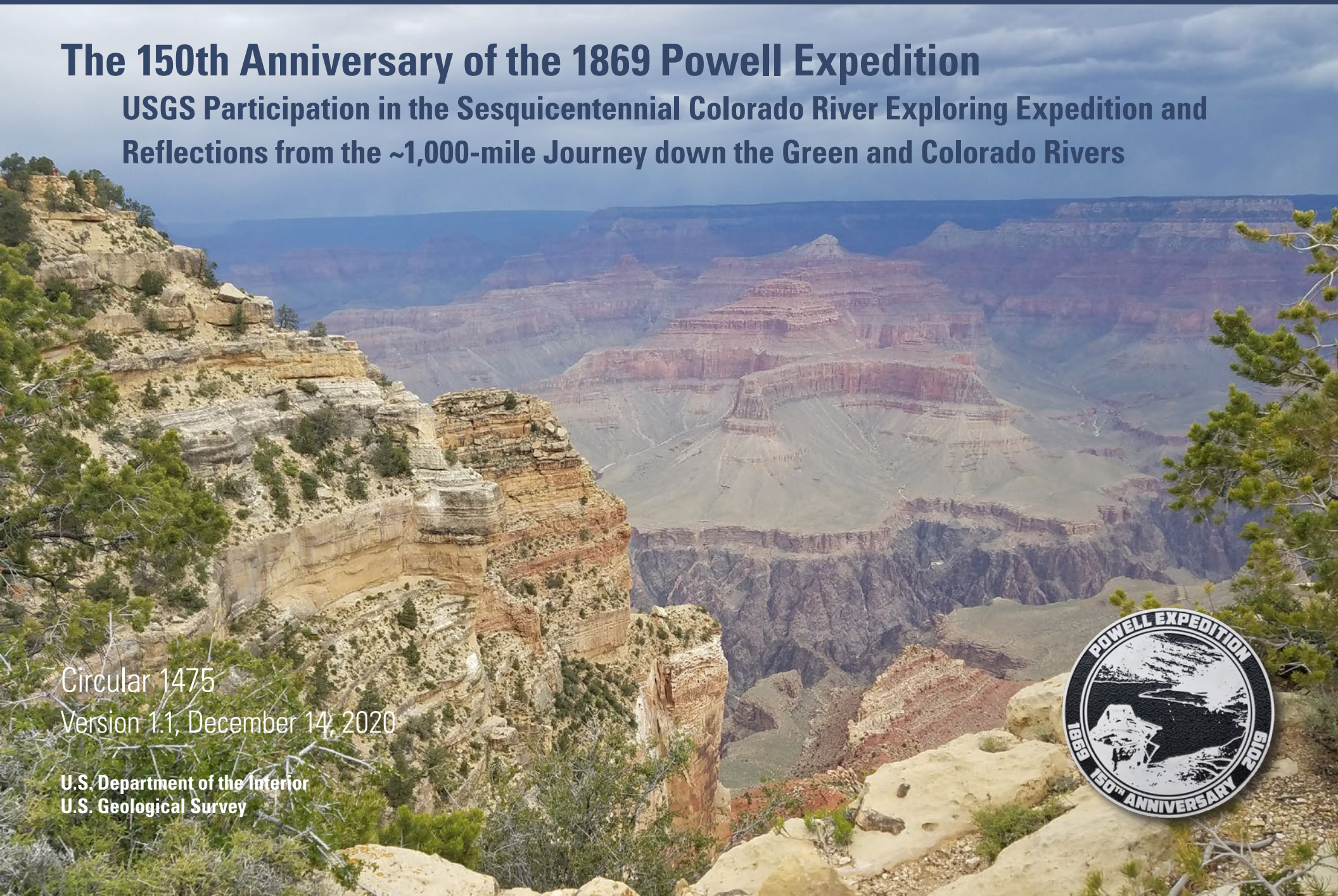
USGS
science for a changing world

The 150th Anniversary of the 1869 Powell Expedition

USGS Participation in the Sesquicentennial Colorado River Exploring Expedition and Reflections from the ~1,000-mile Journey down the Green and Colorado Rivers



Circular 1475
Version 1.1, December 14, 2020

U.S. Department of the Interior
U.S. Geological Survey

Cover: Grand Canyon, Arizona, from Powell Point and plaque dedicated for the Powell Memorial, May 19, 2019. Photographs by Annie Scott, U.S. Geological Survey.

Title page: Flaming Gorge Reservoir, Flaming Gorge National Recreation Area, Wyoming. Photograph by Janis LeMaster, U.S. Geological Survey.

Back cover: John Wesley Powell Memorial, located at Powell Point on the south rim of the Grand Canyon. The 2019 commemorative plaque was added later. Photograph by Annie Scott, U.S. Geological Survey.

The 150th Anniversary of the 1869 Powell Expedition

USGS Participation in the Sesquicentennial Colorado River Exploring Expedition and Reflections from the ~1,000-mile Journey down the Green and Colorado Rivers

By Annie Scott and Eleanour Snow

Circular 1475
Version 1.1, December 14, 2020

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia
First release: December 3, 2020, online
Revised: December 14, 2020 (ver. 1.1), online and in print

Suggested citation:
Scott, A., and Snow, E., 2020, The 150th anniversary of the 1869 Powell expedition—USGS participation in the Sesquicentennial Colorado River Exploring Expedition and reflections from the ~1,000-mile journey down the Green and Colorado Rivers (ver. 1.1, December 14, 2020): U.S. Geological Survey Circular 1475, 88 p., https://doi.org/10.3133/cir1475.

Library of Congress Cataloging-in-Publication Data

https://catalog.loc.gov/

ISSN 1067-084X (print)
ISSN 2330-5703 (online)
ISBN 978-1-4113-4396-2

Foreword

On May 19, 2019, I joined USGS staff from Reston, Virginia, and Flagstaff, Arizona, along with staff from the National Park Service, in the dedication of a 150-year-anniversary plaque on the John Wesley Powell Memorial, located at Powell Point on the south rim of the Grand Canyon. As a fellow veteran, geologist, explorer, and USGS director, it was my honor to provide remarks at this event along with Sarah Creachbaum, Acting Superintendent of Grand Canyon National Park, and Theresa McMullan, CEO of the Grand Canyon Conservancy, to honor Powell and his exploration.

Standing in that spot, I thought about Powell and his words the first night of his long journey: "Standing on a high point, I can look off in every direction over a vast landscape, with salient rocks and cliffs glittering in the evening sun. …clouds and mountains and snow fields and forests and rocklands are blended into one grand view." Powell knew he would have to conquer the great canyon but he didn't really know its size and scale. I was impressed when I first saw the Grand Canyon as a child, but when I saw it from space, I truly understood its grandeur.

When Powell came through the Grand Canyon, he had only simple mapping tools and a strong desire to explore its varied landscapes and winding reaches. A lot has changed in 150 years in the tools we use to do science. I wish Powell could see the GPS satellite technology, Landsat imagery, and lidar data we use today. The 2019 modern version of his epic expedition was led by our partner, the University of Wyoming-based Sesquicentennial Colorado River Exploring Expedition (SCREE). USGS personnel representing all mission areas and regions joined SCREE, with 28 in total floating the river over eight segments. USGS scientists and science support staff conducted sampling activities, took photos, and made observations from the field so that, through them, we have eyes and ears on the 2019 expedition. The USGS Youth and Education in Science (YES) team is using the observations and data collected from the river to engage K-12 students through a range of educational resources. In this way, we hope to encourage a new generation of future scientists to get out, explore, and see the science that is all around them. I joined the expedition for two and a half days on the Lake Powell section and had the opportunity to connect with USGS employees and hear about their science under the stars.

Walking past John Wesley Powell's portrait on the way to my office in the building that bears his name just outside Washington, D.C., I think about Powell's early days of exploration. As I sit at the desk Powell once used, I often reflect on how he used the tools he had at the time to characterize the composition of the land, and how the 8,000-plus USGS employees today continue his legacy 150 years after that first scientific voyage down the "Great Unknown." As it was for JWP, it remains for us: to push out the frontiers of our knowledge and expand our capabilities to understand our remarkable planet.

James F. Reilly II
Director

USGS Director Jim Reilly gazes into the depths of the Grand Canyon at Powell Point after delivering the keynote address at the John Wesley Powell Memorial to present the 150th anniversary plaque commemorating the 1869 expedition.

Acknowledgments

We extend sincerest thanks to Kristen Hamilton, National Science Foundation, for her leadership, dedication, and innumerable contributions to the Powell150 project during her temporary detail at the U.S. Geological Survey (USGS). We appreciate the professionalism of our partners from the Sesquicentennial Colorado River Exploring Expedition (SCREE) at the University of Wyoming (Thomas Minckley, Patrick Kikut, Jessica Flock, Ben Kraushaar, Cody Perry, and all other SCREE members and participants), their willingness to include USGS participants on their expedition, and their cheerful fielding of countless pre-expedition phone calls. The National Park Service (NPS) (Jan Balsom, Ronda Newton, and Vanessa Ceja-Cervantes) was instrumental in helping to secure permits and inviting Director Reilly to deliver the sesquicentennial plaque dedication keynote address at Powell Point in Grand Canyon National Park. We acknowledge the Smithsonian Institution as the original supporter of John Wesley Powell's expeditions, and we thank the National Museum of American History, Division of Culture and the Arts (Kay Peterson and Joan Boudreau) as well as the Smithsonian Libraries (Erin Rushing) for arranging the photo shoot of the original woodblocks with Powell's 1875 publication. We extend our thanks to the National Museum of Natural History (Igor Krupnik) for inviting the lead author to speak at a sesquicentennial seminar attended by the Powell family descendants. Also, our gratitude goes to the Department of the Interior Museum (Tracy Baetz) for arranging permission to include an image of the historical artwork. We appreciate engagement from the Bureau of Reclamation (including expedition participant Jim Prairie) and the Bureau of Land Management (BLM). Our gratitude is extended to all who provided scientific advice, logistical planning (USGS Office of Accounting and Financial Management), communications training, ethics guidance (USGS Ethics Office), and contract preparation support. We especially appreciate the assistance given by the members of the USGS Safety Review Team (Cynthia Duffield, Scott Vanderkooi, Bill Simonds, Cory Stephens, Brent Sigafus, and Timothy Frick), who were awarded the 2019 USGS Safety and Occupational Health Award of Excellence for their work on this out-of-the-ordinary endeavor, and without whose help the USGS could not have participated in the expedition. We thank USGS detailees Tina Solomon, Anna Glover, William Banks, Brenda Densmore, Harper Wavra (student intern), and Debbie Warner Gordon for their contributions, along with the members of the participant selection panel. Through the Department of the Interior, Marina Conner (NPS) and Jaci Wells (BLM) joined the team for short details and helped with social media and educational products. Kristen Hamilton and Anna Glover were pivotal in the development and editing of the Then and Now series articles, which were originally published on our website and have been re-edited for this publication, along with other Then and Now articles written by guest authors. We thank our colleagues at the USGS Southwest Biological Science Center (Ted Melis, Todd Wojtowicz, David Lytle, Scott Vanderkooi, Theodore Kennedy, Ryan Crow, Paul Grams, Joel Sankey, Jeff Muehlbauer, Sasha Reed, Anya Metcalfe, Meredith Hartwell, Camile Diab, Erika Geiger, Michael Duniway, Hilda Smith and all others who participated in science conversations and helped us with equipment) and the USGS Astrogeology Science Center (including Greg Vaughan and Railyn Stokes), all of whom made us feel at home during our visits to Arizona. We acknowledge the USGS Denver Photographic Library staff for their help with compiling online libraries specific to the second Powell Expedition. Our thanks also go to USGS National Museum Curator Bruce Geyman for overseeing art installations related to the 150th anniversary celebration and to the USGS Office of Communications and Publishing (Heidi Koontz, Jennifer LaVista, Stacy Curtis, Melinda Nash, Elizabeth Stewart, Kristina Sussman, Scott Horvath, and the social media team). We acknowledge the noteworthy assistance from USGS reviewers Rick Moscati and Graham Lederer; James Estabrook of the Science Publishing Network (SPN); and Susan Meacham (SPN) for her creative layout and design. Additionally, we thank our families for their tremendous support and patience. Finally, we thank all our colleagues in the USGS Office of Science Quality and Integrity for their many contributions which helped make this project successful.

We are grateful to each of the USGS expedition participants and their respective Science Centers for their involvement in the sesquicentennial project. This publication was inspired by their post-trip debriefing calls and would not have been possible without their amazing photographs, personal vignettes, and science stories. Most important, their willingness to represent the USGS in a positive, professional manner, to share their scientific expertise with new colleagues across the bureau, and to engage their local communities about USGS science and their own river experiences across the Nation is a testimony to their continued commitment to public service.

Jason Alexander
Hydrologist
Cheyenne, WY

Anne Ballmann
Wildlife Disease Specialist
Madison, WI

Genevieve Barron
Geographer
Denver, CO

Robert Barth
Administrative Services Supervisor
Rolla, Missouri

Sharon Borland
Chief, Office of Policy and Analysis
Reston, VA

Breton Bruce
Scientist Emeritus
Denver, CO

Christina Bryant
Hydrologic Technician
Albuquerque, NM

Jessica Lucido Buren
Deputy Program Manager
NWIS Modernization Program
Middleton, WI

William Burton
Research Geologist
Reston, VA

Kathy Conn
Hydrologist
Tacoma, WA

Jaime Delano
Geologist
Golden, CO

Mitchell Eaton
Research Ecologist
Raleigh, NC

Nicholas Hammond
Hydrologic Technician
Charleston, SC

Tess Harden
Hydrologist
Portland, OR

William Harmon
Hydrologic Technician
Little Rock, AR

Heather Kerkering
Science Coordinator
Honolulu, HI

Graham Lederer
Physical Scientist
Reston, VA

Janis LeMaster
Hydrologic Technician
Charleston, SC

Melissa Lombard
Hydrologist
Pembroke, NH

Anya Metcalfe
Ecologist
Flagstaff, AZ

Richard Moscati
Geologist
Denver, CO

David Nail
National Map Liaison
Rolla, MO

John Parks
Information Technology Specialist
Guaynabo, PR

Nigel Pepin
Hydrologic Technician
East Hartford, CT

Jim Reilly
USGS Director
Reston, VA

Russell Sherman
Hydrologic Technician
Tacoma, WA

Katie Walton-Day
Research Hydrologist
Denver, CO

Dee Williams
Deputy Director
Anchorage, AK

Bowknot Bend, Utah

Contents

June 7, 1869: "This evening, as I write, the sun is going down, and the shadows are settling in the canyon. The vermilion gleams and roseate hues, blending with the green and gray tints, are slowly changing to somber brown above, and black shadows are creeping over them below; and now it is a dark portal to a region of gloom the gateway through which we are to enter on our voyage of exploration tomorrow. What shall we find?" ~JWP

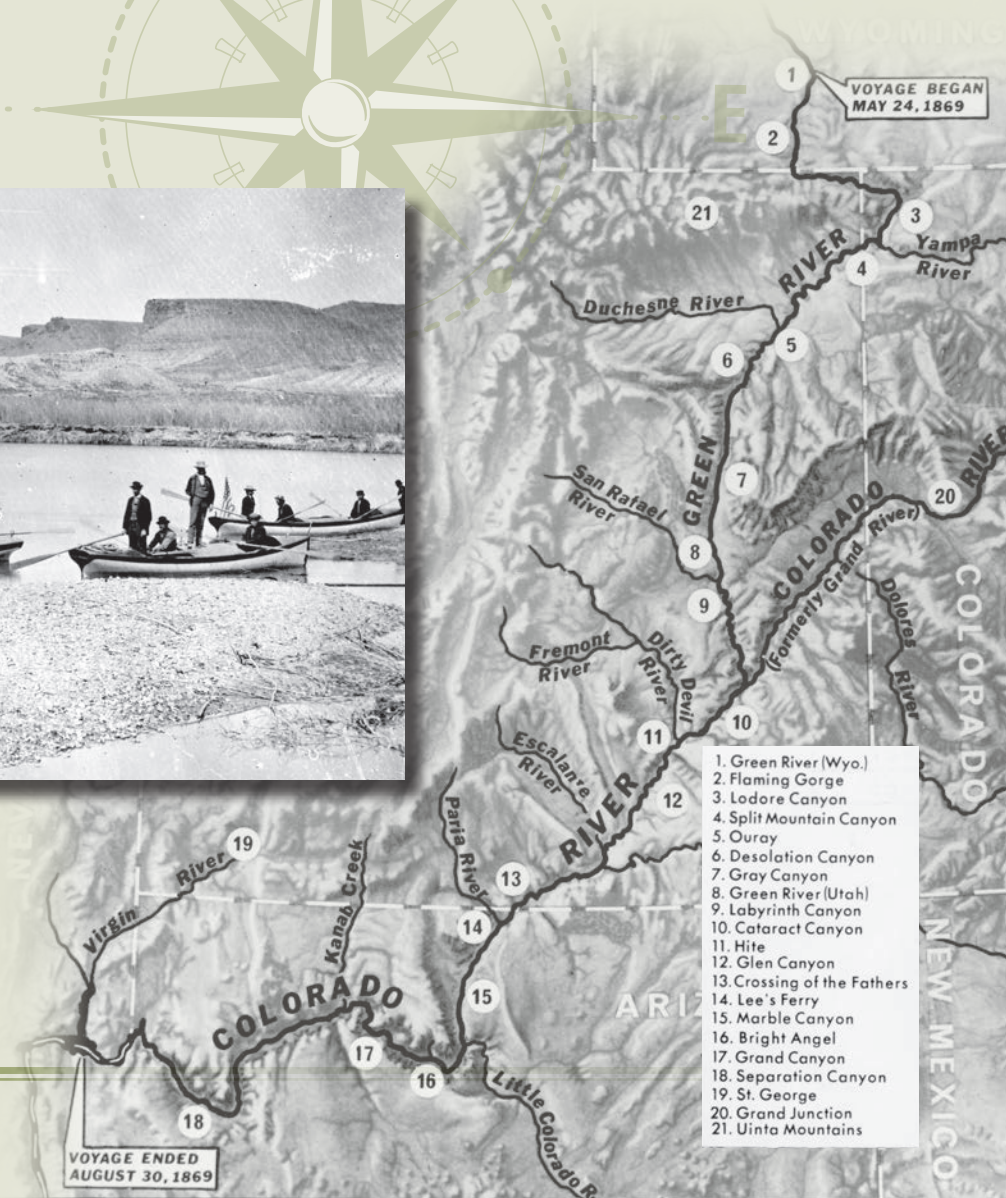
Introduction

In late spring 1869, John Wesley Powell headed down the Green River toward the mighty Colorado, with nine other men in four boats on an exploration into the "Great Unknown." That journey, which we commemorated 150 years later, led to the founding of the U.S. Geological Survey (USGS) and, for Powell and so many others, to a lifelong passion for these rivers and their canyons.

As the science bureau within the Department of the Interior (DOI), the USGS provides unbiased scientific information about the Nation's natural resources, ecosystem and environmental health, and the impacts of climate and land-use change. Founded in 1879 at the urging of Powell and by an act of Congress, the USGS is well-known for topographic and geologic maps and for collecting and monitoring data about natural hazards such as earthquakes and floods. Originally focused on mapping and characterization of the land and its resources, the USGS mission has expanded over time to include water, hazards, and ecosystems. The USGS works closely with States and other stakeholders to provide data and scientific analyses, informing decision making for a changing world.

John Wesley Powell, the second director of the USGS, completed some of the earliest recorded scientific explorations of the West, especially in the Colorado River Basin. The anniversary of Powell's expeditions to map the land near the untamed waters of the Green and Colorado Rivers 150 years ago provides an opportunity to reflect upon the role

Photograph of the 1871–72 Powell expedition preparing to embark on their second exploration from Green River Station, Wyoming Territory, on May 4, 1871. No photographer was present on the 1869 journey.



Relief map of Powell's pioneer river voyage, 1869, from U.S. Geological Survey (1970).

of USGS science today, both along Powell's historic route and across the Nation. The modern Colorado River Basin is very different from what Powell experienced in the mid-1800s. The basin today is heavily managed and highly subdivided. The terrain through which these rivers flow includes Tribal lands; private lands; and public lands managed by the National Park Service (NPS), the Bureau of Land Management (BLM), the Bureau of Reclamation (BOR), the U.S. Fish and Wildlife Service (USFWS), and the U.S. Forest Service (USFS). The river water itself is managed by multiple water districts following numerous laws and compacts. Powell would likely find the modern governing of the Colorado River Basin to be very complex. His vision for the area, laid out in multiple government reports in the late 1800s, suggested that the land should be divided by the natural watershed boundaries, not by arbitrary lines. He envisioned that water would need to be diverted for irrigation and that assigning homestead plots of equal squares would not work in an arid setting.

The USGS continues to conduct important science along this river system and contribute information to decision makers who are working to manage the river basin as a resource for water, recreation, and hydroelectric power. The focus of the education and outreach efforts surrounding the Powell150 expedition was to engage the public around the geology and ecology of the desert Southwest landscape and the hydrology of rivers and to raise public awareness about USGS science. While the USGS marked this occasion as an opportunity to highlight the science of the Colorado River Basin through the lens of an exciting and historic river expedition, it is important to note that indigenous people have inhabited the area for over 10,000 years and Tribes in the 19th century had a great deal of knowledge about the river and the ecosystems of their homeland. Westward migration by white settlers brought conflict and devastating consequences to native peoples and their natural and cultural resources. In acknowledgment of this, we listened to Native American perspectives on river science, including traditional cultural practices, during community outreach events and discussions throughout the expedition.

The USGS marked the centennial of John Wesley Powell's historic journey with a river trip, a film in partnership with Grand Canyon National Park entitled "John Wesley Powell: Canyon Geologist," and several publications about the historic expeditions (Rabbitt and others, 1969; Fowler and others, 1969; U.S. Geological Survey, 1970; Rabbitt, 1974; Stephens and Shoemaker, 1987). Some of the centennial events, including the river journey, took place the year before the centennial because the Arizona-based USGS scientists knew they would be very busy in 1969 training the Apollo astronauts for the first lunar landing in July of that year (Schaber, 2005, for example; see also https://www.usgs.gov/centers/astrogeology-science-center/science/lunar-legacy-usgs-astrogeology-science-center).

Photographs of Powell's 1875 book, "Exploration of the Colorado River of the West and its tributaries," with the original woodblocks carved to create the illustrations, from Division of Culture and the Arts, National Museum of American History, Smithsonian Institution, and the Smithsonian Libraries. In the 19th century, before photography was widespread, highly skilled artists used fine tools to engrave details into small blocks of wood, which were then coated with ink and pressed to create photographic-quality images for reproduction. (Left: Green River; right: Grand Canyon of the Colorado.)

The 2019 sesquicentennial provided an opportunity to communicate USGS science in new ways. The USGS Youth and Education in Science (YES) team seized the rare opportunity to partner with the Sesquicentennial Colorado River Exploring Expedition (SCREE), based at the University of Wyoming, who planned to travel the length of Powell's original route 150 years later. Although SCREE's vision focused more broadly on the current state of water and environmental policies within the Colorado River Basin, the USGS focus was on science and on public outreach. As on Powell's expedition, data were collected to help document the modern conditions of the river. Gathering of data by the USGS and SCREE included sampling sediments for lithology, trace metals, and microplastics; collecting aquatic insects; recording bird and bat sounds; documenting riparian (river-edge) vegetation; and measuring water quality indicators for nearly 1,000 river miles. Each USGS participant, regardless of his or her area of expertise or current job, took part in the daily science experiments using easy-to-follow sampling methods. Each segment transition allowed time for the crew coming off the river to teach the incoming team how to conduct the science experiments. Over time, the USGS plans to use these data to create K-12 educational resources emphasizing data interpretation.

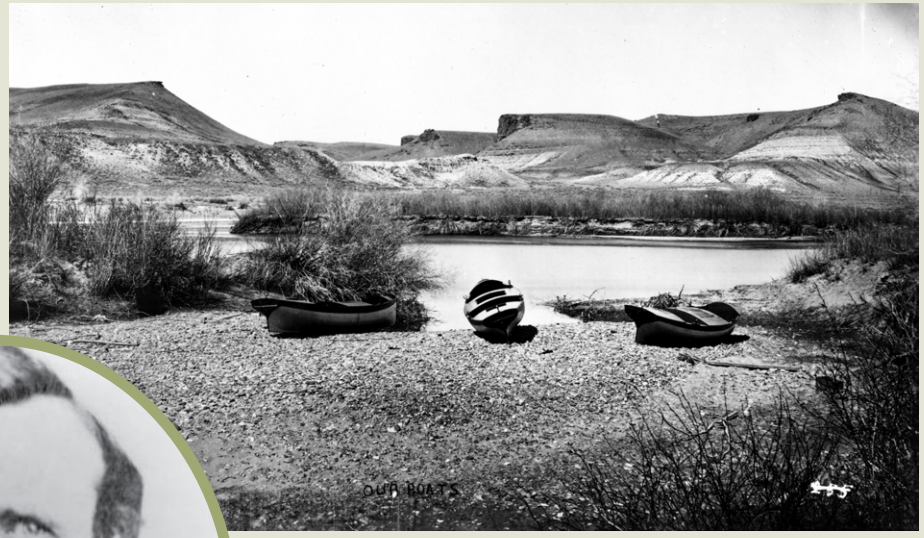
Naturally, many of the people who applied for a place on the Powell150 river trip showed a strong interest in the outdoors and a taste for adventure, but many had never been rafting before, and this experience was not a routine part of their normal duties. Many, but not all, of the USGS participants are scientists. Of the approximately 8,000 employees at the bureau, about half are engaged in science support roles, without which the science could not be done. The USGS employs people with various professional backgrounds, including expertise in business, computer and information technology, administration, communications and publishing, public affairs, and more. USGS staff participated in the SCREE community outreach events along the way and shared their experiences with their own communities and colleagues when they returned home. At the time of this publication, there have been 22 post-expedition outreach events, reaching more than 1,600 people across the country. What the participants gained was immeasurable—working together to navigate strong rapids or solve problems, sharing their perspectives during quiet stretches and structured dialogues, learning new things about themselves, their colleagues, and the USGS. The partcipants came away changed in ways that sometimes surprised them. Their reflections are recorded in this publication, but a comment from SCREE leader Tom Minckley stands out: "During this expedition, I believe I have met the future leaders of the USGS."

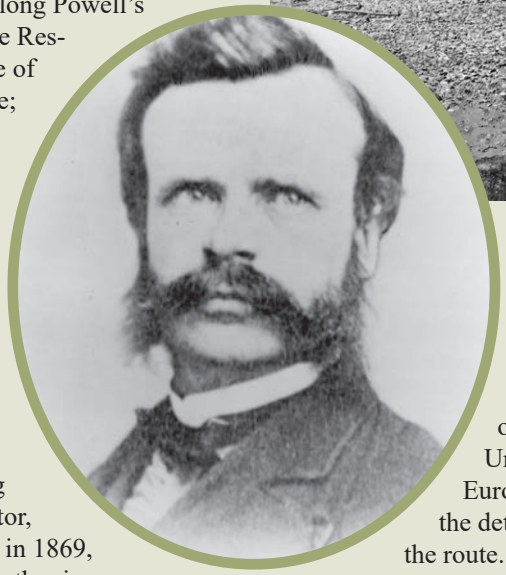
In addition, the USGS YES office launched a series of campaigns to engage the public in the expedition and in USGS science. These included—

- Participation in community outreach events with local stakeholders, held at the following locations. All events were free and open to the public.
  - Grand Canyon National Park, Arizona
  - Green River, Wyoming
  - Dinosaur National Monument, Utah
  - Moab, Utah
  - Page, Arizona
- Then and Now – a series of articles comparing 1869 to 2019, published online in 2019 and updated for this report.
- Powell in the Parks – a series of information sheets about public lands along the expedition route comparing what John Wesley Powell would have seen to what visitors today will see.
- Find-A-Feature Challenge – a photographic challenge to search for analogs to Earth science features.
- Paper Powell – the mascot for the journey.
- Educational resources – a curated collection of new and previously existing educational resources related to the science of rivers and basic geology.
- Be an Explorer – connecting Powell (Grand Canyon - 1869) to Dorothy Vaughan and Neil Armstrong (Moon - 1969) to a future explorer (perhaps Mars - 2069) and inspiring curiosity and adventure in kids.

Historical Background

Several geographic surveys of the West during the late 1800s and early 1900s, led by C. King, F.V. Hayden, J.W. Powell, G. Wheeler, and C.H. Birdseye, provided the baseline science of the geography, geology, and hydrology of the region (Rabbitt, 1974). The early surveys defined the scientific understanding of this region and laid a strong foundation for the systematic USGS fieldwork that continues today. In the late 1800s, the rivers were still wild, not yet used for the generation of hydroelectric power or harvested for agricultural irrigation and booming populations. Unobstructed by physical barriers, fine sediment traveled down the rivers freely, depositing along the outer, curving edge as sandbars and as mud in a delta at the Colorado River's end. Today, dams impede the sediments' flow. Flaming Gorge Dam in Utah, Glen Canyon Dam in Arizona, and Hoover Dam in Nevada now sit along Powell's route, creating the large, still-water bodies of the Flaming Gorge Reservoir, Lake Powell, and Lake Mead behind them. The presence of dams prevents a true-to-1869 re-creation of Powell's exact route; motors were used to transport the rafts across the slow-moving reservoirs, and a ground crew portaged the rafts around the dams on roads that, of course, did not exist in 1869.





On May 24, 1869, John Wesley Powell—a 35-year old educator and Civil War veteran—launched the Powell Geographic Expedition from southern Wyoming, a mere seven years after losing his right arm at the elbow from an injury sustained during the Civil War's Battle of Shiloh. Powell's personally designed boats were shipped by train from Chicago to Wyoming, a route made possible by the completion of the Transcontinental Railroad just two weeks before the start of the expedition. A decade later, Powell was instrumental in founding the U.S. Geological Survey and would become its second director, serving from 1881 to 1894, among other posts. But on that day, in 1869, he was an explorer and self-taught geologist, determined to map the rivers and to document the canyons, resources, and people he met along the way.

Powell's expedition set out down the Green River to pinpoint its confluence with the Colorado River (known in 1869 as the Grand River north of its confluence with the Green) and to complete the region's maps, including the ominous depths of Grand Canyon in Arizona, which Powell called "The Great Unknown." He and his crew were the first known people of European descent to make this journey by river and to document the details of the topography, geology, hydrology, and ecology along the route. Powell's journals detailed the changing landscapes as well as the people, plants, and animals he encountered.

May 24, 1869: "The good people of Green River City turn out to see us start. We raise our little flag, push the boats from shore, and the swift current carries us down."

