.utah.gov/teachers/earth-science-week/.

UGA TEACHER OF THE YEAR

Ms. Kristina Hight of Granite Park Junior High School in Granite School District is this year's recipient of the Utah Geological Association's (UGA) Utah Earth Science Teacher of the Year Award. Ms. Hight has taught middle school science for the past five years and exhibits exceptional performance in lesson design, student engagement, and building positive relationships with students.

Ms. Hight was awarded $1,500 plus $300 in reimbursements for procuring resources related to earth science education. The science department at Granite Park Junior High will also receive $300 in reimbursements for procuring resources related to earth science teaching (e.g., materials, field trips, etc.). Ms. Hight has also been awarded the American Association of Petroleum Geologists (AAPG) Rocky Mountain Section's 2021 Teacher of the Year Award and will go on to compete nationally for the AAPG Teacher of the Year. Congratulations Ms. Hight!

CORE CENTER NEWS

Massive Core Donations Spurred by Low Oil Prices

by Michael Vanden Berg

In spring 2020, the oil and gas industry experienced reduced petroleum demand and crashing oil prices because of the COVID-19 pandemic. Companies drastically cut budgets, reduced spending, and laid off many workers. During these down times, many companies look to donate legacy core and cuttings material to save money on storage fees. The Utah Geological Survey's Utah Core Research Center (UCRC) has often been the beneficiary of such downsizing, and 2020 was no exception. Below we highlight several of the large donations received in 2020. As always, core and cuttings can be viewed by appointment at the UCRC (https://geology.utah.gov/about-us/utah-core-research-center/).

- Finley Resources – Green River Formation (and Wasatch) core from 13 wells located across the Uinta Basin (confidential until 2023).
- Berry Petroleum – Green River Formation core from 1 well, cuttings from 105 wells in southwest Uinta Basin, and cuttings from 5 wells in Garfield County.
- Dominion Energy – core from 39 wells mostly in the Clay Basin and Coalville gas storage fields, as well as core from 8 wells in the Leroy gas storage field in Wyoming.
- Strata Minerals – core from 9 shallow wells that targeted phosphate resources (Park City Formation) north of Vernal, Utah.
- Various operators – core from 4 wells that captured the upper Paradox Formation in southeastern Utah.
- Epic Oil – core from 2 wells that captured the PR Springs oil sand deposit.
- Twenty near-surface cores donated by a local engineering firm taken at various dam sites around the state.
- Legacy Utah material from the Oklahoma Geological Survey – core from 15 wells scattered throughout Utah and cuttings from 3 additional wells.

New shelving installed across the main aisle to accommodate new donations.

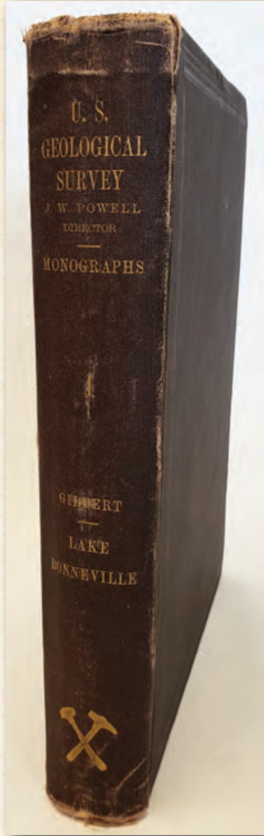
Pallets of core waiting to be inventoried and shelved.

Amoco core from Great Salt Lake

Amoco Production Company had an aggressive exploration program in Utah during the 1970s and early 1980s. The company drilled and cored several wildcat wells all over the state investigating potential oil and gas targets, including wells in what is now Grand Staircase–Escalante National Monument and several wells in Great Salt Lake. After the crash in oil prices in the mid-1980s, Amoco donated their entire core collection to the Oklahoma Geological Survey. Recently, the Utah Geological Survey was able to repatriate the Utah material back to the Utah Core Research Center (UCRC) in Salt Lake City, making this unique collection available to the public for the first time. This collection contains many very interesting cores, but one in particular caught our eye during the inventory process. We found core from 10,400 feet from the State of Utah "E" well, drilled in 1979. This well was drilled in the middle of the south arm of Great Salt Lake! At this depth, the drillers were well into crystalline "basement" rocks and recovered several feet of beautiful gneiss. This unique core is just one of several extraordinary cores that now has a permanent home at the UCRC.

