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CLIMATICALLY CONTROLLED WATER SUPPLY IN THE BRYCE CANYON REGION?

Contents

Design | *John Good*
Cover | View to the north of the East Fork Sevier River entering the Tropic Ditch diversion in Emery Valley. Photo by Janae Wallace.

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DIRECTOR'S PERSPECTIVE

by Bill Keach

Good science, good policy

"Net-zero globally by 2050." Many of us have heard this goal regarding carbon emissions and it has interesting implications for the geoscience community. Clean energy technologies require a different set of geologic resources than those serviced by hydrocarbons. For example, according to a 2021 report by the International Energy Agency (IEA), an electric car requires 117 lbs of copper, 29.6 lbs of lithium, 88 lbs of nickel, 54 lbs of manganese, 23.3 lbs of cobalt and 146 lbs of graphite. Compare those amounts to 49 lbs of copper and 25 lbs of manganese in a traditional gasoline-powered car. Similarly, wind and solar technologies need 2 to 3 times the amount of copper than traditional coal- and gas-fired power plants.

To achieve net-zero by 2050 the world will need to quadruple the production of critical minerals and copper. Aggressive goals can be both inspirational and aspirational, but also pose a major challenge for society: Are we ready and willing to make that magnitude of change in mining? Are we ready to move that much dirt in the coming years? If not, the goals are unattainable. Mining companies are willing to invest in the effort to mine and extract. But unfortunately there is resistance to this effort in the U.S. It seems that society is demanding change, but not willing to support the efforts in their own backyard.

Relatedly, where will the workforce come from to explore for and produce the resources needed to fuel the drive to a greener economy? The world will need more geoscientists if it is truly committed to making the energy transition. Talent is imperative to identify, explore, and develop critical geologic resources. Traditionally many students viewed geology degrees as a pathway to high paying jobs in petroleum-related industries. Today, however, many students shy away from geosciences due to the connection to hydrocarbons, and enrollment in geoscience programs is declining. In recent years, universities worldwide are rethinking the need for academic geoscience programs and geology departments are scrambling to survive. Some perceptive programs are working hard to rapidly adapt by changing their names and adding new courses in an attempt to become more attractive to an increasingly environmentally motivated generation of students. However, others have resisted changing traditional programs. They may be adding new courses, but have yet to redefine core requirements for a geoscience degree program. Regardless, interest in geoscience programs at universities is still waning.

The reality is the world needs people well educated and trained in the geosciences to effectively navigate the energy transition. Geoscientists lead the way to understanding where resources are located, what they can be used for, and how to best extract them. They have a robust role to play as society moves forward. Universities need to recognize the role they play in preparing students to provide the necessary science for a better world. Well trained students deliver good science. I have come to learn that good science leads to good policy. And good policy is an effective driver for positive change.

The 2021 IEA article can be accessed at the following link: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions, License: CC BY 4.0.

Iron County, Utah

CLIMATICALLY CONTROLLED WATER SUPPLY IN THE BRYCE CANYON REGION?

by Janae Wallace, Kathryn Ladig, and Hugh Hurlow

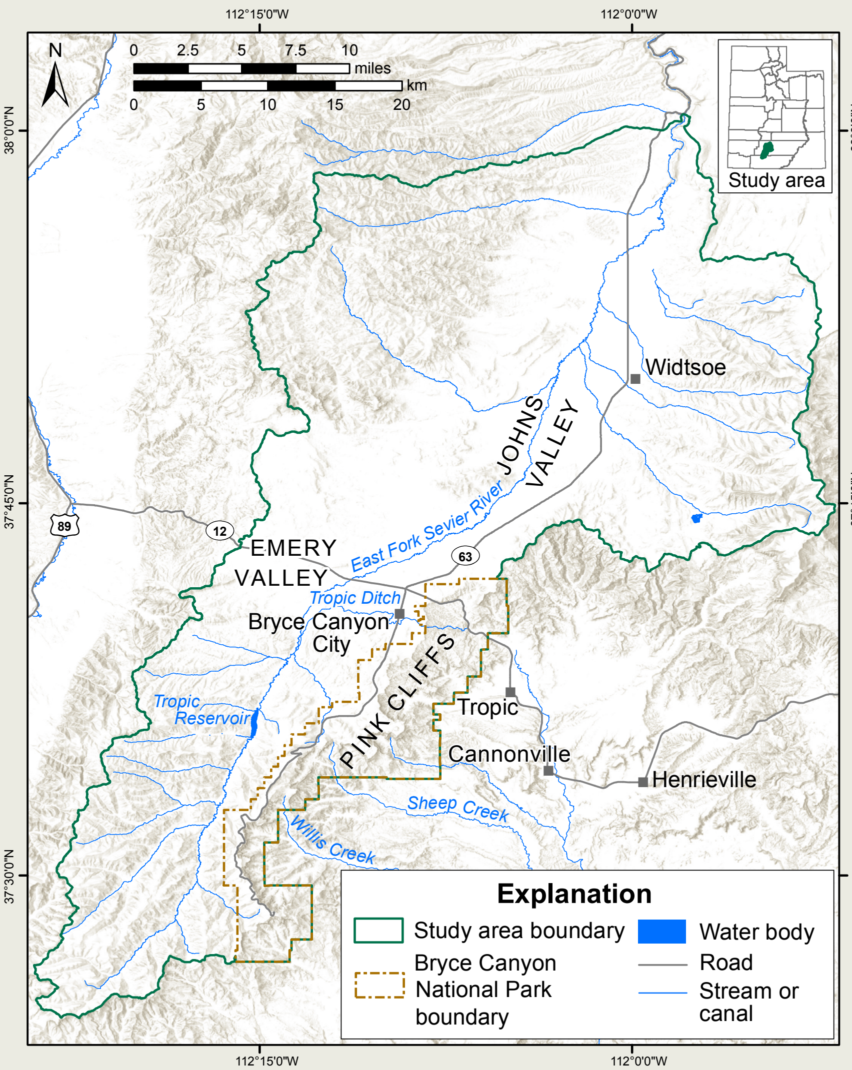
Southwestern Utah is a scenic and beautiful area that hosts several national and state parks with accompanying growing populations; the valleys that surround Bryce Canyon National Park are not unique in this scenario. Johns and Emery Valleys are home to about 360 permanent residents, but millions of tourists visit the area annually and that number is increasing. For example, approximately 1.7 million people visited the park in 2015 compared to 2.4 million people in 2022. Water supply and demand may control future development surrounding this geologic wonder, creating a challenging hurdle for local and state managers.

In the Bryce Canyon region, water generally is provided by groundwater from wells; a seasonal increase in population will likely increase the consumption of this water supply. Valley-fill sediments host the principal groundwater aquifer; however, groundwater storage in this aquifer is relatively limited based on its thickness (less than 300 feet). Although land use and development in the study area is centered around tourism, agriculture remains an important land use in Johns and Emery Valleys. In 2021, over 7,700 acres of land were designated as irrigated, sub-irrigated, or non-irrigated agricultural use. Irrigation in the study area is from surface water sources typically, including the Tropic Ditch in Emery Valley and mountain streams and springs in Johns Valley. Potential future development and the threat of future drought in southwestern Utah prompted our study to develop a groundwater budget, or an accounting of incoming and outgoing water to and from the aquifer, for Johns and Emery Valleys.

We began this project by conducting a hydrogeologic study after which a water budget could be calculated for the valleys. To shed light on identifying a groundwater–surface-water relationship, we measured flow in streams and canals, including an irrigation diversion known as the Tropic Ditch, and measured water levels in wells to generate maps showing contours of water-level elevations used to help understand groundwater flow in the valley. In estimating recharge to the system, we assumed that the surface-water drainage boundary is a groundwater divide, which precludes groundwater inflow from adjacent hydrologic basins. Therefore, the only primary input to the system is precipitation. Water can leave the system by three primary means: evapotranspiration, discharge to the Tropic Ditch, and discharge from the East Fork Sevier River.

We used a soil-water balance (SWB) model to understand the interaction between surface water and the sediments of the valley-fill aquifer. The spatial data used for the model included Daymet climate data, a digital elevation model for calculating water flow direction, a descriptive soils layer, and land cover data. The SWB model shows precipitation averaged approximately 383,000 acre-feet/year and evapotranspiration averaged 372,000 acre-feet/year over the entire study area. The model also indicated an average recharge to the aquifer of 9,400 acre-feet/year and average net loss of 11,000 acre-feet/year.

