National Park Service
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Natural Resource Stewardship and Science

Bluestone National Scenic River, Gauley River National Recreation Area, and New River Gorge National River

Geologic Resources Inventory Report

Natural Resource Report NPS/NRSS/GRD/NRR—2017/1532

ON THE COVER

Photograph of Endless Wall from Diamond Point. Resistant Pennsylvanian sandstones cap certain portion of New River Gorge, which reaches depths of up to 400 m (1,300 ft). This area is popular with rock climbers. Photograph by Gayle H "Scott" McColloch, Jr. (West Virginia Geological and Economic Survey) taken in October 2010.

THIS PAGE

Photographs of rafters on the Gauley River and the coal tipple at Nuttallburg in New River Gorge National River. The natural resources of the three parks have attracted people for centuries. The Nuttallburg coal tipple is a monument to the history of mining the abundant coal resources in the area. Today rafters experience the region in a much different way than miners did. National Park Service photograph by Louise McLaughlin.

Bluestone National Scenic River, Gauley River National Recreation Area, and New River Gorge National River

Geologic Resources Inventory Report

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The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

This report is available from the Geologic Resources Inventory website, and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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Executive Summary

The Geologic Resources Inventory (GRI) program provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI.

This report synthesizes discussions from a scoping meeting held in 2004 and a follow-up conference call in 2016 (see Appendix A). Chapters of this report discuss the geologic setting, distinctive geologic features and processes within Bluestone National Scenic River, Gauley River National Recreation Area, and New River Gorge National River, highlight geologic issues facing resource managers, describe the geologic history leading to the present-day landscape, and provide information about the previously completed GRI map data. Posters (in pocket) illustrate these data.

Rock-rimmed deep gorges, stunning vistas, cascading waterfalls, stirring rapids, and forested slopes—the landscapes of Bluestone National Scenic River, Gauley River National Recreation Area, and New River Gorge National River are breathtaking. The geologic story responsible for these features is no less intriguing. The cultural resources connected with the geology at the parks are vast and reflect thousands of years of human history from American Indians, to the early homesteaders, to the dramatic transformation brought on by the coal-mining industry.

The Bluestone, Gauley, and New rivers continue to carve their deep gorges through the gently undulating bedrock of the Appalachian Plateau physiographic province. Unlike the intensely folded and faulted rocks of the Valley and Ridge province to the east, the Appalachian Mountain-building orogenies of the Paleozoic did not strongly change the sedimentary layers deposited in the longstanding Appalachian Basin. Instead, those mountains supplied vast amounts of sediment that would become the Mississippian and Pennsylvanian rocks on display at the parks today. Over 40 million years of geologic history, from about 347 million to 307 million years ago, is recorded in the mixes of sandstones, siltstones, claystones, and limestones that line the gorges. Vast lagoons and swamps of the Pennsylvanian were the source of the organic material that would later be buried and squeezed into the celebrated coal resources ubiquitous in this part of West Virginia. Weathering, erosion, and slope movements continue to change the landscape. Surficial geologic units such as alluvium, colluvium, and residuum are testament to this ongoing evolution.

This GRI report was written for resource managers to support science-informed decision making. It may also be useful for interpretation. The report was prepared using available geologic information, and the NPS Geologic Resources Division conducted no new fieldwork in association with its preparation. Bedrock and surficial geologic maps were developed for each of the parks by the West Virginia Geological and Economic Survey and West Virginia University. The six maps cover all areas within park boundaries and are available in GIS (ArcMap) and Google Earth-compatible formats. Posters illustrate these data and are included with this report.

Geologic features, processes, and resource management issues identified during the GRI scoping meeting and follow-up conference call include the following:

- **Slope Movements, Hazards, and Risks**. Relief in the parks can vary greatly from vertical cliffs to relatively flat floodplains. Colluvium features prominently in the surficial map deposits for all three parks. These deposits mark areas that experienced slope movements or the downslope transfer of earth material. These areas may have the potential for future slope failures. Slope movement within the parks include falls, slides, flows, and slumps. Disturbances in vegetation and land surface can exacerbate slope issues. Major precipitation causes surge events, which increase the impacts of slope processes; increased storm events predicted by climate change models may increase the likelihood and frequency of slope movements.

- **Paleontological Resource Inventory, Monitoring, and Protection**. The shallow marine, nearshore, and fluvial paleoenvironments in the Appalachian Basin supported a rich diversity of plant and animal life. This ancient life is now preserved as fossils found in all three parks. Plant, invertebrate, and vertebrate fossils are weathering out of bedrock outcrops along the rivers. Park fossils may also be found in cultural contexts. Fossils may be impacted by slope movements, erosion, theft or vandalism. All paleontological resources are nonrenewable and subject to science-informed inventory, monitoring, protection, and interpretation. Field-based, park-specific paleontological resource surveys would support that goal.
- **Coal Mining, Abandoned Mineral Lands, and Disturbed Lands**. Prior to establishment of the parks, much of the landscape was altered by logging, railroads, and coal mining development. Coal-mine sites are the primary abandoned mineral land within the parks. Some of these are also significant cultural resources. Issues associated with mine sites include subsidence, mine portal breakdown, deteriorating infrastructure, acid mine drainage, unvegetated mine tailing piles, and exacerbating slope movement hazards and risk. A comprehensive, accurate inventory is needed to manage these features. Land acquisition for the formation of the parks did not include mineral rights and much of the land within the authorized boundaries remains in private ownership. According to park managers, all valid existing rights within New River Gorge National River and Gauley River National Recreation Area were exhausted many years ago. The Surface Mining Control and Reclamation Act of 1977, 30 USC §§ 1234-1328 (SMCRA) prohibits surface coal mining within the boundaries of any unit of the National Park System and also outlines steps the parks can take if mining is proposed near the parks.
- **Oil and Gas Operations**. Oil and gas development and production are among the top natural resource management concerns at Gauley River National Recreation Area and New River Gorge National River. Land acquisition for the formation of the parks did not include mineral rights and much of the land within the authorized boundaries remains in private ownership. There are currently 28 oil and gas operations in Gauley River National Recreation Area and 1 within New River Gorge National River. All non-federal oil and gas operations within the boundaries of New River Gorge National River and Gauley River National Recreation Area are now subject to the updated (December 2016) 36 CFR Part 9, Subpart B ("9B Regulations"). Oil- and gas-bearing units (e.g., Devonian Marcellus Shale) are located below the units included on the geologic maps. Oil and gas activities have the potential to increase surface runoff; increase soil erosion, rutting and compaction; affect the permeability of soils (and other soil characteristics); and could negatively affect the growth and regeneration of vegetation. Activities may include vehicle use; drilling and detonation; and construction, maintenance, and use of roads, well pads, production facilities, flowlines and pipelines. Oil and gas issues include impacts from current production, abandoned sites, contamination risks, and future development, directional drilling, and hydraulic fracturing.
- **Fluvial Features, Stream Channel Morphology, and Flooding**. Flowing water is a unifying resource at all three parks. Major river systems are the Bluestone, Gauley, Meadow, and New rivers and their tributaries. Fluvial features, past and present, include meandering channels, terraces, gravel bars, alluvial fans, rapids, and narrow gorges. Where these features occur controls the vegetation supported by them. Similarly, the rise and fall of river stages and flows, as well as their timing and duration, set the rhythm of the parks' water-dependent habitats. Much of this flow is controlled by dams upstream, but extreme precipitation can cause flooding in some valleys.
- **Bedrock Exposures**. The Paleozoic bedrock within the park is sedimentary and features relatively flat, undeformed bedding. Erosion-resistant sandstone layers tend to form prominent ledges and rimrocks whereas softer shales erode more readily to form slopes. Waterfalls and rapids form over sandstone ledges. Rock climbing on outcrops of all three parks is a popular activity and climbing management plans should consider minimizing impacts to vegetation, nesting birds, and the Allegheny woodrat. Weathering in the uplands and gorge rims is producing "rock city" types of exposures characterized by isolated pinnacles or stout towers of rocks.
- **Karst and Weathering Features**. Karst features form where soluble rocks, flowing groundwater,

a suitable gradient, and time act in concert to dissolve solid bedrock. Karst potential exists for a limestone-bearing unit (Avis Limestone) in Bluestone National Scenic River, but other dissolution features are not a prominent resource at the parks. Weathering in the parks is producing doline-like (sinkhole) features near the gorge rims. Human-excavated caves (e.g., mines) have many similarities with dissolution caves and may be managed similarly.

- **Shrink-and-Swell Clays**. Shrink-and-swell materials can change volume dramatically in the presence or lack of water. Heaving and buckling caused by shrink-and-swell clays can undermine or damage trails, buildings, roads, and other infrastructure. Some of these clays create relatively weak or slippery layers and can contribute to slope movements.
- **Folds and Faults**. Folds, including synclines (U-shaped) and anticlines (A-shaped) are mapped in the GRI GIS data for all three parks. Faulting in the relatively undeformed sedimentary rocks of the Appalachian Basin is minor and no faults are mapped in the GRI GIS data. Small scale faults and fractures do occur and seem to have a correlation with areas prone to slope movements.
- **Wetlands Inventory**. The parks protect diverse, but not expansive wetlands. Examples include temporarily flooded riverine wetlands on unconsolidated or rocky shores, permanently flooded riverine wetlands, and temporarily flooded, broad-leaved deciduous palustrine wetlands. Wetlands function as nutrient sources, sinks, or transformers, and are sensitive to minute changes in water flow regimes and climate. There is a resource management need to inventory and map all wetland areas within park boundaries. NPS Water Resources Division is the primary contact for technical and policy assistance for wetlands.
- **Seismic Activity**. The parks are not located near an active seismic zone; however, earthquakes are still possible. US Geological Survey hazard mapping suggests a 0.01–0.08 probability (1%–8% "chance") of a magnitude 5 or greater earthquake for the parks' area over 100 years. Earthquakes can directly damage park infrastructure, or trigger other hazards such as liquefaction or slope movements that may impact park resources or visitor safety.

Products and Acknowledgments

The NPS Geologic Resources Division partners with the Colorado State University Department of Geosciences to produce GRI products. Geologists from West Virginia Geological and Economic Survey and the West Virginia University developed the source maps and reviewed GRI content.

GRI Products

The GRI team undertakes three tasks for each park in the Inventory and Monitoring program: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report (this document). These products are designed and written for nongeoscientists.

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to GIS data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report. The GRI team conducts no new field work in association with their products.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), 2006 National Park Service Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). The “Additional References” chapter and Appendix B provide links to these and other resource management documents and information.

Additional information regarding the GRI, including contact information, is available at http://go.nps.gov/gri. The current status and projected completion dates of products are available at http://go.nps.gov/gri_status.

Acknowledgments

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Source Maps

Maps produced by the West Virginia Geological and Economic Survey and West Virginia University
Bluestone NSR bedrock: Matchen et al. (2011)
Bluestone NSR surficial: Yates and Kite (2014)
Gauley River NRA bedrock: Hunt et al. (2010)
Gauley River NRA surficial: Kite (2016)
New River Gorge NR bedrock: McColloch et al. (2013)
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Figure 1. Photographs of New River Bridge. New River Bridge was under construction in the 1970s (inset image) and remains an iconic feature in the park. The gorge reaches depths of up to 400 m (1,300 ft) and was a formidable crossing, isolating the area. National Park Service photograph by Gary Hartley, available at: https://www.nps.gov/neri/learn/photosmultimedia/photogallery.htm. Inset photograph by Gayle H "Scott" McColloch, Jr. (West Virginia Geological and Economic Survey), taken in spring 1977.

Geologic Setting, History, and Significance

This chapter describes the regional geologic setting of the parks and summarizes connections among geologic resources, other park resources, and park stories.

Park Establishment

Bluestone National Scenic River, Gauley River National Recreation Area, and New River Gorge National River (collectively referred to as "the parks") in south-central West Virginia (plate 1, in pocket) protect part of one of the oldest river systems in North America and a portion of a 18,039 km^2 (6,965 mi^2) watershed (Good and Stasick 2008). For millions of years, water flowing through the New River and its tributaries, including Bluestone and Gauley rivers, have carved deep channels through the heart of the Appalachian Mountains exposing hundreds of millions of years of the geologic rock record within breathtaking gorges. All three parks contain natural and cultural resources of the Appalachian plateau and feature diverse habitats such as unfragmented river-to-rim forest, cliffs and rimrocks, streams, forest seeps and wetlands, riverscour prairies (flat rocks), and mature bottomland forests.

Bluestone National Scenic River (NSR) encompasses 1,743.99 ha (4,309.51 ac) along 16.9 km (10.5 mi) of the lower Bluestone River, named for the deep blue limestone streambed, upstream of Bluestone Dam and its confluence with the New River. The national scenic river was authorized on October 26, 1988 and receives more than 36,000 visitors per year. Visitors are attracted to the local recreation opportunities and adjacent Pipestem and Bluestone state parks, as well as the Bluestone Wildlife Management Area. Bluestone NSR is also part of the Wild and Scenic Rivers system because the Bluestone River possesses "outstandingly remarkable" scenic, natural, cultural, geological, and recreational values. The headwaters of the river begin at 1,070 m (3,500 ft) in elevation on East River Mountain near Bluefield, Virginia and flow for 124 km (77 mi) to Bluestone Lake, impounded near Hinton, West Virginia. Along its course, the Bluestone River carved a rugged and ancient gorge 300 m (1,000 ft) deep.

Gauley River National Recreation Area (NRA), authorized on October 26, 1988, includes 41.0 km (25.5 mi) of the Gauley River and 8.9 km (5.5 mi) of the Meadow River within a total area of 4,656 ha (11,506.95 ac). The rivers flow through scenic gorges and valleys before joining the New River at Gauley Bridge to form the Kanawha River. Downstream from Summersville Dam, the Gauley River drops more than 204 m (668 ft) and features more than 100 rapids between alternating pools, boulders, and exposed bedrock to the national recreation area's western boundary at Upper Swiss. The national recreation area attracts more than 105,000 visitors annually in part due to the abundance of whitewater boating opportunities. Among the named river rapids are Insignificant, Pillow Rock, Lost Paddle, Iron Ring, Sweets Falls, Heaven Help You, Upper and Lower Mash, and Pure Screaming Hell rapids.

New River Gorge National River (NR) was authorized on November 10, 1978 and encompasses 29,214.05 ha (72,189.49 ac). It stretches from Hawks Nest State Park near Cotton Hill more than 85 km (53 mi) along the free-flowing New River as far upstream as the town of Hinton. More than 1.1 million visitors come to New River Gorge each year to enjoy its abundant natural, scenic, historic, and recreational features. The national river's resources are dominated by the deepest and longest gorge in the Appalachian Mountains through which numerous rapids occur, including the Grassy Shoals, Quinnimont, Silo, Surprise, Lower and Upper Railroad, Keeneys, Double Z, Dudleys Dip, Greyhound, Millers Folly, and Fayette Station rapids. New River Gorge NR also showcases the area's cultural significance from the railroads that opened this rugged, isolated area in 1872, to the myriad coal mines, towns, settlements, and bridges (fig. 1).

Geologic Setting and History

As they flow through the three parks, the Bluestone, Gauley, Meadow, and New rivers are all incising through relatively flat-lying geologic units of the Appalachian Plateau physiographic province (fig. 2). This province encompasses the western two-thirds of West Virginia. The Appalachian Plateau is separated from the Valley and Ridge province to the east by the Allegheny Front, marking a complicated and abrupt change in topography and geologic structures. The rocks of the Appalachian Plateau physiographic province are younger than those of the Valley and Ridge province. The difference between them is also related to their degree of deformation—the Valley

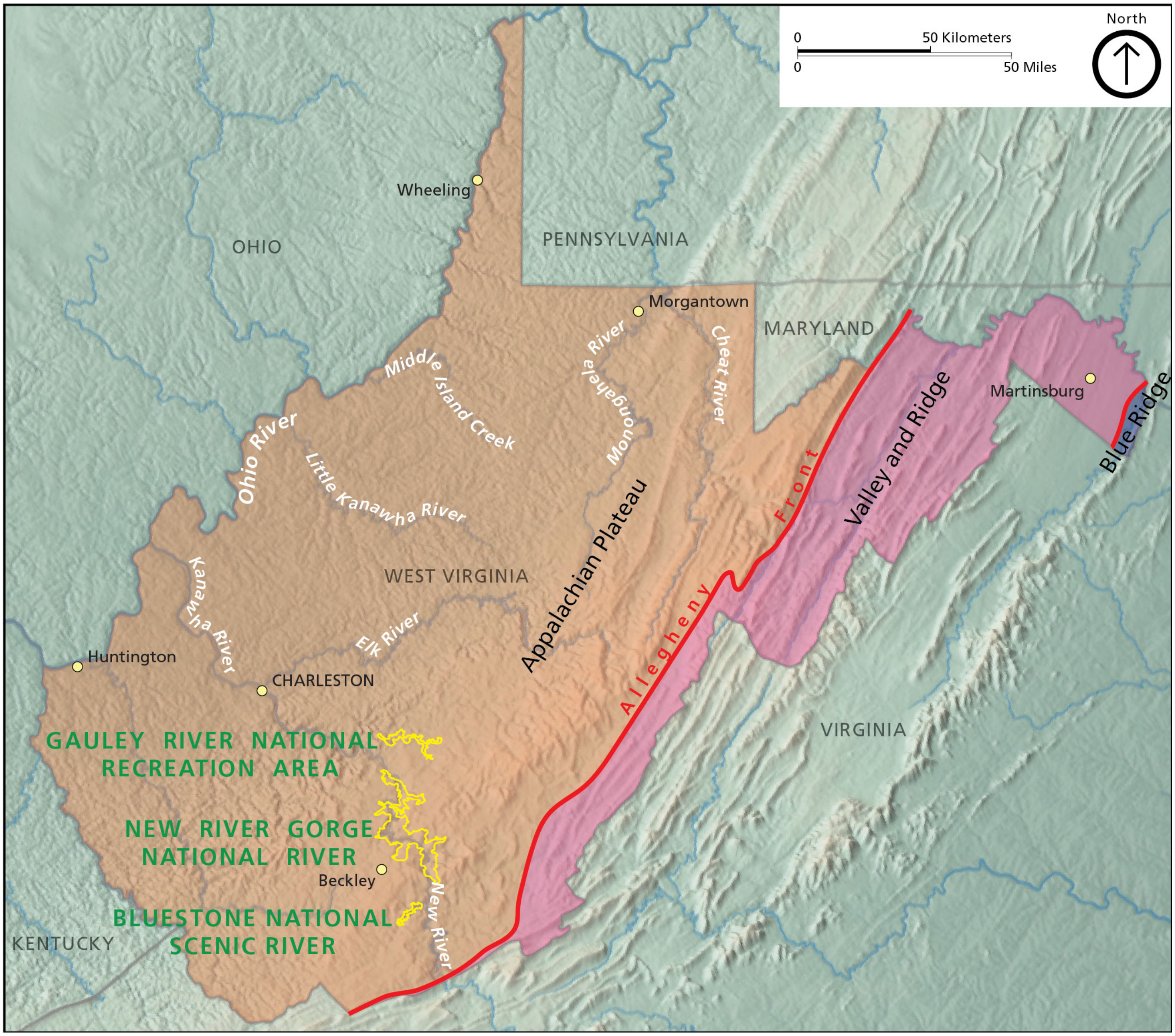


Figure 2. Physiographic province map of West Virginia. The Appalachian Plateau (orange) and the Valley and Ridge (pink) provinces are separated by the Allegheny Front. The front marks the change from the long, linear, northeast to southwest trending ridges and valleys of the Valley and Ridge to the dendritic river gorges carving through the relatively flat-lying layers of the Appalachian Plateau. During mountain-building orogenies, the Valley and Ridge rumpled like a carpet whereas the Appalachian basin was relatively undisturbed, collecting the eroded material from the highlands of the Appalachian Plateau. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) adapted from a figure by the West Virginia Geologic and Economic Survey available at http://www.wvgs.wvnet.edu/www/maps/WVPhysioProvinces.pdf. Shaded relief base map Tom Patterson (National Park Service), available at http://www.shadedrelief.com/physical/index.html.

Figure 3 (facing page). Paleogeographic maps of North America. The red star indicates the approximate location of Bluestone NSR, Gauley River NRA, and New River Gorge NR. Graphic complied by Trista L. Thornberry-Ehrlich (Colorado State University). Basemap is from "North American Key Time Slices" © 2013 Colorado Plateau Geosystems, Inc.; used under license. Refer to http://deeptimemaps.com/ for additional information.

Ordovician
Volcanic arcs colliding with the eastern edge of North America uplifted mountains and opened the Appalachian Basin

Mississippian
Shallow marine conditions dominated the continental interior; sedimentation in the Appalachian Basin continued

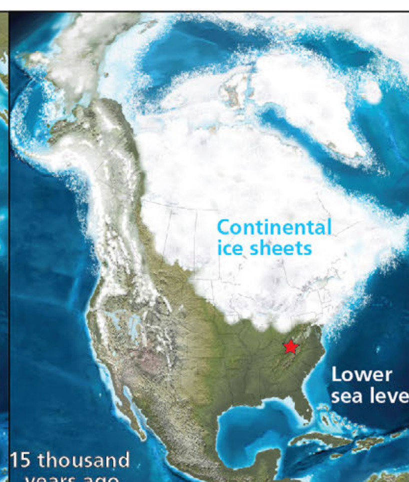
Pennsylvanian
Continents continued to collide, building higher mountains; subaerial conditions included coal-producing swamps and rivers

Permian
Paleozoic orogenies culminated in the Appalachian Mountains and the formation of the supercontinent Pangaea

Jurassic
Rifting opened the Atlantic Ocean basin and separated the continents

Paleocene
Continuous weathering and erosion immediately began to wear away the mountains; Coastal Plain builds out

Miocene
New River is part of the ancient Teays River watershed; gorges continue to form; weathering and erosion



Pleistocene
Glacial ice locks away vast quantities of water and global sea level is lower; ice sheets reroute major river systems

Holocene
Rivers continued to carve their gorges; coal mining changes gorge landscape

Table 1. Geologic time scale. Table continues on next page.

Era	Period	Epoch	MYA	Geologic Map Units	West Virginia Geologic Events
Cenozoic (CZ) "Age of Mammals"	Quaternary (Q)	Holocene (H)	0.01–today	Qd disturbed Qr, Qfc, Hfc continue to meander Qaf, Qbfp, Qtd, Qflp, Qfp, Qrff deposited Qcv, Hcv, Qcm, Hcm, Qca, Hca, Qcf, Hcf, Qbtd, Hbt, Qls, Hls, Qbm accumulated on slopes Qt and Ht deposited at former river levels Qht deposited and left perched above floodplains Qres and CZr form via long term weathering of bedrock	Human history; logging; coal mining
Cenozoic (CZ) "Age of Mammals"	Quaternary (Q)	Pleistocene (PE)	2.6–0.01		Ice age glaciations; glacial outburst floods; Teays River's course is changed
Cenozoic (CZ) "Age of Mammals"	Tertiary (T): Neogene (N)	Pliocene (PL)	5.3–2.6	none mapped	Throughout Tertiary: Ongoing weathering and erosion; river gorges deepened; residuum formed
Cenozoic (CZ) "Age of Mammals"	Tertiary (T): Neogene (N)	Miocene (MI)	23.0–5.3		
Cenozoic (CZ) "Age of Mammals"	Tertiary (T): Paleogene (PG)	Oligocene (OL)	33.9–23.0		
Cenozoic (CZ) "Age of Mammals"	Tertiary (T): Paleogene (PG)	Eocene (E)	56.0–33.9		
Cenozoic (CZ) "Age of Mammals"	Tertiary (T): Paleogene (PG)	Paleocene (EP)	66.0–56.0		
Mesozoic (MZ) "Age of Reptiles"	Cretaceous Period (K)		145.0–66.0	none mapped	Global mass extinction at end of Cretaceous (dinosaurs extict).
Mesozoic (MZ) "Age of Reptiles"	Jurassic Period (J)		201.3–145.0		New River is part of the Teays River watershed
Mesozoic (MZ) "Age of Reptiles"	Triassic Period (TR)		252.2–201.3		Global mass extinction at end of Triassic. Breakup of Pangaea begins
Paleozoic (PZ) (Amphibians common during late Paleozoic)	Permian Period (P)		298.9–252.2	none mapped	Global mass extinction at end of Permian. Supercontinent Pangaea intact. Increased sedimentation in the Appalachian Basin. Appalachians may have rivaled height of modern Himalayas.
Paleozoic (PZ) (Amphibians common during late Paleozoic)	Pennsylvanian Period (PN)		323.2–298.9	"**PN**" units deposited	Alleghany (Appalachian) Orogeny; local rocks are folded. Swamps and rivers (plants and organic material would later become coal) dominate deposition in the Appalachian Basin above sea level.
Paleozoic (PZ) (Amphibians common during late Paleozoic)	Mississippian Period (M)		358.9–323.2	"**M**" units deposited	Marine conditions in the Appalachian Basin.

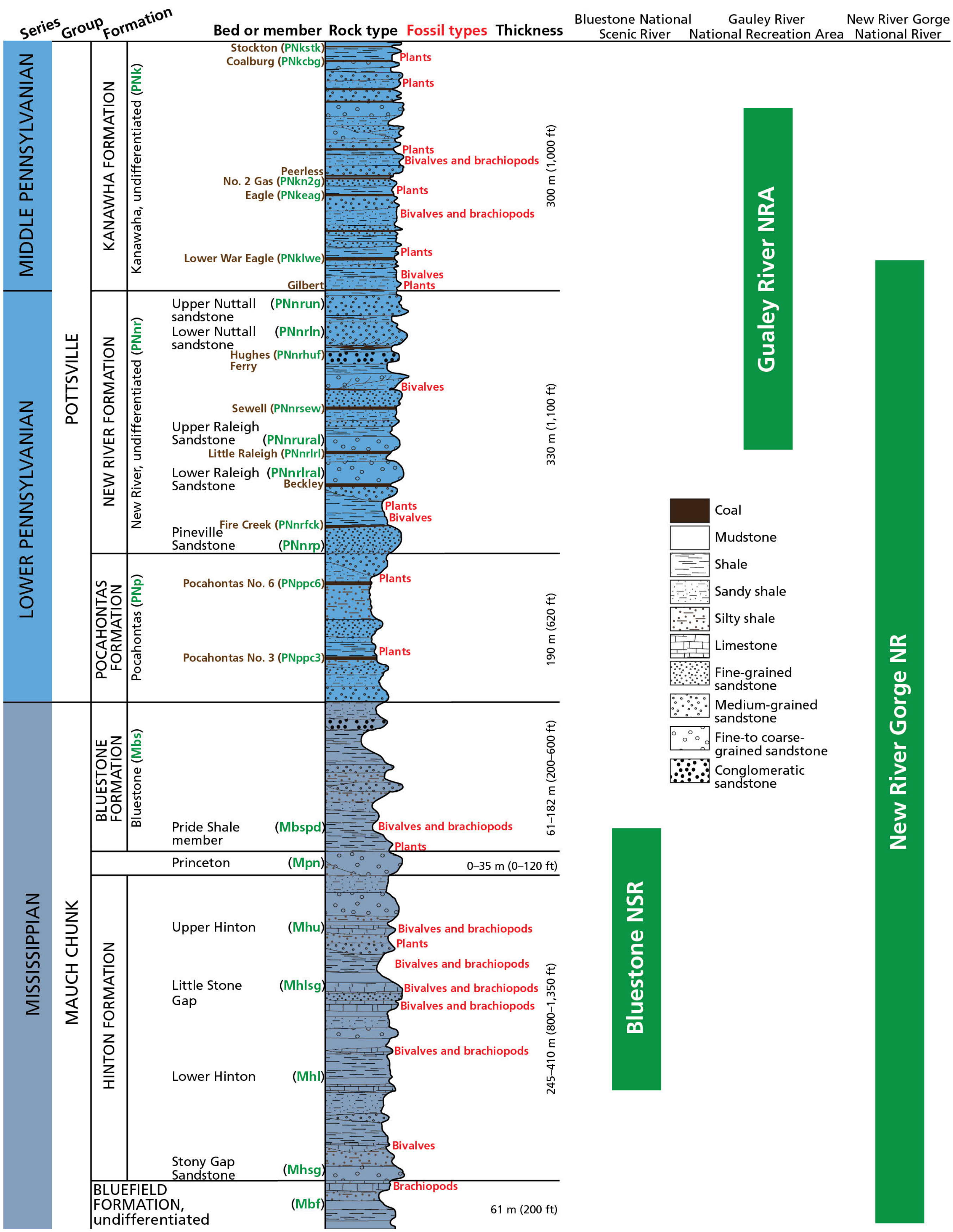
Table 1, continued. Geologic time scale.

Era	Period	Epoch	MYA	Geologic Map Units	West Virginia Geologic Events
Paleozoic (PZ) (Fishes diversify during Devonian)	Devonian Period (D)		419.2–358.9	none mapped	Global mass extinction during late Devonian. Acadian Orogeny during Late Silurian and Devonian.
Paleozoic (PZ) (Marine invertebrates diversify greatly during early Paleozoic)	Silurian Period (S)		443.7–419.2	none mapped	Appalachian Basin subsides and continues to be a center of deposition
Paleozoic (PZ) (Marine invertebrates diversify greatly during early Paleozoic)	Ordovician Period (O)		485.4–443.7	none mapped	Global mass extinction at end of Ordovician. Taconic Orogeny; Appalachian Basin opens and collects sediment
Paleozoic (PZ) (Marine invertebrates diversify greatly during early Paleozoic)	Cambrian Period (C)		541.0–485.4	none mapped	Extensive oceans cover most of proto-North America (Laurentia).
Neoproterozoic Era (Z) "Precambrian"			1,000–541.0	none mapped	Supercontinent rifted apart
Mesoproterozoic Era (Y) "Precambrian"			1,600–1,000	none mapped	Formation of early supercontinent; Grenville Orogeny
Paleoproterozoic Era (X) "Precambrian"			2,500–1,600	none mapped	none reported
Archean Eon "Precambrian"			~4,000–2,500	none mapped	none reported
Hadean Eon "Precambrian"			4,600–4,000	none mapped	Formation of the Earth approximately 4,600 million years ago.

The divisions of the geologic time scale are organized stratigraphically, with the oldest divisions at the bottom and the youngest at the top. GRI map abbreviations for each time division are in parentheses. Boundary ages are millions of years ago (MYA). Geologic units mapped within the parks are included in the "Geologic Map Units" column. Dates from the International Commission on Stratigraphy (http://www.stratigraphy.org/index.php/ics-chart-timescale). Colors are US Geological Survey standard colors for geologic time scale.

and Ridge rocks were intensely deformed, folded, and faulted during the three major Appalachian Mountain orogenies (mountain-building events) of the Paleozoic Era, whereas the Appalachian Plateau was only slightly deformed with sparse faults and gentle folds (Gwinn 1964).

The rock record in the parks is vast. It begins nearly 350 million years ago and covers about 40 million years from the Mississippian to the Middle Pennsylvanian periods (tables 1 and 2; figs. 3 and 4). The oldest exposed geologic unit, the Bluefield Formation (geologic map unit **Mbf**), crops out in the deepest portions of New River Gorge NR (fig. 4; table 2; McColloch et al. 2013). By contrast, the youngest bedrock unit mapped within the parks, the Kanawha Formation (**PNk**), is in the highest points of Gauley River NRA (Hunt et al. 2010). These two end members and all the intervening units were deposited in a variety of fluvial to nearshore depositional environments in the Appalachian basin (Pocahontas subbasin) which began to form in the early Paleozoic Era (Hunt et al. 2010; Olcott 2011; McColloch et al. 2013). The basin was created when a volcanic arc collided with the eastern edge of North America during the first of three orogenies (the Taconic Orogeny) to construct the Appalachian Mountains (fig. 5A). As the mountains rose along the collision zone, Earth's crust bowed downwards farther inland creating the deep Appalachian basin that would persist for hundreds of millions of years and collect the vast amounts of sediments that eroded from the new mountains.



Series
Group
Formation
Bed or member
Rock type
Fossil types
Thickness
Bluestone National Scenic River
Gauley River National Recreation Area
New River Gorge National River
MIDDLE PENNSYLVANIAN
LOWER PENNSYLVANIAN
MISSISSIPPIAN
POTTSVILLE
MAUCH CHUNK
KANAWHA FORMATION
Kanawha, undifferentiated (PNk)
Stockton (PNkstk)
Coalburg (PNkcbg)
Peerless
No. 2 Gas (PNkn2g)
Eagle (PNkeag)
Lower War Eagle (PNklwe)
Gilbert
300 m (1,000 ft)
NEW RIVER FORMATION
New River, undifferentiated (PNnr)
Upper Nuttall sandstone (PNnrun)
Lower Nuttall sandstone (PNnrln)
Hughes Ferry (PNnrhuf)
Sewell (PNnrsew)
Upper Raleigh Sandstone (PNnrural)
Little Raleigh (PNnrlrl)
Lower Raleigh Sandstone (PNnrlral)
Beckley
Fire Creek (PNnrfck)
Pineville Sandstone (PNnrp)
330 m (1,100 ft)
POCAHONTAS FORMATION
Pocahontas (PNp)
Pocahontas No. 6 (PNppc6)
Pocahontas No. 3 (PNppc3)
190 m (620 ft)
BLUESTONE FORMATION
Bluestone (Mbs)
Pride Shale member (Mbspd)
61–182 m (200–600 ft)
Princeton (Mpn)
0–35 m (0–120 ft)
HINTON FORMATION
Upper Hinton (Mhu)
Little Stone Gap (Mhlsg)
Lower Hinton (Mhl)
Stony Gap Sandstone (Mhsg)
245–410 m (800–1,350 ft)
BLUEFIELD FORMATION, undifferentiated (Mbf)
61 m (200 ft)
Plants
Bivalves and brachiopods
Bivalves
Brachiopods
Gualey River NRA
New River Gorge NR
Bluestone NSR
Coal
Mudstone
Shale
Sandy shale
Silty shale
Limestone
Fine-grained sandstone
Medium-grained sandstone
Fine-to coarse-grained sandstone
Conglomeratic sandstone

Figure 4 (facing page). Stratigraphic column. Green bars indicate the extent to which the stratigraphic layers are mapped within each park. Coal bed names appear in brown text. Information is presented in tabular format as table 2. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after McColloch et al. (2013) and with information from Matchen et al. (2011) and Hunt et al. (2010).

Two more orogenies, the Acadian and Alleghany, would build the mountains higher still and supply even more sediment to the Appalachian Basin. Between the two orogenies, in the Mississippian Period, deep to shallow, quiet-water, mostly marine conditions prevailed in the park area (fig. 5B). The interlayered mudstone, shale, silty shale, and limestone of the Bluefield Formation (**Mbf**) record this environment (Matchen et al. 2011). A change in sea level brought a higher-energy depositional setting for the accumulation of the fine- to coarse-grained sandstone of the Stony Gap Sandstone of the Hinton Formation (**Mhsg**). Quiet water, marine conditions dominated again during the deposition of the Lower Hinton member of the Hinton Formation (**Mhl**), the oldest unit exposed at Bluestone NSR (Matchen et al. 2011). Sea level would continue to fluctuate during the deposition of the rest of the Hinton Formation which included the limestone of the Little Stone Gap member (**Mhlsg**; informally known as the Avis Limestone) and the mixed limestone and silty shale to fine to coarse-grained sandstone of the Upper Hinton member (**Mhu**). A global sea level drop accompanied by high energy, fluvial environments contributed to the deposition of the coarse conglomerates and sandstones of the Princeton Formation (**Mpn**) atop the Hinton Formation. Seas encroached again as the last Mississippian units were deposited in mixed marine conditions. The Pride Shale member of the Bluestone Formation (**Mbspd**) is the youngest unit mapped in Bluestone NSR and records a shift to quiet-water conditions followed by nearshore to fluvial layers in the rest of the Bluestone Formation (**Mbs**; Matchen et al. 2011).

