



Upper Delaware Scenic & Recreational River

Geologic and Soil Resources Inventory Summary



On this page: Skinners Falls Rapids just north of river mile 295.0. The rapids are underlain by cross-bedded sandstones of the Devonian Catskill Formation. These sandstones were originally deposited as part of the Catskill deltaic complex, a massive coastal alluvial plain that developed in response to the uplift and erosion of the Acadian Mountains. Today, the modern Delaware River incises through and superimposes atop floodplains of the ancient past. The Skinners Falls-Milanville Bridge is seen in the distant background. NPS photograph.

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Tim C. Henderson
Colorado State University Research Associate
National Park Service Geologic Resources Division
Geologic and Soil Resources Inventory
PO Box 25287
Denver, CO 80225

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Abstract

This document summarizes the status of National Park Service (NPS) Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) deliverables for Upper Delaware Scenic & Recreational River. It also provides information about current geology and soil resources management concerns, with a focus on identified inventory needs related to geologic heritage, geohazards, and related soil features and processes. This document is intended to assist park staff with prioritizing technical assistance or new inventory and assessment funding requests in the near term (roughly 1–5 years).

The GRI hosted a baseline scoping meeting for Upper Delaware Scenic & Recreational River in June 2004. Baseline bedrock and surficial geologic maps were delivered to the park in 2023 and updated in 2024. The SRI delivered a legacy soil database and map in 2015, as well as an “enhanced report” in 2013. Additional soil survey reports have been published by the USDA Natural Resources Conservation Service (NRCS) that include Delaware, Orange, and Sullivan counties, New York, as well as Pike and Wayne counties, Pennsylvania. The most up-to-date soil data for the park is available through [Web Soil Survey](#).

Upper Delaware Scenic & Recreational River’s geologic heritage is ingrained in its paleontological records, Indigenous connections, the Delaware and Hudson Canal, historic stone quarries, stratotypes, and its geologic connections to the Battle of Minisink. The geologic and soil resources inventory needs for the park include various data or GIS information related to the inventory and monitoring of cave and karst features, cultural resources, fossils, geologic resources, geohazards, stratotypes, and water quality, in addition to interpretive and management needs. Geologic hazards identified in the park include climate change, disturbed lands (e.g., abandoned mineral lands, land use changes, shale-gas development), flooding, erosion and mass wasting, radon, seismicity, swelling clays, and toxicological soil.

Additional guidance for park staff regarding proposal processes and timeframes for the new Inventories and Assessment (I&A) program is available on the [GSRI](#) and [I&A](#) SharePoint sites.

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Background of the GSRI

The Geologic and Soil Resources Inventory (GSRI) facilitates the collection of new data, or derives new information from existing data, regarding the presence, absence, abundance, distribution, and significance of geologic or soil features or processes to inform park management decisions and planning.

In the 1990s, the National Park Service (NPS) Geologic Resources Inventory (GRI) and Soil Resource Inventory (SRI) programs were established as two of the original 12 baseline inventories in the Inventory and Monitoring (I&M) program. These baseline inventories compiled existing information, acquired new information, and helped establish a minimum level of data across more than 270 parks, which served as a common starting point for natural resource monitoring. For both the GRI and SRI, the primary deliverable was a digital (GIS) map. Between the 1990s and early 2020s, GRI scoping summaries, geologic map posters, and GRI reports were also produced for most of the 270 parks. As of 2024, the I&M program is transitioning from a baseline inventory strategy to a park-proposed inventory strategy.

The GRI and SRI are now unified as one inventory program, the Geologic and Soil Resources Inventory (GSRI), and will be integrated into the new Inventories & Assessment (I&A) program, in which parks will submit geology- and soil-related project requests in PMIS during the Servicewide Comprehensive Call (SCC). This transition will begin in FY25, with new guidance enacted for GSRI. During this transition period, 13 “priority” parks, including Upper Delaware Scenic & Recreational River (“UPDE,” also referred to as “the park” herein) were identified as missing a baseline GRI report.

This GSRI summary serves as a substitute for a baseline GRI report and is intended to support the national park’s participation in the new inventories program. As such, it summarizes the status of GRI and SRI deliverables for UPDE and provides information on current geology and soil resources management concerns with a focus on identified inventory needs. Information in this summary was compiled from existing reports, meetings with park staff, and the best professional judgment from GRI and WASO Geologic Resources Division (GRD) geoscientists.

Baseline GSRI Products

Geology

The digital geologic and surficial maps for UPDE are available on the NPS DataStore accessed through the Integrated Resource Management Applications (IRMA) portal (see <https://irma.nps.gov/DataStore/Reference/Profile/2194532>). These products are adapted from multiple source maps created by the Pennsylvania Geological Survey, New York State Museum, and the US Geological Survey (USGS). Additional GSRI documents include the NPS Scoping Report (National Park Service 2004).

GSRI source maps:

- Braun, D. D. 2008. Surficial geology of the Aldenville 7.5-Minute Quadrangle, Wayne County, Pennsylvania. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 08–09.0, 15 p., 1 map, scale 1:24,000.

- Braun, D. D. 2008. Surficial geology of the Damascus 7.5-Minute Quadrangle, Wayne County, Pennsylvania. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 08–15.0, 14 p., 1 map, scale 1:24,000.
- Braun, D. D. 2008. Surficial geology of the Galilee 7.5-Minute Quadrangle, Wayne County, Pennsylvania. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 08–10.0, 15 p., 1 map, scale 1:24,000.
- Braun, D. D. 2011. Surficial geology of the Hancock 7.5-Minute Quadrangle, Wayne County, Pennsylvania, and Broome County, New York. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 11–02.0, 13 p., 1 map, scale 1:24,000.
- Braun, D. D. 2011. Surficial geology of the Hawley 7.5-Minute Quadrangle, Wayne County, Pennsylvania. Pennsylvania Geological Survey, Open-File Report OFSM 06–13.0, scale 1:24,000.
- Braun, D. D. 2008. Surficial geology of the Honesdale 7.5-Minute Quadrangle, Wayne County, Pennsylvania. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 08–04.0, 15 p., 1 map, scale 1:24,000.
- Braun, D. D. 2010. Surficial geology of the Lake Como 7.5-Minute Quadrangle, Wayne County, Pennsylvania, and Delaware County, New York. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 10–07.0, 13 p., 1 map, scale 1:24,000.
- Braun, D. D. 2011. Surficial geology of the Long Eddy and Callicoon 7.5-Minute Quadrangles, Wayne County, Pennsylvania. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 11–01.0, 13 p., 1 map, scale 1:24,000.
- Braun, D. D. 2008. Surficial geology of the Wayne County portion of the Narrowsburg 7.5-Minute Quadrangle, Wayne County, Pennsylvania. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 08–06.0, 14 p., 1 map, scale 1:24,000.
- Braun, D. D. 2010. Surficial geology of the Orson 7.5-Minute Quadrangle, Susquehanna and Wayne counties, Pennsylvania. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 10–06.0, 12 p., 1 map, scale 1:24,000.
- Braun, D. D. 2006. Surficial geology of the Starrucca 7.5-Minute Quadrangle, Wayne and Susquehanna counties, Pennsylvania. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 06–05.0, 15 p., 1 map, scale 1:24,000.
- Braun, D. D. 2008. Surficial geology of the Wayne County portion of the White Mills 7.5-Minute Quadrangle, Wayne County, Pennsylvania. Pennsylvania Geological Survey, 4th series, Open-File Report OFSM 08–05.0, 15 p., 1 map, scale 1:24,000.
- Davis, D. K. 1989. Groundwater resources of Pike County, Pennsylvania. Pennsylvania Geological Survey, Water Resource Report 65, 63 p., 2 plates.
- Kowzowski, A. L. 2017. Surficial geology of the New York portion of Upper Delaware Scenic and Recreational River and vicinity, New York. New York State Geological Survey, unpublished data and map, scale 1:24,000.

- Leone, J., K. J. Backhaus, and A. L. Kowzlowski. 2019. Surficial geology of the New York portion of Upper Delaware Scenic and Recreational River and vicinity, New York. New York State Geological Survey, unpublished data and map, scale 1:24,000.
- Sevon, W. D., T. M. Berg, L. D. Schultz, and G. H. Crowl. 1989. Geology and mineral resources of Pike County, Pennsylvania. Pennsylvania Geological Survey, County Report C 52, 141p., 2 plates, scale 1:50,000.
- US Geological Survey. 2018. USGS national hydrography dataset best resolution (NHD) for hydrologic unit (HU) 8: US Geological Survey, scale 1:24,000.

GSRI scoping report:

- National Park Service. 2004. Geologic Resource Evaluation scoping summary: Eastern Rivers and Mountains Inventory and Monitoring Network. National Park Service, Geologic Resources Division.

Soils

Soil maps provide information on soil types, including scores of distinct characteristics and management considerations, including linear extensibility (“shrink-swell”) potential, erosion potential, soil stability, suitability for site development, suitability for recreation development (e.g., trails), and many other topics. Perrone (2023) provides an overview of the use of soil data at the NPS WASO level and lists soil data currently available in the Natural Resources Conservation Service (NRCS) [Web Soil Survey](#) website along with NPS-specific uses for the data. The NRCS plans to complete all soil survey areas in the US by 2026 (Thompson et al. 2020).

The most up-to-date soils data for UPDE is available via Web Soil Survey, which is updated and maintained regularly. Management-focused maps for the park or potential project areas can be developed on demand on the website. The Web Soil Survey homepage gives instructions for how to view and download soil data, which are typically broken down into county-level soil survey areas. Each survey area is assigned a code and a name. The park includes five soil survey areas that are complete (Table 1). To view the soil data for UPDE on the Web Soil Survey website, use the navigation pane on the left side of the homepage to select the soil survey “Area of Interest (‘AOI’)” tab. Under the “National Park Service” dropdown menu, select UPDE to view the soil data. The AOI icons along the top of the screen allow users to select specific areas of the map and generate detailed soil data (e.g., soil suitability and limitations, soil properties, soil qualities, and ecological sites). Use the “Soil Map” tab at the top to view the soil map and the “Soil Data Explorer” tab to view the detailed soil data. See additional Web Soil Survey guidance and FAQs or contact the NRCS state soil scientist for technical assistance.

The SRI delivered a legacy soil database and map to UPDE that was last updated in 2015 (<https://irma.nps.gov/DataStore/Reference/Profile/1048989>), in addition to an “[enhanced report](#)” cooperatively published with the NRCS in 2013. Additional soil survey reports have been published by the NRCS that include Pike and Wayne counties ([Pennsylvania Soil Surveys](#)), as well as Delaware, Orange, and Sullivan counties ([New York Soil Surveys](#)).

Table 1. Web Soil Survey areas related to UPDE.

Web Soil Survey Area Code	Web Soil Survey Area Name	Status
NY025	Delaware County, New York	Complete
NY071	Orange County, New York	Complete
NY105	Sullivan County, New York	Complete
PA103	Pike County, Pennsylvania	Complete
PA127	Wayne County, Pennsylvania	Complete

Possible Future GSRI Products

As the GSRI becomes integrated into the I&A program, future GSRI products will be determined by the project proposals submitted by the parks. Moving forward, the GSRI program will fund inventory projects that include the following:

- Collect new data or derive new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic heritage, soil features or processes, or geohazards.
- Include features or processes on an individual feature- or landscape-scale.
- Include groups of features or maps of multiple features in a defined area of management needs.
- Are a snapshot in time and may set a baseline for monitoring or assessment.
- Typically include a geospatial (GIS) component.

GSRI project examples:

- Features and processes eligible for funding through the GSRI program include cave/karst, geothermal, paleontological (fossils), landslides and rockfall, other geohazards (e.g., avalanche, permafrost, volcanoes, earthquakes, tsunami, sinkholes), eolian, erosion, soil suitability and limitations for use, soil properties and qualities, ecological site descriptions, and other geologic or soil features or processes of management interest.
- Features and processes covered by other sources of funding and **not** eligible for GSRI funding are abandoned mineral lands (AML), orphaned oil and gas wells, coastal processes, coastal storm response, sea level change projections or mitigation, coastal engineering structures, or shoreline sediment movement.
- The GSRI will accept proposals for new baseline map products, such as funding a traditional geologic (bedrock or surficial) or soil mapping effort, especially at new or expanded parks outside the original 270 I&M parks. Parks requesting these products will need to indicate a management need, which the baseline data will support.

