UTAH GEOLOGICAL SURVEY

SURVEY NOTES

Volume 45, Number 1 January 2013

UTAH'S NEW IGUANODONTIAN DINOSAURS

Contents

Design: *Stevie Emerson*
Cover: *Excavation of* Iguanocolossus *at the base of the Cedar Mountain Formation, southeast of Green River, Utah. Inset: UGS paleontologist Don DeBlieux with student interns excavating and field jacketing another iguanodont at the base of the Cedar Mountain Formation.*

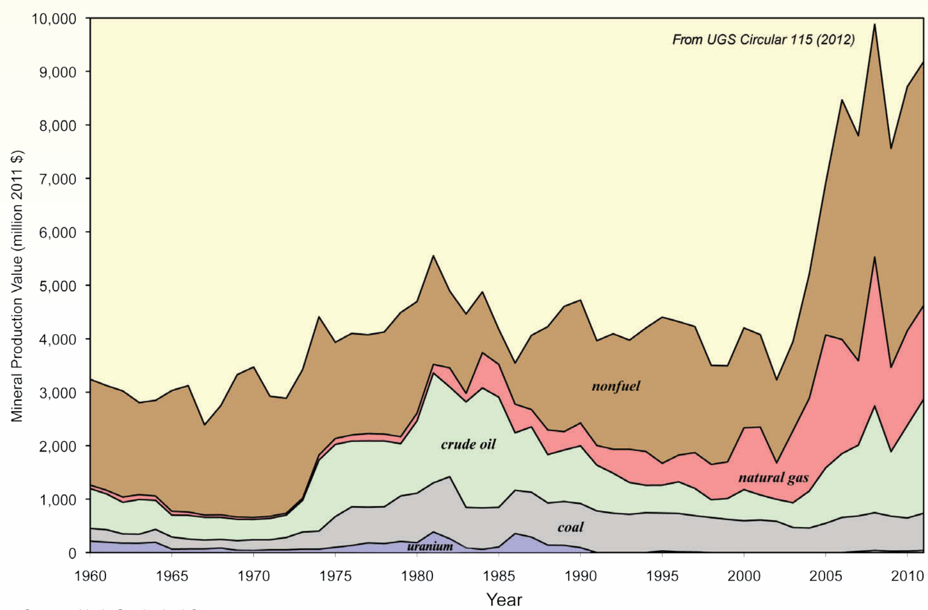
The Director's Perspective

by Richard G. Allis

Each year, the Utah Geological Survey provides two chapters for the "Economic Report to the Governor," which is published by the Governor's Office of Management and Budget in January. The two chapters address energy and mineral industry trends in Utah during the past year. The UGS also summarizes Utah's extractive resource industry trends in an annual publication (recently published UGS Circular 115 summarizes 2011 trends). A key indicator we use to measure the overall contribution of these industries to Utah's economy is the total value of the energy and mineral commodities produced annually. For 2011 this was $9.2 billion, the second-highest value ever (in 2008 the inflation-adjusted figure was $9.8 billion). The most striking feature of the 50-year trend, as shown on the graph below, is that for more than 40 years Utah's extractive industries had a total annual production value of $3–5 billion (inflation-adjusted); however, around 2004 many commodity prices increased dramatically, and the total value has subsequently been in the range of $8–10 billion.

Investment in exploration and production has followed the swings in commodity price, with oil and natural gas probably being the best examples. For most of the past decade, twice as many rigs in Utah drilled for natural gas than for oil. However, since about 2009, when the price of natural gas became decoupled from that of oil and fell to relatively low levels ($2–3 per thousand cubic feet of gas) while the price of oil stayed near historic highs ($80 to more than $100 a barrel), the number of rigs drilling for oil has roughly matched those drilling for natural gas. Oil discoveries have followed, undoubtedly helped by improved drilling technologies. The ratio of proven reserves (barrels) to annual oil production (barrels per year) has increased from typically 6 to 8 years of supply prior to 2000, to 18 years over the past three years. In addition, annual oil production has almost doubled from its low point in 2003 to its level today. The large increase in reserves tells us annual oil production will continue increasing, and assuming the price of oil does not suffer a sustained decrease, oil's contribution to Utah's economy will increase significantly from its present production value of $2 billion per year. Most of this increased production is likely to be from the Uinta Basin.

The outlook for Utah's coal production is not as rosy. The UGS expects annual production in 2012 to decline to a level last seen 25 years ago (17 million short tons per year). Many factors contribute to this low level of production, but it follows a general trend of declining production since the late 1990s. The main factor is shrinking markets for the coal, due in part to a shift in the electricity industry towards gas-fired generation. Another Utah commodity seriously affected by declining demand is uranium. Energy Fuels Inc., the relatively new owner of Utah's three producing mines, has announced it will close all three mines due to the weak price of uranium. Oil, natural gas, coal, and uranium are all examples of how "change" is a fundamental characteristic of our extractive resource industries.



Source: Utah Geological Survey
Note: 2011 data are UGS estimate

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THE THUMB-SPIKED IGUANODONTIANS
Dinosaurian Cows of the Early Cretaceous

Iguanodon ottingeri being attacked by Utahraptor. (Artist – Pat Redman. Used with permission.)

by James I. Kirkland

Iguanodontian dinosaurs are large, bipedal, plant-eating dinosaurs that were the most common large dinosaurs on land in the Northern Hemisphere during the Cretaceous Period (65-145 million years ago). They include the more primitive thumb-spiked iguanodonts of the early and middle parts of the Cretaceous and the duck-billed hadrosaurid dinosaurs of the latest Cretaceous. Recent discoveries by paleontologists at the Utah Geological Survey have revealed a number of new iguanodont species from the Cedar Mountain Formation of east-central Utah that browsed the newly diversifying flowering plants. These dinosaurs can be considered the cows of the Early Cretaceous and were major prey animals of the "raptors" and large "carnosaurs."

Described from Lower Cretaceous strata

Early (1852) reconstruction of Iguanodon *at Crystal Palace, England (Photo source: Wikipedia).*

A duplicate of the model in the back of the photo above actually held a table surrounded by 21 of the leading naturalists of the day to celebrate the achievement (from London Illustrated News, 7 January, 1854).

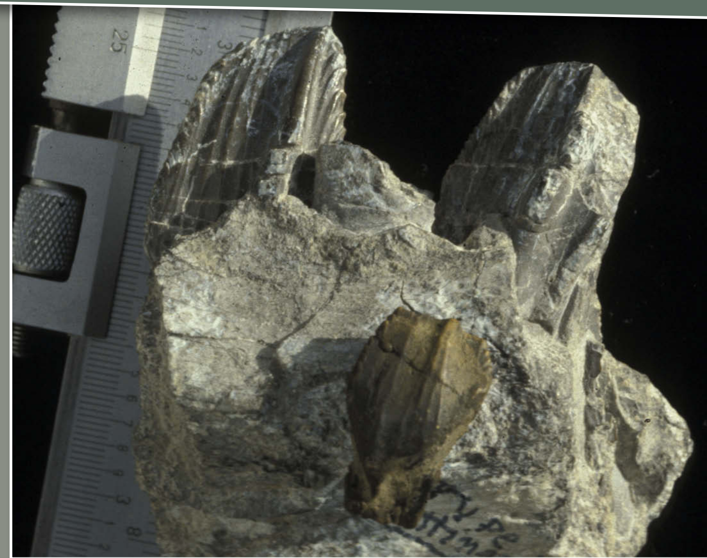
Postage stamp showing kangaroo pose of Iguanodon *popular after the Belgian coal mine discoveries in 1878. Note that the thumb-spike, which had been placed on the animal's nose in earlier reconstruction, is now in its proper place on the hand.*

of southern England in 1825, *Iguanodon* was the second dinosaur ever described. Initially thought to represent an extinct rhinoceros, its teeth were compared to those of an iguana and thus it was named *Iguanodon* meaning "Iguana tooth." This was one of the first three fossils that would be used to define the Dinosauria in 1841 as huge Mesozoic reptiles with an upright posture as in modern mammals. Initially, based on the few fragmentary fossils, *Iguanodon* was interpreted to be an elephant-sized, quadrupedal reptile with a horn on its nose. This fanciful reconstruction was among the first reconstructions of a dinosaur ever made.

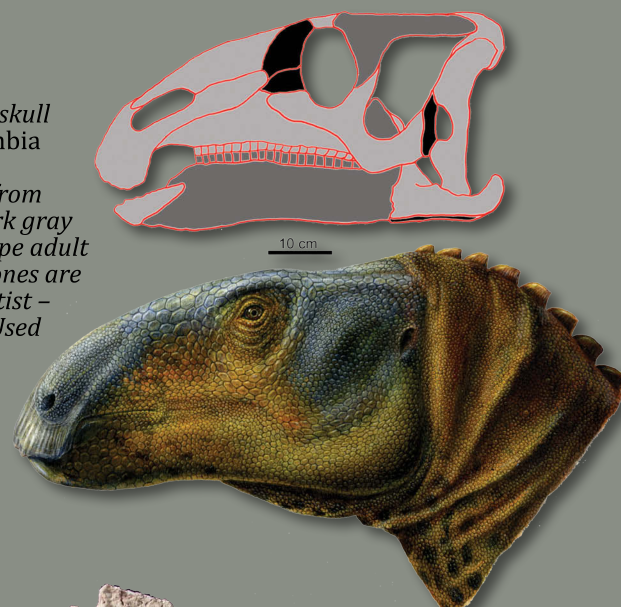
The description of the more complete *Hadrosaurus* skeleton from Upper Cretaceous strata of New Jersey in 1858 led to speculation that *Iguanodon* was bipedal. However, with the 1878 discovery of 24 complete skeletons of *Iguanodon* at the bottom of a coal mine about 1000 feet down at Bernissart, Belgium, the anatomy of this dinosaur became well understood. By comparing the anatomy of these skeletons with those of modern animals, such as flightless birds and kangaroos, *Iguanodon* was reinterpreted as an upright bipedal animal that would have braced itself with its tail. Furthermore, the spike that had previously been placed on its nose was found to actually be a thumb-spike, which may have been used in self-defense. Not until about 100 years later was it noted that these dinosaurs would have had to walk with their back and tail held horizontally in the currently accepted posture for most dinosaurs.