By the beginning of the Pennsylvanian Period (fig. 5C), the Alleghany Orogeny was uplifting the mountains to the east and causing coarser sediments to be shed to the west, into the Appalachian basin. At this time after a period of erosion into the Mississippian layers, rivers meandered across broad floodplains, deltas, and lagoons (Grafton and Grafton 1980; Korus et al. 2008). Sedimentation roughly kept pace with basin subsidence, so the land surface was always just above sea level (Grafton and Grafton 1980). Medium-grained sandstone, silty shale, fine-grained sandstone, and shale accumulated in the basin as part of the Pocahontas Formation (**PNp**), as well as the first of many prominent and important coal horizons throughout the region, Pocahontas No. 3 and No. 6 (**PNppc3** and **PNppc6**). These depositional settings continued during the deposition of the New River Formation (**PNnr**). Within this formation, prominent sandstones such as the Pineville (**PNnrp**), Lower (**PNnrlral**) and Upper Raleigh (**PNnrural**), and Lower (**PNnrln**) and Upper Nuttall (**PNnrun**) sandstones were deposited in higher energy, fluvial settings (McColloch et al. 2013). Between these sandstone layers are units recording lower energy settings where flow was negligible. Shale and coal layers formed there as tree-sized ferns and horsetails grew and decayed in swamps and lagoons (Good and Stasick 2008). Prominent coal horizons include Fire Creek (**PNnrfck**), Beckley, Little Raleigh (**PNnrlrl**), Sewell (**PNnrsew**), and Hughes Ferry (**PNnrhuf**; Hunt et al. 2011; McColloch et al. 2013). Sea level fluctuations led to the deposition of some marine (limestone) layers within the coal-bearing sequence of sandstone, siltstone, shale, and mudstone of the Kanawha Formation (**PNk**). Named coal horizons within this formation include the Gilbert, Lower War Eagle (**PNklwe**), Eagle (**PNkeag**), No. 2 Gas (**PNkn2g**), and Peerless. The Kanawha Formation is the youngest geologic unit mapped within Gauley River NRA and New River Gorge NR (Hunt et al. 2010; McColloch et al. 2013).

By the end of the Alleghany Orogeny in the Permian Period, the Appalachian Mountains may have been comparable in elevation to the modern Himalayas and all of Earth's major landmasses were sutured together into a supercontinent called Pangaea (fig. 6D). The supercontinent was short lived and by the beginning of the Mesozoic Era, it began to rift, opening the Atlantic Ocean basin and many pull-apart basins along the eastern edge of North America. At this time, the modern configuration of continents began to take shape and major drainages of eastern North America were established. The New River was a primary tributary of an ancient watercourse called the Teays River, which flowed west, across the uplifted Appalachian Plateau, to an immense inland sea that covered the central part

Table 2. Summary of map units and stratigraphy. Table continues on next page.

Series, Group, and Formation (age in MYA)	Members[1] (map symbol)	Coal beds[1] (map symbol)	Rock types[2]	Fossils	Parks
Middle Pennsylvanian (~310 MYA) Pottsville Group: Kanawha Formation (undifferentiated mapped as PNk)	none mapped	Stockton (PNkstk) Coalburg (PNkcbg) Peerless (not mapped) No. 2 Gas (PNkn2g) Eagle (PNkeag) Lower War Eagle (PNklwe) Gilbert (not mapped)	Interbedded sandstones, shales, siltstones, and coals. Maximum thickness: 300 m (1,000 ft)	Plants, bivalves, and brachiopods	Gauley River NRA spans much of PNk. Uppermost bedrock of New River Gorge NR is PNk. Not mapped in Bluestone NR.
Lower Pennsylvanian (~318 MYA) Pottsville Group: New River Formation (undifferentiated, mapped as PNnr)	Upper Nuttall Sandstone (PNnrun) Lower Nuttall Sandstone (PNnrln) Upper Raleigh Sandstone (PNnrural) Lower Raleigh Sandstone (PNnrlral) Pineville Sandstone (PNnrp)	Hughes Ferry (PNnrhuf) Sewell (PNnrsew) Little Raleigh (PNnrlrl) Beckley (not mapped) Fire Creek (PNnrfck)	Comprised of two intervals: one between the top of PNnrp and the base of PNnrlral, and other between the top of PNnrural and the base of PNnrln. These intervals are coal-bearing sequences of quartzose and lithic sandstones, siltstones, shales, mudstones, and siderite. Maximum thickness: 330 m (1,100 ft)	Bivalves and plants	Gauley River NRA and New River Gorge NR. Not mapped in Bluestone NR.
Lower Pennsylvanian (~320 MYA) Pottsville Group: Pocahontas Formation (undifferentiated, mapped as PNp)	none mapped	Pocahontas no. 6 (PNppc6) Pocahontas no. 3 (PNppc3)	Variable sequence of sandstone, siltstone, shale, mudstone, coal, and siderite. Maximum thickness: 90 m (620 ft)	Plants	New River Gorge NR. Not mapped in Gauley River NRA nor Bluestone NSR.
Mississippian (~323 MYA) Mauch Chunk Group: Bluestone Formation (Mbs)	Pride Shale member (Mbspd)	none	Variable sequence of mudstone, shale, siltstone, and sandstone with discontinuous beds of coalesced authigenic limestone and siderite nodules Maximum thickness: 61–182 m (200–600 ft)	Bivalves, brachiopods, and plants	Youngest rocks in Bluestone NSR. Mapped in New River Gorge NR. Not mapped in Gauley River NRA.
Mississippian (~325 MYA) Mauch Chunk Group: Princeton Formation (Mpn)	none mapped	none	Sequence of sandstone, conglomerate, silty shales, and silty mudstones and may include a massive basal sandstone Maximum thickness: 0–35 m (0–120 ft)	Plants	Bluestone NSR and New River Gorge NR. Not mapped in Gauley River NRA.

Table 2, continued. Summary of map units and stratigraphy.

Series, Group, and Formation (age in MYA)	Members[1] (map symbol)	Coal beds[1] (map symbol)	Rock types[2]	Fossils	Parks
Mississippian (~330 MYA) Mauch Chunk Group: Hinton Formation	Upper Hinton (Mhu) Little Stone Gap (Mhlsg) Lower Hinton (Mhl) Stony Gap Sandstone (Mhsg)	none	Members have variable sequences of mudstone, sandstone, calcareous shale, limestone. Limited occurences of coal. Maximum thickness: 245–410 m (800–1,350 ft)	Bivalves, brachiopods, plants	Oldest rocks in Bluestone NSR. Mapped in New River Gorge NR. Not mapped in Gauley River NRA.
Mississippian (~350 MYA) Mauch Chunk Group: Bluefield Formation (Mbf)	none mapped	none mapped	Fossiliferous gray calcareous shales and poorly consolidated blocky reddish calcareous mudstones with greenish gray siltstone. Maximum thickness: 61 m (200 ft)	Brachiopods	Oldest rocks in New River Gorge NR.

For a graphic version of this information, refer to fig. 4.

1 members and coal beds are listed in stratigraphic order from top (youngest) to bottom (oldest).

2 rock types are from GRI GIS source map descriptions found in neri_geology.pdf, gari_geology.pdf, and blue_geology.pdf

of North America during part of the Mesozoic Era (Grafton and Grafton 1980). The actual age of the New River is a subject of much debate. Some geologists claim it predates (at 320 million years old) the Appalachian Mountains because it cuts across them while other geologists, using erosion rates in the gorge, surmise the river is only about 3 million years old (Lessing 1986; Mott 1995; Mahan 2004).

Throughout the Mesozoic and into the Cenozoic eras, the primary geologic processes in the three-park area were river incision, slope movements, and weathering and erosion (fig. 6E). Pleistocene glaciations (ice ages) forever changed the course of the Teays River, shifting to follow the modern Ohio River's southerly flow (Grafton and Grafton 1980). Surficial geologic map units record these events and the evolution of the modern landscape along the Bluestone, Gauley, Meadow, and New rivers (fig. 7; Yates and Kite 2014; Yates and Kite 2015; Kite 2016). Deep weathering of the ancient bedrock has formed in situ or nearly in situ accumulations of residuum (**Qres** and **CZr**) that may also include some colluvium. As testament to the longstanding action of earth surface processes on the landscape of the three parks, colluvium, or loose, unconsolidated sediments that have been deposited at the base of hillslopes by slope processes feature in many of the parks' surficial geologic map units, including colluvial veneer (**Hcv** and **Qcv**), colluvial mantle (**Hcm** and **Qcm**), colluvial apron (**Hca** and **Qca**), colluvial fan (**Hcf** and **Qcf**), bouldery tributary deposit (**Hbt** and **Qbtd**), landslide (**Hls** and **Qls**), blocky mantle (**Qbm**), entrenched stream channel (**Qfc**), boulder floodplain (**Qbfp**), tributary deposit (**Qtd**), river channel (**Qr**), and alluvial fan (**Haf** and **Qaf**; Yates and Kite 2014; Yates and Kite 2015; Kite 2016). The rivers are constantly lowering the base of the slopes, causing a recurring unstable situation wherein slopes are oversteepened and prone to failure in the narrow gorges. Rivers are powerful agents of landscape change and also have their associated surficial units, including colluvial veneer, colluvial mantle, colluvial fan, boulder tributary deposit, alluvial fan, fluvial channel (**Hfc** and **Qfc**), entrenched stream channel, floodplain (**Hfp** and **Qflp**), rock-floored floodplain (**Qrff**), boulder floodplain, tributary deposit, and river channel, as well as terrace (**Ht** and **Qt**) and high terrace (**Qht**), which record previous river levels and remain perched above the modern floodplain (Yates and Kite 2014; Yates and Kite 2015; Kite 2016).

The Anthropocene Epoch was recommended to the International Commission on Stratigraphy (ICS) to denote the time of human alteration of the landscape. At Gauley River NRA and New River Gorge NR, the

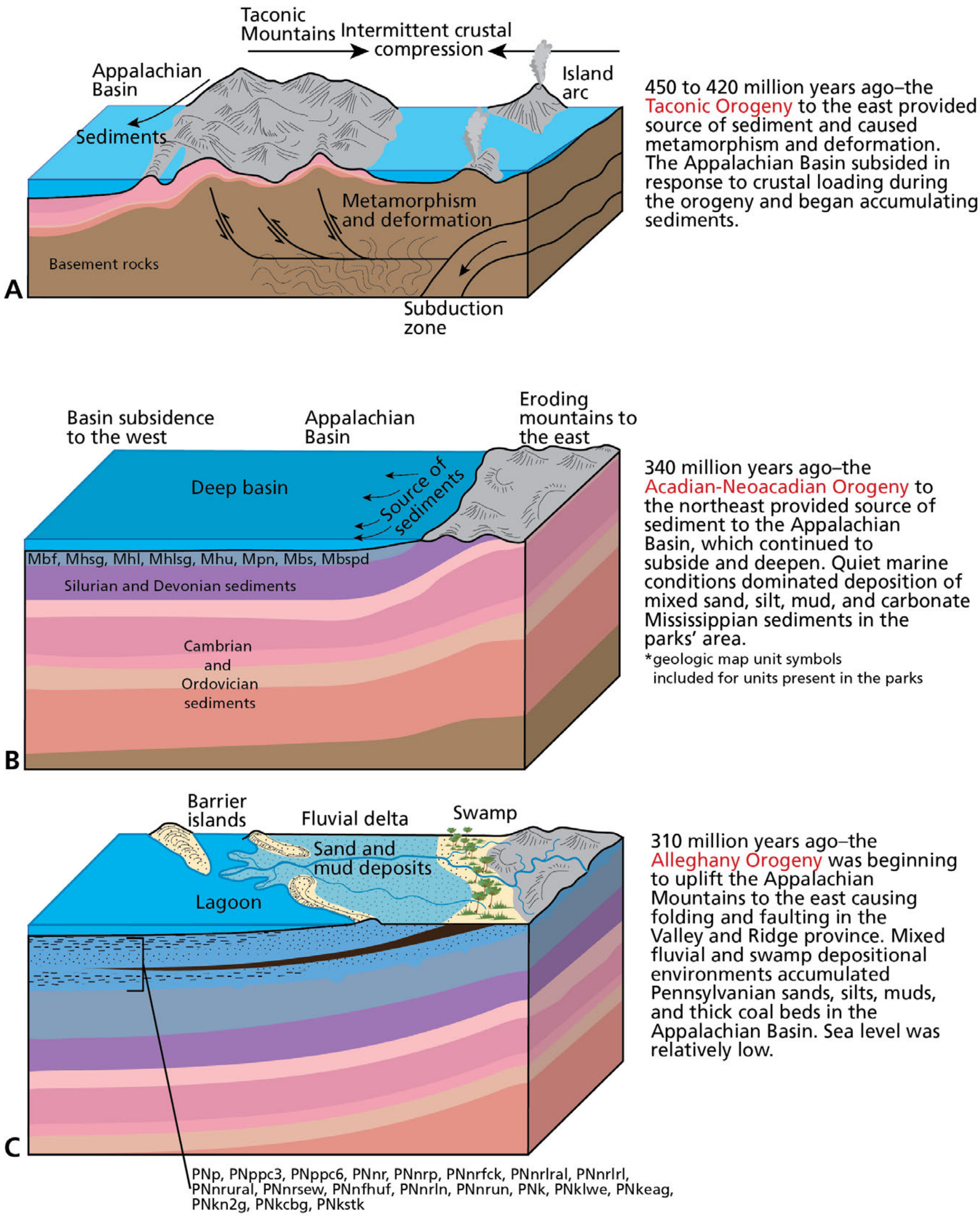


Figure 5A–C. Illustration of the evolution of the landscape and geologic foundation of Bluestone NSR, Gauley River NRA, and New River Gorge NR. Continued on next page. Graphics are not to scale. Colors are standard colors approved by the US Geological Survey to indicate different time periods on geologic maps, and correspond to the colors on the figures in this report. Map symbols are included for the geologic units mapped within the parks. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

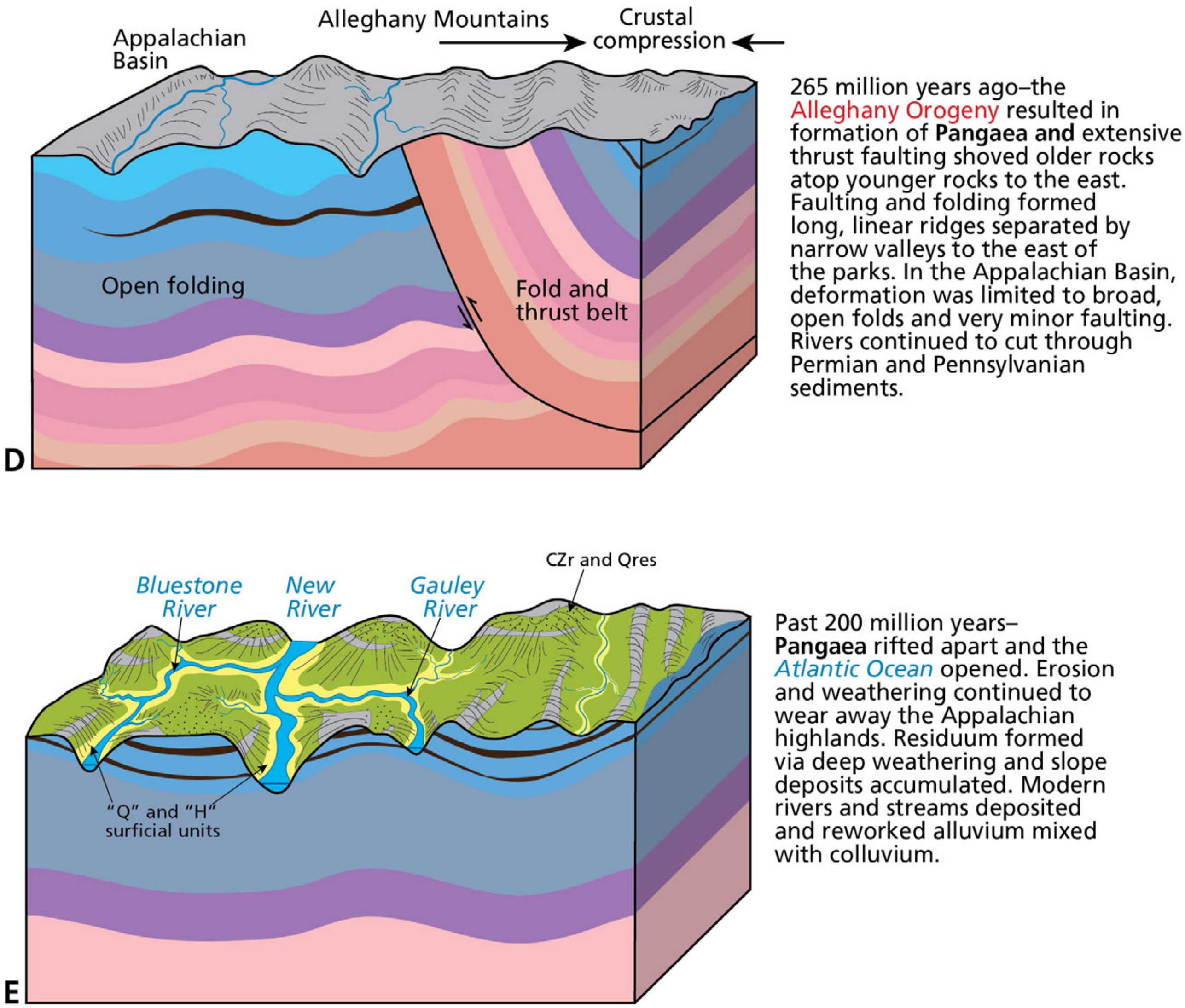


Figure 6D–E. Illustration of the evolution of the landscape and geologic foundation of Bluestone NSR, Gauley River NRA, and New River Gorge NR. Continued from previous page. Graphics are not to scale. Colors are standard colors approved by the US Geological Survey to indicate different time periods on geologic maps, and correspond to the colors on the figures in this report. Map symbols are included for the geologic units mapped within the parks. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

surficial geologic map unit "disturbed" (**Qd**) is testament to this human-driven landscape change (Yates and Kite 2015; Kite 2016). Mapped disturbed lands in the parks include areas in which at least 30% of topography has been altered by excavation, mining, filling, transportation infrastructure, or other anthropogenic processes. Units like "disturbed" record the map-scale human alteration of the landscapes to access and extract the varied geologic resources of Bluestone NSR, Gauley River NRA, and New River Gorge NR.

Geologic Significance and Connections

Geologic features and processes underlie the ecosystems of the parks. Geologic resources prompted and sustained human settlement of the region. For these reasons, the connections between geology and other disciplines, including biology, anthropology, and history are many. The Bluestone gorge, its geography, and its undammed hydrology are among the park-significance highlights stated in its foundation document. Fundamental resources for Bluestone NSR include the Bluestone River, its biodiversity and recreation opportunities, the function of the gorge

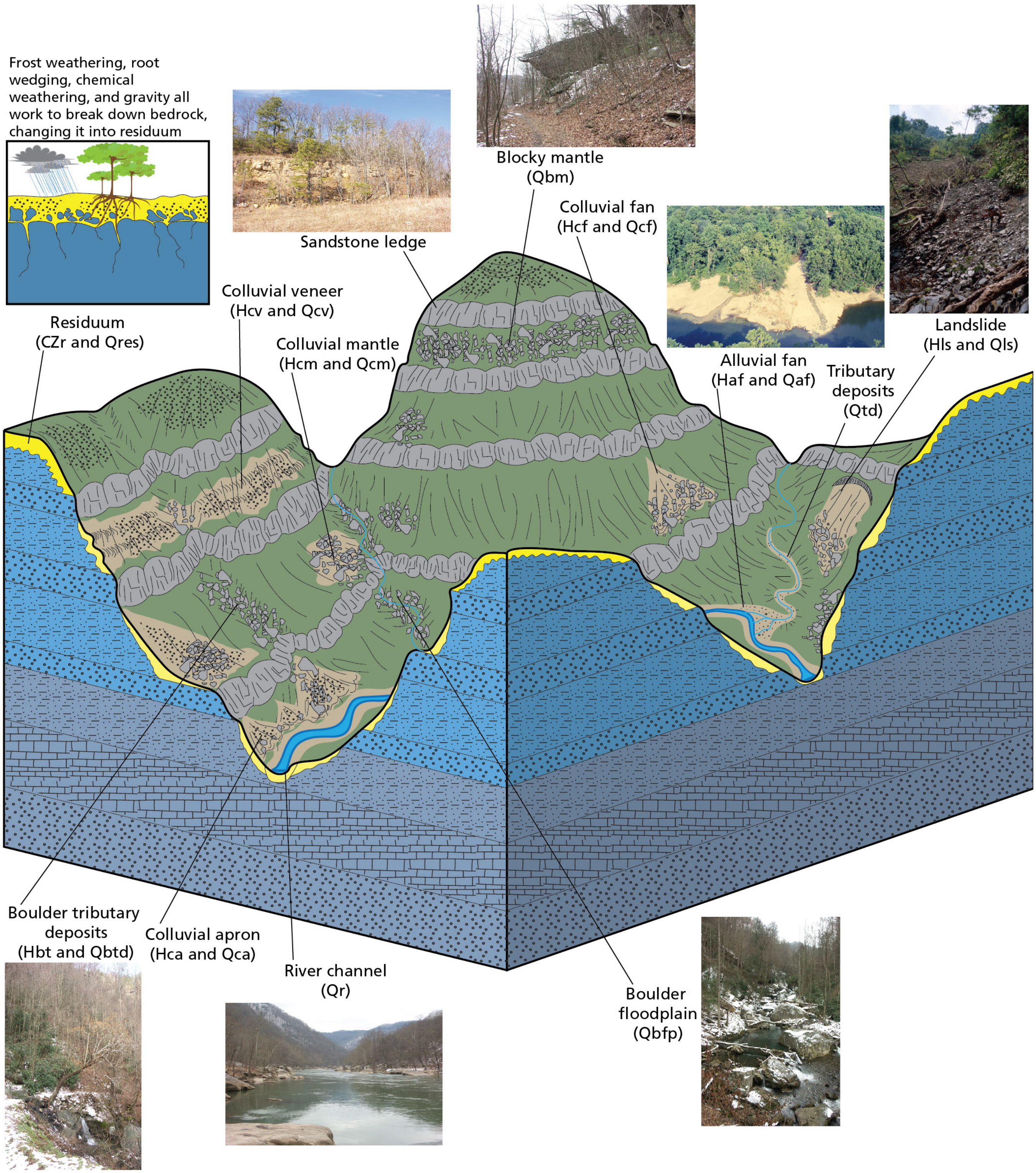


Figure 7. Diagram of surficial units on the gorge landscape. Surficial units relevant to slope processes that are exposed within park boundaries are included. Weathering and fluvial downcutting create steep slopes and abundant unconsolidated material prone to slope processes such as landsliding, slope creep, and debris flows (see figure 10). Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Yates and Kite (2014; 2015), and Kite (2016). All photographs are NPS images taken in 2002, 2006, and 2007.

as a historic travel corridor, and the park's overall undeveloped primitive character (National Park Service 2016a). The complex nature of the Gauley and Meadow river gorges, their rugged geology with associated rock outcrops, cliffs, boulder fields, boulder-choked rapids, and scenic and wild character factor heavily in the park's significance. Gauley River NRA's fundamental resources, as presented in the foundation document, include its rugged, undeveloped geologic landscape which supports its other resources of biodiversity, recreation opportunities, water quality, and cultural history of the Gauley River gorge (National Park Service 2016b). The New River, possibly one of the oldest rivers on the continent, is continually sculpting the longest and deepest gorge in the Appalachian Mountains and supports the park's significant hydrology, diverse forests, historical features, scenic resources, and recreational opportunities. As presented in the foundation document, New River Gorge NR has geologic processes and features, hydrological, ecological, historical, archeological, and scenic resources, as well as visitor opportunities among its fundamental resources and values (National Park Service 2016c).

Early Human Presence

American Indians were the first humans to use the river corridors of the Bluestone, New, and Gauley rivers for transportation and trade; evidence of their presence dates back at least 12,000 years (Good and Stasick 2008). Even though the main north-south prehistoric and historic travel routes by-passed the gorges to the east and west (e.g., Buffalo and Paint Creek trails), the gorges provided a route between the Ohio Valley and Piedmont Virginia and American Indians developed an extensive network of trails. In addition to Buffalo and Paint Creek, the most prominent trails included Midland, Seneca, Pocahontas, Guyandotte, and Big Sandy-Tug Fork trails (Good and Stasick 2008). The route along the Bluestone River and Little Bluestone River was an American Indian trail that was later followed by fur traders and European settlers and became a major transportation corridor (Good and Stasick 2008; National Park Service 2016a). Similarly, the New River was part of a major transport corridor that followed hunting, trading, and migration trails used by American Indians. The corridor extends from the James River in Virginia to the Greenbrier River to the New River and to the Kanawha River (Covington 2005). The Gauley River and its steep gorges historically served as a natural barrier; however, the area was used for fishing and hunting by American Indians for 10,000 years (National Park Service 2016b). New River Gorge supported American Indian settlement, travel, hunting and gathering, and agriculture along its length (National Park Service 2016c).

Periodic, low-intensity fires were employed by American Indians to clear land for agriculture, assist in the management of favored vegetation, clear routes of travel, herd game, and even wage war on neighboring tribes (Abrams 1992; Brose et al. 2001; Mahan 2004). These fires likely varied in intensity and exerted a considerable influence upon vegetative composition, including the creation of a forested landscape that was comprised of mixed-mesophytic forest interspersed with scattered stands of the oak-hickory and pine forest type (Brose et al. 2001). Areas where landslides occurred on unstable sandstone/shale or erodible soils of the steep gorge slopes were devoid of vegetation and avoided by humans.

Railroads and Coal Mining

The steep, rugged topography of the river gorges in the three-parks area presented challenges to large-scale settlement and the area remained relatively isolated compared to places further west during the expansion of the United States. The first European explorer to the New River was Abram Wood in 1654, but in 1671, Thomas Batts and Robert Fallam were the first to systematically investigate the New River in southwest Virginia as part of an attempt to find water on the other side of the mountains. They discovered a stream (tributary) that began to flow west instead of east and claimed the river's entire watershed for England (National Park Service 2001b). Prior to the mid-1800s, settlements were restricted to small communities and subsistence homesteads. In the late 1700s the Lilly, Meadow, and Farley families built homesteads along the Bluestone River. For example, the community of Lilly was located at the confluence of the Bluestone and Little Bluestone Rivers (National Park Service 2016a). Due to the extreme topography, settlements in the Gauley River area were mostly restricted to the uplands (National Park Service 2016b). New River Gorge NR preserves a few rare surviving examples of typical frontier subsistence farms (e.g., Trump-Lilly and Richmond-Hamilton; National Park Service 2016c).

Figure 8. Photograph of original coal mining structures in Nuttallburg circa 1875. Structures included a tipple, the wooden structure with a tower in center of the photograph. Banks of coke ovens were perpendicular to the New River. Photograph NERI 315, included as an unnumbered figure in National Park Service (2001b).

The gorge landscape, dotted with small farmsteads and settlements would be forever changed in the mid-1800s when several entrepreneurs and explorers reported the presence of coalbeds over a wide area of the New River (Grafton and Grafton 1980; Mahan 2004). The gorges' steep walls not only concentrated settlement in valley floors and on top of the Appalachian Plateau, its abundant bedrock exposures facilitated the discovery of coal within shale beds in the region (Mott 1995; Mahan 2004). In the 1870s, the first iron furnace, coal mines, and coke ovens opened near Sewell (fig. 8; Grafton and Grafton 1980). New River coal is bituminous and low in sulfur content, making it easily converted to coke. The Sewell coal (**PNnrsew**) is of global significance because of its exceptional quality due to its low sulfur content, few metal impurities, and high heat value (Mahan 2004). The completion of the Chesapeake and Ohio (C&O) Railroad in January 1873 initiated the economic coal-mining boom along the New River by opening a link between the coal resources and timber of West Virginia and the iron production centers in Virginia (Remo 1999; Mahan 2004; Covington 2005). The C&O constructed branch or spur lines to serve mines located along the New River's larger tributaries, including Mill Creek, Keeney Creek, Arbuckle Creek, Loop Creek, Laurel Creek, and Mann's Creek. The Kaymoor Mine on the south branch of the C&O railroad was opened in 1899 and mining continued there for 63 years (Covington 2005).

More than 150 coal companies were operating in the area by 1910. Mining operations required large-scale alteration of the landscape to construct towns, roads, and other infrastructure (Mahan 2004; Good and Stasick 2008). Extraordinary amounts of timber were harvested for things like posts, headers, ties, buildings, and fuel, as well as use in iron production (Grafton and Grafton 1980; Mahan 2004). By 1930, as much as 90% of the New River gorge had been deforested (e.g., fig. 9). As the forests grew back, the old-growth, mixed-mesophytic forest was replaced by shade-intolerant, early successional hardwood species, such as oak, black cherry (*Pinus serotina*), and red maple (*Acer rubrum*) (Redding 1995; Mahan 2004). Clear cutting had drastic

Figure 9. Photograph of conveyor and tipple in Nuttallburg circa 1927. Fordson Coal Company had just completed the new conveyor and tipple. Note the altered and deforested slopes above the community, as well as the mine refuse dumps on either side of the conveyor. At least four more dumps were later added. These dumps are still present and unstable (G. McColloch, geologist, West Virginia Geological and Economic Survey, written communication, 30 May 2017). Photograph NERI 312, included as an unnumbered figure in National Park Service (2001b).

effects on the New River Gorge landscape. Rainwater falling on the deforested slopes washed away loose topsoil, developed gullies in the sandy loam soils, and increased suspended and bedload sediment in rivers and streams (Lewis 1998; Mahan 2004). Construction of haul roads and mine sites themselves likely exacerbate erosion on steep slopes, particularly during floods (Mahan 2004). Floods in logged and otherwise disturbed areas caused catastrophic debris-flow damage along rivers and their tributaries (Johnson et al. 2000; Mahan 2004).

By the 1930s, industrial development, logging, and coal mining operations were beginning to decline in West Virginia (Lewis 1998; Mahan 2004). While most early mines in the area were subsurface, in the 1940s, large-scale surface coal mining began in the New River Gorge and persisted until the 1990s (Mahan 2004). The long-term, extensive history of mining left spoil and refuse piles across the landscape, which in turn, being deposited on steep slopes of the gorge, were unstable and often failed as debris slides and flows (Remo 1999; Mahan 2004). The parks continue to mitigate and reclaim quarry and mine features. However, some mine sites, including Turkey Knob, Quinnimont, Hope, Thurmond, and Fire Creek, are being preserved to interpret the mining history of the area (Mahan 2004). Some of these abandoned mine portals, adits, and shafts also function as vital bat habitat.

Ecological Connections

In addition to the historical connections briefly presented here, geologic features and processes are fundamentally connected with soils, water resources, vegetation patterns, and many animal habitats. Barren rocks, sandy riverbanks, rock crevices, and deep ravines support globally rare habitat types such as the Appalachian flatrock community, and large expanses of unfragmented and diverse forest types (Mahan 2004; Good and Stasick 2008). Suiter (1995), Vanderhorst (2001), and Mahan (2016) identified many natural vegetation communities in the gorges with several of them related strongly to geologic features and processes, including plant species associated with the Appalachian flatrock community where for centuries intermittent floods flushed the hard, flat sandstone bedrock along the river channels (e.g., **PNrural**, **Mhl**, **Mhu**, **Mpn**, and **Mbf**), stripping away soil and forcing plants to struggle in a perpetual state of renewal. Vegetation communities also include cliff faces (resistant ledges of units such as **PNnrun** and **PNnrln**), sandstone outcrops (e.g., **PNnrp** and **PNnrural**), rimrocks (resistant upland exposures of **PNk**), cold coves, floodplains (**Qbfp**, **Hfp**, **Qflp**, and **Qrff**), seeps, and herbaceous wetlands. The New River Gorge is floristically the most diverse gorge in the central and southern Appalachians (Mahan 2004). Many species of southeastern plants have colonized the gorges due to their southeast-to-northwest orientation towards the Ohio River. Many of the steep ravines found along the tributaries of the New River sustain cool moist environments even in the middle of summer that support species of plants normally found at much higher elevations and latitudes (Fortney et al. 1995; Mahan 2004). The rivers themselves contain a variety of habitats including runs, riffles, pools, pool edges, and environments created by submerged snags that support a diversity of fish and other aquatic wildlife (Purvis et al. 2002; Mahan 2004). Faunal species of concern, including Allegheny woodrats, neotropical migratory birds (including cerulean warbler), salamanders, bats, painted turtles, and native game animals and fish are protected in the three parks (Mahan 2004). White-nose syndrome has been detected within bats at New River Gorge NR. Mines in the park provide important bat habitat.

Additional information about other natural resources is available in the following references.

- Soil Resources Inventories (including GIS data) were updated in 2013 for
  - Bluestone NSR (https://irma.nps.gov/DataStore/Reference/Profile/2170694),
  - Gauley River NRA (https://irma.nps.gov/DataStore/Reference/Profile/2170704), and
  - New River Gorge NR (https://irma.nps.gov/DataStore/Reference/Profile/2170705).
- Information regarding the parks' water resources is available from the NPS Water Resources Division (http://go.nps.gov/waterresources). Information includes a water resources scoping summary for all three parks (https://irma.nps.gov/DataStore/Reference/Profile/578684) and baseline water quality projects for
  - Bluestone NSR (https://irma.nps.gov/DataStore/Reference/Profile/13689),
  - Gauley River NRA (https://irma.nps.gov/DataStore/Reference/Profile/2173860), and
  - New River Gorge NR (https://irma.nps.gov/DataStore/Reference/Profile/2173862)
- Annual weather and climate summary reports are available from the NPS Eastern Rivers and Mountains Network. The most recent available summary report is for 2015 (https://irma.nps.gov/DataStore/Reference/Profile/2231945).
- Vegetation inventories are available for all three parks:
  - Bluestone NSR (https://irma.nps.gov/DataStore/Reference/Profile/664379),
  - Gauley River NRA (https://irma.nps.gov/DataStore/Reference/Profile/2187539), and

- New River Gorge NR (https://irma.nps.gov/DataStore/Reference/Profile/2168883).

- The NPS Eastern Rivers and Mountains Network currently monitors natural resources such as weather, benthic macroinvertebrates, forest vegetation, soils, invasive species, streamside birds, riparian plants, and river water quality (http://science.nature.nps.gov/im/units/ermn/index.cfm).
- Mahan (2004) provided an assessment of the condition of natural resources at New River Gorge NR including air, geologic and geomorphologic, water, plant, and animal resources, as well as discussed potential threats to resources such as non-point source water pollution, oil and gas operations, mining, New River Parkway, I-64 to Hinton, and recreation (rafting, fishing, hiking, rock climbing, etc.). That document also presented management recommendations for all natural resources.
- Mahan (2016) discussed the unique vascular plant, lichen, and bryophyte communities that flourish on New River Gorge's cliff environments, controlled by geology and topography. Natural and man-made slope movements and rock-climbing activities may impact these communities.
- The foundation documents (National Park Service 2016a, 2016b, and 2016c) outlined the purpose, significance, fundamental resources and values, other important resources and values, and interpretive themes, as well as provided an assessment of planning and data needs for all three parks.
- Mahan and Darden (2014) discussed status and stewardship strategies for resources, including geology, hydrology, aquatic ecosystems, riparian zones, clean water, unfragmented forest, panoramic views, and cultural resources for New River Gorge NR.

