



Missouri National Recreational River

Geologic and Soil Resources Inventory Summary



On this page: Aerial photograph of Missouri National Recreational River. View is facing upstream (northwest) across Sanctuary Island along the Missouri River in the 39-Mile District. This braided segment of the river features a main stem, side channels, forested islands, backwaters, and steep river bluffs of Cretaceous bedrock. NPS photograph.

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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 Missouri National Recreational River. It also provides information on 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 Missouri National Recreational River in 2008. Baseline bedrock and surficial geologic maps were delivered to the park in 2021 and updated in 2023. SRI delivered a legacy soil database and map to the park in 2010. The most up-to-date soil data for the recreational river is available through [Web Soil Survey](#).

Missouri National Recreational River’s geologic heritage is ingrained in its paleontology, Indigenous connections, stratotypes, ecological diversity, and scenic values, as well as its connections to the Lewis & Clark Expedition and early steamboat history. Geologic hazards identified in the park include cave and karst development, climate change, disturbed lands (e.g., dams, riverbank stabilization, land use, energy infrastructure), flooding, mass wasting (e.g., slumps, rockfalls, or rockslides), radon, seismicity, swelling clays, and toxicological soils. The geologic and soil resources inventory needs for the park include various data and/or GIS needs related to the inventory and monitoring of cultural resources, geohazards, geomorphology, hydrological resources, and fossils, in addition to natural resource management needs.

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 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 Service-wide Comprehensive Call (SCC). This transition will begin in FY25, with new guidance enacted for GSRI. During this transition period, 13 “priority” parks, including Missouri National Recreational River (“MNRR,” also referred to as the “recreational river” 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 recreational river’s participation in the new inventories program. As such, it summarizes the status of GRI and SRI deliverables for MNRR 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 map for the recreational river is available on the NPS DataStore accessed through the Integrated Resource Management Applications (IRMA) portal (see <https://irma.nps.gov/DataStore/Reference/Profile/2194564>) and is adapted from multiple source maps created by the University of Nebraska-Lincoln and the United States Geological Survey (USGS). Additional GSRI documents include the NPS scoping summary (Graham 2008).

GSRI source maps:

- Joeckel, R. M., N. I. Scofield, D. P. Divine, and L. M. Howard. 2019. Surficial geologic map of Missouri National Recreational River corridor and surrounding areas in Nebraska and South Dakota, Fort Randall Dam and environs to Springfield, Nebraska and South Dakota: University of Nebraska-Lincoln, unpublished digital data, scale 1:24,000.

- Lundstrom, S. C., T. Cowman, P. Hanson, J. Holbrook, S. Mahan, A. Moreno-Ward, and J. Paces. 2022. Geologic map geodatabase of the valley corridor of the 59-mile reach of the Missouri National Recreational River, South Dakota, Nebraska, and Iowa (Gavins Point Dam to North Sioux City): US Geological Survey, unpublished data release, scale 1:100,000.

GSRI scoping report:

- Graham, J. 2008. Geologic Resource Evaluation Scoping Summary: Missouri National Recreational River. <https://irma.nps.gov/DataStore/Reference/Profile/2250373>

Soils

Soil maps provide information on soil types, including scores of different 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 MNRR 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. The Web Soil Survey data are broken down into county-level soil survey areas. Each soil survey area is assigned a code and a name. MNRR includes 11 soil survey areas that are complete (Table 1). To view the soil data 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 MNRR to view the soil data for the recreational river. The AOI icon along the top of the screen allows 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 additional soil data, including linear extensibility and suitability for development. See additional Web Soil Survey guidance and FAQs or contact the NRCS state soil scientist for technical assistance.

Initial soil mapping by the NPS Soil Resources Inventory (SRI) was updated for MNRR in 2015 and is available on the NPS DataStore accessed through IRMA (<https://irma.nps.gov/DataStore/Reference/Profile/1048932>).

Table 1. Web Soil Survey areas related to the recreational river.

Web Soil Survey Area Code	Web Soil Survey Area Name	Status
NE015	Boyd County, Nebraska	Complete
NE027	Cedar County, Nebraska	Complete
NE051	Dixon County, Nebraska	Complete
NE107	Knox County, Nebraska	Complete
SD009	Bon Homme County, South Dakota	Complete
SD023	Charles Mix County, South Dakota	Complete

Web Soil Survey Area Code	Web Soil Survey Area Name	Status
SD027	Clay County, South Dakota	Complete
SD053	Gregory County, South Dakota	Complete
SD127	Union County, South Dakota	Complete
SD135	Yankton County, South Dakota	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, tsunamis, 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

Missouri National Recreational River consists of two distinct segments of the Missouri River system located along the eastern Nebraska–South Dakota border in portions of Boyd, Cedar, Dixon, and Knox counties, Nebraska, and Bon Homme, Charles Mix, Clay, Gregory, Union, and Yankton counties, South Dakota. The upstream (western) portion of the recreational river known as the “39-Mile District” was established in 1991 and preserves a 63 km (39 mi) section of the Missouri River from Fort Randall Dam near Pickstown to Running Water, South Dakota; this district also includes the lower 32 km (20 mi) of the Niobrara River and the last 13 km (8 mi) of Verdigre Creek in Nebraska. The downstream (eastern) “59-Mile District” was designated in 1978 and is a 95 km (59 mi)-long stretch of the Missouri River extending from Gavins Point Dam near Yankton, South Dakota, downriver to Ponca State Park in Nebraska. The 39-Mile and 59-Mile districts are separated by Lewis and Clark Lake, an artificial reservoir managed by the US Army Corps of Engineers with recreational facilities operated by the states of Nebraska and South Dakota. Collectively, both districts of MNRR encompass roughly 27,973 ha (69,124 ac) and protect one of the nation’s last remnant examples of a dynamic river channel habitat featuring a mosaic of bluffs, terraces, floodplains, chutes (steep-sided, erosional passages through which water flows rapidly), sandbars, backwaters (portions of a river where little or no current flows), islands, side channels, prairies, and riparian cottonwood forests (National Park Service 2017a). The recreational river occupies an ecological crossroads that chronicles a rich geologic and cultural history, including Cretaceous and Quaternary fossils, Indigenous societies, early European American explorers, the Lewis & Clark Expedition, and America’s western expansion (see “Geoheritage”). Additionally, the various bedrock and surficial features of the Missouri River add to the outstanding scenic value of MNRR and support a diverse biological community—including several threatened or endangered species.