~John Wesley Powell

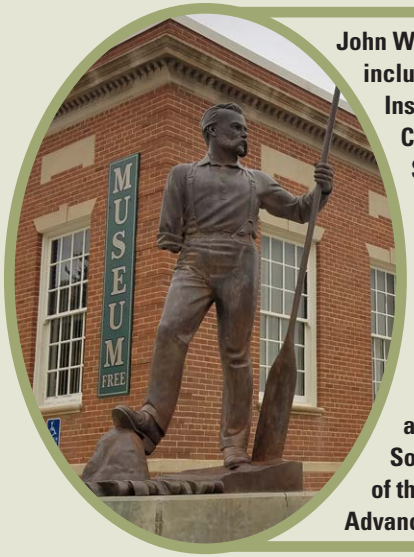
June 6, 1869: "At daybreak I am awakened by a chorus of birds. It seems as if all the feathered songsters of the region have come to the old tree. Several species of warblers, woodpeckers, and flickers above, meadowlarks in the grass, and wild geese in the river." ~JWP

Powell's 1869 crew included his brother, Walter Bramwell "Bram" Powell; George Y. Bradley; William "Billy" Hawkins; Andrew Hall; Oramel Howland and his brother, Seneca Howland; John "Jack" Sumner; William "Billy" Dunn; and Frank Goodman, an Englishman who joined just before the launch, eager for the adventure. The expedition faced many challenges, including running aground on a sandbar just a mile or two downstream from the launch, breaking and losing oars overboard. Within the first two weeks, they had lost one boat to the power of the river, along with many of their scientific instruments and rations. In mid-June, a campfire went awry, engulfing their clothing and gear that had been left out to dry, and leaving their supplies further depleted. Three weeks later, Frank Goodman walked away, having "seen danger enough." Of the nine men in three boats who carried on, only six emerged from the Grand Canyon on August 30.

After securing congressional funding and emphasizing the additional work needed to characterize the land and water of the Colorado River Basin, Powell returned to the river in 1871–72. This time his crew included experienced scientists and cartographers (notably geologist and brother-in-law A.H. Thompson), as well as artists (Thomas Moran) and photographers (J.K. Hillers and E.O. Beaman). Powell's book, "Exploration of the Colorado River of the West and its tributaries" (Powell, 1875) includes journal entries describing the 1869–72 expeditions, along with details of the landscapes and stories about how he chose the names—many of which are still used today—for the rapids and canyons.

Powell was instrumental in establishing the USGS in 1879, and he became its second director (1881–94). The USGS mission to characterize the Nation's land, water, and natural resources has evolved since its founding to encompass geospatial mapping, natural hazards, and more. In 1996, the USGS added biological sciences to its mission with the addition of the National Biological Service, which was renamed the Biological Resources Division, and later established as the Ecosystems Mission Area in 2010. On August 27, 2019, Department of the Interior Secretary David Bernhardt declared August 30 as John Wesley Powell Day in recognition of the importance of the many scientific and historical accomplishments of Major John Wesley Powell and in observation of the 100th anniversary of the establishment of Grand Canyon National Park.

May 24, 1869: "We take with us rations deemed sufficient to last ten months; for we expect, when winter comes on and the river is filled with ice, to lie over at some point until spring arrives; so we take with us abundant supplies of clothing. We have also a large quantity of ammunition and two or three dozen traps. For the purpose of building cabins, repairing boats, and meeting other exigencies, we are supplied with axes, hammers, saws, augers, and other tools, and a quantity of nails and screws. For scientific work, we have two sextants, four chronometers, a number of barometers, thermometers, compasses, and other instruments." ~JWP



John Wesley Powell's other positions included: First Director of the Smithsonian Institution, Bureau of American Ethnology; Co-founder of the National Geographic Society; Member of the National Academy of Sciences; Founder and President of the Anthropological Society of Washington; Organizer of the Geological Society of Washington; Co-founder of the Cosmos Club; Co-founder of the Geological Society of America; Elected Member and President of the Philosophical Society of Washington; and President of the American Association for the Advancement of Science.

Then and Now
Women in Science

Then

At the start of the Civil War, 27-year-old John Wesley Powell married his 25-year-old cousin, Emma Dean. She proved her character from the very beginning of their marriage, joining then-2nd Lt. Powell at Camp Girardeau near St. Louis, where he was in charge of fortifying Gen. Ulysses S. Grant's camp. Only weeks later, then-Capt. Powell was injured during the Battle of Shiloh and had his arm amputated below the elbow. Emma was at the battlefield hospital and nursed him back to health. When Powell returned to service, Emma joined him.

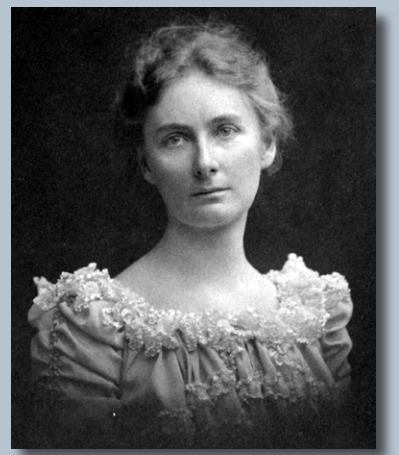
After the war ended and Powell returned to teaching, Emma accompanied him and his students on their geologic and natural history field trips during the 1860s and 70s. She was not listed as a scientist or recognized for her work in the field; however, she was likely involved in the scientific enterprise. For example, in 1867 she ascended Pikes Peak, a 14,115-foot (ft)-high mountain in Colorado, and she was the lead ornithologist during an 1868 expedition, identifying and cataloguing 175 species of birds that were collected.

Emma Dean Powell

Powell's sister, Ellen "Nellie" Thompson, also accompanied the group on some of his expeditions. She was married to Almon Harris Thompson, a surveyor and geologist who was second in command of Powell's 1871–72 expedition. Nellie was an accomplished botanist, and in 1872 described many of the plants she found in Utah. In the winter of 1871–72, both Nellie and Emma, with newborn Mary Dean Powell, joined the expedition at its winter camp. Little notice was afforded women in science before the end of the 19th century; it was common for women, like Emma and Nellie, to contribute to their husbands' scientific work without attribution.

Ellen Powell Thompson

The USGS was established in 1879 and hired its first woman scientist in 1896. Florence Bascom was the first woman to receive a Ph.D. from Johns Hopkins University (1893) and only the second American woman to earn a Ph.D. in the geosciences. She worked at the USGS as a geologist through 1936.



Dr. Florence Bascom

Dr. Elzada Clover

By Eleanour Snow and Annie Scott

The first women to float the river through the Grand Canyon were, like Nellie Thompson, botanists. Dr. Elzada Clover, from the University of Michigan, and graduate student Lois Jotter, who would later earn her Ph.D. and teach at the University of North Carolina, conducted the first botanical survey of the river, along with a crew of five men, using three boats. Their survey covered 600 river miles, from Green River, Utah, through the Grand Canyon. It was 1938, and times being what they were, in addition to conducting the scientific work, the women did all the cooking and other camp chores.

Now

Today, women are leaders in all fields of scientific endeavor. Although they have not achieved parity with men in many fields, a young woman today who aspires to be a scientist or engineer faces fewer barriers than her 19th-century peers (Aragon-Long and others, 2018). At the USGS, hundreds of women scientists and science support staff contribute to the Survey's mission. Two of the last three USGS directors were women, and seven former and current female scientists have been promoted to senior scientist for their exceptional achievements. Nine USGS women have received the prestigious Presidential Early Career Award for Scientists and Engineers in the last ten years.

Before the 2019 Expedition

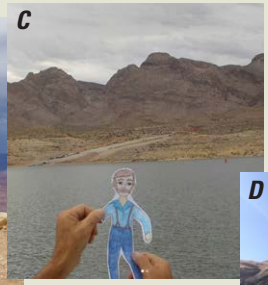
In 2016, Dr. Thomas Minckley, professor at the University of Wyoming Department of Geology and Geophysics, envisioned a full-scale river trip to mirror the 1869 Powell expedition with the goal of engaging the public in discussions about water in the West: history, science, culture, art, environmental law, and the future of the Colorado River Basin. Over the next three years, Minckley and colleagues from several western universities and other organizations developed the Sesquicentennial Colorado River Exploring Expedition (SCREE), putting together a team who would reflect upon the history, culture, science, and future of the river system 150 years after Powell. SCREE secured vital permits, rafts, supplies, off-river support, and funds for their planned 70-day trip that would follow Powell's historic route. They assembled a group of regional experts, including professors and graduate students of geography, geology, law, history, archaeology, fine arts, and more—certainly a contrast to Powell's first crew of mostly frontiersmen up for an adventure.

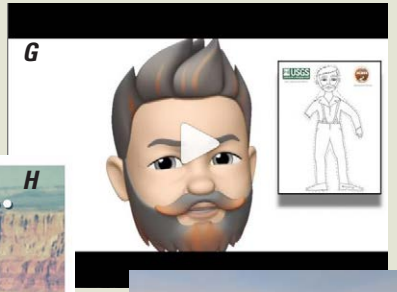
In 2018, a USGS leadership course posed a challenge for participants to envision a national-scale educational project to highlight current USGS science. The group suggested using the upcoming 150th anniversary of the 1869 John Wesley Powell expedition of the Green and Colorado Rivers as an engaging backdrop to introduce the public and youth to the broad scope of USGS science using relevant 21st-century technology such as social media. At the time, the USGS YES team was unaware of SCREE's plans to recreate Powell's river journey, but an introduction to SCREE leaders by USGS emeritus scientist Breton Bruce in September 2018 connected the two entities, paving the way for the formation of an official partnership. Existing educational materials relating to the hydrology, geology, and biology of the Colorado River Basin were collated and new materials were developed. USGS scientists working in this region, primarily based at the USGS Southwest Biological Science Center locations in Flagstaff, Arizona, and Moab, Utah, provided science briefings to the YES team to synthesize the current USGS projects in the region.

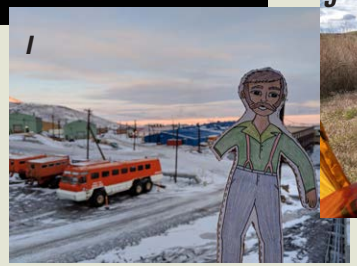
Nearly one hundred USGS employees applied for the opportunity to represent the USGS on the Powell150 expedition as science ambassadors. The YES team assembled a selection panel of seven rating members and one non-rating panel coordinator, who was the sole viewer of names and demographic information until the top-rated participants were chosen. Each participant responded to three essay questions related to their interest and abilities as science communicators and their willingness to support educational efforts to broaden and diversify the USGS YES audience. Applicants were also screened to determine those who demonstrated the skills, knowledge, and abilities that reflect well upon the USGS along with examples of self-sufficiency, a positive attitude about adventure, and a willingness to help and learn. The selection panel chair assigned a number to each applicant so that the committee members were unaware of the names of the applicants. Next, all applicants were rated by their responses to the essay questions, and the top-rated 50 were selected. The area of expertise (Mission Area), geographic location, and top choices for requested segments were noted and grouped to ensure equal representation across all careers and regions of the USGS. Twenty-eight participants were chosen, and an alternate list was created. Ultimately, all 28 were able to make their assigned segment, and the alternates were not called.

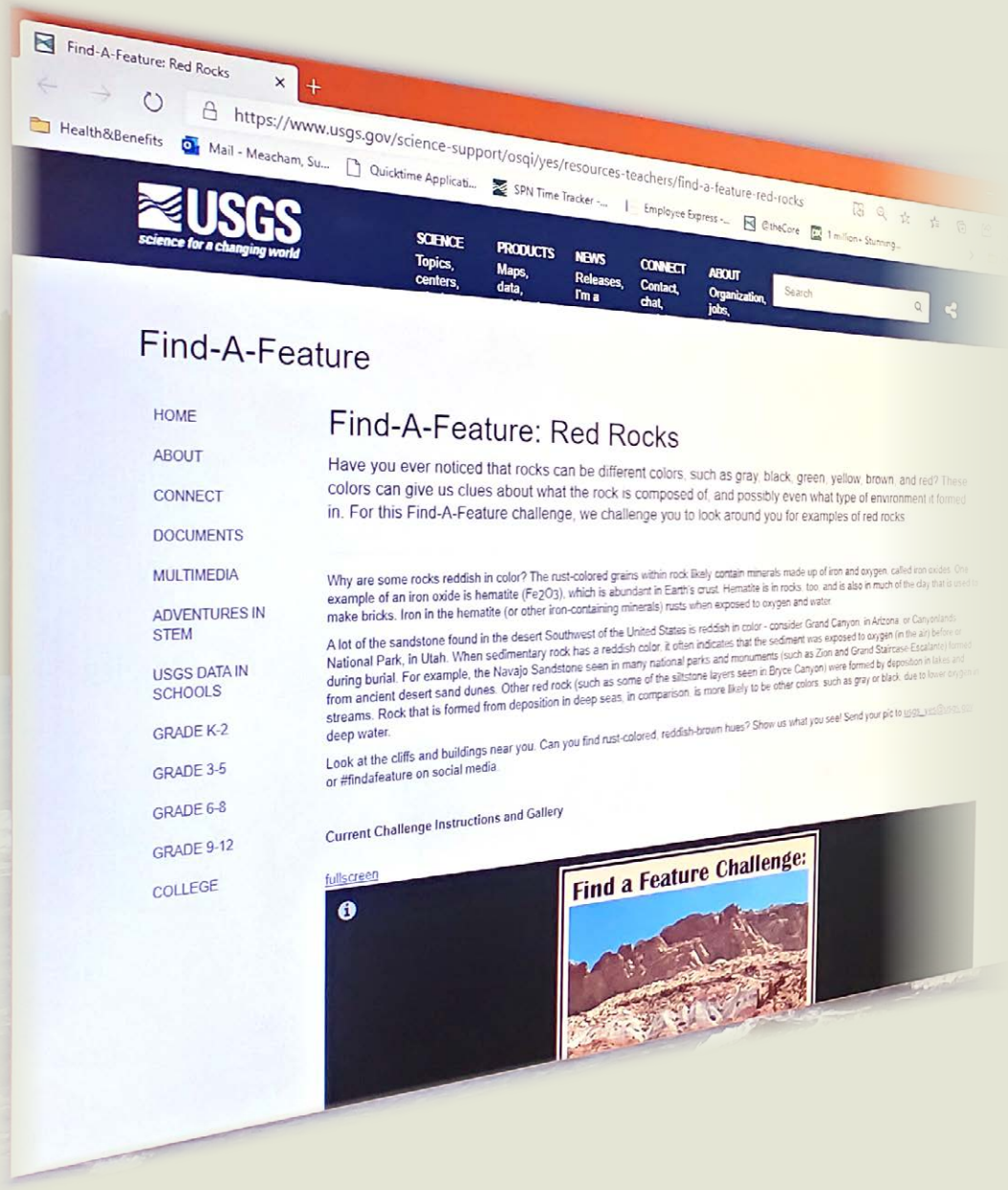
The months leading up to the 2019 expedition were full of intense planning and collaboration across multiple USGS offices. A Safety Review Team was developed to include experts on USGS safety protocols and people specifically familiar with the rough rapids of the Green and Colorado Rivers, vital during 2019 due to higher than average snowmelt. The USGS safety team closely monitored the flow of the rivers on specific days before the rafts were scheduled to access each major rapid. Backup plans were made to divert around the rapids by land if the flow was deemed to be too dangerous to travel by raft. Safety was the highest priority on the expedition and all USGS participants were required to wear a personal flotation device and to participate in USGS safety training and In-Over-Water training before their river segment. In addition, some USGS participants took Swift Water Rescue training, which proved useful later in Cataract Canyon. Current Wilderness First Aid certification was also required for at least two people on every segment, which the YES team coordinated. We also purchased a satellite communication device as an emergency contact so that in the event of an accident we could mobilize help as quickly as possible. Fortunately, no such accident occurred. All USGS participants received communications training by the Office of Communications and Publishing and met regularly with the YES office to coordinate travel logistics to remote areas, often requiring coordination by many people who had never met in person and who were heading to the river from opposite regions of the country. Every participant made it to his or her specified location at the appropriate time, which was a relief to the expedition leaders, especially because cell phone coverage is not always reliable in some isolated locations along the river system.

To prepare for the educational portion of this project, Paper Powell, who served as the mascot for the expedition, was created in consultation with the John Wesley Powell River History Museum in Green River, Utah, which has run a Paper Powell program for many years. Our version of Paper Powell was inspired by a circa 1869 photograph. The shape of Powell's right arm, amputated near the elbow, was drawn to be historically accurate in the hope that it would inspire and encourage explorers who may have physical limitations. This simple, low-tech, low-cost character was created to invite students, teachers, and the public across the Nation to follow the expedition and to take Paper Powell on new adventures. Each USGS participant received a limited-edition, laminated Paper Powell dressed for the river in a personal flotation device to travel the continuous route, the only USGS participant to do so. Paper Powell also traveled around the United States and the world, including far-away locations such as Antarctica; Stonehenge, England; the deep ocean; and India, with a little help from engaged members of the public and our colleagues. Explorers of all ages joined the fun online by printing out their own Paper Powell and learning a bit more about USGS science along the way, and they were introduced to a talking cartoon version of Paper Powell, called a memoji, on social media.



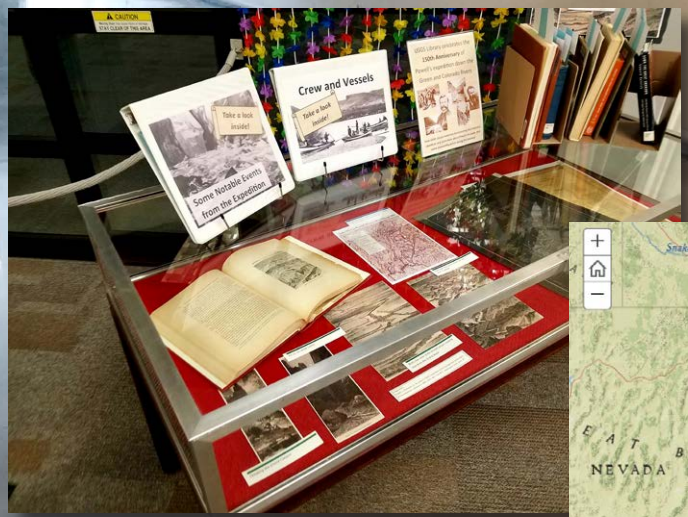






One educational goal was to communicate with new and diverse audiences about current USGS science. To implement this goal, an online campaign known as the Find-A-Feature Challenge was developed to encourage students and the public to think creatively about real-life analogs in their own neighborhoods to natural features. Examples of geologic, hydrologic, and (or) ecological features were shared on the YES website and on social media, and students and the public were challenged to find something (building materials, shapes, people, and food, for example) that is similar to the feature. Find-A-Feature challenges tied to the Powell150 expedition included rivers, meanders, fossils, layers (strata), and red rocks. The Find-A-Feature Challenge was also included in the American Geosciences Institute's 2019 Earth Science Week calendar as a classroom activity that was distributed to more than 20,000 teachers.

To honor artistic contributions and connect with non-scientists, Powell150 outreach activities included components of art and history. In May 2019, the YES team displayed historical photographs with quotes from Powell's journals and a wall-size, painted river roughly to scale with the rivers' path along one side of the art corridor at the USGS National Center in the John Wesley Powell Federal Building in Reston, Virginia. The other side of the art corridor featured modern photographs and staff profiles of each of the selected participants, along with a route map so employees and visitors to Reston could follow along the journey. The USGS Library compiled historical items from the 1869–72 Powell expeditions for display in Reston during April and May 2019 to coincide with National Take Our Daughters and Sons to Work Day. In the spring of 2019, the USGS Earth Resources Observation and Science (EROS) Center published an online geonarrative (story map) showing satellite imagery of the expedition route with historical notes. SCREE artists used historical and modern methods of photography, painting, sketching, sculpture, and multimedia art to document the expedition.


Crew and Vessels
Some Notable Events from the Expedition


WYOMING
Salt Lake City
UTAH
NEVADA
COLORADO
ARIZONA
NEW MEXICO
Los Angeles
Phoenix
Albuquerque
Santa Fe
A geo-narrative by USGS
150th Anniversary:
J.W. Powell's Perilous River Expedition
* From a Remote Sensing Perspective *
Follow Powell's epic journey with a variety of satellite and aerial imagery from the USGS Earth Resources Observation and Science (EROS)

Then and Now

Art

Then

John Wesley Powell quickly leveraged his 1869 fame to start planning his 1871 trip. Art and science would be the justification for this second journey. The 1871 expedition was better organized and better equipped than the first. In contrast to the courageous yet ragtag crew that joined the first journey, the participants on the second journey consisted of carefully chosen artists, photographers, and scientists. The images of this journey we see today were composed by John Karl "Jack" Hillers (photographer), Francis Marion Bishop (topographer), Steven Vandiver Jones (topographer), E.O. Beaman (photographer), and Frederick "Frank" Dellenbaugh (topographer and artist). The science was conducted by Almon Harris Thompson (topographer, geologist), Frank Richardson (assistant geologist), and John Fletcher Steward (geologist). Dellenbaugh was assigned the role of lead artist, and the famed painter Thomas Moran, who was a late addition, was given the role of guest artist. Just 17 years old when they launched, Dellenbaugh learned wet plate photography and sharpened his topography skills on the river. The more seasoned Moran spent very little time, if any, on the water. Powell requested that Moran take an overland route via horseback from Salt Lake City to the Virgin River and then up to the North Rim of the Grand Canyon, in the hope that Moran would create images of the Grand Canyon that would rival and complement his famous painting, The Grand Canyon of the Yellowstone. To accomplish this, Moran and Dellenbaugh worked with graphite, watercolors, and gouache in the field to capture the colors and shapes of the river and the fantastic land formations found throughout the basin. Moran also spent a great deal of time working with young Jack Hillers, helping haul equipment and compose many of the photographs. He would later use these photographs in his studio to help him with the nuances and geological details of the canyon country.

The goal of the second expedition was to gain a deeper understanding of the unique geology, to map the geography, and to capture images of the Green and Colorado Rivers. The tales, science, and images produced by the explorers fed the imagination of a curious public back East. The fantastic images created on the 1871 expedition played a huge role in selling the West and the concept of Manifest Destiny. Along with Powell's popular (yet historically unreliable) journals, the photographs, drawings, etchings, and paintings that were produced helped turn the West from a blank spot on the map into an approachable and attractive space to settle. Together, the written words and images helped promote the West as a promised land to a country preoccupied with post-Civil War Reconstruction. Railroads were in place, most native peoples had been displaced onto western reservations, and the seemingly unlimited natural resources were there for the taking.

The Chasm of the Colorado
Thomas Moran (1837–1926), 1873–1874
Oil on canvas, mounted on aluminum, 84.375" x 144.75"
U.S. Department of the Interior Museum, Washington, D.C.
INTR 03000

Now

Working on the shoulders of John Wesley Powell and Thomas Moran gave me an understanding of how we got to 2019 and helps me think about the future of the West. My challenge was to find content in a landscape that is largely unspoiled, raw, and in a natural state. The "leave no trace" ethic on the river corridor gives us a landscape that feels to me as if it is in a bubble, frozen in time. Most of the land along the river is the kind of protected land that I have avoided in my 30 years of depicting the West, my belief being that Moran, Albert Bierstadt, Frederic Church, and many others did an excellent job of depicting the pre-Manifest Destiny landscape (and natural resources) of North America. With that in mind, I focused my compositions on the less protected lands. The interaction between our encroaching culture and the realities of nature is fascinating to me. I often set up and sketch on the outskirts of town, behind a truck stop, or on the side of the highway while travelers blow by on their way to embrace our pristine national parks. The canyons offered me the chance to face the land in a way that is not all that different from what Powell and Moran experienced. Ironically, the pristine character of much of the landscape today reflects the heavy hand of culture maintaining the appearance of primitive to the benefit of all.

By Patrick Kikut

My role as lead artist had many facets. I was expected to educate myself, research the Colorado River Basin, select pertinent artists to join us on the river, produce original art, and organize numerous art exhibits. Long before the launch, I was committed to spend any free time seeking out locations along the river to camp, draw, and explore this new subject. Also, I was motivated to look deeper into the field drawings of Thomas Moran, whose work has been an inspiration for my studio practice for over ten years. My research into the Moran archives at the Gilcrease Museum in Tulsa, Oklahoma, and at Yellowstone National Park was a treat. Field drawing is a tough task. Even if an artist has all day in perfect conditions, it is a fool's game to try to get it all rendered at once. In the field, Moran was a master of composition, line, and color. I was hoping to gain an understanding of how he was so successful at creating field drawings that hold visual economy yet feature finely tuned specificity. I still am stumped but will not forget my privileged days in the archives.

Our expedition was composed more like Powell's second trip down the Green and Colorado Rivers: scientists, artists, and writers worked together on the trip. SCREE was an outward-facing expedition. With that understanding, we were expected to produce and exhibit relevant work featured in an expanded art exhibit entitled "Contemporary Views of the Arid West: People, Places and Spaces." This expanded art exhibit was featured in museums in riverside communities during our journey. The roster of SCREE artists included David Jones (sculpture), Bailey Russell (photography), Will Wilson (photography), Erika Osborne (painting and drawing), and me (painting). Also, Ben Kraushaar (photography/videography), a geography graduate student at the University of Wyoming, spent much of his shore time behind a video camera documenting the experience. There were no expectations that SCREE artists would respond directly to the science being done on the expedition, which allowed for artists to create images from their personal experiences. The idea was that the artists would make art in the field and that the scientists would collect data and discuss their research in an informal setting. If one practice influenced the other, it would happen in an organic way.

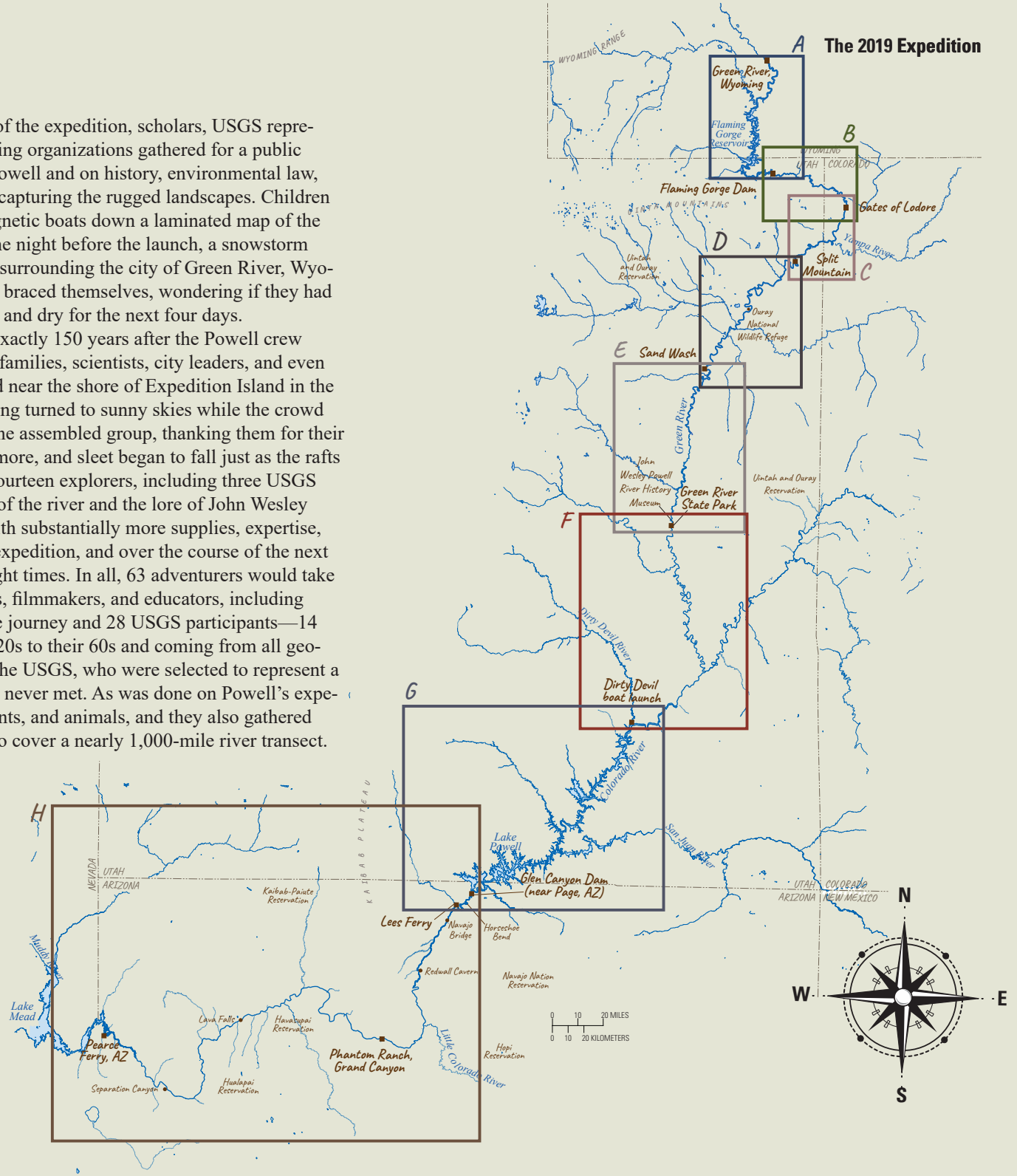
Green River—oil on canvas: From personal collection of Patrick Kikut. Used with permission.