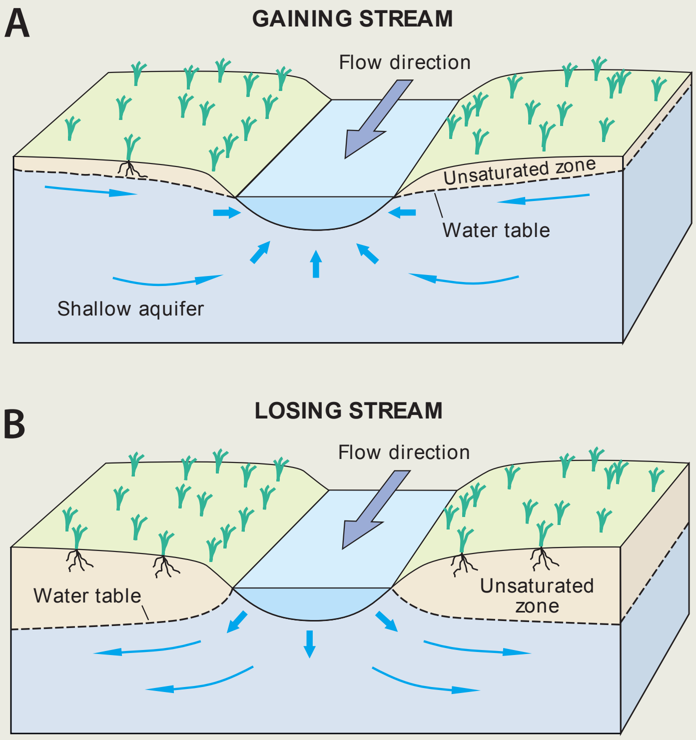
To validate the SWB model, we used data derived from well water-level measurements and stream and spring seepage measurements of the East Fork Sevier River and tributaries. We measured water levels in about 30 wells during the autumn and spring of 2018 through 2022. Our seasonal and annual data show water levels in most valley-fill wells fluctuate depending on winter



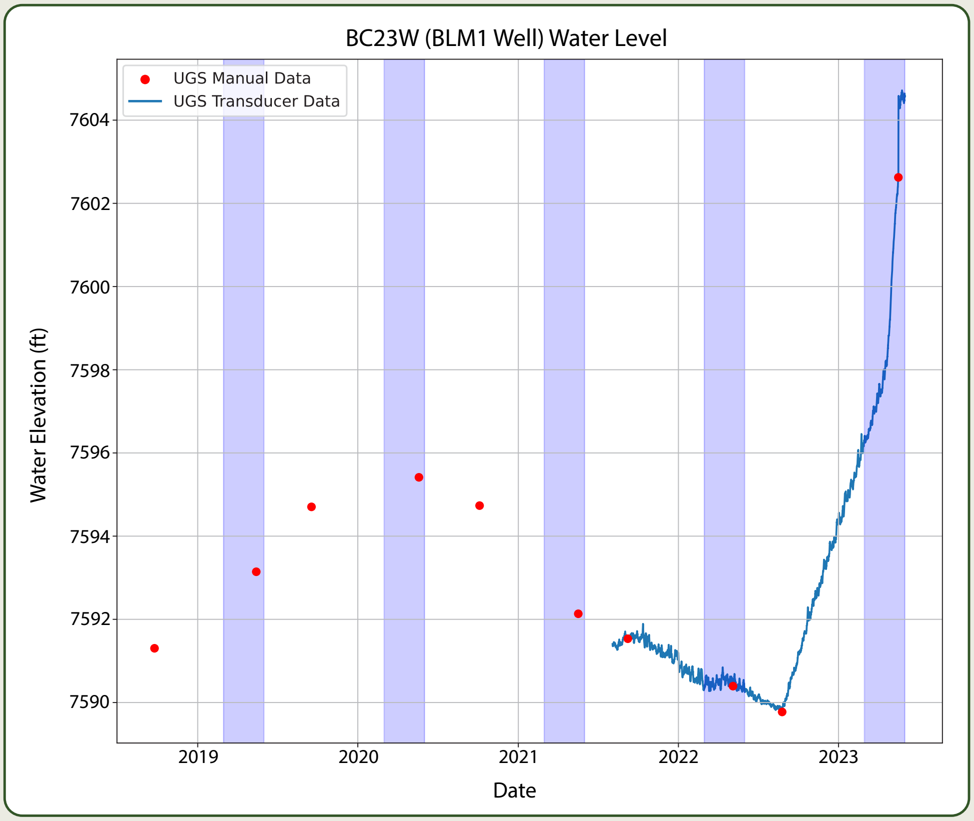
Map of study area.

precipitation. These wells had relatively short-term increases and declines depending on snowfall amounts, indicating storage in the aquifer is limited. The potentiometric surface—water-table level in the subsurface—in the valley-fill aquifer generally increases (rises) in the spring and declines in the fall. Water levels in wells completed in bedrock aquifers were less variable than wells completed in the valley-fill aquifer, with some water levels declining and others rising during different seasons and years, weather independent. Because water level in valley-fill wells increases after heavier winter snowpack, we conclude that the valley-fill aquifer is more sensitive to precipitation from surface water runoff and direct infiltration than the bedrock aquifers. Groundwater pumping also likely contributes to water-level fluctuations in the valley-fill aquifer, particularly along the more densely developed Highway 12 corridor.

Seepage runs—measuring streamflow on multiple sections of a watercourse in as short a time span as possible—allowed us to identify gaining and losing reaches of streams and canals, helping us better understand critical zone processes and the study area's water budget. (The "critical zone" is the physical nexus among shallow groundwater, surface water, the atmosphere, and vegetation.) During 2018, 2019, and 2020, we performed a total of four seepage runs on the East Fork Sevier River and Tropic Ditch in the lower reaches of Emery and southern Johns Valleys. We expanded the study area to include all of Johns Valley to the north into Black Canyon and performed seepage runs in October 2021 and May 2022. Discharge measurements from seepage runs show that the East Fork Sevier River has both gaining and losing reaches that vary in position and length depending on the time of year and groundwater conditions in the adjacent valley-fill aquifer. Based on our observations, the valley-fill aquifer in Johns and Emery Valleys receives recharge from surface water (is net gaining) when surface water is actively flowing through the valleys and the East Fork Sevier River is not fully diverted to the Tropic Ditch. This dynamic transitions to net gaining to surface water at the north end of Johns Valley where the water table intersects the land surface and perennial wetlands are supported.



*Schematic diagram of **A)** a gaining stream and **B)** a losing stream.*



Water-level data for a valley-fill aquifer well north of the Hwy 12 corridor showing slightly increasing water levels during spring snowmelt in 2019 and 2021. For the 2022–2023 water year, water levels steadily increased in direct response to the heavy winter snowpack and subsequent snowmelt, rising 14 feet in elevation. The gray bars represent March 1 through June 1 of each year.

View to the south of an extensive perennial wetland area (~100 acres) that exists between an unnamed spring and the East Fork Sevier River (left of the photo, not shown).

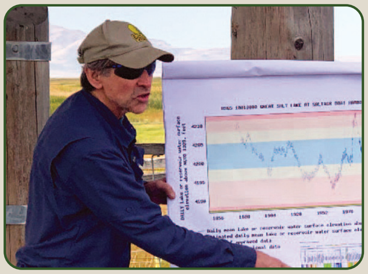
Our study shows the valley-fill aquifer in Johns and Emery Valleys is recharged by precipitation and surface water, responding readily to fluctuations in climate. Wetter than average water years result in increased groundwater levels, whereas drier than average years result in decreased water levels; there is little storage in the aquifer to attenuate climatic fluctuations. In recent times, all water flowing beyond the Tropic Ditch diversion into Emery Valley has been lost to groundwater, highlighting the aquifer's reliance on the East Fork Sevier River and its tributaries. We discovered substantial groundwater discharge in northern Johns Valley that supports an expansive wetlands system and stream flow in the East Fork Sevier River. Some of this groundwater likely recharges in the mountains in the northern part of the valley, far from currently proposed development, but some is derived from the valley-fill aquifer in the Emery/southern Johns Valley area. Extensive groundwater development in the area would cause the potentiometric surface in the aquifer there to decline, reducing the hydraulic gradient to the north and thereby capturing more flow from the East Fork Sevier River and some of the groundwater discharge in northern Johns Valley. Reduced groundwater discharge would potentially affect the groundwater-dependent ecosystem represented by the wetlands and decrease streamflow out of the valley. Reduced flow out of Johns Valley could impact water quality and supply issues in the surrounding region. For example, the Sevier River drainage basin suffered the greatest reduction in stream flow and reservoir storage in Utah during the 2021–2022 extreme drought (data source: USDA).

In summary, the valley-fill aquifer is sensitive to precipitation events—no snow, no water. Due to the close link between groundwater and surface water in Emery and Johns Valleys and limited groundwater storage in the valley-fill aquifer, lowering the water table may impact stream flow in an already vulnerable system. Scant long-term data indicate groundwater levels have historically fluctuated around a steady average, but extended drought could easily alter this balanced pattern and result in decreased water availability. The relatively recent period of drought has increased the percentage of total recharge to the aquifer that comes from the East Fork Sevier River, which depends on how Tropic Reservoir and the Tropic Ditch are managed. Because of the potential increase in growth from tourism-related development, an increased demand for drinking water warrants continuous monitoring that will assist land-use planning and resource management to maintain local water resources.

ABOUT THE AUTHORS

Janae Wallace is a senior scientist who has been employed with the UGS in the Groundwater & Wetlands Program since 1996. She received a B.S. in geology from University of Utah and M.S. in geology from Northern Arizona University. Her principal duties include groundwater-quality projects that focus on valley-fill aquifers, elevated nitrate concentrations in rural valleys, septic-tank density recommendation maps, environmental tracer analysis, pesticide sensitivity and vulnerability maps, watershed studies, and water well-cuttings analysis.

Kathryn Ladig joined the UGS Groundwater & Wetlands Program in 2021. She earned a B.A. in geology and environmental studies from Gustavus Adolphus College and an M.S. in earth science from the University of Maine. Kathryn has studied geology throughout the globe and was employed previously by the National Park Service. Her passions lie in tracking the impacts of climatic variability through both proxy and direct observation.