Does the UGS Library House Any Remarkable Rare Books?

by Suzanne Sawyer, UGS Librarian



Yes, the UGS Library has several rare volumes in our collection, and we regularly receive donations of library materials to add to our collection. In 2020 the Montana Bureau of Mines and Geology sent us a generous gift of numerous Utah geology publications. Included in this donation was quite a treasure—a nearly perfect original of U.S. Geological Survey (USGS) Monograph 1 titled *Lake Bonneville* by Grove Karl (G. K.) Gilbert, published in 1890. This rare acquisition is a pivotal publication on Utah geology. We are excited to add this book to our library collection.

Lake Bonneville is a large-format book with 438 pages and includes 51 plates, some in color, which is quite unusual for a book of its age. Many of the plates are thematic maps illustrating various aspects of Gilbert's exploration of Lake Bonneville features. Several of the plates are beautiful sketches of landscapes throughout the Bonneville basin done by talented assistants on Gilbert's team. One of the highlights is a large color map of Lake Bonneville that is folded into a pocket at the back of the book. It is interesting to note that *Lake Bonneville* was actually the 15th monograph published by the USGS, but was assigned as Monograph I when the publication originally assigned the first number was never completed.

Plate III - "Map of Lake Bonneville showing Routes of Travel".

Lake Bonneville was an enormous freshwater lake that existed from about 30,000 to 13,000 years ago. During this time the climate was much cooler and wetter than it is now. As with Great Salt Lake, which is a remnant of the ancient lake, Lake Bonneville was a terminal lake with no outlet until it breached its threshold near Red Rock Pass, Idaho. After the lake level dropped over 300 feet during the catastrophic Bonneville Flood, the lake then intermittently drained to the Pacific Ocean for a few thousand years before receding below the new threshold and eventually reaching Great Salt Lake levels around 13,000 years ago. At its largest extent, about 18,000 years ago, Lake Bonneville covered an area of almost 20,000 square miles and was about 325 miles long, 135 miles wide, and over 1,000 feet deep. The shorelines of Lake Bonneville are easily seen along the mountains that rimmed the lake, including the Wasatch Range of northern Utah, and islands within the lake, such as Antelope Island. The three most prominent shorelines, which Gilbert named the Bonneville, Provo, and Stansbury, were a major focus of the research documented in *Lake Bonneville*.

G.K. Gilbert (1843–1918) is considered one of the greatest American geologists. He made numerous contributions to the field of geology, and Utah and Lake Bonneville were two major study areas in his career. Gilbert was born in Rochester, New York, near the shores of Lake Ontario. He graduated from the University of Rochester in 1862. Gilbert's first experience in the West was working as a geologist with the U.S. government-sponsored Wheeler Survey from 1871 to 1874. In 1874, he joined the Powell Survey and spent the next three years exploring the Great Basin of Utah and Nevada. In 1879, Gilbert was named Chief of the Great Basin Division of the newly formed U.S. Geological Survey. This gave him the opportunity to study ancient Lake Bonneville, which had interested him since his days with the Wheeler Survey, in greater detail. Gilbert gives credit to several earlier explorers who recognized the existence of a prehistoric lake in the eastern Great Basin, including Clarence King, Arnold Hague, and Samuel Emmons, the geologists of the Fortieth Parallel Survey, who Gilbert stated should have had naming rights based on their exploration dates. However, their publication was delayed, and Gilbert claimed the right. He named the lake in reports for the Wheeler Survey, published in 1874 and 1875, in honor of Captain B.L.E. de Bonneville who described Great Salt Lake in 1833. Gilbert's first major publication on the topic was a report to the USGS titled "Contributions to the History of Lake Bonneville" in 1882.