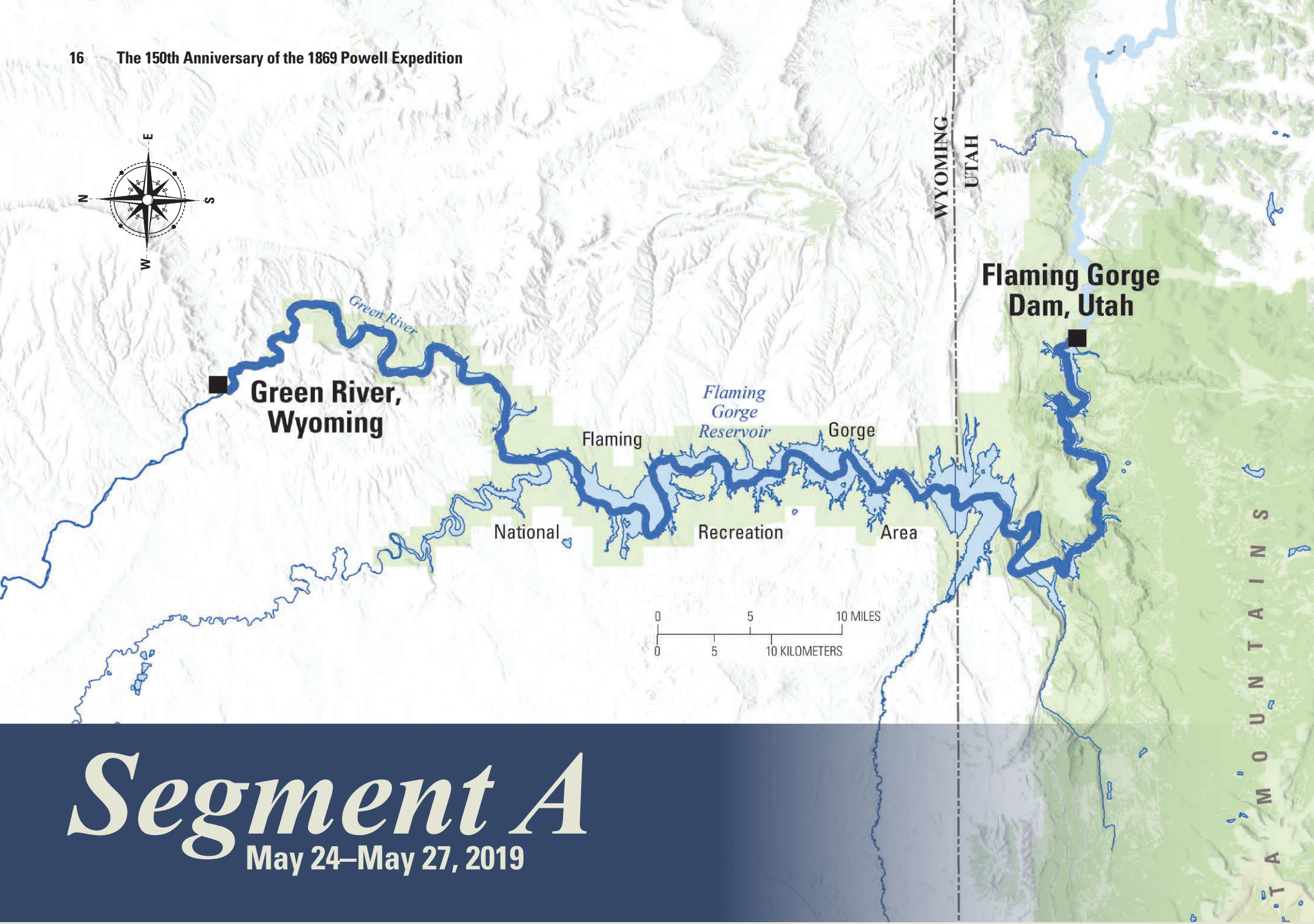
Thinking about the future is difficult. Painting it is even harder. I am unsure how my work will be received, and whether I have any new content to add to the multi-layered conversation. At this point, I can only hope that my work will serve future artists. I hope it serves as a voice for the lesser-known public lands. I am hopeful that the inspiration I have gleaned from Thomas Moran's sketches can be imparted to the next generation of artists. Unlike the 19th-century expeditions, SCREE artists had drones, helmet-mounted video cameras, digital cameras, and sound-recording devices. This left me wondering, will there even be a future artist who will choose to use graphite and watercolors? Now, I expect there will be. After all, I'm using materials that are not that different from those used by the famed Barrier Canyon Style artists whose paintings are 10,000 years old and can be seen today on the canyon walls. I suppose future river voyagers will carry sketchbooks, journals, pencils, and watercolors, along with harmonicas and acoustic guitars. I believe these materials will continue to be attractive to artists who are committed to making direct marks of expression. I hope my work can play some defense for drawing and painting in a world that is becoming saturated with landscape images that are digitally manipulated into idyllic, screen-saver perfection.

The 2019 Expedition

For two days leading up to the start of the expedition, scholars, USGS representatives, and people from many partnering organizations gathered for a public outreach event focused on John Wesley Powell and on history, environmental law, Western Expansion, and modern artwork capturing the rugged landscapes. Children painted their own landscapes, guided magnetic boats down a laminated map of the Green and Colorado Rivers, and more. The night before the launch, a snowstorm blew in, covering the layered rock pillars surrounding the city of Green River, Wyoming. Winds howled, and the participants braced themselves, wondering if they had brought the right gear to keep them warm and dry for the next four days.

The next morning, May 24, 2019—exactly 150 years after the Powell crew launched here—a crowd of history buffs, families, scientists, city leaders, and even a John Wesley Powell interpreter gathered near the shore of Expedition Island in the Green River. A mostly cloudy, cold morning turned to sunny skies while the crowd milled. The expedition leader addressed the assembled group, thanking them for their support. Clouds darkened the skies once more, and sleet began to fall just as the rafts pushed off from shore. In the five rafts, fourteen explorers, including three USGS personnel, headed out, drawn by the lure of the river and the lore of John Wesley Powell. The SCREE flotilla pushed off with substantially more supplies, expertise, and ground support than the first Powell expedition, and over the course of the next 70 days, the river crews would change eight times. In all, 63 adventurers would take part in SCREE: scientists, scholars, artists, filmmakers, and educators, including three SCREE leaders who made the entire journey and 28 USGS participants—14 men and 14 women—ranging from their 20s to their 60s and coming from all geographic regions and areas of expertise at the USGS, who were selected to represent a snapshot of the Survey in 2019. Most had never met. As was done on Powell's expeditions, they observed the landscapes, plants, and animals, and they also gathered new data during this unique opportunity to cover a nearly 1,000-mile river transect.





Segment A

May 24–May 27, 2019

Green River, Wyoming, to Flaming Gorge Dam, Utah

The expedition traveled from Green River, Wyoming, to Flaming Gorge Dam in northeastern Utah, experiencing some rough weather the night before and on the day of the launch. The expedition managed to avoid the perils that Powell and his crew faced during the first few days of their 1869 journey. Safely guided through known waters by experienced boaters, they were able to engage in discussions with new colleagues and spend time fine-tuning the protocols for the science collections.

The river from Green River to Flaming Gorge is not wild anymore. Flaming Gorge Dam, built in 1958–62 and maintained by the U.S. Bureau of Reclamation, tamed the upstream waters. This dam, and others in the basin, provides hydroelectric power, water supply for communities and agriculture, and recreation. John Wesley Powell was very interested in water-use policy and advocated for the important role of science to inform water policy. Today, the USGS continues that mission by providing scientific data to policymakers through monitoring and researching water resources and conditions including streamflow, groundwater, water quality, water use, and water availability. During the Powell150 expedition, daily measurements of the water temperature and pH were recorded, and photographs of a glass of water were taken against a white background to show the clarity of the water. Boat operators also relied on USGS streamgages along the river and its tributaries to estimate discharge, typically measured in cubic feet per second, and to calculate the strength of the rapids. The USGS has been recording data from streamgages since 1889, and these data are used to document and predict floods and droughts and to inform recreational users of rivers through a variety of apps and data portals. Of course, Powell did not have that information on his initial voyage. He climbed cliffs to scout rapids, watched and listened to the river to find the roughest water, and portaged around rapids whenever conditions seemed too dire.

Then and Now

Green River, Wyoming

Then

Standing upon the banks of the Green River in 2019, 150 years after his departure from these shores, one wonders if John Wesley Powell would recognize the place he helped make famous. A person viewing the city, landscape, and environment today, where Powell launched his expeditions in 1869 and 1871, may think that little has changed since Powell walked these shores. In some ways, they would be right. The high mountain desert surrounding the Green River was peppered with sagebrush, shrubs, sedges, and native grasses covering rolling hills. Willows, cottonwood trees, and riparian shrubs crowded the riverbanks. The river ran through the valley unchecked by any human-made structures. Islands dotted the river, providing habitat for animal species including mule deer, pronghorn, beavers, various waterfowl, and many others. As with most rivers, unstable sandy shorelines were constantly eroding, causing persistent, if subtle, changes. The islands in the river near Green River Station in Wyoming Territory (Wyoming became a State in 1890) at the time of Powell's journey were mostly devoid of human occupation. An occasional trapper or fisherman could be seen bobbing along the river visiting their various posts.

The town of Green River was established in 1868 in a small valley, dwarfed by giant cliffs of layered sedimentary rocks on the east side of the Green River. Originally a small stagecoach station along the Overland and Cherokee Trails, the community around the station expanded with the news that the Union Pacific Railroad would be coming through the territory. The population of the town grew in anticipation of the commerce the railroad would bring, until the railroad decided to establish its switching station farther down the line, in the town of Bryan instead. This decision caused the population of the town to plummet from roughly 2,000 people to just over 100 people when Powell chose it as his launching point in 1869.

Powell chose the town of Green River for his launch because that was the only place where the railroad crossed the river he wanted to explore, thus making it possible to transport his boats and supplies directly to the river. The railroad tracks crossed the river on the north side of town. The construction of the tracks and bridge across the river created a gentle slope directly from the tracks to the banks of the river. Powell's crew could more easily carry the heavy boats and copious supplies directly from the railroad car to the river.

Even though people had begun to settle along the banks of the Green River, it was still a wild river that would challenge Powell and his crew as they attempted to navigate its deceptively placid waters.

Now

Cliffs of layered sedimentary rocks still stand watch over the city of Green River, Wyoming, today. With these resilient features of the landscape in place, Powell would likely feel right at home at the origin of his groundbreaking journeys. The city now extends from both sides of the river and the population exceeds 12,000. The rolling hills that were undeveloped at the time of Powell's excursions are now lined with homes and other buildings overlooking the river. The Union Pacific Railroad still follows the same route through

By Jaime (Jaci) Wells

the city as it did in 1869. Perhaps the most striking change to the natural environment would be the vegetation. The riverbanks are lined with cheatgrass, tamarisk, Russian olive trees and non-native grasses, all of which are invasive species. Land use, such as farming, ranching, irrigation, settlement, and other development has taken a toll by affecting the stability of the riverbank and riparian ecosystems. The local community today is working to restore the native vegetation to the shores of the river, but with the ability of the invasive species to outcompete the native species, it is a long battle.

Most wildlife species that Powell and his crew observed in 1869 are still found along the river. Mule deer and pronghorn frequent the city and its islands, as do waterfowl. The most notable missing wildlife is the beaver, which was heavily impacted by the fur trade around the time of Powell's journeys.

Powell would also likely be amazed to see the landscape changes that the city of Green River has undertaken along the river. Concrete walking paths line the banks of the river and wind through the city. Several new pedestrian and automobile bridges span the river. The train yard has expanded significantly since Powell's journeys because the switching station was moved to Green River after drought struck the town of Bryan a few years after the expeditions. Now, several tracks and warehouses line the river.

The largest island within the city limits is known as Expedition Island—in honor of Powell—and many have come to believe it is the location where his expeditions were launched. The island is located just a half-mile downstream from the bridge where the railroad crosses the river. The citizens identified the island early in the history of the city as a good spot to recreate. Originally known as Island Park, it became the best location in the region for picnics, dances, and riverboat cruises on steamboats starting in the early 1900s.

It is unlikely, however, that Expedition Island was the launch point for Powell's expeditions. The island is downstream from the railroad crossing and was not easily accessible in 1869. It would have been difficult to remove the boats and supplies from the train, and then carry or float them down to the island. If the boats were on the island, that would have meant plenty of trips back and forth to the island hauling supplies. It is much more likely the launch point was farther up the river, just off the side of the railroad bridge. E.O. Beaman's photograph from 1871 is a close match to the view today next to the railroad bridge. Furthermore, a 1908 article from the Green River Star newspaper discussed the steamboat launch point as being "above Railroad Bridge." The easy access to the river and the gentler slopes on the banks there made it an ideal location to launch boats, and it became the official launch point of the Green River Navigation Company (Fowler, 2011).

Sometime in the mid-1900s, the citizens began to refer to the island as Expedition Island. The name was officially changed in 1969 to commemorate the 100th anniversary of Powell's expeditions. Today, the island hosts a community building, a parking lot, and a city park. It is lushly covered with Kentucky bluegrass and lined around the perimeter with trees, including cottonwoods. Walking paths cover the island and two bridges connect the island to either side of the river, providing a wonderful place for recreation for the citizens of Green River.

The city has taken measures to stabilize the banks along the shoreline of Expedition Island and on either side of the river to prevent erosion. Large boulders are held in place by concrete, guiding the river neatly around the sandy island. In order to further enhance recreation, the city has developed a small, sheltered cove on the west side of the island where visitors can swim without fighting the natural current of the river. Within the river, false rapids have been built in order to provide some adventure for those who seek to float or kayak.

It is doubtful Powell knew the impact his expeditions would have on the city of Green River when he chose it for his launching point. His ventures have left their mark in the place names across the region that he explored, and it all began in a small-stage station town, population 100.

Segment A—Personal Vignettes

I was fortunate to accompany SCREE from Green River, Wyoming, to Flaming Gorge Dam, Utah, over the course of four remarkable days. The landscape has changed since 1869. The Colorado River Basin is no longer a continuous, natural riparian ecosystem. John Wesley Powell's journal entries about the landscape and geology reflect my own experience. While I can't be certain that the geologic features described by Powell are the exact features identified in the lens of my camera, it is certain that I am in the general vicinity of the gaze of the citizen scientist.

Day 1—

Within his journal entry for Day 1, May 24, 1869, Powell provides a brief description of the sendoff from Green River Station, of the four boats, the supplies and equipment, and an introduction of the crew. As with his crew, I also must become accustomed to the river and our expedition-supplied equipment. Fortunately, the captain of my raft, Jessica Flock, is exceptionally experienced and prepared. No paddles break and no crew members are tossed overboard as in 1869. We do experience a similar, robust variety of spring weather. Early morning sunshine is followed by clouds, rain, and finally sleet until the skies clear later in the evening. We camp on a bed of silt, rather than a "gravelly bar." Unlike the original crew, I enter my section of the trip without fear or trepidation.

May 24, 1869: ... so I climb the cliffs, and walk back among the strangely carved rocks of the Green River bad lands. These are sandstones and shales, gray and buff, red and brown, blue and black strata in many alternations, lying nearly horizontal, and almost without soil and vegetation. They are very friable, and the rain and streams have carved them into quaint shapes. Barren desolation is stretched before me; and yet there is a beauty in the scene. ~JWP

Day 2—

Rather than paddling the rafts through the duration of the first leg, we receive a tow beginning midday through Flaming Gorge Reservoir. Powell's journals note provisions of large amounts of coffee, and a hot cup of coffee at breakfast stands the test of time. Although unable to build a fire, like the Powell expedition we are "soon refreshed and quite merry" as we begin our day. Jack Frost had visited overnight, chilling the air to below freezing, with the stars shining like ice crystals. Toward late afternoon, artist Patrick Kikut finds solitude and solace among the rock outcroppings, sketching preliminary images. We establish camp near the Firehole Campground, away from the Memorial Day weekend revelers.

Day 3—

The landscape appears endless and we are the only ones within view until late afternoon. A quiet stillness upon the water provides a palette of reflected color of the beautiful formations as we venture south. The Uinta Mountains come into view. Unlike the 1869 expedition, we will not enter Flaming Gorge until Day 4. The clear air and limited light pollution provide the perfect backdrop for the Milky Way as buttes stand tall in the foreground.

May 26, 1869: "To-day, we pass several curiously shaped buttes, standing between the west bank of the river and the high bluffs beyond. The buttes are outliers of the same beds of rocks exposed on the faces of the bluffs -- thinly laminated shales and sandstones of many colors, standing above in vertical cliffs, and buttressed below with a water-carved talus; some of them attain an altitude of nearly a thousand feet above the level of the river." ~JWP

Day 4—

Crossing the border between Wyoming and Utah, anticipation grows for what may be considered the hallmark geologic formation of the first section of the trip. Powell aptly named the gorge "Flaming Gorge." The view is stunning and the red rocks glow like fire at sunset.

May 26, 1869 : "The river is running to the south; the mountains have an easterly and westerly trend directly athwart its course, yet it glides on in the quiet way as if it thought a mountain range no formidable obstruction to its course. It enters the range by a flaring, brilliant, red gorge, that may be seen from the north a score of miles away." ~JWP

While Powell and his crew spent the next few days in the area, we traversed the river to a camping spot above Flaming Gorge Dam in one afternoon. Powell endeavored to repair equipment and complete topographic and geologic work; we lounged in the sunshine taking in the sights. We pass Kingfisher Island Campground, which I can only conclude is in the vicinity of Kingfisher Creek, Kingfisher Park, and Kingfisher Canyon described in Powell's journal. We also glide past various unusual sandstone formations that I believe are in the vicinity of Beehive Point and a vast amphitheater.

May 30, 1869: "Our general course this day has been south, but here the river turns to the east around a point which is rounded to the shape of a dome. On its sides little cells have been carved by the action of the water, and in these pits, which cover the face of the dome, hundreds of swallows have built their nests. As they flit about the cliffs, they look like swarms of bees, giving to the whole the appearance of a colossal beehive of the old-time form, and so we name it Beehive Point." ~JWP

Swallows are not in abundance here, but there is an unusually high concentration of osprey. My adventure will end on Day 4. On Day 5 we will help transport rafts and equipment below Flaming Gorge Dam for the second leg of the trip. Crew members will be replaced, and the trip will go on. I am appreciative of John Wesley Powell and his contributions to science. I am also appreciative of those who planned the commemorative sesquicentennial trip to focus attention on the Colorado River and challenges for restoration. Like Powell, I too sometimes lie awake with thoughts of tomorrow and adventures yet to come.

~Robert Barth

After learning that I had been selected to participate in the Powell150 expedition, I quickly went out and purchased a book detailing John Wesley Powell's journey and containing many pages from his journals. The enthusiasm and respect Powell had for the world around him as he ventured into the unknown was incredible, and as I climbed into the raft, surrounded by fellow USGS colleagues, professors, artists, experienced boatmen, and students, I was filled with my own sense of enthusiasm and awe. My time on the river was an exciting experience—viewing the rocks and canyons that Powell saw on his own journey, picking campsites and wondering whether Powell and his team walked near the same spots. Of course, the Green and Colorado Rivers today are very different from how they were in the past. There were no dams on the rivers in Powell's day, and he didn't have the equipment that we, spoiled in our advanced knowledge, are able to have. But the pursuit of science is ageless, and though the questions we ask may change over time, the drive to ask those questions never does. Powell wondered what dangers lay ahead on his initial journey. Today we wonder about our own effects on the river, such as the potential presence of microplastics or impacts on the availability and quality of the water, or impacts on the river ecosystem. But this expedition allowed me to catch just a glimpse of what Powell may have seen, and made me think about how things change. That will always stick with me.

~Janis LeMaster

During my time on the river, I thought a lot about the differences between our trip and John Wesley Powell's. The world is vastly different now in so many ways, it's difficult to comprehend what life on the "Great Unknown" 150 years ago would have been like. Powell's team set off in heavy wooden boats loaded with supplies including hundreds of pounds of flour, bacon, coffee, a few scientific instruments and no complete map, hoping for the best. Our modern expedition had the benefits of a meticulously planned itinerary, durable inflatable rafts, satellite navigation, lightweight and quick-drying clothing, waterproof containers, an entire portable kitchen and pantry stocked with pre-planned meals and snacks for each day on the river, and more. Crew safety was emphasized throughout every stage, from pre-launch training requirements to ensuring everyone was always wearing a personal flotation device on the water. Plus, we had the benefit of knowing that we could use a satellite communications device to request an airlift evacuation to a hospital if any major emergency were to occur.

Of all the hardships the Powell expedition endured, the most challenging may have been the unknown itself—he and his crew never knew what they were going to encounter around the next bend. Thanks to hand-drawn maps created by the Powell expedition and the technology that has continued to evolve and improve since, navigation was a problem we didn't have to deal with. The spread of our modern society and technology, however, has created a host of new problems unknown in Powell's time that we will have to deal with, such as the environmental impacts of impounding a free-flowing river system behind a series of enormous concrete dams and pollution of the water, land, and air. Even in seemingly wild areas, far from any population center, we encountered streambanks littered with trash, free-floating garbage in the water, and noise and particulate air pollution. Like Powell's expedition, however, our journey included scientific instruments to record and document specific conditions (such as water temperature and pH, samples of beach sediment and stream water for microplastics content, and surveys of invertebrates, bats, and birds) that will, I hope, help us create new "maps" that will lead us toward a better future. Everything about this journey was epic: the landscape, the weather, the preparation, the logistics, the scope, and, of course, the dedication and teamwork of the people who made it all happen.

~Russell Sherman

Segment B

May 28–May 31, 2019

Flaming Gorge Dam, Utah, to Gates of Lodore, Colorado

As seen from above, the Green River follows a dramatic path on the next stretch of the journey. Just south of Flaming Gorge Dam, the Green River flows eastward across the northeasternmost corner of Utah as it is forced around the Uinta Mountains, a long east-trending range in northern Utah. The river continues southeastward through Browns Park National Wildlife Refuge in Colorado. Established nearly 100 years after John Wesley Powell passed through the region, this nearly 40-mile-long wildlife refuge, managed by the U.S. Fish and Wildlife Service, is home to over 200 species of birds and nearly 70 mammal species.

Flaming Gorge Dam to the north has changed the river dynamics here since Powell's time. Hydroelectric dams trap water, and everything within it, behind a large concrete barrier, and prevent natural flooding events. The lack of natural floods after dam construction and the deepening of the channel has decreased native species such as cottonwood and willow trees and increased competing species such as tamarisk, pepperwood, and Russian olive. The erosive power of rivers and natural floods also allows sediments to flow freely downstream. As rivers meander, water moves faster on the outermost edge of each bend, removing sediment from the bank. Fine sediments such as silt and clay become suspended in the water, moving downstream within the channel, and settle out downstream where the velocity is slower. Coarser sediments such as sand and gravel bounce along the bottom of the channel and pile up along the inner bend of meanders where the water moves more slowly, forming point bars, or more simply, sand or gravel bars. These piles of sediment are very important, not just for vegetation to take root, but also for recreational boaters who use them as campgrounds. Controlled flows, or high flow experiments (HFEs), carried out by the USGS and the Bureau of Reclamation downstream from Glen Canyon Dam on the Colorado River, are one way to mimic natural floods (Hadley and others, 2018, for example). These flows replenish nutrient-rich, fine sediments and allow for the formation of sand and gravel bars downstream; they also allow aquatic insect larvae to travel downstream, increasing their chances of survival to adulthood.

The route then follows the Green River's path back toward the southwest and into Dinosaur National Monument, where the Green is joined by the Yampa River before flowing westward again, back into Utah.

June 4, 1869: "We start early and run through to Brown's Park. Halfway down the valley, a spur of red mountain stretches across the river, which cuts a canyon through it. Here the walls are comparatively low, but vertical. A vast number of swallows have built their adobe houses on the face of the cliffs, on either side of the river. The waters are deep and quiet, but the swallows are swift and noisy enough, sweeping by in their curved paths through the air or chattering from the rocks, while the young ones stretch their little heads on naked necks through the doorways of their mud houses and clamor for food. They are a noisy people. We call this Swallow Canyon." ~JWP

Then and Now

Food

Then

Adequate food supply was one of the biggest hurdles for the 1869 Powell expedition. The crew started the trip assuming a relatively leisurely pace and packed enough food supplies for 10 months. The explorers had to rely on food preserved by drying (like flour, rice, beans, and dried apples) or salting (like bacon). Cooking relied on fires fueled with collected branches and driftwood.

Although the boats had adequate space for a long trip, proper food storage turned out to be more of a challenge than the explorers anticipated. One boat, the *No Name*, was destroyed three weeks into the trip and a third of the food was lost. Within the salvaged wreckage, Powell was thrilled to discover that the barometers had survived. The crew was more excited that a smuggled keg of whiskey, until then hidden from Powell, had made its way through the rapids unharmed. Not long after losing the *No Name*, an out-of-control campfire caused the men to lose nearly all their kitchen equipment except for a camp kettle and a few cups and bowls.

To supplement their preserved food stores, the men would hunt, fish, and gather wild plants (like currants). The crew also occasionally stole from others' gardens near the river. One stolen bounty proved to be a mistake—root vegetables pilfered from a garden weren't mature enough to eat, so the men cooked and ate the plant greens instead, including potato greens. Potato greens contain moderate levels of the toxin solanine and several of the men became violently ill.

July 6, 1869: "At noon we stop to cook our greens for dinner; but soon one after another of the party is taken sick; nausea first, and then severe vomiting, and we tumble around under the trees, groaning with pain. I feel a little alarmed, lest our poisoning be severe. Emetics are administered to those who are willing to take them, and about the middle of the afternoon we are all rid of the pain. Jack Sumner records in his diary that "potato tops are not good greens on the 6th day of July." ~JWP

Early in the trip, game was more plentiful (waterfowl, fish, beavers, wild sheep, and deer) but the latter part of trip provided little opportunity for fresh meat because of the steep canyon walls and scarce game. Fish were harder to catch in the lower basin, too, due to a combination of swift currents, muddy waters, and poor understanding of the local species.

The boats were frequently flooded and splashed by water, wetting the food and causing it to spoil. Wet, spoiled flour was either thrown out or sifted with mosquito netting. The sugar dissolved into the river. The bacon became rancid, apples frequently had to be re-dried, and supplies ran low. The crew often commented on provision scarcity and how it degraded their morale. One day, while subsisting on half-rations in the Grand Canyon, the explorers happened upon a Native American garden. They stole some squash, which raised everyone's spirits. With the exception of the stolen squash, the explorers only ate biscuits made from spoiled flour and dried apples for the last month of the trip. With two weeks left, the baking soda was lost in the river and the men had to eat unleavened biscuits. Luckily, coffee was plentiful throughout the trip and would help warm the damp explorers and lift their spirits, when they could find enough wood to boil water. The crew emerged from the river with only "about 10 pounds of flour, 15 pounds of dried apples, but 70 or 80 pounds of coffee" left.

By Jaime Delano

Now

Food preservation has come a long way since the first Powell expedition. Canned and other shelf-stable foods are readily available and much more varied than Powell's provisions. Well-insulated coolers allow fresh and frozen food to last as long as the crew has ice. For long trips, meals are pre-planned and staged in date-specific, labeled coolers to reduce ice loss from repeated opening. The biggest advancement is our ability to keep things dry in waterproof bags and sturdy bins, all securely fastened to the rafts. The menu is limited only by the creativity and determination of the group.

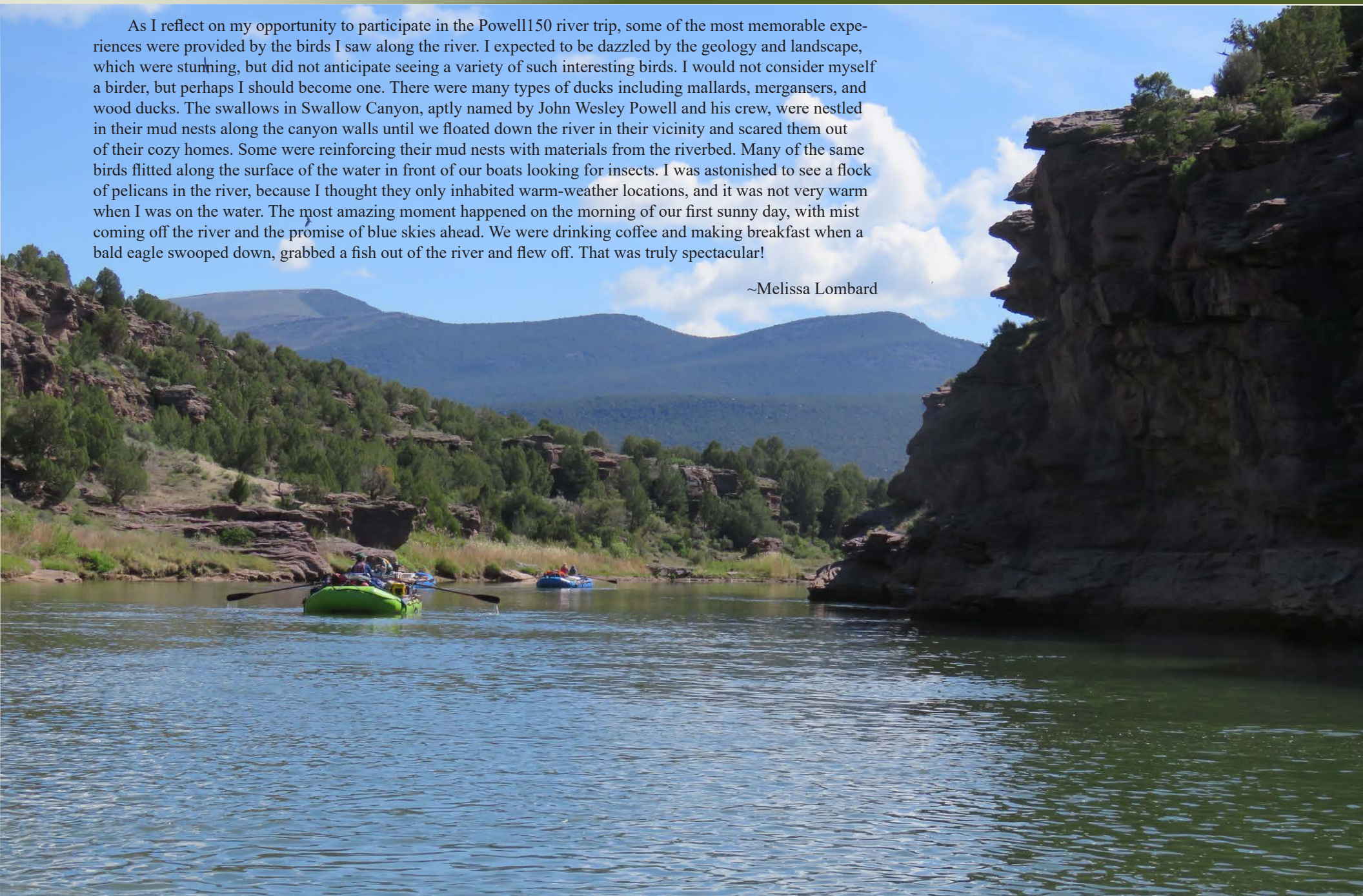
The Sesquicentennial Colorado River Exploring Expedition was well-provisioned, using a professional river outfitter. Fresh supplies and ice were brought in coolers and bins at each segment switch. Food was cooked with propane and charcoal on grills and stoves, without having to rely on driftwood as a fuel source. The menu was varied and flavorful, and included dishes such as fried eggs, oatmeal, and French toast for breakfast; sandwiches, cookies, and snack mixes for lunch; and salmon, steak, and fish tacos for dinner. Like Powell's men, the current crew did not always have such great luck fishing, and also like the 1869 Powell expedition, coffee remained an essential part of the morning ritual. In addition, SCREE located seeds of 10 Hopi heritage bean varieties and reached out to Native American elders in the region to recognize the stolen squash from the historic expedition.