Geologic Setting and History

Park Establishment and Setting

Upper Delaware Scenic & Recreational River is a 118 km (73.4 mi) stretch of the Delaware River located along the Pennsylvania–New York border in Pike and Wayne counties, Pennsylvania, as well as Delaware, Orange, and Sullivan counties, New York. Authorized as an NPS park unit on 10 November 1978, UPDE was designated for its outstandingly remarkable cultural, ecological, geological, recreational, and scenic values (National Park Service 2014). The park encompasses approximately 30,351 hectares (75,000 acres) of fluvial (river) landscape amid rolling hills and riverfront villages and is situated on one of the finest fishing rivers in the northeastern United States. Located within UPDE are several cultural and paleontological sites that include the Minisink Battleground Park, the Zane Grey Museum, the Corwin Farm, remnants of the Delaware and Hudson Canal (including Roebling’s Delaware Aqueduct), as well as historic bluestone quarries (see “Geoheritage”).

UPDE is in the Glaciated Low Plateau section of the Appalachian Plateaus physiographic province (a geographic region with characteristic topography, geology, and climate), an area of variable relief underlain by Paleozoic sedimentary rocks (Figure 1; see “Geologic History”). The Upper Delaware River within the park’s boundaries is an exceptional example of a deep, narrow river valley cutting across the previously glaciated portion of the Appalachian Plateaus (Killion et al. 2015). The Delaware River Gorge has been identified by the Pennsylvania Geological Survey as one of the outstanding scenic geologic features in the state (National Park Service 1986). The gorge begins above Matamoras, Pennsylvania (or Port Jervis, New York), and runs north through most of UPDE, ranging between roughly 610–910 m (2,000–3,000 ft) in width, with an average depth between 90–150 m (300–500 ft; National Park Service 1986). In addition to the gorge, the park contains a unique collection of landforms along the river corridor. A southbound traverse of UPDE passes through undulating topography adorned with rounded hills, broad to narrow valleys, barbed tributaries (tributaries that feed into the river facing an upstream direction), diverse river channel morphologies, bedrock knobs, cutoff incised meanders (abandoned river channel segments), island complexes, peat bogs, swamps, glacial deposits, and resistant sandstone ledges and cliffs with up to 210 m (700 ft) of relief (National Park Service 1986; Sevon et al. 1989; Killion et al. 2015).

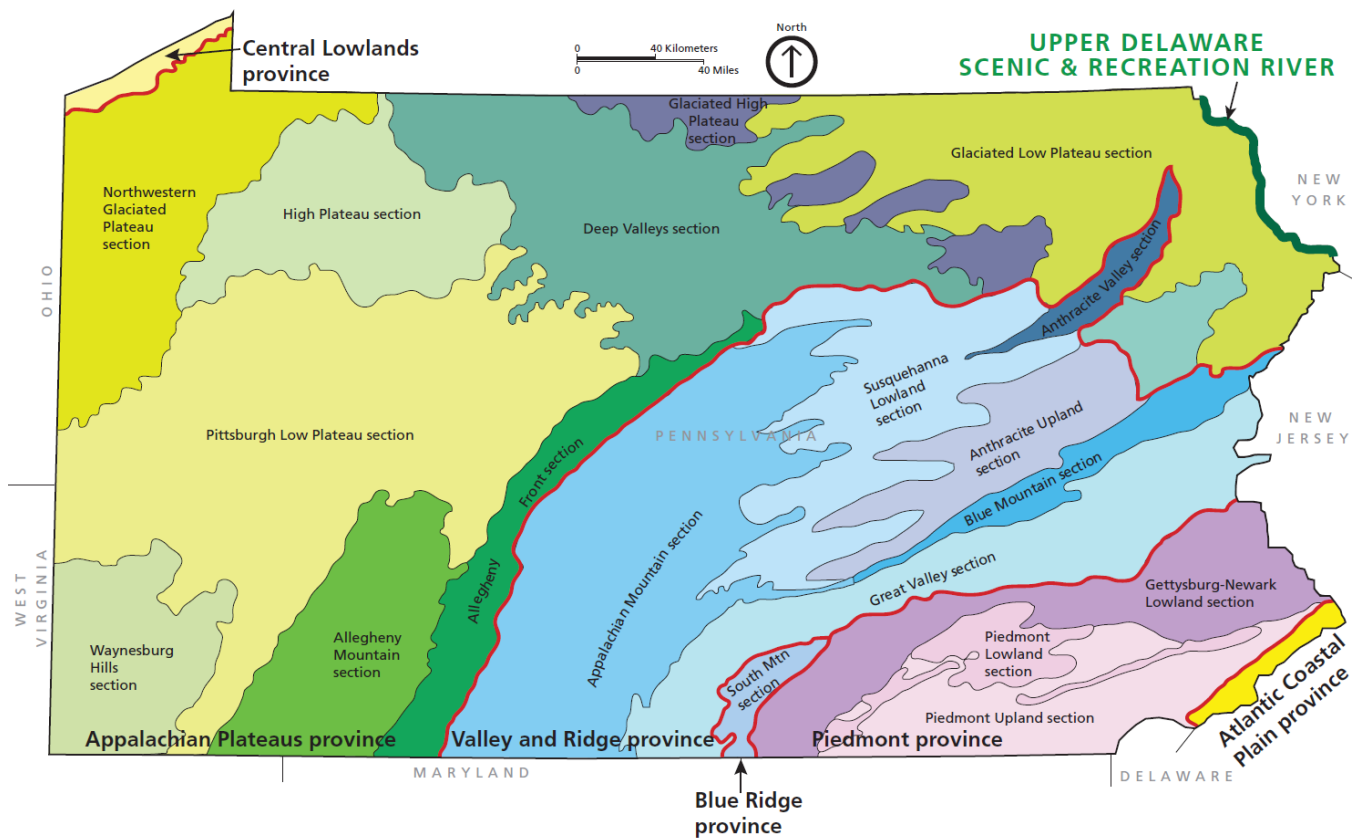


Figure 1. Physiographic province map of Pennsylvania. UPDE is in the Glaciated Low Plateau section of the Appalachian Plateaus province. The red lines mark the boundaries between separate physiographic provinces. Figure created by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic History

Paleozoic Era: The Catskill Deltaic Complex

The bedrock geology of the Upper Delaware River valley consists of Paleozoic sedimentary rocks of the Late Devonian Period (approximately 383 million to 359 million years ago; Table 2). Devonian strata that underlie UPDE are a puzzling mix of sedimentary rocks (e.g., sandstone, siltstone, shale, conglomerate) that record the transition from shallow marine to terrestrial environments. The complexity of these rocks is derived from two factors: 1) the confusing regional nature of the strata themselves and 2) the diverse, even conflicting, schemes by which geologists have defined, named, and ordered the strata (Frank Fletcher, Pennsylvania Geological Survey [retired], personal communication, 2021). Since the park occupies the New York–Pennsylvania boundary, geologists working in the two states have developed different systems for describing, interpreting, and defining the regional geology. In New York, geologists have historically leaned to biostratigraphy (using fossils to correlate rock layers), while Pennsylvania geologists have focused more on the lithostratigraphy (using physical rock properties to correlate rock layers). Stratigraphic units of the park include (from oldest to youngest) the Millrift Member (**Dtm**) of the Trimmers Rock Formation, and the Towamensing (**Dct**), Delaware River (**Dcdr**), and Lackawaxen (**Dcl**) members of the Catskill Formation. The bedrock of UPDE—notably the Catskill Formation—reflects the northwestward advance of the Catskill deltaic complex, a massive coastal alluvial plain that developed in response to the uplift and erosion of the Acadian Mountains (Sevon et al. 1989). As these mountains were uplifted throughout the Middle to Late

Devonian Acadian orogeny (a collisional mountain-building event), eroded sediments were transported by shallow, braided streams that emptied into an ancient shallow sea extending the length of the Appalachian Basin (Figure 2; Sevon et al. 1989).

Table 2. Geologic units mapped within or immediately adjacent to UPDE.

GSRI map abbreviations for each time division and GSRI map unit symbols are in parentheses. Only geologic units mapped within UPDE are included. Boundary ages follow the International Commission on Stratigraphy (2023).

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Quaternary Period (Q); Pleistocene Epoch (PE) and Holocene Epoch (H)	2.58 million years ago to the present	Fill (Qf) Rock and/or gravel pit (Qrg) Alluvium (Qa) Alluvial fan (Qaf) Peat bog (Qp) Wetland (Qw) Stratified sand (Qs) Boulder colluvium (Qbc) Wisconsinan outwash (Qwo) Wisconsinan ice-contact stratified drift (Qwic) Wisconsinan till (Qwt) Olean kame terrace (Qokt) Diamicton (clast supported; Qdcs)	During the Pleistocene Epoch, the Upper Delaware River valley was a glaciated landscape. Over several hundred thousand years, the Laurentide Ice Sheet advanced and retreated across UPDE several times. Glaciers sculpted the river valley to form steep cliffs, rounded hills, and broad to narrow valleys. As the last glaciers receded north approximately 18,000 years ago, they left behind a thick sequence of till and outwash deposits scattered throughout the river corridor.
Devonian (D)	419.2 million to 358.9 million years ago	Sandstone and shale bedrock (Paleozoic and younger; PZbr) Catskill Formation Lackawaxen Member (Dcl; STRATOTYPE) Delaware River Member (Dcdr; STRATOTYPE) Towamensing Member (Dct) Trimmers Rock Formation Millrift Member (Dtm; STRATOTYPE)	The Late Devonian strata that underlie UPDE were originally deposited in nearshore marine and coastal fluvial environments. These sedimentary rocks reflect the northwestward advance of the Catskill deltaic complex in response to the uplift and erosion of the Acadian Mountains east of the Upper Delaware River valley.

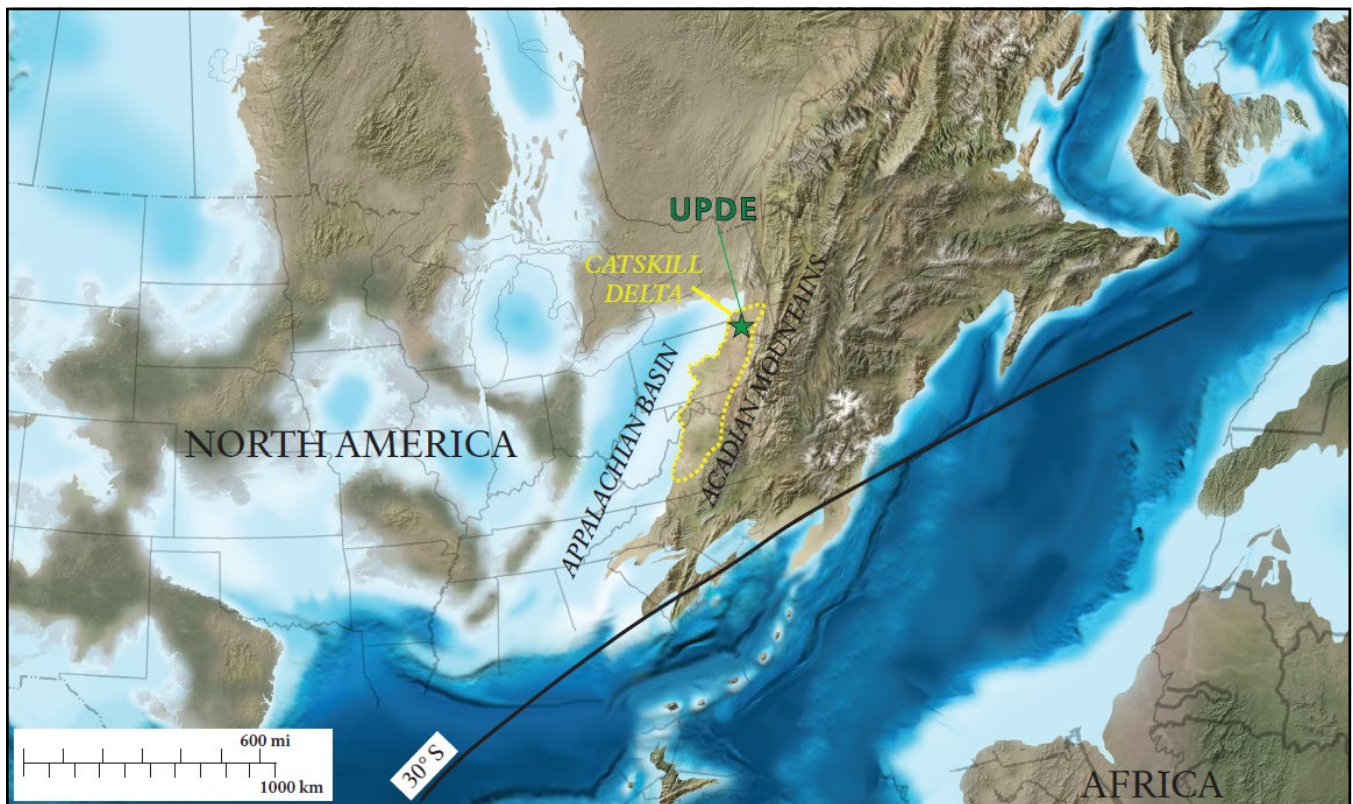


Figure 2. Paleogeographic reconstruction of UPDE during the Late Devonian Period. The bedrock underlying the park was deposited in the Catskill deltaic complex, an extensive coastal alluvial plain sourced from the Acadian Mountains to the east. Sediments shed from the mountains were carried by a network of rivers that emptied into the shallow marine waters of the Appalachian Basin. Throughout the Devonian, UPDE was located at tropical latitudes south of the equator. North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc., modified by Tim C. Henderson (Colorado State University).