As one of the first dinosaurs, more than 20 species from the Lower Cretaceous across the Northern Hemisphere have been classified as *Iguanodon*. In recent years, all of these many species have been assigned to different genera. Described as North America's first *Iguanodon* in 1979, *Iguanodon ottingeri* was based on an upper jaw fragment with just two teeth from near the base of the Cedar Mountain Formation (Yellow Cat Member; about 125 million years old) in Brigham Young University's Dalton Wells Quarry north of Moab, Utah. Because there is more than one iguanodont dinosaur species now known from this important dinosaur locality, this species is no longer considered valid by most scientists.

Utah's first well-documented iguanodontian was initially described by me in 1998 as a basal hadrosaurid. *Eolambia caroljonesa* has a thumb-spike and is the most common dinosaur found at the top of the Cedar Mountain Formation in the Mussentuchit Member (about 98 million years old) on the west side of the San Rafael Swell. As this dinosaur is most closely related to advanced iguanodontians from Asia, *Eolambia* has become important in dating the origins of Alaska and the first immigration of dinosaurs from Asia into

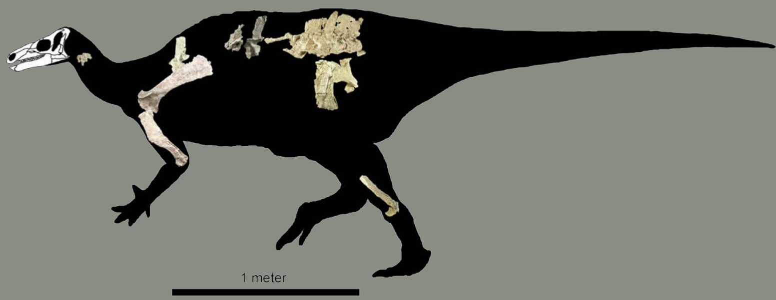


Holotype maxillary (upper jaw) fragment of Iguanodon ottingeri *from Dalton Wells, Utah (teeth about 2 cm across).*

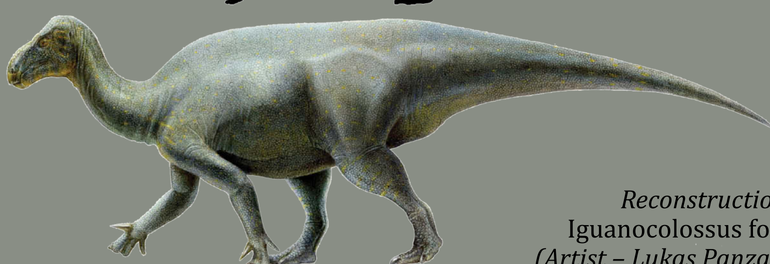


Reconstruction of skull and head of Eolambia caroljonesa*. Light gray bones from juvenile skulls, dark gray bones from holotype adult skull, and black bones are still unknown. (Artist – Lukas Panzaran. Used with permission.)*

Skull of Hippodraco scutodens *on exhibit at the Natural History Museum of Utah in Salt Lake City.*



Reconstruction of Hippodraco. *(Artist – Lukas Panzaran. Used with permission.)*



Reconstruction of Iguanocolossus fortis. *(Artist – Lukas Panzaran. Used with permission.)*

western North America at the end of the Early Cretaceous.

Researchers from the Denver Museum of Nature and Science described *Planacoxa venenica* and *Cedrorestes crichtoni* from the Poison Strip Sandstone Member of the Cedar Mountain Formation (about 120 million years old) northeast of Arches National Park in 2001 and 2007, respectively. Based on the sparse, fragmentary nature of these distinctive fossils, they may represent a juvenile and an adult of the same species. Between the Poison Strip Sandstone and the Mussentuchit Member, the Ruby Ranch Member has yielded scrappy iguanodontian remains that may represent *Tenontosaurus* known from correlative rocks in Montana, Texas, and Oklahoma when North America may have been isolated by rising sea levels. This genus is a very primitive iguanodontian that still maintains a five-fingered hand and lacks a thumb-spike.

The Yellow Cat Member of the Cedar Mountain Formation may preserve the bulk of Utah's iguanodontian diversity. In addition to a new sail-backed iguanodont at Dalton Wells, *Hippodraco scutodens* from the upper Yellow Cat northeast of Arches National Park and *Iguanacolossus fortis* from the lower Yellow Cat south of Green River, were both described in 2010. *Hippodraco* may actually represent the same species as the original *Iguanodon ottingeri,* but unfortunately this may be impossible to test. Our excavations at the Doelling's Bowl dinosaur bonebed near Cisco have revealed a diverse fauna of dinosaurs that we are currently speculating is older than others known in the Yellow Cat, and may be North America's oldest Cretaceous dinosaur site. The dinosaurs are dominated by a new iguanodont species that looks to be more primitive than *Hippodraco*.

Once again, Utah's Cedar Mountain Formation is revealing new chapters in Utah's dinosaur tale that we are only now beginning to appreciate.

ABOUT THE AUTHOR

Dr. James Kirkland is the Utah State Paleontologist with the Utah Geological Survey. He issues permits for paleontological research on Utah state lands, keeps tabs on paleontological research and issues across the state, and promotes Utah's paleontological resources for the public good. An expert on the Mesozoic, Jim has spent 40 years excavating fossils across the southwestern U.S. and Mexico, authoring and coauthoring more than 75 professional papers which include the naming of 18 new dinosaurs. Europe's newest iguanodont is being described in a forthcoming paper with his iguanodontologist colleague Dr. Andrew McDonald and Dr. Luis Alcala of Dinopolis, Teruel, Spain, and is documenting the last Mesozoic connections between Utah and Europe with the opening of the North Atlantic around 110 million years ago.

Main infiltration area, view is eastward toward the mouth of Green Canyon.

Using Aquifers For Water Storage In Cache Valley

by Paul Inkenbrandt and Kevin Thomas

Aquifer storage and recovery (ASR) is the artificial recharge of water into an aquifer, where it is stored for later withdrawal. Water is stored during relatively "wet" periods and is used later during periods of drought and high water demand. Artificial recharge is generally achieved either by ponding water in surface basins, where it can seep into the soil and infiltrate into the aquifer (surface spreading), or by injecting the water directly into the aquifer through a well (injection). Storing water in the subsurface prevents evaporative loss common with surface reservoirs, and allows for fewer infrastructure and space requirements than surface reservoirs.

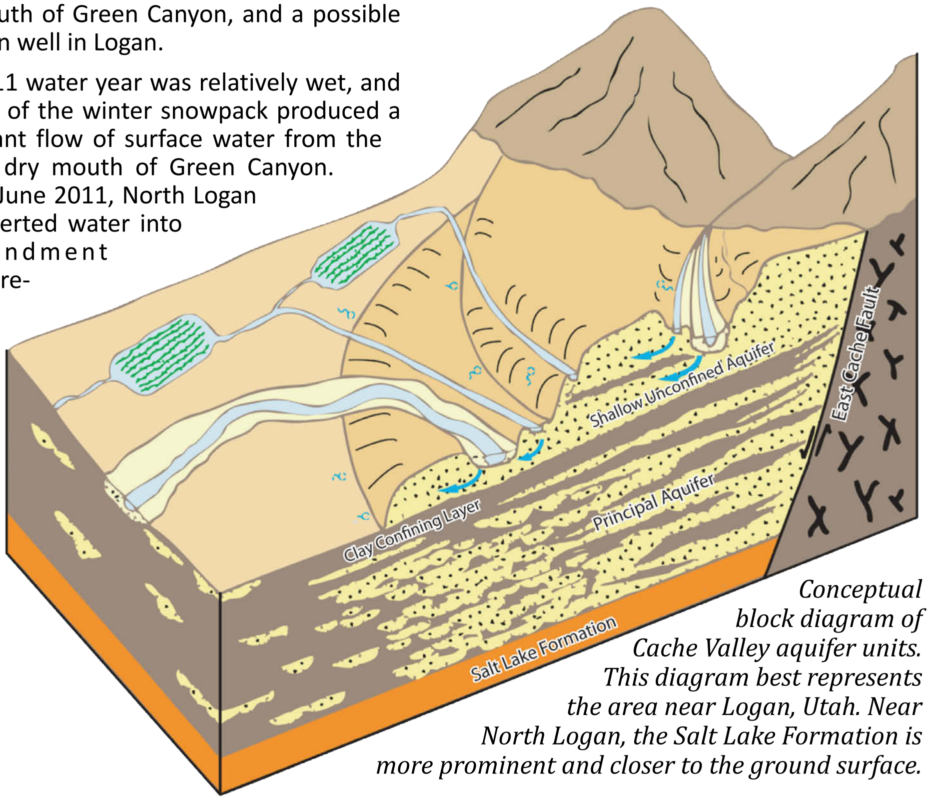
Many entities in Utah, including the Weber Basin Water Conservancy District, Leamington Town, Washington County Water Conservancy District, Brigham City, and the Jordan Valley Water Conservancy District have active ASR projects. Using experience from previous collaborative ASR projects, the UGS has recently evaluated the potential for ASR in Cache Valley.