Gilbert considered Monograph 1 his masterwork. In addition to the groundbreaking study of the geologic history and features of Lake Bonneville, the volume includes at least two major contributions to structural geology. One of these is the recognition of repeated displacement along faults of the Wasatch Front. Gilbert was the first to recognize the earthquake hazard represented by these faults, and wrote a letter published in *The Salt Lake Daily Tribune* in 1883 warning local residents about the implications of the fault scarps that he observed along the foot of the Wasatch Range. Another contribution is the description of "isostatic rebound." Gilbert noted that the lakebed had risen in elevation and domed upward as the lake receded and the weight on Earth's crust was lessened. Many of Gilbert's observations have stood the test of time and have been supported by subsequent scientific studies.

We are excited to share this geologic artifact of Western Americana with you. The book can be viewed onsite at the UGS Library by appointment only. Call 801-537-3333 or email, ugslibrary@utah.gov, to schedule an appointment.

Frontispiece – "Shore-lines of the North End of the Oquirrh Range, Utah, Drawn by W. H. Holmes".

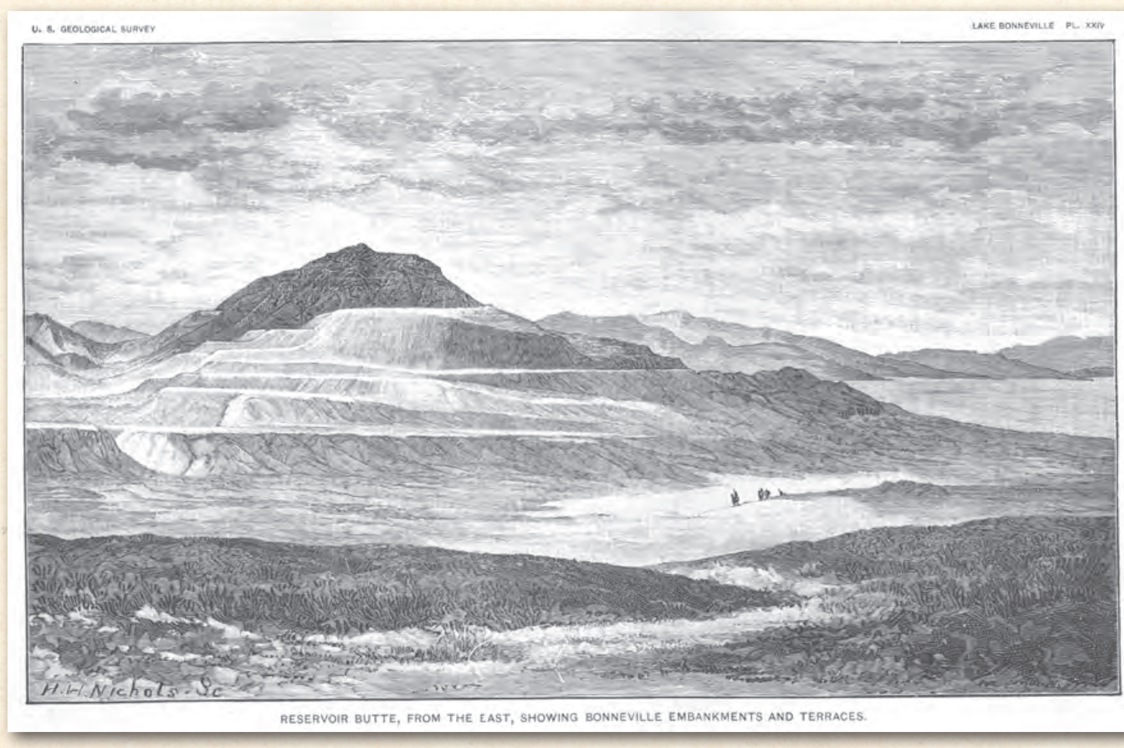


Plate XXIV – "Reservoir Butte, From the East, Showing Bonneville Embankments and Terraces".

GEO SIGHTS

Cannonball Concretions in a Treeless "Buried Forest," Carbon County, Utah

by Pete Kilbourne

Near the start of the 20th century, a Utah photographer captured an image he labeled "Buried Forest," perhaps thinking multiple large circular objects exposed in the cliff face were petrified logs (spoiler alert, they were not). Recently, rediscovery of the "Buried Forest" concretions came at the right time to give folks in Carbon County a distraction from COVID-19 confinement. Price, Utah, resident Scott Wheeler's curiosity to find the location of an old black-and-white photo and his desire to share the historic and geologic find with others led to its eventual designation by the U.S. Bureau of Land Management (BLM) as an interpretive site.