According to Sevon et al. (1989), the Trimmers Rock Formation consists of sandstone and siltstone deposited in a marine delta front environment (a zone of active sedimentation located seaward of a delta) associated with a transition from marine to nonmarine settings. Rivers feeding the delta were draining the Acadian Mountains, which were approximately 48–80 km (30–60 mi) east of the Upper Delaware River valley (Sevon et al. 1989). One of the most interesting exposures of the formation is on the west side of the Delaware River, approximately 0.6 km (0.4 mi) south of Millrift near the southern terminus of UPDE. Referred to locally as the “elephant feet,” the outcrop consists of siltstone and sandstone that have eroded along joint and bedding planes to form broad, rounded columnar shapes (Sevon et al. 1989). The overlying Catskill Formation (named after the Catskill Mountains of New York) preserves the oldest terrestrial rocks in UPDE and predominantly consists of sandstone with lesser amounts of siltstone, claystone, and conglomerate. The rocks of the Catskill Formation were originally laid down by shallow, braided streams that flowed northwest from the Acadian Mountains. Sandstones of the Catskill Formation represent ancient channel deposits and contain a plethora of sedimentary structures indicative of fluvial settings: (1) planar bedding (parallel bedding), (2) ripple bedding (ripples or ridges formed by the flow of wind or water), (3) crossbedding (sets of inclined beds deposited by wind or water), (4) load casts (bulges, lumps, and lobes that form along bedding planes), (5) groove casts (linear grooves etched into underlying beds due to high-velocity flows), (6) carbonized plant fragments, and (7) escape burrows of the freshwater clam *Archaeonodon*

catskillensis (see “Paleontology”; Sevon et al. 1989; Inners and Osborne 2001). These sandstones are highly resistant rocks that form the park’s scenic bluffs or cliffs, such as the Hawk’s Nest (Figure 3). The Catskill Formation contains joints (fracture planes) and bedding planes that allow the rock to be easily broken or split, making it an ideal stone commodity; much of the region’s bluestone (flagstone) was previously quarried from planar bedded sandstones of the Catskill Formation (see “Stone Quarries”; Fletcher and Woodrow 1970; Sevon et al. 1989).



Figure 3. The Hawk’s Nest. The sheer cliffs flanking the Delaware River consist of erosion-resistant sandstone of the Devonian Towamensing Member of the Catskill Formation. The photograph was taken immediately north of the Hawks Nest Lookout along New York State Route 97. NPS photograph.

Quaternary Period: The Ice Age and the Modern

During the Pleistocene Epoch (the “Ice Age”), approximately 2.58 million to 11,700 years ago, the Upper Delaware River valley was a glaciated landscape inundated by thick, extensive ice sheets associated with the Laurentide Ice Sheet. According to Braun (2008a, b; 2011a, b), continental glaciers have repeatedly advanced and retreated across UPDE at least three times and are recorded by distinct moraine deposits (an accumulation of unconsolidated glacial rock debris) marking the southernmost glacial limit. From oldest to youngest, these deposits are considered to be (1) Pre-Illinoian G age (approximately 850,000 years ago) or older, (2) either late Illinoian (about 150,000 years ago) or Pre-Illinoian B age (about 450,000 years ago), and (3) late Wisconsinan (roughly 20,000 years ago). Both the Pre-Illinoian and Illinoian glaciations occurred during the early and middle Pleistocene prior to the most recent Wisconsinan glaciation; the former has several alphabetical subdivisions that represent separate glacial advances (Braun et al. 1994). As glaciers advanced south from Canada, they scoured the Glaciated Low Plateau section of the Appalachian Plateaus province, widening and deepening the region’s preglacial valleys. Akin to frozen sandpaper, the ice sculpted the bedrock to form rounded hills and smoothed summits. Throughout UPDE, the differences in relief and topography are sometimes bedrock-controlled—a result of varying erosion resistance against the abrasive and freeze-thaw forces of glacial activity (USDA and USDOI 2013). For example, the steep cliffs at the Hawk’s Nest are the highest point in the park and are comprised of jointed sandstones of the Devonian Catskill Formation that were repeatedly frost shattered over several thousand years (Braun 2008a, b; 2011a, b; see “Mass Wasting”). As the last glaciers receded north about 18,500 years ago, they left behind a thick accumulation of till and outwash deposits that are scattered along the river corridor. Today, several swamps, wetlands, peat bogs, and small lakes now occupy glaciated depressions or kettles that formed by the melting of ice blocks incorporated within these outwash and till plains (Braun 2008a, b; 2011a, b; USDA and USDOI 2013). The post-Ice Age history of UPDE is one of erosion, as the Delaware River has incised and reworked both bedrock and surficial deposits to form picturesque gorges, sandstone cliffs, barbed tributaries, bedrock knobs, cutoff incised meanders (abandoned river channel segments), and island complexes (see “UPDE Geologic River Guide”; National Park Service 2014).

Geologic Heritage

Geologic heritage (also called “geoheritage”) evokes the idea that the geology of a place is an integral part of its history and cultural identity. In 2015, the NPS GRD, in cooperation with the American Geosciences Institute, published a booklet introducing the American experience of geoheritage, geodiversity, and geoconservation: *America's Geologic Heritage: An Invitation to Leadership*. The publication introduces key principles and concepts of America's geoheritage, which are the focus of ongoing collaboration and cooperation on geologic conservation in the United States. The booklet includes the following five big ideas:

- America’s geologic landscape is an integral part of its history and cultural identity, and Americans have a proud tradition of exploring and preserving geologic heritage.
- America’s geologic heritage, as shaped by geologic processes over billions of years, is diverse and extensive.
- America’s geologic heritage holds abundant values—aesthetic, artistic, cultural, ecological, economic, educational, recreational, and scientific—for all Americans.
- America’s geologic heritage benefits from established conservation methods developed around the world and within the United States.
- America’s geologic heritage engages many communities, and involvement by individuals will ensure its conservation for future generations.

Supplemental geoheritage information for UPDE can be found in the park’s [Trail of Geology](#) (accessed May 2025) story map. Additional information about the geology of Pennsylvania and New York, including their geoheritage connections, can be found at the following websites: [Pennsylvania Geoheritage](#) (accessed May 2025) and [The New York State Museum](#) (accessed May 2025).

Paleontology

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). They may be body fossils (any remains of the actual organism such as bones, teeth, shells, or leaves) or trace fossils (evidence of an organism’s activity such as nests, burrows, tracks, or feces). Fossils may occur in rocks or unconsolidated deposits, in museum collections, or in cultural contexts, such as building stone. The fossil resources found within and immediately surrounding UPDE offer a glimpse into the ancient environments and lifeforms that once existed in the Appalachian Plateaus. Many of the documented fossils along the Upper Delaware River valley are early land plants preserved in the Devonian Catskill Formation (Table 3). Some of the earliest published fossil discoveries from within UPDE date back to the late 19th century and include sites near the Hawk’s Nest, historic stone quarries, and along the Erie Railroad (Prosser 1894; Justin Tweet, NPS GRD, personal communication 25 March 2025). In addition to fossil flora, sandstone exposures of the Towamensing Member (**Dct**) at the Hawk’s Nest site contain vertical, tube-like structures interpreted to be escape burrows of the freshwater bivalve *Archanodon catskillensis* (Sevon et al. 1989; Inners and Osborne 2001). According to Sevon et al. (1989), these burrows are likely the result of rapid sedimentation associated with river-mouth bars of the Catskill deltaic complex (see “Paleozoic Era”). To avoid sudden burial and death, these bivalves had to burrow upward through the sediment. One of the youngest potential fossil sites of interest in UPDE is Ten Mile Rockshelter, which contains mid-Holocene

(4,500 ± 130 radiocarbon years before present) deposits which include bones of turtles and turkeys (Funk et al. 1971; Justin Tweet, NPS GRD, personal communication 25 March 2025). It is important to acknowledge that radiocarbon dates are not equivalent to calendar dates and radiocarbon years require calibration to yield calendar years.

Table 3. Paleontological resources documented within UPDE.

Formation Name	Age	Fossils Within UPDE
Quaternary sediments	Pleistocene–Holocene	None to date (potentially mid-Holocene Ten Mile Rockshelter[?])
Catskill Formation (including the Lackawaxen, Delaware River, and Towamensing members)	Late Devonian	Lycopodiophytes, progymnosperms, other early plants, plant fragments, and probable bivalve escape burrows
Trimmers Rock Formation (Millrift Member)	Late Devonian	None to date

The Delaware (Upper) Wild and Scenic River

As a hydrological park, the landscape, existence, and namesake of UPDE is intimately associated with the Delaware River. When Congress designated the park in 1978, approximately 118 km (73.4 mi) of the Upper Delaware River were inducted into the [National Wild and Scenic Rivers System](#)—the crown jewels of American rivers (Albert and Albert 2002). As stated in the NPS Foundation Document (National Park Service 2014, p. 6), the park “...*protects, conserves, and enhances the free-flowing character, exceptionally high water quality, and the scenic, recreational, ecological, cultural, and geological values of the Upper Delaware River valley through collaborative partnerships and cooperation with state and local government entities.*” As a major value included within UPDE’s enabling legislation, the geologic connections to the park are central to the river’s history, including its landscape evolution, Indigenous inhabitants, pioneer timber rafters, the Delaware Canal, and bluestone quarries. The scenic gorges of the park reflect the underlying bedrock, which has been sculpted by water and ice over millions of years. Some of the most famous individuals who were drawn to the aesthetic and recreational nature of the Upper Delaware River include Zane Grey, the celebrated author known as “the father of the western novel,” as well as the 39th President of the United States, Jimmy Carter (Figures 4–5). As an avid outdoor enthusiast, President Carter not only signed the enabling legislation for UPDE, but he also designated dozens of wild and scenic rivers across the country.

From a geologic perspective, the story of UPDE goes further than just the modern Delaware River. The massive sandstone ledges and cliffs lining the river corridor record ancient, braided streams dating back nearly 380 million years ago; in short, the park represents a fluvial setting superimposed upon the floodplains of the past.



Figure 4. Zane Grey fishing the Delaware River. The famous author was drawn to the aesthetic and recreational nature of the Upper Delaware River, which helped inspire some of his early writings. NPS photograph.



Figure 5. President Jimmy Carter fly fishing in UPDE. Known as an avid outdoor enthusiast, President Carter signed the enabling legislation for UPDE as well as dozens of other wild and scenic rivers. Photo by Barbara Yeaman, September 1984, originally published in the River Reporter.

UPDE Geologic River Guide

UPDE contains several interesting geologic features that can provide valuable educational and interpretive opportunities. Table 4 is a geologic river guide for UPDE that describes several geologic features going in a downstream direction from Hancock to Sparrow Point. The table descriptions are keyed into approximate river miles measured from the mouth of the Delaware River. Information within the table was sourced from Inners and Osbourne (2001), Albert and Albert (2002), and Braun (2012).

Table 4. Geologic river guide for UPDE.