The recreational river flows through the Missouri Plateau and Dissected Till Plains of northeastern Nebraska and southeastern South Dakota, two distinct subregions of the Great Plains and Central Lowlands physiographic provinces, respectively (Figure 1; National Park Service and US Army Corps of Engineers 1999; Graham 2008; Stark et al. 2011). In the 39-Mile District, the Missouri River separates the glaciated and unglaciated portions of the Missouri Plateau. South of the river, the unglaciated Missouri Plateau is characterized by flat, gently sloping terrain that features occasional buttes and badlands shaped by the erosive action of the Missouri River and its tributaries (Manske 2022). North of the river, the glaciated portion of the Missouri Plateau is blanketed by glacial till (unconsolidated, poorly sorted rock material) and outwash (layered meltwater deposits) deposited during the most recent Ice Age approximately 75,000 to 12,000 years ago (Joeckel et al. 2017; Manske 2022). The 59-Mile District transects the Dissected Till Plains, an area defined by rolling hills, fertile soils, loess (wind-blown silt), and glacial till that were also formed during the previous Ice Age and subsequently incised or reworked by modern fluvial (river) processes.

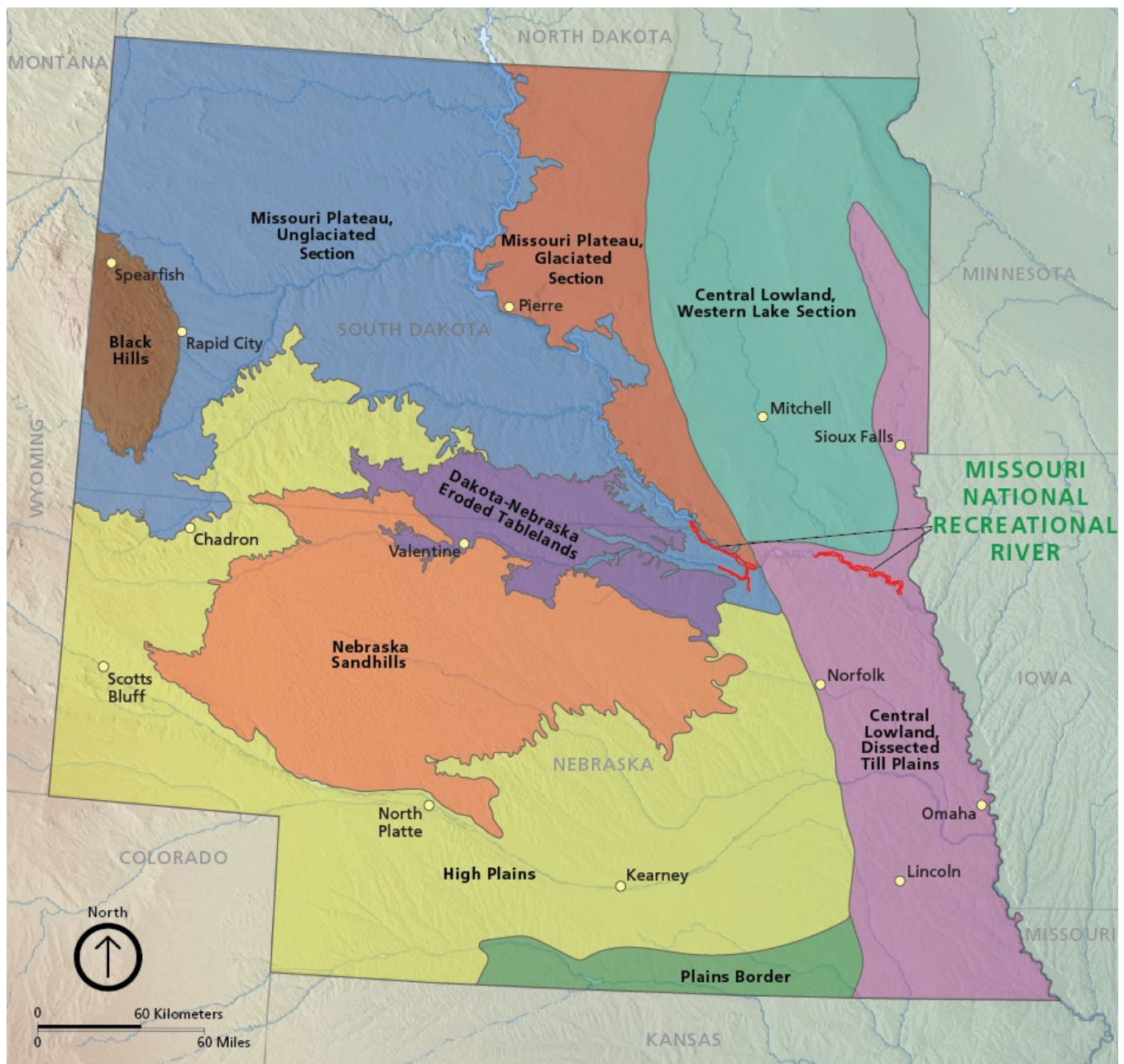


Figure 1. Physiographic subregions of Nebraska and South Dakota. The upstream (western) 39-Mile District of MNRR transects the glaciated and unglaciated Missouri Plateau of the Great Plains physiographic province, while the downstream (eastern) 59-Mile District flows through the Dissected Till Plains of the Central Lowland physiographic province. Figure created by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic History