Geologic Features, Processes, and Resource Management Issues

These geologic features and processes are significant to the parks' landscapes and histories. Some geologic features, processes, or human activities may require management for human safety, protection of infrastructure, and preservation of natural and cultural resources. The NPS Geologic Resources Division provides technical and policy assistance for these issues

During the 2004 scoping meeting (see Covington 2005) and 2016 conference call, participants (see Appendix A) identified the following features, processes, and resource management issues. Each is described in a table that provides basic information, park examples, additional resources, and potential action items.

- Slope movements, hazards, and risks (table 3)
- Paleontological resource inventory, monitoring, and protection (table 4)
- Coal mining, abandoned mineral lands, and disturbed lands (table 5)
- Oil and gas operations (table 6)
- Fluvial features, stream channel morphology, and flooding (table 7)
- Bedrock exposures (table 8)
- Weathering (karst) features (table 10)
- Shrink-and-swell clays (table 11)
- Folds and faults (table 12)
- Wetlands inventory (table 13)
- Seismic activity (table 14)

Geologic Resource Management

The Geologic Resources Division provides technical and policy support for geologic resource management issues surrounding three emphasis areas:

- geologic heritage,
- active processes and hazards, and
- energy and minerals management.

Contact the division (http://go.nps.gov/geology) for assistance with resource inventories, assessments and monitoring; impact mitigation, restoration, and adaptation; hazards risk management; law, policy, and guidance; resource management planning; data and information management; and outreach and youth programs (Geoscientists-in-the-Parks and Mosaics in Science). Park staff can formally request assistance via the Solution to Technical Assistance Requests (STAR) portal (https://irma.nps.gov/Star/).

The Geoscientists-in-the-Parks (GIP; http://go.nps.gov/gip) and Mosaics in Science (http://go.nps.gov/mosaics) programs are internship programs to place scientists (typically undergraduate students) in parks to complete geoscience-related projects that may address resource management issues. Completed projects are listed on the program websites. Products created by the program participants may be available on the websites or by contacting the Geologic Resources Division. Steve Kite, a Geoscientists-in-the-Parks intern, completed a general geology research project at New River Gorge NR in 1999. Later, Kite was a co-author on the surficial geologic maps for the parks.

Resource managers may find Geological Monitoring (Young and Norby 2009; http://go.nps.gov/geomonitoring) useful for addressing geologic resource management issues. The manual provides guidance for monitoring vital signs—measurable parameters of the overall condition of natural resources. Each chapter covers a different geologic resource and includes detailed recommendations for resource managers, suggested methods of monitoring, and case studies.

The parks' foundation documents (National Park Service 2016a, 2016b, and 2016c), New River Gorge NR resource stewardship strategy (Mahan and Darden 2014) and natural resource assessment (Mahan 2004) are primary sources of information for resource management within the parks. The natural resource assessment is currently being updated with a final draft expected in late 2017. Natural resource condition assessments for Bluestone NSR and Gauley River NRA are in the "gathering-information" phase and remain resource management needs (National Park Service 2016a, 2016b). Cultural landscape restoration and management are also addressed in several publications, including cultural landscape inventories (CLI) such as National Park Service (2001b).

The West Virginia Geological and Economic Survey, headquartered in Morgantown, is an excellent resource for local geologic information and technical assistance.

The survey maintains a website (http://www.wvgs.wvnet.edu) with extensive natural resource data to support park management, including the following:

- map services: http://ims.wvgs.wvnet.edu/index.html
- coal mine locations and outcrops: http://www.wvgs.wvnet.edu/GIS/CBMP/all_mining.html http://www.wvgs.wvnet.edu/www/coal/cbmp/coalimsframe.html
- mine-pool atlas: http://www.dep.wv.gov/WWE/wateruse/Documents/MinePoolAtlas.pdf
- oil and gas information: http://ims.wvgs.wvnet.edu/index.html#ogmaps http://www.wvgs.wvnet.edu/pipe2/OGDataHelp.aspx http://www.wvgs.wvnet.edu/pipe2/OGWISHelp.aspx

Slope Movements, Hazards, and Risks

Slope movements, also called "mass movements" or referred to generally as "landslides", have occurred and will continue to occur in all three parks. Slope movements are the downslope transfer of material (e.g., soil, regolith, and/or rock) (fig. 10). Slope movements can occur very rapidly (e.g., debris flows or rockfall) or over long periods of time (e.g., slope creep). The magnitude of slope failures depends on slope, aspect, soil type, and geology. Within the parks, the common types of movements are debris flows, rock slides, rock falls, rock topple, landslides, and river scour (figs. 10, 11, 12).

Slope movements are natural processes; they become hazards when visitors hike near the base of cliffs or under rock overhangs. Particularly hazardous areas are those with visible cracks, loose material, or overhangs. They also become hazards when they undermine or impact infrastructure (trails, roads, parking lots, other facilities) or already disturbed lands such as abandoned mines and tailings. Slope movements can also damage or destroy other natural or cultural resources. For example, material from gorge walls fall into the rivers, altering the stream morphology, suspending sediment (increasing bed load), and potentially altering rapids (table 7). Slope movements could also damage or destroy paleontological resources (table 4). As noted in the resource stewardship strategy for New River Gorge NR, slope movements in the gorge are natural; the target is to make them reflect historic (pre-industrial) frequency so that human activities do not accelerate/create slope movements (Mahan and Darden 2014).

There are many natural factors that contribute to slope movement. Frost weathering, plant-root wedging, streambank erosion, and differential erosion cause slope instability. Areas with denuded or disturbed vegetation are susceptible to increased erosion which can reduce slope stability. Local stratigraphy exacerbates slope issues because it is mostly sandstone and shale. When it rains and the shale becomes saturated with water, water lubricates the glide planes inherent in the platy shale causing slope failure. When the shale slopes fail, overlying sandstone layers may collapse, creating large slides or falls. Slope movements preferentially occur along joints and fractures within the gorges.

Slope movements along the hillslopes in the parks are highly dependent on weather events. Major precipitation (see "Fluvial Features, Stream Channel Morphology, and Flooding" section) causes surge events (brought on by increases in pore-water pressures), which increases the impacts of slope processes, particularly river scour, blowouts, debris flows, and landslides. Rapid, destructive slope movements such as debris flows are features, processes and hazards, all in one. Increased storm events predicted by climate change models may increase the likelihood and frequency of slope movements. Mass movements occur frequently on the outside of river bends due to the undercutting of slopes by the river (Remo 1999). Remo (1999) also found that mass movements occurred along stress-release and tectonic joints within the gorge.

Human activities may also trigger slope movements. Many of the historic and recent landslides in the lower gorge are below an outpouring of water from abandoned underground mines and are also associated with spoil and refuse piles from strip and deep mining (Remo 1999, as noted by Mahan and Darden 2014). Undercutting the toe of slopes for residential development, roads, or railroads may cause slope failure. Rock climbers and ATV use also likely contribute to smaller scale slope movements.

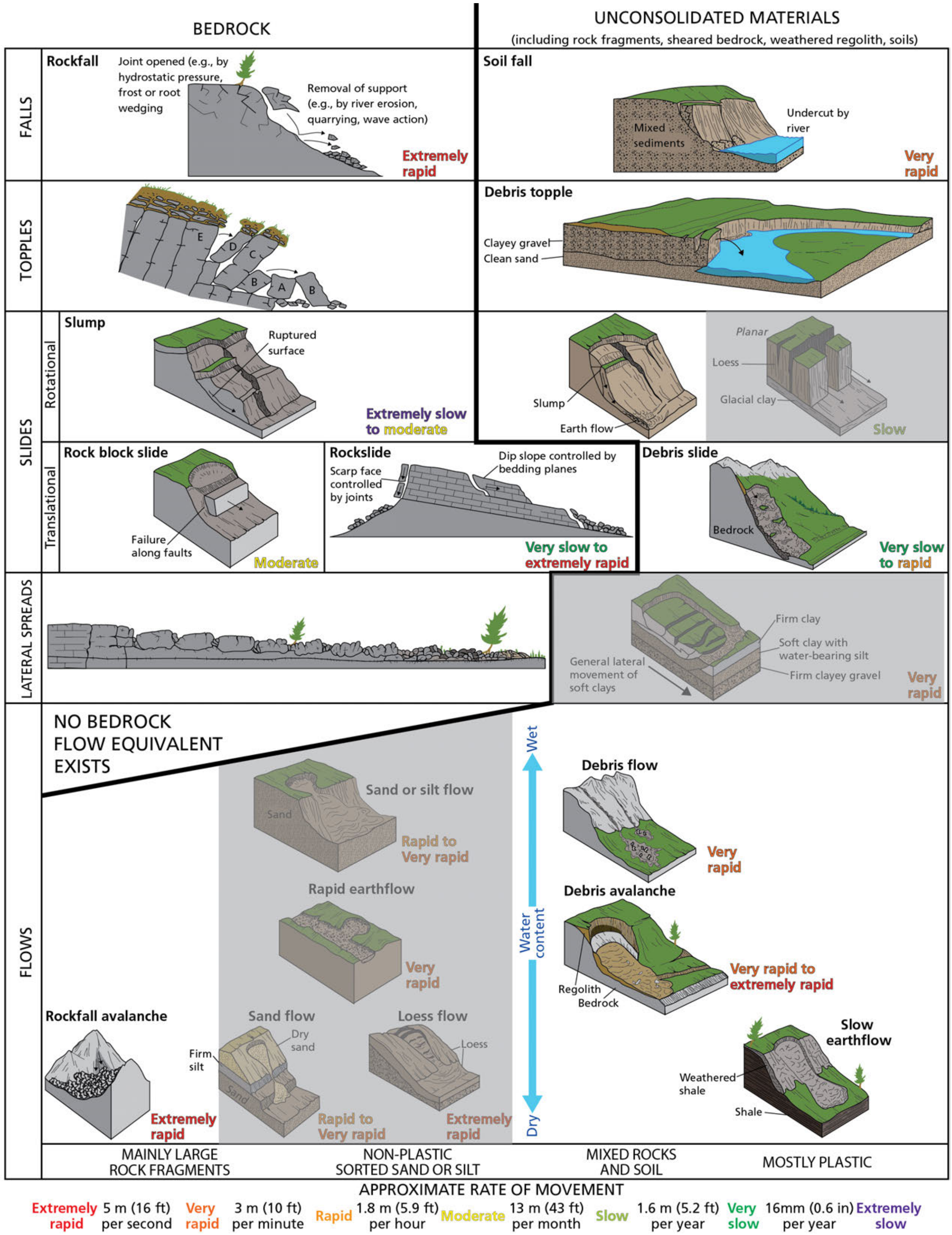


Figure 10. Illustrations of slope movements. Different categories of slope movement are defined by material type, nature of the movement, rate of movement, and moisture content. Grayed areas depict conditions unlikely to exist at Bluestone NSR, Gauley River NRA, or New River Gorge NR. The abundant vegetation in the parks stabilizes some slopes, but slope issues could be exacerbated by factors such as natural or anthropogenic removal of vegetation, mining activity, and climate change. Graphic by Trista Thornberry-Ehrlich (Colorado State University) redrafted after a graphic and information in Varnes (1978) and Cruden and Varnes (1996).

Table 3. Summary of slope movements, hazards, and risks. Table continues on next page.

Geologic Feature and Process	Slope movements, hazards, and risks
Related Map Units And Park Examples	• Many map units document slope movements and/or include slope movement deposits: colluvial veneer (**Hcv** and **Qcv**), colluvial mantle (**Hcm** and **Qcm**), colluvial apron (**Hca** and **Qca**), colluvial fan (**Hcf** and **Qcf**), bouldery tributary deposit (**Hbt** and **Qbtd**), landslide (**Hls** and **Qls**), blocky mantle (**Qbm**), entrenched stream channel (**Qfc**), boulder floodplain (**Qbfp**), tributary deposit (**Qtd**), river channel (**Qr**), and alluvial fan (**Haf** and **Qaf**). "Colluvium" is a generic term for rocks and other material of various sizes that has accumulated at the base of a cliff having been moved by runoff or slow continuous downslope creep. • At least two slide problem areas are in Bluestone NSR (12 slides are part of the GRI GIS data, mapped as **Hls**); 100 active slides occur in New River Gorge NR (212 slides are part of the GRI GIS data mapped as **Qls**); LiDAR was not of high enough resolution for accurate slide mapping in 85% of Gauley River NRA. Many landslides occur in the 15% where data exists (S. Kite, West Virginia University, conference call, 13 December 2016). • Rockfalls in the area may include the largest measured boulders in the eastern United States (S. Kite, West Virginia University, conference call, 13 December 2016). • Debris flows from 2001 floods caused extensive soil erosion, restructured some stream channels, and caused severe sedimentation. These were commonly due to mass-movement events located below abandoned mine sites (see tables 5 and 7). Slater Creek, Wolf Creek, Laurel Creek (near Quinnimont), and Buffalo Creek funneled large debris flows during the July 2001 flood events. Refer to the 2001 emergency rehabilitation plan (National Park Service 2001a) for additional information regarding impacts and mitigation measures following the 2001 storms. • Frequent washouts occur along access roads in Bluestone NSR. In New River Gorge NR, McKendree Road (access to the historical McKendree Hospital) is also susceptible to washouts.
Related Fundamental Resources	• Bluestone NSR: biological diversity, undeveloped primitive character • Gauley River NRA: biological diversity; undeveloped, rugged geologic landscape • New River Gorge NR: geological processes and features, hydrological resources, ecological resources, scenic resources
Related Resource Management Issues and/or Vital Signs	• In addition to direct damage to resources of visitor safety during a slope movement; slides and falls of various scale can impact access via roads or trails. • In addition to natural slope movements, anthropogenic activities (e.g., road and infrastructure construction, historic mining features) contribute to slope movements. Rock climbing could contribute to very small scale, localized slope movements. • Several historic and recent landslides in the lower New River Gorge occur where water flows out from abandoned underground mines. Slides also occur on spoil and refuse piles from strip and underground mining (Mahan 2004). • Contaminants released through mining or other land uses may be absorbed onto sediments that later are deposited downstream via slope movements, both as streambed sediment and as over-bank sediment (Mahan 2004). • Landslides have disrupted access to area. The park has current technical assistance (STAR) requests to help develop landslide hazard maps from existing data, including GRI GIS surficial map data. • At least 23 overlooks are used by visitors to New River Gorge. A STAR request is in progress to assess stability and other risk factors at these overlooks, particularly where underground mine features are present (table 5). • All three parks lack engineering geology expertise for roads, facilities, and construction planning; state and federal highway activity in the parks often requires a critical examination of geologic hazards and potential impacts.

Table 3, continued. Summary of slope movements, hazards, and risks. Table continues on next page.

<table>
<tr><th>Geologic Feature and Process</th><th>Slope movements, hazards, and risks</th></tr>
<tr><td>Potential Action Items</td><td>
Suggested management recommendations from Mahan (2004):

Establish a landslide and flood damage inventory and monitoring program for the gorge that is GIS based. The purpose of this program is to determine hazard zones within the gorge and avoid development and use of the zones.
Conduct yearly analysis in March of satellite and photographic imagery of the gorge to determine if new landslides and/or flood damage has occurred.
A detailed map of all major debris flows, including landslides and rockslides, should be prepared, and the historic versus current frequency of events estimated.

All three parks could utilize the unstable slope management system (potentially available in 2018) being developed by the National Park Service, Federal Highways Administration, and other federal land management agencies to inventory and proactively manage rockfall and landslide issues through a set of online and mobile database tools (e.g., Bilderback 2016).
Overlay GRI GIS surficial geologic map data with detailed digital elevation model maps available through the West Virginia GIS Technical Center (www.wvgis.wvu.edu) to produce landslide hazard maps. Areas with slope angles greater than 35° are particularly at risk. Areas currently mapped as landslides (Hls or Qls) or other slope movement deposits (see above list in table) may be susceptible to future movement as well.
Obtain and interpret observed and projected climate change monitoring data, including weather data (e.g., temperature, precipitation, and storm events) and assessment of climate models (projected climate futures) for the region to support adaptive park planning (e.g., resource stewardship strategy) and management decisions.
More detailed surficial mapping may yield evidence of offset beds or other features that indicate more recent seismicity or local, smaller scale faults (i.e., zones prone to slope movements).
Compare aerial photographs from the present to a series from the past to show the amount of material moved and the sequence of slope failure, as well as note changes in vegetation cover and vegetation type. Historical record sources may include CSX railroad, Landsat photos, and county aerial photos.
Determine the effects of roads, trails, and recreational activities on erosion rates in the gorge; biking and hiking trail development plan and climbing management plan should take into account slope movement risk.
Determine the stability of scenic overlooks on sandstone cliffs (STAR request submitted).
While working along park roads, trails, or structures, staff should document any possible new, or changes to, accumulations of slope deposits or other debris that may have been mobilized during rainfall events.
The NPS Geoscientists-In-the-Parks and Mosaics in Science programs are internship programs that could be utilized to address these issues.
</td></tr>
</table>

Table 3, continued. Summary of slope movements, hazards, and risks.

Geologic Feature and Process	Slope movements, hazards, and risks
Primary References or Resources	• Contact NPS Geologic Resources Division, West Virginia Geological and Economic Survey, and/or Radford University (contact as of 2017 is Chester "Skip" Watts) for geomorphology or engineering geology expertise for infrastructure projects. • Park-specific references: □ GRI GIS data, source maps, and scoping summary (Covington 2005). □ New River Gorge Floods–2001 Emergency Rehabilitation Plan: National Park Service (2001a) □ Landslide initiation factors for 2001 floods: Kish (2004) □ Restore natural mass movement conditions in Resource Stewardship Strategy: Mahan and Darden (2014) □ Natural resource condition assessment: Mahan (2004) □ Geologic controls of mass movement in New River Gorge: Remo (1999) □ Geologic and topographic controls on rapids: Mills (1990) □ Origin of rapids: Moore (1999) □ Landslide map: Davies and Ohlmacher (1977) • General information: □ NPS Geologic Resources Division Geologic Hazards http://go.nps.gov/geohazards □ US Geological Survey landslides website http://landslides.usgs.gov/. □ Monitoring slope movements: Wieczorek and Snyder (2009; http://go.nps.gov/geomonitoring) □ US Geological Survey landslide handbook: Highland and Bobrowsky (2008) □ Landslide hazards and climate change: Coe (2016) □ West Virginia Department of Natural Resources http://www.wvdnr.gov/

Figure 11 (facing page). Photographs of slope movements at New River Gorge NR. Rivers have created deep, steep gorges that are prone to slope movements such as flows (A, D, and E), slides (B, C, F), and falls (G, H, and I). NPS Geologic Resources Division photographs by Deana Greco in 2002 (A, B, and C), Hal Pranger in 2001 (D, E, and F), and John Burghardt in 2006 (G, H, and I).


A
B
C
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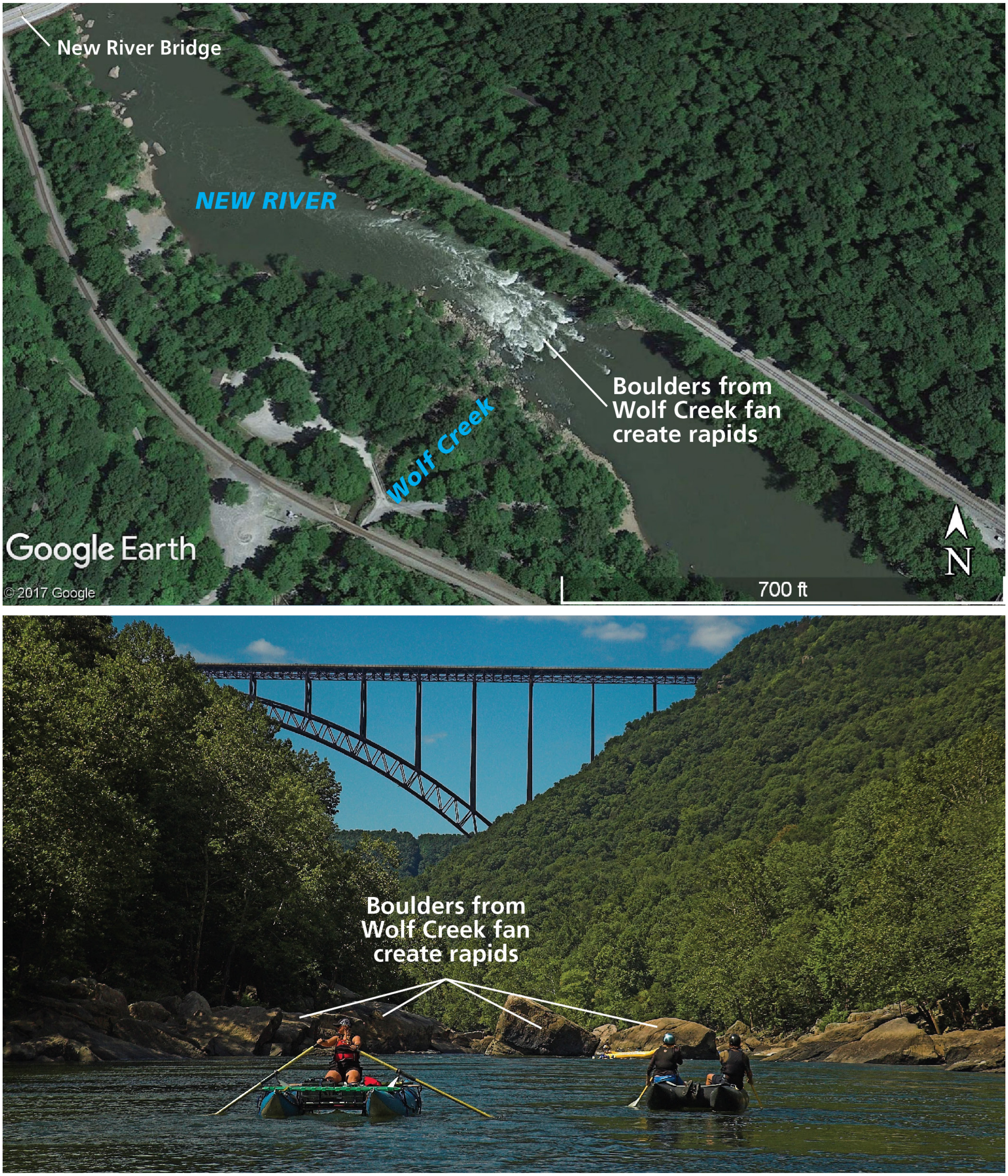


Figure 12. Aerial image and photograph of large boulders from Wolf Creek fan in New River Gorge NR. The large boulders have a median size of more than 4.6 m (15 ft) and were transported downslope into the New River via slope movements. Large debris flows occurred in the parks following storms in 2001. These large boulders created the rapids at Wolf Creek and other areas. Information from Hal Pranger (NPS Geologic Resources Division, geomorphologist, email, 19 May 2017). Aerial image © 2017 Google, extracted from Google Earth. River image is a National Park Service photograph by Gary Hartley, available at https://www.nps.gov/neri/learn/photosmultimedia/photogallery.htm.

Paleontological Resource Inventory, Monitoring, and Protection

Fossils have been discovered in all three parks. Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). All fossils are nonrenewable. Body fossils are any remains of the actual organism such as bones, teeth, shells, or leaves. Trace fossils are evidence of biological activity; examples include burrows, tracks, or coprolites (fossil dung). Fossils in NPS areas occur in rocks or unconsolidated deposits, museum collections, and cultural contexts such as building stones or archeological resources. As of February 2017, 267 parks, including all three parks in this report, had documented paleontological resources in at least one of these contexts. All three parks contain fossils in their bedrock (see table 4); the fossils are primarily marine invertebrates or plant fossils. The parks have not yet been systematically assessed for fossils in cultural contexts but fossils are likely to exist in local building stones. Likewise, a search of museums for fossils from the parks has not yet been undertaken. However fossils from the formations mapped in the park are in the collections of a number of museums including the Smithsonian National Museum of Natural History (Washington, DC), Carnegie Museum of Natural History (Pittsburgh), West Virginia Geological and Economic Survey (Morgantown), West Virginia University (Morgantown), Marshall University (Huntington, WV), and the West Virginia Museum of Culture and History (Charleston) (Prehistoric West Virginia 2005). The NPS Fossils and Paleontology website, http://go.nps.gov/fossils_and_paleo, provides more information about fossils in national parks. Table 4 summarizes fossil examples from the parks, potential action items, and references and additional resources regarding paleontological resource management.

The New River Gorge NR foundation document (National Park Service 2016c) specifically mentions fossils as a fundamental resource or value (as a component of "Geologic Features and Processes"). The need for additional, site-specific information about fossil resources has been noted for New River Gorge NR and would also be beneficial for the other parks.

Table 4. Summary of paleontological resource inventory, monitoring, and protection issues. Table continues on next page.

Resource Management Issue	Paleontological Resource Inventory, Monitoring, and Protection
Related Fundamental Resources	• Bluestone NSR: historic travel corridor and associated cultural resources, undeveloped primitive character • Gauley River NRA: undeveloped, rugged geologic landscape, cultural history of the Gauley River Gorge • New River Gorge NR: geological processes and features, historical and archeological resources, scenic resources
Related map units and park examples (continues on next page)	• Fossils are documented in the bedrock of all three parks (fig. 13), both in situ (still in place) or in "float" (blocks of rock that have tumbled down slope or downstream). • Bluestone NSR: **Mhl**, **Mhlsg**, **Mhu**, **Mpn**, and **Mbspd** contain fossils, which are listed in the unit descriptions in the blue_geology.pdf in the GRI GIS data and Koch and Santucci (2004). Those fossils include plant fossils (e.g., *Stigmaria stellata*, *Lepidodendron veltheimi* [fig. 14], and *Sphenopteris elegans*), rugose corals, conularids, bryozoans, brachiopods, bivalves, pelecypods, gastropods, cephalopods, trilobites, crinoids, fish fossils, echinoderms, and burrows (fig. 15). • Gauley River NRA: **PNrural**, **PNnr**, **PNnrln**, **PNnrun**, and **PNk** contain fossils, which are listed in the unit descriptions in the gari_geology.pdf in the GRI GIS data and Koch and Santucci (2004). Those fossils include plant fossils (e.g., *Neuralethopteris*), and locally rare rugose coral, brachiopods, pelecypods, gastropods, echinoderms, fossil fish, burrows, and plant impressions (fig. 15).

Table 4, continued. Summary of paleontological resource inventory, monitoring, and protection issues.

Resource Management Issue	Paleontological Resource Inventory, Monitoring, and Protection
Related map units and park examples, continued	● New River Gorge NR: **Mbf**, **Mhsg**, **Mhl**, **Mhlsg**, **Mhu**, **Mpn, Mbs**, **PNp**, **PNnrp**, **PNnr**, **PNnrlral**, **PNnr**, **PNrural**, **PNnr**, **PNnrln**, **PNnrun**, and **PNk** contain fossils, which are listed in the unit descriptions in the neri_geology.pdf in the GRI GIS data and Koch and Santucci (2004). Those fossils include plant megafossils (e.g., *Stigmaria ficoides*, *Cyperites bicarinatus*, *Lepidostrobophyllum* spp., *Calamites radiatus*, *Mesocalamites* sp., *Sphenopteris elegans*, *Cordaites* sp., and *Stigmaria stellata*), rugose corals, conularids, bryozoans, brachiopods, bivalves, pelecypods, gastropods, cephalopods, trilobites, crinoids, fish fossils, echinoderms, arthropods, mollusks, and burrows (fig. 15). ● An important plant index fossil occurs in New River Gorge—a seed fern (*Mariopteris muricata*) that indicates the separation between two geologic ages within the Pennsylvanian Period. ● Fossils in the parks are potentially subject to impacts by erosion and slope movements, as well as unauthorized collecting, theft, or vandalism.
Potential Action Items	● A field inventory (GIS based) and survey of fossil resources would provide site-specific information if the park is interested in more detailed paleontological resource inventory and monitoring. Such an effort was considered a "low priority" in the New River Gorge NR foundation document. ● Identify potential interpretive quarries or sites for visitors can view fossils in a controlled, monitored setting. Potential target units include the Hinton Formation, Little Stone Gap Member (Avis limestone; **Mhlsg**). ● The New River Gorge NR resource stewardship strategy (Mahan and Darden 2014) sets a target that significant geologic features (including fossil localities) are mapped, evaluated for management, and protected, including from vandalism and collecting. ● One strategy from Mahan and Darden (2014) is to locate, interpret, and protect geologic type localities and other significant geologic and paleontological features (sandstone, quarries, etc.) and use this information to create a geologic tour. ● These items could be addressed via technical assistance request to the Geologic Resources Division, and/or via the Geoscientists-in-the-Parks or Mosaics in Science internship programs.
References and Additional Resources	● Park-specific references: □ Paleontology Literature Review & Collections Survey Of Vertebrate and Invertebrate Fossils: Prehistoric West Virginia (2005) □ Natural resource condition assessment: Mahan (2004) □ Mapping paleontological resources in Resource Stewardship Strategy: Mahan and Darden (2014) □ Eastern Rivers and Mountains Network paleontology summary: Koch and Santucci (2004) □ General geology and paleontology: Gillespie et al. (1978), Grafton and Grafton (1980) □ Plant fossils guide: Gillespie and Pfefferkorn (1984) □ GRI information: fossils mentioned in scoping summary (Covington 2005) and bedrock source map unit descriptions (see blue_geology.pdf, gari_geology.pdf, and neri_geology.pdf) ● General information: □ Monitoring in situ paleontological resources: Santucci et al. (2009; http://go.nps.gov/geomonitoring) □ NPS Fossils and Paleontology website: http://go.nps.gov/fossils_and_paleo

Figure 13. Photographs of plant fossils. Fossils can appear in situ of bedrock outcrops or as float (blocks of rock that have tumbled down slope or downstream). The bedrock in all three parks is fossiliferous and the most common fossils are plants (this figure) and marine invertebrates (fig. 15). (A) is partial tree stump, likely *Sigillaria* exposed in a road cut near Bragg, outside New River Gorge NR. (B) is a compressed plant fossil, also likely *Sigillaria*. (C) is a bark impression from *Lepidodendron* showing its distinctive morphology. The *Sigillaria* stump in (A) illustrates the fossil preservation processes and resource management challenges for fossils in the parks. As described by G. McColloch (geologist, West Virginia Geologic and Economic Survey, written communication, 30 May 2017), this *Sigillaria* was one of the last standing while the coal swamp, represented by the thin, unnamed coal below the stump, while the swamp eventually gives way to drier siltier environment. The *Sigillaria* cast was preserved by fine sediments that buried it, after which the internal pithy material decomposed. Later a river channel (Pineville Sandstone) truncated the Sigillaria stump, eroded the top, and filled the cavity with sand that would become sandstone. Features like this called “kettle bottoms” by miners are sometimes common in underground coal mines in thicker coals. They are dangerous unless supported as typically the fossil drops out along its boundary or the enveloping coal layer fails allowing the fossil cast to fall unpredictably. This example met the same fate in the roadcut as it collapsed and was no longer visible a year after this photo was taken. Fossils in the parks are subject to natural erosion processes, as well as theft or vandalism or unintentional damage by visitor use. Photographs by Gayle H "Scott" McColloch, Jr. (West Virginia Geologic and Economic Survey), taken in July 2012 (large stump) and September 2011 (other photos). Annotations by Trista L. Thornberry-Ehrlich (Colorado State University).

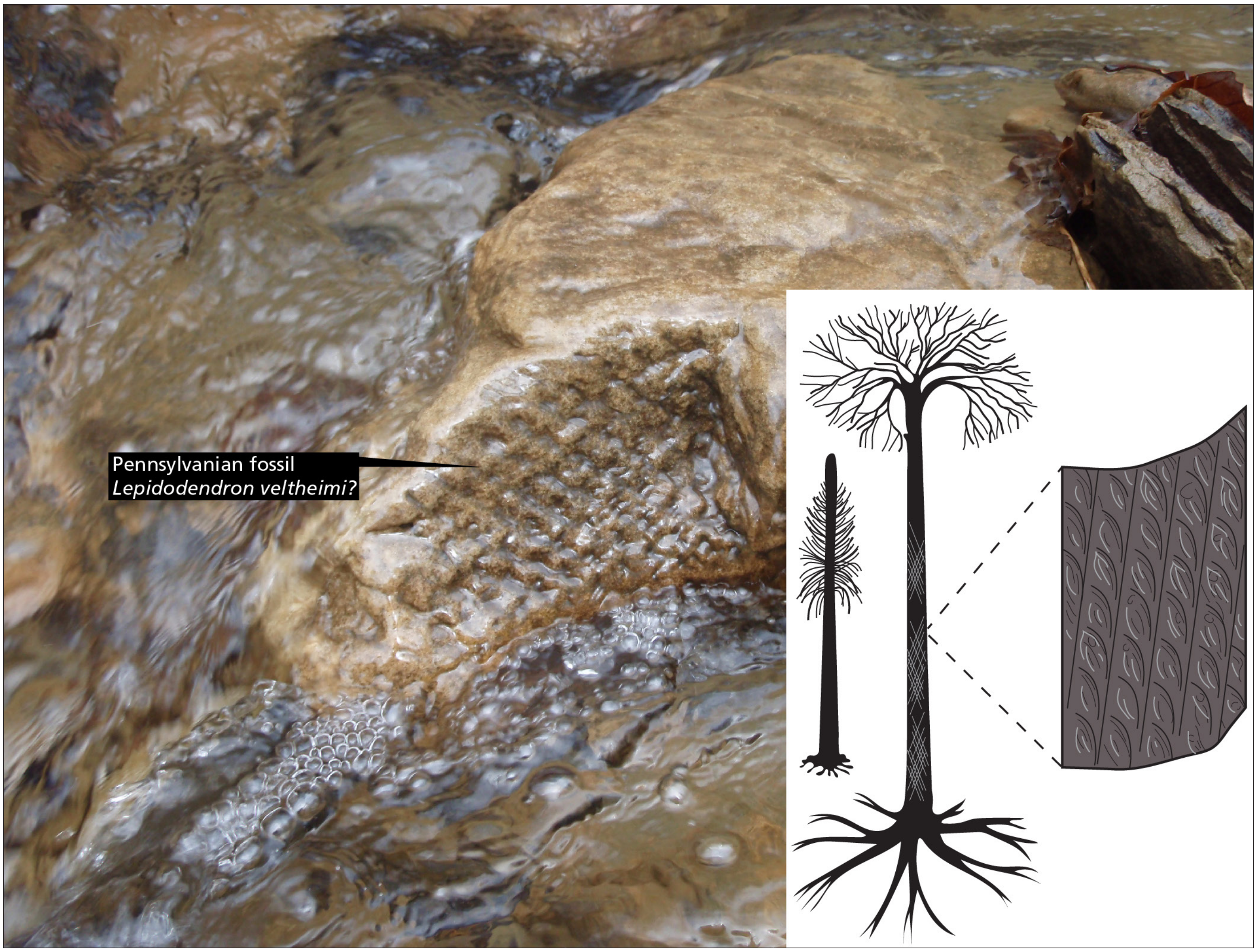
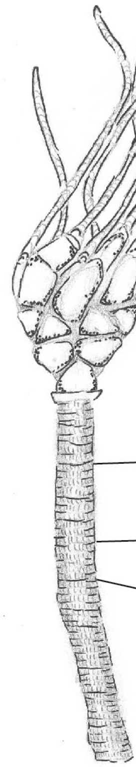
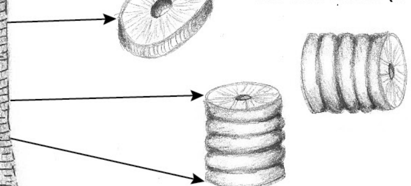


Figure 14 (above). Photograph of a fossil impression in Buffalo Creek, a tributary to the New River. Fossils of Pennsylvanian plants are common in the parks, this is likely a "bark" impression from a large tree-like plant called *Lepidodendron*, or "scale tree." These plants (see inset for reconstruction) were common in the coal swamps of the time and could be up to 30 m (100 ft) tall. In this example, the fossil is on a boulder within a creek and will eventually erode away. NPS photograph by Andrew Weber taken on 26 March 2011. Sketch by Trista L. Thornberry-Ehrlich (Colorado State University).