Hugh Hurlow joined the UGS in 1995 and is a hydrogeologist and the Program Manager of the Groundwater & Wetlands Program. He has a Ph.D. from the University of Washington, an M.S. from the University of Wyoming, and an Sc.B. from Brown University, all in geological sciences. His current focus is studying the hydrologic effects of large-scale environmental restoration of sage-steppe ecosystems.

WHERE IS THE WILDLIFE?

Improving Key Aquatic Habitats in the Updated Utah Wildlife Action Plan

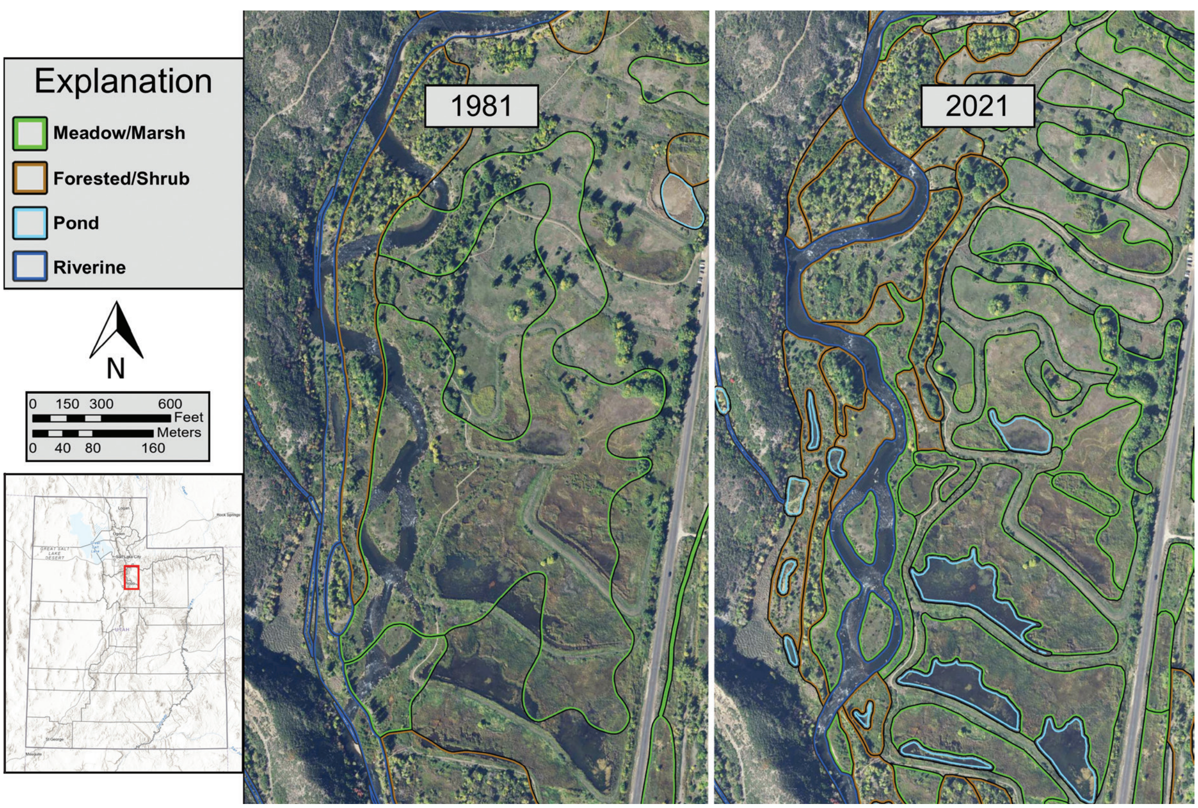
by Diane Menuz and Pete Goodwin

Shallowly flooded mudflat at a privately owned duck club near Bear River Bay of Great Salt Lake. Millions of birds depend on mudflats and other wetland habitat on the shores of Great Salt Lake to support migration and breeding.

The Utah Wildlife Action Plan (UWAP) identifies species in need of conservation attention in Utah, their essential habitats, and strategies for addressing threats to their survival (https://wildlife.utah.gov/wildlife-action-plan.html). The UWAP is important for prioritizing restoration and conservation actions and is often used to demonstrate restoration project funding needs. By following the strategies in the UWAP, the State of Utah can help preserve plant and wildlife populations, help prevent new species from being listed under the Endangered Species Act, and reduce the need for the federal regulatory oversight that occurs when species are listed as threatened or endangered. The Utah Division of Wildlife Resources (UDWR) revises the plan every 10 years in collaboration with a broad coalition of conservation partners. The UWAP is currently under revision, with the updated plan scheduled for completion by late 2025.

The Utah Geological Survey (UGS) is participating in a UWAP committee to improve how "key" aquatic habitats are represented in the plan, including serving as the committee co-chair. Key habitats are those that are essential to the conservation of rare and declining species. The 2015 UWAP relied entirely on data from the National Wetlands Inventory (NWI) to identify aquatic habitats. NWI is a nationwide spatial dataset overseen by the U.S. Fish and Wildlife Service that maps the location and types of wetlands, streams, lakes, and ponds across the nation. The aquatic habitat committee is addressing two major issues with how aquatic habitats were selected in the 2015 UWAP. First, some important Utah habitats, including riparian areas, springs, and critically important mudflats near Great Salt Lake, were not included because they were not well represented in the NWI data or did not score highly enough in a ranking rubric developed for terrestrial habitats. Second, the 2015 UWAP adopted aquatic resource terms directly from NWI, so habitats were defined by technical terms such as "Emergent" and "Riverine" rather than common terms like wet meadow and stream.

The UWAP aquatic habitat committee adopted a new and much simpler approach for identifying key aquatic habitats for the 2025 plan. All aquatic habitats will be considered key without the need for a ranking rubric, in recognition of the critical importance of water in arid states like Utah. Additionally, key aquatic habitats will be defined using terminology much more familiar to conservation and restoration practitioners. The committee identified five key habitats for the new 2025 UWAP: 1) rivers and streams, 2) lakes and



Comparison of old (left) versus new (right) NWI mapping along the Provo River downstream from Jordanelle Reservoir in Wasatch County, using imagery from 1981 and 2021, respectively. Both panels are underlain with imagery from 2021. The new mapping data captures the bends in the Provo River and ponds that serve as important breeding habitat for Columbia spotted frogs.

A Columbia spotted frog in wetlands along the Provo River near Woodland, Utah. This species is listed as a species in need of conservation attention in the UWAP because of concern over threats such as loss of riparian vegetation, drought, and competition with non-native species.

Springhead pool near The Meadows shopping complex in American Fork, Utah. The SSI dataset includes this spring but identifies the location as nearly 500 feet west of the true point of emergence. The new UGS dataset includes this spring and several others not included in the SSI, state or federal datasets mapped to the best identifiable point of emergence.

reservoirs, 3) wetlands, 4) springs, and 5) saline lakes, represented by the entire Great Salt Lake ecosystem. Riparian habitat—areas adjacent to streams and lakes with distinct vegetation that are not wet enough to qualify as wetland—are included as a key terrestrial habitat. While components of the Great Salt Lake ecosystem overlap with other habitat categories (e.g., lakes, wetlands), the committee decided to highlight saline lakes in recognition of the importance of these systems for wildlife and the growing momentum to preserve these systems across the West.

The UGS has played a major role in improving the accuracy of some of the spatial layers used to identify key aquatic habitats in the UWAP, particularly the NWI data. When the last UWAP was published in 2015, more than 92% of the state had NWI data that was at least 10 years old and much of the data were over 30 years old. In recent years, the UGS has updated NWI data in rapidly urbanizing areas of the state including Cache and Utah Valleys, and the Bureau of Land Management (BLM) has invested substantially in updating NWI mapping on BLM land throughout the West. Thanks to these efforts, by 2025, more than 60% of the state will have NWI data mapped using imagery from 2015 or later and using modern technology and mapping standards. UGS lead wetlands mapper Pete Goodwin coordinates regular meetings between organizations mapping in the West to foster consistent mapping across all project areas, share current methods and data sources, and promote use of updated wetland mapping datasets.

The newest NWI mapping data has several improvements over the older versions. Mappers have access to higher resolution imagery which allows them to more accurately capture features as small as 0.1 acres, whereas older mapping excluded any features smaller than 0.5 acres. Drier riparian areas are now mapped alongside wetlands and other aquatic features. And, mappers are classifying wetlands with additional attributes that highlight critical features like connectivity between wetlands, major water sources, and the functions that the wetlands provide (see *Survey Notes*, v. 54, no. 3, p. 4–5).

For our most recent mapping projects, we developed an additional mapping improvement that will benefit another UWAP key aquatic habitat—springs. Springs are incredibly important to wildlife because they provide relatively stable water sources in the driest stretches of the state, and they support many species of mollusks, one of our most threatened species groups. Unfortunately, NWI data do not adequately capture most spring features—small springs are omitted and there is no simple way to identify point-based springhead locations with wetland polygon data—and other spring datasets available in Utah are incomplete and contain many spatial inaccuracies. In our Provo River (see UGS Open-File Report 755) and Utah Valley mapping projects, we created a set of point features for spring locations simultaneously while we mapped wetland polygons. The new workflow adds minimal extra time to the traditional mapping process while providing valuable new information to wildlife managers and others by accurately mapping spring locations and identifying new springs not included in any dataset. We are currently sharing these data in the Springs Stewardship Institute's (SSI) Springs Online database (https://springsdata.org) and these data will become part of a new springs database under development by the UDWR.