Cache County expressed interest in ASR projects to provide the county with increased flexibility in managing groundwater resources. Although Cache Valley has an abundance of water resources relative to other areas in Utah, agricultural activities and a growing population create a demand for a well-managed hydrologic system. Excess spring runoff can augment groundwater resources through artificial groundwater recharge as part of one or more ASR projects. A provision by the Utah Division of Water Rights requires the forfeiture of a water right if not used for seven years. Due to redevelopment of agricultural lands, groundwater rights for those lands are forfeited due to nonuse. ASR would allow Cache County to secure the water rights through water banking before they are forfeited to other entities. The UGS proposed to establish an ASR project in multiple phases to (1) locate areas that would likely be suitable for ASR, (2) determine the suitability of selected sites via more in-depth investigation, (3) design and implement an ASR pilot project, and (4) conduct a post-project investigation.

In 2011 the UGS, in cooperation with Utah State University emeritus professor Robert Oaks, Jr., documented the initial phase (site assessment) of the ASR investigation in UGS Open-File Report 579. Potentially suitable areas had a downward hydrologic gradient, lack of laterally continuous clay confining units, available land for use, and available water source(s) for infiltration. A clay confining layer above the principal aquifer, coupled with the near-surface extent of the relatively low-permeability Salt Lake Formation, limits the potential surface-spreading sites to a narrow band along the eastern mountain front of Cache Valley, between Smithfield and Hyrum. Three sites were identified as adequate for ASR, including a surface-infiltration sand pit east of Providence, a surface-infiltration gravel pit east of North Logan at the mouth of Green Canyon, and a possible injection well in Logan.

The 2011 water year was relatively wet, and melting of the winter snowpack produced a significant flow of surface water from the usually dry mouth of Green Canyon. During June 2011, North Logan City diverted water into impoundment ponds created in the gravel pit area adjacent to the mouth of Green Canyon to accommodate excess flow. The water diversion provided an opportunity for us to monitor how well the site worked for ASR.

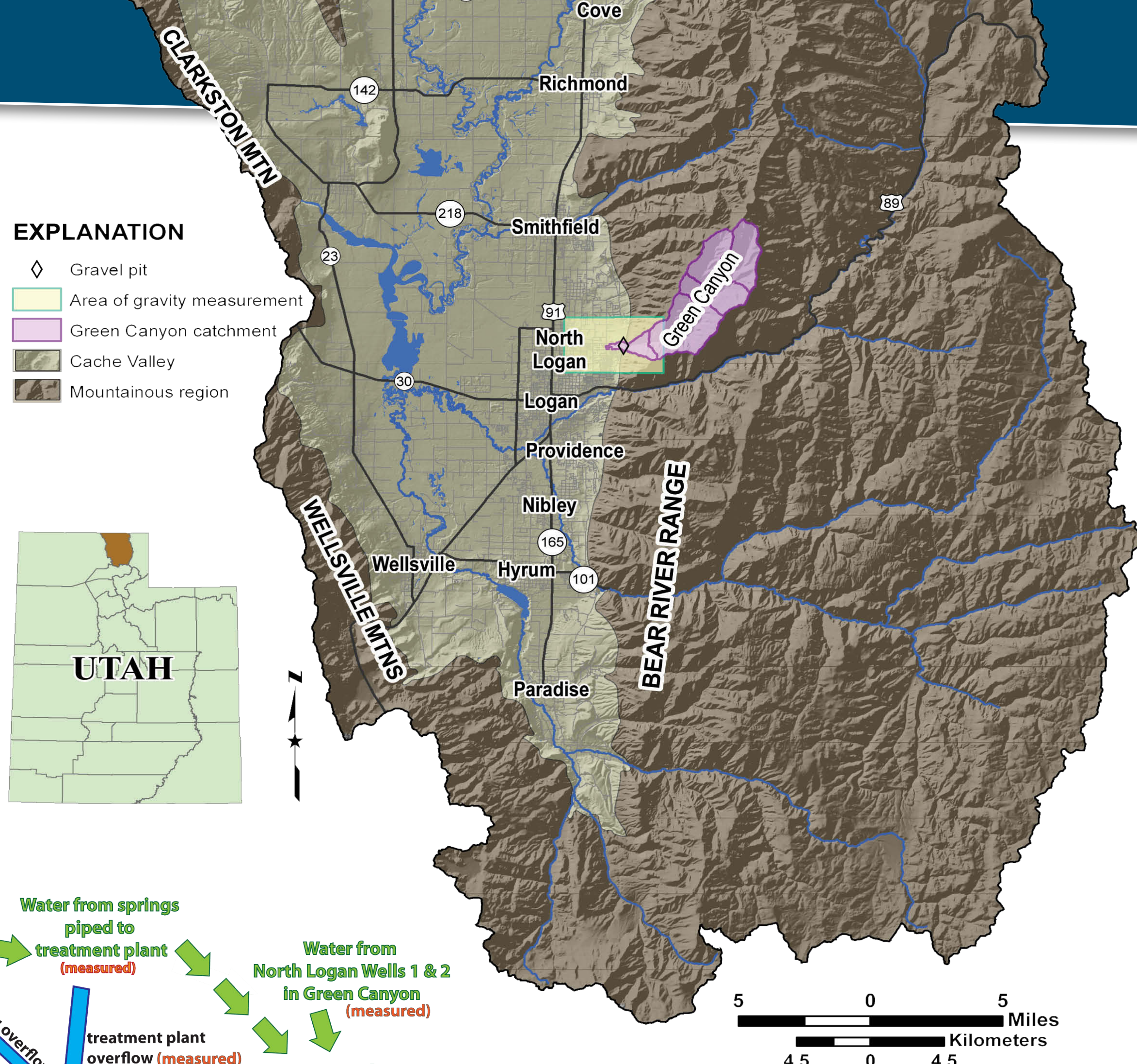
In August, the UGS investigated the infiltration at Green Canyon using a high-precision gravimeter to measure movement of the mass of infiltrating water in the subsurface. High-precision gravity data comprise an important tool that helps document the movement of groundwater that has infiltrated in recharge areas. Paul Gettings of the University of Utah helped create a radial network of gravity stations around the area of infiltration (gravity pit), at which the UGS measured the gravity during several measuring campaigns. These measuring campaigns were conducted in late August 2011, late September 2011, late October 2011, and early March 2012, measuring gravity at the same sites each time.



Conceptual block diagram of Cache Valley aquifer units. This diagram best represents the area near Logan, Utah. Near North Logan, the Salt Lake Formation is more prominent and closer to the ground surface.

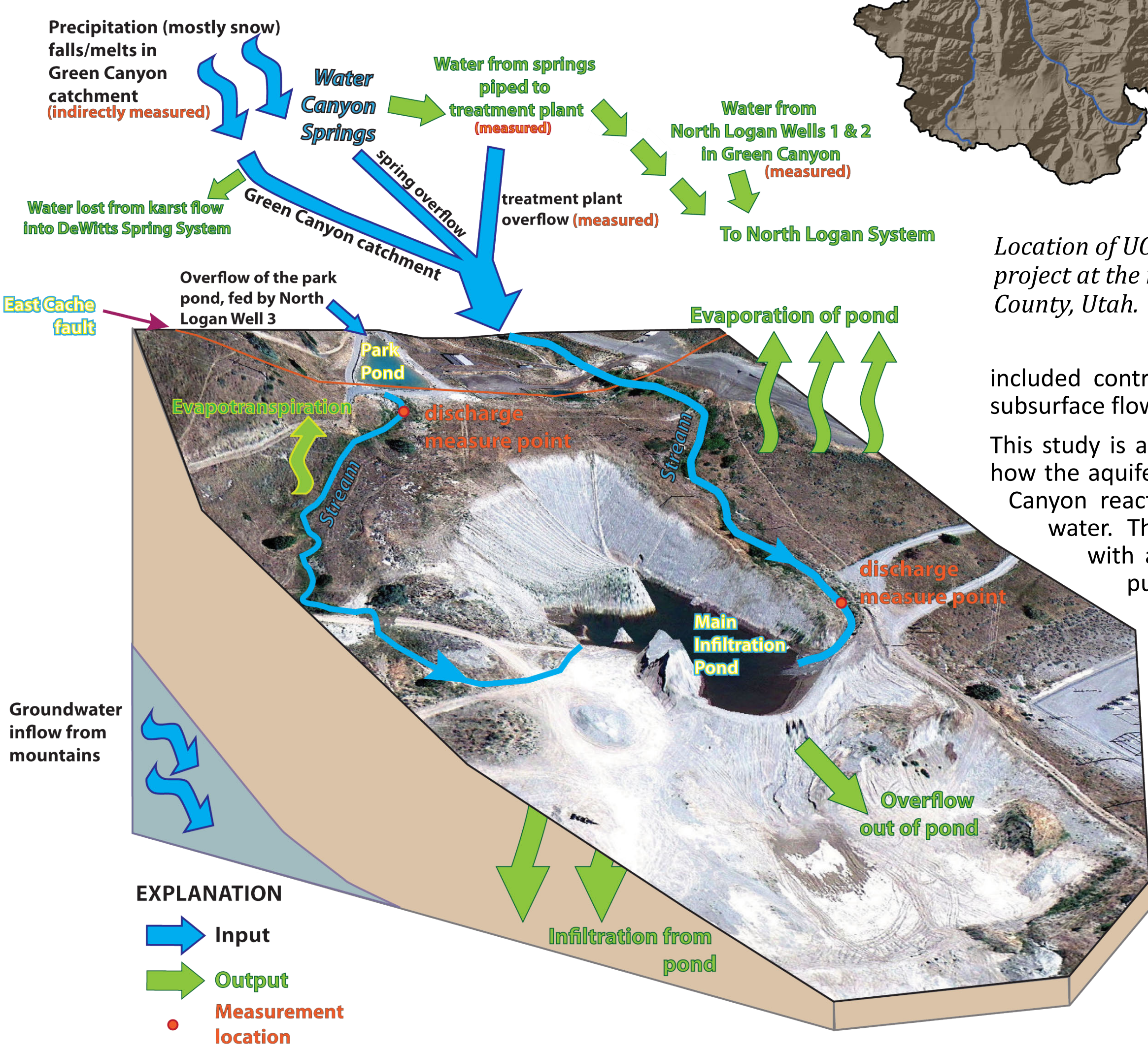
Computer software created by Paul Gettings enabled us to calculate changes in mass based on the very small changes in gravity observed between measurements. All changes in mass determined from the gravity changes were likely changes in the total mass of water at each gravity station.