The photo, taken circa 1899, shows large spheres of rock up to 8 feet in diameter embedded in a cliff that photographer George Edward Anderson had deemed the "Buried Forest." Anderson identified the location as Sunnyside, which we know today as a town at the base of the Book Cliffs. After months of work, Scott, with the help of Google Earth and friend Alan Peterson, found the cliff 10 miles to the southwest in the Mounds area above Grassy Trail Creek, a tributary to the Price River. Discovering that Mounds had been called Sunnyside in the 1800s, they were able to hone in on the correct location.

In less than a year, the Carbon County Trail Committee and the BLM worked with Scott to provide visitors improved access, a trailhead kiosk, and a rudimentary trail that leads less than a mile to the site of the original photo. Since then, locals and out-of-towners alike have been making the 2 mile out-and-back trek to inspect the mystery.

On close inspection, the apparent ends of petrified logs are really the cross sections of large balls of rock commonly known as cannonball concretions. They were formed in a shallow marine environment at the edge of a Cretaceous-age seaway 90 million years ago, in sediments that would eventually comprise the Ferron Sandstone Member of the Mancos Shale. They are virtually the same as the cannonball concretions of the Molen Reef on the west side of the San Rafael Swell near Emery, Utah (see *Survey Notes*, v. 47, no. 3).

How did these concretions form? This is a bit of a mystery, at least in the details. Imagine clusters and beds of bivalve mollusks such as clams and oysters residing in the sandy bottom of the shallow waters at the edge of the Cretaceous Seaway. Eventually the wet sand and fossils became rock, as calcium

Circa 1899 photo labeled "Buried Forest" Sunnyside, G. Ed. Anderson Photo, Springville Utah.
Image used with permission from Brigham Young University L. Tom Perry Special Collections.

ions circulating in groundwater between the sand grains precipitated calcium carbonate (calcite). This process cemented the sand grains together aided by the pressure of additional sediment deposited above. The concretions formed as the calcium ions were preferentially and chemically drawn to organic matter such as the clusters of dead clams and their shells. The organic matter formed a nucleus around which the spherical concretions could grow.

Later, strong forces, including tectonic deformation and de-pressuring by erosion (removal of overlying rock), fractured the sandstone, coincidentally splitting the concretions at this location. Over the last few million years, uplift and erosion of the Colorado Plateau exposed the rock layers of this ancient shallow marine environment and the concretions within. The concretions, being more highly cemented than the surrounding rock, have been preferentially preserved as evidenced by the numerous large fragments scattered along the base of the cliff.

Mold of Inoceramus*, a mussel-like bivalve, about 2 inches long.*

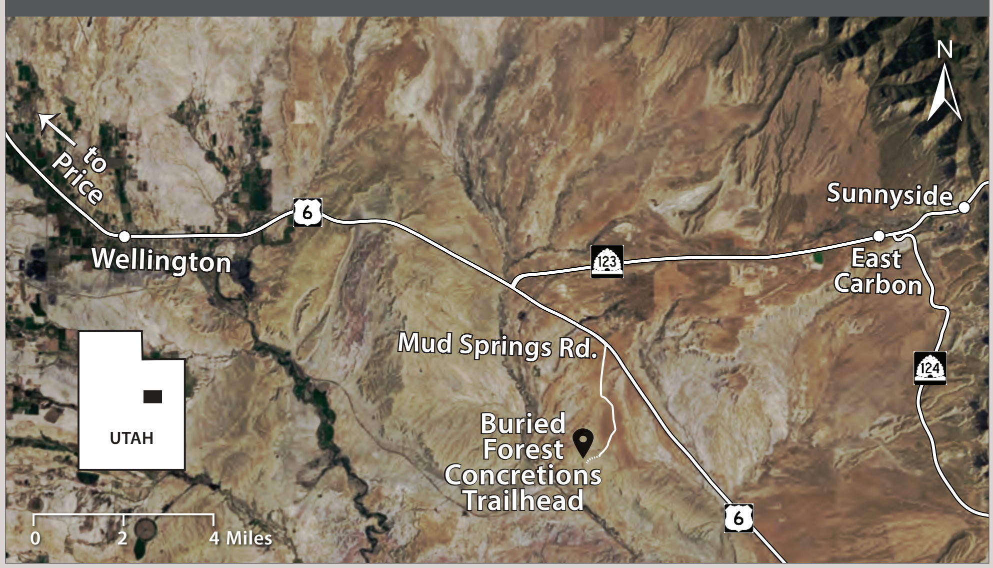
Cannonball concretions roughly 5 feet in diameter.