Segment B—Personal Vignettes

June 8, 1869: "Lying down, we look up through the canyon and see that only a little of the blue heaven appears overhead—a crescent of blue sky, with two or three constellations peering down upon us. I do not sleep for some time, as the excitement of the day has not worn off." ~JWP

When I first saw the announcement advertising the Powell150 expedition in the USGS e-newsletter, I couldn't believe that such a unique opportunity would be open to anyone in the bureau. Who wouldn't jump at the chance to raft down portions of the Green and Colorado Rivers, camp under the stars, share with and glean knowledge from a multidisciplinary group, and educate the general public? So, needless to say, I was thrilled to be chosen as a representative of the USGS National Wildlife Health Center to participate in a four-day, 46-mile-long segment of the trip through northern Utah and northwestern Colorado from below Flaming Gorge Dam to the Gates of Lodore, and felt only a transient pang of guilt that my family couldn't join me on this adventure. There were many memorable moments on this journey. First, there was driving from Vernal, Utah, to our starting point at Flaming Gorge Dam on May 28 and running into a snowstorm at high elevation. I hoped I had packed enough warm clothes. Next, there was my introduction to the groover, the river runner community's word for the one shared toilet. There was the peaceful lapping of water at the sides of the raft and the steady splash of the oars propelling us forward on flat water compared to the noisy rush of water over hidden rocks that could be heard before being seen. Thankfully—since I'm only a whitewater novice—there were none of the treacherous wild river encounters that the Powell crew endured on their 1869 journey, but the water lines on the canyon walls were a sobering reminder of what the dam holds back. Here are some of the memories that will stick with me: traveling past towering walls of red rock and through swarms of cliff and barn swallows foraging for insects over the river; watching a mature bald eagle struggle to get airborne with a massive fish in its talons; mule deer poised like statues at the river's edge; a rainbow of flowering plants awaiting photo identification when I returned to Internet connectivity; and unexpectedly calling upon my veterinary medical training to assist a wary, four-legged companion in a remote setting, to the great relief of its owners. Nothing, however, compared to leaving the cozy confines of my tent in the middle of the night to step out into the crisp air and gaze upon a dark sky alight with what seemed like trillions of stars—a poignant reminder of how fragile and precious planet Earth is. It was hard to say goodbye to the river and camaraderie after only four days, and I wished I could have continued longer, although that first hot shower back in civilization never felt so good. I have also come to realize that the legacy of John Wesley Powell means being a tenacious, lifelong learner and a strong believer in the value of sustainable land stewardship, science as an important tool to inform government policies, and respect for Native American cultures and knowledge. Many thanks to those who conceived this idea, and to all those behind the scenes who made this incredible trip possible. Thanks also to my USGS crewmates Jason, Melissa, and Sharon for sharing this adventure with me. Moreover, an extra big thank-you to the commander of our raft, who was genuinely encouraging at my laughable attempts to briefly guide the raft.

~Anne Ballmann



As I reflect on my opportunity to participate in the Powell150 river trip, some of the most memorable experiences were provided by the birds I saw along the river. I expected to be dazzled by the geology and landscape, which were stunning, but did not anticipate seeing a variety of such interesting birds. I would not consider myself a birder, but perhaps I should become one. There were many types of ducks including mallards, mergansers, and wood ducks. The swallows in Swallow Canyon, aptly named by John Wesley Powell and his crew, were nestled in their mud nests along the canyon walls until we floated down the river in their vicinity and scared them out of their cozy homes. Some were reinforcing their mud nests with materials from the riverbed. Many of the same birds flitted along the surface of the water in front of our boats looking for insects. I was astonished to see a flock of pelicans in the river, because I thought they only inhabited warm-weather locations, and it was not very warm when I was on the water. The most amazing moment happened on the morning of our first sunny day, with mist coming off the river and the promise of blue skies ahead. We were drinking coffee and making breakfast when a bald eagle swooped down, grabbed a fish out of the river and flew off. That was truly spectacular!

~Melissa Lombard

I grew up in the Midwestern United States and, like John Wesley Powell, spent my spare time playing in rivers, lakes, and creeks. When I moved to the West at the age of 19, access to the vast and wild public lands kindled a sense of freedom and adventure that made me never want to leave. I imagine Powell felt the same when he first visited the West to collect fossils. Nowhere is his legacy more apparent than in the Western United States, and this is particularly true of the Colorado River and its tributaries, where many features on the landscape bear the names Powell assigned. Putting my hands on a pair of oars and floating down the Green River reconnected me with Powell's legacy. The segment of the Green River from Flaming Gorge Dam to Gates of Lodore is representative of the various public lands and their abundant resources in the American West. The segment began where the Green River flows out of the power turbines of the dam (managed by the Bureau of Reclamation), through the lands of Ashley National Forest (managed by the U.S. Forest Service), Browns Park (managed by the Bureau of Land Management), and Browns Park National Wildlife Refuge (managed by the U.S. Fish and Wildlife Service), before coming to the Gates of Lodore in Dinosaur National Monument (managed by the National Park Service). Powell understood the challenges posed to society by the arid lands of the West, and he poured the foundation for scientifically informed planning and management in his vision of the USGS as a provider of accurate, impartial Earth science information for the Nation. I joined the USGS to be part of that mission. Over campfires and standing in places where Powell and his crews surely stood, I was inspired and energized to hear the stories of my fellow USGS colleagues who, despite a wide diversity of education and backgrounds, had joined the bureau because of a belief in the same mission. It was an honor and a pleasure to be on the river with the group of scientists, artists, writers, historians, and others organized to honor and highlight Powell's legacy and contemplate the future of the American West—a beautifully messy melting pot of people, ideas, and landscapes.

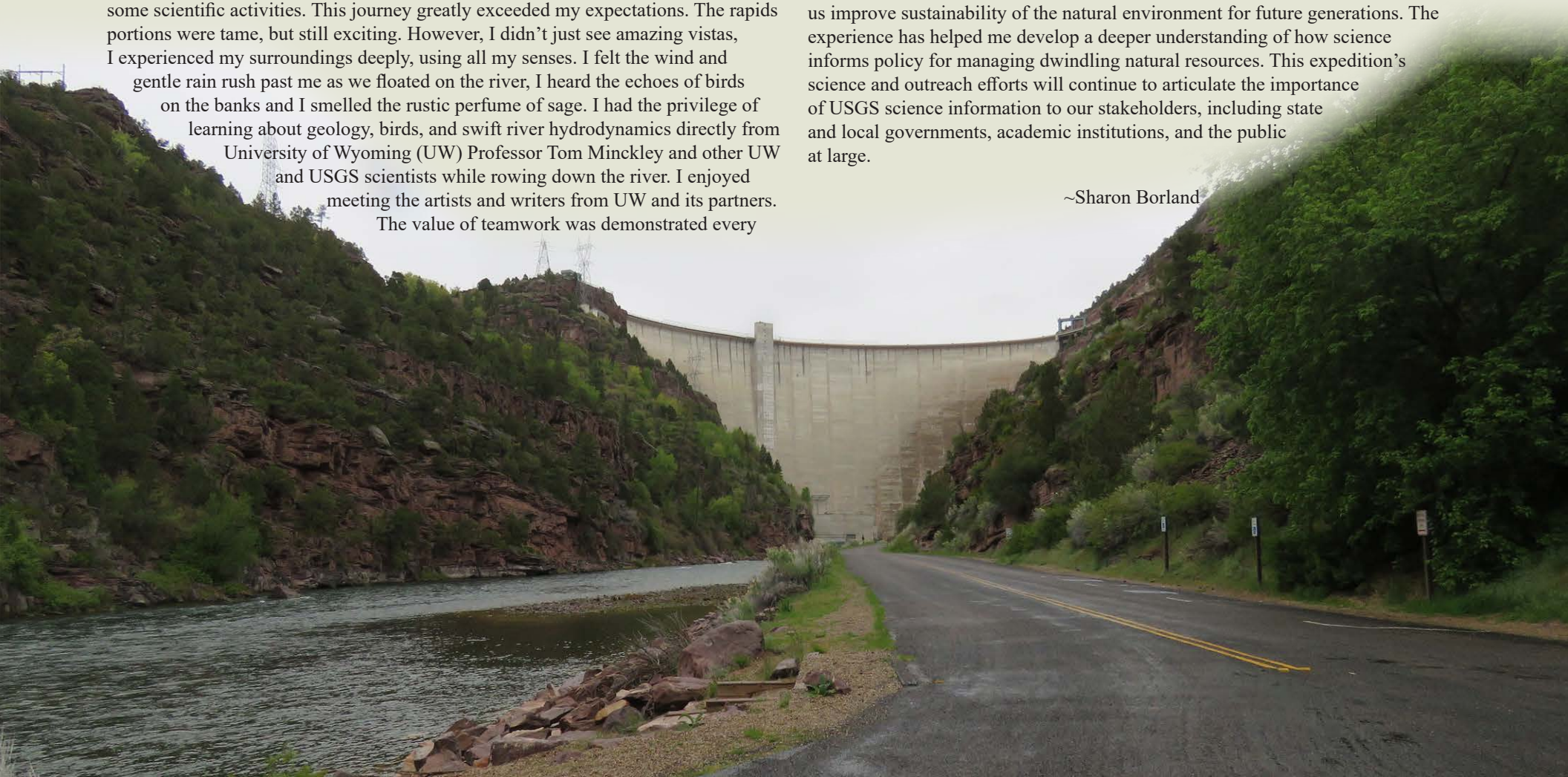
~Jason Alexander

This expedition along the Green and Colorado Rivers sought to commemorate the expedition of discovery and science by John Wesley Powell. At the time of the first Powell expedition in 1869, the Nation had just come through a painful chapter dominated by the Civil War. There was a need to map and observe the rivers and lands in the West. The original expedition conducted a great deal of scientific research and mapping, and the commemorative expedition also pursued scientific studies and promoted public engagement.

I was on the Green River leg from Flaming Gorge Dam to the entrance to the Gates of Lodore. I had never done anything like a river journey with camping before. I expected to see new vistas, raft through white water and participate in some scientific activities. This journey greatly exceeded my expectations. The rapids portions were tame, but still exciting. However, I didn't just see amazing vistas, I experienced my surroundings deeply, using all my senses. I felt the wind and gentle rain rush past me as we floated on the river, I heard the echoes of birds on the banks and I smelled the rustic perfume of sage. I had the privilege of learning about geology, birds, and swift river hydrodynamics directly from University of Wyoming (UW) Professor Tom Minckley and other UW and USGS scientists while rowing down the river. I enjoyed meeting the artists and writers from UW and its partners. The value of teamwork was demonstrated every moment of each day in the conducting of daily survival tasks, unloading and loading of boats, staging of experiments, doing videography and photography, setting up camp, purifying water, and preparing food. The expedition had a diverse and talented group of dedicated individuals sharing common interests in the history, lore, and nature of the West. I participated in the collection of sediment samples and helped set out the collection box for insects, which reminded me of my early days as a researcher.

The natural world inspired explorers and scientists in Powell's day with promises of rich resources, new lands, and seemingly infinite possibilities. This journey showed me the continuing need for reliable scientific data that can help us improve sustainability of the natural environment for future generations. The experience has helped me develop a deeper understanding of how science informs policy for managing dwindling natural resources. This expedition's science and outreach efforts will continue to articulate the importance of USGS science information to our stakeholders, including state and local governments, academic institutions, and the public at large.

~Sharon Borland



Segment C

June 1–June 4, 2019

Gates of Lodore, Colorado, to Split Mountain, Utah

This relatively short segment of the Green River through Dinosaur National Monument tested John Wesley Powell and his crew, and the ominous names they selected for features on the landscape remain today. While Powell was scouting the rapids from the banks of the river, their boat, the *No Name*, with the Howland brothers and Frank Goodman aboard, struck a rock and broke into pieces. All three men swam to safety, but many supplies were lost, and the party had to continue the journey in the three remaining boats. They named the rapids Disaster Falls and the canyon Lodore. The Green River was not done challenging them. A few days after the loss of the *No Name*, their cooking fire, whipped up by the wind, engulfed their camp and burned clothing, bedding, and other supplies that had been laid out on the rocks to dry. They stopped at the confluence of the Yampa and Green Rivers and spent three days working on their maps. It was near this location that Powell recorded a dramatic rescue. Powell was climbing a cliff face, not an easy task with one arm, and became stuck on a ledge with seemingly no way up or down. Lacking a branch or rope to reach him, George Bradley removed his own pants, or perhaps long underwear, lowered them to Powell, then pulled him to safety.

June 18, 1869: "I gain a foothold in a little crevice, and grasp an angle of the rock overhead. I find I can get up no farther, and cannot step back...Standing on my toes, my muscles begin to tremble. It is sixty or eighty feet to the foot of the precipice. If I lose my hold I shall fall to the bottom, and then perhaps roll over the bench...At this instant it occurs to Bradley to take off his drawers, which he does, and swings them down to me. I hug close to the rock, let go with my hand, seize the dangling legs and, with his assistance, I am enabled to gain the top..." ~JWP

As a geologist, Powell paid a great deal of attention to the large-scale geologic features and made note of the plants and trees he observed. The Powell150 expedition made observations about the riparian vegetation along the way and SCREE created artful cyanotypes, a method of preserving leaf images that was created by botanists in the 1840s before photography became common. Powell noted the cottonwoods, willows, and other native plant species, many of which were previously undescribed. Today, scientists

at the USGS Southwest Biological Science Center monitor and study invasive and non-native plants, such as tamarisk, which have colonized the banks of the river, altering the original ecosystem and outcompeting native species.

Before hydroelectric dams, natural floods periodically drowned plants near the river with nutrient-rich, sediment-laden water, and only those having deep, strong roots thrived. Building a dam obstructs water flow, creating a reservoir upstream of the physical barrier. Sediment carried within the water is also obstructed and settles out in the slow-flowing water behind the dam. Water released at dams is clear, because sediment has settled out, and cold, because it is generally released from well below the surface of the reservoir. This fundamentally changes the ecosystem of a river below a dam.

Segment C ended at Split Mountain in present-day Dinosaur National Monument. Here, the uplift of the Uinta Mountains drove the sedimentary rocks nearly straight up into the sky (Hansen, 1969, for example). Steep, rugged cliffs of tan-colored, sparsely vegetated sandstone line the river. Powell did not document the abundant Mesozoic dinosaurs recorded in the sedimentary layers here, though today one can visit the amazing, in-situ assemblages of sauropods, therapods, and others, very close to the Green River that winds through the park.

June 24, 1869: "The river wheeled to the right at the foot of Whirlpool Canyon in a great curve through Island Park. At the lower end, the river cut into the mountain, creating a gorge that split the mountain ridge for six miles. All this we could see from where we stood on the summit at Mount Hawkins. We named the gorge Split Mountain Canyon." ~JWP

Then and Now

Flora and Fauna

Then

Imagine a vast wilderness, and the fascination that people back East had for the exotic wildlife of the frontier. Physical specimens, preserved either by taxidermy or by other means, were an exciting way to study these species.

John Wesley Powell had experience collecting specimens from a young age, when he would learn about natural history through field exploration. As he traveled the Ohio and Mississippi Rivers, he amassed a collection of fossils and mollusk shells. Later, when he was a professor, he became the head of the Illinois Natural History Society and curated its collections. One of the objectives of his early field surveys with students was to add to the museum's collection, as well as to identify and characterize new taxa. Powell's wife, Emma Dean Powell, served as an ornithologist during his academic field trips and described 175 species of birds.

At that time, it was understood that fossils reveal a history of faunal succession, by which species become extinct and are replaced by new species, and that assemblages of fossils can therefore help us to infer the relative ages of the rock layers where they are found. During the river expedition of 1869, the crew collected whatever small, transportable fossils they could find, such as those of trilobites, leaves, and fish.

Through the journals of Powell and crew members Jack Sumner and Billy Hawkins, we have descriptions of not only the geology and terrain, but also the riparian vegetation and wildlife that they observed during their three months traversing the Colorado River Basin. They referenced making camp near cottonwood groves and hackberry bushes, and noted the presence of mesquite in the arid portions of the basin. While the men observed, with seeming fondness, kingfishers, songbirds, and cliff swallows, the majority of their written references to wildlife relate to its potential as a meal for the hungry explorers. They hunted geese, mountain sheep, mule deer, ducks, grouse, beavers, and rabbits, and they fished the productive waters of the Green River (and, with less success, the Colorado River) for mackerel, sucker, "Colorado salmon," and whitefish. Powell noted, while in the upper basin on the Green River, that "Mule deer and elk abound; grizzly bears, too, are abundant; wild cats, wolverines and mountain lions are here at home." In his report of their first week on the river, Jack Sumner noted, "Passing by the falls, we leisurely rowed down and camped in about the middle of Brown's Hole, a fine camp, where we enjoyed ourselves to the limit, fishing, shooting ducks and geologizing."

As shown by these descriptions, wildlife at that time was largely viewed as a resource to be exploited, with scientific efforts mostly focused on identification and classification of organisms, and it was not until the following century that the more integrated field of ecology developed, leading to such subdisciplines as population dynamics, restoration ecology, and ecosystem services.

By Anna Glover and Kristen Hamilton

Now

The Green-Colorado river system has been fundamentally altered since Powell's time, with the addition of three major dams on the portion that he traveled (and many more throughout the main stem and tributaries), hydropower generation, and irrigation infrastructure. Through monitoring, experimental research, and modeling, USGS scientists study this ecosystem to inform decisions about how to manage natural resources, such as fisheries, riparian vegetation, and streamflow.

One such research topic relates to a fish that would have been abundant during Powell's time, the humpback chub (*Gila cypha*). Now an endangered species, this fish is being studied by the USGS for its population dynamics in the Grand Canyon, downstream from Glen Canyon Dam. Declines in the population during the 1990s are believed to have been caused largely by decreased water temperature (from deep-impoundment dam releases), which impacts reproduction, and by competition and predation by non-native salmonid species such as rainbow trout. The humpback chub population grew during the late 2000s, when drought conditions resulted in warmer (shallower) water being released at Glen Canyon Dam, leading to lower salmonid numbers. The population since then has been stable, and the USGS is using mark-and-recapture studies and population modeling in order to predict how the humpback chub could respond to potential management strategies, such as control of invasive species or flow modification.

Another area of study relating to altered flow regimes has to do with tamarisk (*Tamarix ramosissima*), also known as saltcedar. This non-native, invasive riparian shrub succeeds in areas of low water availability, high salinity, and streamflow altered by dams and irrigation infrastructure. Unlike in Powell's time, it now lines the Colorado River in many places. Because of its rapid spread and ability to alter its habitat, it displaces native woody plants such as cottonwoods, willows, and western honey mesquite. Local, State, and Federal entities have tried a variety of control methods, including biological control by the northern tamarisk beetle (*Diorhabda carinulata*). The USGS uses remote sensing techniques to measure tamarisk biomass in areas where the beetle has been introduced and studies ecosystem changes associated with biological control of tamarisk, which will help to prioritize management actions and methods, facilitating restoration of native plant communities.

River runners and fishermen are assisting the USGS in one of its ecosystem studies in the Grand Canyon. Through Citizen Science Light Trapping in Grand Canyon, the USGS has collected far more data on insects that emerge from the river than otherwise would have been possible; these insects are a critical component of the aquatic and terrestrial food webs. An important finding from this study is that the abundance and diversity of aquatic insects are constrained by hydropower operation at Glen Canyon Dam (Kennedy and others, 2016). The USGS is studying the effects of experimental flow releases on aquatic insects to better understand this relationship and inform decision making. USGS participants on SCREE used the same light-trapping technique each evening at camp, so that the expedition could provide additional data to complement this important area of study.

After Powell completed his two scientific expeditions on the Colorado River, he published his findings, enlisted artists and photographers to portray the stunning landscapes, and engaged with the public and policymakers to inform them about western resources. The USGS hopes that the story of the 2019 expedition, as told through artwork and photography by our partners and through the results of the USGS' sampling and data collection, will likewise inspire curiosity in and stewardship of the unique resources of the Colorado River Basin.

Segment D

June 5–June 10, 2019

Split Mountain to Sand Wash, Utah

The beginning of this section of the Green River meanders through the Ouray National Wildlife Refuge in northeastern Utah and features picturesque landscapes, with lush foliage along the riverbanks. Here, the canyon walls widen, and the landscape is dominated by low hills of flat-lying, soft sedimentary rocks. It was near this location that Frank Goodman left the 1869 journey. He had lost most of his clothes and supplies by this point and decided to stay in Utah, where he lived for many years.

Powell150 participants observed and recorded bird songs every morning and bat acoustics every evening. Although humans cannot hear many of the frequencies made by bats, special software installed on an accompanying tablet allows the sound signals to be recorded and bat species to be identified. These data are being analyzed to give understanding about how the abundance and types of species change along the river and how this may play a role in local and broadscale food webs. It is hoped that the knowledge gained will yield a better understanding of the ecosystem health of the Colorado River Basin.

The types and amounts of aquatic insects that emerge from the water at dusk tell scientists about the health of the river food web, because these insects are food for fish, birds, reptiles, bats, and other animals. During the Powell150 expedition, USGS participants followed specific protocols to collect aquatic invertebrates within an hour of dusk every evening, guided by aquatic ecologists from the USGS Southwest Biological Science Center in Flagstaff, Arizona. These samples are being analyzed and will fill a significant data gap in this part of the watershed for an ongoing citizen science project about aquatic invertebrates in the Colorado River Basin.

Science Story

By Anya Metcalfe

Aquatic Insects

Aquatic insects are fundamental components of a healthy river ecosystem. Most aquatic insects spend their juvenile life stages (egg, larva, pupa) in the river and their winged adult life stage flying along the riparian corridor. Throughout these metamorphoses, they are important prey for fish, birds, bats, lizards, and even other invertebrates. They are also important bioindicators of stream health. In most rivers, scientists sample for juvenile aquatic insects by wading into rivers and collecting specimens from the river bottom. The swift currents, great depths, and large rapids in many sections of the Green and Colorado Rivers make traditional river-bottom (benthic) sampling dangerous to impossible. Each night of the Powell150 expedition, participants set out light traps that are designed to sample aquatic insects in their winged adult life stage. Light traps are plastic containers (having a 17- x 28-centimeter (cm) opening, and 7-cm depth) with a fluorescent light placed on the short edge of the container. At dusk, collectors placed light traps within three meters of the river's edge, poured 250 milliliters (mL) of 95 percent ethanol into the trap and turned on the fluorescent light. After one hour of deployment, collectors turned off the light, transferred the contents into a plastic bottle, labeled the sample, and recorded sample location and duration on an associated data sheet. This sampling protocol was developed by researchers at the USGS Grand Canyon Monitoring and Research Center in Flagstaff, Arizona. By equipping river runners as citizen scientists, the USGS has collected thousands of samples of aquatic insects from the Grand Canyon and throughout the Colorado River Basin since the project's implementation in 2012.

Segment D—Personal Vignettes

More than Integrated Science…Integrated Scientists. Growing up, I recall that my father had more than a thousand books on his shelves and encouraged us to look at them anytime we chose to, even when we were very young. One of the books on his shelves was the Seventh Annual Report of the United States Geological Survey (USGS) to the Secretary of the Interior, published in 1888 by John Wesley Powell. In that book were a number of pen and ink drawings that much more resembled black and white photographs, from all corners of the United States. This book, and others from my father's library, likely guided me down the path of becoming a geographer and finding work with the USGS, a Department of the Interior bureau dedicated to science. John Wesley Powell embarked on his Colorado River expedition 150 years ago to explore the unknown and gain an understanding of the geography of the region. While much is known today about the Colorado River Basin, we do not understand everything about it, and our scientific investigations are not complete. As the West was settled and increasing use made of the water and land, our need to understand our impact on it, and our ability to properly manage it, have evolved. Our need to more thoroughly understand the complex relationships among the geological, hydrological, and ecological processes in the basin is greater now than ever before.

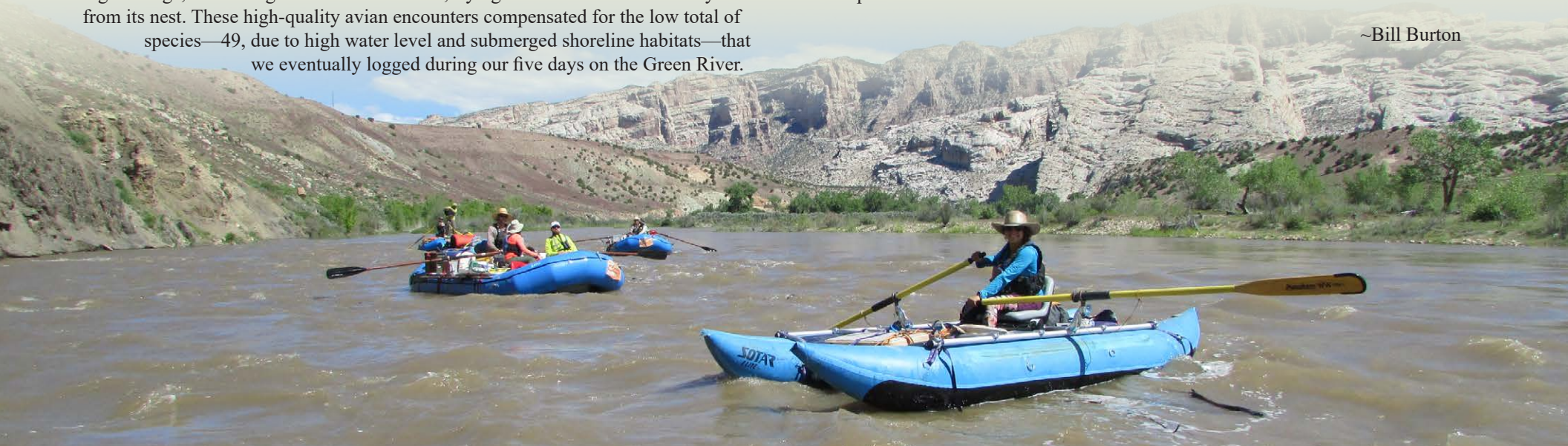
As I started my six-day segment from Split Mountain Campground near Jensen, Utah, to the Sand Wash launch point downriver, I understood the benefit of integrating various science topics to better understand the complex ecosystems and processes found in the Colorado River Basin. What I had not considered was the value of integrating the scientists and educators themselves—bringing them together from wide-ranging backgrounds so they could quickly and easily engage in a broad and extensive exchange of information. Experiencing this rapport and collaboration among the members of the expedition was inspiring. Discussions flowed from quantitative work on endangered, threatened, and invasive species, bird counts, bat detection, discharge measurements of the Green River, and numerous remotely sensed datasets, to more qualitative topics such as wildlife encounters along the river, spectacular sunrises and sunsets, stunning vistas, and the simple fact that we are permitted to use the river and nearby lands to enjoy and study. Integrating our scientists with one another, with stakeholders in the public and private sectors, with artists, with conservationists and educators, helps us better understand the complex needs of the Colorado River Basin and provides valuable information essential to maintaining it as a beautiful natural resource for us all. Involving youth offers the opportunity to share in that future, much the way my own father did.

~John Parks

It was the end of a long day of rowing, and I sank deeply into a folding canvas chair. Reddish-gold sunlight bathed the stratified cliffs across the river. Austin and Tall Ben had already set up their portable kitchen and were preparing dinner, while Pat was off sketching the landscape. "Who can assist with the stream sediment sampling?" asked Jaime. I sank further into the chair, lamely hoping my status as the oldest member of the Segment D team—who had, after all, voluntarily rowed 10 miles that day—would exempt me from this necessary scientific chore. Our daily data-gathering, which included sampling of sediment, aquatic invertebrates, and riparian vegetation; measurements of temperature, pH, and dissolved solids; and acoustic monitoring of bats and nocturnal insects, was, after all, in the spirit of the original Powell expedition. "I'll help!" Graham and Nick each cheerily called out, and the three of them disappeared up the streambank, Jaime bringing her cyanotype as well to make old-fashioned images of streamside leaves. Ah, the energy of youth! At the other end of the technology spectrum, our leader Tom was setting up his state-of-the-art bioacoustics monitor, which can analyze the sounds of bats and insects to identify both species and number of individuals of each species. My scientific contribution to the Powell150 expedition was to keep track of the bird species we were seeing along the way, using binoculars. Yellow-breasted chats, a species I rarely see in the East, did their rapper imitations from the Russian olives about every 100 yards as we floated along. Three sandhill cranes circled high up in the sunlight. A golden eagle, perched on a rock, kept a wary eye on us as we moved by. Once, we sidled up to a bluff to admire the cliff swallows that flitted in and out of their bulbous, mud-daubed nests on the underside of a ledge. Suddenly, a peregrine falcon soared out from a higher ledge, screeching as it wheeled around, trying to chase us intruders away from its nest. These high-quality avian encounters compensated for the low total of species—49, due to high water level and submerged shoreline habitats—that we eventually logged during our five days on the Green River.

"Time to go do something, like everybody else!" my mind nagged at me, still in the chair and feeling guilty. I got up and headed toward the hills behind the campsite. We were in the flat-lying mudstones of the Uinta Formation, of Eocene age, which here formed gentle purple- and green-colored slopes. My geologist instinct told me there might be vertebrate fossils eroding out of those slopes. The first clue that they held promise was a rock riddled with nickel-size holes; these looked like the burrows of some type of tubeworm, drilled into a shallow-water mudflat some 40 to 50 million years ago. Just beyond, on the next slope, was pay dirt—pieces of white bone littering the hillside. I picked one up and examined it: flat and thin, with fine cracks crisscrossing the smooth enamel-like surface on one side and little golf ball-like divots on the other—a shell fragment from a softshell turtle. Then the dinner bell rang. "You got to check this out," I told everyone as we headed back to the fossil site after dinner, our bellies full of delicious homemade tacos. Soon everyone was finding bone fragments in the fading daylight. Anya picked up what looked like part of the legbone of a small deer, and Filmmaker Ben showed me the femur ball joint of an elk-size ungulate. I looked around carefully, and finally picked up a small, irregularly shaped, tan-colored fragment. There were little gray nubs sticking out of the bone—a mammal jaw with teeth! Teeth are the best identifiers of fossil vertebrate species; since we did not have a collecting permit for this BLM land, I photographed the fragment carefully, and the finds of everyone else, before we redeposited our finds and headed back to camp. The star clouds of the Milky Way were becoming visible in the gathering darkness as I eventually crawled into my tent. Content that I had finally made a sufficient contribution to the great Team D effort that day, I soon fell fast asleep.

~Bill Burton



I'm an experienced river runner and have descended all the exciting and spectacular whitewater segments of Powell's 1869 journey that remain today. However, the segment of the Powell150 journey I was most interested in joining was the slow and winding 103-mile segment of the Green River that flows through the Uinta Basin in northern Utah, notable for being the lowest gradient river segment in the Colorado River Basin. Most boaters find themselves avoiding this mosquito-haven flatwater, so I didn't hear many firsthand accounts. I was intrigued mostly because it was a blank spot on my map. The Green River through the Uinta Basin doesn't match my typical, somewhat romanticized, notion of western rivers. It doesn't have gnarly rapids or towering canyon walls. Instead there are grazing cattle, green fields of alfalfa, and tire tracks in dry drainages. I woke up to the sound of pumpjacks thumping in the morning and often had cell phone reception. We saw people along the river working the land every day. The Green River is a working river that likely fits Powell's vision better than any other river segment in the Colorado River Basin, a river corridor that provides the fuel, water, and agriculture that the West relies on. The Uinta Basin is also a wildlife sanctuary and refuge. We saw sandhill cranes, peregrine falcons, beavers, and pronghorn daily. We were fortunate to ride a pulse flow release from Flaming Gorge Dam that flushed larval razorback suckers (an endangered fish) into edge habitat where managers hope they will prosper. Rivers truly are the lifeblood of the West, and the Green River was the perfect place during the Powell150 expedition to reflect on the vital role of America's public lands and waterways in our country's past, present, and future.