River Mile	Description
331.0	Point Mountain, Hancock, New York. The mountain is an isolated bedrock knob, or umlaufberg (a German word meaning “circumference mountain”), that separates the East Branch and West Branch of the Delaware River. The mountain is bordered to the north by an abandoned incised meander of the Delaware River that is filled in with glacial deposits—an area now underlying the city of Hancock. Umlaufbergs are usually formed by glacial meltwater erosion cutting through a ridgeline between the confluence of two streams; however, glacial meltwater probably did not cut the channel on the north side of Point Mountain. It is likely that two separate incised meanders of the East Branch and West Branch cut through the spur and isolated Point Mountain. Immediately after the spur was incised, the East Branch joined the West Branch along the north side of Point Mountain, and the valley on the west side of the mountain was abandoned except where Shehawken Creek occupied it. Over time, the spur was filled in with glacial material, and the West Branch reconfigured to its current path along the western flank of the mountain.
330.5	The confluence of Shehawken Creek and the West Branch Delaware River. Shehawken Creek is a barbed tributary, meaning that it merges with the river in an upstream direction, or “against the grain,” forming a sharp, hook-shaped bend that points upstream. Such tributaries are considered evidence that the river’s drainage system used to flow north and has been reversed to the south by headward-eroding streams.
330.5–329.0	An anastomosing (two or more interconnected channels) reach of the Delaware River containing several islands.
327.5	Stockport, Pennsylvania. An alluvial fan (a large apron of unconsolidated rock) from Stockport Creek projects out onto the floodplain along the river’s western (right) bank. A side road goes up Stockport Creek through a narrow bedrock gorge. A till shadow (a thick, asymmetric mass of till) buried the creek valley, and the post-glacial creek cut a new channel in the bedrock wall on the south side of the valley.
325.0	Buckingham river access point at Dillontown, Pennsylvania. A small alluvial fan projects out onto the floodplain from an unnamed tributary draining Nabbys Lake. A well sample collected at the lake penetrated a roughly 52 m (170 ft) thick sequence of glacial till to reach bedrock. The stream draining Nabbys Lake has a “two-sided” bedrock gorge, meaning the southern walls consist of older bedrock while the northern walls are made of till.
322.5	Equinunk, Pennsylvania. The Equinunk Creek valley is aligned nearly parallel to glacial ice flow during the previous Ice Age and has been deeply scoured and widened by glacial erosion. The valley was then partly backfilled by till and outwash sediments deposited during glacial recession roughly 18,500 years ago.
322.5–316.0	Well-developed incised meanders. In this relatively narrow, roadless reach, the Delaware River has carved excellent bedrock exposures along the southern (right) riverbank from miles 320 to 321 and 317 to 316.
313.0	Kames and kettles near Kellams Bridge. Just east of the Kellams Bridge are a series of kames (glacial knobs or hills) and wetland-filled kettles (glacial depressions or holes) underlain by ice-contact stratified drift, outwash deposits, and till.
306.5–299.5	An anastomosing reach of the Delaware River with several islands. This mostly straight segment of the river has some of the widest floodplain and the greatest number of islands of any reach along the river.
304.0	The confluence of Callicoon Creek and the Delaware River, Callicoon, New York. Similar to Shehawken Creek (river mile 330.5), Callicoon Creek is a barbed tributary that enters the river in an upstream direction, forming a bend that points upstream. Such tributaries are considered evidence that the river’s drainage system used to flow north and has been reversed to the south by headward-eroding streams.
295.5	Skinnners Falls and Milanville, Pennsylvania. At Milanville, Calkins Creek is another barbed tributary that enters the Delaware River in an upstream direction, forming a bend that points upstream. Skinnners Falls consists of bedrock rapids and a rocky beach underlain by sandstone of the Devonian Catskill Formation. A preglacial channel of the river is buried by glacial deposits just to the west of the present channel. Just above Skinnners Falls, glacial till is exposed in the western (right) riverbank; these rocks were exposed following a flood event. The buried channel’s bedrock floor is about 30 m (100 ft) deeper than the present channel. The river in post-glacial time has recently cut into the bedrock on its east valley wall. Future downcutting of the river may form a bedrock gorge at the site, or the channel may just incise along the east side of the buried valley, excavating the buried valley. The resistant bedrock at Skinnners Falls helps control the downcutting of the river for a considerable distance upstream of the site.

River Mile	Description
290.0	Incised meanders and Big Eddy, Narrowsburg, New York. There are three elongate, incised meanders of the Delaware River at Narrowsburg that were cut in preglacial times—two that are active and one abandoned. The Narrows at Narrowsburg is the post-glacial cutoff of the abandoned middle meander that extends from the Narrows to Hunts Corner, New York; Feagle's Lake occupies part of the abandoned meander channel. The Narrows is a short gorge cut through the bedrock of the incised meander spur ridge that once occupied the site. At the Narrows, the river is restricted to about one-third or one-fourth of its normal width. There is about 45 m (150 ft) of glacial fill underlying the river channel both immediately upstream and downstream of the Narrows. Today, Big Eddy is a plunge pool (a deep streambed depression) at the downstream end of the Narrows and represents the deepest portion of the river in UPDE. Big Eddy developed due to an “underwater waterfall” that forms during floods. The water shoots through the narrow, shallow bedrock channel at the Narrows and then deeply scours the glacial deposits in the buried preglacial channel. During rising flood stages, the river may scour down the full 45 m (150 ft) and then backfill 15 m (50 ft) or more during falling flood stages. Eddies like this one, where the river current moves in a circle and flows upstream, were ideal for parking lumber rafts during the 18 th and 19 th centuries. The Big Eddy, however, could trap rafts for days if the wind blowing upriver was strong enough.
288.0	Eel weir. Eel weirs are V-shaped rock formations that funnel river water to trap American eels. Several are present on the river (Figure 6). Spawned in the Sargasso Sea in the Atlantic Ocean, American eels migrate as juveniles to fresh water, where they grow into adults. A traditional food source for Indigenous occupants of the Upper Delaware River valley, smoked eels are still a local delicacy. The weirs can act as hazards to boaters.
277.5	Lackawaxen River confluence, Lackawaxen, Pennsylvania. The latter stages of Glacial Lake Wallenpaupack drained eastward through a series of ice-marginal channels cut in the hills above the Lackawaxen River valley. There was a short-lived (i.e., a few decades to a century or so) proglacial lake (a lake impounded at the edge of a glacier or the margin of an ice sheet) in the lower Lackawaxen valley that drained eastward in a series of ice-marginal channels cut in the hills above the Delaware River valley from the Lackawaxen confluence to near the southern end of UPDE. Those channels also received meltwater drainage directly from the adjacent ice front that at the time still buried UPDE downstream of the Lackawaxen confluence.
276.5	Minisink Ford. Downstream of the Lackawaxen River confluence, the Delaware River shallows for nearly 1.6 km (1.0 mi) due to the deposition and reworking of unconsolidated sand and gravel distributed by its tributary. Minisink Ford is a shallow crossing of the Delaware River that was used during the Battle of Minisink, the only major battle fought along the Upper Delaware River during the American Revolutionary War (see “Minisink Battleground Park”).
273.0	Shohola bedrock gorge and rapids. The Shohola bedrock gorge is a meandering reach of the river surrounded by rounded sandstone knobs of the Devonian Delaware River Member (Dcdr) of the Catskill Formation. In preglacial times, the Delaware River flowed through the village of Shohola and curved sharply to the east through the saddle that the Erie-Lackawanna Railroad presently follows. The mouth of Shohola Creek used to be located further downstream than it is today and formerly merged with the river at Handsome Eddy; the abandoned course of the creek is now partly filled by glacial deposits and is now followed by Bee Hollow Rd. In preglacial or early glacial times, the Delaware River undercut the ridge separating it from the Shohola Creek valley and had almost cut into (“captured”) Shohola Creek at the Shohola bedrock gorge site. Since the Ice Age, the Delaware River and Shohola Creek have incised through at least 60 m (200 ft) of bedrock to form the gorge at Shohola Rapids. Both upstream and downstream of the gorge, Shohola Creek's floodplain abruptly widens where the creek has eroded the glacial fill occupying the preglacial valleys.
271.0–259.0	Incised meander reach. Excellent exposures of bedrock are located at several sites where the river is undercutting the valley walls—notably the Hawk's Nest. These bedrock exposures consist of sandstones of the Devonian Delaware River (Dcdr) and Towamensing (Dct) members of the Catskill Formation.
268.5	Cutoff incised meander at Hillside Cemetery, New York. An abandoned meander loop extends about 1.6 km (1 mi) north of the present river and was cut off in preglacial time and then partly filled in by glacial deposits. The cemetery is at the site of the meander spur cutoff. From New York County Road 97, turn onto Van Tuyl Road to ascend the glacial fill.
263.0	Stairway Rapids. Sandstone ledges project out into the Delaware River from the western (right) bank. The river corridor along the rapids marks the transition between the Devonian Delaware River (Dcdr) and Towamensing (Dct) members of the Catskill Formation. This is a good site to view bedding planes and river scour features at low water.

River Mile	Description
262.0	Eel weir. Located just downstream of a mid-channel island. See the description above for river mile 288.0. The weir can act as a hazard to boaters.
261.0	Mongaup Rapids. Bouldery sediments deposited along the mouth of the Mongaup River form the rapids, just like some tributary junctions do on other rivers like the Colorado River in the Grand Canyon.
260.0	Butlers Rift. Sandstone ledges of the Devonian Towamensing Member (Dct) of the Catskill Formation crop out along the eastern (left) riverbank—including the scenic Hawk’s Nest.



Figure 6. Eel weir warning. Eel weirs are V-shaped structures constructed out of stone that channel the river (and American eels) into a wooden trap. Although eels spawn in the Sargasso Sea in the Atlantic Ocean, they migrate as juveniles to fresh water, where they grow into adults. Boaters should avoid weirs and follow warning signs.

Indigenous Connections

Following the previous Ice Age, the Appalachian Plateaus province began to thaw and was more hospitable to life and human habitation. According to National Park Service (2014), there are more than 430 documented Indigenous sites along the Upper Delaware River valley that convey the region’s early subsistence history. For thousands of years, humans have been attracted to the river corridor for its fertile

land, vegetation, and wildlife, as well as a means of transportation and trade. Some of the oldest inhabitants of the Upper Delaware River valley were Indigenous cultures from the Paleo-Indian Period (roughly 12,000 to 10,000 years ago); artifacts from this period are considered very rare (Killion et al. 2015; Killion and Young 2016). However, there is an abundance of cultural materials dating to the Archaic Period (about 10,000 to 4,000 years ago) that demonstrate humankind's adaptation to the surrounding landscape. Preserved along the river valley are Indigenous settlements (e.g., wooden longhouses, rockshelters, and caves), burial sites, as well as stone tools and weapons, including grooved axe heads, bannerstones (enigmatic, carved or notched stones), net-sinkers (small stones sewn into fishing nets), and several types of projectile points (Killion et al. 2015). During the early excavations of the Delaware and Hudson Canal in 1825–1828, burial sites were encountered near what is now Roebling's Delaware Aqueduct (Leslie 1975; Killion and Young 2016). Additional cultural sites have been found along the riverbanks near the confluence of major tributaries as well as at Minisink Battleground Park. Artifacts found at Minisink Spring Rockshelter indicate humans used the shelter as a temporary hunting camp at various times extending back approximately 3,000 to 4,000 years ago (Inners and Osborne 2001).

Minisink Battleground Park

One of the notable sites in UPDE is [Minisink Battleground Park](#), located directly across the Delaware River from the Zane Grey Museum and adjacent to Roebling's Delaware Aqueduct. The battleground park is dedicated to the brave soldiers who fought and died at the Battle of Minisink, the only major skirmish of the American Revolutionary War fought along the Upper Delaware River valley. In general, the term “Minisink” has many geographical and Indigenous meanings (including “at the island” in Algonquin), but here it refers to the Delaware River corridor centered around Port Jervis. The battle took place on 22 July 1779 and was a decisive victory for the British army, which included Loyalist (Tories) and Iroquois soldiers under the command of Iroquois Chief Joseph Brant. The Battle of Minisink was impacted by several geologic elements that determined the location, tactics, and outcome of the battle. Prior to the military engagement, Brant led a series of raids along the Upper Delaware River valley that resulted in burned or destroyed property, stolen livestock, and the deaths of several settlers. Following a raid on 20 July 1779, an American militia pursued and caught up with Brant at Minisink Ford, a shallow crossing of the Delaware River located about 0.8 km (0.5 mi) downstream of Roebling's Delaware Aqueduct (Inners and Osborne 2001). Downstream of its confluence with the Lackawaxen River, the Delaware River shallows for nearly 1.6 km (1.0 mi) due to the deposition and reworking of unconsolidated sand and gravel distributed by its tributary (Inners and Osborne 2001). Under the command of Colonel John Hathorn, the American militia attempted to secretly ambush Brant and his soldiers as they were crossing the river, but their positions were gravely compromised by premature gunfire. The site of the ensuing battle is located on two connected hilltops—informally referred to as “Ambush Hill” and “Rocky Hill”—that feature steep slopes, cliffs, ledges, and a spring-fed ravine locally known as “Dry Brook” (Inners and Osborne 2001). These topographic features reflect the underlying bedrock, which consists of erosion-resistant sandstones of the Delaware River (**Dcdr**) and Lackawaxen (**Dcl**) members of the Catskill Formation. Following the initial engagement at Minisink Ford, Brant quickly mobilized his soldiers up Dry Brook and successfully outflanked the militia, effectively splitting the American forces in half. More than half the militia fled the battlefield, while the remainder retreated northward from the ledges atop Ambush Hill to make a fateful last stand on Rocky Hill (Inners and Osborne 2001).