Split concretion, about 5 feet in diameter, displays organic-rich nucleus.

Bed of bivalve mollusk fossils (scale indicated by blades of grass).

HOW TO GET THERE

Drive approximately 18 miles southeast from Price on U.S. Route 6 to the Mud Springs Road, which is about 2.5 miles past the East Carbon turnoff (SR-123) at the top of the hill on the right. Mud Springs Road is unsigned. Watch for fast moving traffic as you slow down to make this turn. After a short distance, turn left at the junction with a kiosk and map. Continue on the gravel road for about 3 miles following the signs to the "Buried Forest Concretions" trailhead. Park and hike the trail. The trailhead's coordinates are 39.4688° N, 110.5428° W.



SURVEY NEWS

Sponsorship Opportunity for Utah's State Dinosaur *Utahraptor* Megablock Preservation Project

In February 2020, Utah's most spectacular dinosaur fossil block, the 18,000-pound *Utahraptor* megablock, moved from the Museum of Ancient Life at Thanksgiving Point to a new dedicated fossil preparation lab at the Utah Geological Survey's Core Research Center.

Paleontologist Scott Madsen working at the Utah Geological Survey on the Utahraptor *megablock in February 2021. Most of the work is done with the aid of small pneumatic air tools (think tiny jack hammer) while looking through a microscope.*

Paleontologists have completed more than 3,500 hours on fossil preparation, but have really only scratched the surface. Ninety percent of the work lies ahead and the preparation effort is being funded primarily by donations. The UGS provides laboratory space, expert oversight, limited preparation, and laboratory materials. Salary for the chief preparator, who works at a 50 percent discount and donates many hours, must be covered by donated funds. A private donor has given more than $50,000 and has offered to match additional donations up to another $50,000. The UGS is currently soliciting corporate and individual donations to reach this matching goal. For information on sponsorship opportunities and tax-deductible donations, please visit https://geology.utah.gov/docs/pdf/STEM-utahraptor-megablock-letter.pdf.

The UGS holds the *Utahraptor* megablock on behalf of Utah's citizens. Recovered fossils will be reassembled into a pack of *Utahraptor* dinosaurs and displayed at the Natural History Museum of Utah. For more information on the *Utahraptor* megablock visit https://geology.utah.gov/popular/general-geology/dinosaurs-fossils/megablock/.

Utah Arch Challenge

In March the UGS launched an online tournament to pit some of Utah's well-known and lesser-known natural arches and bridges against each other for statewide geologic superiority. The Utah Arch Challenge included 64 Utah natural arches and bridges that were randomly selected to compete against each other in six rounds. Participants were able to vote each round for their favorite arch or bridge as the field was trimmed to the "Faunal Four" contenders. For the championship round there was a big upset when Double Arch defeated famous Delicate Arch for Utah geologic superiority. Although each natural arch and bridge is unique, Double Arch is distinct with its spectacular double formation. Both finalists reside in Arches National Park.

Energy Pioneer Award

The Utah Governor's Office of Energy Development recognized former UGS Director and State Geologist Rick Allis and others as Utah's Energy Pioneers at the annual Governor's Energy Summit. Utah's Energy Pioneer Award recognizes individuals who provide immense contributions to Utah's energy and minerals economy. Rick was selected as a recipient of this award for his years of leadership at the UGS and his commitment to advancing our understanding of Utah's geothermal resources, particularly his research in Utah's Black Rock Desert and contributions that supported Utah being awarded the DOE FORGE grant. To learn more about Utah FORGE please visit https://utahforge.com/.