~Anya Metcalfe

As I was preparing for the Powell150 expedition, I experienced some ambivalence about what to expect. On one hand, I was incredibly excited to be participating in this once-in-a-lifetime adventure. But on the other hand, I knew that my designated section of the expedition was in the Uinta Basin. This is purportedly the lowest gradient section of river in the entire Colorado River Basin, containing none of the legendary rapids and dramatic canyons for which other sections of the river are known. Instead, it gains its infamy among rafters for its pernicious hordes of mosquitoes and comparatively lackluster scenery. I must admit that the adventurer in me was disappointed that I would not be rafting one of the wilder sections of river, such as the Gates of Lodore or Desolation Canyon. I had to remind myself that my purpose on this expedition was not to have an adrenaline-fueled, swashbuckling experience, but rather to learn about and engage in the myriad scientific, social, and political issues that surround the Colorado River Basin. This was not an expedition just for the sake of adventure, although that was inevitably a part of it, but one that sought to generate science, dialogue, artistic creation, and new perspectives on a complex topic.

Looking back on my experience, I can frankly say that my expectations were exceeded, both in terms of the natural beauty I encountered and the profound insights I gained from this experience. What it lacks in breathtaking scenery, the Uinta Basin makes up in the complex intersection of the human and natural worlds, which provided an excellent backdrop for conducting scientific and artistic endeavors that grappled with important issues: water resource management in the arid West; balancing ecological integrity with resource extraction; and the relationship between indigenous people and the land. As we traversed the Uinta Basin, we passed through scenes reflecting the myriad relationships that humans have developed with the river and the land. We saw sections of the river that were dominated by agriculture—a seemingly unnatural phenomenon in the arid desert. Along many of the plateaus that flanked the river, we spotted the silhouettes of oil derricks, stark reminders of the widespread presence of extractive industries in the region.

Although the Uinta Basin is sparsely populated, it was never hard to find some indicator of human presence. But we also passed through wild places, such as the Ouray National Wildlife Refuge, where dense galleries of cottonwood trees provide habitat for thousands of migratory birds. And although we did encounter the notorious hordes of bloodthirsty mosquitoes, we also discovered that they are an integral link in the riparian food chain, underpinning the resplendent diversity of birds, bats, and aquatic organisms that we reveled in. I gained a new appreciation for how much life can exist even in a human-impacted environment, as well as an understanding of the critical importance of these ecosystems. Unfortunately, although pristine natural places like the Grand Canyon are becoming exceedingly rare and receive a lot of attention, it is my hope that we also give proper attention to environments like the Uinta Basin—the unsung heroes of the natural world—which represent such a large portion of the modern landscape. In the field of ecology, there is much debate over whether the human environment should be considered a part of an ecosystem. To me, the answer is clear now: the two are indelibly linked, and it is impossible to study, manage, and preserve ecosystems without considering the human components. In the end, I am enormously grateful to have experienced the Uinta Basin; its lessons are as deep and profound as the mysterious, swirling waters of the Green River itself.

~Nicholas Hammond

The most notable takeaway for me from the Powell150 expedition was a sense of connection to the places and people I spent a week with on the river. On the flight home from the field, I had a bird's-eye view of our route and could see through my tiny airplane window the entire 100-mile course that took us over five days to paddle. I noticed how the thin green ribbon of the river contrasted sharply with the warm-colored sedimentary rocks of the Uinta Basin. I saw the circular fields of green, irrigated cropland, the rectilinear footprints of oil and gas development, and the sinuous bends in the river that seemed so enormous as we floated by them. As the river threads its way through the surrounding landscape, it ties together the geology, ecology, agriculture, and industry of the region. But as amazing as it was to see from the air, the truest sense of place came from having been there on the ground and on the water. My time on the river was shared with river guides, artists, and academics as well as with six other USGS participants representing different mission areas, science centers, and States across the country. Although we each have different academic backgrounds and research priorities, we spoke a common language rooted in the natural sciences and could relate personally to the important issues affecting the Colorado River Basin. What's more is that we found common ground and shared interests through our recreational activities, including fishing, birding, music, photography, and art. I even felt inspired to try songwriting. On a personal note, just a few weeks after I returned from the Green River, my wife and I welcomed our daughter into the world. We are now enjoying showing her and teaching her about the Earth and planning future adventures as a family. I trust that the opportunity to experience the Green and Colorado Rivers by raft will remain for many generations to come.

~Graham Lederer

I still feel incredibly lucky to have participated in the Powell150 expedition. I'm a field geologist, so I am used to experiencing wilderness, but I really gained an appreciation for new things on this trip outside of my normal scope of work. This trip highlighted the importance of establishing a connection between people and places, especially outside of regular routines. I knew very little about this part of the Colorado River Basin before joining, and even less about the connections among people, habitat, and history, but now I have a new connection to this part of the world. I loved being able to immerse myself into a trip so fully; the isolation and opportunity to focus allowed me to learn things I might have otherwise overlooked. I also made new friends whom I would never have met otherwise, and everyone had something unique to share. Mixing people from different backgrounds creates a richer environment for everyone involved. Overall, the Powell150 trip was a wake-up call to step out of our comfort zones and a reminder that engaging people firsthand is the best way to develop connections to important ideas and causes.

~Jaime Delano

June 8, 2019. On this, our fourth day of a 100-mile exploration of the Uinta Basin, we passed through Ouray National Wildlife Refuge and the Uintah and Ouray Reservation of the Northern Ute Tribe. Although the basin, situated between Lodore Canyon to the east and Desolation and Gray Canyons to the south, is better known for its farms, ranches, and pumpjacks than for red rock canyons and whitewater, our team was pleasantly surprised by the muted, sometimes striking, beauty of this stretch of the Green River. This region in particular is a candid representation of the balance between natural beauty, wildlife, Native American sovereignty, and human use of the land. Utah operates the fourth highest number of oil and natural gas leases on Federal land, and eastern Utah contains the largest oil sand reserve in the United States as well as some of the Nation's largest natural gas and coalbed methane fields. The Uinta Basin is also among the State's top producers of beef cattle, feed corn, and alfalfa, with numerous small farms and ranches. Nature-based tourism is now a major contributor to the local economy in eastern Utah, with Dinosaur National Monument and the Green River taking center stage. This region highlights J.W. Powell's legacy of conservation, his scientific assessment of the use and carrying capacity of water resources in the arid West, and his interest in indigenous peoples. Failure to heed his recommendations for prudent development, water use, and farming practices is believed by some to have contributed to the Dust Bowl of the 1930s. Today, however, we rejoice in seeing bighorn sheep, pronghorn, several beavers, peregrine falcons, waterfowl, white pelicans, and a lone coyote—and even a curious porcupine that strolled through our camp in the middle of the night.

~Mitchell Eaton

Segment E

June 11–June 21, 2019

July 12, 1869: "Just here we emerge from the Canyon of Desolation, as we have named it, into a more open country, which extends for a distance of nearly a mile, when we enter another canyon cut through gray sandstone." ~JWP

Sand Wash to Green River State Park, Utah

Here the Green River briefly meanders through the wetland-bounded banks of the Ouray National Wildlife Refuge before once again traveling through narrow, steep-walled, mostly treeless canyons. The section of river through Desolation and Gray Canyons, commonly known as Deso-Gray, is a scenic stretch of terraced canyons carved into the flat-lying sedimentary rocks. In places the canyon walls rise 5,000 ft above the river. This section, which requires several days of travel, is characterized by swift water, steep canyon walls, and cottonwood bottomlands. Stone ruins and petroglyphs were left by the indigenous people of these lands. There are also remnants of settlements attempted in the late 1800s to early 1900s, which did not endure because the land proved to be too isolated and wild.

July 13, 1869: "At noon we emerge from Gray Canyon, as we have named it, and camp for dinner under a cottonwood tree standing on the left bank. Extensive sand plains extend from the immediate river valley as far as we can see on either side. These naked, drifting sands gleam brilliantly in the midday sun of July...Plains and hills and cliffs seem to be floating vaguely about in a trembling, wave-rocked sea, and patches of landscape seem to float away and be lost, and then to reappear...Just opposite, there are buttes, outliers of cliffs to the left. Below they are composed of shales and marls of light blue and slate colors; above, the rocks are buff and gray, then brown. The buttes are buttressed below, where the azure rocks are seen, and terraced above through the gray and brown beds. A long line of cliffs or rock escarpments separates the tablelands through which Gray Canyon is cut, from the lower plain. The eye can trace these azure beds and cliffs on either side of the river, in a long line extending across its course, until they fade away in the perspective. These cliffs are many miles in length and hundreds of feet high; all these buttes—great mountain-masses of rock—are dancing and fading away and reappearing, softly moving about, or so they seem to the eye as seen through the shifting atmosphere." ~JWP

Science Story

By Katie Walton-Day

Sediments

About 50 samples of beach sediment were collected, from almost every expedition camping beach, for analysis of trace-element content, determination of lithology (rock type), and analysis of microplastic content. Trace-element analysis looks for variation in important trace elements (such as uranium) which may be due to variation in geology and rock type, and possibly to human activities.

Samples collected for variations in lithology were part of the Youth and Education in Science (YES) education activities planned for the expedition, with the goal of being included in classroom activities and educational resources distributed after the expedition. As a general rule, sediments are expected to vary over the length of a river in both lithology and size and shape of the sediment particles. If these changes are robust enough to be recognized by students, the samples will make a nice teaching collection of river sediments.

Samples were collected into acid-washed bottles using a square-meter grid design with 36 collection points. Participants wore cotton clothing and used metal scoops to avoid contaminating the samples with microplastics. Consistent application of this sampling method allowed us to make robust comparisons of data from site to site.

Segment E—Personal Vignettes

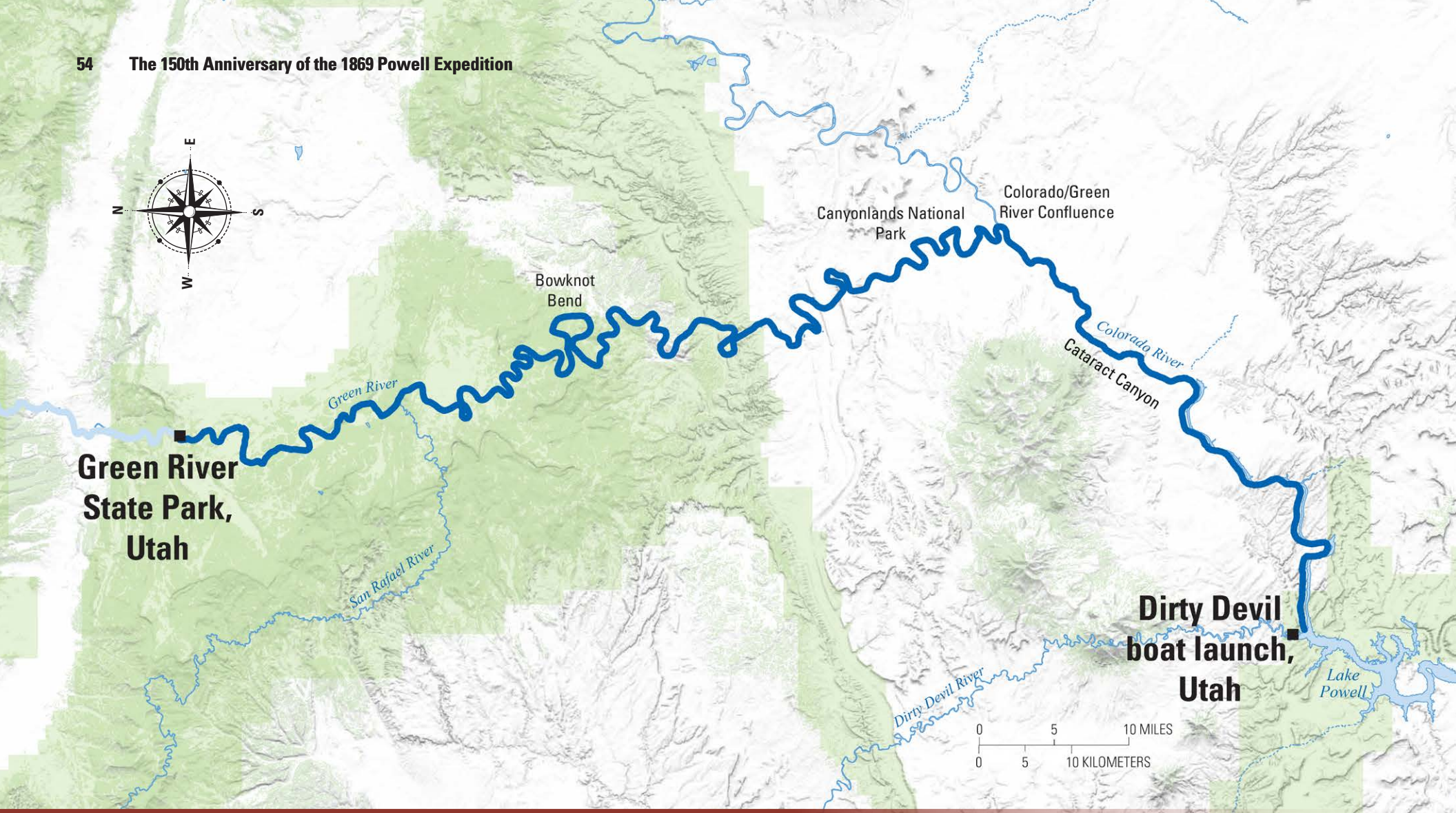
I had the immense fortune to float Desolation-Gray Canyon for my first raft trip (of many to come, I hope). The grandeur and beauty of the landscape would have been enough for a trip of a lifetime. But, for nine days, I learned about the Colorado River Basin from new viewpoints, SCREE members who have dedicated their lives to its conservation: from scientists like Tom Minckley, possessing endless knowledge of flora and fauna; to academics like Dan McCool and Paul Hirt, who speak with persuasive eloquence on decades of history and policy; to communicators like Paul Larmer, Ben Kraushaar, and Patrick Kikut, who inform the public through journalism, documentary, and art, respectively; to unifiers like Daryl Vigil and Matt McKinney, who are helping to make the voices of the basin's Tribal inhabitants heard; to Austin Alvarado and Ben Capelin, who give inspiration for the future of conservation. John Weisheit embodied all of those in one—a walking encyclopedia of science, policy, and advocacy—all while calmly navigating the rapids and providing campground entertainment. For nine days, while we paddled, talked, hiked, found petroglyphs, photographed, chopped veggies, washed dishes, ate brownies with whipped cream, carried the groover, counted bats, bugs, and stars…we also learned from each other. We learned that you need all the components—the science, history and law, purpose and partnership, communication, and inspiration—to, in John Wesley Powell's words, "add a mite to the great sum of human knowledge" for the protection of the Colorado River Basin for generations to come.

~Kathy Conn

As I sit on the edge of a mountain stream in the bottom of a narrow bedrock gorge on the East Coast of the United States, my thoughts carry me back to my rafting trip through Desolation Canyon along the Green River as part of the Powell150 expedition. Here, long-fallen pine trees bridge the moss-covered granite walls sprouting from the boulder-strewn banks of Bunnell Brook in northeast Connecticut. There, a tree this size would be cast off like a toothpick in one of the numerous eddies found between the towering stone curtains woven by millions of years of deposition and erosion. Everything about my surroundings here, compared with them there, could not be more different, or so I thought.

When I close my eyes, the sound of a 15-ft-high waterfall fanning out over a scoured ledge of Connecticut bedrock transports me back to the sound of undulating rapids flowing over cobbles and boulders pushed from dry side canyons into the Green River by some long-gone rainstorm. The sights may be different, but the sounds remain the same. Just as the sound of water is similar everywhere, so too are the people who are drawn to it. It was inspiring to share this trip with a group of people so dedicated to the health, stability, and appreciation of the Colorado River watershed and watersheds across the country. I listened to professors, artists, journalists, water administrators, river guides, and scientists all express their ideas about the future of the river which carried us along our 80-mile journey and its vitality to life in the West. Hearing their concern and commitment regarding the issues surrounding the watershed in which they live only deepened the appreciation and commitment I have regarding my own. I will be forever thankful to those who went through Desolation Canyon with me, and I sincerely hope our paths will cross again.

~Nigel Pepin



Segment F

June 25–July 5, 2019

Green River State Park to Dirty Devil River, Utah

This section of the expedition moves through the steep-walled cliffs of red and tan sedimentary rock of the San Raphael swell, a geologic structure known as an anticline. The striking landscape in and near Canyonlands National Park is primarily the result of erosion by the Colorado and Green Rivers and their tributaries carving downward through the rock layers of the Colorado Plateau. Long before the Colorado River was here, the rocks in this region were formed over millions of years as layer upon layer of sand, silt, and mud were deposited by water in shallow seas, rivers, and mudflats, and by wind during times when large swaths of the region were covered with massive sand dunes, as evidenced by thick deposits of crossbedded sandstone. As more sediment piled up, deeper layers were compressed and solidified, eventually forming sedimentary rocks such as sandstone, limestone, and shale. Later, tectonic forces caused the uplift of the Colorado Plateau, raising it above sea level even higher than its current elevation of 5,000 to 8,000 ft.

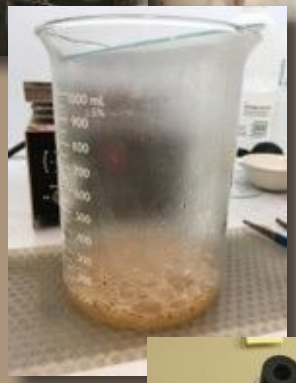
The Green and Colorado Rivers and their tributaries flowed across the land during and after uplift, carving ever deeper into the landscape. Imagine slicing downward into a layered cake while also lifting the cake at the same time. The canyons seen here are still forming today, powered by the slow, persistent process of erosion. Another striking feature seen in and near the Canyonlands region is known as differential weathering, meaning that different rock types weather and erode differently, making distinctions between rock types easy to see. Sandstone, which is relatively hard and resistant to weathering, forms steep cliffs and ledges. Shale, on the other hand, is made of smaller, finer grained particles (clay and silt, or mud) and erodes more easily, leaving behind gradual slopes. Common colors of barren rock in the desert Southwest include white, tan, and various shades of red. The surface is often covered in dark red to black streaks called desert varnish, which is common in dry environments.

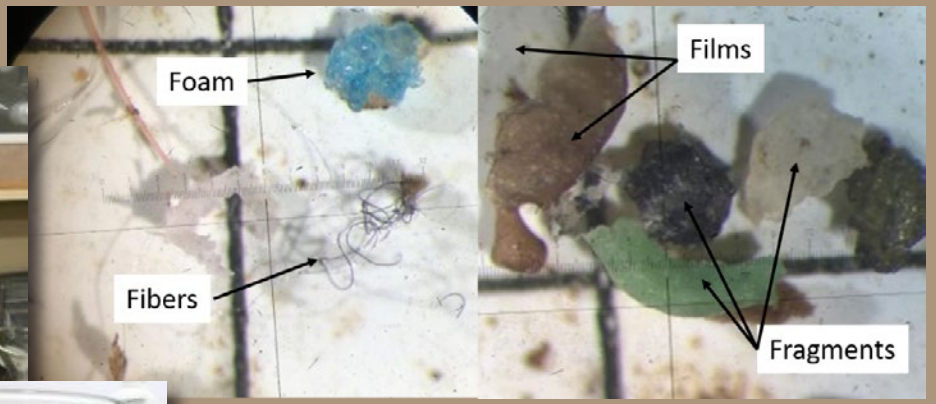
July 17, 1869: "The landscape was rock—cliffs of rock, tables of rock, plateaus of rock, terraces of rock, crags of rock—ten thousand strangely carved forms. Rocks everywhere and no vegetation, no soil, no sand." ~JWP

Science Story

By Kathy Conn, Katie Walton-Day, Andrew Spanjer[1], and Bob Black[1]

Microplastics



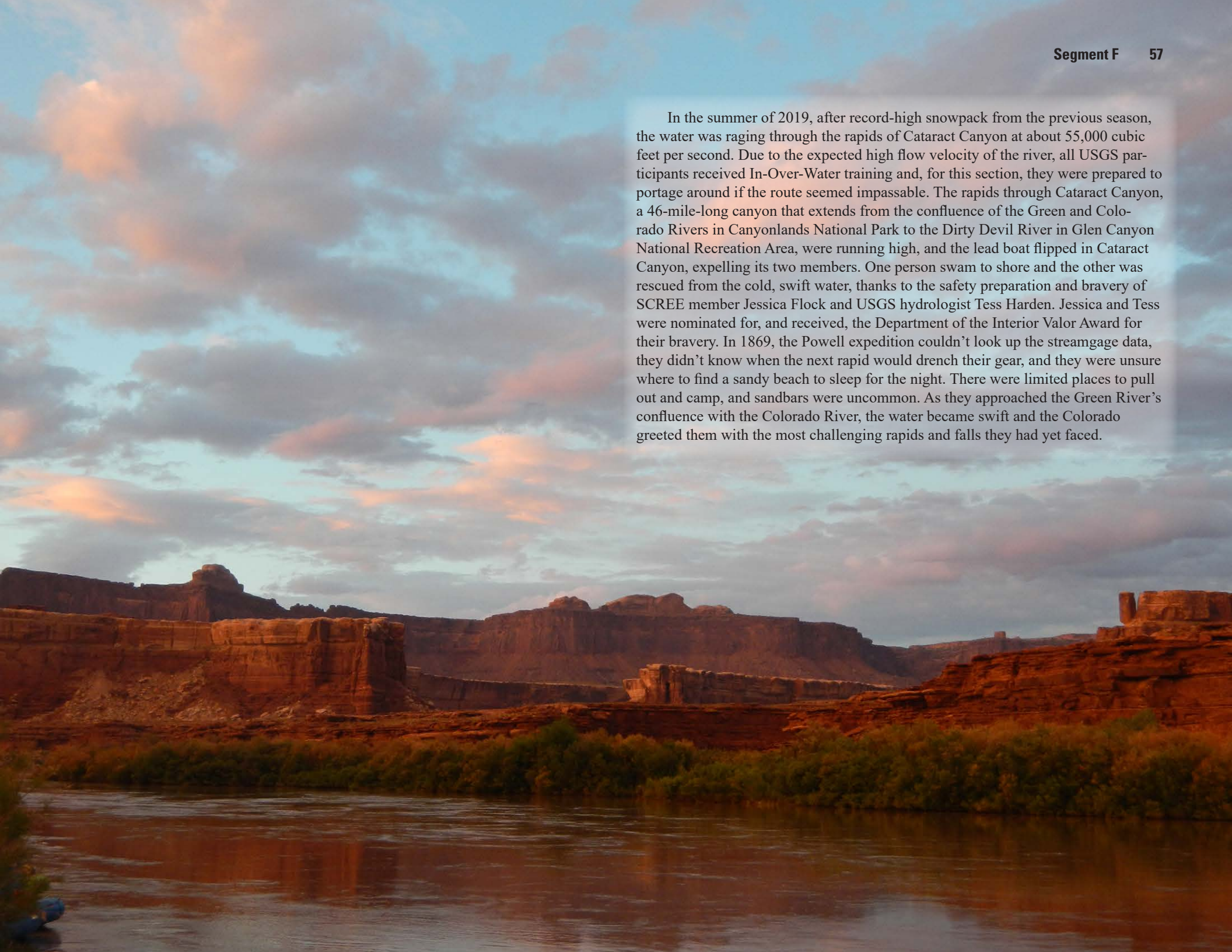


Plastics have become an integral part of our lives, from packaging material to medical devices, to outdoor clothing and equipment. When plastics are thrown away, they can break down in the environment into smaller and smaller pieces as a result of abrasion, sun, wind, and other processes. Microplastics, which are pieces of plastic smaller than five millimeters (mm) in size, have been found nearly everywhere they have been looked for. This includes the oceans, rivers, lakes, deep marine sediment, soils, air, and even the food we eat. It is estimated that five trillion pieces of plastic are floating on the surface of the oceans alone. Because of their size, microplastics can be ingested by animals at many trophic levels, including plankton, insects, fish, birds, and mammals (including humans). The plastic fragments have the potential to cause digestive system blockages or cause a false feeling of fullness resulting in reduced food intake in biota. Small (0.001 mm) microplastics have been shown to cross cell walls and be absorbed into the body. Additionally, there is a concern that plastics may transfer contaminants into organisms. Much is still unknown about chronic effects at the gene, organism, and community levels of microplastics in the environment.

Few studies have measured microplastics in remote river basins far from a source of plastics. During the Powell150 trip, samples of beach sediment were collected along the entire journey on the Green and Colorado Rivers to provide baseline information about the amounts and types of microplastics present along the shoreline. Samples will be analyzed for microplastics at the University of Washington-Tacoma, in partnership with the USGS Washington Water Science Center. Plastics are separated from sediment using a density separation technique (plastics and organic matter float and sediment sinks), organic material is removed through a digestion process (a chemical is applied that dissolves organic matter such as leaf fragments, but leaves plastics intact), and the microplastics are counted and categorized visually through a microscope. Categories of microplastics include foams, fibers, films, and fragments. Finally, advanced laboratory spectral techniques are used to identify and confirm plastic molecular composition and source.

Given that much of the Green and Colorado Rivers are distant from urban centers and other sources of microplastics, it is hypothesized that any plastics measured in beach sediment samples likely originate from camp activities, such as food packaging, personal care products, polyester clothing, and boating equipment. Dry (wind) and wet (rain) air transport may be another source. The river level rises and lowers throughout the year, so plastics found along a shoreline during low flow conditions later may be submerged and transported downriver in high flow conditions. The results will provide the longest known longitudinal survey of microplastics in a river system and may show how microplastic occurrence and characteristics change along the route. The data will provide baseline information against which future studies may be compared.

[1]USGS employee who assisted in the microplastics studies but was not a participant in the expedition



In the summer of 2019, after record-high snowpack from the previous season, the water was raging through the rapids of Cataract Canyon at about 55,000 cubic feet per second. Due to the expected high flow velocity of the river, all USGS participants received In-Over-Water training and, for this section, they were prepared to portage around if the route seemed impassable. The rapids through Cataract Canyon, a 46-mile-long canyon that extends from the confluence of the Green and Colorado Rivers in Canyonlands National Park to the Dirty Devil River in Glen Canyon National Recreation Area, were running high, and the lead boat flipped in Cataract Canyon, expelling its two members. One person swam to shore and the other was rescued from the cold, swift water, thanks to the safety preparation and bravery of SCREE member Jessica Flock and USGS hydrologist Tess Harden. Jessica and Tess were nominated for, and received, the Department of the Interior Valor Award for their bravery. In 1869, the Powell expedition couldn't look up the streamgage data, they didn't know when the next rapid would drench their gear, and they were unsure where to find a sandy beach to sleep for the night. There were limited places to pull out and camp, and sandbars were uncommon. As they approached the Green River's confluence with the Colorado River, the water became swift and the Colorado greeted them with the most challenging rapids and falls they had yet faced.

Then and Now

River Travel

Then

When John Wesley Powell and his crew set off with three 21-ft round-bottomed rowboats and a 16-ft lightweight rowboat, each outfitted with three watertight compartments to carry food, instruments, and supplies, they faced a wild and naturally flowing river with no dams or reservoirs. It was a journey of exploration and adventure, and safety precautions were minimal.

Powell's boats were sleek and deep-hulled Whitehall craft, designed to move quickly through harbors and lakes. One or two boat operators faced upstream while paddling, with a man in the stern steering via an oar or rudder. By the turn of the century, Colorado River navigators had abandoned this design in favor of shallower hulls and downstream-facing paddlers.

Since the Whitehalls did not navigate well through shallow, rocky rapids, the crew had to portage all four of the boats through most of the whitewater reaches. At the more severe rapids, they had to remove and carry all the supplies and equipment from the boats. The boats either were laboriously carried or were "lined" down as far as the ropes would take them, then dropped for the men below to catch them.

On June 9, 1869, the team reached "the wildest rapid yet seen," which they named Disaster Falls. Three of the four boats were pulled onto shore to be portaged but the fourth, aptly named *No Name*, was too far out in the current and had taken on water in the rapid above. The boat hit rocks, but the crew managed to swim to a small island as the boat struck more rocks and was destroyed. The team lost all the supplies on that boat but managed to recover a small amount of the equipment used for elevation measurements… and a jug of whiskey.

By Kristen Hamilton and Anna Glover

Now

The 2019 Sesquicentennial Colorado River Exploring Expedition (SCREE), which included 28 participants from the USGS, shared the same goal as John Wesley Powell of traversing nearly 1,000 miles of the Green and Colorado Rivers and collecting data, but the equipment and rivers are much changed since his era.

SCREE navigated the river on five 18-ft, self-bailing inflatable rafts, equipped with rigging to facilitate paddling, seating, and storage of supplies. Boat operators faced downstream, so they could see the rapids ahead of them, and the rafts were highly maneuverable. Their gear included lifejackets, throwbags, helmets, and satellite communication devices, and participants received many hours of safety training.