The 2025 UWAP will have major improvements compared to 2015 both in how aquatic habitats are defined in the new plan and the supporting spatial layers that map where these habitats are on the landscape. The UGS has been happy to lend our specialized expertise to support the efforts of the UWAP, and we are proud of the progress made toward improving spatial layers over the past 10 years. Of course, identifying wildlife habitat is just one of many uses of the spatial data we create—NWI also plays an important role in activities such as land use planning, regulatory permitting decisions, and guiding conservation decisions to support other wetland functions, such as clean water and flood control. The UGS, along with other mapping organizations, will continue our efforts to provide high quality mapping data to support these and other data needs.

Habitat Name in 2025 UWAP	Data source in 2025 UWAP	Explanation	Habitat Name in 2015 Plan
Rivers and streams	NHDPlus	Intermittent and perennial rivers and streams	Riverine
Lakes and reservoirs	NHDPlus	Waterbodies greater than 20 acres in size	Open Water
Wetlands	NWI	Vegetated wetlands and waterbodies 20 acres or less in size	Only vegetated wetlands included, listed as Emergent, Aquatic-Scrub/Shrub, and Aquatic-Forested
Springs	SSI/UDWR Database	Groundwater-dependent features that are mapped as points or springbrooks	Not separately included; partially captured by wetland classes
Saline lakes	NWI or Landfire	Great Salt Lake ecosystem, including areas around the lake below 4218' elevation	Not separately included; partially captured in wetland and lake classes; mudflats and playas excluded
Riparian	Landfire	Distinct vegetation that grows adjacent to streams and lakes on dry land during most seasonal conditions	Not included

Key aquatic habitats and associated data sources in the 2025 UWAP and comparison with habitat names in the 2015 plan. NHDPlus is a national stream network dataset managed by the U.S. Geological Survey, and Landfire is a federal program that produces geospatial data depicting vegetation, wildland fuel, and fire regimes.

THE FUTURE OF GEOLOGIC MAPPING IN UTAH

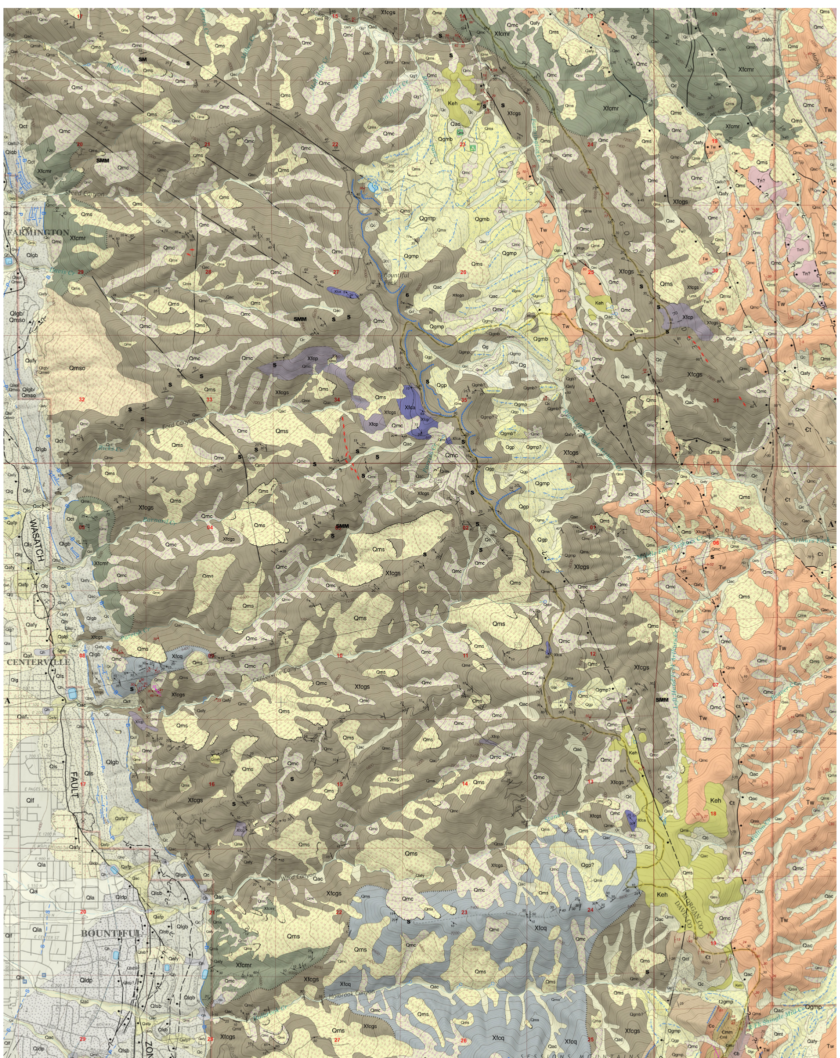
New Tools and Techniques

by Stefan Kirby, Matthew Morriss, Lauren Reeher, Zachary Anderson, Donald Clark, Keilee Higgs, and Emily Kleber

Geologic maps form the basis for a multitude of natural resource-related decisions. The maps and their derivatives define the character and extent of Earth's geologic history, resources, and hazards. As such, geologic maps are essential to discovering, researching, and obtaining the natural resources humans rely on daily. To satisfy the need for this information, the Utah Geological Survey (UGS) has been creating and publishing geologic maps since its inception nearly 75 years ago.

Geologic mapping is a rapidly evolving discipline that employs a range of modern techniques including satellite and drone imagery, multispectral analysis, 3D visualization, custom lidar (high-resolution topography), complex relational databases, and the new and evolving field of machine learning, a subfield of artificial intelligence (AI). In the Geologic Mapping Program, we are actively upgrading our map-making process to include these new tools. Our goal is to produce high quality geologic maps faster than ever before to serve the diverse geoscience needs of Utahns.

3D visualization is a time-tested approach to geologic mapping, which began with the earliest widely available aerial photography following the first World War. This technique involves a simple parallax produced by looking at appropriately paired aerial photographs (stereo photos) through a magnifying scope. Landforms and geologic units could be differentiated and then traced on the paper photographs. This technique formed the basis of geologic mapping for over 80 years and when done carefully yielded high quality spatially accurate maps. The primary downside of this method was the difficulty of editing geologic lines on paper photos and potential problems with transferring geologic map data to rectified basemaps.



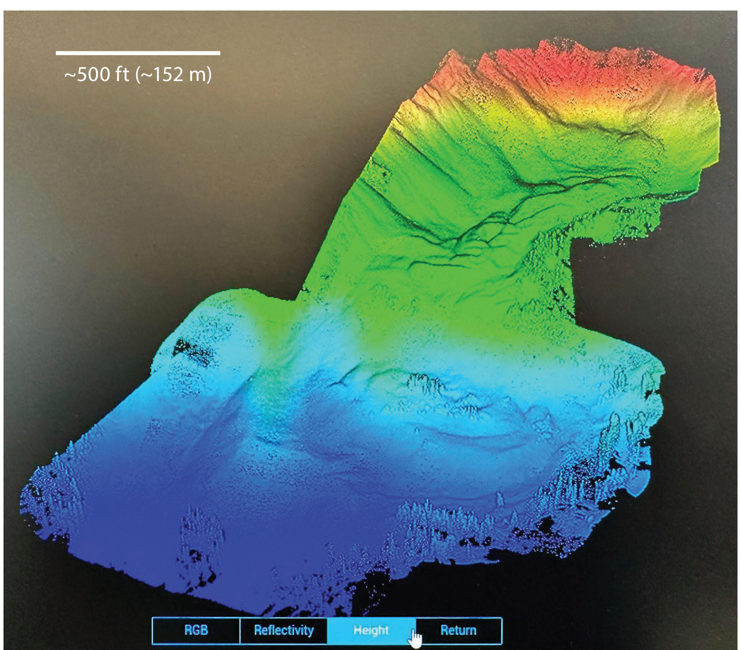
Geologic map of the Bountiful Peak quadrangle.

With the onset of digital geologic map creation around 40 years ago, new modes of 3D visualization were developed. Initially these techniques used proprietary software that utilized a unique data structure, which created a range of problems and additional work that slowed map production and publication. The UGS Geologic Mapping Program is currently investigating and refining a 3D stereo mapping and visualization technique and workflow that will allow start-to-finish map publication in a single software and data structure using ArcGIS Pro.

Because the UGS now uses ArcGIS Pro for most mapping tasks including lidar analysis, database management, linework, and final map preparation, we are transitioning 3D stereo mapping from the previously used software into our existing ArcGIS Pro workflow. Further, previous UGS GIS experts have created 3D stereo models that cover the entire state, permitting mappers to view any location in the state on screen in 3D. These models can be visualized with 3D glasses in current ArcGIS Pro projects where mappers can view and edit existing linework in 3D. This method gives the mapping geologist a realistic perspective on the landscape, key for understanding geologic processes.