Located along the Minisink Battleground Trail are three prominent geologic markers or sites associated with the Battle of Minisink, including Hospital Rock, Sentinel Rock, and Indian Rock. Hospital Rock is perhaps the most historically significant place in the battleground park and is hallowed ground where American Lieutenant Colonel Benjamin Tusten (a physician)—and 17 wounded militiamen under his care—were trapped, surrounded, and perished (Figure 7; Leslie 1975). Sentinel Rock has long been speculated to be the location where Brant's forces pushed into the heart of the American militia's defensive positions; it is also believed to be the location where a sentinel died while standing guard (Inners and Osborne 2001). Indian Rock is a large boulder or slab of rock that is rumored to have been placed by Loyalists and Iroquois to honor their dead and wounded following the battle (Figure 8). In addition to these sites, the [Minisink Battle Monument](#) is a stone monument erected in 1879 that is dedicated to those who perished during the Battle of Minisink. The monument rests upon exposed bedrock of the Devonian Catskill Formation and is constructed out of local bluestone topped by a rounded glacial erratic (a large boulder of glacial origin; Inners and Osborne 2001). An additional trail at the battleground park, the Old Quarry-Rockshelter Trail, allows visitors to see Indigenous rockshelters (e.g., Minisink Spring Rockshelter) as well as Bartle's Quarry, an old 19th-century bluestone quarry.



Figure 7. Hospital Rock. During the Battle of Minisink, Hospital Rock is where the American militia made a final stand against Joseph Brant's forces. These sandstone ledges, consisting of the Devonian Lackawaxen Member of the Catskill Formation, mark the site where American Lieutenant Colonel Benjamin Tusten—and 17 wounded militiamen under his medical care—were trapped, surrounded, and killed. NPS photograph.



Figure 8. Indian Rock. The rock slab is believed to have been placed by Joseph Brant's forces following the Battle of Minisink to honor their dead and wounded. NPS photograph.

The Delaware and Hudson Canal

Over millions of years, geologic processes bestowed a wealth of mineral resources along the Upper Delaware River valley that spurred the technological development of the Delaware and Hudson Canal and the economic growth of the region. The Delaware and Hudson Canal was a historic 173 km (108 mi)-long canal constructed in the 1820s to help with the shipment of anthracite coal that was mined along the hills of northeastern Pennsylvania. At the time there were no reliable means of transportation, and the canal provided an opportunity for operators to send large shipments downstream to major cities along the east coast. The canal began in Honesdale, Pennsylvania, and followed the Lackawaxen River to its confluence with the Delaware River. At Lackawaxen, the canal crossed the Delaware River by rope ferry (a river crossing guided by rope—this was later replaced by Roebling's Delaware Aqueduct), then followed the New York side of the river to Port Jervis, where it tracked along the Neversink River and Rondout Creek to Kingston, New York (Killion and Young 2016). In the late 1840s, the construction of the New York and Erie Railroad introduced a more favorable means of shipment and transportation that slowly rendered the function of the canal obsolete. The railroad's powerful locomotives, higher-capacity cars, and longer train assemblies were more competitive and profitable than the canal (Killion et al. 2015; Killion and Young 2016). Additionally, railroad operations weren't hindered by ice, snow, droughts, and floods that plagued the canal and made it less efficient (Killion and Young 2016). Coal shipments along the Delaware and Hudson Canal reached a peak of three million tons in 1872, but by 1898 the canal was discontinued and dewatered.

Roebling's Delaware Aqueduct

Roebling's Delaware Aqueduct is the oldest existing wire cable suspension bridge in the United States and is a surviving relic of the 19th-century Delaware and Hudson Canal (Figure 9). Designed by John A. Roebling (famously known as the architect of the Brooklyn Bridge in New York), the aqueduct is listed as both a national historic landmark and a national historic civil engineering landmark (Conference of Upper Delaware Townships and National Park Service 1986; National Park Service 2014). During the 1840s, the Delaware and Hudson Canal was enlarged on three separate occasions to widen, deepen, and reinforce its channels and locks. These improvements were made to not only accommodate larger ships but also to improve transportation issues. Roebling designed four aqueducts that were built in 1848 to alleviate bottlenecks and collisions along the former rope ferry at Lackawaxen; the completion of these projects marked the peak of the canal's performance and technology (Killion et al. 2015). Following the discontinuation of the canal, Roebling's Delaware Aqueduct underwent adaptive reuse restoration in the 1980s and was converted into a one-lane highway toll bridge (Roebling Bridge), which is still in use today.

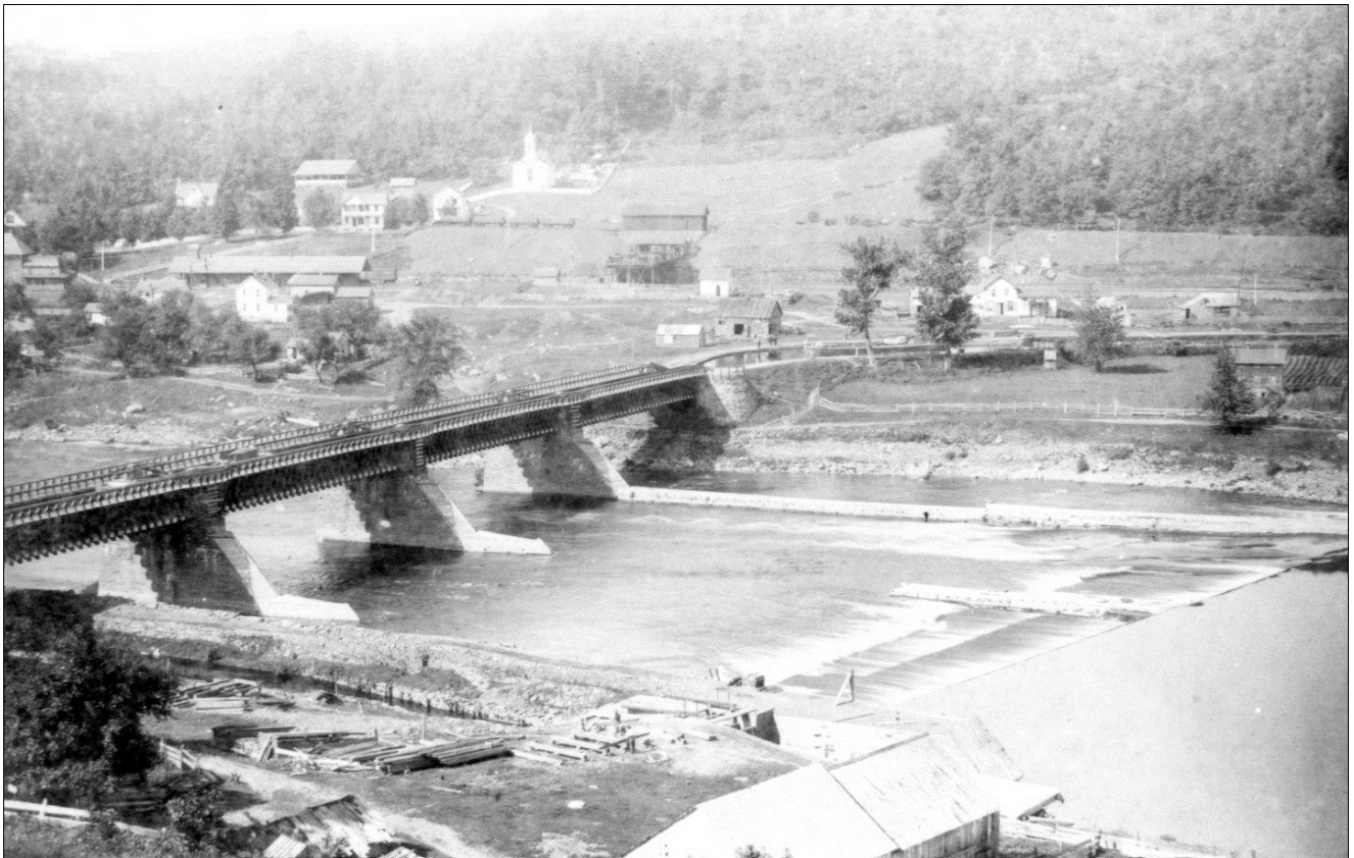


Figure 9. Roebling's Delaware Aqueduct circa 1850. During the 19th century, John A. Roebling designed four aqueducts as part of the historic Delaware and Hudson Canal; today only one remains in the form of the Roebling Bridge. The Roebling Delaware Aqueduct replaced a former rope ferry at Lackawaxen and alleviated bottlenecks and collisions along the Delaware River. NPS photograph.

Stone Quarries

Stone quarries are widely distributed along the banks of UPDE and include mineral resources such as bluestone, shale-chip rubble (angular, platy fragments of claystone and siltstone), aggregate, and peat. The

name “bluestone” is given to bluish-gray flagstone, a dense, hard, fine-grained sandstone that easily splits along planes of weakness and can be slabbed for building materials such as paving blocks, curbs, and decorative stone (e.g., hearthstones, mantles, wall stones). Bluestone along the Upper Delaware River valley is commonly sourced from planar bedded sandstones of the Towamensing (**Dct**), Delaware River (**Dcdr**), and Lackawaxen (**Dcl**) members of the Catskill Formation. These sandstones contain joints and parallel bedding planes that naturally weaken the rock and make them ideal bluestone source material; these same characteristics also make these rocks vulnerable to mass wasting (see “Mass Wasting”). Stone cut from the Catskill Formation was used in many of the local Erie-Lackawanna Railroad bridges as well as the piers and abutments of aqueducts famously designed by John Roebling for the Delaware and Hudson Canal (Fletcher and Woodrow 1970; Inners and Osborne 2001). Following the creation of the Delaware Canal, bluestone quarries emerged as an important industry in the late 19th century; regular bluestone shipments were delivered along the canal and the Erie Railway following the Civil War (Sevon et al. 1989). By 1886, the Kilgour Blue-Stone Company (headquartered at Parkers Glen) operated about 150 different bluestone quarries and was only one of several operators in Pike County, Pennsylvania (Sevon et al. 1989). During the peak production years of the early 20th century, the bluestone industry of the Upper Delaware River valley produced building materials of exceptional quality and beauty, with shipments to major cities across the eastern United States and as far away as Cuba (Sevon et al. 1989).

Today, abandoned quarries can be seen along some of UPDE’s trails, including the Bouchoux Trail (Jensen’s Ledges) in northern UPDE. At the summit of Jensen’s Ledges are scattered bluestone fragments that have been arranged by visitors into cairns (stacked rock markers) as well as “bluestone thrones”—rocky benches or chairs constructed from the quarry tailings (Figure 10). Additional quarries can be easily seen at Minisink Battleground Park. It is worth noting that the Minisink Battleground Park was initially established by the Minisink Valley Historical Society in the 1890s to preserve the American Revolutionary War site from destruction caused by flagstone quarrying operations (see “Minisink Battleground Park”).



Figure 10. Bluestone cairn located along Jensen's Ledges. Sandstones of the Devonian Catskill Formation were an important source material for bluestone since they are erosion-resistant and can be easily broken into flat slabs. NPS photograph.

Stratotypes

Stratotypes are important geologic reference exposures that help identify, define, and correlate geologic units from one location to another. When geologists propose or describe a new layer or body of rock, a stratotype is assigned to exposures containing all (or most) of the unique diagnostic criteria. Stratotypes have significant scientific value and are often easily accessible, world-class locations to study outcrops of rock. Akin to natural libraries of Earth history, stratotypes preserve meaningful clues to the past and serve as geologic classrooms (Henderson et al. 2023, 2025). The stratotype concept is ingrained in the modern system of geologic nomenclature, as many formal geologic unit names are derived from geologic or geographic features found near stratotype locations. Some particularly recognizable examples from within the National

Park System (and their stratotype assignments) include the Permian De Chelly Sandstone (Canyon de Chelly National Monument, Arizona), the Cretaceous Mesaverde Group (Mesa Verde National Park, Colorado), and the Pleistocene Valles Rhyolite (Valles Caldera National Preserve, New Mexico). More information about the various kinds of stratotypes and how to propose or modify them can be found in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature 2021) as well as Stamm (2023).

UPDE contains four stratotypes that represent (in order from oldest to youngest) the Late Devonian Millrift Member (**Dtm**) of the Trimmers Rock Formation, as well as the Delaware River (**Dcdr**) and Lackawaxen (**Dcl**) members of the Catskill Formation (see Table 2; Henderson et al. 2021). The scenic cliffs of the Hawk's Nest were previously designated the type section of the "Delaware River Formation" by Fletcher and Woodrow (1970); these exposures are now assigned to the Devonian Towamensing Member (**Dct**) of the Catskill Formation. Although the Devonian Damascus and Shohola members of the Catskill Formation were named by Willard (1936) after outcrops along the Delaware River in Damascus and Shohola, respectively, no formal stratotypes have been designated (see "Inventory Needs").