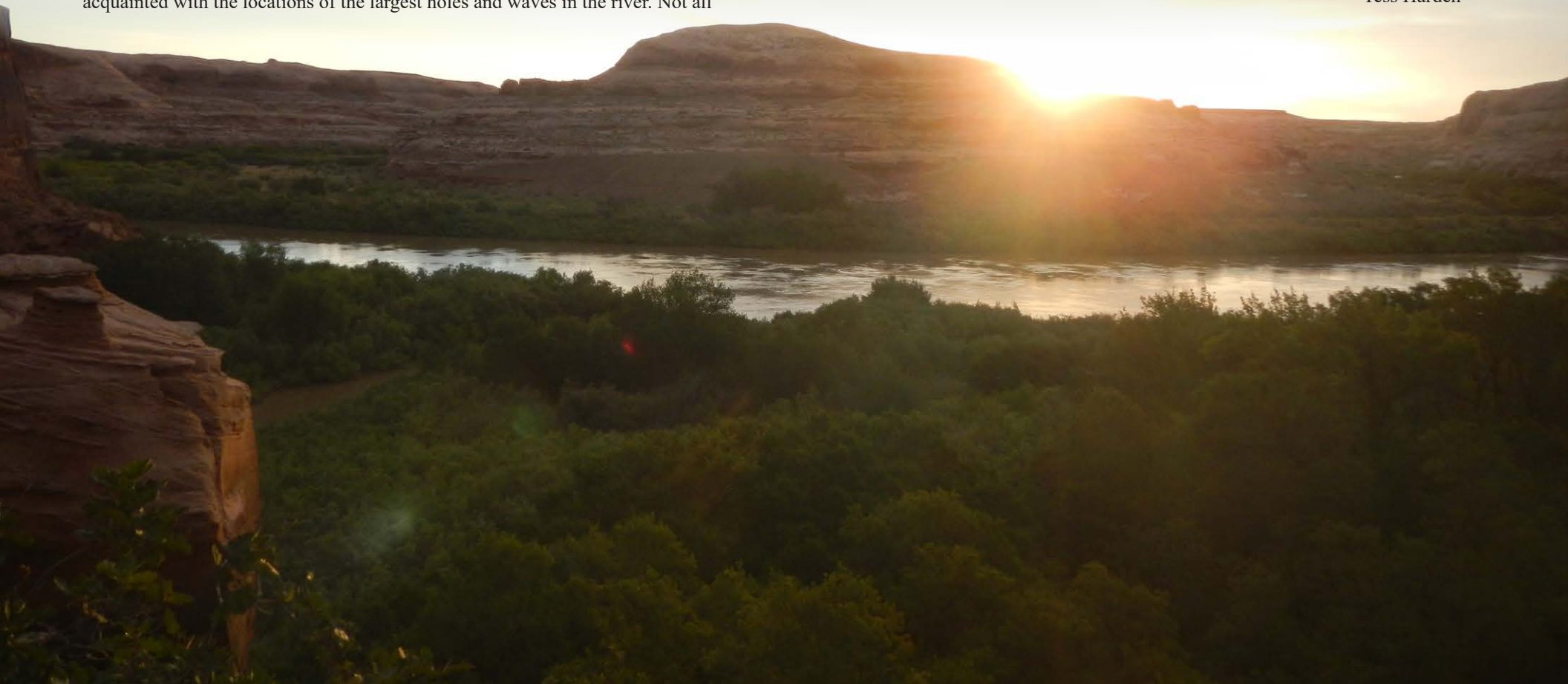
Three major dams—Flaming Gorge, Glen Canyon, and Hoover—have been built on this stretch of the Green and Colorado Rivers since Powell's expedition. SCREE took advantage of well-developed roads and take-out/put-in ramps to get around these and other barriers. The previously roiling waters of the rivers now include extensive stretches of slow-moving and even flat water, though there are still class IV and V rapids on both rivers that challenged the crew.

In early June, it was SCREE's turn to face Disaster Falls, the feature that had caused so many problems for their predecessors, as well as Hell's Half Mile, which the 1869 crew had to line, or portage. Fortunately, modern rafts are far more forgiving than wooden boats and easy to move laterally across the river, and this year's crew was extremely experienced in comparison to Powell's. Nonetheless, it was an exciting stretch, requiring high-siding (moving bodies to the high side of the boat to redistribute weight) and paddle work to keep the rafts off the rocks. One of the rafts got hung up on a rock in the middle of the falls for several minutes before the boatman could maneuver it off the obstacle. All the 2019 participants and boats came through Disaster Falls unscathed.

Segment F—Personal Vignettes

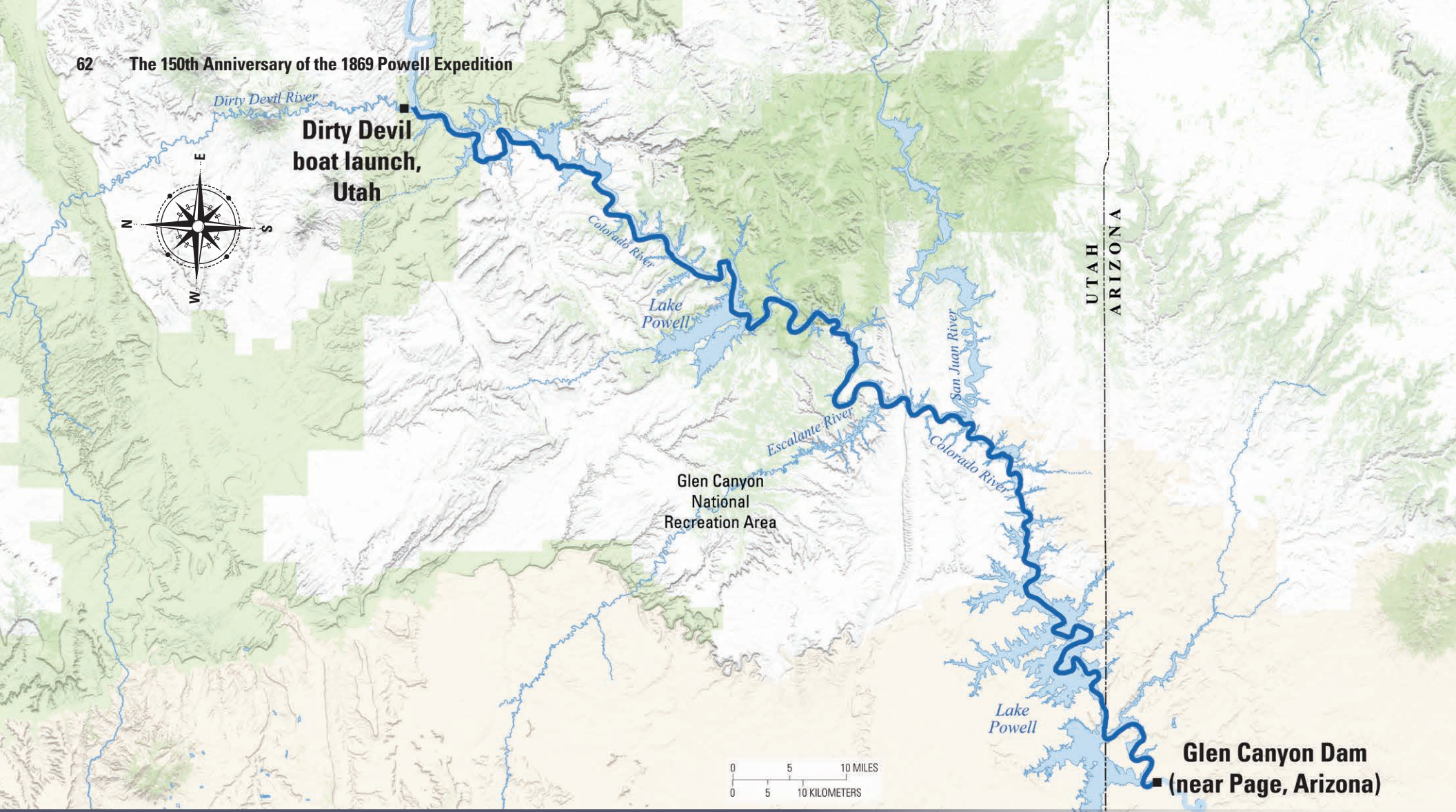
For nearly two wonderful weeks in June and July 2019, I had the opportunity to combine my love of science, rivers, the outdoors, and adventure and join an engaging group of scientists, artists, lawyers, authors, filmmakers, and environmentalists. The small core group of "through floaters" welcomed us "segment floaters" with open minds and easy dialogue. The first several days on the calm waters of the Green River passed with beautiful bedrock canyons, colorful sunsets, scientific inquiry (heavy on the questions, light on the answers), camp chores, sample collection, and mosquito swatting. More than halfway through the trip segment the Green River joined the Colorado River and we were immediately greeted with a sign reading "DANGER – Cataract Canyon, Hazardous Rapids Two Miles." Anxiety increased, life vests were secured, helmets were donned, and many river miles passed in a blur of adrenaline, whitewater, broken oars, shouted commands, cheers, and choice words. Many of us have no idea what the canyon walls looked like, but we are well acquainted with the locations of the largest holes and waves in the river. Not all of the rafts of our segment of the expedition had the runs they had planned—one raft flipped in one of the first rapids, so those participants ran the rest of the rapids without a raft—but what sticks out in my mind (aside from some giant waves!) was how well everyone performed under pressure. Sure, it felt a little chaotic at times, but every single member of the expedition kept a positive attitude and did exactly what they were supposed to do at exactly the right time. The outcome was a successful trip though Cataract Canyon at high water and, for many of us, the best day ever! I'd like to think that is how John Wesley Powell and his crew were ultimately successful 150 years ago. Things did not always go as planned. They rarely do. Powell's crew lost clothing, food, camping supplies, scientific instruments, and even boats (we only lost five of twelve oars and some snacks), but still they persevered and those who stayed on the river ultimately reached their goal.

~Tess Harden



As a geologist and someone who loves the outdoors, I was thrilled when I found out I had been selected to participate in the segment of the Powell150 expedition from Green River, Utah, to Lake Powell. I saw the amazing vistas of Labyrinth and Stillwater Canyons, felt the energy of floating through the confluence where the Green and Colorado Rivers join forces, and experienced the thrill of running the hydrologic rage of Cataract Canyon. I felt I had won the lottery! In retrospect, those experiences certainly lived up to my expectations. However, they paled in comparison to gaining 12 new friends with whom I spent an isolated eleven days and 166 river miles. It is the people I was with who have seared a more vivid memory in my brain than those breathtaking landscapes and wild experiences. I never would have imagined this to be so. We were a diverse lot from all types of backgrounds. Among us were a lawyer, a riverkeeper, filmmakers, a small-business owner, a writer, artists, a paleohydrologist, a wildlife biologist, and a paleoecologist. Despite our differences in age (from 20s to 70s), professions, and backgrounds, we hold a common passion for the river. Over each mile, we shared memories, good food, thought-provoking conversations, dreams, sunscreen, camp chores, family photos, body odor, laughter, swarms of mosquitoes, the hot sun, the cold river, and even the groover. This bond will forever fill our minds with fond memories and shape our individual futures, particularly mine.

~Richard Moscati



Segment G

July 5–July 11, 2019

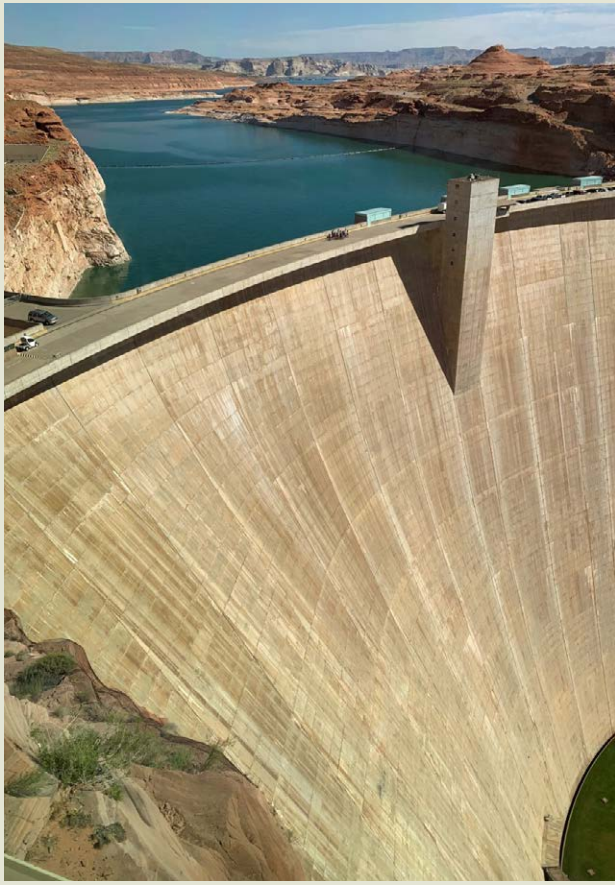
Lake Powell: Dirty Devil River, Utah, to Glen Canyon Dam (near Page, Arizona)

The wild ride through the rapids of Cataract Canyon was just the opposite of the next phase of the journey into Lake Powell, a 186-mile stretch of placid water that draws over three million visitors annually. Before 1963, this section of the Colorado River was known as Glen Canyon.

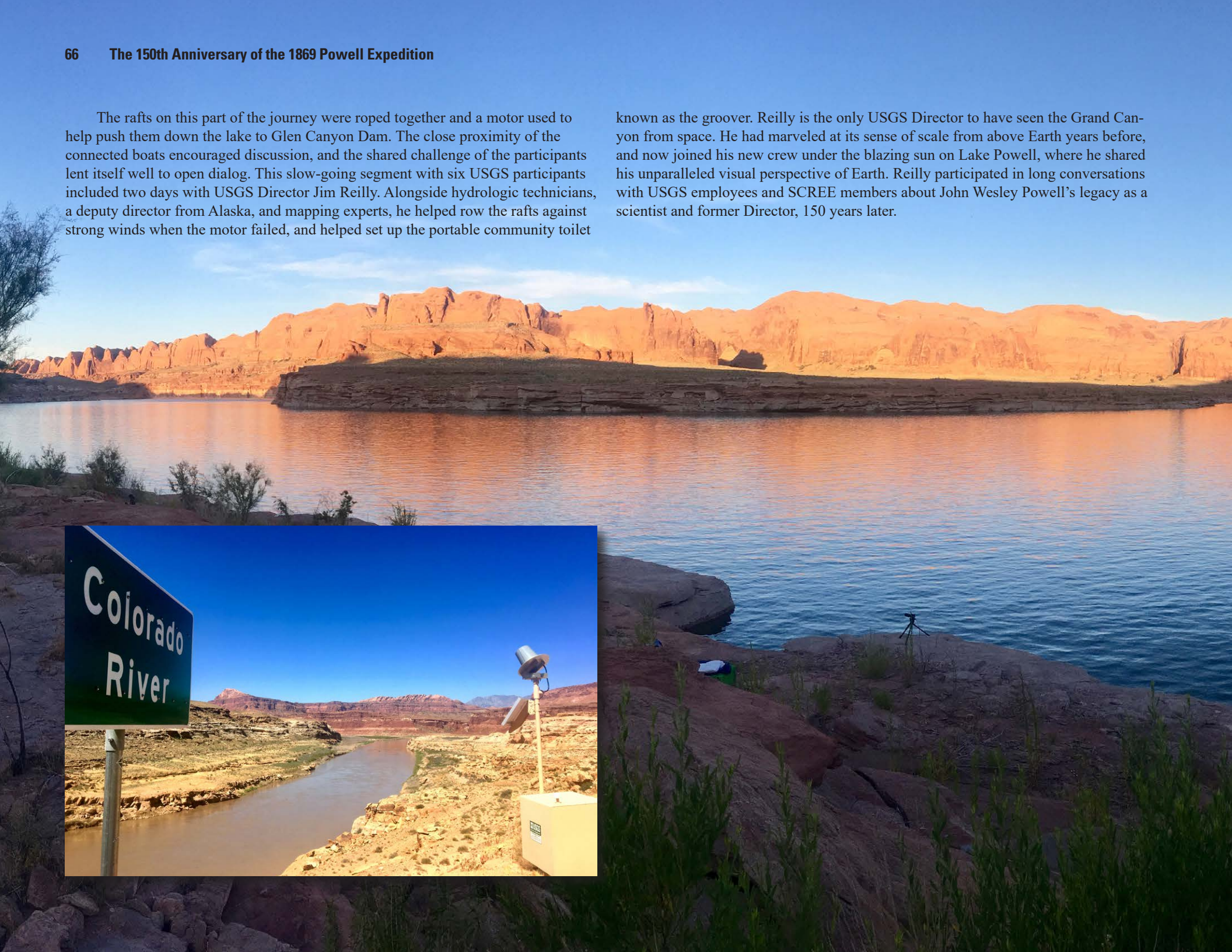
Many features seen by Powell and his crew can no longer be seen in Glen Canyon today. Completion of Glen Canyon Dam in 1963 stopped the natural flow of the Colorado River here, filled the canyon with water, and created Lake Powell, the large reservoir named after John Wesley Powell.

August 3, 1869: "On the walls, and back many miles into the country, numbers of monument-shaped buttes are observed. So we have a curious ensemble of wonderful features—curved walls, royal arches, glens, alcove gulches, mounds, and monuments. From which of these features shall we select a name? We decide to call it Glen Canyon" ~JWP

One of the most famous geologic features in this area is highly photographed Horseshoe Bend, just downstream from the dam, a place where the Colorado River forms a tight loop through steep sandstone cliffs. This impressive meander loop is one of many incised (or entrenched) meanders in the desert Southwest, created when tectonic uplift raised the land while the river continued to cut downward. These types of meanders are one way that geologists know the Colorado River is older than the uplift of the Colorado Plateau itself.



The rafts on this part of the journey were roped together and a motor used to help push them down the lake to Glen Canyon Dam. The close proximity of the connected boats encouraged discussion, and the shared challenge of the participants lent itself well to open dialog. This slow-going segment with six USGS participants included two days with USGS Director Jim Reilly. Alongside hydrologic technicians, a deputy director from Alaska, and mapping experts, he helped row the rafts against strong winds when the motor failed, and helped set up the portable community toilet known as the groover. Reilly is the only USGS Director to have seen the Grand Canyon from space. He had marveled at its sense of scale from above Earth years before, and now joined his new crew under the blazing sun on Lake Powell, where he shared his unparalleled visual perspective of Earth. Reilly participated in long conversations with USGS employees and SCREE members about John Wesley Powell's legacy as a scientist and former Director, 150 years later.



Then and Now

Mapping

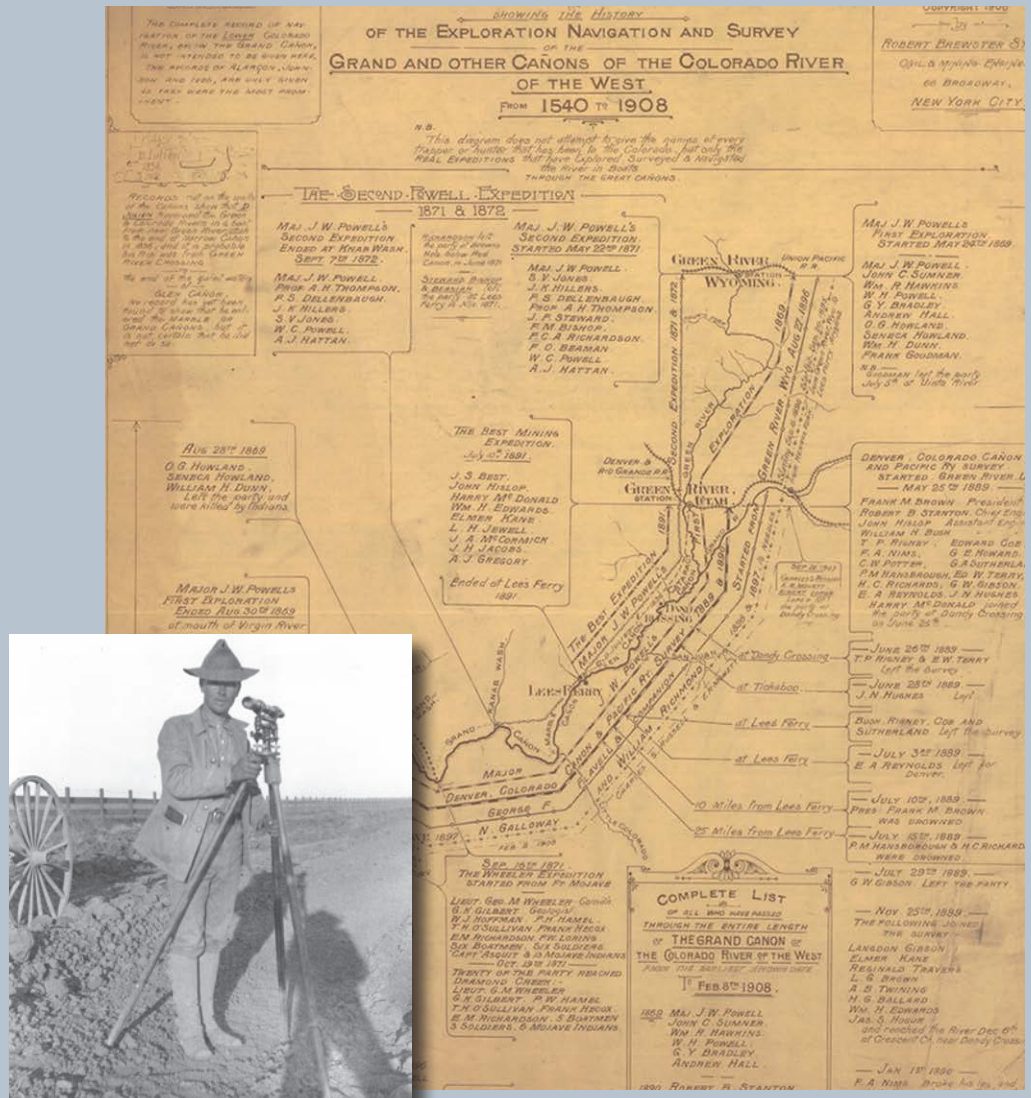
Then

Maps have long been used as a navigation tool, for delineating physical and political boundaries, for forecasting weather, and for infrastructure planning, among other purposes. Geologic maps were used along with topographic maps to determine the best locations for roads and settlements, and to develop natural resources. Topographic mapping of what was to become the United States started in the early days of exploration and colonization. By the time of Powell's 1869 expedition, the Eastern and Midwestern States had been mapped but much less was known about the geology and terrain of the western part of the country.

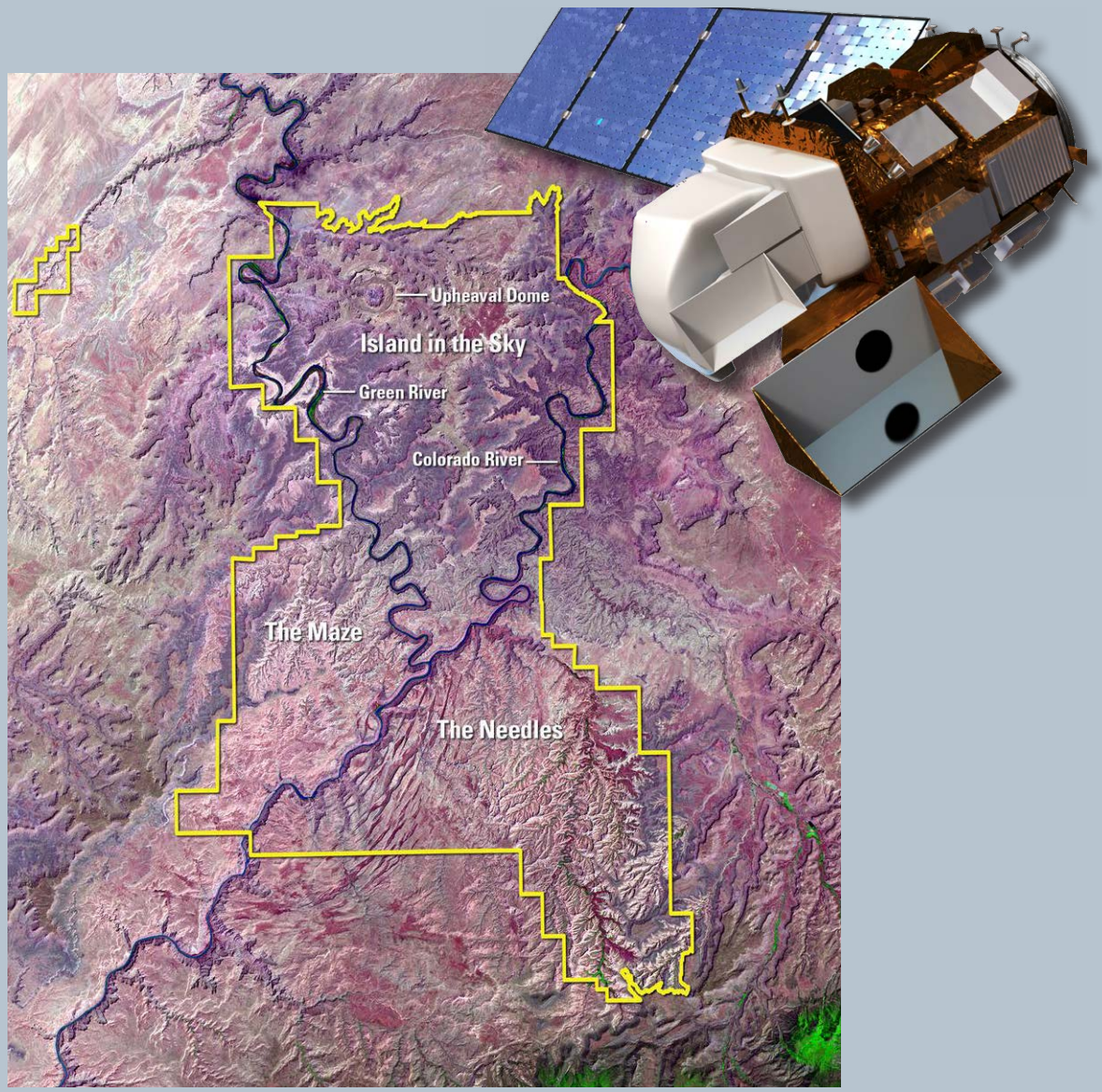
During the 1869 expedition, John Wesley Powell and fellow geologist George Bradley took copious notes on the geology, collected rock and fossil samples, and made maps as the team went down the rivers and through the canyons. Accompanied by one or two other men, they would embark on side trips at various spots along the way to take measurements needed for topographic and geologic mapping. Their primary instruments were mercury barometers, sextants, thermometers, chronometers, and compasses. The barometers (used for measuring atmospheric pressure) were used with thermometers (temperature) and chronometers (time) to calculate elevation above sea level. Sextants allowed for geometric calculations between two objects, and compasses were used to determine cardinal directions.

It was not until Powell's second expedition in 1871–72, however, that enough accurate measurements were collected to produce reconnaissance geologic maps. By 1879, when Congress created the U.S. Geological Survey, more than half a dozen State geological surveys were already actively engaged in geologic mapping, and some had been active for more than 50 years. In 1882, the USGS was authorized to "continue preparation of the geological map of the United States," which Powell took as authorization to prepare a topographic map of the United States as well.

After an initial foray into unified geologic and topographic mapping, the cost of the effort became prohibitive and interest in a single map of the Nation declined. As problems became more diverse and data needs became more specialized, mapmakers figured out that mapping was not "one size fits all" and that there were many uses for topographic maps apart from geology.



By David Nail



Now

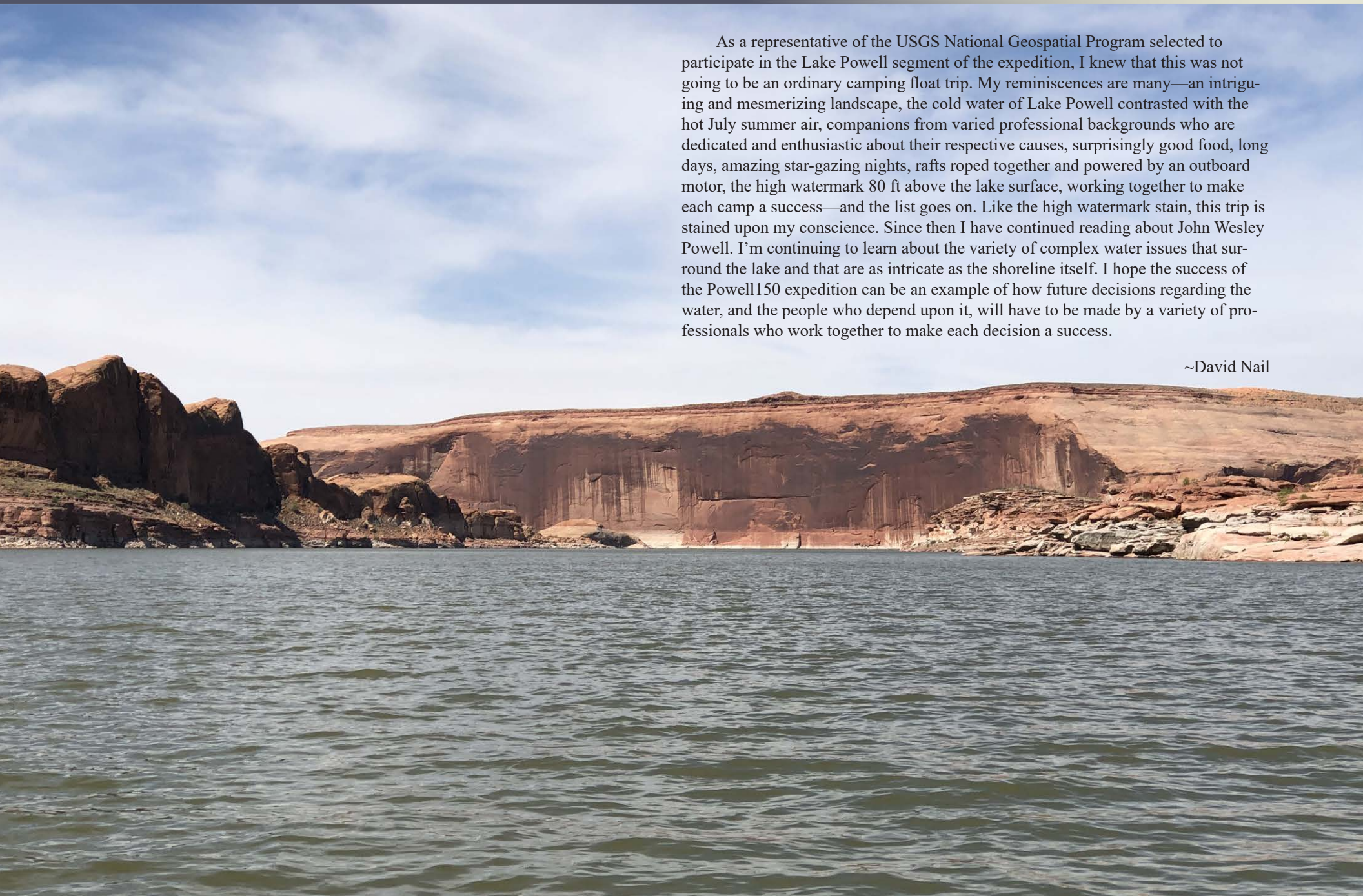
Mapping in the 20th century became focused on areas of economic interest, special concern, or critical scientific interest. For example, the North Slope of Alaska was mapped for its petroleum potential in the early 1920s and the Nevada Test Site (1951–2010) for the feasibility of long-term storage of nuclear waste.

Current mapping is focused on stewardship of mineral and water resources and the environment, safe disposal of waste, and natural hazards. Geologic mapping focuses on practical aspects of geology such as active faults that pose earthquake hazards, areas particularly subject to landslides, volcanic hazards, and the movement of water, petroleum, natural gas, and waste through geologic materials. Topographic mapping is done throughout the United States regardless of the scientific interest of the area and is increasingly automated.

The tools of geologic and topographic mapping have changed over the past century. Even though boots-on-the-ground geologists still use a compass, hammer, hand lens, and notebook, they are now aided by digital imagery and geophysical data from satellites, aircraft, GPS satellite technology, and airborne unmanned vehicles. Topographic mapping has recently undergone a revolution with the advent of airborne mapping using laser-based light detection and ranging (LIDAR), which can measure changes in topography on the scale of centimeters or smaller to produce very high-resolution topographic maps. The USGS National Map is updated on a rotational basis every three years. Citizen scientists can contribute to the map by ground-truthing the location of structures, roads, and other features in their area.