The UGS mapping group is also using various drone-sourced data collection methods to facilitate geologic mapping. We recently used a lidar-scanning drone to survey a rock glacier in Gad Valley in the Wasatch Range. Rock glaciers are talus-covered bodies of intermittent ice that move downhill like ice glaciers, but at much slower rates (for example, less than a few inches a year). The Wasatch Range has over 60 rock glaciers, many of which may be moving. These features could represent potential water resources through the melting of internal ice or even geologic hazards if they become unstable. By deploying the new lidar-scanning drone, we collected a high-resolution, 3D image of the rock glacier. Repeat imaging enables the precise measurement of changes in the glacier's volume, movement, and structural integrity over time, which is crucial for assessing its potential impact on the surrounding environment, infrastructure, and the operations of Snowbird ski resort. Moreover, this lidar scanner is only one of a host of drone-based instruments (multispectral camera, thermal camera, etc.) that we can use to build more comprehensive datasets to support mapping projects.

Drone photograph of unconsolidated deposits and a rock glacier in upper Gad Valley scanned with new drone-based lidar. View is to the northeast.



High-resolution drone-based lidar view (digital elevation model) of the Gad Valley rock glacier. High-resolution lidar allows mapping in detail not previously possible and can constrain movement of active landscapes. View is to the southwest.

Drone take-off in Gad Valley.

The drone survey is part of a project to complete a new 1:24,000-scale geologic map of the Dromedary Peak quadrangle in the Little Cottonwood Canyon area of the Wasatch Range. Many of the Quaternary deposits present in the quadrangle have been poorly described or not previously recognized. Now, with both aerial- and drone-based datasets, we are working on a comprehensive mapping effort and description of these units.

Machine learning is an ever-growing field of digital decision making and data creation. In the field of geologic mapping it has been investigated in various forms for several decades. The ultimate goal of using AI would be to automate much of the geologic map creation process, which could greatly accelerate map creation and allow mapping geologists to cover much larger areas and focus on complicated geological issues while still creating high quality maps. The workflow would use various input data including imagery, elevation, and training. Training data could consist of geological relationships defined at discrete sites and/or previously published maps. AI would then be leveraged to make linework and accompanying geologic maps based on observed repeatable relationships and characteristics inherent in the input data. So far, however, this workflow has shown that repeatable relationships are difficult for current machine learning algorithms to pick out at the resolution and quality of human mappers. In practice, automated techniques can map simple geologic contacts in some areas. However, input and training data fine-tuning requires trained geoscientists and, in the end, yields a geologic map that is much simpler and lower quality than the human-created standard for maps of a given scale.

Geologic maps published by the UGS are the foundation of a broad range of natural resource and land use decisions. The process of map creation is ever evolving and the UGS Geologic Mapping Program is actively pursuing new techniques and solutions to efficiently create accurate maps to serve Utah's citizens. The future of geologic mapping in Utah is bright and is growing in new avenues as new technology and techniques become available.

Where Does Utah's Kings Peak Rank on the List of U.S. State Highpoints?

by Michael Hylland

Kings Peak stands as a sunlit pyramid beyond the shadowed cliffs at the head of the Henrys Fork basin.

The 50 U.S. states showcase an incredible diversity of natural landscapes and geology. However, there is one thing that all states have in common—a highest point. Many state highpoints are obvious mountain summits that tower above the surrounding landscape, whereas others are subtle topographic locations that require careful surveying to confidently identify as a state's highest elevation. Utah has nearly two-dozen mountain summits higher than 13,000 feet, all of them in the Uinta Mountains in the northeastern part of the state. The highest of these, Kings Peak in Duchesne County, reaches an elevation of 13,528 feet. So how does Kings Peak's elevation stack up against the highest points in other states across the country? And how does the geology of Kings Peak relate to the unusual east-west trend of the Uinta Mountains? Finally, what "King" was the mountain named after?

Highpoint Ranking

Kings Peak holds the position of number 7 on the U.S. state highpoint list. It is a few hundred feet higher than New Mexico's Wheeler Peak in the Sangre de Cristo Mountains, and a few hundred feet lower than the lofty volcanic summit of Mauna Kea on the Big Island of Hawaii. Kings Peak actually comprises two summits: the higher main peak, and South Peak which has a summit elevation of 13,512 feet.

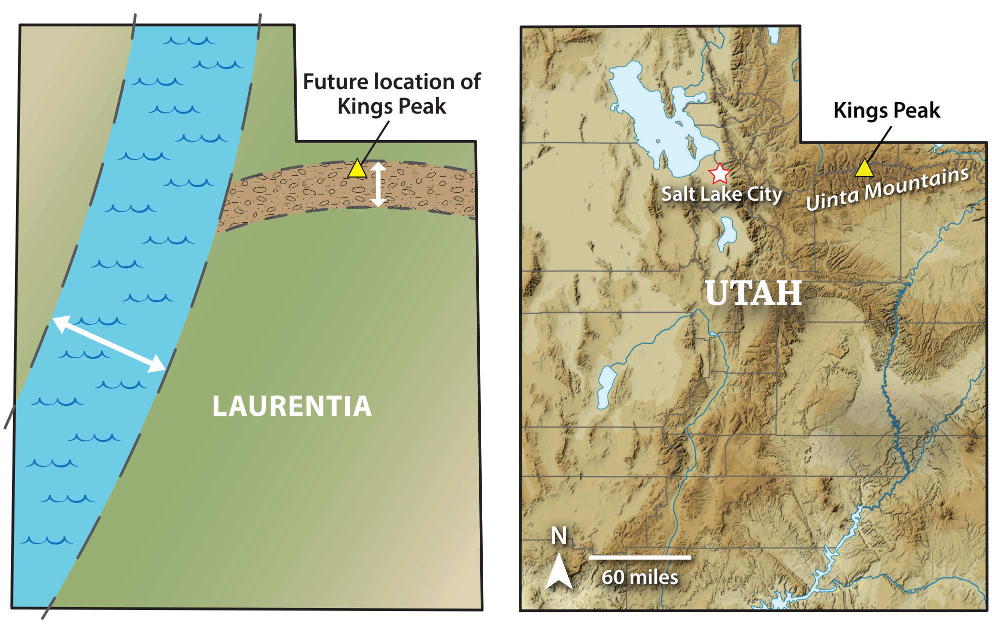
TOP 10 STATE HIGHPOINTS, BY ELEVATION

Rank	State	Highpoint	Elevation* (ft)	Elevation* (m)
1	Alaska	Denali	20,310	6,190
2	California	Mount Whitney	14,497	4,417
3	Colorado	Mount Elbert	14,433	4,399
4	Washington	Mount Rainier	14,411	4,392
5	Wyoming	Gannett Peak	13,804	4,207
6	Hawaii	Mauna Kea	13,796	4,205
7	**Utah**	**Kings Peak**	**13,528**	**4,123**
8	New Mexico	Wheeler Peak	13,161	4,011
9	Nevada	Boundary Peak	13,140	4,006
10	Montana	Granite Peak	12,799	3,901

*Above mean sea level

Geologic Overview

The origins of Kings Peak go back about 750 million years to late Precambrian time, when life on Earth consisted solely of very simple organisms such as cyanobacteria (blue-green algae). Utah occupied a place on the edge of a former continent called Laurentia, which at that time was beginning to separate from what would eventually become Antarctica and Australia along a continental rift zone. As Laurentia slowly moved away from the other continents, an arm of the rift opened and extended inland, forming a long, narrow basin. Over time, sand, gravel, silt, and clay were deposited in the rift basin in a variety of coastal environments including deltas, tidal flats, lagoons, and shallow marine waters, as well as in alluvial fans and the channels and floodplains of streams flowing from the continental interior. The resulting sequence of sedimentary rocks (shale, sandstone, siltstone, orthoquartzite, and conglomerate), over 20,000 feet thick, is known as the Uinta Mountain Group and contains cyanobacteria that were preserved to become Utah's oldest fossils (see *Survey Notes*, v. 37, no. 2, p. 6–7).

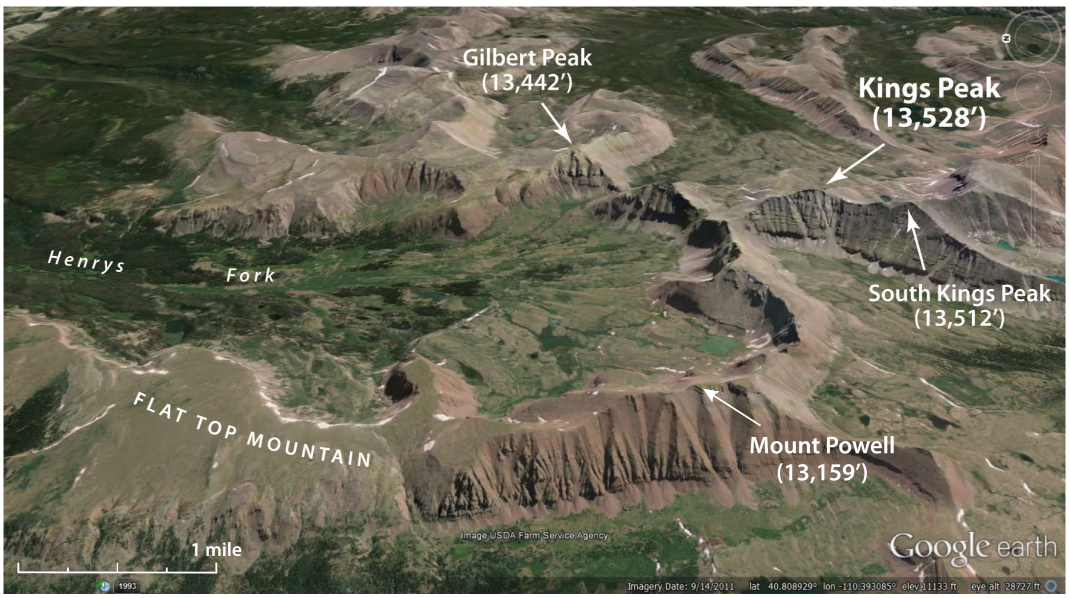


Left – Schematic diagram of rifting along the margin of the former continent of Laurentia in late Precambrian time. Arrows indicate crustal extension. The narrow arm of the rift across northern Utah filled with sediments that would become the sedimentary rock of the Uinta Mountain Group, eventually forming the east-west-trending core of the Uinta Mountains. Right – Present-day physiography of the Uinta Mountains and location of Kings Peak.