Geologic Resource Management Issues and Inventory Needs

This section briefly summarizes the geologic resource management issues, inventory needs, and geologic hazards that have been identified by discussions with UPDE staff. Geologic resource management issues refer to problems related to geologic resources. Inventory needs are highlighted to summarize what is currently known and what is needed to ensure good management of UPDE. Geologic hazards refer to notable hazards stemming from geologic features or processes that may require active management. Refer to the [Guidance for Resource Management SharePoint](#) for more information regarding geologic resource management.

Summary of Geologic and Soil Hazards

Park resources are not only visitor attractions but may also be potentially hazardous. The landscape of UPDE presents a variety of geologic hazards, or “geohazards”—naturally occurring, dynamic geologic processes that have the potential to cause damage, loss of property, and/or injury and loss of life. The Addressing Climate Change and Natural Hazards Handbook (National Park Service 2015a, 2023), grounded in NPS Policy Memorandum 15-01 (Jarvis 2015), provides a process and information to help teams and decision-makers identify, avoid, and mitigate risks associated with environmental change hazards and effects on proposed and planned facility investments. The handbook supports NPS planning guidance, policy directives, and executive orders and does not supersede existing mandated compliance processes and policies. Additional guidance for facility management (e.g., [Climate-Smart Planning Principles](#) and [Recommended Practices](#)) has been developed to support effective decision-making.

According to PM 15-01, managers should apply the handbook guidance to identify options to manage natural hazard and climate change risks throughout all levels of facility planning and design. Project teams are required to submit the completed Natural Hazards Checklist (Table 5) as part of Regional and Bureau Investment Review Board submissions. This information can also be used as part of the updated (2024) Automated Investment Review Board (AIRB) submittal process at the Investment Concept (IC) stage. Table 5 includes selected geologic and soil hazards listed in Part 1 of NPS (2023). The GSRI team has added additional hazards where appropriate for the park. If needed, Part 2 of the handbook could inform the completion of the checklist, such as whether a hazard is applicable. Contact the NPS GRD with any questions.

Table 5. Geologic hazards checklist.

This summary table is a synthesis of existing GSRI-compiled map data and information, as well as published US Geological Survey and other government agency information. It is suitable for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or NEPA analysis. Ground-disturbing activities should neither be approved nor denied based on the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2015a, 2023 and Jarvis 2015). It is meant to provide general information to identify the full range of natural hazard-based risks for the park.

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Earthquake	Falling objects Collapsing structures Inoperability of major building systems (e.g., power, sewer, water) Trigger to other hazards (e.g., landslides) Human injury or casualty	Potential hazard (low; DOI SHIRA and Petersen et al. 2023)	Stover et al. (1987a, b) The New York State Museum Earthquake Center The Pennsylvania State Seismic Network US Department of Interior (DOI) Strategic Hazard Identification and Risk Assessment (SHIRA) Risk Mapper Report United State Geological Survey (USGS) Earthquake Hazard Probability Map (Petersen et al. 2023) USGS Seismicity by Region: New York
Slope movements (also called “mass wasting”)	Landslides (e.g., mudflows, rockfalls, slumping or creep) Damage to or loss of park infrastructure Damage to or loss of natural or cultural resource sites or features Human injury or casualty	Known hazard (very high; DOI SHIRA)	Braun (2008a, b; 2011a, b) DOI SHIRA Risk Mapper Report Fletcher and Woodrow (1970) GSRI GIS hazard layers or slope movement deposits (e.g., “boulder colluvium”) Inners and Osbourne (2001) Sevon et al. (1989) USGS Landslide Inventory and Susceptibility
Permafrost	Not applicable	Not applicable	Not applicable
Cave/karst	Not applicable	Not applicable	Not applicable
Shrink/swell soils	Sinking or lateral shifting of the ground beneath roads, trails, or structures Damage to infrastructure (e.g., buildings, utility systems) Increased susceptibility to slope movements Human injury or casualty	Potential hazard (low; USDA Web Soil Survey)	USDA Web Soil Survey
Coastal storm surge/ sea or lake level change/shoreline erosion	Not applicable	Not applicable	Not applicable
Tsunami	Not applicable	Not applicable	Not applicable

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Riverine Flood	Flooding driven by storms, prolonged rainfall or snowmelt, and ice jams Stream channel migration Stream bank erosion Enhanced mass wasting susceptibility Enhanced surface runoff and stream flow capable of carrying sediment, rock, and woody debris Destruction of infrastructure (e.g., roads, trails) Destruction of cultural or paleontological sites, including historic remnants of the Delaware and Hudson Canal, as well as the Zane Grey Museum Ice jams can leave behind stranded, car- or house-sized blocks of ice Human injury or casualty	Potential hazard (extreme; DOI SHIRA)	Albert (2010) Brooks (2005) DOI SHIRA Risk Mapper Report Federal Emergency Management Agency (FEMA) Map Service Center Killion and Young (2016) Killion et al. (2023) National Park Service (2014) Siemion and Murdoch (2010) US Army Corps of Engineers (USACE; 1984)
Flash Flood	Rapid flooding along the Upper Delaware River and its tributaries Stream channel migration Stream bank erosion Enhanced mass wasting susceptibility Enhanced surface runoff and stream flow capable of carrying sediment, rock, and woody debris Destruction of infrastructure (e.g., roads, trails) Destruction of cultural or paleontological sites, including historic remnants of the Delaware and Hudson Canal, as well as the Zane Grey Museum Human injury or casualty	Potential hazard	USACE (1984)
Volcanic eruption	Not applicable	Not applicable	Not applicable
Hydrothermal activity	Not applicable	Not applicable	Not applicable
Radon	Health hazard	Potential hazard (high to moderate; US EPA).	DOI SHIRA Risk Mapper Report Otton (1992) US Environmental Protection Agency (EPA) Map of Radon Zones
Toxicological soil (arsenic ¹ , <i>Bacillus anthracis</i> [causes anthrax] ² , cadmium ³ , lead ¹ , and selenium ³)	Health hazard	¹ Potential hazard (very high) ² Potential hazard (low) ³ Potential hazard (high)	DOI SHIRA Risk Mapper Report

Climate Change

Although climate change planning is beyond the scope of this GSRI summary, a discussion of climate change is included because of the potential disruption it may cause to the park's resources, including geologic resources. The climate at UPDE is already changing; all future climate model projections include temperatures above the recent historical average (1979–2012), and average annual precipitation is anticipated to be highly variable (Climate Change Response Program 2024). Projected increases in several variables (e.g., air temperatures, evaporation rates, droughts, and precipitation) may negatively affect river or stream levels, groundwater aquifer recharge, as well as watershed quality and flow. Rising temperatures can enhance evaporation rates and lead to intense heat waves, which will likely impact the availability of water and threaten the ecological integrity of the Upper Delaware River valley. These modifications to water availability are likely to affect additional geologic processes (e.g., floods, landslides, channel erosion), in addition to ecological processes (e.g., invasive species, phenology), visitation, and park management procedures (Climate Change Response Program 2024). Dry conditions enhance the risk of wildfire, which can remove stabilizing vegetation along the river and promote erosion or landslides, including mudslides, debris flows, or rockfalls. Additionally, several invasive species at UPDE—notably hemlock woolly adelgid and Japanese knotweed—threaten the vegetative communities of the park and may lead to slope instability or erosion problems.

Climate change manifestations that may intensify geologic hazards include the following:

- Increased average temperatures
- Increased likelihood of wildfires
- Increased frequency and intensity of storms
- Increased susceptibility to mass wasting events
- Increased extreme weather scenarios, including drought and flooding
- Decreased water availability and biodiversity

Disturbed Lands

Disturbed lands are those areas where natural conditions and processes have been directly impacted by development, including facilities, mining, roads, dams, and campgrounds; agricultural activities such as farming, grazing, timber harvest, and irrigation ditches; and overuse or inappropriate use. Restoration aims to restore a site, watershed, or landscape to a previous condition, typically a desirable historic baseline. Human activity often disturbs lands, leading to unintended and long-lasting issues that affect other resources. Many of these disturbances obliterate soil profiles, exacerbate the invasion of exotic plants, result in contamination of water and soil, and/or cause erosion and sedimentation. These damages, in turn, frequently impair the quality of habitats, disrupt ecosystem functions, and cause problems for park staff managing areas as wildlands. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities.

Abandoned Mineral Lands

Numerous quarries are located along the banks of the Delaware River both within and adjacent to UPDE. Many of these quarry sites are associated with the historic bluestone industry that thrived following the

advent of the Delaware and Hudson Canal and the Erie Railroad. Today, these abandoned quarries pose a considerable threat with respect to mass wasting events such as landslides or rockfalls. Bluestone quarry operators commonly targeted the jointed, planar bedded sandstones of the Catskill Formation, as these properties allow the rock to preferentially cleave or break. While these physical properties make sandstones of the Catskill Formation an ideal bluestone source material, these characteristics also naturally weaken the rock and increase its mass wasting susceptibility (see “Mass Wasting”).

Land Use Changes

The long, linear nature of UPDE makes it sensitive to land use changes adjacent to or upstream from the park. A combination of agricultural, industrial, residential, and transportation developments has negatively modified the banks of the Delaware River, altering the river’s natural drainage pattern by increasing runoff and sedimentation while introducing non-native or invasive species (Siemion and Murdoch 2010; National Park Service 2014). Infrastructural development along the banks of UPDE increases stream flashiness (speed of runoff), as impervious surface installation (e.g., roadways, parking lots) exacerbates runoff and promotes channelization. Enhanced runoff is sometimes directed toward the river, where it erodes the rocky bluffs or cliffs lining the river corridor (National Park Service 2014). Large-scale changes in land cover or land use can also negatively affect water quality by introducing contaminants sourced from sewage treatment facilities and septic systems, as well as agricultural and roadway runoff (Siemion and Murdoch 2010; National Park Service 2014). As the population continues to grow, increased water needs may further stress or threaten the quality and quantity of the local watersheds sustaining the Upper Delaware River.

Shale-gas Development

UPDE is one of 33 national park sites that overlie or are in the vicinity of the Middle Devonian Marcellus Shale, a prolific oil and gas formation that underlies portions of New York, Pennsylvania, West Virginia, and Ohio (Moss 2008). The oil and gas industry has shown increasing interest in developing the Marcellus Shale, as natural gas estimates by the USGS have increased from roughly 53.8 billion m³ (1.9 trillion ft³) in 2002 to as much as 877 billion m³ (31 trillion ft³) in 2006 (US Geological Survey 2002; Milici and Swezey 2006). Although innovations in drilling technology have made the extraction of natural gas more economical, there are many environmental and socioeconomic issues associated with horizontal drilling and hydraulic fracturing. Shale-gas development involves a large industrial presence that can lead to (1) water contamination related to drilling and disposal of drilling fluids, (2) air quality degradation from internal combustion engines on drill rigs and trucks, (3) excess dust from equipment transportation, (4) impacts to solitude and night skies from noise and lighting, and (5) visitor use and safety concerns associated with the large number of trucks needed to support drilling operations (Moss 2008). Water-related issues rank among some of the highest concerns, as large quantities of water are often contaminated and need to be properly disposed. Projected increases in Marcellus Shale development surrounding UPDE will further stress the regional hydrological system and demand a significant amount of water to develop and sustain gas recovery operations (Moss 2008).

Flooding

Flooding is a natural, routine phenomenon along the Upper Delaware River valley and was historically relied upon by residents and families during the 18th and 19th centuries. Prior to the construction of the New York City reservoirs, the spring freshet (the annual high water) enabled raftsmen to navigate the length of the river from its headwaters to Philadelphia, Pennsylvania (Figure 11). Some crews were able to make multiple trips

per season, which brought in critical income; many families lived off these earnings for the remainder of the year. Flooding at UPDE primarily occurs in the spring due to seasonal rains and snowmelt but can also be caused by ice jams or large storms (e.g., tropical storms, hurricanes, nor'easters) traveling up the eastern seaboard (Killion and Young 2016; Killion et al. 2023). Increased precipitation and runoff strengthen tributary flow and erosion, producing a large amount of sediment or debris that is transported toward and along the main stem of the Delaware River. Enhanced runoff from parking lots and roadways negatively impacts water quality (e.g., conductivity, salinity, nutrient levels) because of road salt and surface contaminants (National Park Service 2014). Flood impacts at UPDE can range from minor inconveniences to life-threatening emergencies, as rising river levels can temporarily inundate park infrastructure and resources, destabilize or erode riverbanks, instigate landslides, damage roadways and bridges, and carry large rocks or woody debris. Several storms and floods have damaged historic structures such as the Zane Grey Museum, Roebling's Delaware Aqueduct, the Towpath Trail, and other remnants of the Delaware and Hudson Canal (Figures 12–13; National Park Service 2014; Killion and Young 2016; Killion et al. 2023). According to National Park Service (2014), climate change is causing an increased level of storm activity that contributes to erosional problems throughout the park (see "Climate Change").