Mesozoic Era (251.9 million to 66.0 million years ago): The Western Interior Seaway

The geology that underlies MNRR consists of marine, fluvial (river), deltaic, eolian (wind), and glacial deposits that record the evolution of the American interior since the Age of the Dinosaurs. According to Joeckel et al. (2017), geologists started to develop the stratigraphy of the Cretaceous bedrock underlying the area of MNRR in the middle to late 1850s. One of the earliest geologic maps of the Great Plains region was

completed by famous British geologist Sir Charles Lyell, who visited North America four times from 1841 to 1853; his early map that includes the region of MNRR was published in 1845 (Lyell 1845; Dott 1998; Joeckel et al. 2018). Early geologic studies, such as Lyell’s, noted the occurrence of Cretaceous strata along the Missouri River of Nebraska and South Dakota and contributed to a regional geologic framework that extended across the western interior of the US as far as the Rocky Mountains (Joeckel et al. 2017).

The geology underlying MNRR dates to the Late Cretaceous Period, approximately 100 million years ago, but also includes younger deposits separated by several unconformities, or gaps of “missing time,” in the rock record (see Table 2 for a geologic time scale). Cretaceous sedimentary strata underlying the recreational river include (in order from oldest to youngest) the Dakota Formation (**Kd**, **Kgd**; also referred to as the “Dakota Group” in Nebraska), Graneros Shale (**Kgd**, **Kgg**), Greenhorn Limestone (**Kgd**, **Kgg**), Carlile Shale (**Kc**, **Knc**), Niobrara Formation (**Knc**, **Kn**, **Knsh**), and Pierre Shale (**Kp**; Joeckel et al. 2017, 2019; Lundstrom et al. 2022). Within this sequence, only the sandstones, shales, mudstones, and claystones of the Dakota Formation/Group were deposited by rivers or estuaries along an ancient, low-lying coastline (Joeckel et al. 2017). The rest of the Cretaceous bedrock in MNRR is largely marine in origin and was deposited in the Western Interior Seaway, an ancient shallow sea that formerly inundated the interior of North America about 100 million to 70 million years ago (Figure 2; see “[Currents of Change](#)” – accessed June 2025; National Park Service and US Army Corps of Engineers 1999; Tweet et al. 2011; Joeckel et al. 2017, 2018). The succession of Cretaceous marine sedimentary rocks underlying MNRR reflects widespread crustal subsidence (sinking or settling) accompanied by multiple sea level rises and falls (Joeckel et al. 2017).

Table 2. Geologic time scale.

Eon	Era(s)	Period(s)	Epoch(s)	Million Years Ago
Phanerozoic	Cenozoic	Quaternary (Q)	Holocene (H)	0.0117–today
Phanerozoic	Cenozoic	Quaternary (Q)	Pleistocene (PE)	2.6–0.0117
Phanerozoic	Cenozoic	Neogene (N)	Pliocene (PL)	5.3–2.6
Phanerozoic	Cenozoic	Neogene (N)	Miocene (MI)	23.0–5.3
Phanerozoic	Cenozoic	Paleogene (PG)	Oligocene (OL)	33.9–23.0
Phanerozoic	Cenozoic	Paleogene (PG)	Eocene (E)	56.0–33.9
Phanerozoic	Cenozoic	Paleogene (PG)	Paleocene (EP)	66.0–56.0
Phanerozoic	Mesozoic	Cretaceous (K)	Upper, Lower	145.0–66.0
Phanerozoic	Mesozoic	Jurassic (J)	Upper, Middle, Lower	201.3–145.0
Phanerozoic	Mesozoic	Triassic (TR)	Upper, Middle, Lower	251.9–201.3
Phanerozoic	Paleozoic	Permian (P)	Lopingian, Guadalupian, Cisuralian	298.9–251.9
Phanerozoic	Paleozoic	Pennsylvanian (PN)	Upper, Middle, Lower	323.2–298.9
Phanerozoic	Paleozoic	Mississippian (M)	Upper, Middle, Lower	358.9–323.2
Phanerozoic	Paleozoic	Devonian (D)	Upper, Middle, Lower	419.2–358.9

Eon	Era(s)	Period(s)	Epoch(s)	Million Years Ago
Phanerozoic	Paleozoic	Silurian (S)	Pridoli, Ludlow, Wenlock, Llandovery	443.8–419.2
Phanerozoic	Paleozoic	Ordovician (O)	Upper, Middle, Lower	485.4–443.8
Phanerozoic	Paleozoic	Cambrian (C)	Furongian, Miaolingian, Series 2, Terreneuvian	538.8–485.4
Proterozoic	Neoproterozoic (Z)	Ediacaran, Cryogenian, Tonian	n/a	1,000–538.8
Proterozoic	Mesoproterozoic (Y)	Stenian, Ectasian, Calymmian	n/a	1,600–1,000
Proterozoic	Paleoproterozoic (X)	Statherian, Orosirian, Rhyacian, Siderian	n/a	2,500–1,600
Archean	Neo-, Meso-, Paleo-, Eo-archean	n/a	n/a	4,000–2,500
Hadean	n/a	n/a	n/a	~4,600–4,000



Figure 2. North America during the Late Cretaceous Period. Approximately 100 million to 70 million years ago, the Great Plains were inundated by the Western Interior Seaway. The recreational river was located along the eastern margins of the seaway. Cretaceous bedrock underlying MNRR reflects ancient marine and coastal environments. North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc., modified by Tim C. Henderson (Colorado State University).