Both geologic and topographic data can be processed through computer software to produce three-dimensional models and illustrations. The geologic map of the future may be a fly-through, virtual-reality experience that will allow us to understand the architecture of the Earth as never before.

Segment G—Personal Vignettes

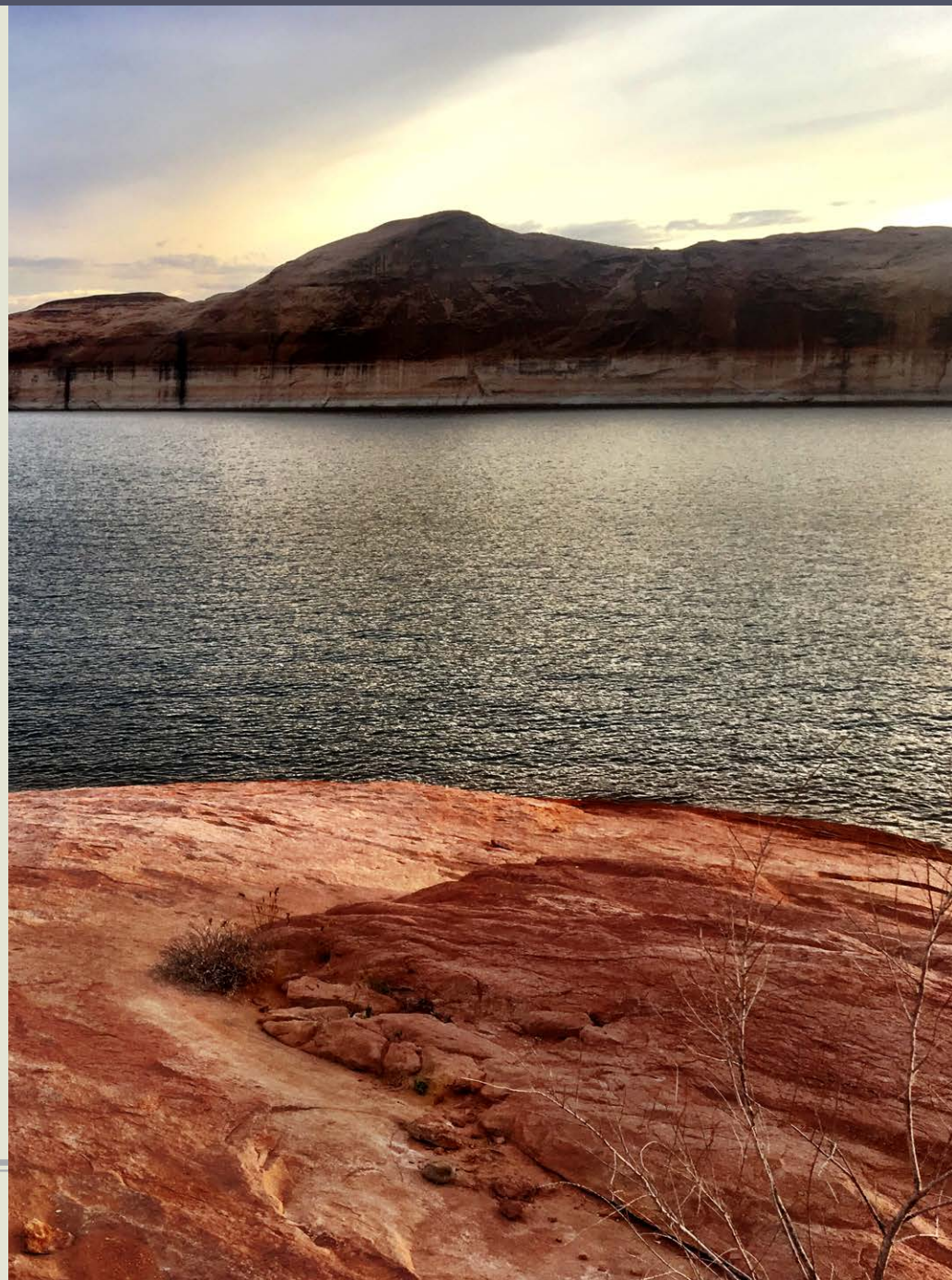


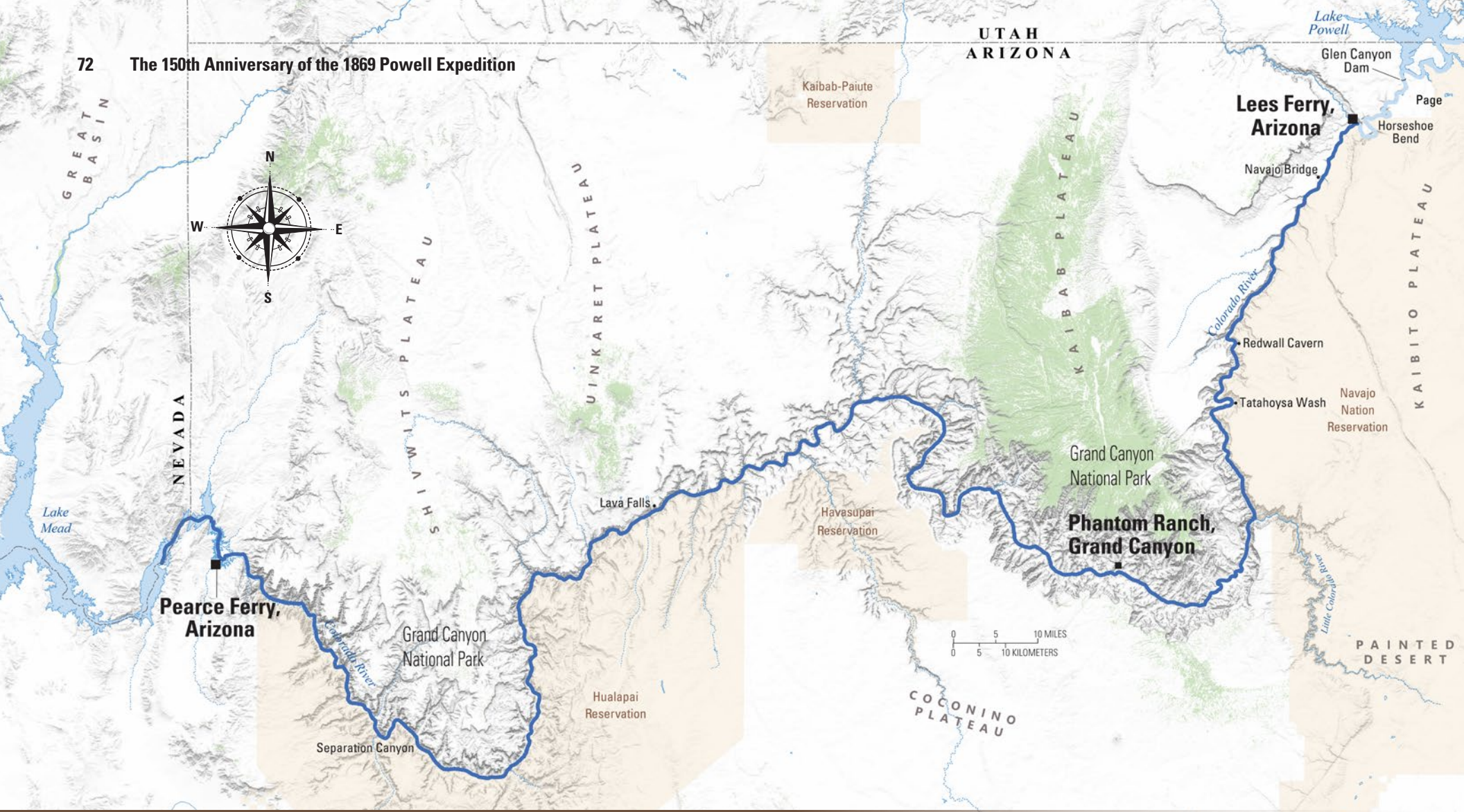
As a representative of the USGS National Geospatial Program selected to participate in the Lake Powell segment of the expedition, I knew that this was not going to be an ordinary camping float trip. My reminiscences are many—an intriguing and mesmerizing landscape, the cold water of Lake Powell contrasted with the hot July summer air, companions from varied professional backgrounds who are dedicated and enthusiastic about their respective causes, surprisingly good food, long days, amazing star-gazing nights, rafts roped together and powered by an outboard motor, the high watermark 80 ft above the lake surface, working together to make each camp a success—and the list goes on. Like the high watermark stain, this trip is stained upon my conscience. Since then I have continued reading about John Wesley Powell. I'm continuing to learn about the variety of complex water issues that surround the lake and that are as intricate as the shoreline itself. I hope the success of the Powell150 expedition can be an example of how future decisions regarding the water, and the people who depend upon it, will have to be made by a variety of professionals who work together to make each decision a success.

~David Nail

Joining SCREE from the great State of Alaska, I am naturally energized by the explicit interest within the Powell150 expedition to expand the visioning exercise in a way that promotes sustainability beyond the Colorado River Basin and to frame the commemoration in the broader context of resource management challenges that face all the Western States. I spent some time during our six-day float through the 186 miles of Lake Powell thinking about relevant connections between John Wesley Powell and Alaska. Perhaps the most substantive connection between Powell and areas beyond the Colorado River Basin lies in the legacy he created around science collaboration for public benefit. The more I learn about Powell, the fairer it strikes me to credit him with pioneering the concept of what has come to be known as "stakeholder engagement." Though the term was not coined until the 1960s, it was Powell who championed the timely emphasis that proper stewardship of resources requires scientific knowledge mixed with broad public education and adaptive institutional outcomes. Powell repeatedly argued that the new conditions of the West demanded new institutions that properly reflected public interest. He labored in many ways to help America better understand the West through a deliberate transition from fable to fact. In the process, he substantially changed American ideas of what government ought to do and how it should work to achieve its proper role. In 1890, Powell expanded his vision of stakeholder engagement in journal articles and in testimony before Congress and State legislatures. He argued that each watershed should be surveyed and opened to settlers as a single integrated unit. Topographic awareness should be followed by new arrangements of governance and responsibility that would allow each resident to obtain both knowledge and opportunity to influence the making of the rules of resource management. In this regard, my favorite Powell quotes are taken from his essay, "Institutions for the Arid Lands," published in Century Magazine, 1890, volume 40: *"Hard is the heart, dull is the mind, and weak is the will of [those] who do not strive to secure wise institutions for the developing world of America…The people are intelligent, industrious, enterprising, and wide awake to their own interest. On this wide globe and in all the centuries of human history there has never before been such a people. Their love of liberty is unbounded, their obedience to law unparalleled, and their reverence for justice profound. Every-man is a freeman king with power to rule himself, and they must be trusted with their own interests."* These are stirring words that remind us even today to trust in democracy, and to pursue within our institutions an adaptive management strategy for a truly dynamic society.

~Dee Williams





Segment H

July 13–July 31, 2019

Grand Canyon: Lees Ferry to Pearce Ferry, Arizona

By the time John Wesley Powell and his crew reached Grand Canyon, they were nearly out of rations and morale was low.

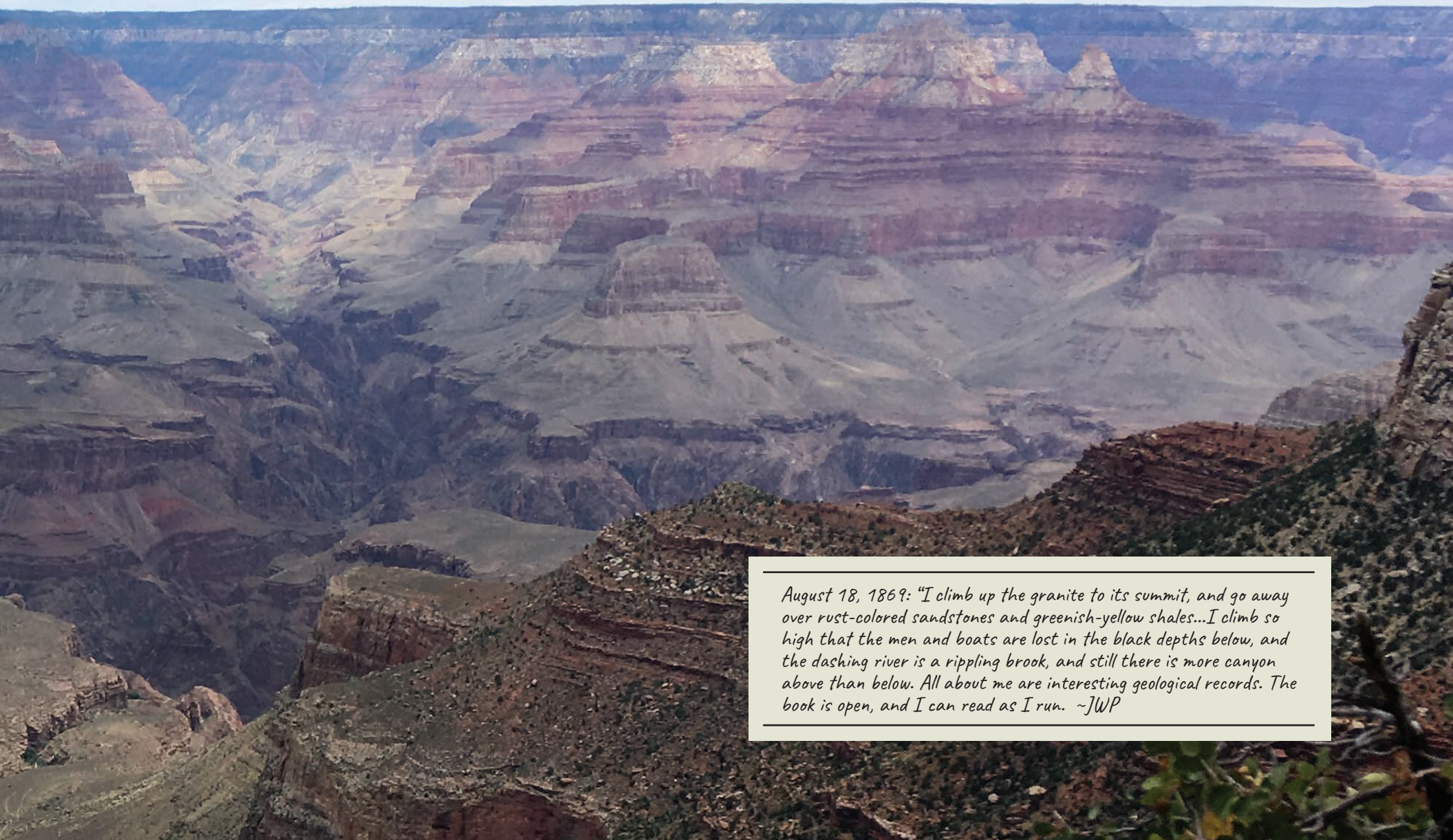
August 13, 1869: "We are now ready to start on our way down the Great Unknown. Our boats, tied to a common stake, chafe each other as they are tossed by the fretful river. They ride high and buoyant, for their loads are lighter than we could desire. We have but a month's rations remaining. The flour has been resifted through the mosquito-net sieve; the soiled bacon has been dried and the worst of it boiled; the few pounds of dried apples have been spread in the sun and reshrunken to their normal bulk. The sugar has all melted and gone on its way down the river. But we have a large sack of coffee. The lightening of the boats has this advantage; they will ride the waves better and we shall have but little to carry when we make a portage. We are three-quarters of a mile in the depths of the earth, and the great river shrinks into insignificance as it dashes its angry waves against the walls and cliffs that rise to the world above...We have an unknown distance yet to run, and unknown river to explore. What falls there are, we know not; what rocks beset the channel, we know not; what walls rise over the river, we know not. Ah, well! We may conjecture many things." ~JWP

The Grand Canyon of the Colorado River, a UNESCO World Heritage Site, is enjoyed by millions of visitors from around the world each year, and is revered by geologists as one of the best places to learn about stratigraphy, see all three major rock types in one place, and walk from the rim to the river while traveling back through time. At the bottom of the canyon, nearly two-billion-year-old basement rocks, the roots of ancient mountains, are exposed. Above the basement rocks, tilted, mostly sedimentary Precambrian rocks record over 100 million years of Earth history before complex, shelled life arose. Above the tilted Grand Canyon Supergroup lie the vast, horizontal layers of sedimentary rocks spanning nearly 300 million years of time, trapping a rich fossil record in layer upon layer from oldest to youngest like a stack of progressively fresher pancakes. Incision of the modern canyon is very young relative to the very old rocks it reveals. Powell sketched its cliffs, and later referred to Grand Canyon as "the best geological section on the continent."

Powell's sketches of the stratigraphy, or rock layers, including the Great Unconformity of Grand Canyon, hold true today. He noticed the dark lava deposits that interrupted the light-colored sedimentary layers and pondered how they must have once blocked the powerful river's flow. These basaltic flows continue to be studied by USGS scientists and many other researchers, who now understand much more about the complex history of volcanism in northern Arizona (House and others, 2018, for example).

When Powell's expedition eventually emerged from Grand Canyon in present-day Lake Mead, ninety-nine days after leaving Green River, Wyoming, his crew was left with few belongings. Three men had climbed out of Grand Canyon only

two days before the end of the expedition and were never seen again. Only six men and two boats made it to the journey's end. Despite all the hardships, Powell wanted more data. He assembled a new crew and government support and repeated this journey in 1871–72, bringing the lessons learned from his first trip, along with photographers, artists, more experienced scientists, and cartographers. The USGS remains the premier mapping bureau of the Federal Government. Our maps are used by individuals, businesses, and public officials to allow planning for resource assessment, infrastructure projects, hazards prediction, or recreation, among many uses. Many budding geoscientists get their first exercise in the concepts of stratigraphy and geologic time using geologic maps of the Grand Canyon.



August 18, 1869: "I climb up the granite to its summit, and go away over rust-colored sandstones and greenish-yellow shales...I climb so high that the men and boats are lost in the black depths below, and the dashing river is a rippling brook, and still there is more canyon above than below. All about me are interesting geological records. The book is open, and I can read as I run. ~JWP

Then and Now
Geologic Time

Then

John Wesley Powell was a self-taught geologist, but he was well read and certainly knew the geologic thinking of the times. He would have been aware of the work of William Thompson, more commonly remembered as Lord Kelvin, who, in 1862, had calculated an age of the Earth based on thermodynamic modeling, with the goal of identifying how long it would take to cool a molten Earth to current temperatures. Thermodynamics was well understood, and Lord Kelvin's calculations were an early attempt to take a quantitative approach to the question, "How old is the Earth?" Lord Kelvin's cooling-magma calculations yielded an age of 20–400 million years. Geologists thought that estimate was too small, based on geologic principles, and biologists were skeptical that evolution could happen on that time scale (Darwin's "On the Origin of Species" had been published in 1859), but Lord Kelvin's calculations were the most rigorous attempted at that time. Let's take a look at those ideas before returning to the late 19th century.

People have been making careful observations of rocks and fossils for centuries. In the late 1400s, Leonardo da Vinci noticed shell fossils in the Alps and concluded that this land must once have been under the ocean. He was hardly the only early thinker to contemplate geologic change—Aristotle had formed similar conclusions centuries earlier, as had early Chinese and Persian scholars. Nicholas Steno, in 1669, gets credit for first writing down basic geological principles as laws. The law of original horizontality states that layers of sediment are deposited horizontally, and that if sedimentary layers are not horizontal they have undergone another change since they were deposited, such as faulting or folding. The law of superposition says that older rocks are on the bottom and younger rocks are on the top. The law of crosscutting relationships says that something that cuts across a boundary must be younger than that boundary. These basic principles of stratigraphy—the branch of geology concerned with the study of rock layers—allow observers to put geologic events in order to tell the story of relative time, but they don't provide an absolute age.

In 1788, James Hutton proposed what would become the foundational principle of geology—uniformitarianism. This relatively simple but powerful principle states that the processes we see happening on Earth today are the same processes that shaped Earth in the past, and that they will continue in the future. This idea has profound implications for geologic time. As Hutton saw it, if sand is deposited on a river point bar at a rate of about 2–5 cm per year, then vast sandstones must also have been deposited at that very slow rate. At the iconic unconformity at Siccar Point in Scotland, Hutton said of geologic time that it had "no vestige of a beginning. No prospect of an end."

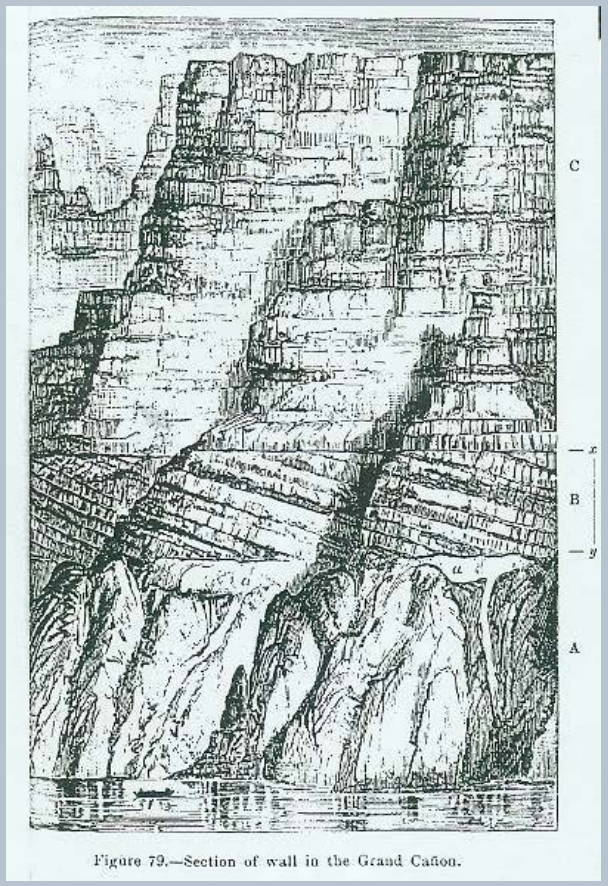


Figure 79.—Section of wall in the Grand Cañon.

The next significant leap in our understanding of geologic time came from William Smith, a road surveyor in England and an amateur paleontologist. He noticed that fossils occurred in distinctive assemblages, or groups, and furthermore that these fossil assemblages always appeared in the same order everywhere they were seen. In 1815, Smith developed the law of faunal succession, which states that species become extinct and are replaced by new species, and that characteristic fossils of a certain age are that age everywhere.

The 1820s–1850s were a remarkably fertile period for paleontology, and the work of scientists around the world developed a geologic time scale based on characteristic fossil assemblages. As much of this work was done in England, many of the names of geologic periods derive from locations in England—for example, Devonian for Devon and Cambrian for Cambria (the Latin name for Wales). The first geologic time scale was published in 1841—Powell certainly would have known of it and used it in his geologic trips to the West. He also understood the concept of unconformities (gaps in the geologic record that represent missing time); he was the first geologist to sketch the Great Unconformity in the Grand Canyon.

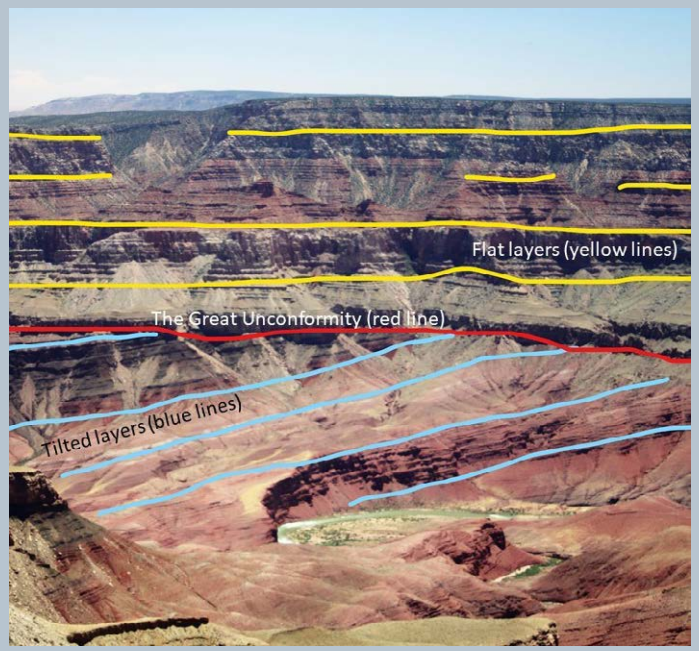
By Eleanour Snow and Annie Scott

In 1869, the same year Powell launched his expedition, English scientist Thomas Huxley challenged Lord Kelvin's calculation, asserting that his base assumptions were incorrect. It turned out that his assertion was right, but we wouldn't have the evidence for another 30 years. It was the discovery of radioactivity in 1896 that changed the heat-flow picture dramatically. French physicist Henri Becquerel made the discovery that penetrating radiation could come from uranium itself and was not caused by excitation by an external energy source, like the sun, as was previously thought. In the next few decades major advances were made in geochronology. Radioactive decay solved the heat-flow question—with a source of heat in the cooling Earth, geologic time could be much longer—and gave us a tool for measuring time.

Now

Our current understanding of geologic time is based on radiometric dating work conducted during the 20th century, as well as on data from new technologies. The English geologist Arthur Holmes, given the nickname Father of Modern Geochronology, carried out the first accurate uranium-lead radiometric dating analyses, published in 1911. The next forty years would be pivotal. Chemists and physicists discovered hundreds of radioactive isotopes and their half-lives*. Technology advanced to make measurement more precise at smaller volumes. Geologists scoured the Earth for rocks to date, studying the boundaries of the already defined geologic time scale and looking for the oldest rocks they could find. It was 1956 when Clair Cameron Patterson, an American geochemist, used lead-lead dating to determine that the Canyon Diablo meteorite from Meteor Crater, Arizona, was 4.55 billion years old. Since meteorites were formed at the same time as the Earth, but have not been constantly recycled since, this date was accepted as the age of the Earth and is very close to its accepted age today.

As with any scientific endeavor, new technology allows us to better refine what we know about the way the Earth works. The late 20th century brought technological advances in the usability and availability of highly sensitive instruments such as mass spectrometers and the Sensitive High Resolution Ion Microprobe-Reverse Geometry, or SHRIMP-RG, which analyzes the ratio of uranium and lead isotopes in zircon and in other accessory minerals to calculate numerical values (in years) of the age of rocks. The more we learn, the more refined the absolute dates of the geologic time scale have become. Every few years, the "Divisions of Geologic Time," a chart showing major geologic units and their estimated ages, is updated by the International Commission on Stratigraphy, which receives input from USGS geologists. Perhaps in the next century, with advances in technology and improvement of isotopic laboratory techniques, geochronologists will be able to even better refine our understanding of the timing of geologic events.



*A half-life is the length of time it takes for half of the number of original, or parent, isotopes to decay to a stable daughter isotope. It is a fundamental characteristic of a particular isotope. For example, uranium-235, an unstable parent isotope that decays to lead-207, has a half-life of 703.8 million years.

Let's consider a shorter time frame—say you have a delicious cake and you want to stretch out eating it over as many days as possible, so you vow to eat only half of the cake each day. On day one, you would eat half the cake and have half left (and probably go to bed with a bellyache). On day two, you would eat half of the remainder, one-quarter, and have one-quarter left. Day three, one-eighth. Day four, one-sixteenth. And so on. In this example, the half-life is one day. You can tell how old the cake is by measuring how much you have left; if you have one-eighth left, it is three half-lives old, or three days.

Now back to rocks. You might ask, "But how do you know what fraction you have left if you don't know how much you started with?" Fortunately, you are not eating the lead-207! It is still in the rock, so you can measure how much of each isotope you have. If seven-eighths of the total is lead-207 and one-eighth is uranium-235, how old is the rock? Answer: three half-lives old, or 2.11 billion years.

Segment H—Personal Vignettes

It's nighttime in the Grand Canyon. A full moon shines above, partially obscured by clouds. Below, the moon's silver light is reflected by the river, turning it into a flowing ribbon of mercury. All around me, bats tear in and out of the darkness as they hunt for their nightly feast. When I remember my time on the Powell150 expedition, first and foremost I think of this moment sitting on the canyon ledge by the Nankoweap Granary. This trip included a lot of firsts for me: first time reaching the bottom of the Grand Canyon, first time on a rafting trip in the canyon, first time on a rafting trip *period*. Throughout my segment I experienced moments of anxiety, excitement, awe, inspiration, and peace. I also developed a deeper respect for John Wesley Powell's many aptitudes as a scientist, oarsman, and leader. I collected data from the shoreline each night; he scaled rocky cliffs one-armed to get barometric readings to determine the elevation. My rowing skills amounted to playing bumper cars with the canyon walls; he navigated untamed waters in a small wooden boat. I was treated to gourmet meals and a comfortable trip; he led a team of men through the loss of supplies, near drownings, extreme weather, and other severe hazards. This expedition was also a reminder that the legacy of the USGS runs deeper than the science we produce. For example, some USGS streamgage stations, such as the one at Embudo, New Mexico, go back to 1889, during Powell's time as USGS Director. When a measurement is made at one of those sites, we are not just collecting data, but also are contributing to the history of that location. The rich past of the USGS is part of what makes it so special.

~Christina Bryant

From July 14 to 19, 2019, I was fortunate to be included on SCREE. In recent years I have been conducting research on the north and south rims of the Grand Canyon. Those areas are starkly scenic, quiet, almost completely devoid of water, and largely devoid of people. The trip down the Colorado River, in the first half of the Grand Canyon from Lees Ferry to Phantom Ranch, was also starkly scenic. I vividly remember cobalt blue skies, geologic formations that surrounded us and were ever rising as we descended the canyon, and the river that was amazingly transparent at the beginning of our journey but that soon assumed a more appropriately opaque brown, orange, or greenish tint for the rest of the trip to Phantom Ranch. In contrast to being on the rim, being on the river was not so quiet. From the quiet dipping of the paddle in a calm stretch to the roar of the rapids, sounds of water dominated our senses. Calls of the canyon wren, crows, hawks, and other birds also livened the soundtrack. There were plenty of people on the river. Each day, in leap-frog fashion we passed or were passed by others descending the river, but it never felt crowded. The SCREE leadership gently forged the participants into a convivial community where there were plenty of chores to be done in easy conversation with boatmates. From the first morning coffee to the last of the dinner dishes, to groover duty and water filtration, we all worked together to support the camp community. In addition to recollections of the monumental scenery is a lingering memory of the reflection of rock on water, a tiny view of all that is to be seen along the Colorado River in the Grand Canyon.