The greatest flood recorded along the main stem of the Delaware River occurred 18–19 August 1955 because of two back-to-back hurricanes—Hurricanes Connie and Diane. Hurricane Connie set the stage on 13 August and dropped about 25–30 cm (10–12 in) of rain in the mountains of eastern Pennsylvania (USACE 1984). Five days later, Hurricane Diane produced a torrent of rain that added another 20 cm (8 in) of water within a matter of four hours (USACE 1984). The ground throughout the river valley, already saturated by Hurricane Connie, simply could not absorb any more water; the resulting flood damage was swift and immense. The 1955 flood is best considered a "flash flood," as small streams and tributaries quickly overwhelmed their banks in response to Hurricane Diane's deluge. Safety warnings came late or not at all, and those that were received were not acted upon quickly enough to prevent loss of life (USACE 1984). While air rescues were instrumental in saving many lives, some communities along the river were completely wiped out or left isolated (USACE 1984). In addition to the 1955 flood, Table 6 provides a list of historic and modern flood events along the Upper Delaware River valley. Information in the table is sourced from USACE (1984), Brooks (2005), Albert (2010), Siemion and Murdoch (2010), Killion and Young (2016), and Killion et al. (2023).

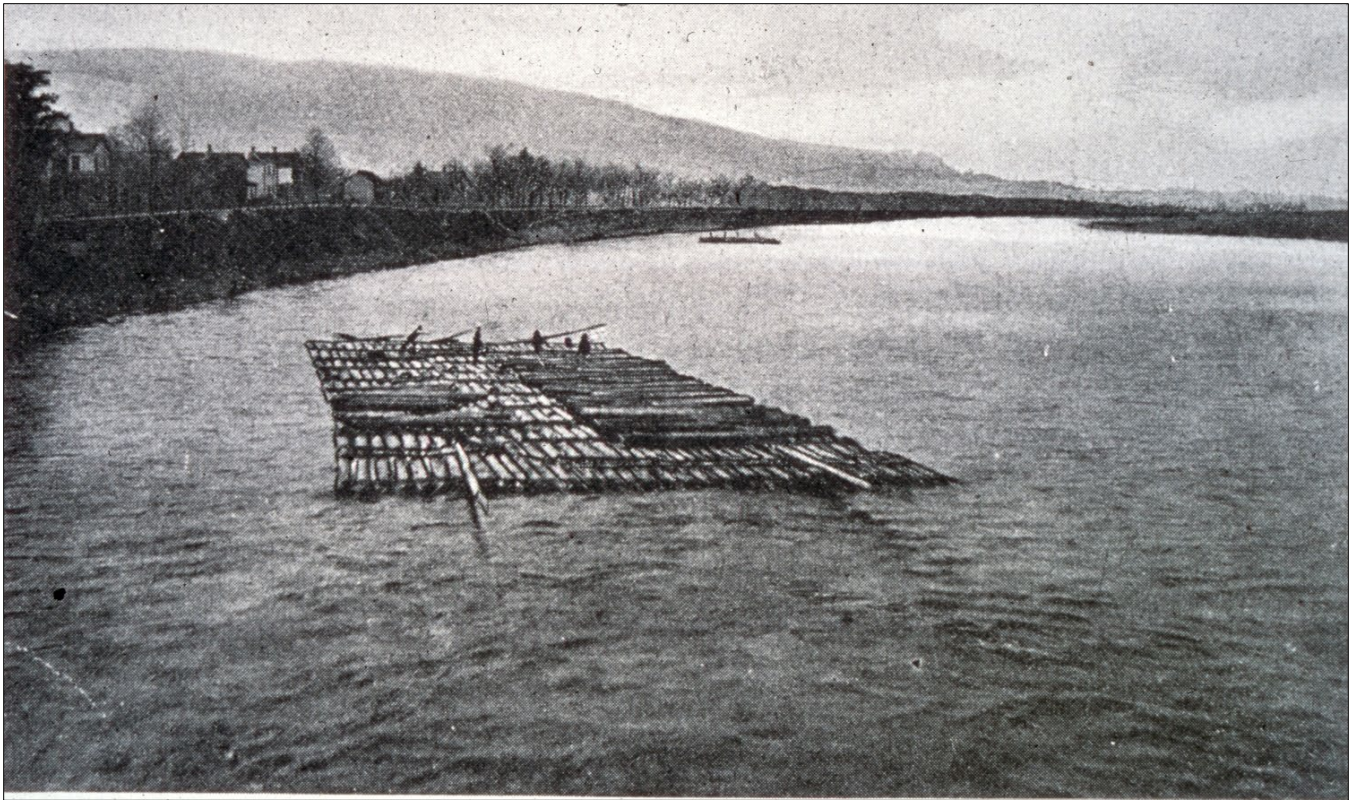


Figure 11. Historic raftsmen of the Upper Delaware River. During the 18th and 19th centuries, the spring freshet enabled raftsmen to pilot the entire length of the river from its headwaters to Philadelphia. Today, the river's flood regime has been modified following the construction of the New York City reservoirs. NPS photograph.



Figure 12. Flooding at the Zane Grey Museum in 2006. The floodwaters surrounded the house and partially inundated the property, reaching the top of the bluestone steps next to the lawn. NPS photograph.



Figure 13. Flood damage sustained to Roebling's Delaware Aqueduct in 2005. Hurricane Ivan in September 2004 and excessive rainfall in April 2005 produced near-record flooding and partially collapsed the aqueduct/bridge's stone wing wall extending upstream (north) from the New York side abutment. NPS employee for scale. Figure 1.81 from Killion et al. (2023).

Table 6. A list of historic and modern flood events at UPDE.

Date	Flood Description
January 1841, 1862 December 1901 March 1902	Historic major floods lacking complete storm and damage data.
October 1903	A major tropical storm-related flood event. Referred to locally as the “Pumpkin Flood,” the 1903 flood impacted a farm on Point Mountain, sending ripe pumpkins into the flooded Delaware River. A total of 25 cm (10 in) of precipitation was recorded at Port Jervis, New York. As a result of this hurricane-associated storm, most of the Delaware River basin above Trenton, New Jersey experienced severe flooding, and records were established that remained unbroken for 52 years. Flood flows in the upper basin were exceedingly high, and flood stages were reached along the east and west branches of the Delaware River. The 1903 flood took out several bridges, notably the Lordville Bridge on the Upper Delaware River.
August 1933	A major tropical storm-related flood event.
July 1935	A major thunderstorm-related flood event.
March 1936	A major nor’easter-related flood event. From 9–22 March, four separate storm centers passed over the northeastern US. Heavy precipitation caused major flooding throughout the entire Delaware River basin.
September 1938	A major tropical storm-related flood event.
May 1942	A major nor’easter-related flood event.
August 1955	The greatest recorded flood on record along the Delaware River basin. Two back-to-back hurricanes (Hurricanes Connie and Diane) accounting for nearly 50 cm (20 in) of rain resulted in devastating flash flooding that wiped out river communities and claimed 99 lives.
June 1972	A major tropical storm-related flood event (Hurricane Agnes).
February 1981	The Ice Gorge Flood of 1981. High water caused an unusual amount of ice accumulation on the Delaware River between Port Jervis, New York, and Matamoras, Pennsylvania. The ice formed a temporary dam, which flooded neighboring communities and left car- and house-sized blocks of ice sitting in the streets (Figure 14).
September 2004	A major tropical storm-related flood event. Remnants of tropical depression Ivan produced 10–15 cm (4–6 in) of rain over a 24-hour period, resulting in significant flooding along the East Branch Delaware River and its main stem. The flood damaged more than 100 homes and displaced over 1,000 people. Counties within the river basin were declared federal disaster areas. Peak water elevations at some sites along the river exceeded the 500-year floodplain. The 2004 Hurricane Ivan floods caused major damage to Roebling’s Delaware Aqueduct, including its former stone wing wall extending upstream from the abutment on the New York side. Seasonal campgrounds along the Beaver Kill, East Branch Delaware, and Delaware Rivers were flooded, and reports of camper trailer damage were common. Thirty-five camper vans were swept into the Delaware River near Hankins. Flood damages in Sullivan County, New York, alone were estimated to be \$10 million and accounted for bridge replacements and road damages.
April 2005	Flooding caused damage to Roebling’s Delaware Aqueduct and other historic remnants of the Delaware and Hudson Canal, including portions of the Towpath Trail.
June 2006	This region-wide flood event had a recurrence interval of greater than 100 and less than 500 years at all intensive sites, except for Port Jervis, where the recurrence interval was 80 years. The 2006 flood remains the highest flood on record since the infamous 1955 flood. Flooding damaged the roadside trunk walls and ice breakers at Roebling’s Delaware Aqueduct.
June 2007	On 19 June 2007, a period of intense rainfall occurred in the watershed of the Beaver Kill, a tributary to the East Branch Delaware River in the western Catskill Mountains of New York. The occurrence of this localized, intense storm measurably influenced water quality 100 km (62 mi) downstream on the Delaware River. Approximately 15–20 cm (6–8 in) of rain fell over the span of three hours. The return period for the flood in one of the affected headwater streams was estimated to be 500 years.
2010 and 2011	Flooding and storms in 2010 and 2011 damage the access road/trail.
December 2020	A large thunderstorm caused flooding, violent currents, floating debris, ice hazards, and obstructions along the river corridor.

Date	Flood Description
October 2021	Heavy rainfall and widespread flash flooding damage the Towpath Trail, leading to its closure. The October flood generated violent currents, floating debris, and hazardous obstructions along the river corridor.
December 2023	High water conditions caused portions of the Towpath Trail located at Roebling's Delaware Aqueduct to be washed out and temporarily closed.
August 2024	A major tropical storm-related flood event (Tropical Storm Debby).



Figure 14. Flooding associated with the Ice Gorge Flood in February 1981. High water caused an unusual amount of ice accumulation on the Delaware River between Port Jervis, New York and Matamoras, Pennsylvania. The ice formed a short-lived natural dam, which flooded neighboring communities and left car- and house-sized blocks of ice sitting in the streets. NPS photograph.

Erosion and Mass Wasting

The term “mass wasting” is used to describe downhill movements of rock, soil, or ice and includes several types of landslide phenomena, such as debris (or snow) avalanches, debris flows, slumping or slope creep, and rockfalls. The bedrock underlying UPDE predominantly consists of the Late Devonian Catskill Formation, a sandstone-dominated sequence known to contain joints, bedding planes, and other features that

weaken the rock and allow it to naturally break into slabs or blocks (Fletcher and Woodrow 1970; Sevon et al. 1989; Inners and Osborne 2001). Although these physical features made the Catskill Formation a favorable bluestone source material during the late 19th and early 20th centuries, they also increase its mass wasting susceptibility. At the Hawk's Nest, exposures of the Towamensing Member (**Dct**) of the Catskill Formation contain well-developed joints that have allowed conglomerate lenses to weather out, forming a large overhang with a potential danger for rockfall (Inners and Osborne 2001). According to Sevon et al. (1989) and Braun (2008a, b; 2011a, b), sandstone cliffs or ledge faces in the Catskill Formation generally form parallel to joint systems and have been enhanced by glacial erosion as well as frost wedging (weathering induced by the freezing of water). During the previous Ice Age, exposed sandstones were frost shattered, and spalled blocks were transported down slope by various processes collectively known as gelifluction (Braun 2008a, b; 2011a, b). During this process, overlying glacial till deposits were also mobilized downslope to form till-derived colluvium (Braun 2008a, b; 2011a, b).

Radon

Radon is a naturally occurring gas created by the decay of radioactive elements present in many rocks. Although radon is almost always present in small amounts in soil and rocks, some types of rock (e.g., volcanic rocks, granites, dark shales, phosphate-rich rocks, and metamorphic rocks) have the potential to produce above-average amounts of radon gas that can pose a known health risk (Otton 1992). According to the New York EPA map of radon zones, Delaware, Orange, and Sullivan counties are identified as zones of highest potential (zone 1) for elevated indoor radon levels that may exceed 4 pCi/L; in Pennsylvania, both Pike and Wayne counties are zones of moderate potential (zone 2) between 2 and 4 pCi/L (see <https://www.epa.gov/radon/epa-maps-radon-zones-and-supporting-documents-state>; accessed February 2025). The EPA has guidance for radon mitigation.