The Graneros Shale is a dark gray shale with thin, carbonate-rich layers and minor lenses of sandstone that have been interpreted as a prodelta (the offshore portion of a delta) or near-shore marine sequence (Tweet et al. 2011; Joeckel et al. 2017). In the recreational river region, the Graneros Shale is known to be fossiliferous and may be responsible for the preservation of the “Ponca Monster,” a large marine reptile or plesiosaur discovered at Ponca State Park (see “Paleontological Resources”). The Greenhorn Limestone overlies the Graneros Shale and consists of gray limestone interbedded with shale that represents an offshore marine depositional setting (Tweet et al. 2011; Joeckel et al. 2017). In Nebraska, the Graneros Shale and Greenhorn Limestone are often mapped together because they are both relatively thin and difficult to differentiate (Joeckel et al. 2017). Exposures of these ancient bedrock units form prominent ledges at the Ponca State Park boat ramp (Figure 3). Conformably overlying the Greenhorn Limestone is the Carlile Shale, a medium to

dark gray shale that has been subdivided into several members, including (in order from youngest to oldest) the Fairport Chalk, Blue Hill Shale, and the Codell Sandstone members (Figure 4; Tweet et al. 2011; Joeckel et al. 2017). The Niobrara Formation is composed of gray shale-rich chalk, gray to orange limestone, and white bentonite beds (altered volcanic ash layers) that outcrop throughout most of the 39-Mile District. Outcrops of the formation disappear downstream, as the geology transitions into older bedrock along the 59-Mile District (Lundstrom et al. 2022). The formation is divided into two members that include (in order from oldest to youngest) the Fort Hays Limestone and Smoky Hill Chalk members (Figures 4–5). The Niobrara Formation is bounded by disconformities (unconformities between sedimentary layers) that have eroded and removed the Fort Hays Limestone Member in proximity to MNRR; the upper contact with the Pierre Shale represents roughly 4 million to 6 million years of missing geologic time (Tweet et al. 2011). Within the recreational river, the Pierre Shale chiefly consists of dark shale, light gray shale-rich chalk, and white to gray bentonite layers that are exposed along the 39-Mile District. The formation is divided into multiple members that include (in order from oldest to youngest) the Sharon Springs, Gregory, Crow Creek, DeGrey, Verendrye, Virgin Creek, Mobridge, and Elk Butte members. Except for the Elk Butte Member, these members are all present at various points along MNRR (Tweet et al. 2011). Fine-grained shale, limestone, and chalk beds of the Cretaceous Period in MNRR (e.g., Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, and Pierre Shale) represent marine depositional settings associated with the Western Interior Seaway.



Figure 3. Prominent ledges of Cretaceous bedrock at Ponca State Park boat ramp. Lighter-colored limestone and chalk of the Greenhorn Limestone overlie gray shale of the Graneros Shale. NPS photograph.

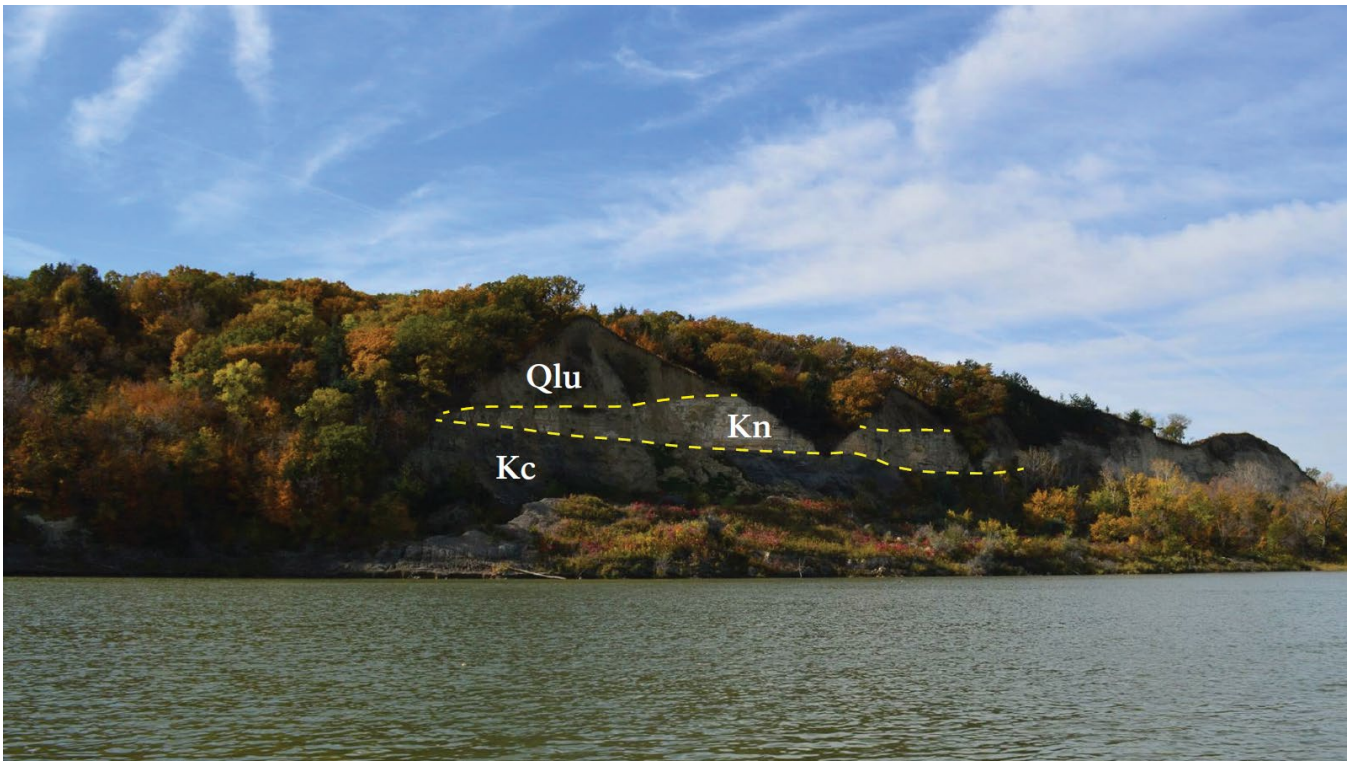


Figure 4. Steep river bluffs near the confluence of Bow Creek and the Missouri River. The bluffs consist of the Cretaceous Carlile Shale (basal dark-colored rocks; Kc) overlain by the Smoky Hill Chalk Member of the Niobrara Formation (light-colored rocks; Kn) and capped by the Pleistocene Peoria Loess (uppermost medium-colored rocks; Qlu). NPS photograph.