Fast-forward to about 70 million years ago, near the end of the Mesozoic Era (the "Age of Dinosaurs"). What had been the rifted margin of Laurentia has undergone geologic and tectonic changes and evolved into the continental margin of western North America. And instead of being extended and pulled apart, the crust is now being squeezed and compressed in a mountain-building event called the Laramide orogeny. During Laramide time (about 70 to 34 million years ago), numerous upwarps and adjacent basins formed throughout the Rocky Mountain region, including what would become known as the Uinta Mountains, the Green River Basin to the north, and the Uinta Basin to the south. Uplift of the Uinta Mountains occurred partly by broad folding and partly by movement along reverse faults that extend the entire length of the range along both the north and south flanks. So, the sediments that accumulated 750 million years ago in a rift basin near sea level now lie as sedimentary rocks 13,000 feet above sea level, forming a mountain range whose unusual east-west orientation reflects the configuration of the ancient rift basin.

Hikers negotiate loose talus on interbedded sandstone, siltstone, and shale of the Uinta Mountain Group at the head of the Henrys Fork basin; view looking north. Like all the major valleys throughout the Uintas, the Henrys Fork basin contained ice during Pleistocene glacial episodes, the most recent being around 24,000 to 12,000 years ago.

Much more recently, glacial erosion sculpted the present topography of the Uinta Mountains during Pleistocene glacial episodes, the most recent having reached its maximum extent about 20,000 years ago. Cirque glaciers joined to form confined valley glaciers, which generally did not cover the crest of the range or major drainage divides. The results are deep, glacially scoured valleys separated by sharp ridges (arêtes) and broad, unglaciated alpine plateaus (collectively known as "biscuit-board topography" for the resemblance to dough left on a cutting board after the biscuits have been cut). The main and south summits of Kings Peak form the highest points on a short arête that extends south from the main crest of the Uinta Mountains.



Oblique aerial view looking east at Kings Peak and the upper Henrys Fork basin, showing the characteristic biscuit-board topography of the Uinta Mountains. Peaks, ridges, and alpine plateaus preserve bedrock that remains after glaciers eroded the valleys. Google Earth image © 2015 Google Inc. Map data: Google, USDA Farm Service Agency.

Kings Peak is named after Clarence King, leader of the Fortieth Parallel Survey (1867–72) and first director of the U.S. Geological Survey (1879–81). Photo source: U.S. Geological Survey, public domain.

Story Behind the Name

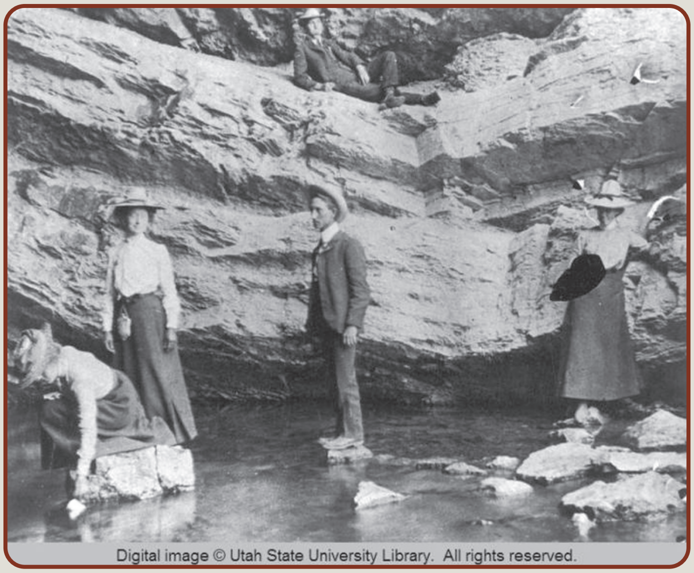
Utah's highest point was called Tei'an-Ku-ai (meaning "a small peak" or "peak with a small tip") by the Eastern Shoshone who formerly occupied the area. Later, the mountain was named for Clarence King, an American geologist, mountaineer, and author who, along with Ferdinand Hayden, John Wesley Powell, and George Wheeler, led one of the "Great Surveys" that explored the American West after the Civil War. King's survey was focused along the 40th Parallel and extended from Wyoming to eastern California, including northern Utah. The four western surveys led to creation of the U.S. Geological Survey as a federal science agency, and King served as the agency's first director from 1879 to 1881. King was succeeded by John Wesley Powell, famous for his explorations of the Colorado River through the Grand Canyon. Mount Powell (13,159 feet), a few miles west of Kings Peak, honors this intrepid explorer and scientist, and Gilbert Peak (13,442 feet), a few miles northeast of Kings Peak, bears the name of G.K. Gilbert, a key geologist on the Wheeler and Powell Surveys who went on to conduct groundbreaking research on Utah's Henry Mountains and prehistoric Lake Bonneville.

A note on ascending Kings Peak: **Kings Peak is in the High Uintas Wilderness of Ashley National Forest, and lies about 12 miles from the nearest trailhead. Although an ascent does not involve technical climbing, hikers should be prepared for strenuous scrambling at high altitude as well as sudden changes in weather conditions including wide temperature fluctuations and thunderstorms. Safe backcountry travel requires sound judgment, experience, personal fitness, and proper clothing and equipment. Please be respectful of the land and practice the environmentally friendly travel ethic of "take only pictures, leave only footprints."**

Ricks Spring, Cache County

by Stephanie Carney

Logan Canyon, which winds its way through the Bear River Range along Highway 89 in Cache County, gives access to many interesting karst features including springs and caves. One well-known feature is Ricks Spring, which has been a roadside attraction for more than 100 years since it was discovered and named in the late 1800s. The spring issues from a submerged cave system and karst aquifer in the Ordovician-age Garden City Formation, and flows from a large, easily accessible grotto right next to Highway 89.

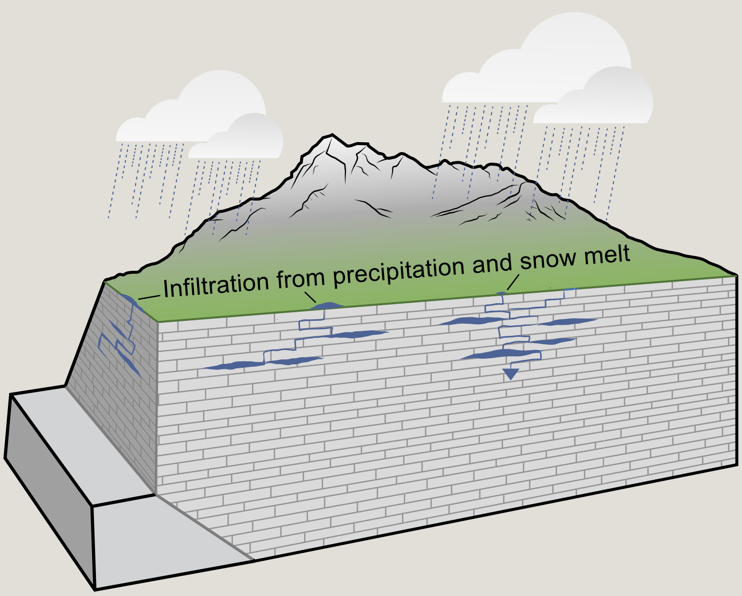


Visitors to Ricks Spring in the early 1900s. Note the woman scooping a cup of the spring water.