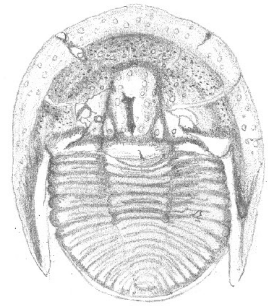
Figure 15 (facing page). Sketches of representative Paleozoic fossils. The sandstone, siltstone, shale, and coal layers in all three parks are fossiliferous. These sketches are representative of some of the fossil marine invertebrates that may be present in the parks' geologic units, particularly the Mississippian age carbonates. Fossils are at risk of burial or degradation by natural and anthropogenic slope processes, as well as theft. Sketches by Trista L. Thornberry-Ehrlich (Colorado State University).



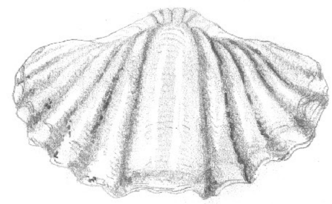
Mississippian crinoid



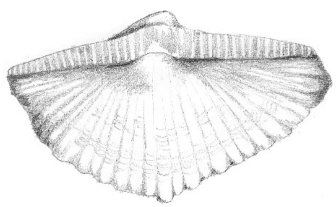
Crinoid disks (1 cm)



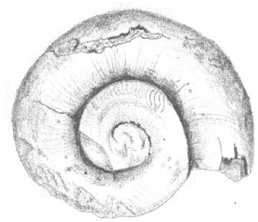
Trilobite (1.5 cm)



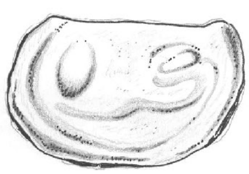
Brachiopod (3 cm)



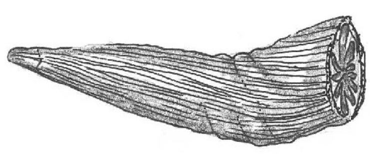
Mississippian brachiopod (4 cm)



Gastropod (2 cm)

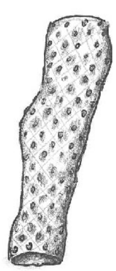


Pennsylvanian ostracode (x50)

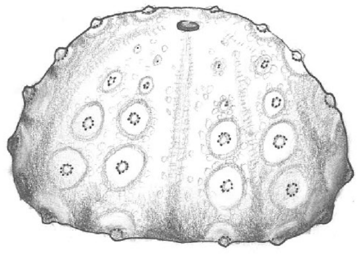


Pennsylvanian horn coral (5.5 cm)

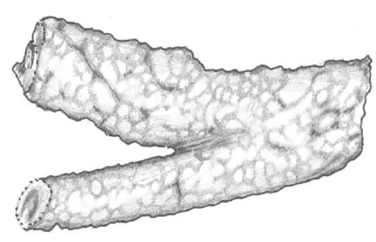
Cephalopod (6 cm)



Ordovician–Permian bryozoan (6 cm)



Echinoderm (4 cm)



Burrow cast (x0.5)

Coal Mining, Abandoned Mineral Lands, and Disturbed Lands.

As described in the "Geologic Setting, History, and Significance" chapter, surface and underground mining—particularly for coal—has been a part of the local history and economy for many years. In addition, quartz-rich sandstones were mined for glass because of their high silica content (98–99%; e.g., Nuttall Sandstone [**PNnrun**, **PNnrln**]). This long legacy also created a network of abandoned mineral lands and other disturbed lands particularly in New River Gorge NR and Gauley River NRA. Abandoned mineral lands (AML) are lands, waters, and surrounding watersheds that contain facilities, structures, improvements, and disturbances associated with past mineral exploration, extraction, processing, and transportation, including coal mining features (fig. 16). Disturbed lands are where natural conditions and processes have been directly impacted by development, including facilities, roads, dams, landfills, and abandoned campgrounds; agricultural activities such as farming, grazing, timber harvest, and abandoned irrigation ditches; overuse; or inappropriate use. Abandoned underground mines (deep mine portals) present hazards to visitors including danger of roof falls, poisonous and explosive gases (methane), and deep pools of water, as well as decrepit structures associated with the mines such as collapsed buildings, unstable walls, conveyors, rail lines, bridges, hazardous equipment and debris (fig. 17).

In addition to direct resource management issues, AML and other disturbed lands can also exacerbate other resource management issues, including slope movements (table 3) and water quality. Acid mine drainage from oxidation of iron sulfide (pyrite) in coal is of particular concern. Water exiting AML features (e.g., through auger holes or portals) saturates slopes, creating increased potential for slope movements. Sediment load in local streams and pollutants including iron, manganese, and aluminum are consistently higher in mining areas. Mining causes changes in gravel bar composition; coal particulates are introduced to the sediment load and deposited in the bars. Large-scale surface coal mining and associated valley fill from adjacent areas may change the response of streams to storm events. During storms when rainfall exceeded 2.5 cm (1 in) per hour, runoff from streams in a valley-filled watershed exceeds peak runoff from an unmined watershed—possibly due to loss of canopy cover, which intercepts and retains some rainfall.

AML features are important bat habitat and an additional concern for AML features in the parks is the detection of white-nose syndrome in New River Gorge NR in 2011. White-nose syndrome (WNS) is a fatal disease in bats caused by the fungus Pseudogymnoascus destructans. The disease affects cave-dwelling bats. Researchers first discovered the disease in New York in the winter of 2006. Since then, it has spread to more than half of the United States, killing millions of bats—up to 99% of some bat colonies. The National Park Service works with many other state and federal agencies as well as conservation organizations to learn more about the fatal disease and how to slow its spread (refer to https://go.nps.gov/wns and https://www.whitenosesyndrome.org/ for more information). In West Virginia, the West Virginia Division of Natural Resources (http://www.wvdnr.gov/) monitors bat distribution and populations.

The Surface Mining Control and Reclamation Act of 1977, 30 USC §§ 1234-1328 (SMCRA) prohibits surface coal mining within the boundaries of any unit of the National Park System, subject to "valid existing rights" (VER). This act states: "no surface coal mining operations except those which exist on the date of enactment of this Act [enacted Aug. 3, 1977] shall be permitted…On any lands within the boundaries of units of the National Park System… [and] which will adversely affect any publicly owned park or places included in the National Register of Historic Sites unless approved jointly by the regulatory authority and the Federal, State, or local agency with jurisdiction over the park or the historic site…" (30 USC § 1272(e)).

Land acquisition for the formation of the Bluestone NSR, Gauley River NRA, and New River Gorge NR did not include mineral rights and much of the land within the authorized boundaries remains in private ownership. According to park managers, all valid existing rights within New River Gorge NR and Gauley River NRA were exhausted many years ago. Therefore, surface coal mining operations cannot take place in the parks. If a surface coal mine operation is proposed near the boundary and the NPS concludes that the operation will adversely affect park resources, then the NPS becomes a joint permitting agency with the state agency that administers the Office of Surface Mining Reclamation and Enforcement (OSMRE)-approved program. The NPS should require mitigation measures designed to reduce the impacts to park resources. If mitigation measures cannot be sufficiently designed to avoid the adverse effects, then the National Park Service should decline, as consistent with the law, to approve the operation as proposed.

An alternative to disapproval is for the National Park Service and/or other interested parties to petition the Office of Surface Mining Reclamation and Enforcement to declare the lands proposed for the surface mine unsuitable for surface coal mining. This is a preferable option as it increases predictability for all parties.

SMCRA also prohibits surface coal mining operations "within three hundred feet from any occupied dwelling, unless waived by the owner thereof, nor within three hundred feet of any public building, school, church, community, or institutional building, public park, or within one hundred feet of a cemetery."

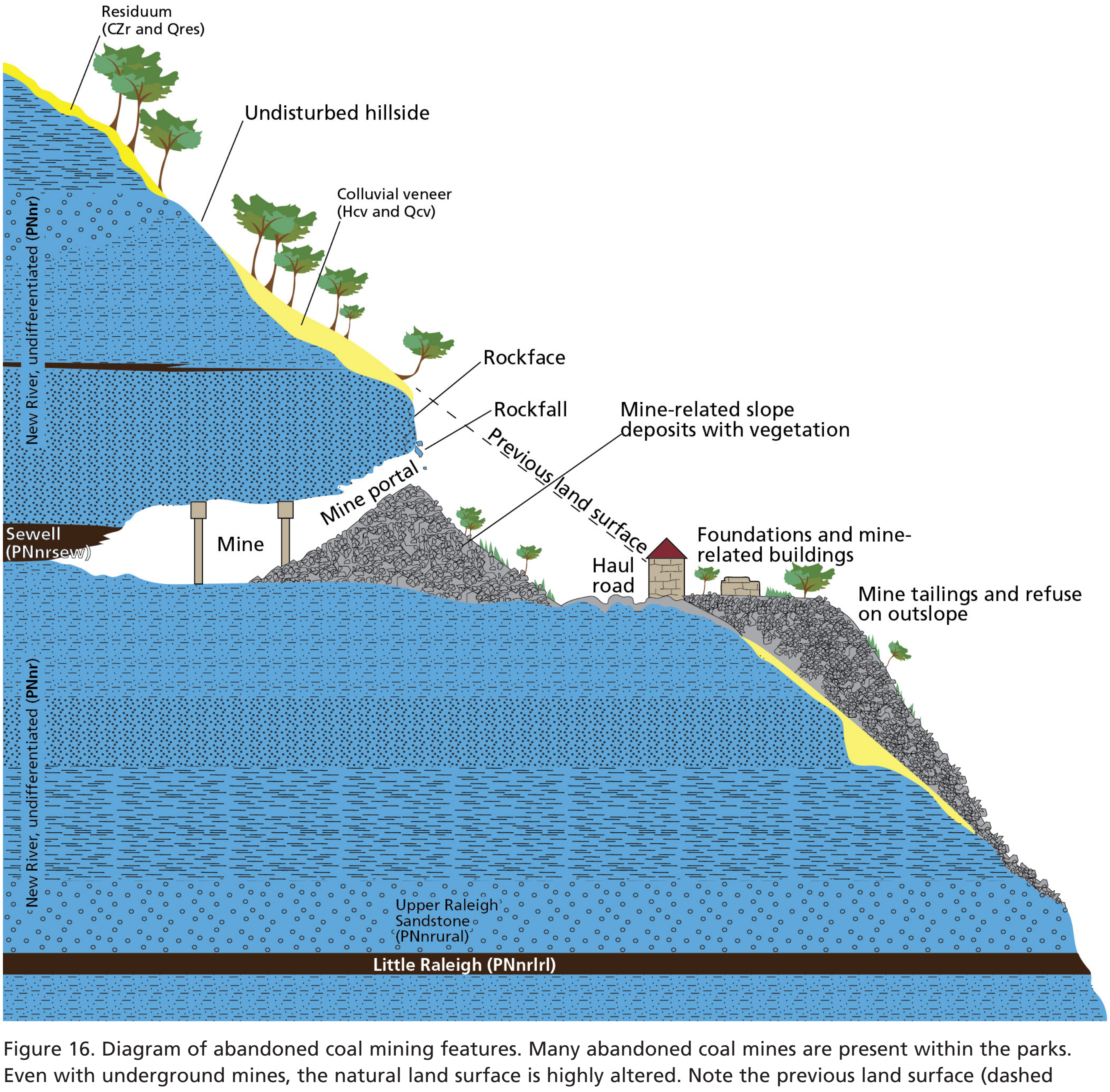


Figure 16. Diagram of abandoned coal mining features. Many abandoned coal mines are present within the parks. Even with underground mines, the natural land surface is highly altered. Note the previous land surface (dashed line). Landform change continues as the mines collapse and tailing (refuse or spoil) piles undergo exacerbated slope processes. Vegetation is slow to reestablish on mine tailings. Units were chosen to represent a mine into the Sewell coal seam (geologic map unit PNnrsew). Graphic adapted from diagram 1 in Pollio (1991) by Trista L. Thornberry-Ehrlich (Colorado State University).

Table 5. Summary of coal mining, abandoned mineral lands, and disturbed lands issues. Table continues on next page.

Resource Management Issue	Coal mining, abandoned mineral lands, and disturbed lands
Related Fundamental Resources	• Bluestone NSR: biological diversity, the Bluestone River, historic travel corridor and associated cultural resources, recreation opportunities, undeveloped primitive character • Gauley River NRA: biological diversity; undeveloped, rugged geologic landscape; opportunities for world-class recreation; water quality, cultural history of the Gauley River Gorge • New River Gorge NR: geological processes and features, hydrological resources, ecological resources, historical and archeological resources, scenic resources, visitor opportunities
Related map units and park examples (continued on next page)	• **PNppc3, PNppc6, PNnrfck, PNnrlrl, PNnrsew, PNnfhuf, PNklwe, PNkeag, PNkn2g, PNkcbg,** and **PNkstk.** • Prominent coal beds are linear geologic units in the GRI GIS data. • Structure contour lines, showing the elevation of the top of the coal layer across the map area are included in the GRI GIS data for Gauley River NRA and New River Gorge NR for PNKeag, PNnrfck, and PNrsew. • Coal sample locations, mines, borehole and core locations are included in the GRI GIS data. • Silica was mined from the New River Formation (**PNnr**) during the construction of the Hawk's Nest tunnel for use in electroprocessing steel; many miners died of silicosis after inhaling the toxic dust associated with mining silica and tunnel blasting (Dotson-Lewis 2009). • Many mine areas are classified as cultural landscapes, including Nuttallburg (figs. 18 and 19), Cunard Mine Site, Kaymoor (figs. 20 and 21), and Quinnimont. Cultural landscape features associated with mining may include mine portals, tailing piles, coke ovens, tipples, conveyors, head houses, haul roads, mine benches, retaining walls, cap houses, powder houses, fan houses, tramway lines, and tramway foundations. • Burghardt et al. (2014) documented the following AML features and sites within the parks as part of the NPS AML database: □ Gauley River NRA: 39 features at five sites; 21 of those features are considered high priority for mitigation. □ New River Gorge NR: 696 features at 122 sites; 124 features have already been mitigated, 105 require mitigation. 92 of those features, at 39 sites, are considered high priority for mitigation; 13 features at 10 sites are considered medium priority for mitigation. □ Bluestone NSR: no AML features or sites were documented. • Monitoring at 36 abandoned mine portals in New River Gorge NR revealed the importance of the human-made habitats to bats, woodrats, and salamanders. • The NPS Geologic Resources Division helped fund closures of mine openings (with bat gates where appropriate) at Nuttallburg, Beurytown, Terry Top, Stonecliff, Concho, Alaska, Wolf Creek, Fayette Station, Fire Creek, Beury, Bachman, Whitney, Brooklyn, Rush Run, Red Ash, at Kaymoor Mine, Eleverton Mine, Craig's Branch Mine, Ames Complex and Anderson (Gauley River NRA). • Through funding from the Office of Surface Mining (OSM), a five-year program (1987–1992) closed 161 mine openings in New River Gorge NR (e.g., fig. 18). • Mining was recently proposed for the Glade Creek area into the Fire Creek coal bed (PNnrfck); this is located near Babcock Park, but has not yet been pursued as concerns persist about the shallow nature of the seam and the structural integrity of the overburden. The mine roof could collapse or the creek's drainage may divert through the mine. • Streams draining basins that have been mined since 1980 show increased dissolved sulfate, decreased median bed-sediment particle size, and impaired benthic-invertebrate habitats compared to streams not mined. • Low pH (between 3.5 and 4.8) and high iron and aluminum content are common in soil testing near "gob" piles (coal waste) such as the Brooklyn refuse pile. Vegetation is slow to establish itself on the steep refuse piles.

Table 5, continued. Summary of coal mining, abandoned mineral lands, and disturbed lands issues. Table continues on next page.

Resource Management Issue	Coal mining, abandoned mineral lands, and disturbed lands
Related map units and park examples, continued	• Water from mine portals is generally potable; however, water from gob piles at production facilities has a low pH (~2.5) and can severely impact downstream water quality; the Claremont site (planned for reclamation) has acid mine drainage from its associated tailing pile. • Elevated sulfate concentration and slightly acidic water were more common at wells within 300 m (1,000 ft) of reclaimed mines than elsewhere. • Culverts in the park tend to pond water on some of the gob piles resulting in acid mine drainage. • Waste piles (overburden) from surface mining are side-cast from the mines forming linear piles at least 15 m (49 ft) deep by about 50 m (164 ft) wide and about 0.5 km (0.3 mi) long. • In the Kanawha River basin, sediment yields more than doubled in locations that supported large areas of surface mining and associated road construction. • New River tributaries with mine runoff problems are Rush Run (acid mine drainage), Piney (elevated metals), Meadow (acid mine drainage), Wolf (acid mine drainage), Arbuckle (elevated metals), Dunloup (elevated aluminum), and Peters creeks. • Following the floods of 2001, the spoil pile near Elverton, the Claremont waste bank, and the Marr Branch reclaimed spoil pile had slides and severe gullying at accelerated rates when compared with natural settings. • A trail was washed away in 2015 in New River Gorge NR where water exiting a mine—an unnatural drainage—caused slope failure (see table 3). • Potential issue such as leaks, spills, derailments and other accidents are associated with rail transport of ore and other mining related materials. • Illegal ATV use on abandoned mining roads causes accelerated erosion which may lead to slope movement issues. • White-nose syndrome was detected in bats using AML features as habitat within New River Gorge NR in 2011. • Abandoned county landfills near the boundary of New River Gorge NR are may be sources of pollutants to the river system. More investigation is needed at these sites. • Many impoundments (dams, catchments, and other sediment control features) exist in the parks, at least six in New River Gorge NR alone. Some of these features are several acres in size. Many impoundments are in disrepair or are leaking. An inventory and inspection plan is suggested for impoundments in the parks.
Potential Action Items	• Inventory and enter mine discharge locations and groundwater seeps into a GIS. • Identify and properly gate additional mine portals used by bat species and/or salamanders. • Determine locations and volumes of mine tailings in all three parks. Determine revegetation or other reclamation status and potential. • Monitor reclaimed mine areas with repeat photography of revegetated slopes to determine reclamation success and identify areas in need of further action. • Document potential mining claims or expansion of existing mines near the parks and participate in planning processes to limit impact to park resources. • Develop reclamation plans for AML and other disturbed features as appropriate. • Inventory dams, catchments, and other sediment control structures; inspect for integrity and need of remediation/reclamation or lack thereof (potential contacts include USDA Natural Resources Conservation Service and the West Virginia Department of Environmental Protection [http://www.dep.wv.gov/Pages/default.aspx]). Determine if discharges from these structures have the potential to impact water resources.

Table 5, continued. Summary of coal mining, abandoned mineral lands, and disturbed lands issues. Table continues on next page.

Resource Management Issue	Coal mining, abandoned mineral lands, and disturbed lands
References and Additional Resources	• Park-specific references: • Abandoned mine land site visit: Cloues and Geise (1998) • Storm response: Messinger (2003) • Water quality: Paybins et al. (2000) • Natural resource condition assessment: Mahan (2004) • Administrative history of the parks: Good and Stasick (2008) • GRI GIS data, source maps, and scoping summary (Covington 2005). • Reclamation recommendations following 2001 flood and slope movement events: National Park Service (2001a) • Geology and history of the Nuttall Mine and Nuttallburg: McColloch and McColloch (2014) • Buffalo Creek flood: http://www.wvculture.org/history/buffcreek/bctitle.html • General information: • NPS Geologic Resources Division Abandoned Mineral Lands website http://go.nps.gov/aml • Abandoned mineral lands in the National Park System: comprehensive inventory and assessment by Burghardt et al. (2014) • West Virginia Geological and Economic Survey coal mine locations and coal outcrop maps (all coals) http://www.wvgs.wvnet.edu/GIS/CBMP/all_mining.html and maps by individual bed http://www.wvgs.wvnet.edu/www/coal/cbmp/coalimsframe.html; these are available as GIS layers • West Virginia Geological and Economic Survey mine-pool atlas (modeling software available) http://www.dep.wv.gov/WWE/wateruse/Documents/MinePoolAtlas.pdf • Mine pool information, researchers Brian A. Carr and Andrew N. Schaer with West Virginia Department of Environmental Protection • West Virginia Department of Environmental Protection GIS service http://tagis.dep.wv.gov/home/ • Technical assistance for water quality issues: NPS Water Resources Division http://go.nps.gov/waterresources

Figure 17. Photographs of the interiors of abandoned mines. As of 2017, most mine openings have been gated; however, some openings remain open and mines present various hazards to visitors including crumbling (sloughing) ceilings, abandoned mine infrastructure, and deep holes. Mines are also habitat for bat species, some of which have contracted white-nose syndrome. Photographs taken in 2006 by John Burghardt (NPS Geologic Resources Division), annotations by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 18. Photographs of gated mines and remnant coal tailing piles. As of 2017, most mine openings have been gated. Bat-friendly gates decrease potential for danger to visitors while preserving access for animals and insects. Photographs taken in 2006 by John Burghardt (NPS Geologic Resources Division), annotations by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 19. Photographs of cultural resources associated with the Nuttallburg mining area. Mining continues in the New River area, but operations in the gorge had largely ceased by the 1960s. Company towns such as Nuttallburg were largely left to ruin. Some of these features provide valuable interpretive opportunities, but may also pose hazards to visitors and park staff. Photographs presented as unnumbered figures in National Park Service (2001b), annotations by Trista L. Thornberry-Ehrlich (Colorado State University).

Figure 20. Photograph of coal miners at Kaymoor in the 1920s. Many people came to the area to work in the mines extracting the valuable, clean-burning coal from the Pennsylvanian Pocahontas, New River, and Kanawha formations. Photograph is figure 33 in Good and Stasick (2008).

Figure 21 (facing page). Photographs of Kaymoor Mine. Top photograph shows the gated entrance to the mine. Bottom photograph shows a safety sign that welcomed miners, and now visitors, to Kaymoor with the words "Your Family Wants You To Work Safely". National Park Service photographs by Dave Bieri, available at https://www.nps.gov/neri/learn/photosmultimedia/photogallery.htm.


YOUR FAMILY WANTS YOU TO WORK SAFELY
SEC 53 MUST BE OBSERVED

Oil and Gas Operations

New River Gorge NR and Gauley River NRA are two of 12 NPS areas in which nonfederal oil and/or gas is extracted. There are no oil and gas operations in Bluestone NSR. Current operations, potential action items, and additional resources are summarized in table 6. "Natural gas exploration and other development" is considered a key issue that affects many of the fundamental and other important resources and values within Gauley River NRA as discussed in the park's foundation document (National Park Service 2016b). Issues discussed in that document are also broadly applicable to New River Gorge NR. The natural resources condition assessment for New River Gorge NR (Mahan 2004) considered oil and gas operations potential threats to natural resources within that park. The NPS manages non-federal oil and gas operations in parks through regulations found at 36 CFR Part 9, Subpart B ("9B Regulations"). Currently there is 1 operation in New River Gorge NR and 28 operations in Gauley River NRA. On November 4, 2016, the NPS published a final rule in the Federal Register (81 FR 77972) updating the 9B Regulations. The final rule became effective December 5, 2016. Among other things, the updates to the 9B Regulations made all nonfederal oil or gas operations located within System unit boundaries subject to the 9B regulations. Therefore, all non-federal oil and gas operations within the boundaries of New River Gorge NR and Gauley River NRA are now subject to the 9B Regulations.

Improvements in directional drilling techniques and hydraulic fracturing completion methods, commonly called "fracking," have renewed industry interest in many areas of the US, including West Virginia, and throughout the northeast United States where the oil and gas source, the Marcellus Shale (and other organic-rich formations, e.g., the Cambrian Rogersville Shale), is located (fig. 22). Horizontal drilling typically involves drilling vertically to the top of a target geologic formation and then turning the drill bit horizontally into the target formation in order to expose more of the production zone to the wellbore and intersect vertical fractures or other structures to increase hydrocarbon production. Hydrocarbon production is further enhanced by multiple-stage hydraulic fracturing during which a liquid, typically water, is mixed with sand and chemicals and then injected at high pressure into a wellbore to create artificial fractures in the surrounding reservoir rock. After the artificial hydraulic pressure is removed from the wellbore, small grains of sand or aluminum oxide, called "proppant," hold open the new fractures and allow oil and gas to migrate into the wellbore.

There are many resource management concerns associated with oil and gas operations. New gas or oil well drilling may cause a decline in surface water quality due to erosion from access roads, drill sites, and pipeline corridors. The potential exists for contamination of surface water and groundwater by drilling muds, fuels, brine, wastes, and other pollutants, as well as deep zone salt water intrusion into shallow freshwater zones if wells are inadequately constructed, maintained, or plugged wells. Soil erosion and soil instability can also occur due to clearing, grading, and cut-and-fill activities associated with roads, pipelines, and drilling site preparation. Oil and gas development impacts may also include damage to archeological, cultural, and geologic resources due to blasting for road or pad construction, seismic exploration, construction, drilling, and production operations. Resource managers are also concerned over oil- and gas-related waste dumping and underground injection wells in the area of the parks. Underground injection control is permitted by the West Virginia Department of Environmental Quality with review by the West Virginia Geological and Economic Survey.

The West Virginia Geological and Economic Survey (http://www.wvgs.wvnet.edu/) is an excellent resource for oil and gas information and assistance in the state. The West Virginia Department of Environmental Protection Office of Oil and Gas regulates and monitors all actions related to the exploration, drilling, storage, and production of oil and natural gas in the state. It also ensures protection of groundwater aquifers from oil and gas activities. Title 35, Legislative Rule, West Virginia Division of Environmental Protection, Office of Oil and Gas, Section 10.5.c., (35CSR4) states that "... interested persons may intervene in the application by filing written comments with the Office of Oil and Gas within fifteen (15) days from the date that the circular is published. If objections are made by any interested person, or by the Office of Oil and Gas, or if the chief determines that other information may be necessary in order to make a determination, a public hearing will be held in accordance with 35 CSR 20." Also refer to the NPS Energy and Minerals website, http://go.nps.gov/energyandminerals and table 6.

Figure 22. Map of National Park System units and approximate extent of Marcellus Shale (orange area). The dashed line indicates the extent of other Devonian-aged shales. NPS units atop or near the Marcellus Shale are labeled. Yellow stars denote the locations of Bluestone NSR, Gauley River NRA, and New River Gorge NR. Green dots and areas denote other NPS units. Map by Trista Thornberry-Ehrlich (Colorado State University) with information from Moss (2009) and Soeder and Kappel (2009). National Park Service base map available at http://www.nps.gov/hfc/cfm/carto-detail.cfm?Alpha=nps.

Table 6. Summary of issues associated with oil and gas operations. Table continues on next page.

Resource Management Issue	Oil and gas operations
Related Fundamental Resources	• Gauley River NRA: biological diversity; undeveloped, rugged geologic landscape; opportunities for world-class recreation; water quality, cultural history of the Gauley River Gorge • New River Gorge NR: geological processes and features, hydrological resources, ecological resources, historical and archeological resources, scenic resources, visitor opportunities
Related map units and park examples.	• Oil- and gas-bearing units (primarily of Mississippian and Devonian age) are buried beneath the mapped geologic units in all three parks and thus do not appear on the geologic maps for the parks (fig. 22). • Gas well locations and status (dry, dry with show, or uncertain) are included in the GRI GIS data. • US Geological Survey estimates undiscovered potential combined oil and gas resources at 82.1 million m^3 (2.9 billion ft^3)—1.6 thousand barrels of oil, and 45 thousand barrels of natural gas liquids—to part of Gauley River NRA, and 1.1 billion m^3 (39 billion ft^3)—24 thousand barrels of oil, and 644 thousand barrels of natural gas liquids—to New River Gorge NR (Schenk et al. 2003). The Marcellus Shale formation, present beneath all three parks, may hold as much as 878 billion m^3 (31 trillion ft^3) of total recoverable gas (figs. 23 and 24; Moss 2009). • In New River Gorge NR, disturbances associated with well pads vary in size from spots that fit within the width of a road up to about 0.8 ha (2 ac). • One abandoned gas well at a trailhead in New River NR is leaking gas. This and two other abandoned wells are near an area of high visitor use. • There are 18 shallow (less than 1,500 m [5,000 ft]) natural gas wells within Gauley River NRA; potential exists for the development of five or six more wells.
Potential Action Items	• An updated assessment of future natural gas development potential (e.g., a "Reasonable Foreseeable Development Scenario") is considered a high priority data need for Gauley River NRA (National Park Service 2016b). A previous assessment was completed in 2003 (Geologic Resources Division 2003). • New River Gorge NR needs a natural gas exploration management plan to identify strategies to effectively regulate and manage drilling activity. • Develop a plan for implementation of the updated 9B oil and gas regulations. • Identify and document oil and gas sites that need further reclamation or restoration. • Determine ownership status of current wells, the routes of gas lines, the parties responsible for their maintenance and operations. For example, the Mountain Valley Pipeline is planned for southern West Virginia (https://www.mountainvalleypipeline.info/; Paula Hunt, geologist, West Virginia Geological and Economic Survey, written communication, 16 June 2017). • Establish a schedule and protocol for monitoring oil and gas operations. • Clearly mark park boundaries in the field and gate access roads as appropriate. • Communicate effectively with mineral and energy owners, operators, other involved agencies, and other stakeholders. • Develop interpretive programs or materials regarding the oil and gas history of the parks and surrounding area, as well as noting current efforts to mitigate past (and current) impacts to park resources and visitor safety.

Table 6, continued. Summary of issues associated with oil and gas operations.

Resource Management Issue	Coal mining, abandoned mineral lands, and disturbed lands
References and Additional Resources	• Park-specific references: □ Oil and gas inventory of Gauley River NRA: Pugh (2003) □ Oil and gas reconnaissance and site visit to Gauley River NRA and New River Gorge NR: O'Dell and Norby (2002) □ Oil and gas development potential: Geologic Resources Division (2003) □ Undiscovered oil and gas resources: Schenk et al. (2003) □ Water resources issues overview: Mott (1995) □ West Virginia Department of Environmental Protection GIS service http://tagis.dep.wv.gov/home/ □ West Virginia Department of Environmental Protection oil and gas wells and data https://apps.dep.wv.gov/oog/wellsearch_new.cfm http://www.dep.wv.gov/oil-and-gas/databaseinfo/Pages/default.aspx □ West Virginia Geological and Economic Survey oil and gas mapping portal and well data http://ims.wvgs.wvnet.edu/index.html#ogmaps http://ims.wvgs.wvnet.edu/WVOG/viewer.htm http://www.wvgs.wvnet.edu/pipe2/OGDataHelp.aspx http://www.wvgs.wvnet.edu/pipe2/OGWISHelp.aspx □ Natural resource condition assessment: Mahan (2004) □ Administrative history of the parks: Good and Stasick (2008) □ West Virginia Oil and Gas Regulations: http://www.wvsos.com/csrdocs/worddocs/35-04.doc • Servicewide or general information: □ Marcellus Shale extraction potential and recommendations: Moss (2009) □ Assessment of undiscovered oil and gas resources of the Devonian Marcellus Shale: Coleman et al. (2011) □ NPS Geologic Resources Division, Energy and Minerals Branch for technical and policy expertise and assistance http://go.nps.gov/grd_energyminerals. □ NPS Environmental Quality Division (lead division for any project requiring NEPA process) http://go.nps.gov/environmentalquality □ NPS Water Resources Division for water quality issues: https://go.nps.gov/waterresources.

Figure 23. Photograph of well pad for directional drilling and hydraulic fracturing of the Marcellus Shale. The truck-mounted pumps and temporary storage tanks needed to fracture-treat the Marcellus Shale require larger well locations than conventional oil and gas. There is also an increase in traffic to and from well pad during drilling and fracturing. The equipment and materials on location in this photograph represent at least 100 roundtrips to the well location. Photo source is unknown, included as an unnumbered figure in Moss (2009).

Figure 24. Photographs of gas well operations in Gauley River NRA. The area surrounding a gas well is disturbed, with compaction and limited vegetation. Photographs by Gayle H "Scott" McColloch, Jr. (West Virginia Geological and Economic Survey) taken in July 2010. Annotations by Trista L. Thornberry-Ehrlich (Colorado State University).

Fluvial Features, Stream Channel Morphology, and Flooding

Fluvial features are those which are formed by flowing water. Fluvial processes both construct (by deposition of alluvium) and erode landforms (e.g., gorges). Fluvial features occur on many scales in the parks ranging from the grand gorges to small tributary valleys to the smallest rivulets. Examples of the parks' fluvial features include meandering river channels, point bars, floodplains, and terraces (figs. 25 and 26). River channels are the perennial course of the flowing water. In the parks, they have extremely coarse bed loads, including boulders that give rise to rapids. Slope movements, including dramatic debris flows (see "Slope Movements, Hazards, and Risks" section) transport the largest clasts from the gorge slopes to the valley bottoms.

As a river flows around curves the flow velocity (and thus erosive energy) is greatest on the outside of the bend. The river erodes into its bank on the outside of a curve (fig. 27) and leaves point bar deposits on the inside of the bend. Point bars are crescent-shaped ridges of sand, silt, and clay deposited on the inside of meander loops where the water's velocity is slowest. As the process continues, the outside bend retreats farther, while the inside bend migrates laterally, thus creating migrating meanders. The parks' rivers are primarily flowing through entrenched meanders, incised directly into bedrock. Their lateral migration is slow compared to classic meandering streams through unconsolidated surficial deposits.

Immediately adjacent to the parks' rivers are narrow, relatively flat and rocky floodplains. Many local floodplains contain mixtures of alluvium and colluvium, eroded and transported from adjacent slopes. Tributary streams flowing down steep adjacent slopes may form entrenched channels through slope deposits and alluvial fans where they intersect the larger valley floor or floodplain. Floodplains may also contain terraces, which are perched surfaces that record former, higher river levels above the modern floodplain.

Floods are the primary geomorphological agents shaping the fluvial environment, and have an important role in controlling the pattern of riparian vegetation along channels and floodplains. During high flows or floods, a river deposits natural levees of sand and silt along its banks. These deposits represent the relatively coarse-grained component of a river's suspended sediment load and form a high area on an alluvial region's land surface. In the gorges, floods also scour the adjacent bedrock, contributing to flat-rock habitats. Natural riparian areas (includes the stream channel between low- and high-water marks) are some of the most diverse, dynamic, and complex biophysical habitats in the terrestrial environment.

Ancient river terraces, former floodplains, have long been areas where people could camp, travel, or forage along the rivers. There may be cultural resource connections in some areas.