We compared the gravity measurements to hydrologic measurements, including water levels in two wells, discharge of a spring, flow into the infiltration area, and elevation of the water in the infiltration area, to estimate the volume of infiltrated water. At least 2000 acre-feet (about 650 million gallons) of water infiltrated into the gravel pit from mid–June 2011 to late September 2011. Well water levels and gravity changes indicate groundwater recharge included contributions from regional infiltration, subsurface flow, and infiltration into the gravel pit.



Location of UGS aquifer storage and recovery project at the mouth of Green Canyon in Cache County, Utah.

This study is an excellent opportunity to observe how the aquifer system near the mouth of Green Canyon reacts to large amounts of infiltrating water. The area is hydrologically complex, with a large number of inputs and outputs of water (see diagram). The ASR study in Cache Valley is ongoing, but we are confident that artificial recharge was occurring as a result of the water being diverted into the impoundment ponds. Cache County has interest in further developing this site as an area for ASR, which would consist of adding more flow control, a monitoring well, measuring water chemistry, and continued gravity measurements. Overall, if the county pursues ASR, they will have another tool to help them better manage water resources.



Conceptual diagram of the Green Canyon catchment and the infiltration pond hydrologic buget. Aerial photograph from U.S. Department of Agriculture National Agriculture Imagery Program, 2012.

ESTABLISHING BASELINE WATER QUALITY IN THE SOUTHEASTERN UINTA BASIN

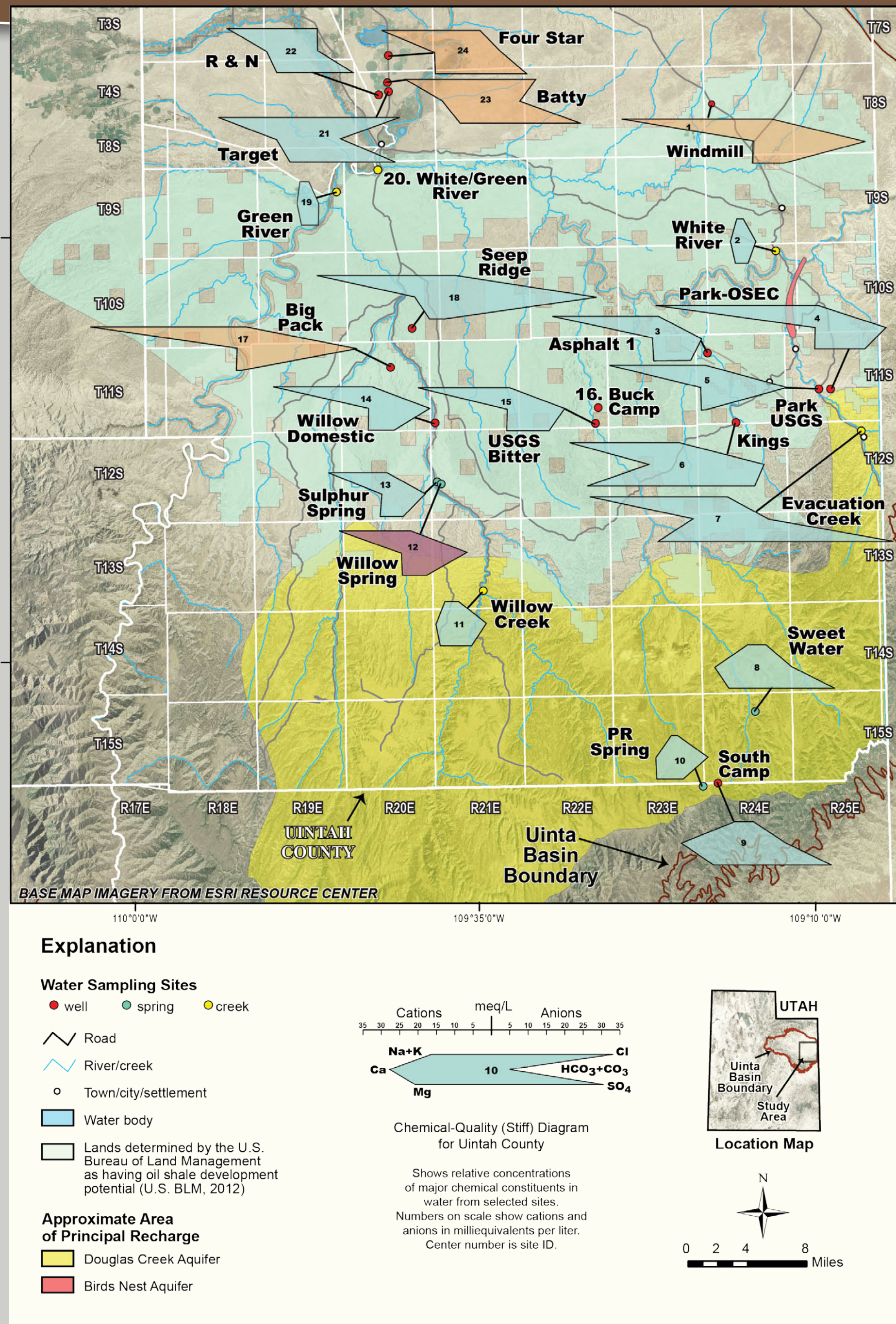
by Janae Wallace

The vast Uinta Basin in eastern Utah is better known for productive oil and gas wells than for water resources. With the continued demand for domestic energy production, research and development activities for unconventional sources of oil and gas, such as oil shale and oil sand, have increased. In particular, the southeastern Uinta Basin has been recognized as having oil shale development potential, and this area generally lacks sufficient water-quality data for surface waters and relatively shallow groundwater. The primary goal of a recent study by the Utah Geological Survey (UGS) is to establish baseline water quality in this area to evaluate and compare any future impacts to water resources.

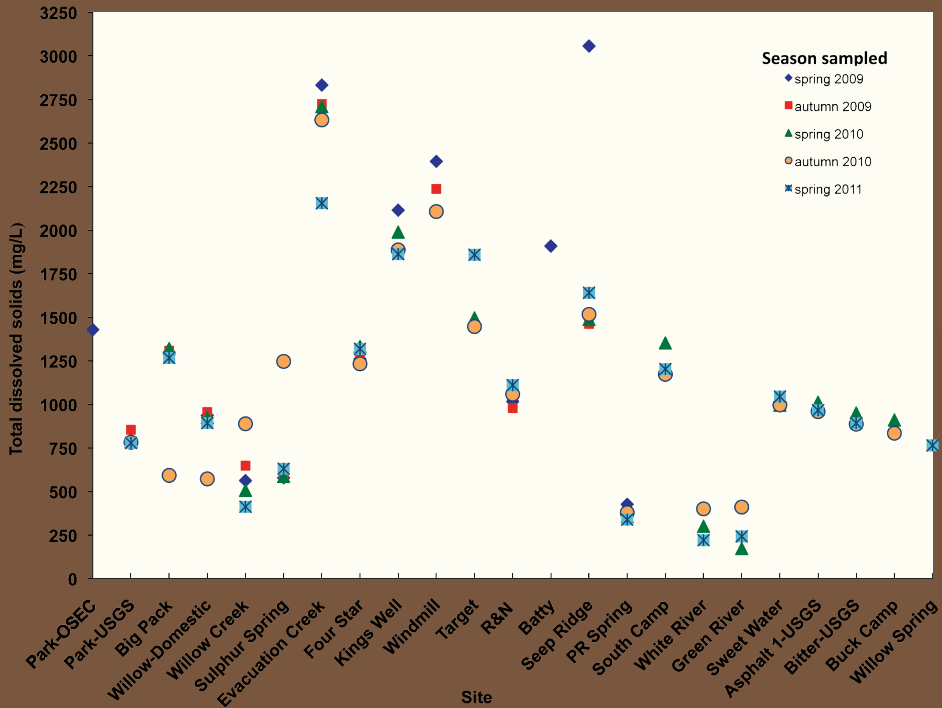
The southeastern Uinta Basin lacks information from water wells, streams, and springs due to the area's reliance primarily on river water as a public-supply source. Thousands of wells within the basin tap groundwater that is not potable; this water exists hundreds or thousands of feet below the surface in oil- and gas-producing zones where it is classified as too salty for human consumption. So, why does the quality of water from the Uinta Basin's shallower wells and springs matter when they are generally not used for drinking water? First, rock units exposed at the surface can be tilted in the subsurface at an angle that slopes toward river levels, where they can discharge water into the Green and White Rivers and their tributaries. A chemical spill on the ground surface, or a substance introduced to a well via leakage or poor wellhead construction, can migrate downgradient and eventually reach streams, which are important drinking water sources, recreation areas, and wildlife habitats. Second, some sites provide water to campers and hunters; although only used seasonally, these sites are still considered public sources. And finally, some of the wells and streams supply water to oil and gas fields within the basin; this water applied on the surface can potentially recharge subsurface aquifers and impact water quality.