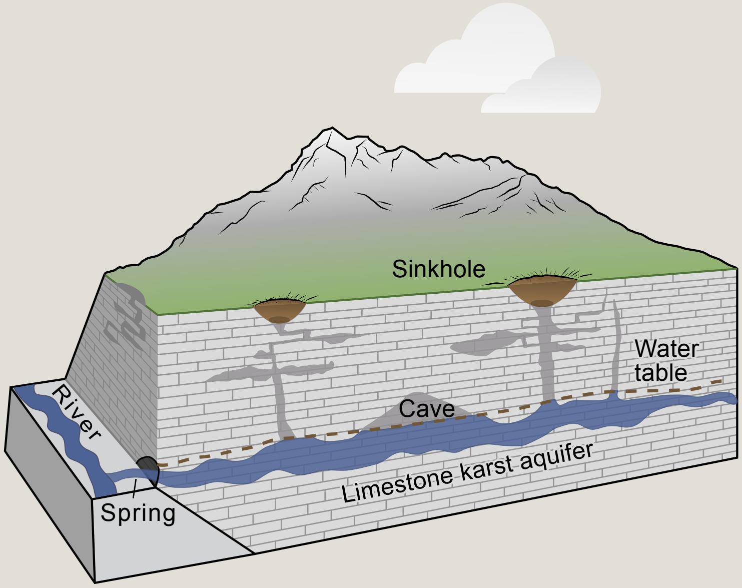
The term "karst" refers to a type of landscape formed in areas that have easily dissolvable rocks like limestone, dolomite, or gypsum. Landforms in these areas include sinkholes, caves, and towers that are created by the dissolution of rock by mildly acidic groundwater and surface water. When rainwater falls, some of it reacts with carbon dioxide in the atmosphere to become carbonic acid. As this weak acid flows through cracks and fractures in limestone or dolomite rock, a chemical reaction occurs that causes the rock to slowly dissolve. Over thousands of years, the flow path of the groundwater through the limestone can widen and form a cave system large enough for people to enter.

The Garden City Formation is composed of limestone (calcium carbonate, $CaCO_3$) that was deposited about 465 million years ago in a shallow, tropical, nearshore environment. About 100 million years ago, long after lithification and burial, the sedimentary layers were simultaneously uplifted, compressed, and gently folded into the Logan syncline during a tectonic mountain-building event called the Sevier orogeny. Then, starting about 20 million years ago and continuing to present day, the Bear River Range, which includes the Logan syncline, was uplifted by normal faulting created by east-west extension in what is now called the Basin and Range Province.

Over thousands of years, acidic groundwater etched out and widened the fractures and faults in the Garden City Formation, forming multiple cave systems. One popular example is the extensive submerged cave system that "daylights," or breaches the surface, at Ricks Spring. The spring rises into a pool inside a large alcove and flows under Highway 89 to empty into the Logan River. The cave was first explored by a Utah team of cave divers in 2007, and over several years and dozens of dives, they mapped out nearly 2,300 feet of the cave system.



Rain and melted snow infiltrate limestone rock through cracks, fractures, faults, and along bedding planes.



Over time, the weakly acidic groundwater slowly dissolves the rock creating ever widening conduits and, eventually, caves.

View looking toward the alcove at Ricks Spring. The photo was taken in fall and the water flow is low. Photo courtesy Dr. Susanne Janecke, Emeritus Professor, Utah State University Geosciences Department.

View looking south from Ricks Spring. Note low flow of the spring in fall months. Photo courtesy Dr. Susanne Janecke, emeritus professor, Utah State University Geosciences Department.

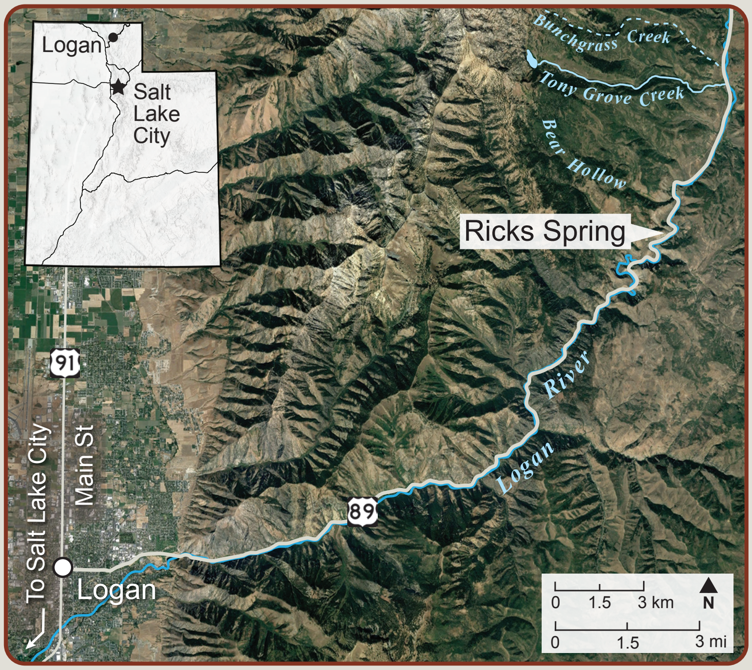
The spring is named after Thomas Ricks, who lived in the Cache Valley area in the mid- to late 1800s. At the recommendation of Mormon leader Brigham Young, he and several others began constructing a road eastward along the Logan River with the goal to connect Cache and Bear Lake Valleys. The first "leg" of the road ended at Ricks Spring. Residents in the area originally believed the spring water was sourced from a deep and pristine aquifer. They would trek to the spring to partake of fresh spring water, only to be later sickened from Giardia. Because this parasite enters surface waters through the feces of animals, folks soon realized that the spring water was likely from a surficial source.

In the 1950s, hydrogeologists proposed a possible link between the Logan River and Ricks Spring based on similar seasonal flow rates. During spring runoff, both the river and the spring would have very high flow rates. Conversely, when river flow rates slowed during winter, Ricks Spring would slow to a trickle or cease flowing entirely. In the summer of 1972, this connection was confirmed through a dye trace test conducted on the Logan River. The non-toxic fluorescent dye added to the river upstream of the spring showed up in the water discharging from the spring. Scientists theorize that the dye likely entered the karst aquifer through a northeast-trending fault that intersects both the aquifer and the river. In the 1990s, more dye trace tests were conducted by a U.S. Geological Survey hydrogeologist in several basins north and northwest of Ricks Spring to see if there were other surficial sources of the spring water. These tests confirmed that Bear Hollow, Tony Grove Creek, and Bunchgrass Creek provide water to the system, most of which comes from the melting of winter snowpack during spring and early summer.

How to Get There

GPS Coordinates: 41° 50′ 25″ N., 111° 35′ 19″ W

From Main Street in Logan, Utah, head east into Logan Canyon on 400 North/U.S. Route 89 for about 17 miles. Pull-off areas are located on the north and south sides of the highway for parking. Be very careful if crossing the highway. Signs about the spring and its history are posted. The spring flows during the spring, summer, and fall.



SURVEY NEWS

2023 Hintze Award

The Utah Geological Association (UGA) and the Utah Geological Survey (UGS) presented the 2023 Lehi Hintze Award to **Dr. Adolph Yonkee** for his outstanding contributions to Utah geology. Adolph was born and raised in Thermopolis, Wyoming, where early on he became fascinated with geology while on rock hunting adventures with his mom. He went on to attend the University of Wyoming where he received a B.S. and an M.S. in geology, and then to the University of Utah where he earned a Ph.D. studying Cretaceous-age thrust faulting in northern Utah. Adolph then worked as a mapping geologist for the Utah Geological Survey (with which he continues to collaborate), before heading to Weber State University where he has shared his passion for teaching with students and a tremendous group of faculty colleagues for the past 33 years. His recent research has covered a range of geologic features in Utah, including formation of basement rocks of the Farmington Canyon Complex, the record of Snowball Earth and rifting of Rodinia, and tectonic evolution of the Sevier and Laramide mountain systems.

Named for the first recipient, the late Dr. Lehi F. Hintze of Brigham Young University, the Lehi Hintze Award was established in 2003 by the UGA and UGS to recognize outstanding contributions to the understanding of Utah geology.

2023 Employee of the Year

Congratulations to **Paul Inkenbrandt** who was selected by his peers as the UGS 2023 Employee of the Year. Paul has been with the UGS since 2009 and brings leadership and technical expertise to his job as senior geologist with the Groundwater and Wetlands Program. Paul is an outstanding colleague, mentor, and an excellent role model, showing unmatched enthusiasm for his work and an eagerness to help and teach others. He is the groundwater program's hydrologic modeling expert and is always thinking of new ways to provide data and communicate findings to water users throughout the state. Paul goes out of his way to perform outreach as a science communicator, inspiring future geologists with his enthusiasm, energy, and excitement around geology and earth science. His unwavering commitment to excellence, coupled with his positive attitude and genuine concern for the well-being of his coworkers, makes him an outstanding employee and deserving recipient of this special recognition.

2023 Alumni Achievement Award

The College of Physical and Mathematical Sciences at Brigham Young University presented the 2023 Alumni Achievement Award to **Thomas C. Chidsey, Jr.** This award recognizes Tom's 45-year career including 31 years at the Utah Geological Survey, and his research in Utah petroleum geology, carbon dioxide resources and sequestration, hydrogeology, microbial carbonates, Mars rover protocols, and the general geology of Utah's parks. Congratulations Tom on this prestigious honor.

Left to right: Bill Keach, Utah Geological Survey; Thomas C. Chidsey, Jr., Utah Geological Survey, Emeritus; Scott Ritter, Brigham Young University.