Table 7. Summary of fluvial features, stream channel morphology, and flooding. Table continues on next page.

Geologic Feature or Process	Fluvial features and stream channel morphology
Related Map Units And Park Examples	• Many of the surficial units mapped in the parks are related to the modern rivers and/or modern or past fluvial processes: River channel (**Qr**), fluvial channel (**Hfc**), tributary deposit (**Qtd**), rock-floored floodplain (**Qrff**), floodplain (**Qflp** and **Hfp**), boulder floodplain (**Qbfp**), fluvial channel/entrenched stream channel (**Qfc** and **Hfc**), alluvial fan (**Qaf** and **Haf**), boulder tributary deposit (**Qbtd** and **Hbt**), terrace (**Qt** and **Ht**), high terrace (**Qht**). • Estimates of the age of the New River vary from 320 million years old, second in age to the Nile, because it cuts across old features of the Appalachians, to 3 million years old, estimated from erosion rates in the gorge. Study and debate about the river's age continue. • New River gorge cliffs are nearly vertical and extend for a distance of 32.2. km (20 mi) along a cut that reaches as much as 393.8 m (1,292 ft) from rim to valley bottom. • The deepest reaches of the channel are about 30 m (100ft). • US Geological Survey flow monitoring stations (https://waterwatch.usgs.gov/?m=real&r=wv&w=map) are on the New River at Thurmond and Hinton, one on the Bluestone River, and two on the Gauley River. • Until the 1940s when the Bluestone Dam was constructed upstream of New River Gorge NR, towns in the valleys were highly susceptible to flood damage. Historically, the New River experienced catastrophic floods every 50 to 100 years. • Meadow River experienced a 100-year flood event in June 2016; however, the system is historically capable of moving a large volume of water. • Modifications (addition of power generating capacity) to Bluestone Dam and flow control activities on the Greenbrier River could result in changes to the hydrologic regime of New River. • Since construction of the Summersville Dam on the Gauley River in 1960, the frequency and magnitude of large flood events have drastically declined and has impacted rare plant communities dependent on large seasonal fluctuations in stream flow. • Proposed construction of the New River Parkway and increased infrastructure development may result in increased streambank erosion and decreased riparian zone continuity. • The globally rare Appalachian flatrock community type is composed of locally rare sedges, cedars, pines, and other plants and is known from three sites in New River Gorge NR (Camp Brookside, Sandstone Falls, and Keeny Creek-Flatrock) occurring on flat sandstone ledges along the river and is dependent on the scouring caused by occasional flooding for its long-term integrity. • Flooding threatens archeological resources along the Meadow River in Gauley River NRA; climate change could exacerbate this issue. • In 2001, high intensity, short duration rain storms dumped as much as 28 cm (11 in) of rain in localized areas of New River Gorge NR over a period of just six hours. • Flooding in 2001 damaged trails, homes, boat ramps, and retaining walls, and caused numerous debris flows (see table 3). Flood waters moved boulders within New River Gorge NR. • The median clast size in New River from Wolf Creek tributary fan is 5 m (15 ft; see fig. 12), stemming from debris flows (see "Slope Movements, Hazards, and Risks" section) that occurred following large storm events in 2001. Such large boulders produce local rapids.
Related Fundamental Resources	• Bluestone NSR: biological diversity, the Bluestone River, historic travel corridor and associated cultural resources, recreation opportunities, undeveloped primitive character • Gauley River NRA: biological diversity; undeveloped, rugged geologic landscape; opportunities for world-class recreation; water quality, cultural history of the Gauley River Gorge • New River Gorge NR: geological processes and features, hydrological resources, ecological resources, historical and archeological resources, scenic resources, visitor opportunities

Table 7, continued. Summary of fluvial features, stream channel morphology, and flooding. Table continues on next page.

Geologic Feature or Process	Fluvial features and stream channel morphology
Related Resource Management Issues	• Bluestone Dam has been successful in reducing flood peaks by at least 50% but has affected natural biophysical processes by disturbing the natural nourishment of the floodplain, the scouring of habitats such as the flat-rock communities, the redistribution of fluvial sediments, and the altering of dependent vegetation patterns. • Changes in flow dynamics have affected the location and composition of gravel bars in the New River, which are important habitats for mussel communities. • Flood regime alterations facilitates invasions by nonnative organisms that might not otherwise survive extreme flows. • Manipulation of flood and drought timing in dam-regulated rivers can change fish distributions by favoring species that spawn only during certain times of the year. • A threat to the physical and biological attributes of the New River associated with Bluestone Dam is debris build up behind the dam. • The rivers are negatively affected by trace metals (antimony, cadmium, lead, mercury, and thallium), sedimentation, trace chemical elements (arsenic, beryllium, chromium, copper, cyanide, fluoride, nickel, silver, sulfate, and zinc), and acidic runoff; some of this is associated with mining (see table 5). • Extreme sedimentation from floods may have negative effects on the globally rare Appalachian flatrock community. • High recreational use at areas such as Camp Brookside and Sandstone Falls threatens the globally rare flatrock Appalachian communities there. • An increase in mean annual temperature (+1.8°C to 2.7°C [+3.2°F to 4.9°F] by 2050) and precipitation (+6% by 2050), increases in storm frequency and intensity, and increases in extreme heat events (>35°C [95°F]) projected for the region due to climate change could impact hydrology for all three river parks (Melillo et al. 2014).
Potential Action Items	• Perform stream flow and sediment load studies for the three rivers, especially the New River to establish baseline conditions for monitoring. This is a potential GIP or Mosaics in Science project. • A channel profile for New River exists near the New River Gorge Bridge. More profiles would facilitate comprehensive river-channel studies. LiDAR would be useful for monitoring river channel change and for profiles of the gorges. Updated LiDAR data of the park's watershed was designated a "high priority" in the foundation document for New River Gorge NR. • Determine what base flow is needed to maintain aquatic communities in New River. • Study sediment transport and deposition along the rivers. • Map, inventory, and monitor gravel bars in the three rivers to study change in bar distribution and morphology based on changes in water flow. • A potential research topic is the effects of reestablishing a periodic flood regime in the New River Gorge below Bluestone Dam. • A potential research topic is to identify bottomland and riparian zone surface features throughout the parks and overlay these features with maps of the vegetation communities to determine how bottomland surfaces and flow dynamics affect terrestrial ecosystems. • Monitor road crossings of ephemeral streams during high runoff events to determine if they are adequate for those high flows. • Culvert and inboard ditch maintenance, particularly after storm events, can maintain and/or restore adequate drainage and reduce the amount of material that may plug culverts. • Compare the New River riparian communities to those on rivers that have unregulated and relatively unstressed conditions such as Bluestone River or Gauley River. • Develop a comprehensive river management plan for Bluestone NSR. • Inventory and monitor cultural resources associated with river terraces.

Table 7, continued. Summary of fluvial features, stream channel morphology, and flooding.

Geologic Feature or Process	Fluvial features and stream channel morphology
Primary References or Resources	• Park-specific references: □ Post-flood recommendations (after 2001 extreme event): National Park Service (2001a) □ GRI GIS data, source maps, and scoping summary (Covington 2005). □ Natural resource condition assessment: Mahan (2004) □ Water resources management plan: Purvis et al. (2002) □ Flood characteristics with regulated flow: Wiley and Cunningham (1994) □ Geologic and topographic controls on rapids: Mills (1990) □ Origin of rapids: Moore (1999) □ Flood responses to debris: Johnson et al. (2000) □ Geologic and topographic controls on rapids: Mills (1990) □ Restore natural hydrology and riparian zone in Resource Stewardship Strategy: Mahan and Darden (2014) □ Administrative history of the parks: Good and Stasick (2008) □ Geologic overviews and New River age: Grafton and Grafton (1980), Mott (1995); Lessing (1986) • Servicewide or general information: □ Monitoring fluvial geomorphology: Lord et al. (2009; https://go.nps.gov/geomonitoring) □ Climate change impacts: Melillo et al. (2014)

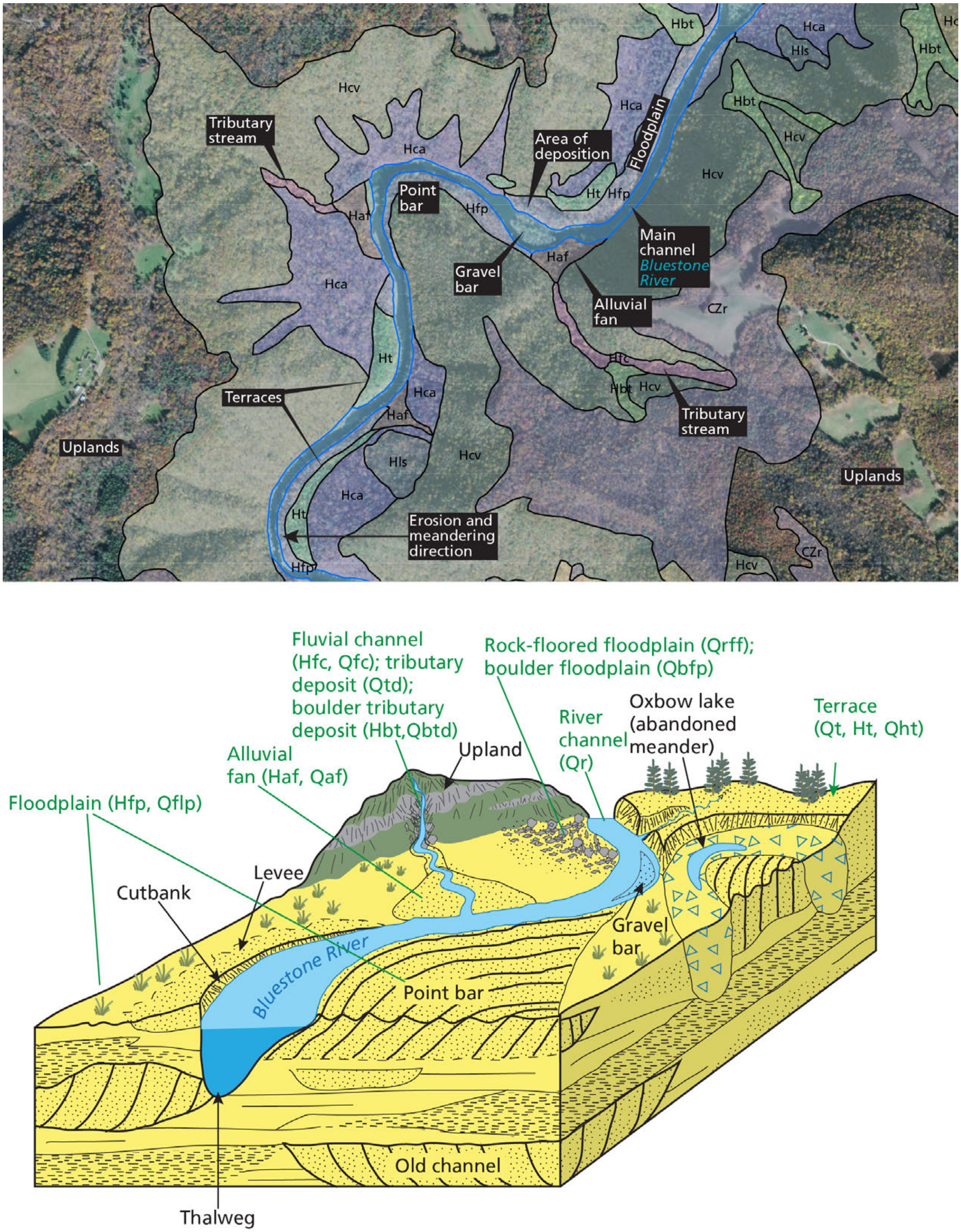


Figure 25. Aerial image and diagram of fluvial features and depositional settings. The Bluestone, New, and Gauley rivers cut down through weathered bedrock to carve deep gorges. Along their lengths are myriad fluvial features formed as the rivers meander across their floodplains depositing alluvium in some areas and scouring the valley floor in others. Green text refers to local examples and relevant geologic map units present in the three parks. Diagram is not to scale. Graphics by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and ESRI World Imagery basemap.

Figure 26. Aerial image of Meadow River with fluvial features labelled. Meadow River, a tributary of Gauley River, carves a narrow gorge through colluvium-mantled bedrock. The floodplain is narrow and composed of mixed alluvium and colluvium weathered from the adjacent slopes. Data displayed is near Mt Lookout Road. Geologic units are as follows (in alphabetical order): Qaf=alluvial fan, Qbfp=bouldery floodplain, Qbm=blocky mantle, Qca=colluvial apron, Qcf=colluvial fan, Qcm=colluvial mantle, Qcv=colluvial veneer, Qd=disturbed, Qfc=fluvial channel, Qr=river channel, Qres=residuum, Qt=terrace, and Qtd=tributary deposit. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) using GRI GIS data and ESRI World Imagery basemap. NPS photographs by Sid Covington (summer 2004) and Deanna Greco (autumn 2002).

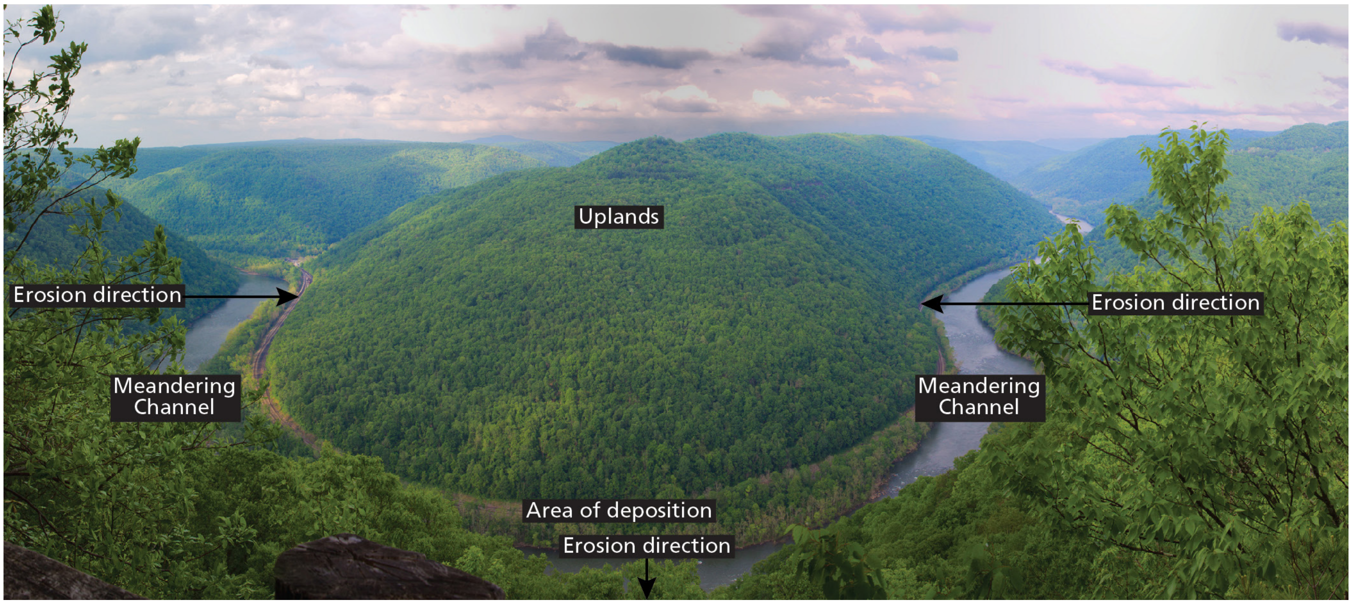


Figure 27. Photograph of Horseshoe Bend in New River Gorge NR. Bluestone, Gauley, and New rivers are entrenched in bedrock and migrate laterally very slowly compared to rivers that flow over unconsolidated surficial deposits. Their floodplains are very narrow, confined to v-shaped bedrock valleys. Photograph by Louise McLaughlin, available at https://www.nps.gov/media/photo/gallery.htm?id=1C7AA5F4-155D-451F-67AB25EA15C7B8F4. Annotations by Trista L. Thornberry-Ehrlich (Colorado State University).

Bedrock Exposures

"Bedrock" is the solid very old rock that underlies the younger unconsolidated surficial and glacial deposits of the parks. Bedrock is dramatically exposed in all three parks, particularly as cliffs along the namesake rivers. Bedrock can be sedimentary, igneous, or metamorphic. Sedimentary rocks form from fragments of other rocks or chemical precipitation. Igneous rocks form by the cooling of molten material. Metamorphic rocks are those that have been altered by high temperature, high pressure, and/or fluids. All the bedrock in the three parks is sedimentary and was primarily deposited in marine, nearshore, or terrestrial settings (see "Geologic Setting, History, and Significance"). The cliffs are a primary component of the geologic heritage and scenery of the three parks and have drawn sightseers and rock climbers for decades. Bedrock in all three parks is mantled by surficial deposits (separately mapped in the GRI GIS data) including those associated with the rivers (see table 7), landslides, colluvial fans, aprons, mantle, veneer, and residuum.

The sedimentary rocks within the three parks are primarily clastic rocks such as sandstone and shale. Clastic sedimentary rocks are the products of weathering, erosion, transportation, and deposition of rock fragments called "clasts." Clastic sedimentary rocks are named after the size of clasts (table 9). High energy depositional environments, such as fast-moving streams, deposit larger (heavier) clasts while transporting smaller (lighter) clasts. Where water moves slowly or is stagnant, such as in lakes, the water cannot transport even the smallest clasts and they are deposited. Wind also transports and deposits sand-sized or smaller clasts (table 9). Detailed descriptions of the bedrock map units are available in the ancillary map information documents (neri_geology.pdf, blue_geology.pdf, gari_geology.pdf) in the GRI GIS data. Fossils are found in many of the bedrock units within the parks (see "Paleontological Resource Inventory, Monitoring, and Protection").

Waterfalls and rapids are dramatic features in all three parks where water flows (see table 7) over layers of different types of bedrock. For example, Sandstone Falls in New River Gorge NR (fig. 28) is a ledge of Stony Gap Sandstone (**Mhsg**) where the river flows over a more easily erodible layer. The falls also mark a transition from broader river (more easily erodible bedrock) below the falls to a narrower, steeper valley (harder to eroded bedrock) above the falls. Rapids along all three major rivers and their tributaries tend to form where water flows over resistant sandstone layers through narrower valleys with steeper gradients in resistant units such as the New River Formation (e.g. PNrural or PNnrlral); and where large, rapid-forming boulders tumble from adjacent slopes (see table 3).

Some bedrock weathers into interesting features, including karst (see table 10), spheroidal weathering, and areas mapped as "Rock City" (**Qec**) within New River Gorge NR. Some very thinly bedded shales and siltstones of the Hinton Formation (**Mhsg**, **Mhl**, **Mhlsg**, and **Mhu**) weather into unusual spheroidal shapes found throughout the parks. Rock cities are clusters of rock blocks and very large boulders separated by narrow avenues on low-relief to slightly sloping uplands or along canyon rims. Large blocks of bedrock are also present in surficial deposits such as blocky mantle (**Qbm**), bouldery tributary deposit (**Qbtd**), bouldery floodplain (**Qbfp**), and rock-floored floodplain (**Qrff**).

A geologic formation is named for a geographic feature, such as a stream, ride, or town located near its type locality, a geographic location where a rock formation is best displayed or first described. More particularly, an outcrop may display the formation so well as to become a reference location referred to as a "type section." Type localities and type sections have both scientific and educational significance. Because type localities and type sections commonly occur where a formation was originally described and named, they also may have historical significance. Many of the geologic map unit names in the GRI GIS data refer to local geographic features and some were named for locations in the parks, as summarized on table 8.

Table 8. Summary of bedrock exposures. Table continues on next page.

Geologic Feature or Process	Bedrock exposures
Related Fundamental Resources	• Bluestone NSR: biological diversity, historic travel corridor and associated cultural resources, recreation opportunities, undeveloped primitive character • Gauley River NRA: biological diversity; undeveloped, rugged geologic landscape; opportunities for world-class recreation; cultural history of the Gauley River Gorge • New River Gorge NR: geological processes and features, ecological resources, historical and archeological resources, scenic resources, visitor opportunities
Related Map Units And Park Examples (continued on next page)	• Bluestone NSR: **Mhl, Mhlsg, Mhu, Mpn,** and **Mbspd**. • Gauley River NRA: **PNrural, PNnr, PNnrln, PNnrun,** and **PNk**. • New River Gorge NR: **Mbf, Mhsg, Mhl, Mhlsg, Mhu, Mpn. Mbs, PNp, PNnrp, PNnr, PNnrlral, PNnr, PNrural, PNnr, PNnrln, PNnrun,** and **PNk**. • New River Gorge NR contains the type locality of the Raleigh Formation and the New River Formation ("**PNnr**" units; see neri_geology.pdf). • Bluestone River is named for the deep blue limestone streambed of its upper reaches. • Bedrock observation localities, geologic contact locations, and known county geologic report localities are included in the GRI GIS data. • Structure contour lines, showing the elevation of a marker bed or index layer's surface across the map area are included in the GRI GIS data for Bluestone NSR for **Mpn** and New River Gorge NR for **Mhlsg**. • Cross sections, showing the vertical relationships of rock units on the geologic maps, are part of the GRI GIS data (see blue_geology.pdf, gari_geology.pdf, neri_geology.pdf). • Resistant sandstone layers form ledges and cliffs along the steep gorge slopes (fig. 28); over 30 km (18 mi) of linear sandstone cliffs occur along the walls of New River Gorge. • Frost weathering—a process by which water freezes and thaws and wedges rocks apart—has formed columnar rock city-like features typically located at or near the rim of the gorges in resistant sandstone layers (e.g., Nuttall Sandstone [**PNnrun**, **PNnrln**]; see fig. 29).

Table 8, continued. Summary of bedrock exposures. Table continues on next page.

Geologic Feature or Process	Bedrock exposures
Related Map Units And Park Examples, continued	● Rock climbing is popular on the Nuttall Sandstone that rims the New River Gorge in the northern map area, and on some of the other exposed sandstones along the New River. The clean hard sandstone units form imposing cliffs and offer many popular climbing routes throughout the area (McColloch et al. 2013). ● The Nuttall Sandstone (**PNnrun, PNnrln**) is uncommonly high in quartz (98%) and is exposed in the lower gorge; its composition, planar cliff faces, unique surface features (e.g., huecos or shallow hollows), and goethite as secondary cement along vertical tectonic joints make the Nuttall sandstone blocks and cliffs suitable for climbing. ● There are over 1,500 climbing routes documented on over 80 cliff sections in New River Gorge NR alone; new routes are developed through a permit system. ● Most climbing occurs on the lower Nuttall Sandstone (**PNnrln**); other sandstone layers are less attractive for climbing due to their thinner bedding and heterogeneous surface features; they are a less competent climbing target. ● The area around Batoff Creek provides one of the best-exposed stacks of upper-Mississippian through lower-Pennsylvanian bedrock in the area. ● Rock outcrops and boulder fields provide important habitat for the Allegheny woodrat populations in Gauley River NRA; cliff faces, rims, and bases support diverse vascular plant, bryophyte, and lichen communities. ● South Nuttall, Upper Endless Wall, and Upper Kaymoor support valuable cliff habitats. ● Complex paleovalley fill exposures in the New River Formation are serving as analogs for modern systems of valley cut-and-fill. Paleovalleys represent ancient incision by rivers and sedimentary bypass during periods of falling sea level or base level, with later deposition, and mark regionally-correlatable unconformities (gaps in the geologic record) that represent significant hiatuses in deposition.
Related Resource Management Issues	● Slope movements, hazards, and risks (see table 3) ● Paleontological resource inventory, monitoring, and protection (see table 4) ● Rock climbing (fig. 30) can impact habitat for Allegheny woodrats and other natural resources such as vegetation and nesting bird species ● Visitors occasionally vandalize or deface geologic features ● Geology is a fundamental resource at the parks and an interpretive geologic guide or tour would facilitate visitor understanding and connections.
Potential Action Items	● Prepare a climbing management plan for cliff habitats and other bedrock exposures. This was listed as a “high priority” planning need in the New River Gorge NR foundation document. ● Examine cliff resources at Bluestone NSR and Gauley River NRA as per the study at New River Gorge NR by Mahan (2016). ● Perform stability studies for scenic overlooks on sandstone cliffs. This was listed as a “high priority” planning need in the New River Gorge NR foundation document. ● Continue and expand cliff habitat monitoring for all three parks. ● Undertake education, research, and monitoring suggestions outlined in Mahan (2016); expand to all three parks as appropriate. ● Perform boundary marking; map social trails, ATV trails, and climbing routes in Gauley River NRA. ● Collaborate with West Virginia Geological and Economic Survey and other groups to develop a geologic tour guide for the parks, outline stops at geologic features such as Nuttall cliffs, Sandstone falls, falls and rapids in the gorges, enormous boulders, prominent coal seams, the Mauch Chunk Group (**Mbf, Mhsg, Mhl, Mhlsg, Mhu, Mpn, Mbspd, Mbs**) exposures, as well as identifying and describing the type localities in the parks.

Table 8, continued. Summary of bedrock exposures.

Geologic Feature or Process	Bedrock exposures
Primary References or Resources	• Park-specific resources: □ GRI GIS data, source maps, and scoping summary (Covington 2005). □ Cliff resources study: Mahan (2016) □ What makes a good climbing rock? Sandstone guide: Olcott (2011) □ Natural resource condition assessment: Mahan (2004) □ Geologic overviews: Grafton and Grafton (1980) and Remo (1999) □ Geologic and topographic controls on rapids: Mills (1990) □ Mapping bedrock and other significant geologic resources in Resource Stewardship Strategy: Mahan and Darden (2014) □ Origin of rapids: Moore (1999) □ Paleovalley fills: Korus et al. (2008) □ Geology of the New River Gorge: http://www.wvgs.wvnet.edu/www/geology/geoles01.htm • General information: □ Highway Geology of West Virginia book (currently in press) □ Information about type sections, compiled by US Geological Survey: https://ngmdb.usgs.gov/Geolex/search □ NPS Geologic Resources Division rocks and minerals website: https://www.nps.gov/subjects/geology/rocks-and-minerals.htm

Table 9. Clastic sedimentary rock classification and characteristics.

Rock Name	Clast Size	Park Examples	Depositional Setting
Conglomerate (rounded clasts) or Breccia (angular clasts)	>2 mm (0.08 in) [larger]	Layers in Bluestone Formation (**Mbs**) and Lower Nuttall sandstone (**PNnrln**)	High-energy streams
Sandstone	1/16–2 mm (0.0025–0.08 in)	Layers in Upper Raleigh Sandstone (**PNnrural**) and Princeton Formation (**Mpn**)	Streams and rivers, nearshore areas
Siltstone	1/256–1/16 mm (0.00015–0.0025 in)	Layers in Pocahontas Formation (**PNp**)	Low-energy streams
Claystone	<1/256 mm (0.00015 in) [smaller]	Pride Shale member of Bluestone Formation (**Mbspd**)	Swamps and lagoons

Note: Claystones and siltstones are commonly lumped together in the term “mudstone,” or if they break into thin layers, “shale.”

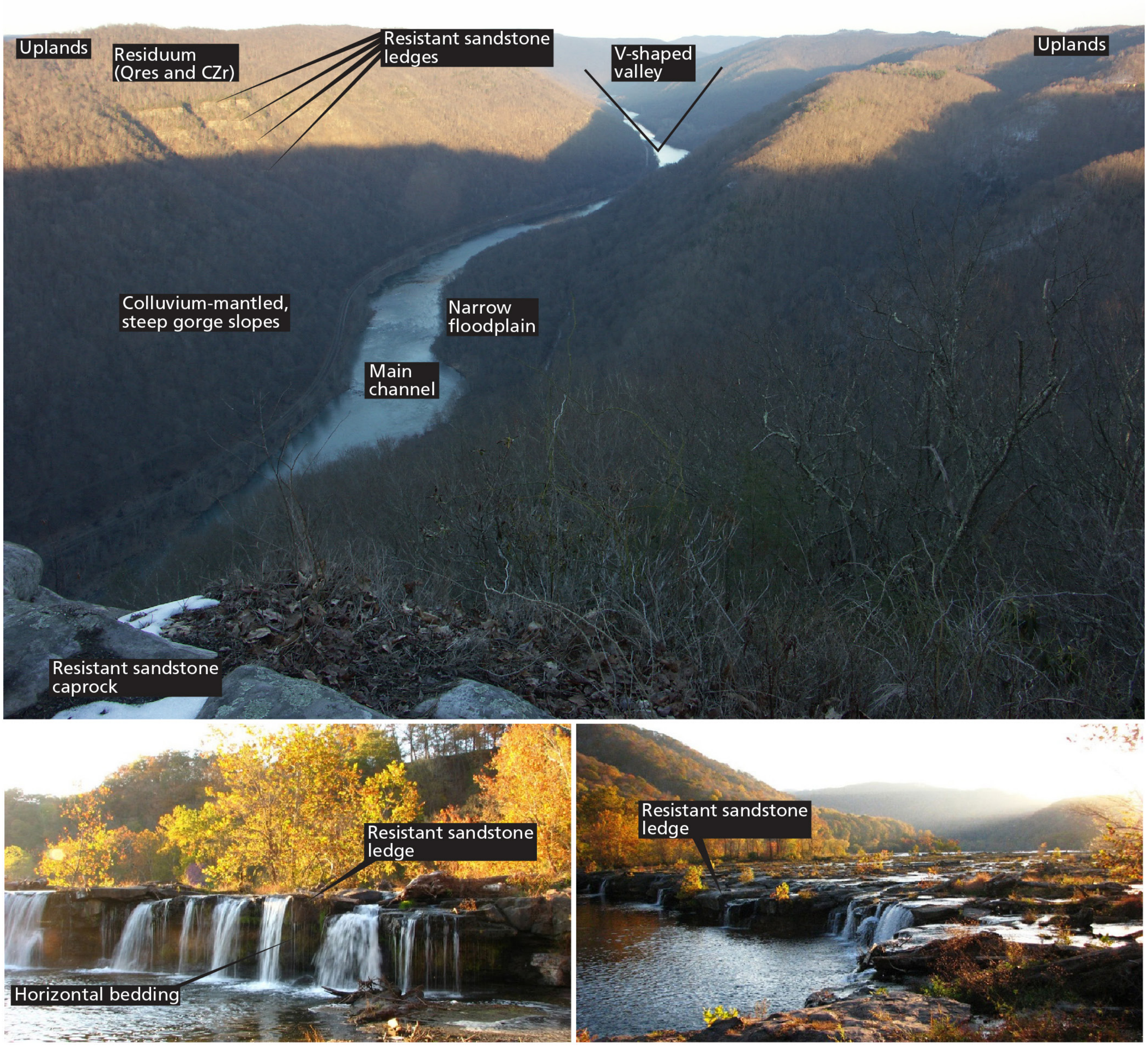
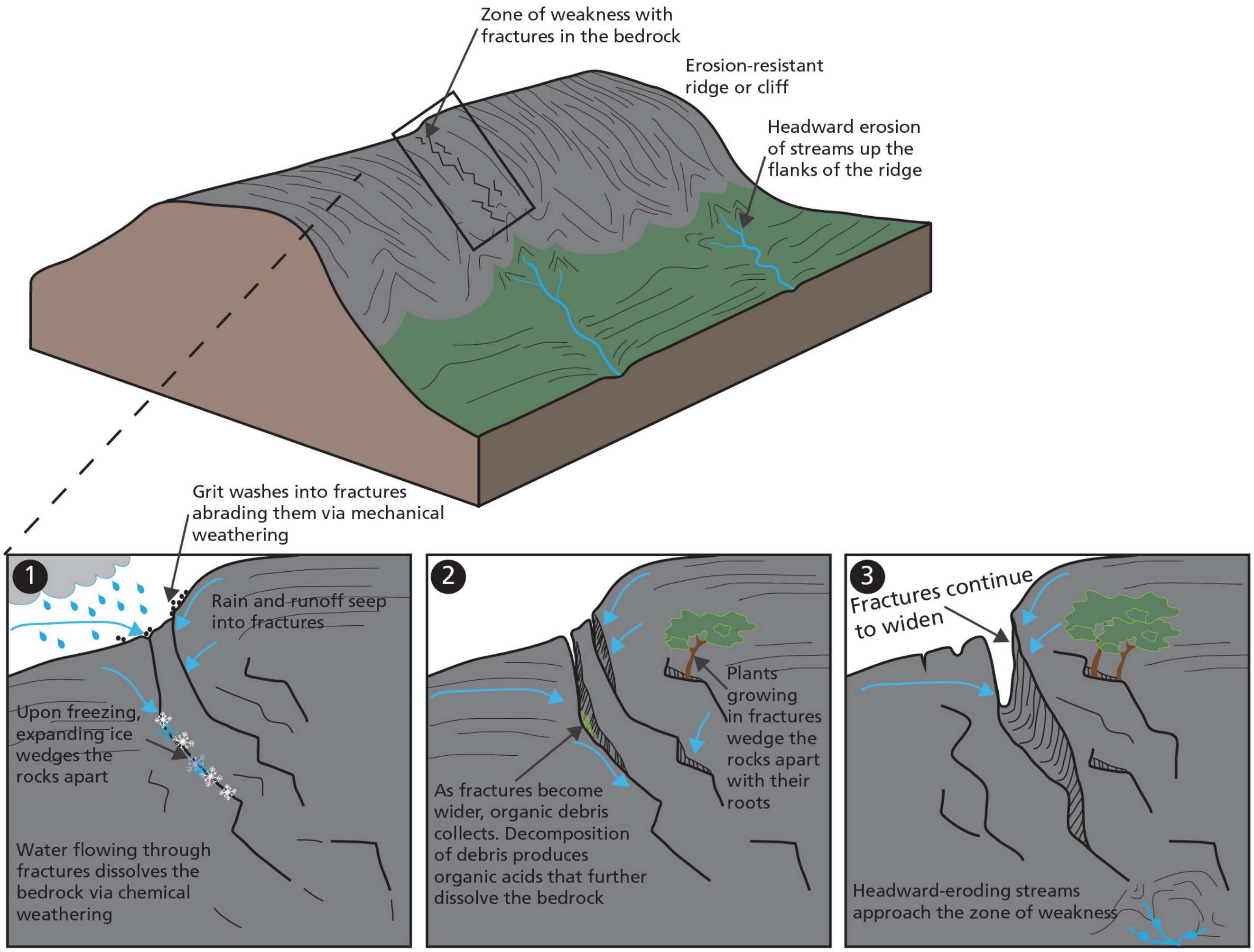
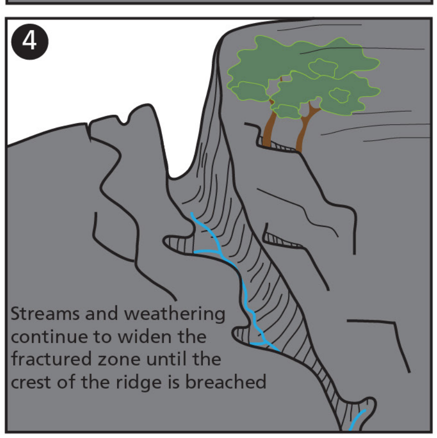


Figure 28. Photographs of sandstone ledges in New River Gorge NR. Resistant sandstone layers stand out as ledges and cliffs between areas underlain by deeply weathered residuum and colluvium-mantled slopes in New River Gorge. Lower ledges form waterfalls, such as Sandstone Falls, that are slowly eroding headward or upstream. Ledges provide habitat for raptors as well as recreation opportunities for climbers. Ledges are prone to rockfall. Resistant layers also underlie many areas of rapids in the three parks. Upper photograph by John Burghardt (NPS Geologic Resources Division) in 2006, lower photographs by Leah Perkowski-Sisk, available at https://www.nps.gov/media/photo/gallery.htm?id=1CAFE9D4-155D-451F-67E0639DC1DA1313, annotations by Trista L. Thornberry-Ehrlich (Colorado State University).