Figure 5. River bluffs of the Cretaceous Smoky Hill Chalk Member of the Niobrara Formation. Rocks that comprise the Niobrara Formation were deposited in the Western Interior Seaway, a shallow, tropical seaway that inundated the interior of North America during the Cretaceous Period. NPS photograph.

Cenozoic Era (66.0 million years ago to present): The Laramide Orogeny, Ice Age, and birth of the Missouri River

The Mesozoic–Cenozoic transition marks the withdrawal of the Western Interior Seaway and coincides with the Laramide orogeny (approximately 80 million to 45 million years ago), a major mountain-building event responsible for the uplift of the Rocky Mountains, the Black Hills, and various domes or ridges in Nebraska and South Dakota (Joeckel et al. 2018). Following the deposition of the Pierre Shale, there is a significant unconformity in the rock record at MNRR from approximately 70 million to 14 million years ago, which represents the uplift and erosion of the Rockies (Terry et al. 1995; Tweet et al. 2011; Joeckel et al. 2015). Although Paleogene rocks (see Table 2) are missing along the recreational river, they are well-preserved in western Nebraska (Agate Fossil Beds National Monument and Scotts Bluff National Monument), southwestern South Dakota (Badlands National Park), and western North Dakota (Theodore Roosevelt National Park). Tertiary sediments (i.e., Paleogene and Neogene periods) found along MNRR were sourced from the mountains and transported eastward by several river systems; today these deposits are part of an alluvial fan sequence (a gently sloping, fan-shaped mass of unconsolidated rock material) and consist of the

Middle Miocene Valentine Formation of the Ogallala Group (approximately 14 million to 12 million years ago; **No, Nov**; Joeckel et al. 2015, 2017; Smith et al. 2025). The Valentine Formation is a fossiliferous sequence of sandstone, unconsolidated sand, gravel, and volcanic ash representing various fluvial and eolian depositional settings (Tweet et al. 2011). Further west of MNRR, the Valentine Formation serves as a critical groundwater recharge zone that sustains the Niobrara River—including Niobrara National Scenic River—and is part of the regional High Plains or Ogallala Aquifer.

The modern landscape of the recreational river is a product of glacial, fluvial, and eolian processes that formed the Missouri River system during the Pleistocene and Holocene epochs. Extensive, thick glaciers of the Laurentide Ice Sheet advanced southward across the United States multiple times during the Pleistocene Epoch (2.58 million to 11,700 years ago), scouring topographic highs and releasing massive amounts of till and meltwater when they receded at the end of the Ice Age (Figure 6). Northeastern Nebraska was blanketed with ice during the older pre-Illinoian glaciation between 2.5 million and 640,000 years ago, in addition to the most recent Wisconsinan glaciation approximately 75,000 to 12,000 years ago; nearby parts of southeastern South Dakota and northwestern Iowa were glaciated at least twice as often as Nebraska (Joeckel et al. 2017). A notable feature of the Laurentide Ice Sheet was the James Lobe, an ice stream (a narrow corridor of fast-moving ice within a larger ice sheet) that originated from the northwest in present-day Saskatchewan and extended about 1,250 km (775 mi) across eastern South Dakota to the Nebraska border (Margold et al. 2015; Joeckel et al. 2017; Clausen 2018). As the name implies, the James Lobe is responsible for creating the modern James River Lowland that drains into the Missouri River. During the Pleistocene, wind also played a major role in sculpting the scenery of MNRR through erosion and deposition. The Peoria Loess (**Qp, Qpo, Qlu**; see Figure 4) is a widespread deposit of wind-blown silt that dates to the last glacial period roughly 25,000 to 14,000 years ago and is one of several significant, formally named loess deposits found in Nebraska and South Dakota (Joeckel et al. 2017). Strong winds picked up loose material from glacial debris and created thick loess deposits along the uplands of MNRR, including Ponca State Park, where the Peoria Loess is up to 23 m (75 ft) thick (Tweet et al. 2011; Joeckel et al. 2017). As a hydrological park, the establishment, mission, and identity of MNRR are intimately associated with the Missouri River, which is a dynamic and geologically young natural feature that has maintained its present course only since the Ice Age. Prior to the Laurentide Ice Sheet, major rivers in South Dakota flowed eastward and northward toward Hudson Bay in Canada. By the end of the Ice Age, these river drainages—including the ancestral Missouri River—were diverted as ice progressively advanced south across North America (Joeckel et al. 2017; Manske 2022). Today, the river continues to dramatically alter its environment as it erodes, incises, meanders, and reworks older sediments, but also as it builds sensitive habitats and sustains diverse ecosystems.



Figure 6. North America during the Late Pleistocene Epoch. Approximately 12,000 years ago, large portions of the northern United States were covered by the extensive Laurentide Ice Sheet. The recreational river is located near the southernmost extent of the ice sheet. North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc., modified by Tim C. Henderson (Colorado State University).

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 National Park Service's 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*. This 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.