~Katie Walton-Day

On a 12-day section of the most adrenaline-pumping, consecutive rapids of the Colorado River in the Grand Canyon, I was surrounded by die-hard and knowledgeable river-running experts, affectionately referred to as "river rats," who swore the river was never so clear and the weather never so calm. It was the monsoon season, after all, but the days were hot and dry. A lover of warm, clear, salty water living on Oahu, I had not been subjected to such high temperatures and dry heat in a long time. The soles of my shoes melted during my hike down Bright Angel Trail to meet the group at Phantom Ranch at the bottom of the Grand Canyon. I welcomed the cold temperature of the Colorado River and was glad it wasn't a raging torrent of chocolate brown waves ready to devour me. There is so much that moved me on this trip and too many memories to write in a short vignette. I have spent about 15 years of my life guiding or participating in two- to eight-week-long global expeditions involving a mix of activities from rafting to mountaineering. No matter the challenge or the accomplishment, it is the people who make the trip, or break it. Hands down, this group of eclectic characters, from rising filmmakers to accomplished academics and artists, from young to old, from serious to wild, was one of the best groups I've had the privilege to join. Jessica Flock, the most amazing leader, chef, and oarswoman, turned my initial anxiety of intense rapids into a grand appreciation of the thrill of navigating, running, and getting swamped by a rapid. The only women in my segment of the expedition—Jessica, Amorina Lee-Martinez, and myself—kept company as raft buddies and shared many stories and laughs along the way. Jessica was raised to run rivers and has the gift of safely guiding others. Her experience and stories were heartfelt, strong, hilarious, and awe inspiring. Amorina, a PhD student, was wise beyond her years in her knowledge of the complex intersection of water policy, environmental issues, and Tribal rights surrounding rivers in the West. I enjoyed every minute of our float together from Phantom Ranch to Pearce Ferry.

Spirits were alive and high the entire trip. The film crew brought laugher and an appreciation for getting the "perfect shot" and storytelling. I deeply admired the strong relationship and incredible experiences shared by Dan McCool and his son, Weston. The academics and artists brought perspective and history, connecting us to a sense of place. The river rats brought heartiness, strength, humor, and the ability to have and share a good time. I hope I contributed equally as a scientist

and environmentalist, and I love the combination of science and adventure. I also hope that all the sediment samples I packed and bugs I stayed up late to count will make it into a USGS science story. There were so many good times, side hikes, a lazy layover day at Parashant—where the sand temperature measured 140 degrees Fahrenheit but the river a cool 60 degrees—and so very many amazing rapids. I think my favorite was Hermit Rapid, where our boat was swallowed by a wave and spit through one of the biggest whitewater sections in North America.

On a hike down from the winding, water-carved canyons of Deer Creek Trail on Day 7, it finally began to rain. It was the day before Class V Lava Falls, and all of us were anxious and excited. The rain tapered a bit as we stopped and swam in the turquoise waters of Havasu Creek and saw the elusive humpback chub fish, but then the rain picked up. On Lava Falls eve, we experienced an intense thunderstorm as we camped along the river at Fern Glen. Waterfalls began pouring over canyon walls, lightning shocked the dark night to life and lit up our tents, and I listened as the river became louder and stronger…more like thick brown chocolate. As the sun rose the next morning and lit up one side of the canyon walls, everyone cheered. The river was no longer uncharacteristic for this time of year. It was churning, wild, frothy, brown, and thick, on what seemed like a mission to race to the end. Everyone said it was good luck and a great premonition for our turn down Lava Falls. Jessica, Amorina, and I floated the river, paid our respects to Vulcan's Anvil, scouted the rapids with the team, and, full of hope, fear, and suspense…crushed it! We watched our friends and colleagues navigate tight turns, colossal waves, and bow-dives into deep holes, and all came out alive and celebratory on the other side.

I will always remember the intensity of the storm on Lava Falls eve, the celebration at the bottom of Lava Falls, the relief exuded by our fearless leader, Tom, and thinking that thick, chocolate brown waters are the way rivers in the West should run. Post-Lava Falls was relaxing and bonding as we floated peacefully, enjoyed a few final fun rapids, and watched the rock walls lower and the river flatten as we exited the Grand Canyon. What an incredible, lucky, once-in-a-lifetime experience to honor John Wesley Powell's expedition 150 years later

~Heather Kerkering

After the 2019 Expedition—and into the Future

As participants from each segment returned home, debrief calls captured their immediate perspectives and later asked them to write vignettes about their time on the river. Post-trip presentations about the expedition were also delivered by the participants. The YES team presented details from the Powell150 expedition at the 2019 Geological Society of America Annual Conference (Snow and others, 2019), at the Flagstaff Festival of Science and National Fossil Day in Arizona, and at a John Wesley Powell 150th anniversary symposium at the Smithsonian National Museum of Natural History, Department of Anthropology, in Washington, D.C., where historians, anthropologists, artists, scientists, and Powell descendants gathered for presentations and discussions about Powell's lessons and legacy. To close out the sesquicentennial, the SCREE artwork created during the expedition was displayed in the USGS National Center art corridor from March through July 2020, and a short film of the expedition was produced to summarize the USGS efforts. The authors of this report were humbled upon learning that they had been selected to receive the 2019 USGS Early Career Excellence in Leadership Award for this project, a once-in-a-career honor.

As we look forward to the next Powell anniversary, the USGS will continue to characterize the Nation's land and water, its energy, mineral, and biological resources, and natural hazards to provide sound science for decision makers. We'll need creative and adventurous people to help us accomplish our mission. To inspire those future scientists, the YES office launched the Be an Explorer campaign at the end of this expedition, linking John Wesley Powell and the Grand Canyon (1869) to Apollo astronauts (1969) to a possible future exploration of Mars (2069) with its largest canyon, Valles Marineris, five times as long and four times as deep as the Grand Canyon. Perhaps Powell's bicentennial celebration will be out of this world.

U.S. Department of the Interior
U.S. Geological Survey

©Original art by Tyler Nordgren, used with permission. https://www.tylernordgren.com/

USGS Youth and Education in Science
Be an Explorer Campaign
www.usgs.gov/education
www.usgs.gov/BeAnExplorer

@usgs_yes on Instagram

USGS
science for a changing world

1869: John Wesley Powell, with a crew of nine men, descended the Green and Colorado Rivers, including the unmapped Grand Canyon. He would later become Director of the USGS.

1969: U.S. astronauts were the first explorers to land and walk on the surface of the moon. USGS scientists trained NASA astronauts of Apollo 11 to safely walk on the lunar surface.

2069: As scientists continue to collaborate on the exploration of space, will you help the USGS and NASA discover the mysteries hidden in Valles Marineris, the Grand Canyon of Mars?

"...I lie awake with thoughts of the morrow and the canyons to come..."

~John Wesley Powell, 1869

References Cited

Aragon-Long, S.C., Burkett, V.R., Weyers, H.S., Haig, S.M., Davenport, M.S., and Warner, K.L., 2018, A snapshot of women of the U.S. Geological Survey in STEM and related careers: U.S. Geological Survey Circular 1443, 100 p. [Also available at https://doi.org/10.3133/cir1443.]

Fowler, D.D., ed., 2011, Cleaving an unknown world: The Powell expeditions and the scientific exploration of the Colorado Plateau: Salt Lake City, University of Utah Press, 280 p.

Fowler, D.D., Euler, R.C., and Fowler, C.S., 1969, John Wesley Powell and the anthropology of the Canyon Country: U.S. Geological Survey Professional Paper 670, 30 p., accessed May 29, 2020, at https://doi.org/10.3133/pp670.

Hadley, D.R., Grams, P.E., Kaplinski, M.A., Hazel, J.E., Jr., and Parnell, R.A., 2018, Geomorphology and vegetation change at Colorado River campsites, Marble and Grand Canyons, Arizona: U.S. Geological Survey Scientific Investigations Report 2017–5096, 64 p., accessed August 2020 at https://doi.org/10.3133/sir20175096.

Hansen, W.R., 1969, The geologic story of the Uinta Mountains: U.S. Geological Survey Bulletin 1291, 144 p., accessed May 29, 2020, at https://doi.org/10.3133/b1291.

House, P.K., John, B.E., Malmon, D.V., Block, D., Beard, L.S., Felger, T.J., Crow, R.S., Schwing, J.E., and Cassidy, C.E., 2018, Geologic map of the Castle Rock 7.5' quadrangle, Arizona and California: U.S. Geological Survey Scientific Investigations Map 3411, scale 1:24,000, 15-p. pamphlet, accessed August 2020 at https://doi.org/10.3133/sim3411.

Kennedy, T.A., Muehlbauer, J.D., Yackulic, C.B., Lytle, D.A., Miller, S.W., Dibble, K.L., Kortenhoeven, E.W., Metcalfe, A.N., and Baxter, C.V., 2016, Flow management for hydropower extirpates aquatic insects, undermining river food webs: BioScience, v. 66, no. 7, p. 561–575, accessed November 2018 at https://doi.org/10.1093/biosci/biw059.

Powell, J.W., 1875, Exploration of the Colorado River of the West and its tributaries, explored in 1869, 1870, 1871, and 1872, under the direction of the Secretary of the Smithsonian Institution: U.S. Government Printing Office, 291 p., accessed September 2018 at https://doi.org/10.3133/70039238.

Rabbitt, M.C., 1974, John Wesley Powell's exploration of the Colorado River: U.S. Geological Survey unnumbered series report, 28 p., accessed September 2018 at https://doi.org/10.3133/70007448.

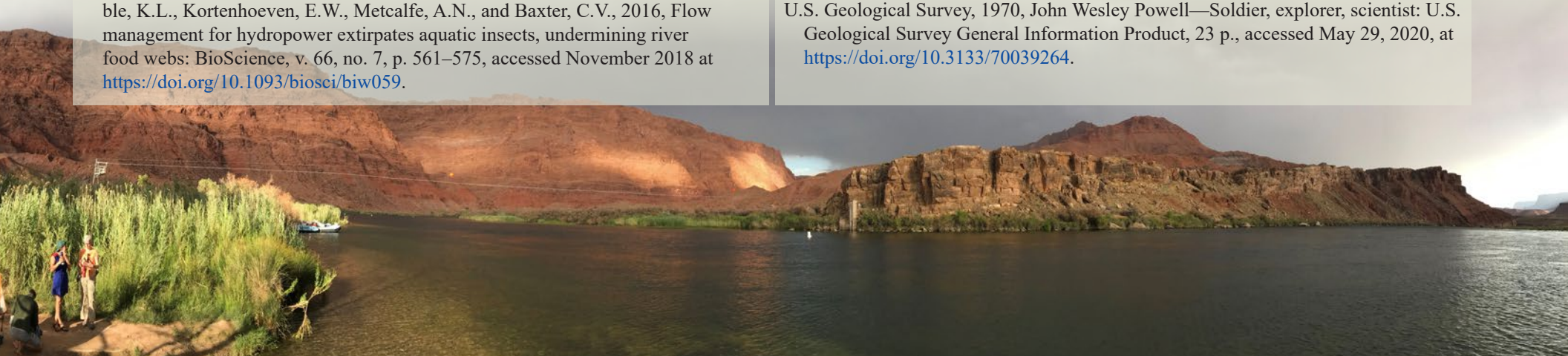
Rabbitt, M.C., McKee, E.D., Hunt, C.B., and Leopold, L.B., 1969, The Colorado River region and John Wesley Powell: U.S. Geological Survey Professional Paper 669, 145 p., accessed September 2018 at https://doi.org/10.3133/pp669.

Schaber, G.G., 2005, The U.S. Geological Survey, Branch of Astrogeology—A chronology of activities from conception through the end of Project Apollo (1960–1973): U.S. Geological Survey Open-File Report 2005–1190, 347 p. text (5.6 MB) and separate folder of figures, tables, and appendixes (814 p., 853 MB), accessed September 2020 at https://doi.org/10.3133/ofr20051190.

Snow, E., Scott, A.M., and Hamilton, K., 2019, The Powell150 Project: Celebrating the legacy of John Wesley Powell at USGS: Geological Society of America Abstracts with Programs, v. 51, no. 5, accessed September 2020 at https://gsa.confex.com/gsa/2019AM/webprogram/Paper333745.html.

Stephens, H.G., and Shoemaker, E.M.,1987, In the footsteps of John Wesley Powell—An album of comparative photographs of the Green and Colorado Rivers, 1871–72 and 1968: Boulder, Colo., Johnson Books; Denver, Powell Society, 286 p.

U.S. Geological Survey, 1970, John Wesley Powell—Soldier, explorer, scientist: U.S. Geological Survey General Information Product, 23 p., accessed May 29, 2020, at https://doi.org/10.3133/70039264.



Additional Background Information

Billingsley, G.H., 2000, Geologic map of the Grand Canyon 30′ x 60′ quadrangle, Coconino and Mohave Counties, northwestern Arizona: U.S. Geological Survey Geologic Investigations Series Map I–2688, scale 1:100,000, ver. 1.0. [Also available at https://pubs.usgs.gov/imap/i-2688/.]

Bruce, B.W., Prairie, J.R., Maupin, M.A., Dodds, J.R., Eckhardt, D.W., Ivahnenko, T.I., Matuska, P.J., Evenson, E.J., and Harrison, A.D., 2018, Comparison of U.S. Geological Survey and Bureau of Reclamation water-use reporting in the Colorado River Basin (ver. 1.1, September 2019): U.S. Geological Survey Scientific Investigations Report 2018–5021, 41 p., https://doi.org/10.3133/sir20185021.

Reeside, J.B., 1925, Notes on the geology of Green River Valley between Green River, Wyoming, and Green River, Utah: U.S. Geological Survey Professional Paper 132–C, 16 p. [Also available at https://doi.org/10.3133/pp132C.]

Sankey, T.T., Sankey, J.B., Horne, R., and Bedford, A., 2016, Remote sensing of tamarisk biomass, insect herbivory, and defoliation—Novel methods in the Grand Canyon region, Arizona: Photogrammetric Engineering & Remote Sensing, v. 82, no. 8, p. 645–652.

U.S. Geological Survey, 2014, USGS gave NASA the right stuff [Alex Demas, videographer]: U.S. Geological Survey video, 00:03:30, https://www.usgs.gov/media/videos/usgs-gave-nasa-right-stuff.

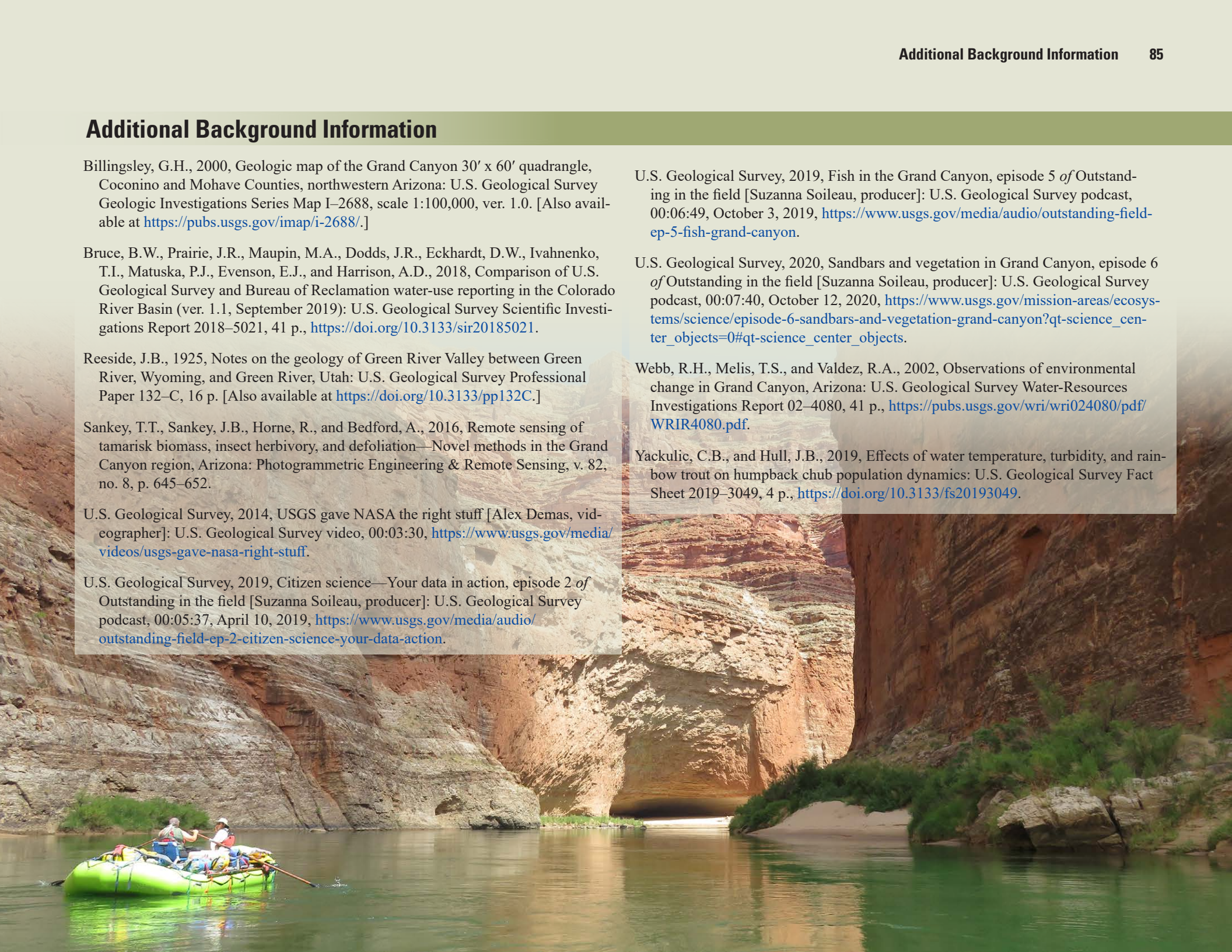
U.S. Geological Survey, 2019, Citizen science—Your data in action, episode 2 *of* Outstanding in the field [Suzanna Soileau, producer]: U.S. Geological Survey podcast, 00:05:37, April 10, 2019, https://www.usgs.gov/media/audio/outstanding-field-ep-2-citizen-science-your-data-action.

U.S. Geological Survey, 2019, Fish in the Grand Canyon, episode 5 *of* Outstanding in the field [Suzanna Soileau, producer]: U.S. Geological Survey podcast, 00:06:49, October 3, 2019, https://www.usgs.gov/media/audio/outstanding-field-ep-5-fish-grand-canyon.

U.S. Geological Survey, 2020, Sandbars and vegetation in Grand Canyon, episode 6 *of* Outstanding in the field [Suzanna Soileau, producer]: U.S. Geological Survey podcast, 00:07:40, October 12, 2020, https://www.usgs.gov/mission-areas/ecosystems/science/episode-6-sandbars-and-vegetation-grand-canyon?qt-science_center_objects=0#qt-science_center_objects.

Webb, R.H., Melis, T.S., and Valdez, R.A., 2002, Observations of environmental change in Grand Canyon, Arizona: U.S. Geological Survey Water-Resources Investigations Report 02–4080, 41 p., https://pubs.usgs.gov/wri/wri024080/pdf/WRIR4080.pdf.

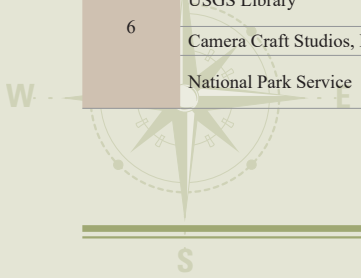
Yackulic, C.B., and Hull, J.B., 2019, Effects of water temperature, turbidity, and rainbow trout on humpback chub population dynamics: U.S. Geological Survey Fact Sheet 2019–3049, 4 p., https://doi.org/10.3133/fs20193049.



Photograph Credits

All photographs by the U.S. Geological Survey unless otherwise stated. Abbreviations: *, public domain; NP, National Park; NRA, National Recreation Area.

Page No.	Credit	Description/caption
	Cover	
Front cover	Annie Scott	Powell Point, Grand Canyon National Park, AZ, 2019
	Annie Scott	150th Anniversary of the 1869 Powell Expedition Plaque at Grand Canyon National Park, AZ, 2019
Back cover	Annie Scott	Powell Memorial at Powell Point, Grand Canyon National Park, AZ, south rim, 2019
	Front matter	
i	Janis LeMaster	Flaming Gorge Reservoir, WY, 2019
iii	Annie Scott	USGS Director Reilly at Powell Point, Grand Canyon National Park, AZ, 2019
iv-v	Annie Scott	Boats at the launch site, Green River, WY, 2019
vi	J.K. Hillers*	Bowknot Bend in the Green River, UT, north of Canyonlands National Park, 1871
	Richard Moscati	Bowknot Bend in the Green River, UT, north of Canyonlands National Park, 2019
vii	Heather Kerkering	Grand Canyon, AZ, west of Phantom Ranch, 2019
viii	Robert Barth	Night sky, Flaming Gorge NRA, WY, 2019
	Body	
1	E.O. Beaman*	Launch of the second Powell expedition from Green River Station, WY, May 4, 1871
	USGS	Expedition map from "John Wesley Powell—Soldier, explorer, scientist" (U.S. Geological Survey, 1970).
2	Division of Culture and the Arts, National Museum of American History, Smithsonian Institution; and Smithsonian Libraries	Photographs of Powell's 1875 book and the original woodblocks (Left: Green River, WY; Right: Grand Canyon, AZ), 2019
4	USGS Collection	Portrait of John Wesley Powell, age 35
	E.O. Beaman*	Empty boats near present-day Green River, WY, 1871
5	J.K. Hillers*	Grand Canyon, AZ, 1872
	Annie Scott	John Wesley Powell statue outside the Sweetwater County Historical Museum, Green River, WY, 2019
Various	Janis LeMaster	Then and Now Banner: Flaming Gorge Reservoir, WY, 2019
6	National Park Service	Emma Dean Powell, wife of John Wesley Powell, Chicago, IL, 1869
	USGS Library	Ellen Powell Thompson, photograph extracted from the last Powell family group photo taken in Topeka, KS, on November 10, 1900
	Camera Craft Studios, MN*	Dr. Florence Bascom (1862–1945), 1900
	National Park Service	Dr. Elzada Clover at Bright Angel Beach in Grand Canyon, July 1938. First Nevills Colorado River Expedition
7	Russell Sherman	USGS scientist Janis LeMaster holding the USGS flag, 2019
	Kristen Hamilton	Collage of USGS women of the Powell150 expedition
9	Annie Scott	***A.*** Paper Powell downloadable pdf image, 2019
	Annie Scott	***B.*** Director Reilly, Grand Canyon National Park, AZ, 2019
	Wayne Belcher	***C.*** Paper Powell at Lake Mead, AZ, 2019
	David Nail	***D.*** Paper Powell on Lake Powell, AZ, 2019
	Katie Walton-Day	***E.*** Christina Bryant at Bright Angel Trail, Grand Canyon, AZ, 2019
	Anya Metcalfe	***F.*** Bill Burton with Paper Powell and Florence Bascom, UT, 2019
	Scott Horvath	***G.*** Screenshot of Paper Powell memoji (talking cartoon), 2019
	Kristen Hamilton	***H.*** Be an explorer graphic for social media, 2019
	Erin Heard	***I.*** Paper Powell at NSF field station in Antarctica, 2019
	Janis LeMaster	***J.*** Paper Powell in southern WY, 2019
	Shanna Ratnesar-Shumate	***K.*** Byron Shumate with Paper Powells at Stonehenge, England, 2019
	Russell Sherman	***L.*** Paper Powell along the Green River in southern WY, 2019
10	Susan L Meacham	Find-A-Feature web page, 2020
11	Annie Scott	Art corridor at USGS National Center, Reston, VA, 2019
	Annie Scott	Powell150 Display - USGS Library, 2019
	USGS EROS	Screenshot of EROS story map, 2019
12	Thomas Moran	The Chasm of the Colorado, 1873–1874
13	Heather Kerkering	Artist Patrick Kikut sketching in Grand Canyon
	Patrick Kikut	Patrick Kikut painting of the Green River, 2018
14	Robert Barth	Green River and cliffs, southern WY, 2019
17	Robert Barth	Green River in southern WY, 2019
18-19	Annie Scott	Cliffs northeast of Interstate 80 in Green River, WY, 2019
20	Robert Barth	Flaming Gorge Reservoir, Sheep River Overlook, WY, 2019
21	Robert Barth	Reflection of cliffs along the Green River, southern WY, 2019
22	Janis LeMaster	Flaming Gorge National Recreation Area, WY, 2019
23	Russell Sherman	Flaming Gorge National Recreation Area, WY, 2019
	Russell Sherman	Flaming Gorge National Recreation Area, WY, 2019
25	Jason Alexander	Green River south of Flaming Gorge Dam, northeastern UT, 2019
26	Melissa Lombard	Green River just south of Flaming Gorge Dam, UT, 2019
27		Dinosaur National Monument, UT, 2019
28	E.O. Beaman*	Expedition kitchen, near Green River, WY, 1871
29	Jaime Delano	Sandwich in hand while rafting down the Green River, UT, 2019
	Jaime Delano	Fish taco dinner along the Green River, UT, 2019
30	Anne Ballmann	Red Canyon along the Green River, northeastern UT, 2019
31	Melissa Lombard	Swallow Canyon along the Green River, northeastern UT, 2019
32	Jason Alexander	Green River through Brown's Park, northeastern UT, 2019



Page No.	Credit	Description/caption
33	Melissa Lombard	Flaming Gorge Dam, UT, 2019
35	Breton Bruce	Gates of Lodore, CO, 2019
36	Breton Bruce	Gates of Lodore, CO, 2019
	Breton Bruce	Stream near Gates of Lodore, CO, 2019
37	Breton Bruce	Steamboat Rock, CO, 2019
38	Robert Barth	Wren, southern WY, 2019
	Katie Walton-Day	Bighorn sheep, Grand Canyon, AZ, 2019
	John Parks	Tamarisk, UT, 2019
39	Janis LeMaster	Primrose, southern WY, 2019
	Robert Barth	Pelicans, southern WY, 2019
	Nicholas Hammond	Prickly pear cactus bloom, Green River, UT, 2019
	Melissa Lombard	Bald eagle, 2019
41	Jaime Delano	Green River, UT, 2019
42	Anya Metcalfe	Mayfly hatch, 2019
	Anya Metcalfe	Light trap, 2019
	Jamie Delano	Light trap on shore, 2019
		Test tube aquatic insects, 2019
	Melissa Lombard	Green River, UT, 2019
43	John Parks	Green River with Split Mountain in the distance, UT, 2019
44	William Burton	Green River near Split Mountain, UT, 2019
45	Anya Metcalfe	Graham Lederer birding, UT, 2019
	John Parks	Bill Burton examining rocks, UT, 2019
46	Nicholas Hammond	Loading boats, UT, 2019
47	John Parks	Split Mountain, UT, 2019
48	Jaime Delano	Green River, UT, 2019
	Jaime Delano	Anya Metcalfe, Split Mountain, UT, 2019
49	Mitchell Eaton	Valley panorama, UT, 2019
	Mitchell Eaton	Split Mountain and irrigated field, UT, 2019
51	Kathy Conn	Lighthouse Rock, Green River, UT, 2019
52	Katie Walton-Day	Sediment sampling, AZ, 2019
	Robert Barth	Janis LeMaster and Russell Sherman sediment sampling, WY, 2019
	Jessica Lucido Buren	Sediment sampling, Lake Powell, UT, 2019
53	Kathy Conn	Desolation Canyon, UT, 2019
55	Richard Moscati	Turks Head, Canyonlands NP, UT, 2019
56	Andrew Spanjer	Density separation equipment, 2019
	Andrew Spanjer	Beaker, 2019
	Andrew Spanjer	Microscope, 2019
	Andrew Spanjer	Microplastics under magnification, 2019
57	Tess Harden	Turks Head, Canyonlands NP, UT, 2019
58	Annie Scott	Historic boat collection, Grand Canyon NP, 2019

Page No.	Credit	Description/caption
59	Robert Barth	Rafts, southern WY, 2019
60	Tess Harden	Sunrise along the Green River, UT, 2019
61	Richard Moscati	Dellenbaugh Butte, UT, 2019
63	Genevieve Barron	Capitol Reef NP, UT, 2019
64	Annie Scott	Horseshoe Bend, AZ, 2019
	Annie Scott	Glen Canyon Dam, AZ, 2019
65	Genevieve Barron	Lake Powell reflection, UT, 2019
66	Jessica Lucido Buren	Dirty Devil confluence streamgage, UT, 2019
66–67	Jessica Lucido Buren	Sunrise at Lake Powell, UT, 2019
68	USGS Library	Colorado River expeditions map, 1908
	USGS Library	USGS topographer poses with leveling instrument, unknown date
69	USGS/NASA*	Landsat 8 image of Canyonlands NP, UT, 2016
	NASA*	Artist's rendering of Landsat 8, unknown date
70	David Nail	Lake Powell, Glen Canyon NRA, UT, 2019
71	Jessica Lucido Buren	Lake Powell, UT, 2019
73	Katie Walton-Day	Grand Canyon NP, AZ, Bright Angel view, 2019
74–75	Katie Walton-Day	
76	J.W. Powell*	Grand Canyon stratigraphy sketch, 1875
77	Annie Scott	Walhalla Plateau from the north rim of the Grand Canyon, AZ, 2019
78	Christina Bryant	Grand Canyon from Nankoweap Granary, 2019
79	Katie Walton-Day	Redwall Cavern, Grand Canyon, AZ, 2019
80	Heather Kerkering	Grand Canyon, AZ, 2019
		Sidecreek in Grand Canyon, AZ, 2019
81	Heather Kerkering	Cave in Grand Canyon National Park, AZ, 2019
	Heather Kerkering	Grand Canyon National Park, AZ, 2019
	Heather Kerkering	Deer Creek campsite, Grand Canyon National Park, AZ, 2019
82	NASA*	Valles marineris (canyon on Mars)
	Tyler Nordgren	Poster, design consultation by Annie Scott and Eleanour Snow
83	Robert Barth	Tent with headlamp and stars, WY, 2019
84	Christina Bryant	Colorado River at Lees Ferry, AZ, 2019
85	Katie Walton-Day	View of Redwall Cavern, Grand Canyon, AZ, 2019
88	Heather Kerkering	Signed expedition banner, 2019
		Graphics
Various	Pixabay.com	Compass

1875: "You cannot see the Grand Canyon in one view, as if it were a changeless spectacle from which a curtain might be lifted, but to see it you have to toil from month to month through its labyrinths."

~JWP

For additional information:
https://www.usgs.gov
https://www.usgs.gov/powell150

Prepared by the USGS Science Publishing Network
Reston and Pembroke Publishing Service Centers
Editing by James R. Estabrook
Design and layout by Susan L. Meacham
Web support by Molly L. Newbrough
Printing support by Cathy Y. Knutson

USGS

Scott and Snow—**The 150th Anniversary of the 1869 Powell Expedition**—Circular 1475, ver. 1.1

ISSN 1067-084X (print)
ISSN 2330-5703 (online)
https://doi.org/10.3133/cir1475

ISBN 978-1-4113-4396-2