Zone of weakness with fractures in the bedrock
Erosion-resistant ridge or cliff
Headward erosion of streams up the flanks of the ridge
Grit washes into fractures abrading them via mechanical weathering
1
Rain and runoff seep into fractures
Upon freezing, expanding ice wedges the rocks apart
Water flowing through fractures dissolves the bedrock via chemical weathering
2
Plants growing in fractures wedge the rocks apart with their roots
As fractures become wider, organic debris collects. Decomposition of debris produces organic acids that further dissolve the bedrock
3
Fractures continue to widen
Headward-eroding streams approach the zone of weakness



4
Streams and weathering continue to widen the fractured zone until the crest of the ridge is breached

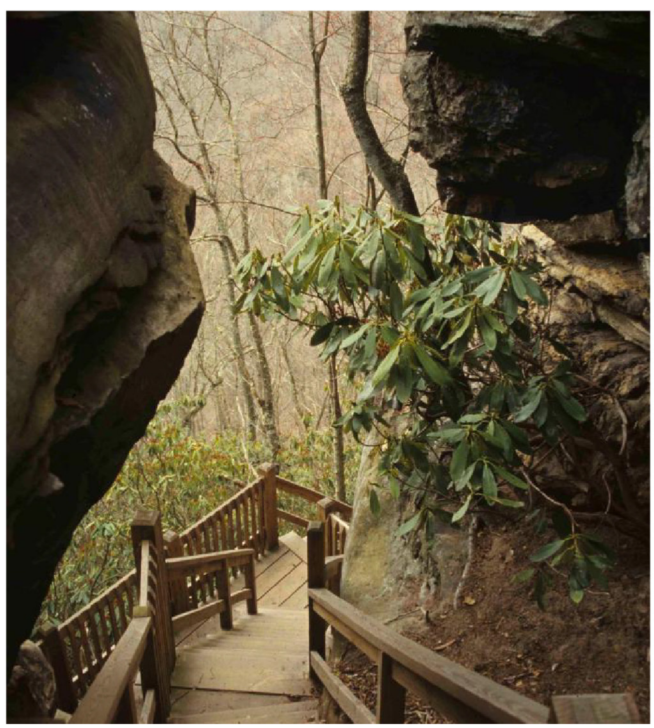


Figure 29 (facing page). Illustration of how fractures develop in rock, leading to "rock city" type features. Many areas along the rims of New River Gorge weather to produce wide "avenues" through large blocks of rock to create "rock city" features. Some areas such as the Grandview Overlook area (pictured) have trails through the widened fractures. Frost weathering, organic debris, and plant roots likely all contribute to this kind of weathering. NPS photograph available at: https://www.nps.gov/neri/learn/photosmultimedia/photogallery.htm. Schematic graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

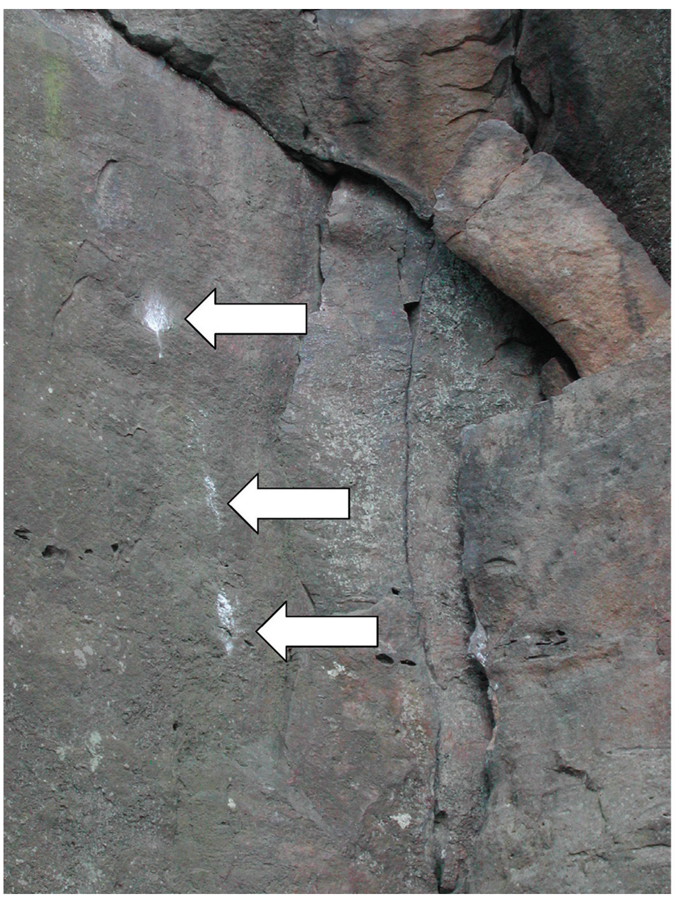


Figure 30 (above). Photographs of climbing areas in New River Gorge NR. The abundant, near-vertical bedrock exposures in the three parks are popular for rock climbers (note chalk marking a route on left image). Park staff mitigate issues associated with high use by building "robust" trails such as the one at Fayette Station near New River Gorge Bridge (right image). Photographs by Gregory A. Good in 2006 presented as figures 43 and 44 in Good and Stasick (2008).

Weathering and Karst Features

Karst is a landscape that forms through the dissolution of soluble rock, most commonly carbonates such as limestone or dolomite. Caves, dolines (sinkholes), "losing streams," springs, and internal drainage are characteristic features of karst landscapes. As of September 2017, cave and/or karst resources are documented in 159 NPS areas, including Bluestone NSR and New River Gorge NR. Both parks are considered to have "Less Significant" karst and no caves are currently documented from the parks (data compiled and tracked by NPS Geologic Resources Division, spreadsheet updated 11 August 2017). The only unit potentially containing karst in New River Gorge NR and Bluestone NSR is the Little Stone Gap member of the Hinton Formation (informally known as the Avis Limestone) (**Mhlsg**). This unit is not mapped in Gauley River NRA. Weary and Doctor (2014) considered the Avis Limestone a potential karst unit because it is classified as "carbonate rocks at or near the surface in a humid climate" and because the Hinton Formation "contains caves in the Avis Limestone." This unit is also considered by the West Virginia Geologic and Economic Survey to be one of the principal karst-forming carbonate rocks in the state (WVGES 2016; http://www.wvgs.wvnet.edu/www/geology/Karst_Terrain_Potential.html; fig. 31). While caves are known to exist in this relatively thin (15 to 20 m [50 to 65 ft]) calcareous unit, other well-developed karst features were not observed during mapping (Paula Hunt, geologist, West Virginia Geological and Economic Survey, written communication, 16 June 2017).

Table 10. Summary of weathering and karst features.

Geologic Feature or Process	Weathering and karst features
Related Fundamental Resources	• Bluestone NSR: biological diversity, undeveloped primitive character • Gauley River NRA: biological diversity; undeveloped, rugged geologic landscape • New River Gorge NR: geological processes and features, ecological resources
Related Map Units And Park Examples	• **Mhlsg**. • No major karst features are formed in the parks' area; however, the 10 m (30 ft) thick, fossiliferous Little Stone Gap member (Avis Limestone) of the Hinton Formation (**Mhlsg**) occurs in Bluestone NSR and New River Gorge NR (fig. 31); karst dissolution is probable in this unit and two caves are anecdotally reported within the park; small caves are noted along Indian Ridge, which forms the southern edge of Bluestone NSR (Matchen et al. 2011). • There are small pothole-like structures that are forming in the Nuttall sandstone at the top of the gorges (Covington 2005). • Natural caves and abandoned mines have similar management issues (see table 5).
Related Resource Management Issues	• Rockfall and topple (see table 3) • Cave (or mine) collapse or breakdown (see table 5)
Potential Action Items	• Confirm, identify, and document the presence of any caves in the parks. Potentially contact Nick Schear at West Virginia Division of Environmental Protection (http://www.dep.wv.gov/Pages/default.aspx).
Primary References or Resources	• Park-specific information □ GRI GIS data, source maps, and scoping summary (Covington 2005). • General information: □ National karst database and map: Weary and Doctor (2014) □ Cave and karst monitoring: Toomey (2009; https://go.nps.gov/geomonitoring) □ Evaluation of cave and karst programs and issues at US national parks: Land et al. (2013) □ WVGES Karst Terrain Potential Maps: http://www.wvgs.wvnet.edu/www/geology/Karst_Terrain_Potential.html □ National Park Service cave and karst website: https://www.nps.gov/subjects/caves/index.htm

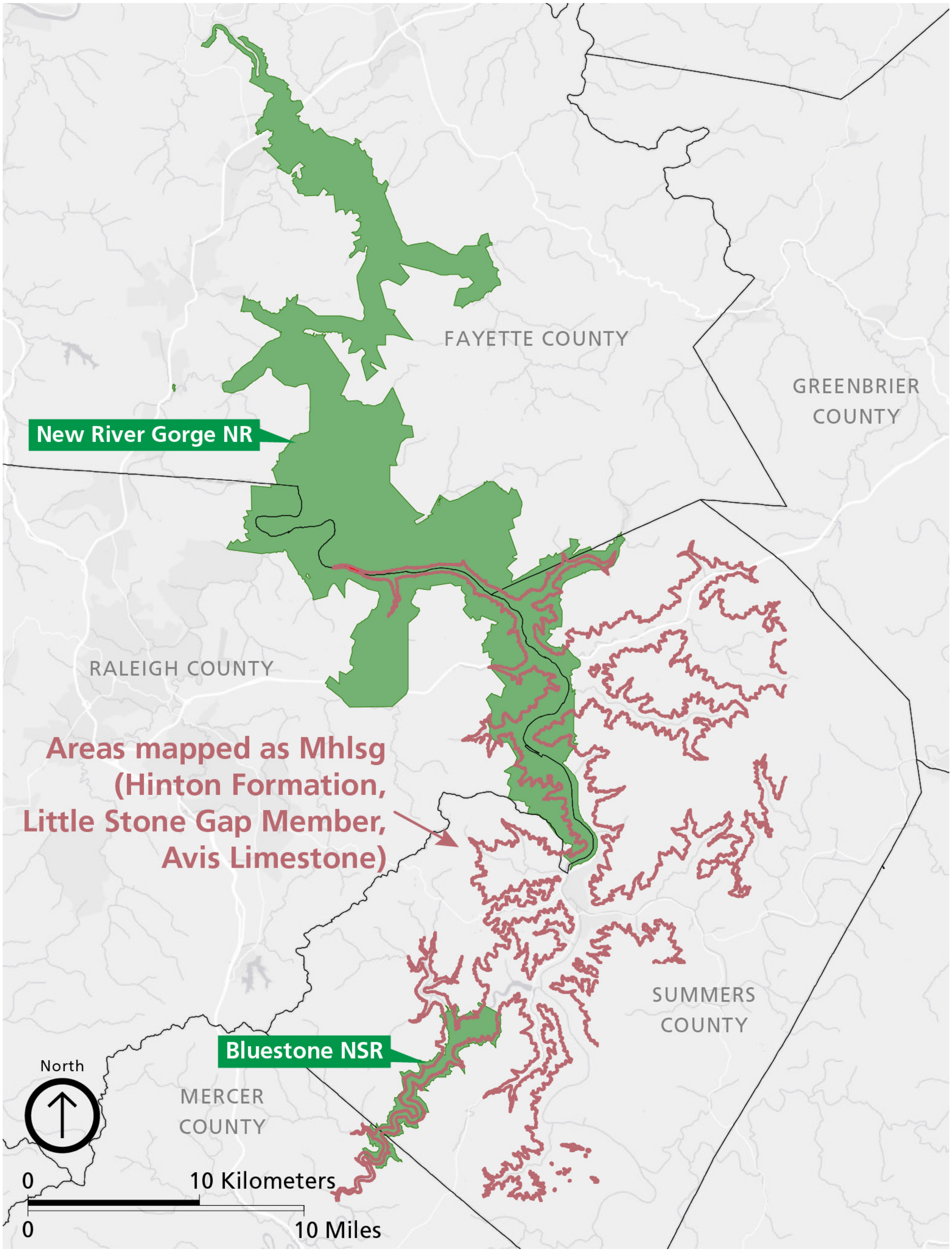


Figure 31. Map showing areas of Hinton Formation, Little Stone Gap Member, Avis Limestone (map unit Mhlsg). Mhlsg is the only formation within the parks considered to be a "principal karst-forming carbonate" by the West Virginia Geologic and Economic Survey. Mhlsg is not mapped within Gauley River NRA. Map by Jason Kenworthy (NPS Geologic Resources Division) using GRI GIS data. Basemap is ESRI World Light Gray Canvas Base (accessed 25 September 2017).

Shrink-and-Swell Clays

Shrink-and-swell materials are those that significantly change volume when saturated with water. Some mica-rich clays can absorb great quantities of water in their crystalline structures and increase in volume. Volume then decreases when the clays dry out. Changes in clay volume may cause upheaval and buckling that may damage infrastructure such as roads, trails, and building foundations. “Flaky” planar minerals like mica are particularly susceptible and can initiate movement when saturated with water and exposed on slopes (table 3).

Although they were discussed at the GRI scoping meeting, shrink-and-swell materials are typically addressed in soil reports. Soil Resources Inventory reports and maps have been produced for all three parks and should be referenced for information on shrink-and-swell materials.

Bedrock is one component of the parent material and mica-rich geologic units could weather to produce shrink-and-swell clays as noted on the table below. Shales are rocks that typically exhibit planar weathering; they could also be areas of failure and at risk for slope movements (see table 3).

Table 11. Summary of shrink-and-swell clay issues.

Resource Management Issue	Shrink-and-swell clays
Related Fundamental Resources	• Bluestone NSR: biological diversity, undeveloped primitive character • Gauley River NRA: biological diversity; undeveloped, rugged geologic landscape • New River Gorge NR: geological processes and features, ecological resources
Related Map Units And Park Examples	• Hinton Formation (**Mhu, Mhlsg, Mhl,** and **Mhsg**) in Bluestone NSR and New River Gorge NR. • Many shales in the parks are thin-bedded and have multiple planes of potential movement. • Possible shale layers in Kanawha Formation (**PNk**), New River Formation (**PNnr**), Pocahontas Formation (**PNp**), Bluestone Formation (**Mbs**), Pride Shale member of the Bluestone Formation (**Mbspd**), and Bluefield Formation (**Mbf**).
Potential Action Items	• Utilize Soil Resources Inventory maps and data to determine potential areas of concern for shrink-and-swell clays.
Primary References or Resources	• Park-specific information: □ Soil Resources Inventory data and maps: Bluestone NSR: https://irma.nps.gov/DataStore/Reference/Profile/2170694 Gauley River NRA: https://irma.nps.gov/DataStore/Reference/Profile/2170704 New River Gorge NR: https://irma.nps.gov/DataStore/Reference/Profile/2170705 □ GRI GIS data, source maps, and scoping summary (Covington 2005). • General information: □ See table 3 for slope movements □ Slope monitoring guide: Wieczorek and Snyder (2009; https://go.nps.gov/geomonitoring)

Folds and Faults

Folds and faults occur where rocks have been compressed, stretched, sheared, or fractured and moved. They are common structural features in areas where mountain building has occurred, such as the Appalachian Mountains. Folds are where the rock layers buckled into concave upward (syncline) and concave downward (anticline) forms. They often occur in association with faults and are indicative of stress and tectonic forces. A fault is a fracture in rock along which rocks have moved. Faults are defined by the direction of movement along the fracture as normal faults, reverse faults, and strike-slip faults (fig. 32).

Table 12. Summary of folds and faults.

Geologic Feature or Process	Folds and faults
Related Fundamental Resources	• Bluestone NSR: undeveloped primitive character • Gauley River NRA: undeveloped, rugged geologic landscape • New River Gorge NR: geological processes and features
Related Map Units And Park Examples	• Fold axes are included for all three parks in the GRI GIS data in the “Folds” layers. The major local structures include the Boggs Knob, Dunn, and Mann Mountain anticlines, as well as the Clifftop, Lawton, Bellepoint, and Springdale synclines (fig. 32), and unnamed fold axes. The large folds are relatively “wide” meaning the limbs are not steeply dipping (fig. 32). • Fold axes and symbology, indicating fold type (anticline or syncline) and plunge, are included in the GRI GIS data. • Faulting is minor in the three-park area and was not mapped at the scale of the GRI GIS source maps. Mappers noticed small-scale faults in excavations in the bed of the New River near Bluestone Dam (G. McColloch, geologist, West Virginia Geological and Economic Survey, written communication, 31 May 2017).
Related Resource Management Issues	• Deformed bedrock could be more susceptible to slope movements, creating additional hazards and risk (table 3).
Potential Action Items	• Identifying areas along fold axes that are also on steep slopes and near infrastructure could provide a rough estimate of locations at potentially higher risk for slope movements.
Primary References or Resources	• GRI GIS data, source maps, and scoping summary (Covington 2005).

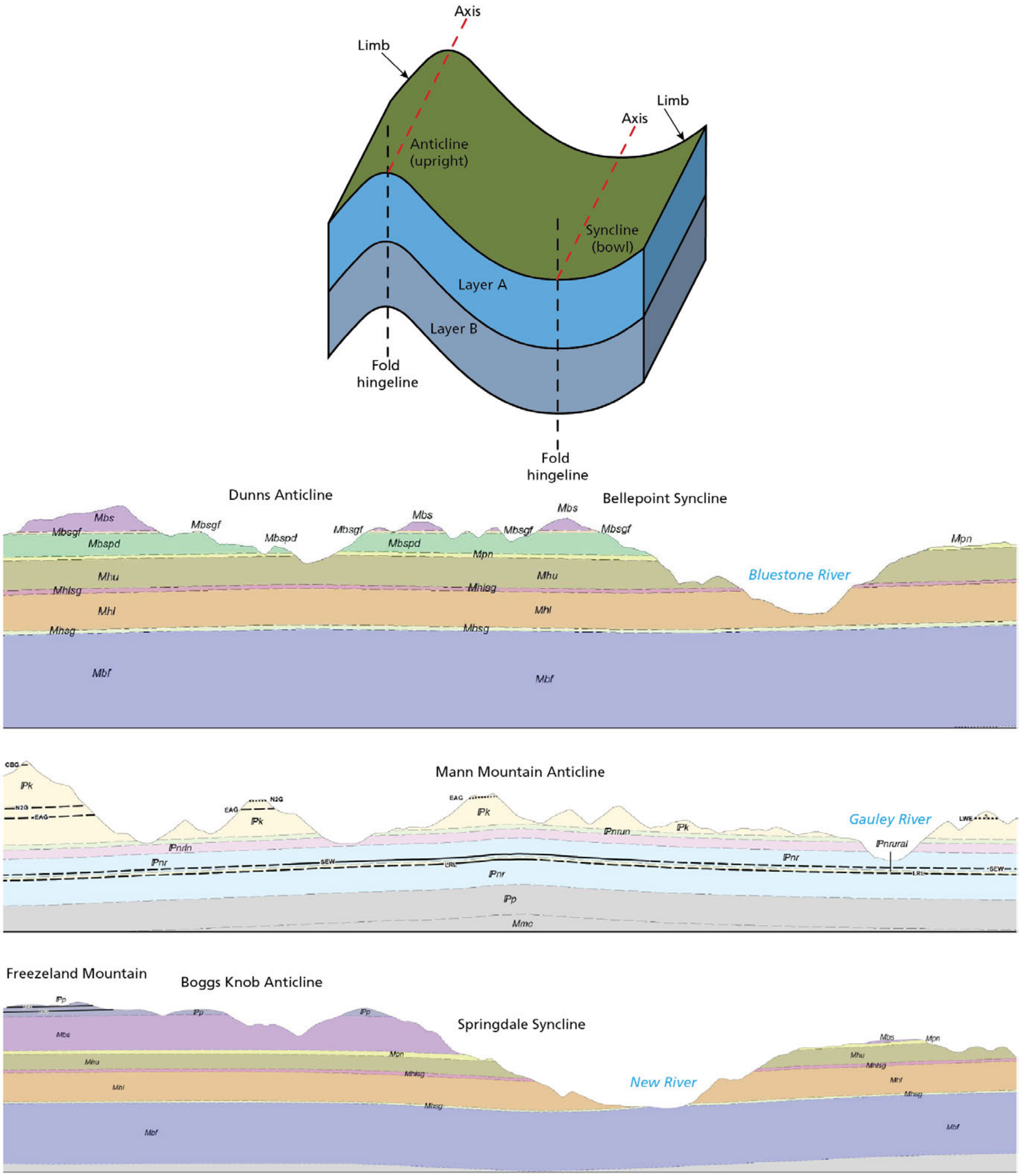


Figure 32. Diagram of fold features with examples. Folds are part of the GRI GIS data; from top to bottom excerpted from cross section A-A′ in blue_geology.pdf, from B-B′ in gari_geology.pdf, and from D-D′ in neri_geology.pdf. Both synclines and anticlines are subtle features in the parks' landscape on the Appalachian Plateau. Folding is much more dramatic and pervasive in the Valley and Ridge province to the east. Folds can act as traps for hydrocarbons and are thus important to the oil and gas industry. Folds may also impact how the bedrock is weathered away, particularly near the hinge areas where small fractures may accompany folding and cause local areas of weakness. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with cross sections from Matchen et al. (2011), Hunt et al. (2010), and McColloch et al. (2013).

Wetlands Inventory

Wetlands are transitional areas between land and water bodies, where water periodically floods the land or saturates the soil and includes marshes, swamps, seeps, pools, and bogs. About 1% of the Lower New River watershed is considered wetlands (see Mahan and Darden 2014). Although they cover a small area of the parks, they are considered an "other important resource or value" by Mahan and Darden (2014). In the park wetlands also include vernal pools, ephemeral streams, and seeps that are significant habitat for rare species particularly terrestrial salamanders and other anurans (Mahan and Darden 2014).

Wetlands in the parks may be covered in shallow water most of the year, or be wet only seasonally. Wetlands provide several significant functions, including (1) provision of bird and other wildlife habitat, (2) surface water detention, (3) nutrient transformation, and (4) retention of sediments. The National Wetlands Inventory (NWI) of the US Fish and Wildlife Service (USFWS) shows the location, type, and distribution of wetlands as small as 0.5 ha (1.2 acre). The parks have NWI maps; however, significant wetland areas are too small to be on the NWI maps or to be discernable on aerial photographs.

Wetlands are typically only mentioned in GRI reports where there are particular geologic connections to their development or resource management. At New River Gorge NR, some wetlands are found in association with AML features and/or developed alongside roads or other infrastructure. Bedrock type can also influence the presence of wetlands (fig. 33). The NPS Water Resources Division is the primary contact for technical and policy assistance regarding wetlands.

Table 13. Summary of wetlands inventory issues. Table continues on next page.

Resource Management Issue	Wetlands inventory
Related Fundamental Resources	• Bluestone NSR: biological diversity, the Bluestone River, undeveloped primitive character • Gauley River NRA: biological diversity; undeveloped, rugged geologic landscape; water quality • New River Gorge NR: geological processes and features, hydrological resources, ecological resources, scenic resources
Related Map Units And Park Examples	• Glade Creek supports a regionally significant wetlands complex. • Polls Branch and Kates Branch wetlands in New River Gorge NR (fig. 33). • The most dominant wetland types found in the New River Gorge area are temporarily flooded riverine wetlands on unconsolidated or rocky shores, permanently flooded riverine wetlands, and temporarily flooded, broad-leaved deciduous palustrine wetlands. • Degraded water quality, development of roads, and dam-controlled flow of the rivers potentially threaten wetlands. • Nearby development and resource extraction industries have led to a decline in wetland resources surrounding New River Gorge NR (National Park Service 2016c). • Unpermitted use of off-road vehicles can cause substantial damage to wetland resources in New River Gorge NR (National Park Service 2016c).
Potential Action Items	• Inventory and map wetlands, including those formed at seeps, mine portals, and those created by roads and trails (map was considered a low priority data need in National Park Service 2016c). • Mahan and Darden (2014) suggested conducting an inventory and map and maintain seeps, vernal pools, springs, road side ditches/pools, and wetland resources in New River Gorge NR was a high ("level 1") priority, in the context of understanding habitat for terrestrial salamanders and anurans. • Visitor education could limit disturbance of known wetlands; limit development of park infrastructure in or near wetlands.

Table 13, continued. Summary of wetlands inventory issues.

Resource Management Issue	Wetlands inventory
Primary References or Resources	• Park-specific information: □ Natural resource condition assessment for New River Gorge NR: Mahan (2004) □ Resource stewardship strategy for New River Gorge NR: Mahan and Darden (2014) □ GRI scoping summary: Covington (2005) • General information: □ NPS Wetlands website: https://www.nps.gov/subjects/wetlands/index.htm □ NPS Water Resources Division is primary contact for wetlands policy and technical assistance: https://www.nps.gov/orgs/1439/index.htm □ Wetland types: Cowardin et al. (1979)

Figure 33. Photographs of wetlands at New River Gorge NR. Many reaches of the gorge, flowing over very resistant sandstone (see table 8) are too narrow to support significant wetland areas. In areas where streams have eroded broader valleys through softer bedrock, larger wetlands can develop. Some wetlands are underlain by clay-rich layers that act as aquicludes to prevent downward percolation of groundwater. Water pools atop such layers and remains for a time. NPS photographs taken in winter 2012 (Kates Branch, left) and autumn 2016 (Polls Branch, right).

Seismic Activity (Earthquakes)

Seismic activity refers to ground vibrations that occur when rocks suddenly move along a fault, releasing accumulated energy as in an earthquake. Earthquake intensity ranges from imperceptible by humans to total destruction of developed areas and alteration of the landscape. All three parks have a relatively low risk for seismic hazards (fig. 34). Earthquakes can directly damage park infrastructure, or trigger other hazards such as liquefaction (the transformation of a solid soil to a liquid) or slope movements that may impact park resources, infrastructure, or visitor safety. The potential for induced seismicity exists where deep injection wells lubricate nearby faults however, little horizontal-well drilling, a source of fluids for injection wells elsewhere in the gas fields, is occurring near the park units at the time of this report. The gas plays where horizontal drilling has been used the most are located in northern and western West Virginia, north of the parks. One injection well used for frack water is located in Mercer County; however, it is fairly shallow injecting into a unit probably equivalent to the Avis Limestone (Mhlsg). This is probably not deep enough to lubricate possible big faults in the lower Devonian units or below (G. McColloch, geologist, West Virginia Geological and Economic Survey, written communication, 31 May 2017).

Table 14. Summary of seismic activity issues.

Resource Management Issue	**Seismic Activity (Earthquakes)**
Related Fundamental Resources	• Bluestone NSR: undeveloped primitive character • Gauley River NRA: undeveloped, rugged geologic landscape • New River Gorge NR: geological processes and features
Related Map Units And Park Examples	• Although the parks are not considered to be at high risk of strong earthquakes, seismicity could impact park natural and cultural resources, particularly in areas of steep slopes (see table 3), within unconsolidated fluvial and colluvial deposits (see tables 3 and 7), as well as AML features such as mines and tailing piles (see table 5).
Potential Action Items	• Identifying and monitoring slopes for non-seismic movement (table 3) would provide information on what slopes could fail during an earthquake. • Contact West Virginia Geological and Economic Survey (Ron McDowell) for additional information and support.
Primary References or Resources	• General information: □ West Virginia Geological and Economic Survey, Earthquakes and Seismicity website: http://www.wvgs.wvnet.edu/www/earthquakes/seismic.html □ Seismic Monitoring (Braile 2009; http://go.nps.gov/geomonitoring) □ US Geological Survey Earthquakes Hazards website: http://earthquake.usgs.gov/ □ Seismic hazard maps: Petersen et al. (2008) □ Map of Marcellus wells: http://ims.wvgs.wvnet.edu/Mar/viewer.htm

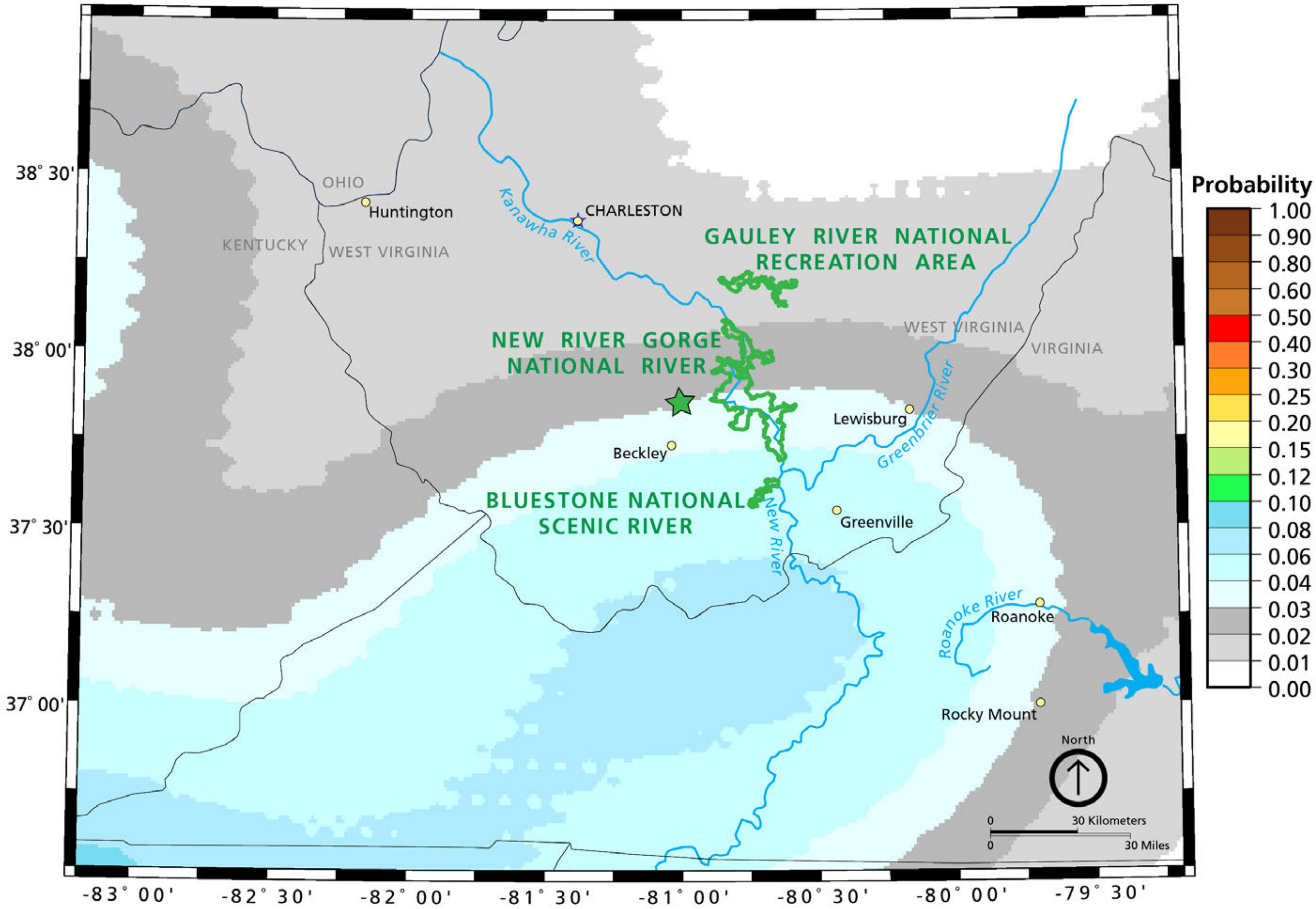


Figure 34. Map of probability of earthquakes with magnitude greater than 5.0 (moderate earthquake). This probability assumes a 100-year timespan and a 50-km (30-mi) radius around Glen Jean, West Virginia (green star). Graphic was generated by the US Geological Survey earthquake probability mapping program (https://geohazards.usgs.gov/eqprob/2009/index.php).

Geologic Map Data

A geologic map in GIS format is the principal deliverable of the GRI program. GRI GIS data produced for the parks follows the source maps and includes components listed here. Posters (in pocket) display the data over shaded relief of the parks and surrounding area. Complete GIS data are available at the GRI website: http://go.nps.gov/gripubs. See figure 35 for GIS updates received during final review.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the age (fig. 4; table 2) and lowercase letters indicating the formation's name. Other symbols depict structures such as faults or folds, locations of past geologic hazards that may be susceptible to future activity, and other geologic features. Anthropogenic features such as mines or quarries, as well as observation or collection locations, may be indicated on geologic maps. The American Geosciences Institute website, http://www.americangeosciences.org/environment/publications/mapping, provides more information about geologic maps and their uses.

Geologic maps are typically one of two types: surficial or bedrock. Surficial geologic maps typically encompass deposits that are unconsolidated and formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type. GRI produced a surficial and a bedrock map for Bluestone NSR, Gauley River NRA, and New River Gorge NR.

Source Maps

The GRI team does not conduct original geologic mapping. The team digitizes paper maps and compiles and converts digital data to conform to the GRI GIS data model. The GRI GIS data set includes essential elements of the source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, cross sections, figures, and references. These items are included in the blue_geology.pdf, gari_geology.pdf, and neri_geology.pdf. The GRI team used the following sources to produce the GRI GIS data set for Bluestone NSR, Gauley River NRA, and New River Gorge NR. These sources also provided information for this report.

- Bedrock Map for Bluestone NSR:
  Matchen et al. (2011)
- Surficial Map for Bluestone NSR:
  Yates and Kite (2014)
- Bedrock Map for Gauley River NRA:
  Hunt et al. (2010)
- Surficial Map for Gauley River NRA:
  Kite (2016)
- Bedrock Map for New River Gorge NR:
  McColloch et al. (2013)
- Surficial Map for New River Gorge NR:
  Yates and Kite (2015)

GRI GIS Data

The GRI team standardizes map deliverables by using a data model. The GRI GIS data for Bluestone NSR, Gauley River NRA, and New River Gorge NR was compiled using data model version 2.1, which is available is available at http://go.nps.gov/gridatamodel. This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI Geologic Maps website, http://go.nps.gov/geomaps, provides more information about the program's map products.

GRI GIS data are available on the GRI publications website http://go.nps.gov/gripubs and through the NPS Integrated Resource Management Applications (IRMA) portal https://irma.nps.gov/App/Portal/Home. Enter "GRI" as the search text and select a park from the unit list.

The following components are part of the data set:

- A GIS readme file (blue_gis_readme.pdf, gari_gis_readme.pdf, or neri_gis_readme.pdf) that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information.
- Data in ESRI geodatabase GIS format;
- Layer files with feature symbology (tables 15–20);
- Federal Geographic Data Committee (FGDC)–compliant metadata;
- An ancillary map information document (blue_geology.pdf, gari_geology.pdf, or neri_geology.pdf) that contains information captured from source maps such as map unit descriptions, geologic unit correlation tables, legends, cross-sections, and figures;
- An ESRI map document (blue_geology.mxd, blus_geology.mxd, gari_geology.mxd, gars_geology.mxd, neri_geology.mixd, or ners_geology.mxd) that displays the GRI GIS data; and
- A version of the data viewable in Google Earth (blue_geology.kmz, gari_geology.kmz, or neri_geology.kmz; tables 15–20).