Between spring of 2009 and summer of 2011, the UGS collected 85 water samples from up to 24 water wells and surface-water sites. Most of the samples were collected biannually to document seasonal water chemistry changes. Water-quality constituents analyzed include general chemistry, nutrients, metals, and volatile organic compounds (VOCs).

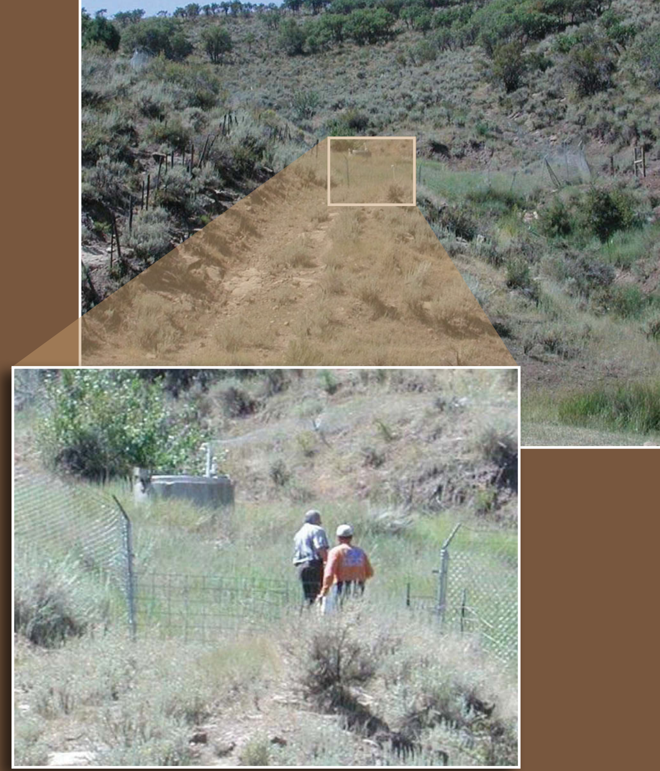
Groundwater quality in the study area varies and is generally good, with total-dissolved-solids (TDS) concentrations primarily below 3000 mg/L, although elevated nitrate, arsenic, lead, selenium, barium, and boron concentrations exist in the aquifers at some



Locations of water sampling sites in the southeastern Uinta Basin. The sites are identified by their location number and/or well owner or formal name (e.g., 13, Sulphur Spring). Stiff diagrams illustrate solute chemistry. Most data are from 2011, except sites 1, 4, and 23, which were sampled in 2009. Blue polygons indicate the site was sampled for and had detectable VOCs; orange indicates no VOCs were detected; purple indicates no VOC analysis was performed. Two sites (sites 16 and 20) were analyzed for TDS only. Diagrams having similar shapes and sizes reflect similar chemistry types; the variability of diagrams reflects the different and mixed aquifer sources. Recharge areas are shown for two important aquifers of the Green River Formation—the Birds Nest and Douglas Creek aquifers.



Total-dissolved-solids (TDS) concentrations for each sample site for up to five different seasons. TDS concentrations for all samples range from 172 to 2832 mg/L. Water having TDS greater than 3000 mg/L exists in one sample (distal pond sample for site 18 Seep Ridge), but this value is considered anomalous as the sample was obtained at a different location within the pond than subsequent samples that were obtained near the pipe flowing into the pond. Water-quality data show that the sites maintain similar water quality during different seasons and years. Future sampling of these sites may show whether water quality has been impacted by changes in land use.



PR Spring (site 10). Groundwater discharge permits have been approved near the PR Spring area for a tar sand project; because the spring itself is a public-supply source, monitoring water quality would be beneficial. Monitoring is not meant to regulate current or future land-use development, but to track the quality of water as a cautionary measure; early detection of pollutants could help avoid costly cleanup.

locations. Our analysis indicates variable water quality throughout the study area, with water likely sourced from multiple aquifers that are not connected, except locally (e.g., shallow alluvium in the northwesternmost part of the study area). TDS concentrations showed little seasonal variation, with about half the sites consistently less than 1000 mg/L and the other half consistently greater than 1000 mg/L. The best quality water (less than 500 mg/L) is from PR Spring, the Green and White Rivers, and one sample obtained during spring runoff from Willow Creek in 2011. The poorest quality water, in terms of high TDS, exists in bedrock wells penetrating the Green River Formation and from low-flow waters of perennial Evacuation Creek (Evacuation Creek flows along outcrop of the Birds Nest zone of the Green River Formation, which contains significant saline mineral deposition and subsequent dissolution). Elevated TDS concentrations likely result from long residence time of water in the bedrock aquifer, surface contamination in shallow alluvial wells, and dissolved constituents contributed from the Green River Formation to discharge areas (streams). Most sites have nitrate concentrations below 0.1 mg/L, except alluvial wells downgradient from irrigated fields and a cattle ranch in the northwestern part of the study area (12 to 18.8 mg/L; the source of nitrate is likely from agricultural activity), and a well penetrating bedrock in the central part of the study area (9.8 mg/L; source unknown).

VOCs were analyzed annually for most sites. VOCs are carbon-based chemicals that typically evaporate at the Earth's surface, but can reach groundwater under certain conditions. Airborne Uinta Basin VOCs are likely from oil and gas emissions, but can be introduced to groundwater from direct industrial or wastewater discharge, leaky underground storage tanks, infiltration from surface spills, atmospheric deposition of vehicle and industrial emissions, and also from natural sources such as bitumen or gilsonite common within local formations (e.g., the Green River Formation). Seventeen of 21 sites sampled for VOCs had detectable levels, and 13 different types of VOCs were detected. No VOC exceeded U.S. Environmental Protection Agency maximum contaminant levels, but many samples had detectable levels of certain VOCs. The most frequently detected was chlorobenzene (in 17 samples over all sampling intervals) followed by chloromethane and xylene (5 samples). Even though the concentrations in groundwater and surface water are low, once VOCs are introduced into the groundwater system, they can become mobile and difficult to remediate.

Overall, the samples show variable water quality throughout the study area, but little seasonal variation at any given site. All of the sites sampled vary in terms of their water resource value. Some are perennial streams or springs, some are water supply sources for the oil and gas industry, some supply water for wildlife, and a few are public water supply sources. Most of the water could be used as a source for drinking if treated properly (desalination), having TDS concentrations below 3000 mg/L, the upper limit set by the Utah Water Quality Board as "Drinking Water Quality." Water-quality degradation may result from an increase in development activity if sound water management practices are not implemented.

Many studies rely on sampling after the environment has been contaminated, and try to trace the contaminant back to a source. Our study provides a current "snap-shot in time" picture, which will make pinpointing the source of any future water quality degradation more direct and accurate. The overall goal is to promote responsible resource development without negatively impacting the environment.

GEOSIGHTS

GANDY WARM SPRINGS, NORTHWESTERN MILLARD COUNTY, UTAH

by Jim Davis

Gandy Warm Springs is a refreshing oasis of tiny waterfalls, pools, caves, and crystal clear streams with water temperatures up to 81˚F. Located on the western edge of Snake Valley, near the Nevada border, the springs are at the base of the southern tip of Spring Mountain (also called Gandy Mountain). The spring water that cascades down the slope of Spring Mountain joins a larger spring that emerges from a cave, initiating the eastward-flowing Warm Creek (also called Gandy Creek). Lush green vegetation, including mosses, watercress, and bright green algae, and animals such as aquatic snails (including the endemic springsnail, *Pyrgulopsis saxatilis*, found only at Gandy) and the native speckled dace wonderfully stand in stark contrast to the surrounding dry yellow grasses and desert shrubs. Gandy is a popular spot for locals who use the area for soaking, swimming, and baptisms.

Given the small size of Spring Mountain, a cluster of hills extending a mile north-to-south and rising just 1000 feet above the surrounding landscape, as well as the noticeably dry climate, one is amazed when considering the voluminous output of Gandy Warm Springs. Every minute, the springs discharge nearly 9000 gallons of water. In other words, Gandy Warm Springs can fill 20 Olympic-sized swimming pools every day.

Geologic Information

The source of water for Gandy Warm Springs is the northern Snake Range and perhaps locales farther west. Possible conduits to the surface for the warm water are faults located in Snake Valley. Alternatively, the springs could flow from sediments containing groundwater that is forced to the surface by the bedrock barrier of Spring Mountain. Passageways through limestone bedrock could also channel groundwater to Gandy. Chemical analysis of the spring water's isotopes suggests some older regional groundwater thousands of years old mixing with more recently recharged groundwater.