Paleontology

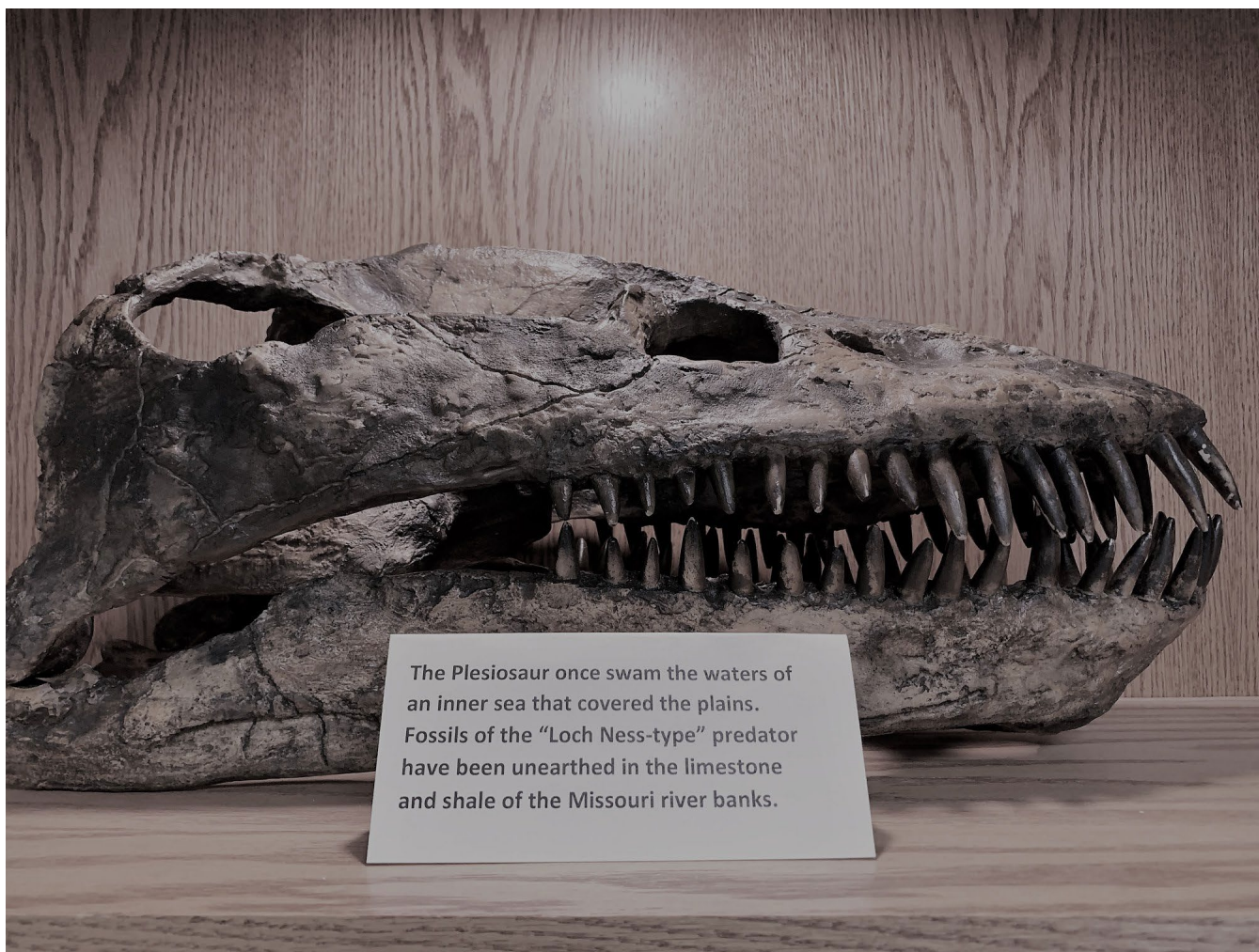
Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). They may be body fossils (any remains of the actual organism such as bones, teeth, shells, or leaves) or trace fossils (evidence of an organism’s activity such as nests, burrows, tracks, or feces). Fossils may occur in rocks or unconsolidated deposits, in museum collections, or in cultural contexts, such as building stone. Most of the rocks underlying MNRR are known to be fossiliferous, except for the Miocene Valentine Formation (Table 3; Justin Tweet, NPS GRD, personal communication May 2025). In the early 19th century, the Lewis & Clark Expedition discovered a fossil skeleton of a marine reptile in the Gavins Point area; however, the specimen was not collected (see “Lewis & Clark Expedition”; Smithsonian et al. n.d.). Some of the earliest identified fossils from along the recreational river date back to the 1850s and 1860s and include reports from renowned paleontologists [Fielding Bradford Meek](#) and [Ferdinand Vandever Hayden](#) (Hall and Meek 1855; Meek and Hayden 1857, 1860). Meek and Hayden are also credited for assigning the name “Niobrara” to the chalky limestone and silt exposed along the Missouri River near the mouth of the Niobrara River (see “Stratotypes”; Meek and Hayden 1861).

The Cretaceous bedrock within MNRR preserves the remains of ancient marine organisms that once lived in the Cretaceous Western Interior Seaway roughly 100 million to 70 million years ago (see “Geologic History”; National Park Service and US Army Corps of Engineers 1999; Tweet et al. 2011; Joeckel et al. 2017, 2018). These fossils include a diverse collection of microfossils, ammonites, bivalves, fish, shark teeth, worm tubes, burrows, and large marine reptiles such as mosasaurs and long-necked plesiosaurs (Table 3; Figure 7; Meek and Hayden 1857, 1860; Cope 1877; Bailey and Diffendal 1997; Matson et al. 2002; Tweet