Seismicity

The eastern continental margin of the United States is considered passive, meaning that it lacks high levels of earthquake, volcanic, or mountain-building activity associated with tectonic plate motion. However, seismic events still occur along the eastern seaboard as geologic structures (e.g., faults and fractures) accommodate stress deep within the Earth's crust. The Appalachian Plateaus of eastern Pennsylvania and western New York represent an area of relatively low seismic risk compared to the rest of the country (Petersen et al. 2023). Although earthquakes have historically (1900 AD–present) occurred in Orange County, New York, these are typically low-magnitude events less than M3.0 (Stover et al. 1987b; see also [USGS Seismicity by Region: New York](#); accessed May 2025). Surrounding UPDE are several nearby seismic stations in both New York and Pennsylvania. In the southern part of the park, the closest station is located approximately 32 km (20 mi) southwest of Shohola in Promised Land State Park (Greentown, Pennsylvania). In northern UPDE, the closest seismic station is approximately 32 km (20 mi) northeast of Hancock in Walton, New York.

Swelling Clays

Swelling clays, or shrink-swell clays, include minerals such as smectites that are physically altered by the presence of water and tend to swell when wet and shrink when dry. As swelling clays expand or contract, the change in volume can undermine the integrity of the substrate, increase the susceptibility of slope failure, and cause infrastructural problems along roadways or trails. According to the USDA NRCS Web Soil Survey,

soils mapped adjacent to UPDE are rated “low” in linear extensibility (a determination of shrink-swell potential; see “Soils”). Linear extensibility ratings are based on the percentage of volume change as soil dries and include four assessment categories: (1) low, <3%; (2) medium, 3–6%; (3) high, 6–9%; and (4) very high, >9%. The ratings for UPDE indicate that swelling clays can generate minor volume changes capable of damaging infrastructure such as buildings, roads, and other structures.

Toxicological Soil

According to the DOI SHIRA Risk Mapper report, soils within UPDE have potentially high amounts of arsenic, cadmium, lead, selenium, and *Bacillus anthracis*—a naturally occurring soil pathogen known to cause anthrax. Soil maps show that potentially hazardous concentrations of arsenic, cadmium, lead, and selenium occur within the top 5 cm (2 in) of soil based on 2010 sampling (DOI SHIRA). For more information on naturally occurring arsenic, cadmium, lead, selenium, and their potential health impacts, visit the US Department of Health and Human Services Agency for Toxic Substances and Disease Registry (see <https://www.atsdr.cdc.gov/>; accessed February 2025). The bacteria *Bacillus anthracis* causes the rare, naturally occurring disease anthrax, which can cause severe illness in both humans and livestock exposed to spores. For more information on the public health risks associated with anthrax, visit the US Centers for Disease Control and Prevention's anthrax website (see <https://www.cdc.gov/anthrax/about/index.html>; accessed February 2025).

Geologic Resource Protection

Legislatively Required Geologic Inventories

The NPS GRD has developed an article series (<https://www.nps.gov/articles/series.htm?id=FA0A8F89-CD67-1CCE-5A6608B444E8A7C0>; accessed February 2025) that summarizes the laws, regulations, and policies that specifically apply to geologic and soil resources or processes. These protection measures were established to maintain the integrity of these resources or processes while minimizing the impacts of natural or human activity.

The core responsibility of the NPS is to preserve and protect park resources, processes, systems, and values unimpaired for present and future generations. According to National Park Service (2006), the NPS will preserve and protect geologic resources, features, and processes as integral components of park natural systems. The goals of the NPS are to assess the impacts of natural processes and human activities on geologic resources; maintain and restore the integrity of existing geologic resources; integrate geologic resources management into NPS operations and planning; and interpret geologic resources for the benefit and enjoyment of park visitors (National Park Service 2006). Various management protection policies applicable to geologic resources, features, and processes are included in National Park Service (2006) and are also organized at the following website: <https://home.nps.gov/subjects/geology/geoheritage-nps-management-policies.htm> (accessed February 2025).

Paleontological and Cultural Resources

The paleontological and cultural resources of UPDE are invaluable and provide a unique glimpse into the geologic and historic past. Numerous fossil sites, archeological deposits, and historic structures are located along the banks of the Upper Delaware River valley and are susceptible to disturbance, deterioration, or loss resulting from natural and human causes (National Park Service 2014). Remnants of the Delaware and

Hudson Canal are subject to flooding, freeze/thaw cycles, erosion, and storm damage; Roebling’s Delaware Aqueduct requires constant maintenance due to routine flooding (Killion and Young 2016). Additionally, areas such as the Zane Grey Museum are threatened by wildfire and potential future developments in adjacent sites (National Park Service 2014). Climate change predictions for UPDE include an increased probability of high-intensity storms and extreme weather scenarios (e.g., drought and flooding; Climate Change Response Program 2024). These projections have both direct and indirect consequences on wildfire occurrence, riverbank stability, and erosion, which may threaten or endanger the park’s fossil and cultural resources (see “Climate Change”).

All paleontological resources are nonrenewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act (PRPA). Fossils in NPS areas occur in rocks or unconsolidated deposits, museum collections, and cultural contexts such as building stones or archeological resources.

Hydrological Resources

As a hydrological park, one of the main management concerns for UPDE is the water quality and quantity of the Upper Delaware River system, including its numerous tributaries. The water quality (e.g., temperature, pH, dissolved oxygen, nutrients) and quantity of the river are complex and critical resource issues impacted by a myriad of variables such as climate change, land usage, visitation, drought, flooding, river incision or riverbank erosion, and landslides. The Upper Delaware River valley has a long industrial history and was once surrounded by lumbermills, acid factories, coal mines, and quarries that discharged pollutants or waste material into the river (Albert and Albert 2002). Since 1995, all portions of the West Branch Delaware River and the Delaware River’s main stem within UPDE have been listed as impaired by the state of Pennsylvania for elevated levels of mercury and polychlorinated biphenyls (PCBs; Sheeder et al. 2004). These pollutants were likely sourced from nearby property developments, short-circuiting septic systems, discharge from wastewater treatment facilities, atmospheric deposition, or stormwater runoff (Sheeder et al. 2004). The EPA has banned the production of PCBs because, like mercury, these substances accumulate inside living things, gradually increasing in concentration as they move up the food chain. Although mercury and PCBs may originate upriver of UPDE, these pollutants contaminate the water and adhere to river sediments that can migrate downstream, impacting a broad range of ecosystems. According to Sheeder et al. (2004), there are four active water monitoring stations and five USGS stream discharge stations within or near the UPDE boundary that could be utilized in a monitoring program.

Inventory Needs

The following table (Table 7) presents geologic and soil resources inventory needs that were identified during the 2024 follow-up meeting, in NPS planning documents, or through literature review.

Table 7. List of identified geologic and soil resources inventory needs for UPDE.

Subject	Inventory Need(s)	Reference(s)
Cave and karst	Complete a comprehensive cave and karst inventory for UPDE. Caves, alcoves, and rockshelters are present within the park and often have cultural connections, but their distribution and abundance are uncertain.	2025 follow-up meeting

Subject	Inventory Need(s)	Reference(s)
Climate change	Perform a wildfire risk assessment. The assessment should help determine which areas along the Upper Delaware River corridor are most susceptible to wildfire impact, including potential erosion or landslide susceptibility.	2025 follow-up meeting
Disturbed lands	Perform a risk assessment regarding shale-gas development for lands adjacent to or upstream of UPDE. The assessment should focus on how shale-gas development within the Devonian Marcellus Shale will impact the natural resources of the Upper Delaware River watershed and UPDE.	2025 follow-up meeting
Interpretation	Develop a long-range interpretive plan. A long-range interpretive plan is needed to identify specific strategies for communicating Upper Delaware Scenic & Recreational River's interpretive themes (e.g., cultural, ecological, geological) to visitors and the public.	National Park Service (2014)
Inventory and monitoring	Develop a comprehensive inventory and assessment of significant geological features. This inventory would guide preservation, interpretation, and education regarding geologic resources.	National Park Service (2014)
Inventory and monitoring	Improve the baseline cultural and natural resource information of UPDE. Further developing or improving baseline datasets documenting the cultural and natural resources within the river corridor is an important need for management that relates to all its fundamental resources and values. These datasets are needed to effectively track change to the resources over time and the sources of and influences on that change. Providing a robust resource tracking system will help the NPS and its partners make informed decisions about resource management within the river corridor.	National Park Service (2014)
Inventory and monitoring	Develop a land protection plan. A land protection plan would identify particularly unique, fragile, or important cultural and natural resources within the designated river corridor and specific options for their long-term protection and preservation. The plan may also identify potential protection measures such as conservation easements, local zoning ordinances, or acquisition by federal, state, local, or nonprofit entities from willing sellers or donors. Maintaining private property rights would be paramount in developing this plan.	National Park Service (2014)
Inventory and monitoring	Develop a data prioritization and management plan that would enhance the strategy for the identification of datasets needed to measure baseline conditions and provide for long-term monitoring of resources and impacts. The plan would include an assessment of the interrelationships of the identified needs and would identify strategies for long-term data collection, stewardship, and data management updates.	National Park Service (2014)
Inventory and monitoring	Develop a geospatial data management plan. The geospatial data management plan is needed to identify geospatial and tabular datasets required to provide decision support for the management of the scenic and recreational river. The plan would identify strategies for long-term data collection, stewardship, and updating. The management plan would also identify analysis products that the unit could use to support ongoing planning and management efforts.	National Park Service (2014)

Subject	Inventory Need(s)	Reference(s)
Inventory and monitoring	Develop a viewshed inventory. This would inventory and assess iconic visual resources in the river corridor—including historic bridges and prominent viewpoints—to provide a baseline assessment of these visual resources and how future development might affect them.	National Park Service (2014)
Inventory and monitoring	Develop a free-flow assessment and impediments inventory. This study would build on limited existing data to comprehensively document the existing impediments to free flow along the entire Upper Delaware River and would provide an analysis to assess the overall cumulative impact of various impediments to free flow, such as bank hardening.	National Park Service (2014)
Management	Draft a river management plan addendum. New management challenges that did not exist during the development of the original river management plan (Conference of Upper Delaware Townships and National Park Service 1986) for the Upper Delaware River necessitate an amendment to the plan. Through collaboration with local, state, and community partners, the river management plan addendum would identify current issues, trends, threats, and opportunities within the river corridor and identify specific recommendations for the protection of the wild and scenic river's remarkable values.	National Park Service (2014)
Management	Develop a visitor use management plan that identifies appropriate types and levels of recreational use on the river. The plan would assess existing visitor use characteristics and patterns, assess visitor impacts on resources; enhance opportunities for key visitor experiences; reduce conflicts between different user groups or between visitors and wildlife; minimize impacts to resources, private property, and visitor experiences caused by visitor use; and manage visitor demand at popular destinations.	National Park Service (2014)
Stratotypes	Designate formal stratotypes for the Devonian Damascus and Shohola members of the Catskill Formation. Although these members were named by Willard (1936) after outcrops along the Delaware River in Damascus and Shohola, respectively, no formal stratotypes have been designated.	Henderson et al. (2022)
Water quality	Develop a long-term water quality monitoring program. Long-term coordinated water quality monitoring on the Delaware River and its tributaries would require permanent funding. This might be developed as a permanent cooperative effort between the Delaware Basin River Commission, the NPS, and the states of New York, Pennsylvania, and New Jersey.	National Park Service (2014)
Water quality	Develop a basin-wide watershed management plan. The basin-wide watershed management plan is a planning effort in which NPS staff should actively participate. The effort is led by other basin stakeholders.	National Park Service (2014)
Water quality	Perform source detection studies. These studies would identify non-point and point source contamination that could contribute to degrading water quality in the river.	National Park Service (2014)

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2004 Scoping Participants

Tim Connors (NPS Geologic Resources Division)

Bruce Heise (NPS Geologic Resources Division)

Matt Marshall (NPS Eastern Rivers and Mountains Inventory & Monitoring Network)

Nate Piekielek (NPS Eastern Rivers and Mountains Inventory & Monitoring Network)

John Harper (Pennsylvania Geological Survey)

John Inners (Pennsylvania Geological Survey)

Vince Santucci (NPS George Washington Memorial Parkway)

Kathy Penrod (NPS Allegheny Portage Railroad National Historic Site and John Fitzgerald Kennedy National Historic Site)

2025 Follow-up Meeting Participants

Cullen Scheland (NPS Geologic Resources Division)

Thomas Kearns (NPS Upper Delaware Scenic & Recreational River)

Victoria Crystal (Colorado State University)

Tim C. Henderson (Colorado State University)

Summary Author

Tim C. Henderson (Colorado State University)

Summary Review

Victoria Crystal (Colorado State University)

Thomas Kearns (NPS Upper Delaware Scenic & Recreational River)

Summary Editing

Suzanne McKetta (Colorado State University)

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