In Memoriam

It is with great sadness that we report the passing of **Hellmut H. Doelling** on November 29, 2023, at the age of 93. Hellmut's service with the Utah Geological Survey spanned a remarkable 70 years, beginning in 1953 as a part-time student draftsman and later as a staff geologist. He eventually served as chief of what would become the Energy & Minerals program (1966–83), manager of the Geologic Mapping program (1983–96), part-time geologic mapper (1996–2003), and then volunteer geologic mapper in his "full retirement" (2003–present). Hellmut authored or co-authored nearly 300 UGS publications, including more than 225 geologic maps. He received numerous awards and honors during his career, including the 1993 Governor's Medal for Science and Technology, 2004 Lehi Hintze Award for Outstanding Contributions to the Geology of Utah, 2018 Governor's Distinguished Service Award, and 2019 Albert Nelson Marquis Lifetime Achievement Award (Marquis Who's Who). In 2012 the dinosaur *Yurgovuchia doellingi* was named in his honor. Hellmut leaves behind his beloved wife Gerda and an amazing legacy of geologic contributions to the state of Utah. He will be greatly missed.

Employee News

Jodi Thacker retired from the UGS in November after 10 years of service as Financial Manager. Before joining the UGS in 2013 Jodi worked for various agencies within the State of Utah for 20 years and was responsible for budgeting, accounting, and grant management. She was a great asset to our division, and we will miss her keen financial advice and admirable work ethic. Jodi is pivoting to a second career as a Personal Financial Counselor for military service members and plans to continue her volunteerism promoting financial literacy. We wish her well in her future endeavors!

Congratulations to **Rosemary Fasselin** who was promoted to GIS Manager. Rosemary has worked in the Geologic Mapping Program for four years as a senior GIS analyst and will provide support to mapping geologists and GIS analysts across all programs at the UGS. A warm welcome to **Ben Dlin** who joined the UGS as a contracts and grants analyst, focusing on contract/grant management and administration. Ben has B.A. degrees in political science, international studies, and sociology from Johns Hopkins University, and a Masters of Natural Resources from Virginia Tech. After 19 years of service with the Groundwater & Wetlands program, **Lucy Jordan** has scaled back to part-time and taken the position of a technical reviewer. We wish her well in her new role.

In December the Utah Department of Natural Resources 2023 Community Outreach Award was presented to the UGS Earth Science Week Team in recognition of their hard work and dedication. Congratulations to **Jim Davis**, **Mark Milligan**, **Jackson Smith**, **Torri Duncan**, **Mackenzie Cope**, and **Stephanie Carney**.

Recent Outside Publications *by UGS Authors*

Formation of Magnesium-Clay in a Lacustrine Microbialite-Bearing Carbonate Deposit, Eocene Green River Formation, Sanpete County, Utah, by D.F., Cupertino, C.W. Ramnani, **M.D. Vanden Berg**, and S.M. Awramik: Sedimentology, 30 p., doi: 10.1111/sed.13136

Structural Analysis and Chronologic Constraints on Progressive Deformation Within the Rincon Mountains, Arizona—Implications for Development of Metamorphic Core Complexes, by G.H. Davis, E.B. Orent, C. Clinkscales, F.R. Ferroni, G.E. Gehrels, S.W.M. George, K.A. Guns, C.E. Hanagan, A. Hughes, A. Iriondo, G. Jepson, C. Kelty, R.W. Krantz, B.M. Levenstein, S.H. Lingrey, D.P. Miggins, T. Moore, S.E. Portnoy, **L.J. Reeher**, J.W. Wang: Geological Society of America Memoir 222, https://doi.org/10.1130/MWR222

TEACHER'S CORNER

EARTH SCIENCE WEEK 2023

In October, the Utah Geological Survey held its annual Earth Science Week (ESW) celebration at the Utah Core Research Center. More than 550 students from eight schools came to learn about geology and paleontology through fun, hands-on activities. This year for the first time we hosted three 5th grade classes from Mary W. Jackson Elementary, the Department of Natural Resources (DNR) sponsored Title I school. Jackson is a dual immersion school, teaching in English and Spanish. To accommodate this teaching model, the ESW team recruited volunteers to present in Spanish and we also provided an Arabic translator for new students who are not yet proficient in English or Spanish. Many thanks to our volunteers from professional associations, public- and private-sector institutions, other divisions within the DNR, and individual geology enthusiasts who helped make ESW 2023 a success.

For more information about Earth Science Week, visit the AGI's website at www.earthsciweek.org. For information on next year's ESW activities at the Utah Geological Survey, see our web page at geology.utah.gov/teachers/earth-science-week.

CALL FOR NOMINATIONS FOR THE 2024 UTAH EARTH SCIENCE TEACHER OF THE YEAR AWARD

For Excellence in the Teaching of Natural Resources in the Earth Sciences

The Utah Geological Association (UGA) is seeking nominations for the 2024 Utah Earth Science Teacher of the Year Award. The winning teacher is awarded $1,500 and is automatically entered in the regional contest sponsored by the Rocky Mountain Section of the American Association of Petroleum Geologists (AAPG). All K–12 teachers of **natural resources** in the earth sciences are eligible. Application deadline is January 15, 2024. Additional information, requirements, and entry forms are available on the UGA website at utahgeology.org/outreach/teacher-of-the-year.

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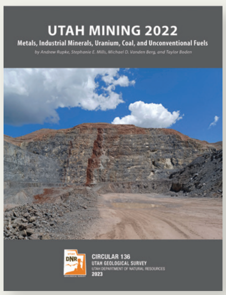
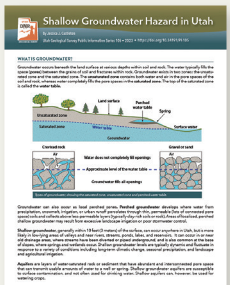
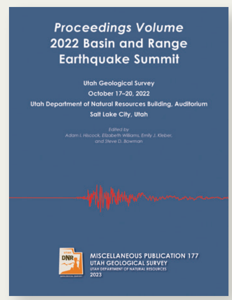


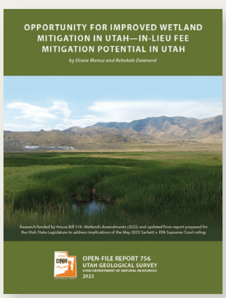
Utah Mining 2022—Metals, Industrial Minerals, Uranium, Coal, and Unconventional Fuels, by Andrew Rupke, Stephanie E. Mills, Michael D. Vanden Berg, and Taylor Boden, 47 p., **C-136**, https://doi.org/10.34191/C-136



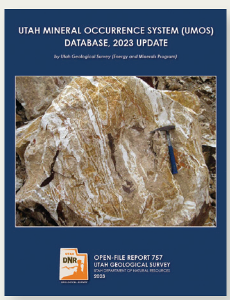
Shallow Groundwater Hazard in Utah, by Jessica J. Castleton, 4 p., **PI-105**, https://doi.org/10.34191/PI-105



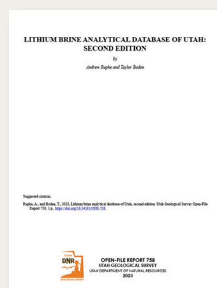
Proceedings Volume, 2022 Basin and Range Earthquake Summit, edited by Adam I. Hiscock, Elizabeth Williams, Emily J. Kleber, and Steve D. Bowman, 6 technical sessions, 29 presentations, 25 posters, **MP-177**, https://doi.org/10.34191/MP-177



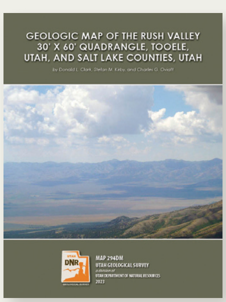
Opportunity for Improved Wetland Mitigation in Utah—In-Lieu Fee Mitigation Potential in Utah, by Diane Menuz and Rebekah Downard, 22 p., **OFR-756**, https://doi.org/10.34191/OFR-756



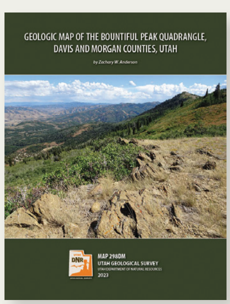
Utah Mineral Occurrence System (UMOS) Database, 2023 Update, by Utah Geological Survey (Energy and Minerals Program), 11 p., **OFR-757**, https://doi.org/10.34191/OFR-757



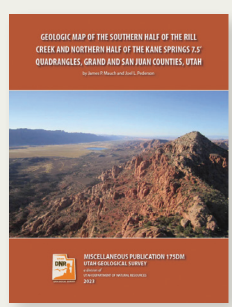
Lithium Brine Analytical Database of Utah: Second Edition, by Andrew Rupke and Taylor Boden, 3 p., **OFR-758**, https://doi.org/10.34191/OFR-758



Geologic Map of the Rush Valley 30' X 60' Quadrangle, Tooele, Utah, and Salt Lake Counties, Utah, by Donald L. Clark, Stefan M. Kirby, and Charles G. Oviatt, 46 p., 2 appendices, 3 plates, scale 1:62,500, **M-294DM**, https://doi.org/10.34191/M-294DM



Geologic Map of the Bountiful Peak Quadrangle, Davis and Morgan Counties, Utah, by Zachary W. Anderson, 17 p., 2 plates, scale 1:24,000, **M-298DM**, https://doi.org/10.34191/M-298DM



Geologic Map of the Southern Half of the Rill Creek and Northern Half of the Kane Springs 7.5´ Quadrangles, Grand and San Juan Counties, Utah, by James P. Mauch and Joel L. Pederson, 19 p., 2 plates, scale 1:24,000, **MP-175DM**, https://doi.org/10.34191/MP-175DM