The rock of Spring Mountain is largely Ordovician to Cambrian-age Notch Peak Formation, a dark brownish-gray dolomite and gray limestone originally deposited on the seafloor about 500 million years ago. The springs flow from another limestone—the Cambrian-age Orr Formation. The limestones create intricate and intriguing topography (known as karst) characterized by cavities, alcoves, and caves; some of the spring-derived streams disappear into caves and reemerge down slope. A mile north of the springs is Crystal Ball Cave, which contains large, roundish, sparkly calcite crystals, called "nailhead spar" (thus the name Crystal Ball Cave) up to a foot thick on the cave walls, as well as stalactites and stalagmites, columns, and platforms that mark ancient groundwater levels. A large assemblage of Ice Age mammal bones have been collected from the cave (for example, saber-toothed cat, camel, "large-headed llama," and musk ox). Discovered in 1956, the cave is privately owned through a mineral claim on Bureau of Land Management land.

The entrance to a cave, unofficially called "Beware Cave," is marked by an overhang under which springs emerge at the deepest part of Gandy Warm Springs and Warm Creek—almost 4 feet deep.

A constructed pool at the foot of Spring Mountain is filled by a cascading stream. The snowy Snake Range in Nevada can be seen in the distance to the southwest.

Spring water flows as miniature falls and rapids into Warm Creek; Spring Mountain in the background.

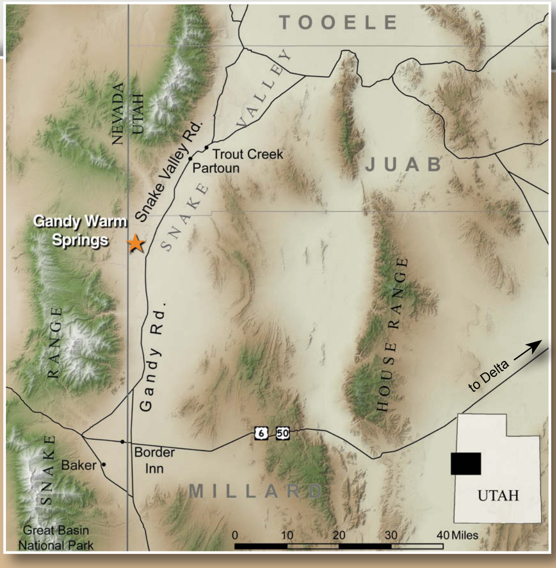
How to get there: Gandy Warm Springs is remote, but not difficult to find. Heading west on U.S. Highway 50/6 from Delta toward the Nevada border and Great Basin National Park, turn right on Gandy Road, two-thirds of a mile before the border, and drive 28 miles north. At the sign for Gandy turn left (this turn is 100 feet before Warm Creek, a green ribbon of vegetation in the desert) and drive west, beginning along the south edge of a farm, for 2.7 miles. A good landmark for this turn is the Matterhorn-like Spring Mountain a couple of miles to the west-northwest; you will want to end up at the southern end of the mountain. The road after this last turn is a little bumpy, but passable for all vehicles in dry weather. For the final few hundred yards the road loops around to the northeast, descending to the creek and ending at a turnabout and parking area. Gandy Warm Springs can also be accessed from the north, via the towns of Trout Creek and Partoun on the Snake Valley Road; however, distances from pavement and services are farther than by way of the southern route.

There are no facilities near the springs. There is a gas station/motel/service station/restaurant (The Border Inn) at the state line on U.S. 50/6, about 30 miles south of Gandy, and the nearby town of Baker, Nevada. The next closest services are in Delta, Utah, about 120 miles east. Camping is an option in the vicinity of the springs, which is Bureau of Land Management land, and directly to the west of the springs, on Utah State Trust Lands.

Useful Maps: Tule USGS 30' x 60' quadrangle (1:100,000 scale); Spring Mountain 7.5-minute quadrangle (1:24,000 scale)

Location: N39.4602778 W114.036667

Elevation: ~5235 feet



GLAD YOU ASKED

IS THERE WINTER SCUBA DIVING IN UTAH?

by Jim Davis

Although scuba diving and the second-driest state in the Union would seem a mismatch, there are numerous sites divers venture to around the state. Perhaps more surprisingly, given the chilly winters in northern Utah, scuba diving is possible year-round in this region of the state. One can ski in cold, fluffy powder snow and then scuba dive in warm, tropical water on the same day along the Wasatch Front.

An abundance of geothermal springs in Utah is a result of the state's active geologic history that has created deep faults and fractures in the bedrock, providing conduits to the surface for heated groundwater. Warm springs with large, deep pools—or artificial pools constructed from springs—make attractive sites for cold-weather diving. Four locales exist that have temperate waters, each different in character and all popular destinations for winter scuba diving, diving classes, and certification.

Bonneville Seabase in northwestern Tooele Valley is the closest thing to warm ocean water in the Intermountain West. Built on the Grantsville Warm Springs, Bonneville Seabase was designed and created by divers for diving. Three "bays," two connected by an 8-foot tunnel, were excavated and filled with the warm, salty spring water that approximates the salinity of the sea. The bays are stocked with colorful marine tropical fish including crevalle jacks, puffers, clownfish, angelfish, a pompano, a sting ray, and bamboo and nurse sharks.

Bonneville Seabase offers lots of diving amenities with the aim of training and certifying divers in a variety of environments. Services include compressors, air storage, equipment rentals, lodging and camping, concessions, a

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Utah Geothermal Scuba Attractions

Location	Status and Overnight Accommodations	Pool Maximum Depth (feet)	Pool Temperature (°F)	Pool Elevation (feet)
Bonneville Seabase	Scuba destination and tropical marine habitat, on-site camping and trailers for rent	62	Pools in the 70s and 80s, cooler in winter	4255
Blue Lake	Wildlife refuge, camping on public lands	59	Around 84°, cooler in winter	4255
Udy	Resort, camping, and full RV hookups	35	90° in winter, warmer in summer	4327
The Crater Mineral Dome	Affiliated neighboring resort, historic hotel, and spa	65	90-95° year-round	5690

1. The Abyss is the warmest, clearest, and deepest of the three diving pools at Bonneville Seabase. 2. White Rock Bay at Bonneville Seabase is fully covered to prevent heat loss. 3. The boardwalk and docks at Blue Lake. 4. The large pond at Udy Hot Springs prior to resort development (photo date unknown). 5. A scuba certification class in The Crater Mineral Dome.

ENERGY NEWS

NEW UTAH GEOLOGICAL SURVEY STUDY TO DETERMINE WHAT BEST TO DO WITH WATER PRODUCED FROM GAS FIELDS IN THE UINTA BASIN

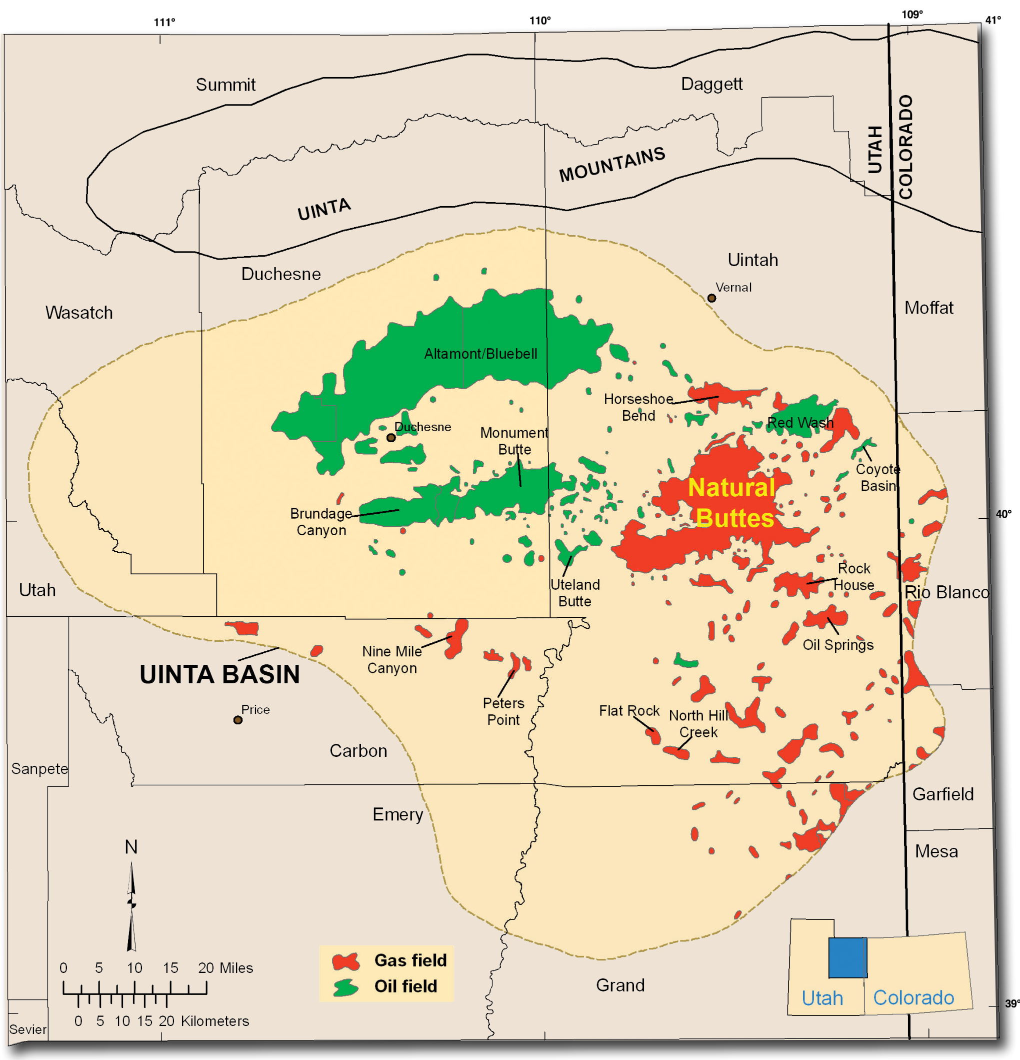
by Thomas C. Chidsey, Jr., and David E. Tabet