et al. 2011; Hodnett et al. 2022). In 1987, a 10 m (33 ft)-long mosasaur specimen was discovered by the Nebraska Game and Park Commission in the Mobridge Member of the Pierre Shale (**Kp**) in a road cut following road construction (Bailey and Diffendal 1997; Johnsgard et al. 2007). Multiple plesiosaur specimens have been documented from within the recreational river, with the notable “Ponca Monster” discovered in 1873 at Ponca State Park (Cope 1877; Matson et al. 2002; Graham 2008; Otero 2016). According to Matson (2002), the Ponca Monster could be the articulated plesiosaur type specimen (reference specimen that the species description is based on) of *Hydralmosaurus serpentinus* later published by Cope (1877, p. 583) from “...the blue shale of Cretaceous N°3, in a bluff of Nebraska, on the southwest side of the Missouri, between Sioux City, Iowa, and Yankton, Dakota.” A reconstruction by Otero (2016) estimates that Cope’s type specimen is roughly 12 m (39 ft) long. Younger Cenozoic fossils within MNRR include gastropods recovered from the Pleistocene Peoria Loess (**Qp**, **Qpo**, **Qlu**), in addition to Holocene (roughly 2,000 to 1,000 years ago) specimens of skunk, deer, bison, and humans (Tweet et al. 2011).

Table 3. List of documented fossil resources within the recreational river.

Formation	Age	Fossils Within MNRR
Quaternary Sediments	Pleistocene-Holocene	Late Holocene-age (roughly 2,000 to 1,000 years ago) humans, skunks, bison, and deer
Peoria Loess	Late Pleistocene	Gastropods
Valentine Formation	Middle Miocene	None to date
Pierre Shale	Late Cretaceous	Fish (possibly) and a mosasaur skeleton of <i>Mosasaurus missouriensis</i>
Niobrara Formation	Late Cretaceous	Foraminifera, bivalves, ammonites, burrows, shark teeth, and fish scales and teeth
Carlile Shale	Late Cretaceous	Bivalves, ammonites, serpulid worm tubes, and shark teeth
Greenhorn Limestone	Late Cretaceous	Marine microfossils, bivalves, and fish scales
Granero Shale	Late Cretaceous	Bivalves, burrows, fish, and the plesiosaur <i>Hydralmosaurus serpentinus</i>
Dakota Group	Early Late Cretaceous	Bivalves



The Plesiosaur once swam the waters of an inner sea that covered the plains. Fossils of the “Loch Ness-type” predator have been unearthed in the limestone and shale of the Missouri river banks.

Figure 7. A plesiosaur skull on display at Missouri National Recreational River. Plesiosaurs were large, marine reptile predators that occupied the Cretaceous Western Interior Seaway during the Age of the Dinosaurs. Several plesiosaur specimens have been reported from within MNRR. NPS photograph.

Indigenous Connections

The Missouri River valley of MNRR is the ancestral homeland to several Indigenous groups who have been living in the area for more than 10,000 years, including the Sioux, Mandans, Omahas, Lakota/Dakota, and Poncas (National Park Service 2012, 2017a; see [Water of Life](#); accessed June 2025). The presence of the river makes the region an attractive territory where humans gather food, hunt, trap, fish, trade, and travel; even the name “Missouri” is attributed to the Missouri tribe of Sioux descent, who have strong connections with the river (Harvey and Harvey 2016). Evidence of early Indigenous societies includes village remains, farming terraces, burial sites, camps, and artifacts such as pottery, tools, beads, fibers, bones, antlers, and shells (Ludwickson et al. 1981; National Park Service and US Army Corps of Engineers 1999, 2017; Elliot and Jacobson 2022). According to Ludwickson et al. (1981), geologists who have studied the MNRR area have paid minor attention to the mineral resources that were of interest to the Indigenous inhabitants of the region. In Nebraska, the Late Cretaceous Omadi Sandstone of the Dakota Group was utilized as an abrasive stone tool and is commonly found in archeological sites along the Missouri River (Ludwickson et al. 1981). The formation is named after river bluff outcrops in Omadi Precinct, Nebraska, which can be traced to within

a few miles of Ponca State Park (Condra and Reed 1943; Ludwickson et al. 1981). One of the most identifiable geologic structures surrounding MNRR is Spirit Mound, a prominent hill that rises above the prairie north of the 59-Mile District. Spirit Mound is considered a significant Indigenous cultural site and was also visited by the Lewis & Clark Expedition in August 1804 (see “Lewis & Clark Expedition”; Graham 2008; Harvey and Harvey 2016; National Park Service 2012, 2017a).

The Lewis & Clark Expedition

The Louisiana Purchase of 1803 greatly expanded the American western frontier and provided a unique opportunity for exploration, scientific inquiry, and broadening commercial interests with Indigenous Peoples. President Thomas Jefferson commissioned an expedition to explore the newly acquired territory and appointed his personal secretary, Captain [Meriwether Lewis](#), to lead the endeavor. As a former Army officer, Lewis had experience in the Louisiana Territory and was mentored by Jefferson in various subjects such as North American geography, botany, mineralogy, astronomy, and ethnology in preparation for the expedition (Ambrose 1996). As his second in command, Lewis relied upon his former Army colleague, [William Clark](#), who also had extensive experience in the western frontier. The expedition party—also known as the Corps of Discovery—departed St. Louis in May 1804 in hopes of finding the “Northwest Passage,” a navigable route connecting the Atlantic and Pacific oceans. To gain access to the west, the expedition navigated the Missouri River, including what is now MNRR, which offered the most direct and practical means of transportation. The successful journey lasted over two years and traversed approximately 13,000 km (8,000 mi); the Corps of Discovery reached the Pacific Ocean in November 1805 and had returned to St. Louis by September 1806.