GRI Map Posters

Posters of the GRI GIS draped over a shaded relief image of the parks and surrounding areas are included with this report. Not all GIS feature classes are included on the posters (tables 15–20). Geographic information and selected parks features have been added to the posters. Digital elevation data and added geographic information are not included in the GRI GIS data, but are available online from a variety of sources. Contact GRI for assistance locating these data.

Use Constraints

Graphic and written information provided in this report is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based upon the information provided here. Please contact GRI with any questions.

Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features on the posters. Based on the source map scales (1:12,000, 1:24,000, and 1:48,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are expected to be horizontally within 6 m (20 ft), 12 m (40 ft), and 24 m (80 ft), respectively of their true locations..

Table 15. Bedrock GRI GIS data layers for Bluestone NSR (blue_geology.mxd).

Data Layer	On Poster?	Google Earth Layer?
Mine Point Features	No	No
Geologic Observation Localities	No	No
Folds	Yes	Yes
Linear Geologic Units	Yes	Yes
Geologic Cross Section Lines	Yes	Yes
Structure Contours Showing Base of the Princeton Formation	No	No
Geologic Contacts	Yes	Yes
Geologic Units	Yes	Yes

Table 16. Bedrock GRI GIS data layers for Gauley River NRA (gari_geology.mxd).

Data Layer	On Poster?	Google Earth Layer?
Geologic Observation Localities	No	No
Mine Point Features	No	No
Folds	Yes	Yes
Geologic Cross Section Lines	Yes	No
Linear Geologic Units	Yes	Yes
Structure Contour Lines, Sewell Coal Horizon	No	No
Geologic Contacts	Yes	Yes
Geologic Units	Yes	Yes

Table 17. Bedrock GRI GIS data layers for New River Gorge NR (neri_geology.mxd).

Data Layer	On Poster?	Google Earth Layer?
Geologic Observation Localities	No	No
Mine Point features	No	No
Folds	Yes	Yes
Geologic Cross Section Lines	Yes	No
Linear Geologic Units	Yes	Yes
Structure Contour Lines, Eagle Coal (PNKeag)	No	No
Structure Contour Lines, Fire Creek Coal (PNnrfck)	No	No
Structure Contour Lines, Little Stone Gap, Avis Limestone (Mhlsg)	No	No
Structure Contour Lines, Sewell Coal (PNnrsew)	No	No
Bedrock Geologic Contacts	Yes	Yes
Bedrock Geologic Units	Yes	Yes

Table 18. Surficial GRI GIS data layers for Bluestone NSR (blus_geology.mxd).

Data Layer	On Poster?	Google Earth Layer?
Surficial Contacts	Yes	Yes
Surficial Units	Yes	Yes

Table 19. Surficial GRI GIS data layers for Gauley River NRA (gars_geology.mxd).

Data Layer	On Poster?	Google Earth Layer?
Surficial Contacts	Yes	Yes
Surficial Units	Yes	Yes

Table 20. Surficial GRI GIS data layers for New River Gorge NR (ners_geology.mxd).

Data Layer	On Poster?	Google Earth Layer?
Surficial Contacts	Yes	Yes
Surficial Units	Yes	Yes

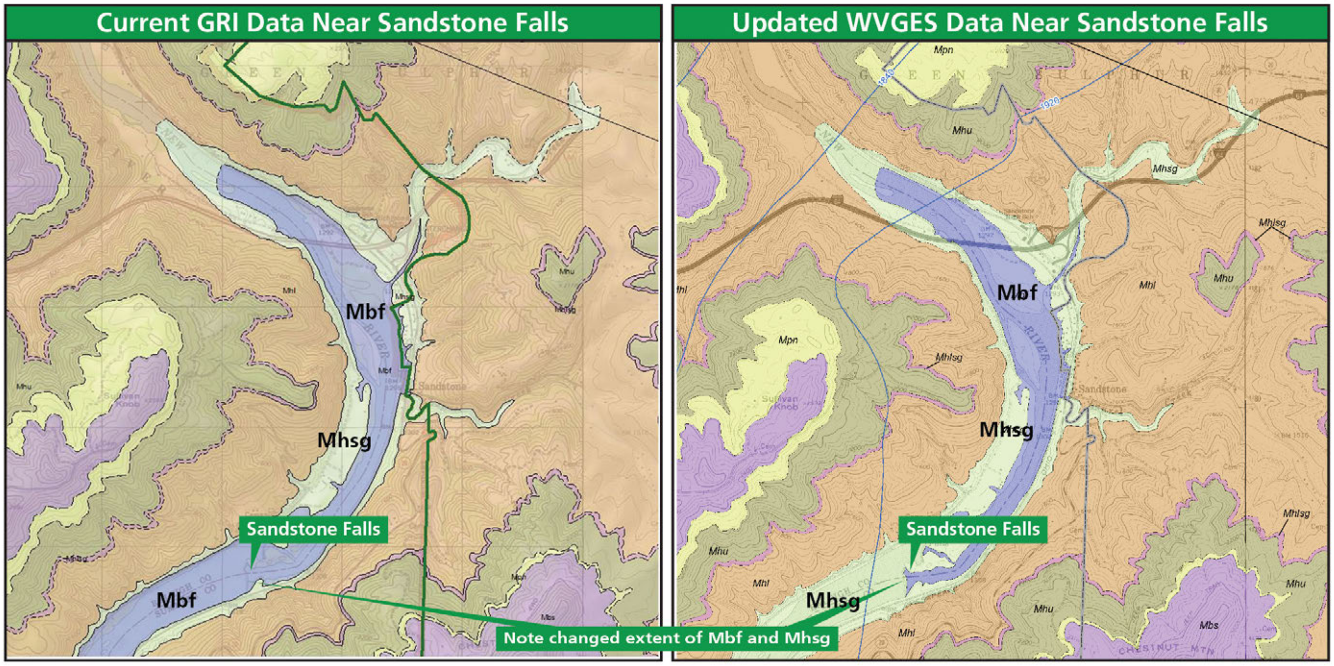


Figure 35. Comparison of current and updated GIS data for the area near Sandstone Falls in New River Gorge NR. While this report was in final formatting and production, an error was discovered in the GIS data near Sandstone Falls on the Hinton and Meadow Creek quadrangles. The screen shots above show changes in extent of units Mbf (Mississippian Bluefield Formation, undifferentiated) and Mhsg (Mississippian Hinton Formation, Stony Gap Sandstone Member). The changes in extent continue south to Brooks Falls (not visible on fig. 35). The updates are not reflected on the posters included with this report. The GRI GIS data will be updated in the future to reflect these changes and GRI staff will contact park staff when it is available. Mapping was updated by Bob Peck (West Virginia Geological and Economic Survey). Thanks to Paula Hunt and Sarah Gooding (both of West Virginia Geological and Economic Survey) for coordinating the revisions and providing updated GIS to GRI staff.

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Additional References

These may be of use to resource managers. Refer to Appendix B for laws, regulations, and policies that apply to NPS geologic resources.

Geology of National Park Service Areas

- NPS Geologic Resources Division—*Energy and Minerals, Active Processes and Hazards, and Geologic Heritage*: http://go.nps.gov/geology/
- NPS Geologic Resources Inventory: http://go.nps.gov/gri
- NPS Geoscientist-In-the-Parks (GIP) internship and guest scientist program: http://go.nps.gov/gip
- NPS Views program (geology-themed modules are available for Geologic Time, Paleontology, Glaciers, Caves and Karst, Coastal Geology, Volcanoes, and a variety of geologic parks): http://go.nps.gov/views

NPS Resource Management Guidance and Documents

- 1998 National Parks Omnibus Management Act: http://www.gpo.gov/fdsys/pkg/PLAW-105publ391/pdf/PLAW-105publ391.pdf
- Geologic monitoring manual: http://go.nps.gov/geomonitoring
- Management Policies 2006 (Chapter 4: Natural resource management): http://www.nps.gov/policy/mp/policies.html
- NPS-75: Natural resource inventory and monitoring guideline: http://www.nature.nps.gov/nps75/nps75.pdf
- NPS Natural resource management reference manual #77: http://www.nature.nps.gov/Rm77/
- NPS Technical Information Center (TIC) (Denver, Colorado; repository for technical documents): http://www.nps.gov/dsc/technicalinfocenter.htm http://etic.nps.gov/

Climate Change Resources

- NPS Climate Change Response Program Resources: http://www.nps.gov/subjects/climatechange/resources.htm
- US Global Change Research Program: http://globalchange.gov/home
- Intergovernmental Panel on Climate Change: http://www.ipcc.ch/

Geological Surveys and Societies

- West Virginia Geological and Economic Survey: http://www.wvgs.wvnet.edu/
- US Geological Survey: http://www.usgs.gov/
- USGS Publications: http://pubs.er.usgs.gov/
- Geological Society of America: http://www.geosociety.org/
- American Geophysical Union: http://sites.agu.org/
- American Geosciences Institute: http://www.americangeosciences.org/
- Association of American State Geologists: http://www.stategeologists.org/

US Geological Survey Reference Tools

- Geologic glossary (simplified definitions): http://geomaps.wr.usgs.gov/parks/misc/glossarya.html
- Geologic names lexicon (Geolex; geologic unit nomenclature and summary): http://ngmdb.usgs.gov/Geolex/geolex_home.html
- Geographic names information system (GNIS; official listing of place names and geographic features): http://gnis.usgs.gov/
- GeoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Find Maps")
- National geologic map database (NGMDB): http://ngmdb.usgs.gov/
- Publications warehouse (many publications available online): http://pubs.er.usgs.gov
- Tapestry of time and terrain (descriptions of physiographic provinces): http://pubs.usgs.gov/imap/i2720/

Appendix A: Scoping Participants

The following people attended the GRI scoping meeting, held on 13 and 15 July, 2004, or the follow-up report writing conference call, held on 13 December 2016. Discussions during these meetings supplied a foundation for this GRI report. The scoping summary document is available on the GRI publications website: http://go.nps.gov/gripubs.

2004 Scoping Meeting Participants

Name	Affiliation	Position
Mitch Blake	West Virginia Geologic and Economic Survey	Geologist
Gene Clare	NPS New River Gorge National River	Geologist
Tim Connors	NPS Geologic Resources Division	Geologist
Sid Covington	NPS Geologic Resources Division	Geologist
Debbie Darden	NPS New River Gorge National River	Deputy superintendent
Michael Hohn	West Virginia Geologic and Economic Survey	Geologist
Steve Kite	West Virginia University	Geologist
Matt Marshall	NPS Eastern Rivers and Mountains Network	Network coordinator
Nathan Piekielek	NPS Eastern Rivers and Mountains Network	Data manager
Stephen Schindler	West Virginia University	Geologist

2016 Conference Call Participants

Name	Affiliation	Position
Conrad Clewell	NPS New River Gorge National River	SCA intern
Tim Connors	NPS Geologic Resources Division	Geologist
Paula Hunt	West Virginia Geological and Economic Survey	Geologist
Jason Kenworthy	NPS Geologic Resources Division	Geologist, GRI reports coordinator
Steve Kite	West Virginia University	Surficial geologist, geomorphologist
Gayle H "Scott" McColloch, Jr.	West Virginia Geological and Economic Survey	Geologist
Kathy Oney	NPS New River Gorge National River	Biological science technician
Lenza Paul	NPS New River Gorge National River	Biological science technician
John Perez	NPS New River Gorge National River	Plant biologist
Jesse Purvis	NPS New River Gorge National River	Fisheries biologist
Claire Rozdilski	NPS New River Gorge National River	Acting chief of natural resources
Pete Sharpe	NPS Northeast Region	Hydrologist
Layne Strickler	NPS New River Gorge National River	Biological science technician
Trista L. Thornberry-Ehrlich	Colorado State University	Geologist, report writer, graphic designer
Lisa Wilson	NPS New River Gorge National River	Biological science technician

Appendix B: Geologic Resource Laws, Regulations, and Policies

The NPS Geologic Resources Division developed this table to summarize laws, regulations, and policies that specifically apply to National Park Service minerals and geologic resources. The table does not include laws of general application (e.g., Endangered Species Act, Clean Water Act, Wilderness Act, National Environmental Policy Act, or National Historic Preservation Act). The table does include the NPS Organic Act when it serves as the main authority for protection of a particular resource or when other, more specific laws are not available. Information is current as of August 2016. Contact the NPS Geologic Resources Division for detailed guidance.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Paleontology	**National Parks Omnibus Management Act of 1998, 16 USC § 5937** protects the confidentiality of the nature and specific location of paleontological resources and objects. **Paleontological Resources Preservation Act of 2009, 16 USC § 470aaa et seq.** provides for the management and protection of paleontological resources on federal lands.	**36 CFR § 2.1(a)(1)(iii)** prohibits destroying, injuring, defacing, removing, digging or disturbing paleontological specimens or parts thereof. **Prohibition in 36 CFR § 13.35** applies even in Alaska parks, where the surface collection of other geologic resources is permitted. DOI regulations in association with 2009 PRPA are being finalized (July 2017).	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity. **Section 4.8.2.1** emphasizes Inventory and Monitoring, encourages scientific research, directs parks to maintain confidentiality of paleontological information, and allows parks to buy fossils only in accordance with certain criteria.
Rocks and Minerals	**NPS Organic Act, 16 USC § 1 et seq.** directs the NPS to conserve all resources in parks (including rock and mineral resources), unless otherwise authorized by law.	**36 CFR § 2.1** prohibits possessing, destroying, disturbing mineral resources… in park units. **Exception: 36 CFR § 13.35** allows some surface collection of rocks and minerals in some Alaska parks (not Klondike Gold Rush, Sitka, Denali, Glacier Bay, or Katmai) by non-disturbing methods (e.g., no pickaxes), which can be stopped by superintendent if collection causes significant adverse effects on park resources and visitor enjoyment.	**Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity.
Park Use of Sand and Gravel	**Materials Act of 1947, 30 USC § 601** does not authorize the NPS to dispose of mineral materials outside of park units.	None applicable.	**Section 9.1.3.3** clarifies that only the NPS or its agent can extract park-owned common variety minerals (e.g., sand and gravel), and: -only for park administrative uses; -after compliance with NEPA and other federal, state, and local laws, and a finding of non-impairment; -after finding the use is park's most reasonable alternative based on environment and economics; -parks should use existing pits and create new pits only in accordance with park-wide borrow management plan; -spoil areas must comply with Part 6 standards; and -NPS must evaluate use of external quarries. Any deviation from this policy requires a written waiver from the Secretary, Assistant Secretary, or Director.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Upland and Fluvial Processes	**Rivers and Harbors Appropriation Act of 1899, 33 USC § 403** prohibits the construction of any obstruction on the waters of the United States not authorized by Congress or approved by the USACE. **Clean Water Act 33 USC § 1342** requires a permit from the USACE prior to any discharge of dredged or fill material into navigable waters (waters of the US [including streams]). **Executive Order 11988** requires federal agencies to avoid adverse impacts to floodplains. (see also **D.O. 77-2**) **Executive Order 11990** requires plans for potentially affected wetlands (including riparian wetlands). (see also **D.O. 77-1**)	None applicable.	**Section 4.1** requires NPS to manage natural resources to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities; maintain all components and processes of naturally evolving park ecosystems. **Section 4.1.5** directs the NPS to re-establish natural functions and processes in human-disturbed components of natural systems in parks, unless directed otherwise by Congress. **Section 4.4.2.4** directs the NPS to allow natural recovery of landscapes disturbed by natural phenomena, unless manipulation of the landscape is necessary to protect park development or human safety. **Section 4.6.4** directs the NPS to (1) manage for the preservation of floodplain values; [and] (2) minimize potentially hazardous conditions associated with flooding. **Section 4.6.6** directs the NPS to manage watersheds as complete hydrologic systems and minimize human-caused disturbance to the natural upland processes that deliver water, sediment, and woody debris to streams. **Section 4.8.1** directs the NPS to allow natural geologic processes to proceed unimpeded. Geologic processes…include… erosion and sedimentation…processes. **Section 4.8.2** directs the NPS to protect geologic features from the unacceptable impacts of human activity while allowing natural processes to continue.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Soils	**Soil and Water Resources Conservation Act, 16 USC §§ 2011–2009** provides for the collection and analysis of soil and related resource data and the appraisal of the status, condition, and trends for these resources. **Farmland Protection Policy Act, 7 USC § 4201 et. seq**. requires NPS to identify and take into account the adverse effects of Federal programs on the preservation of farmland; consider alternative actions, and assure that such Federal programs are compatible with State, unit of local government, and private programs and policies to protect farmland. NPS actions are subject to the FPPA if they may irreversibly convert farmland (directly or indirectly) to nonagricultural use and are completed by a Federal agency or with assistance from a Federal agency. Applicable projects require coordination with the Department of Agriculture's Natural Resources Conservation Service (NRCS).	**7 CFR Parts 610 and 611** are the US Department of Agriculture regulations for the Natural Resources Conservation Service. Part 610 governs the NRCS technical assistance program, soil erosion predictions, and the conservation of private grazing land. Part 611 governs soil surveys and cartographic operations. The NRCS works with the NPS through cooperative arrangements.	**Section 4.8.2.4** requires NPS to -prevent unnatural erosion, removal, and contamination; -conduct soil surveys; -minimize unavoidable excavation; and -develop/follow written prescriptions (instructions).
Caves and Karst Systems	**Federal Cave Resources Protection Act of 1988, 16 USC §§ 4301 – 4309** requires Interior/Agriculture to identify "significant caves" on Federal lands, regulate/ restrict use of those caves as appropriate, and include significant caves in land management planning efforts. Imposes civil and criminal penalties for harming a cave or cave resources. Authorizes Secretaries to withhold information about specific location of a significant cave from a Freedom of Information Act (FOIA) requester. **National Parks Omnibus Management Act of 1998, 54 USC § 100701** protects the confidentiality of the nature and specific location of cave and karst resources. **Lechuguilla Cave Protection Act of 1993, Public Law 103-169** created a cave protection zone (CPZ) around Lechuguilla Cave in Carlsbad Caverns National Park. Within the CPZ, access and the removal of cave resources may be limited or prohibited; existing leases may be cancelled with appropriate compensation; and lands are withdrawn from mineral entry.	**36 CFR § 2.1** prohibits possessing/ destroying/disturbing…cave resources…in park units. **43 CFR Part 37** states that all NPS caves are "significant" and sets forth procedures for determining/releasing confidential information about specific cave locations to a FOIA requester.	**Section 4.8.1.2** requires NPS to maintain karst integrity, minimize impacts. **Section 4.8.2** requires NPS to protect geologic features from adverse effects of human activity. **Section 4.8.2.2** requires NPS to protect caves, allow new development in or on caves if it will not impact cave environment, and to remove existing developments if they impair caves. **Section 6.3.11.2** explains how to manage caves in/adjacent to wilderness.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Mining Claims	**Mining in the Parks Act of 1976, 54 USC § 100731 et seq**. authorizes NPS to regulate all activities resulting from exercise of mineral rights, on patented and unpatented mining claims in all areas of the System, in order to preserve and manage those areas. **General Mining Law of 1872, 30 USC § 21 et seq**. allows US citizens to locate mining claims on Federal lands. Imposes administrative and economic validity requirements for "unpatented" claims (the right to extract Federally-owned locatable minerals). Imposes additional requirements for the processing of "patenting" claims (claimant owns surface and subsurface). Use of patented mining claims may be limited in Wild and Scenic Rivers and OLYM, GLBA, CORO, ORPI, and DEVA. **Surface Uses Resources Act of 1955, 30 USC § 612** restricts surface use of unpatented mining claims to mineral activities.	**36 CFR § 5.14** prohibits prospecting, mining, and the location of mining claims under the general mining laws in park areas except as authorized by law. **36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart A** requires the owners/operators of mining claims to demonstrate bona fide title to mining claim; submit a plan of operations to NPS describing where, when, and how; prepare/submit a reclamation plan; and submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to mining claims located in, or adjacent to, National Park System units in Alaska.	**Section 6.4.9** requires NPS to seek to remove or extinguish valid mining claims in wilderness through authorized processes, including purchasing valid rights. Where rights are left outstanding, NPS policy is to manage mineral-related activities in NPS wilderness in accordance with the regulations at **36 CFR Parts 6 and 9A**. **Section 8.7.1** prohibits location of new mining claims in parks; requires validity examination prior to operations on unpatented claims; and confines operations to claim boundaries.
Nonfederal Oil and Gas	**NPS Organic Act, 54 USC § 100751 et seq**. authorizes the NPS to promulgate regulations to protect park resources and values (from, for example, the exercise of mining and mineral rights). Individual Park Enabling Statutes: **16 USC § 230a** (Jean Lafitte NHP & Pres.) **16 USC §450kk** (Fort Union NM), **16 USC § 459d-3** (Padre Island NS), **16 USC § 459h-3** (Gulf Islands NS), **16 USC § 460ee** (Big South Fork NRRA), **16 USC § 460cc-2(i)** (Gateway NRA), **16 USC § 460m** (Ozark NSR), **16 USC§698c** (Big Thicket N Pres.), **16 USC §698f** (Big Cypress N Pres.)	**36 CFR Part 6** regulates solid waste disposal sites in park units. **36 CFR Part 9, Subpart B** requires the owners/operators of nonfederally owned oil and gas rights to -demonstrate bona fide title to mineral rights; -submit a plan of operations to NPS describing where, when, how they intend to conduct operations; -prepare/submit a reclamation plan; and -submit a bond to cover reclamation and potential liability. **43 CFR Part 36** governs access to nonfederal oil and gas rights located in, or adjacent to, National Park System units in Alaska.	**Section 8.7.3** requires operators to comply with 9B regulations.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Nonfederal minerals other than oil and gas (e.g., coal)	**NPS Organic Act, 54 USC §§ 100101 and 100751** **Surface Mining Control and Reclamation Act of 1977, 30 USC § 1201 et. seq**. prohibits surface coal mining operations on any lands within the boundaries of a NPS unit, subject to valid existing rights.	NPS regulations at **36 CFR Parts 1, 5, and 6** require the owners/operators of other types of mineral rights to obtain a special use permit from the NPS as a § 5.3 business operation, and § 5.7 – Construction of buildings or other facilities, and to comply with the solid waste regulations at Part 6. **SMCRA Regulations at 30 CFR Chapter VII** govern surface mining operations on Federal lands and Indian lands by requiring permits, bonding, insurance, reclamation, and employee protection. **Part 7** of the regulations states that National Park System lands are unsuitable for surface mining.	**Section 8.7.3** states that operators exercising rights in a park unit must comply with **36 CFR Parts 1 and 5**.

Resource	Resource-specific Laws	Resource-specific Regulations	2006 Management Policies
Climate Change	**Secretarial Order 3289** (Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources) (2009) requires DOI bureaus and offices to incorporate climate change impacts into long-range planning; and establishes DOI regional climate change response centers and Landscape Conservation Cooperatives to better integrate science and management to address climate change and other landscape scale issues. **Executive Order 13693** (Planning for Federal Sustainability in the Next Decade) (2015) established to maintain Federal leadership in sustainability and greenhouse gas emission reductions.	**No specific regulations, although applicable NPS policy memos include the following:** **Policy Memo 12-02** (Applying National Park Service Management Policies in the Context of Climate Change) (2012) applies considerations of climate change to the impairment prohibition and to maintaining "natural conditions". **Policy Memo 14-02** (Climate Change and Stewardship of Cultural Resources) (2014) provides guidance and direction regarding the stewardship of cultural resources in relation to climate change. **Policy Memo 15-01** (Climate Change and Natural Hazards for Facilities) (2015) provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks.	**Section 4.1** requires NPS to investigate the possibility to restore natural ecosystem functioning that has been disrupted by past or ongoing human activities. This would include climate change, as put forth in the NPS Coastal Adaptation Strategies Handbook (Beavers et al. 2016). **DO-100 "Resource Stewardship for the 21st Century"** (2016) requires parks to incorporate the Precautionary Principle and adaptive management into resource stewardship, and affirms that park resources and values take precedence over park uses. **NPS Coastal Adaptation Strategies Handbook** (Beavers et al. 2016) provides strategies and decision-making frameworks to support adaptation of natural and cultural resources to climate change. **NPS Climate Change Response Strategy** (2010) describes goals and objectives to guide NPS actions under four integrated components: science, adaptation, mitigation, and communication. **DOI Manual Part 523, Chapter 1** establishes policy and provides guidance for addressing climate change impacts upon the Department's mission, programs, operations, and personnel. **Revisiting Leopold: Resource Stewardship in the National Parks** (2012) will guide US National Park natural and cultural resource management into a second century of continuous change, including climate change. **Climate Change Action Plan** (2012) articulates a set of high-priority no-regrets actions the NPS will undertake over the next few years **Green Parks Plan** (2013) is a long-term strategic plan for sustainable management of NPS operations.

NPS 619/140406, 600/140406, 637/140406, October 2017

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
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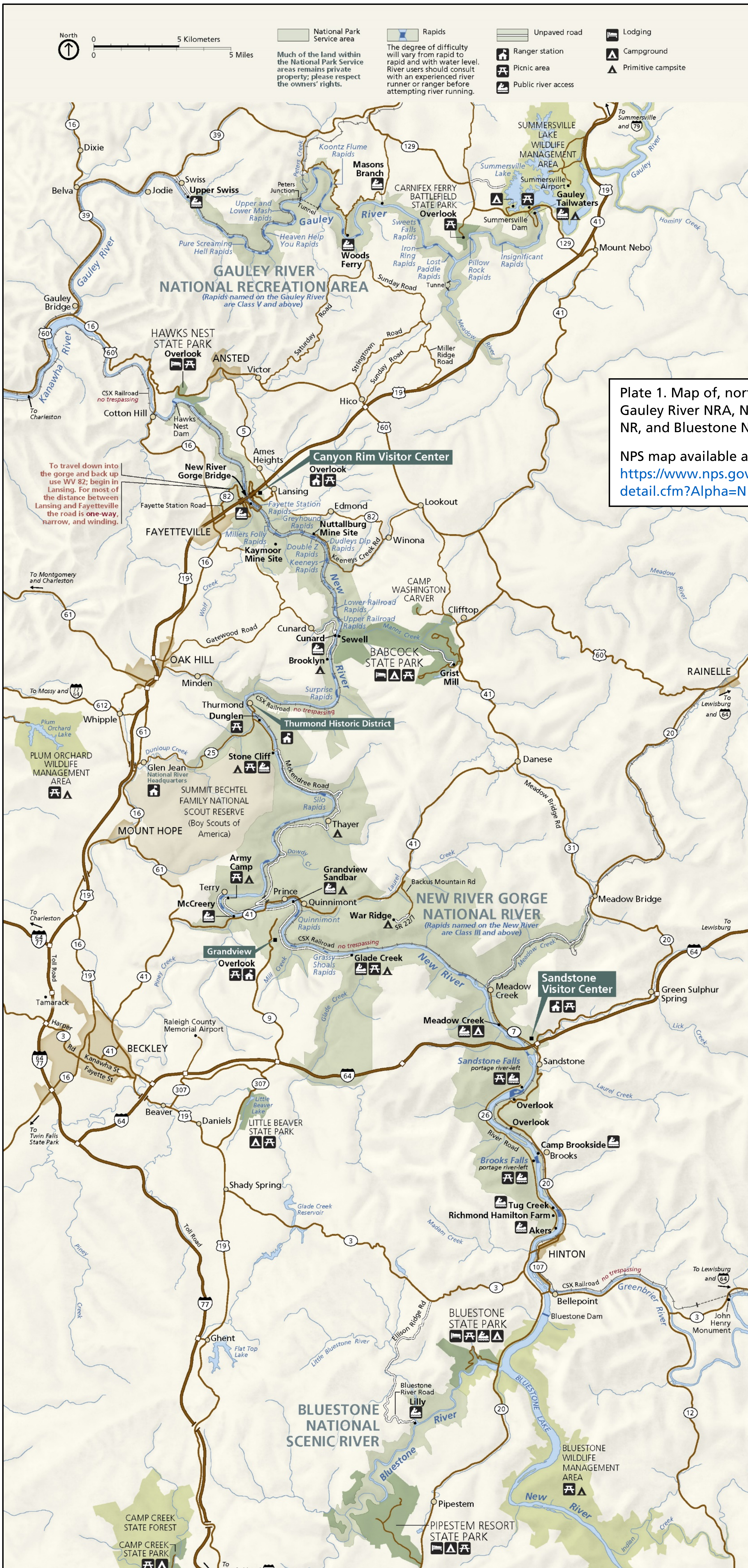


Plate 1. Map of, north to south, Gauley River NRA, New River Gorge NR, and Bluestone NSR.

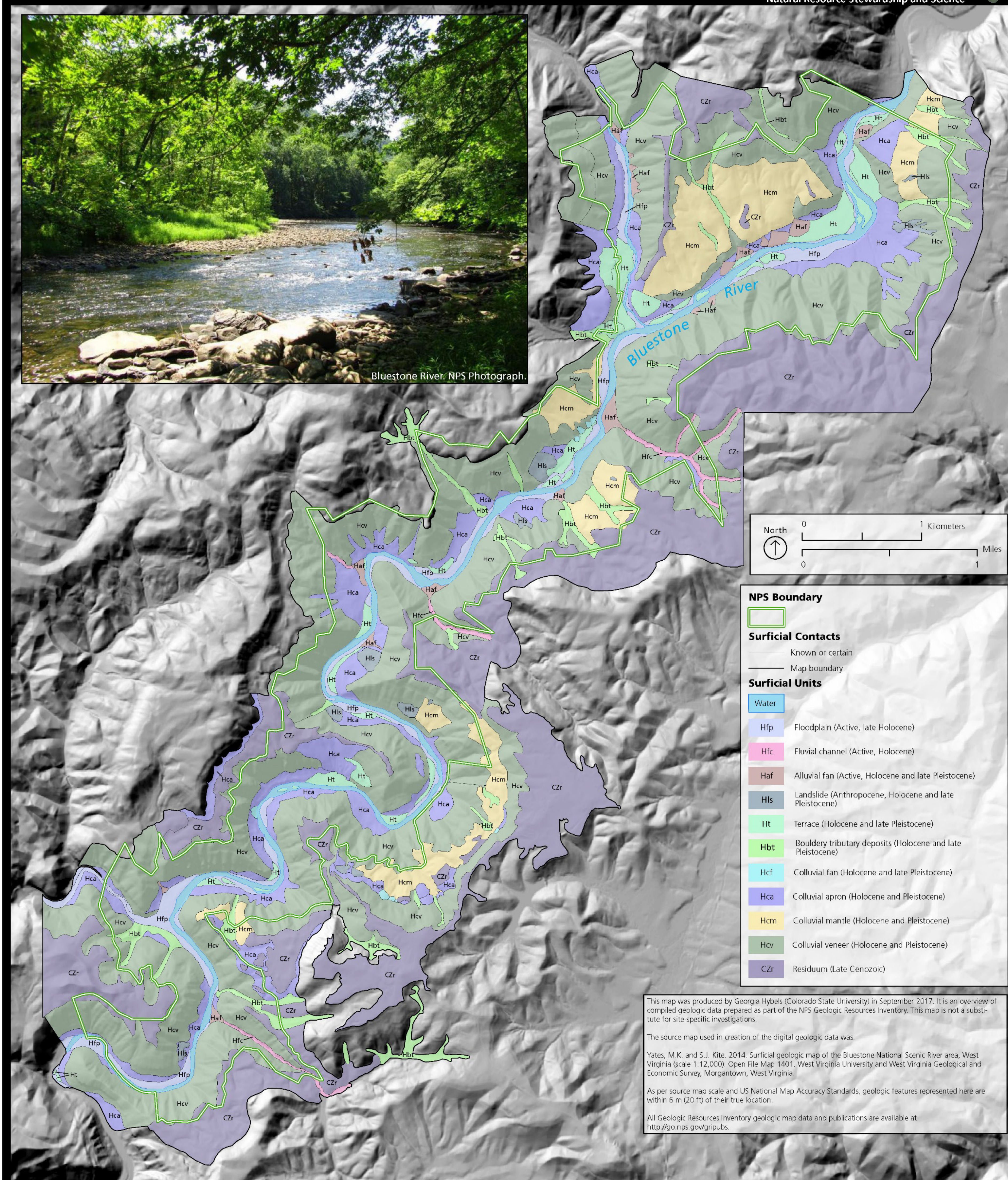
NPS map available at: https://www.nps.gov/hfc/cfm/carto-detail.cfm?Alpha=NERI