Distinguished Service Award

The American Association of Petroleum Geologists (AAPG) Executive Committee is presenting the Distinguished Service Award to **Michael Vanden Berg** for his service to the profession, the science, the Association, and the public. This award will be presented during the opening ceremony of the 2021 Annual Convention and Exhibition, set for May 23–26 in Denver, Colorado.

Lifetime Contribution Award

The Rocky Mountain Section (RMS) of the American Association of Petroleum Geologists (AAPG) has awarded the Robert J. Weimer Lifetime Contribution Award to **Thomas C. Chidsey, Jr.** for his contributions to the practice of petroleum geology in the region of the Rocky Mountains. This award is the most distinguished award given by the RMS of AAPG.

New Employee News

A warm welcome to **Kathryn Ladig** and **Claire Kellner** who joined the Groundwater & Wetlands Program. Kathryn has a B.A. in geology and environmental studies from Gustavus Adolphus College and a M.Sc. in earth science from the University of Maine-Orono. She comes to us from North Cascades National Park in Washington State. Claire majored in environmental geoscience and environmental biology at the University of St. Thomas in St. Paul, Minnesota, then worked as a hydrologic technician at Grand Canyon National Park and as a hydrologist and environmental monitoring specialist at the Minnesota Department of Transportation.

Play fairway analysis of Steptoe Valley, Nevada—Integrating geology, geochemistry, geophysics, and heat flow modeling in the search for blind resources, by Nicholas H. Hinz, J. E. Faulds, M. F. Coolbaugh, **C. Hardwick**, M. Gwynn, J. Queen, and B. Ayling: Geothermal Resources Council Transactions, v. 44, p. 593–612.

The Traverse Ridge paleoseismic site and ruptures crossing the boundary between the Provo and Salt Lake City segments of the Wasatch fault zone, Utah, United States, by N.A. Toke, J. Phillips, C. Langevin, **E. Kleber**, C.B. DuRoss, **A.I. Hiscock**, **G.N. McDonald**, J.D., Wells, J.K. Carlson, and D.M. Horns: Frontiers in Earth Science, https://doi.org/10.3389/feart.2021.607018.

Geologic setting, ground effects, and proposed structural model for the 18 March 2020 M_w 5.7 Magna, Utah, Earthquake, by **E.J. Kleber**, **A.P. McKean**, **A.I. Hiscock**, **M.D. Hylland**, **C.L. Hardwick**, **G.N. McDonald**, **Z.W. Anderson**, **S.D. Bowman**, **G.C. Willis**, and **B.A. Erickson**: Seismological Research Letters, v. 92, p. 710–724, https://doi.org/10.1785/0220200331.

Utah Geosites edited by **M. Milligan**, **R.F. Biek**, **P. Inkenbrandt**, and **P. Nielsen**: Utah Geological Association Publication 48, https://doi.org/10.31711/geosites.v1i1.

Brian Head Peak, Iron County, by **R.F. Biek** and P.D. Rowley, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 11 p., https://doi.org/10.31711/geosites.v1i1.47.

Cedar Breaks National Monument, North View Overlook, by **R.F. Biek** and P.D. Rowley, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 11 p., https://doi.org/10.31711/geosites.v1i1.50.

Hurricane Fault, by **R.F. Biek**, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 12 p., https://doi.org/10.31711/geosites.v1i1.51.

Virgin Anticline and Quail Creek Reservior, by **R.F. Biek**, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 8 p., https://doi.org/10.31711/geosites.v1i1.52.

Sevier Fault at Red Canyon, by **R.F. Biek**, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 6 p., https://doi.org/10.31711/geosites.v1i1.53.

Landscape Arch, Delicate Arch, and Double Arch in Arches National Park, southeastern Utah, by **T.C. Chidsey, Jr.**, and **G.C. Willis**, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 12 p., https://doi.org/10.31711/geosites.v1i1.54.

A breccia pipe in the Deseret Limestone, south flank of the Uinta Mountains, northern Utah, by **T.C. Chidsey, Jr.**, D.E. Eby, D.A. Sprinkel, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 10 p., https://doi.org/10.31711/geosites.v1i1.55.