The Utah Geological Survey (UGS) has been funded by the Research Partnership to Secure Energy for America (RPSEA) to conduct a two-year study to characterize the quantity and quality of water produced from tight-gas reservoirs in the Uinta Basin of eastern Utah, and help define best management tools and options to deal with the produced water. Thousands of producing gas wells exist in the eastern part of the basin and hundreds more are planned to be drilled in the years to come (see article by Thomas Chidsey in *Survey Notes*, May 2011, v. 43, no. 2). These wells produce gas stored in small pores within very fine grained (tight) sandstone (the reservoir rock). Future wells may produce gas from shale, a mud- and clay-rich rock having even smaller pores. Improved drilling and well-completion techniques, such as horizontal drilling and hydraulic fracturing (fracking), respectively (see "Energy News" article by Robert Ressetar in *Survey Notes*, May 2012, v. 44, no. 2), have spurred the huge success and surge in drilling activity in the Uinta Basin and elsewhere in the U.S. for these types of gas-bearing rocks. However, large volumes of saline (briny) water are also naturally produced with any hydrocarbons. Typically, this water is disposed of by hauling it from the well site to specially designed evaporation ponds or by injection into deep, porous rock at a sufficient depth as to not cause contamination of shallow freshwater aquifers (porous rock from which water is drawn primarily for household and agricultural use).

With the increased drilling for gas in tight-sandstone and shale reservoirs of the Uinta Basin, the resulting production and disposal of water has recently become a topic of much public debate and concern. In addition, the cost of safely disposing the produced water affects the economics of gas resource development. Thus, there is an economic incentive to minimize the amount of water produced, and/or generate revenue by treating and reusing produced water in hydrocarbon production, particularly in arid regions of the West. Possibilities for reuse include dust abatement, drilling, fracking, and secondary oil recovery (water flooding oil-bearing sandstone reservoirs to increase oil production). Produced water might also be used in future oil shale operations, or other industrial water uses. In addition, some hot water from oil and gas wells has potential for geothermal energy production. The new UGS study will address all these issues.

The UGS study will comprise the following four major components:

1. Compilation and analysis within a geographic information system (GIS) format of past and new information on (a) the thickness, structure, depth, and rock characteristics of all aquifer/reservoir units in the basin from the surface down through the deep Jurassic-age formations (206 million years old); (b) the regional variations in quality, flow direction, and temperature of water produced from tight-sandstone and shale reservoirs; (c) the location, water satur-



Oil and gas fields of the Uinta Basin, eastern Utah.

ation volume, and quality of alluvial aquifers (unconsolidated sands and gravels); (d) the existing infrastructure for water management/reuse; (e) the energy generation potential of geothermal produced waters; and (f) the location and geochemical and hydrologic characteristics of aquifers used/proposed for disposal of produced water.

2. Compilation and statistical analysis of water production quantity and quality to identify and forecast produced water production volume trends for each discrete tight-sandstone and shale reservoir to help determine the options for treatment, transportation, disposal, geothermal energy production, and alternative use.

3. Development of alluvial aquifer models to estimate vulnerability to potential contamination from water produced from tight-sandstone and shale development.

4. Evaluation of produced-water management practices and recommendations for improvement.

Drilling operations in the Uinta Basin. Photo by Michael Vanden Berg.

This study will involve the staff and expertise of both the UGS groundwater and energy sections. The UGS will also collaborate extensively with sister regulatory agencies within the Utah Department of Natural Resources (Division of Oil, Gas, and Mining, Division of Water Rights, Division of Water Resources) and other agencies such as the Utah Department of Environmental Quality, U.S. Bureau of Land Management, and U.S. Environmental Protection Agency, as well as tribal authorities in the Uinta Basin. Participating industry partners are Anadarko Petroleum, EP Energy, Wind River Resources, EOG Resources, QEP Resources, and XTO Energy. These collaborators will help the UGS identify (1) current produced water management practices, (2) the volume and quality of produced water, and how produced water is disposed, and (3) new recommendations for better ways to economically and safely manage the water produced from increased gas well drilling in the Uinta Basin. Once completed, the results of this study can be applied immediately by all basin producers, regulators, and stakeholders. Finally, by providing sound scientific information, the UGS study will help allay public concerns about the potential for drinking water contamination.

continued from page 9

desalinization station that provides warm freshwater showers, and night dives. If you are not a diver or snorkeler you can enjoy fish feeding time or a "mollie pedicure," where schools of tiny fish nibble on your feet and toes. Platforms, ladders, an air-filled underwater conversation area, a shipwreck, and other paraphernalia have been added to the bays. Greenhouse coverings over some of the water surface reduce heat loss in winter.

Blue Lake is within a 215-acre Wildlife Management Area comprised of several spring-fed ponds amongst wetlands at the far western edge of the Great Salt Lake Desert, south of Wendover in Tooele County. Blue Lake is the largest natural geothermal pool in the state, with a surface area of 9 acres. The ponds and wetlands host rich fish and bird faunas. A boardwalk lets visitors access the lake during times when a shallow water table makes the lakeshore marshy, and docks and ladders have been constructed for entering and exiting the lake. Blue Lake's floor is strewn with curious objects such as metal animal sculptures and a boat to explore. Late fall and early spring weekdays are the best times of the year to visit; the former has the best clarity of water and fewer bothersome insects. Blue Lake is the only warm-water diving destination in Utah where dogs are permitted—hunters regularly bring their retrievers. The last several miles of the road are unpaved and roughly wash-boarded, but passable for most vehicles in dry weather. The nearest services of any kind are in Wendover, about 25 miles away.

On the western bank of the Malad River in Box Elder County, **Udy Hot Springs** (frequently spelled Uddy) is a cluster of some 50 hot springs and seeps with waters emerging as hot as 125°F. Some of the springs create a pond and others small pools in the area. These waters were developed into Belmont Springs Park which later became Camperworld Hot Springs Resort. The geothermal pond is open for scuba diving from mid-September or early October to mid-May; in summer the pond becomes too hot for diving. The resort also has a hot spring-fed swimming pool and therapeutic hot tubs, a 9-hole golf course, and 300 acres of open space with walking trails and 70 acres with ATV trails.

The Crater Mineral Dome at the Homestead Resort is in Heber Valley north of the town of Midway in Wasatch County. The Midway geothermal area has a number of individual hot springs that form "hot pots," which are roundish, rough-rimmed basins of tufa rock (porous limestone) that has precipitated from the spring water. The Crater is the flagship of the Midway hot pots—a hollow tufa dome measuring some 55 feet high and 300 feet in diameter with a circular opening at the summit that allows sunlight to flood into the void and pool below. In 1996, a 110-foot tunnel was dug into the hot pot wall, permitting horizontal access to the warm pool. Docks, platforms, changing rooms, and lighting have been installed to allow for convenient diving and soaking. Outside the dome, a staircase leads to the summit of The Crater where one can look down into the hot pot through the natural skylight.

Whether you are an experienced diver or just interested in trying it, you don't have to leave the state of Utah for tropical diving. Or if you are a warm spring enthusiast, these springs are well worth a visit.

TEACHER'S CORNER
Earth Science Week 2012

Over 650 enthusiastic elementary students from 10 school groups joined us at the Utah Core Research Center for Earth Science Week* in October. As each group arrived they were split into subgroups and rotated through five 15-minute hands-on activity stations:

- The stream trailer, where they created and then destroyed a river landscape while learning about deposition and erosion.
- The rock talk, where they studied sedimentary, igneous, and metamorphic rocks while learning about the rock cycle.
- The paleontology prep lab, where they examined dinosaur and Ice Age fossils while learning about geologic history.
- The mineral room, where they tested and identified minerals while learning about mineral physical and chemical properties.
- The "gold" panning troughs, where they panned for pyrite, magnetite, and other minerals while learning that geology is fun!

Thanks to the numerous volunteers from various agencies, universities, corporations, and professional organizations, Earth Science Week 2012 was an unequivocal success.

**Since its creation in 1998 by the American Geosciences Institute, Earth Science Week has encouraged people everywhere to explore the natural world and learn about the geosciences.*

If Martharaptor *was omnivourous, it could very well have looked like its cousin* Falcarius utahensis *shown in this photo.*

Utah Geological Survey Scientist Honored in Naming of Utah's Newest Dinosaur: *Martharaptor greenriverensis*

Utah's newest and slightly mysterious dinosaur, *Martharaptor greenriverensis*, is named in honor of Martha Hayden, a UGS paleontological assistant and a dedicated advocate of paleontology. She has served for over 30 years as the aide to several Utah state paleontologists and has also donated numerous volunteer hours in her paleontological endeavors.