Surficial Geologic Map of Bluestone National Scenic River

West Virginia

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science

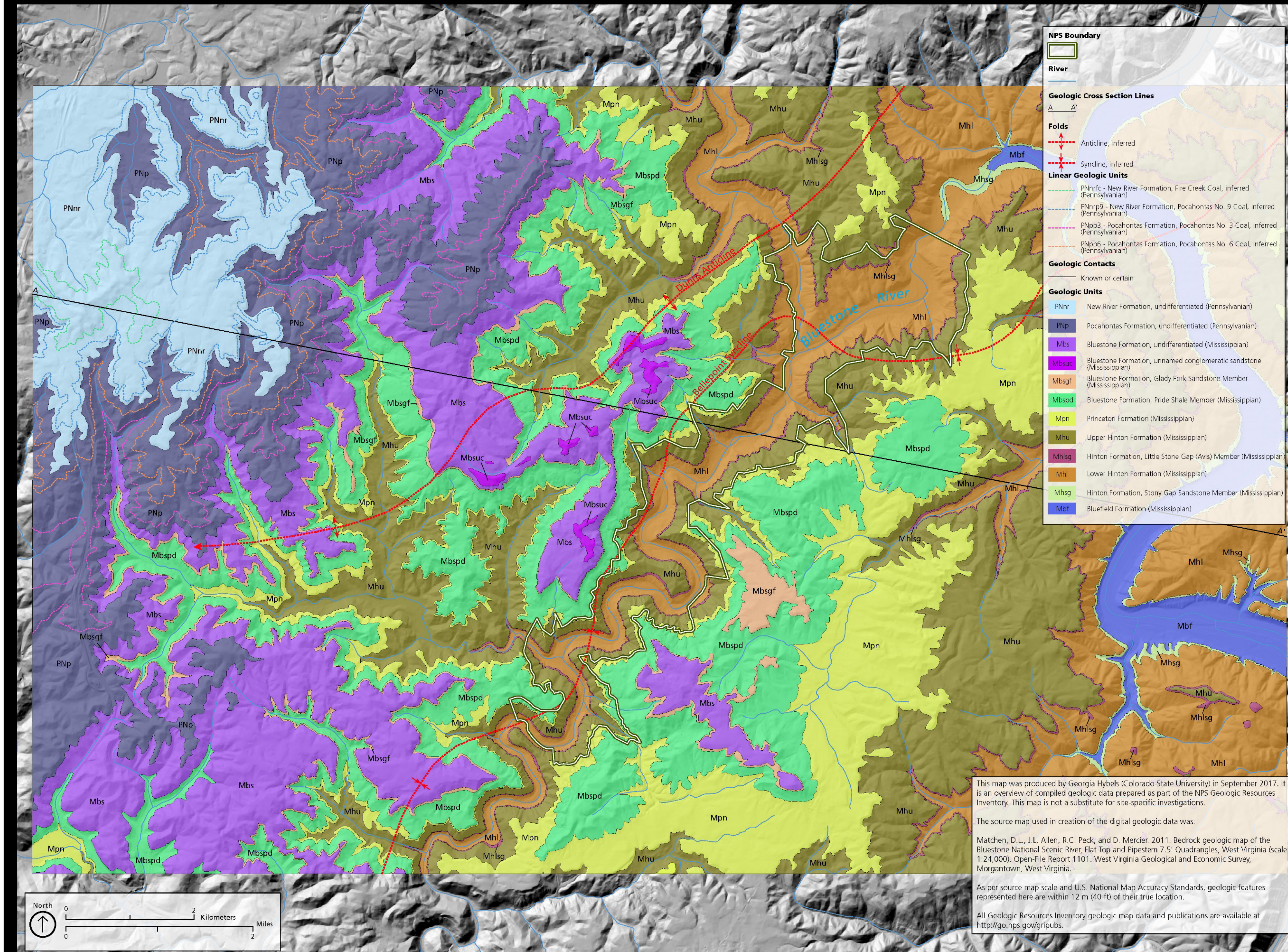


Bedrock Geologic Map of Bluestone National Scenic River

West Virginia

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science

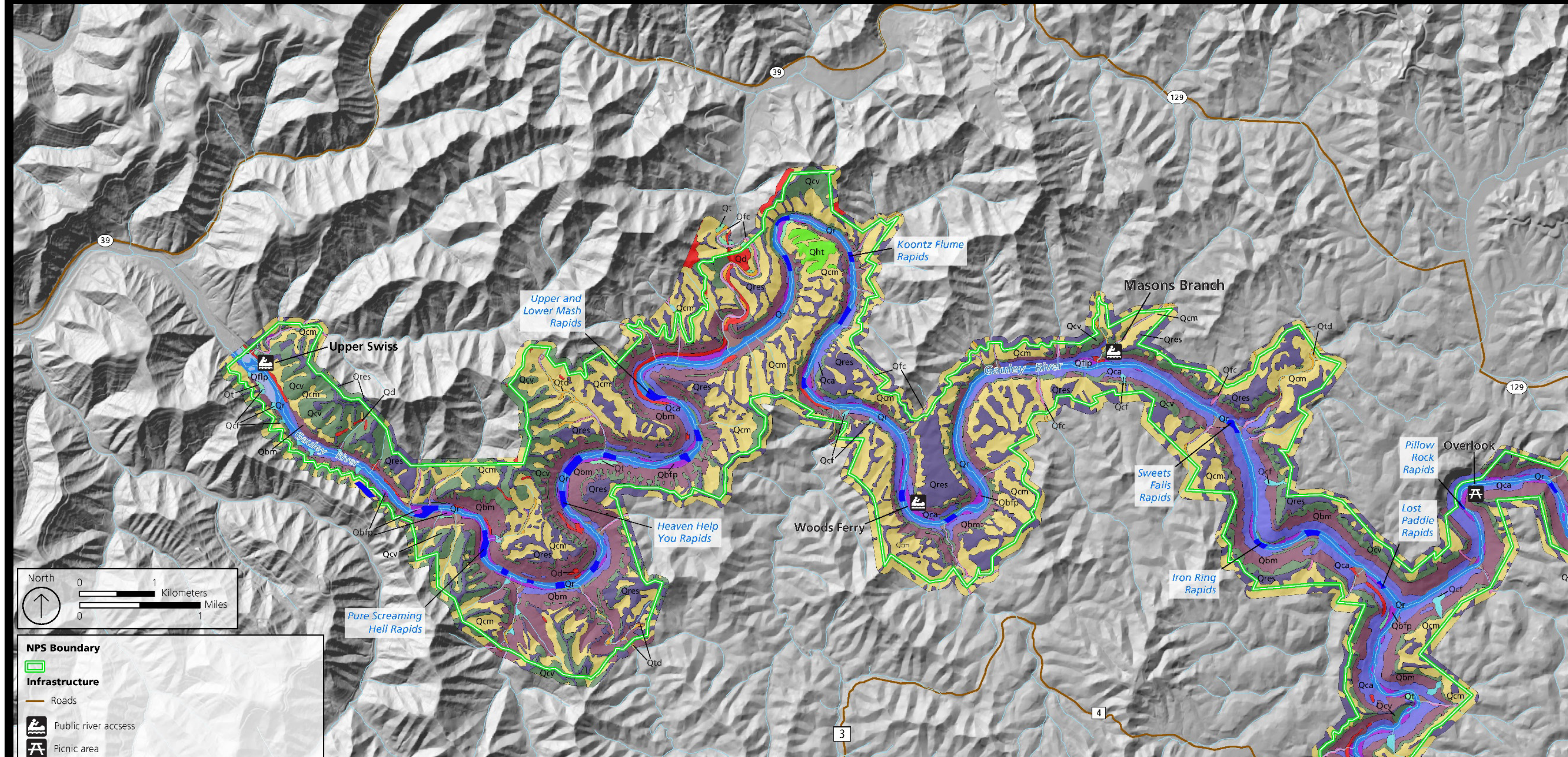


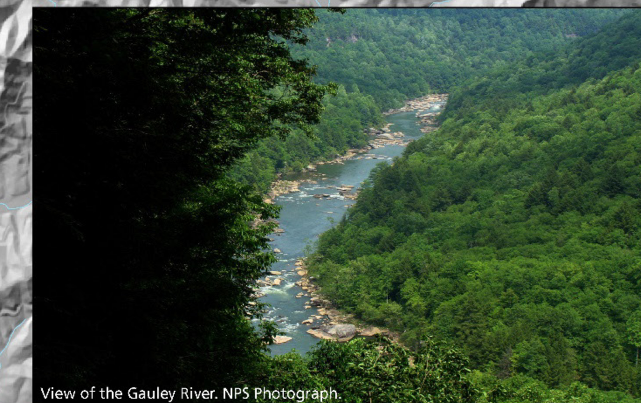
Surficial Geologic Map of Gauley River National Recreation Area

West Virginia

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science




View of the Gauley River. NPS Photograph.

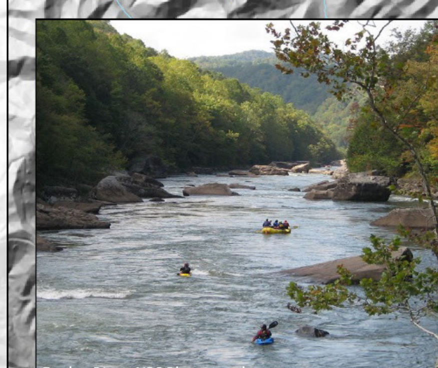
NPS Boundary

Infrastructure
- Roads
- Public river accsess
- Picnic area
- Campground
- Dam

Surficial Contacts
- Known or certain
- Water or shoreline

Water
- Water
- Rapids

Surficial Units
- Qd — Disturbed (active, Holocene)
- Qc — River channel (active, Holocene)
- Qtd — Tributary deposit (active, Holocene and late Pleistocene)
- Qfp — Floodplain (active, late Holocene)
- Qbfp — Bouldery floodplain (active, late Holocene)
- Qfc — Fluvial channel / Entrenched stream channel (active, Holocene)
- Qaf — Alluvial fan (active, Holocene)
- Qbm — Blocky mantle (Holocene and Pleistocene)
- Qca — Colluvial apron (Holocene and late Pleistocene)
- Qcf — Colluvial fan (Holocene and late Pleistocene)
- Qcm — Colluvial mantle (Holocene and late Pleistocene)
- Qcv — Colluvial veneer (Holocene and late Pleistocene)
- Qt — Terrace (Holocene and late Pleistocene)
- Qht — High terrace (early to middle Pleistocene)
- Qres — Residuum (Late Cenozoic)


Gauley River. NPS Photograph.


Gauley River Gorge. NPS Photograph.

This map displays geologic map data compiled by the National Park Service Geologic Resources Inventory. It is not a substitute for site-specific investigations.

Source Map
Kite, S.J. 2016. Surficial geologic map of the Gauley River National Recreation Area, West Virginia (scale 1:12,000). Open File Report 1601. West Virginia Geologic and Economic Survey, Morgantown, West Virginia.

Source Scale 1:12,000
According to US National Map accuracy standards, features are within 6 m (20 ft) of their true location.

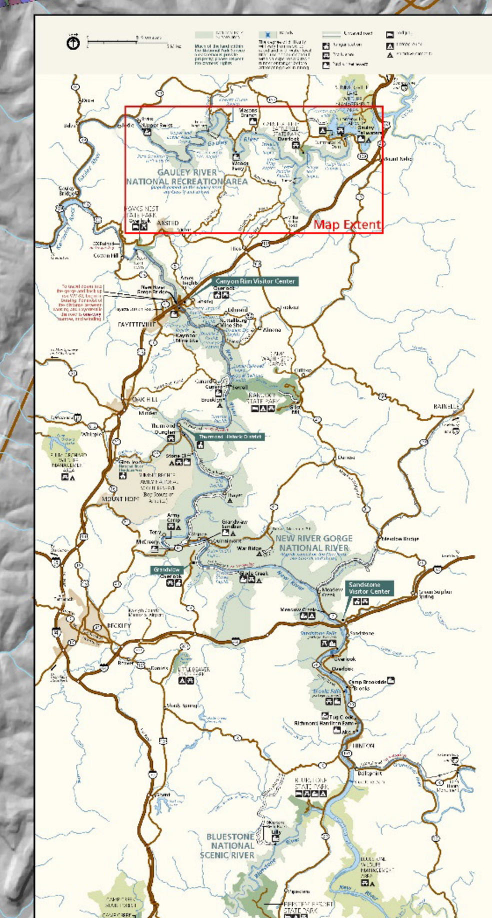
Poster Layout
Dalton Meyer and Georgia Hybels
(Colorado State University)

Poster Date
September 2017

GRI Data Date
2016

Source Map Date
2016

All Geologic Resources Inventory geologic map data and publications are available at http://go.nps.gov/gripubs.

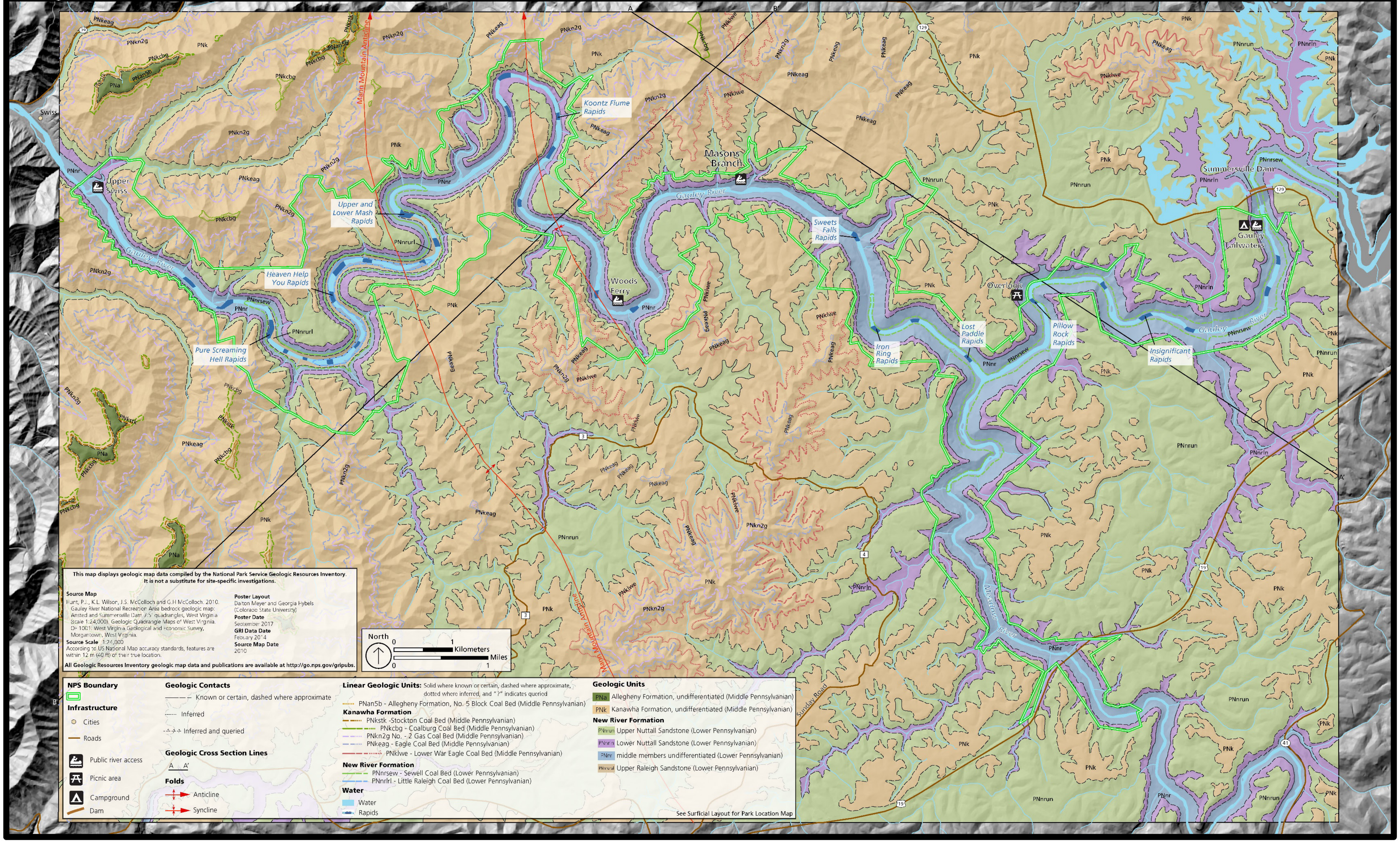


Bedrock Geologic Map of Gauley River National Recreation Area

West Virginia

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science



This map displays geologic map data compiled by the National Park Service Geologic Resources Inventory. It is not a substitute for site-specific investigations.

Source Map
Hunt, P.J., K.L. Wilson, J.S. McColloch and G.H McColloch. 2010. Gauley River National Recreation Area bedrock geologic map: Ansted and Summersville Dam 7.5' quadrangles, West Virginia (scale 1:24,000). Geologic Quadrangle Maps of West Virginia. OF 1001. West Virginia Geological and Economic Survey, Morgantown, West Virginia.

Source Scale 1:24,000
According to US National Map accuracy standards, features are within 12 m (40 ft) of their true location.

Poster Layout
Dalton Meyer and Georgia Hybels (Colorado State University)

Poster Date
September 2017

GRI Data Date
Febuary 2014

Source Map Date
2010

All Geologic Resources Inventory geologic map data and publications are available at http://go.nps.gov/gripubs.

NPS Boundary

Infrastructure
- Cities
- Roads
- Public river access
- Picnic area
- Campground
- Dam

Geologic Contacts
- Known or certain, dashed where approximate
- Inferred
- Inferred and queried

Geologic Cross Section Lines
A A'

Folds
- Anticline
- Syncline

Linear Geologic Units: Solid where known or certain, dashed where approximate, dotted where inferred, and "?" indicates queried
- PNan5b - Allegheny Formation, No. 5 Block Coal Bed (Middle Pennsylvanian)

Kanawha Formation
- PNkstk -Stockton Coal Bed (Middle Pennsylvanian)
- PNkcbg - Coalburg Coal Bed (Middle Pennsylvanian)
- PNkn2g No. - 2 Gas Coal Bed (Middle Pennsylvanian)
- PNkeag - Eagle Coal Bed (Middle Pennsylvanian)
- PNklwe - Lower War Eagle Coal Bed (Middle Pennsylvanian)

New River Formation
- PNnrsew - Sewell Coal Bed (Lower Pennsylvanian)
- PNnrlrl - Little Raleigh Coal Bed (Lower Pennsylvanian)

Water
- Water
- Rapids

Geologic Units
- PNa Allegheny Formation, undifferentiated (Middle Pennsylvanian)
- PNk Kanawha Formation, undifferentiated (Middle Pennsylvanian)

New River Formation
- PNnrun Upper Nuttall Sandstone (Lower Pennsylvanian)
- PNnrln Lower Nuttall Sandstone (Lower Pennsylvanian)
- PNnr middle members undifferentiated (Lower Pennsylvanian)
- PNnrurl Upper Raleigh Sandstone (Lower Pennsylvanian)

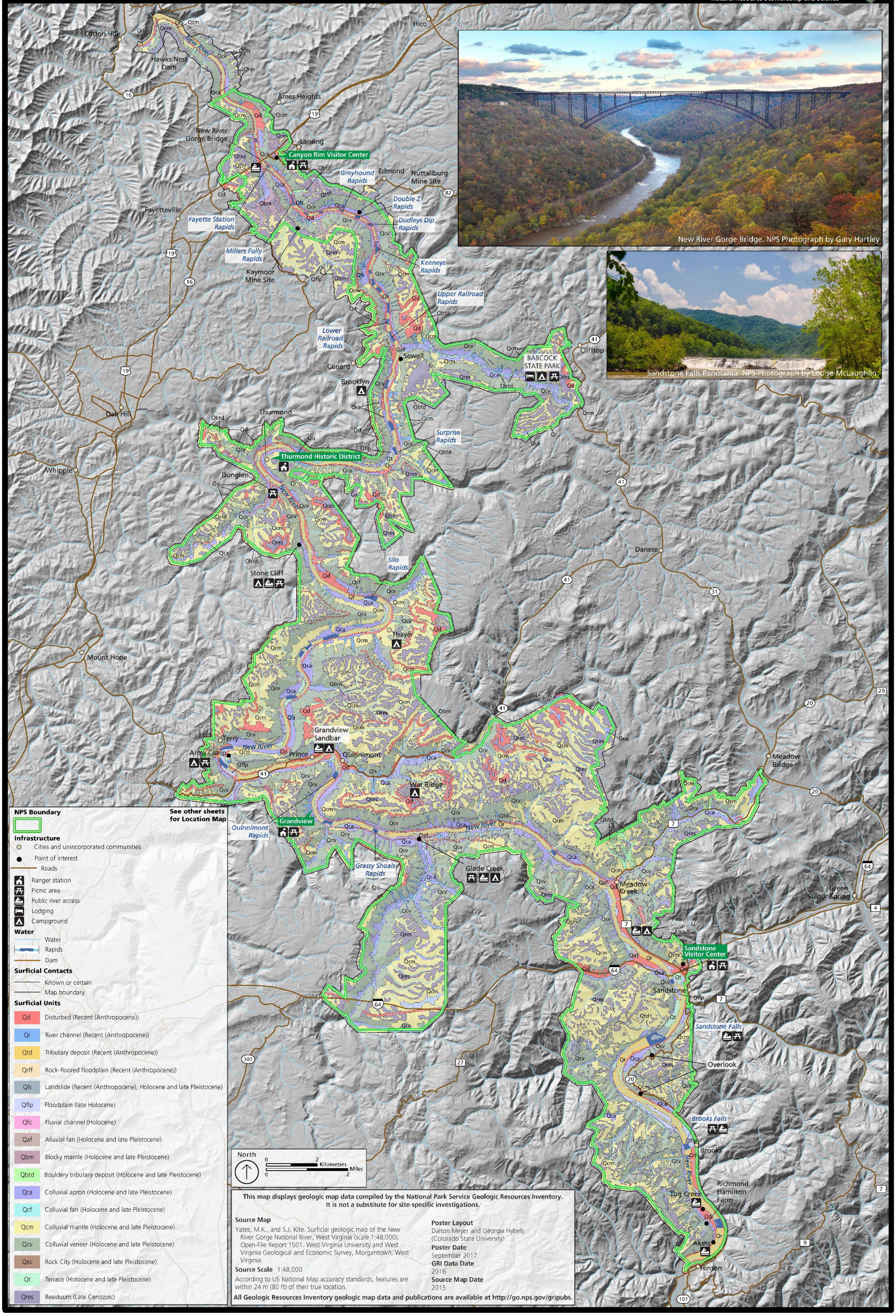
See Surficial Layout for Park Location Map

Surficial Geologic Map of New River Gorge National River

West Virginia

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science



This map displays geologic map data compiled by the National Park Service Geologic Resources Inventory. It is not a substitute for site-specific investigations.

Source Map
Yates, M.K., and S.J. Kite. Surficial geologic map of the New River Gorge National River, West Virginia (scale 1:48,000). Open-File Report 1501. West Virginia University and West Virginia Geological and Economic Survey, Morgantown, West Virginia.

Source Scale 1:48,000

According to US National Map accuracy standards, features are within 24 m (80 ft) of their true location.

Poster Layout
Dalton Meyer and Georgia Hybels (Colorado State University)

Poster Date
September 2017

GRI Data Date
2016

Source Map Date
2015

All Geologic Resources Inventory geologic map data and publications are available at http://go.nps.gov/gripubs.

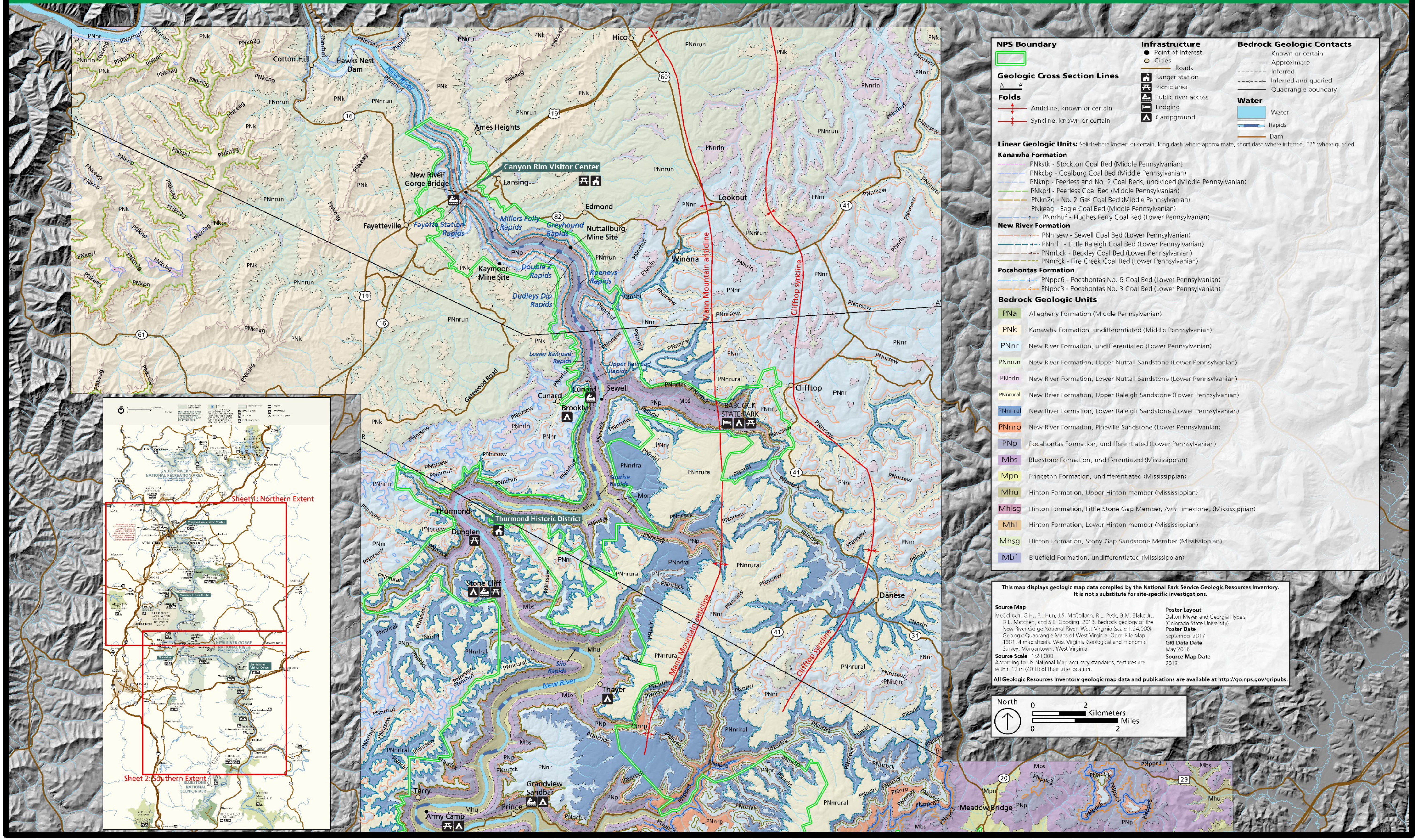
Bedrock Geologic Map of New River Gorge National River

West Virginia

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science

Sheet 1: Northern Extent



NPS Boundary

Geologic Cross Section Lines

A A'

Folds

- Anticline, known or certain
- Syncline, known or certain

Infrastructure

- Point of Interest
- Cities
- Roads
- Ranger station
- Picnic area
- Public river access
- Lodging
- Campground

Bedrock Geologic Contacts

- Known or certain
- Approximate
- Inferred
- Inferred and queried
- Quadrangle boundary

Water

- Water
- Rapids
- Dam

Linear Geologic Units: Solid where known or certain, long dash where approximate, short dash where inferred, "?" where queried

Kanawha Formation

- PNkstk - Stockton Coal Bed (Middle Pennsylvanian)
- PNkcbg - Coalburg Coal Bed (Middle Pennsylvanian)
- PNknp - Peerless and No. 2 Coal Beds, undivided (Middle Pennsylvanian)
- PNkprl - Peerless Coal Bed (Middle Pennsylvanian)
- PNkn2g - No. 2 Gas Coal Bed (Middle Pennsylvanian)
- PNkeag - Eagle Coal Bed (Middle Pennsylvanian)
- PNnrhuf - Hughes Ferry Coal Bed (Lower Pennsylvanian)

New River Formation

- PNnrsew - Sewell Coal Bed (Lower Pennsylvanian)
- PNnrlrl - Little Raleigh Coal Bed (Lower Pennsylvanian)
- PNnrbck - Beckley Coal Bed (Lower Pennsylvanian)
- PNnrfck - Fire Creek Coal Bed (Lower Pennsylvanian)

Pocahontas Formation

- PNppc6 - Pocahontas No. 6 Coal Bed (Lower Pennsylvanian)
- PNppc3 - Pocahontas No. 3 Coal Bed (Lower Pennsylvanian)

Bedrock Geologic Units

PNa	Allegheny Formation (Middle Pennsylvanian)
PNk	Kanawha Formation, undifferentiated (Middle Pennsylvanian)
PNnr	New River Formation, undifferentiated (Lower Pennsylvanian)
PNnrun	New River Formation, Upper Nuttall Sandstone (Lower Pennsylvanian)
PNnrln	New River Formation, Lower Nuttall Sandstone (Lower Pennsylvanian)
PNnrural	New River Formation, Upper Raleigh Sandstone (Lower Pennsylvanian)
PNnrlral	New River Formation, Lower Raleigh Sandstone (Lower Pennsylvanian)
PNnrp	New River Formation, Pineville Sandstone (Lower Pennsylvanian)
PNp	Pocahontas Formation, undifferentiated (Lower Pennsylvanian)
Mbs	Bluestone Formation, undifferentiated (Mississippian)
Mpn	Princeton Formation, undifferentiated (Mississippian)
Mhu	Hinton Formation, Upper Hinton member (Mississippian)
Mhlsg	Hinton Formation, Little Stone Gap Member, Avis Limestone, (Mississippian)
Mhl	Hinton Formation, Lower Hinton member (Mississippian)
Mhsg	Hinton Formation, Stony Gap Sandstone Member (Mississippian)
Mbf	Bluefield Formation, undifferentiated (Mississippian)

This map displays geologic map data compiled by the National Park Service Geologic Resources Inventory. It is not a substitute for site-specific investigations.

Source Map

McColloch, G.H., P.J Hun, J.S. McColloch, R.L. Peck, B.M. Blake Jr., D.L. Matchen, and S.E. Gooding. 2013. Bedrock geology of the New River Gorge National River, West Virginia (scale 1:24,000). Geologic Quadrangle Maps of West Virginia, Open File Map 1301, 4 map sheets. West Virginia Geological and Economic Survey, Morgantown, West Virginia.

Source Scale 1:24,000

According to US National Map accuracy standards, features are within 12 m (40 ft) of their true location.

Poster Layout

Dalton Meyer and Georgia Hybels (Colorado State University)

Poster Date

September 2017

GRI Data Date

May 2016

Source Map Date

2013

All Geologic Resources Inventory geologic map data and publications are available at http://go.nps.gov/gripubs.

North

0 2 Kilometers

0 2 Miles

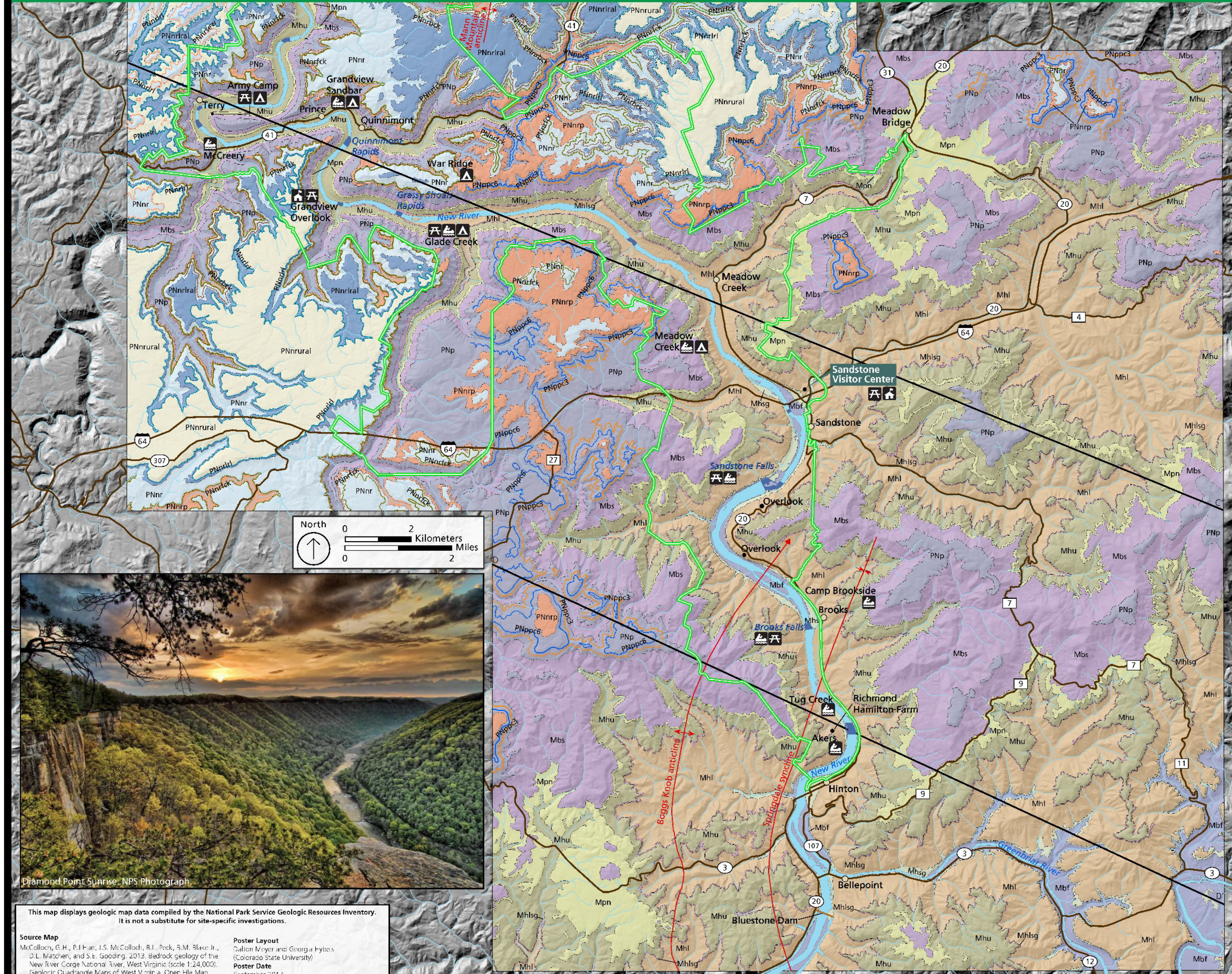
Bedrock Geologic Map of New River Gorge National River

West Virginia

National Park Service
U.S. Department of the Interior

Geologic Resources Inventory
Natural Resource Stewardship and Science

Sheet 2: Southern Extent



Diamond Point Sunrise. NPS Photograph.

This map displays geologic map data compiled by the National Park Service Geologic Resources Inventory. It is not a substitute for site-specific investigations.

Source Map
McColloch, G.H., P.J Hun, J.S. McColloch, R.L. Peck, B.M. Blake Jr., D.L. Matchen, and S.E. Gooding. 2013. Bedrock geology of the New River Gorge National River, West Virginia (scale 1:24,000). Geologic Quadrangle Maps of West Virginia. Open File Map OF-1301, 4 map sheets. West Virginia Geological and Economic Survey, Morgantown, West Virginia.

Source Scale 1:24,000
According to US National Map accuracy standards, features are within 12 m (40 ft) of their true location.

Poster Layout
Dalton Meyer and Georgia Hybels (Colorado State University)
Poster Date
September 2017
GRI Data Date
May 2016
Source Map Date
2013

All Geologic Resources Inventory geologic map data and publications are available at http://go.nps.gov/gripubs.

NPS Boundary

See Sheet 1 for Location Map

Infrastructure
- Point of interest
- Cities
- Roads
- Ranger station
- Picnic area
- Public river access
- Campground

Geologic Cross Section Lines
C C'

Folds
- Anticline, known or certain
- Syncline, known or certain

Linear Geologic Units: Solid where certain, long dashed where approximate, short dashes where inferred, "?" where queried

Kanawha Formation
- PNkstk - Stockton Coal Bed (Middle Pennsylvanian)
- PNkcbg - Coalburg Coal Bed (Middle Pennsylvanian)
- PNknp - Peerless and No. 2 Coal Beds, undivided (Middle Pennsylvanian)
- PNkprl - Peerless Coal Bed (Middle Pennsylvanian)
- PNkn2g - No. 2 Gas Coal Bed (Middle Pennsylvanian)
- PNkeag - Eagle Coal Bed (Middle Pennsylvanian)
- PNnrhuf - Hughes Ferry Coal Bed (Lower Pennsylvanian)

New River Formation
- PNnrsew - Sewell Coal Bed (Lower Pennsylvanian)
- PNnrlrl - Little Raleigh Coal Bed (Lower Pennsylvanian)
- PNnrbck - Beckley Coal Bed (Lower Pennsylvanian)
- PNnrfck - Fire Creek Coal Bed (Lower Pennsylvanian)

Pocahontas Formation
- PNppc6 - Pocahontas No. 6 Coal Bed (Lower Pennsylvanian)
- PNppc3 - Pocahontas No. 3 Coal Bed (Lower Pennsylvanian)

Bedrock Geologic Contacts
- Known or certain
- Approximate
- Inferred
- Inferred and queried
- Quadrangle boundary

Water
- Water
- Rapids
- Dam

Bedrock Geologic Units

PNa	Allegheny Formation (Middle Pennsylvanian)
PNk	Kanawha Formation, undifferentiated (Middle Pennsylvanian)
PNnr	New River Formation, undifferentiated (Lower Pennsylvanian)
PNnrun	New River Formation, Upper Nuttall Sandstone (Lower Pennsylvanian)
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PNnrural	New River Formation, Upper Raleigh Sandstone (Lower Pennsylvanian)
PNnrlral	New River Formation, Lower Raleigh Sandstone (Lower Pennsylvanian)
PNnrp	New River Formation, Pineville Sandstone (Lower Pennsylvanian)
PNp	Pocahontas Formation, undifferentiated (Lower Pennsylvanian)
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Mhl	Hinton Formation, Lower Hinton member (Mississippian)
Mhsg	Hinton Formation, Stony Gap Sandstone Member (Mississippian)
Mbf	Bluefield Formation, undifferentiated (Mississippian)