Dead Horse Point, southeastern Utah, by **T.C. Chidsey, Jr.**, and H.H. Doelling, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 17 p., https://doi.org/10.31711/geosites.v1i1.56.

Northern Cedar Mountains red beds, Tooele County, by **D.L. Clark**, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 5 p., https://doi.org/10.31711/geosites.v1i1.57.

Paradise from cataclysm—Zion Canyon's Sentinel Landslide, by A.M. Stanczyk, J.R. Moore, B.J. Quirk, and **J.J. Castleton**, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 9 p., https://doi.org/10.31711/geosites.v1i1.65.

Ancient delta deposits in the Ivie Creek area, Ferron Sandstone Member of the Mancos Shale, western Rafael Swell, east-central Utah, by **T.C. Chidsey Jr.**, and P.B. Anderson, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 18 p., https://doi.org/10.31711/geosites.v1i1.74.

Spectacular crinkled crust—A detachment fold train in the Carmel Formation, western San Rafael Swell, Utah, by **T.C. Chidsey Jr.**, and P.B. Anderson, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 9 p., https://doi.org/10.31711/geosites.v1i1.75.

Green River overlook, Island in the Sky District, Canyonlands National Park, southeastern Utah, by **T.C. Chidsey, Jr.**, and H.H. Doelling, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 12 p., https://doi.org/10.31711/geosites.v1i1.76.

Independent gilsonite vein, Uintah County, by **T. Boden**, *in* M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors, Utah Geosites: Utah Geological Association Publication 48, v. 1, 8 p., https://doi.org/10.31711/geosites.v1i1.78.

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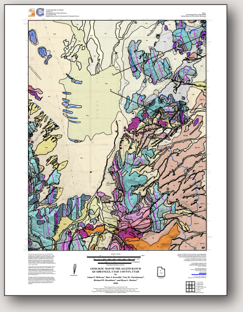

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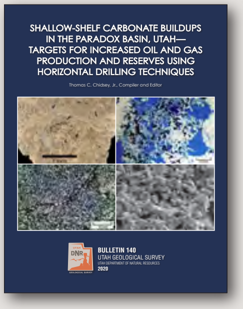

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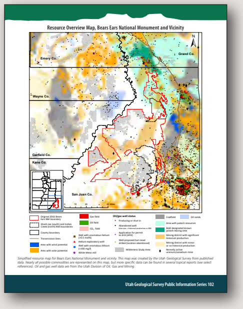

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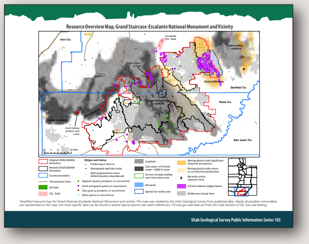

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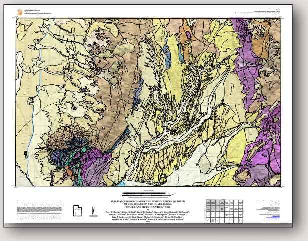

Interim Geologic Map of the Northwestern Quarter of the Beaver 30' x 60' Quadrangle, Beaver and Piute Counties, Utah, by Peter D. Rowley, Robert F. Biek, David B. Hacker, Garrett S. Vice, Robert E. McDonald, David J. Maxwell, Zachary D. Smith, Charles G. Cunningham, Thomas A. Steven, John J. Anderson, E. Bart Ekren, Michael N. Machette, Bruce R. Wardlaw, Stephan M. Kirby, Tyler R. Knudsen, Emily J. Kleber, and Adam I. Hiscock, 25 p., 2 plates, scale 1:62.500, **OFR-729DM**, https://doi.org/10.34191/OFR-729DM.

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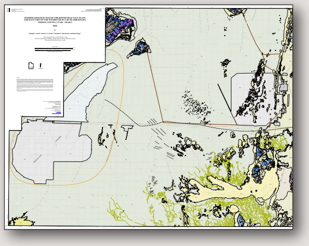

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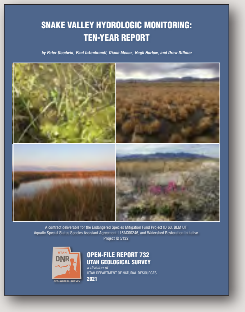

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