Martha co-discovered the fossilized skeletal remains near Green River in east-central Utah. The bones, found in the roughly 125-million-year-old basal rock of the Cedar Mountain that other carnivorous dinosaurs (such as the famous *Utahraptor*) have been found in the same rocks of the same age. However, some of *Martharaptor's* remains, especially the scapula and claws, resemble the pot-bellied, bipedal dinosaurs called therizinosaurs that are omnivorous. These omnivorous and/or herbivorous dinosaurs stand out in having long necks and large hand claws and include the well-known therizinosaur *Falcarius utahensis* that was found nearby in slightly older rocks.

For now, the fossilized bones have been placed into the collections of the Natural History Museum of Utah in Salt Lake City. Until a complete skeleton is found, *Martharaptor greenriverensis* may well remain an enigma. And possibly, Hayden herself will make the next discovery.

Martha excavating dinosaur fossils.

EMPLOYEE NEWS

The Groundwater and Paleontology Program welcomes **Jennifer Jones** as the new wetlands specialist. She comes to us from Fairbanks, Alaska, where she was working for the National Park Service. Jennifer has a B.S in Botany and an M.S. in Ecology from Colorado State University.

SURVEY NEWS

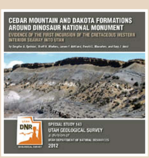
2012 LEHI HINTZE AWARD

The Utah Geological Association and the Utah Geological Survey (UGS) presented the 2012 Lehi Hintze Award to William R. (Bill) Lund for his extraordinary scientific contributions in the field of geologic hazards of Utah. Bill has 40 years of experience as an engineering geologist—7 years in private industry and 33 years with the UGS. Bill is a former Deputy Director of the UGS, and is presently Senior Scientist for the Geologic Hazards Program and manager of the UGS Southern Regional Office in Cedar City. In addition to his extensive work on landslides, debris flows, rock falls, and earth fissures, Bill is also a nationally recognized expert in the field of paleoseismology. His field studies to determine the timing and displacement of large prehistoric earthquakes on Utah's Wasatch fault, and his decade-long leadership of earthquake working groups comprise the most comprehensive body of work to understand and reduce the risk from Utah's earthquake hazards. Among his numerous publications and contributions to geology in Utah is his editorship of the UGS's Paleoseismology of Utah Series, which consists of 22 volumes. Bill's exemplary geologic work has been recognized by a number of prestigious awards, including the Governor's Medal for Science and Technology (2009; State of Utah), the John C. Frye Award (2010; Geological Society of America and Association of American State Geologists), the Claire P. Holdredge Award (2010; Association of Environmental and Engineering Geologists), and the Crawford Award (2011; UGS). Bill is a tremendously knowledgeable scientist as well as a wonderful teacher and insightful mentor, and he is well-deserving of the Lehi Hintze Award.

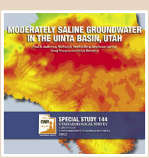
Named for the first recipient, Dr. Lehi F. Hintze of Brigham Young University, the Lehi Hintze Award was established in 2003 by the Utah Geological Association and the UGS to recognize outstanding contributions to the understanding of Utah geology.

NEW PUBLICATIONS

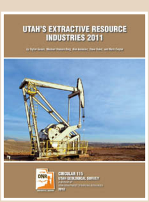
Late Holocene earthquake history of the Brigham City segment of the Wasatch fault zone at the Hansen Canyon, Kotter Canyon, and Pearsons Canyon trench sites, Box Elder County, Utah, by Christopher B. DuRoss, Stephen F. Personius, Anthony J. Crone, Greg N. McDonald, and Richard W. Briggs, CD (27 p. + 35 p. appendices, 3 pl.), ISBN 978-1-55791-861-1,
Special Study 142 .... $19.95



Cedar Mountain and Dakota Formations around Dinosaur National Monument—evidence of the first incursion of the Cretaceous Western Interior Seaway into Utah, by Douglas A. Sprinkel, Scott K. Madsen, James I. Kirkland, Gerald L. Waanders, and Gary J. Hunt, CD (20 p. + 6 appendices), ISBN 978-1-55791-863-5,
Special Study 143 .... $14.95

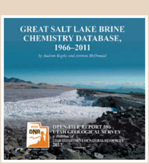


Moderately saline groundwater in the Uinta Basin, Utah, by Paul B. Anderson, Michael D. Vanden Berg, Stephanie Carney, Craig Morgan, and Sonja Heuscher, CD (30 p., 9 pl., [contains GIS data]), ISBN 978-1-55791-8564-2,
Special Study 144 .... $24.95

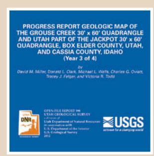


Utah's extractive resource industries 2011, by Taylor Boden, Michael Vanden Berg, Ken Krahulec, Dave Tabet, and Mark Gwynn, 27 p., ISBN 978-1-55791-866-6,
Circular 115 .... $9.95

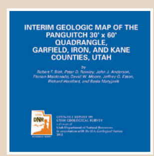
Baseline water quality and estimated quantity for selected sites in the southeastern Uinta Basin, Utah, by Janae Wallace, CD (24 p. + 4 appendices),
Open-File Report 595 .... $14.95



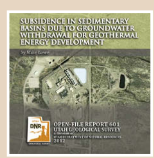
Great Salt Lake brine chemistry database, 1966–2011, by Andrew Rupke and Ammon McDonald, 7 p.,
Open-File Report 596 .... $14.95



Progress report geologic map of the Grouse Creek 30' x 60' quadrangle and Utah part of the Jackpot 30' x 60' quadrangle, Box Elder County, Utah, and Cassia County, Idaho (year 3 of 4), by David M. Miller, Donald L. Clark, Michael L. Wells, Charles G. Oviatt, Tracey J. Felger, and Victoria R. Todd, CD (31 p., 1 plate), scale 1:62.500,
Open-File Report 598 .... $19.95



Interim geologic map of the Panguitch 30' x 60' quadrangle, Garfield, Iron, and Kane Counties, Utah, by Robert F. Biek, Peter D. Rowley, John J. Anderson, Florian Maldonado, David W. Moore, Jeffrey G. Eaton, Richard Hereford, and Basia Matyjasik, CD (127 p., 3 plates), scale 1:65,000,
Open-File Report 599 .... $19.95



Subsidence in sedimentary basins due to groundwater withdrawal for geothermal energy development, by Mike Lowe, CD (9 p.),
Open-File Report 601 .... $14.95

Summary of compiled permeability with depth measurements for basin fill, igneous, carbonate, and siliciclastic rocks in the Great Basin and adjoining regions, by Stefan M. Kirby, CD (9 p.),
Open-File Report 602 .... $14.95

Summary of compiled fluid geochemistry with depth analyses in the Great Basin and adjoining regions, by Stefan M. Kirby, CD (10 p.),
Open-File Report 603 .... $14.95

Interim geologic map of the Goshen quadrangle, Utah and Juab Counties, Utah, by Adam P. McKean and Barry J. Solomon, 31 p., 1 pl., 1:24,000 scale,
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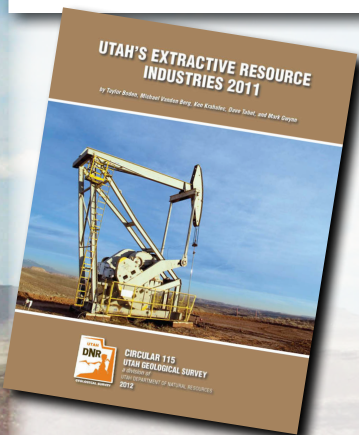
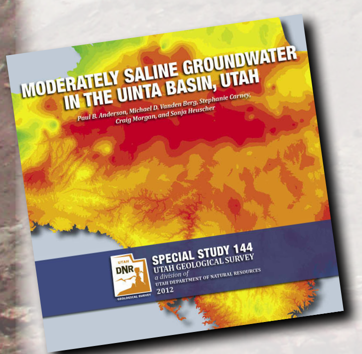


Utah's Extractive Resource Industries 2011

by Taylor Boden, Michael Vanden Berg, Ken Krahulec, Dave Tabet, and Mark Gwynn

Utah's geology provides a remarkable range of energy and mineral wealth. The development of these resources for over 160 years has been and will continue to be very important, benefitting not only Utah, but also the entire United States. Utah mineral activity summaries have been compiled annually since 1989 by the Utah Geological Survey. This year marks the first inclusion of crude oil, natural gas, and unconventional fuels production, value, exploration, and development activity summaries, resulting in one comprehensive energy and mining activity report for Utah. Utah energy and mineral companies produced an estimated gross value of $9.2 billion in energy and mineral commodities in 2011, consisting of $4.6 billion from energy production and $4.6 billion from nonfuel mineral production. Utah remains the only state in the nation to produce magnesium metal, beryllium concentrate, and gilsonite.

Circular 115 .... $9.95



Moderately Saline Groundwater in the Uinta Basin, Utah

by Paul B. Anderson, Michael D. Vanden Berg, Stephanie Carney, Craig Morgan, and Sonja Heuscher

The base of the moderately saline water (BMSW) (10,000 mg/L TDS transition) in the Uinta Basin was first mapped in 1987 and re-mapped in this study using similar methods. Water samples from primarily oil and gas activities through the basin's history were compiled into a database (2788 records) and used as an aid in mapping. In addition, geophysical logs from 260 wells distributed throughout the basin were interpreted and used in mapping the BMSW. Regional groundwater flow paths, saline minerals, structural shape of the basin, and faults and fractures strongly influence the distribution of TDS levels. Both older and new data points were used to create an elevation contour map of the position of the shallowest occurrence of the BMSW below the surface. (on CD)

Special Study 144 .... $24.95