Throughout the 1804–1806 expedition, Lewis and Clark mapped the locations of several geologic resources, including coal, grinding stone (durable, abrasive rock material used to grind or sharpen tools), and freshwater springs (Joeckel et al. 2018). Although these maps are not considered geologic in the modern sense, they are accurate enough to relocate these resources today (Diffendal and Diffendal 2003; Joeckel et al. 2018). In 1804, the expedition discovered the fossilized remains of a marine reptile in the Gavins Point area that was approximately 14 m (45 ft) long; unfortunately, the specimen was never collected (Smithsonian et al. n.d.). While few of Lewis and Clark's campsites have been verified archeologically (e.g., [Traveler's Rest](#) and [Pompey's Pillar](#)), general locations have been identified from journals and local landmarks (Carolyn Campbell, NPS MNRR, personal communication July 2025). Campsite locations in proximity to MNRR include Mineral Bluffs (just above Elk Point), Sweeney Bend, the mouth of the Vermillion River, Goat Island, northeast of St. James, near the mouth of the James River, and opposite of and a little downstream from the present city of Yankton (National Park Service and US Army Corps of Engineers 1999). On their return voyage in 1806, the expedition camped in the vicinity of Rush Island (National Park Service and US Army Corps of Engineers 1999). Several geologic features along the recreational river factored into the westward journey and offer glimpses into the expedition's early encounters from late August through early September of 1804. These are described below in chronological order.

Ionia Volcano

On 24 August 1804, members of the Corps of Discovery witnessed smoke emerging from a bluff along the southern side of the Missouri River. Lewis and Clark investigated the natural feature, which they named [Ionia Volcano](#) (after the historic nearby town of Ionia, Nebraska), and noted intense heat and smoke emanating from a crevice in the rock (Figure 8; Harvey and Harvey 2016). At President Jefferson's request, the expedition party was alert to the possibility of volcanic activity during their journey (Harvey and Harvey

2016). However, the “volcano” is a historical source of misconception regarding igneous activity, as the intense heat and smoke observed by Lewis and Clark were produced by a chemical reaction of the various minerals eroding from the bluff, and not volcanic activity (National Park Service n.d.-a). According to Joeckel et al. (2017) and Lundstrom et al. (2022), the phenomena observed at Ionia Volcano are associated with acid rock weathering of the Cretaceous Carlile Shale (Kc), a process in which sulfide minerals (e.g., pyrite) break down in the presence of water and oxygen to produce sulfuric acid and water vapor. This is an exothermic reaction, which produces heat. Overall, the products of this reaction have a similar appearance to the steam and heat produced by volcanic activity (Joeckel et al. 2017). During the late 19th century, flooding caused the Missouri River to undercut the site and meander away from Ionia Volcano, leaving it as a tall bluff with expansive views of the river’s broad floodplain; many of the reactive sulfide minerals have washed away, and the bluff is no longer considered “hot” (National Park Service n.d.-a, National Park Service 2012; Harvey and Harvey 2016).



Figure 8. Remnants of Ionia Volcano, also referred to as Volcano Hill. During the Lewis & Clark Expedition, the Corps of Discovery investigated the bluffs due to “smoke” and heat emanating from crevices within the rock. The site has historically been a source of misconception regarding igneous activity that was actually the result of acid rock weathering. NPS photograph.

Spirit Mound

On 25 August 1804, several members of the Corps of Discovery journeyed a short distance north of the Missouri River to [Spirit Mound](#), a prominent hill rising above the flat floodplain and prairie of South Dakota (Figure 9; National Park Service n.d.-a, National Park Service and US Army Corps of Engineers 1999).

Upon learning about the site's spiritual significance among the Indigenous tribes of the region, the members hiked to Spirit Mound from their camp and stood atop its summit; the site offers a rare opportunity to stand in the same spot as Lewis and Clark (National Park Service 2012; Harvey and Harvey 2016). Due to its cultural and historical significance, Spirit Mound is one of four sites surrounding MNRR that are listed in the National Register of Historic Places (Graham 2008; National Park Service n.d.-a, 2017a). From a geologic perspective, Spirit Mound represents a glacial erosional remnant of the previous Ice Age. The mound is a rock-cored drumlin, a smooth, streamlined hill of bedrock (Niobrara Formation, κn) that is covered with a layer of glacial till (Graham 2008; Miller 2010; Millikin 2014).



Figure 9. Spirit Mound. Located a short distance north of the 59-Mile District, the mound is a culturally significant site among Indigenous tribes of the Great Plains and was visited by the Corps of Discovery during the Lewis & Clark Expedition. Spirit Mound is a product of the previous Ice Age and represents a rock-cored drumlin sculpted by large mobile ice sheets. Due to its cultural and historical significance, the site is listed in the National Register of Historic Places. NPS photograph.

Calumet Bluff

On 28–31 August 1804, the Corps of Discovery camped below Calumet Bluff in a narrow plain on the southern side of the Missouri River in what is now Cedar County, Nebraska (Figure 10; National Park Service n.d.-a). The bluff (consisting of the Cretaceous Niobrara Formation, **Kn**) was the setting of the expedition's first council with Indigenous tribes of the Great Plains within present-day MNRR and symbolizes one of Lewis and Clark's early diplomatic accomplishments (Franklin et al. 1994). Historic meetings with Yankton Sioux leaders on 30 August 1804 were extremely important for establishing good relations with one of the most powerful tribes in the region but also helped set the precedent of nonviolent contact (Franklin et al. 1994). During these meetings, parties from both sides engaged in ceremony, speech-making, dancing, feasting, and gift-giving (Franklin et al. 1994; Ambrose 1996; see also [Captain Meriwether Lewis's Speech to the Yankton Sioux, August 30, 1804](#); accessed May 2025). Centuries of river migration, combined with the construction of the Gavins Point Dam in the 1950s, have significantly altered the historic landscape of the Missouri River, and there is still uncertainty about the council site's exact location (National Park Service n.d.-a; Franklin et al. 1994). Today, the US Army Corps of Engineers' Lewis & Clark Visitor Center sits atop Calumet Bluff, which is located immediately downstream of Gavin's Point Dam along Nebraska Route 121 about 8 km (5 mi) southwest of Yankton, South Dakota.

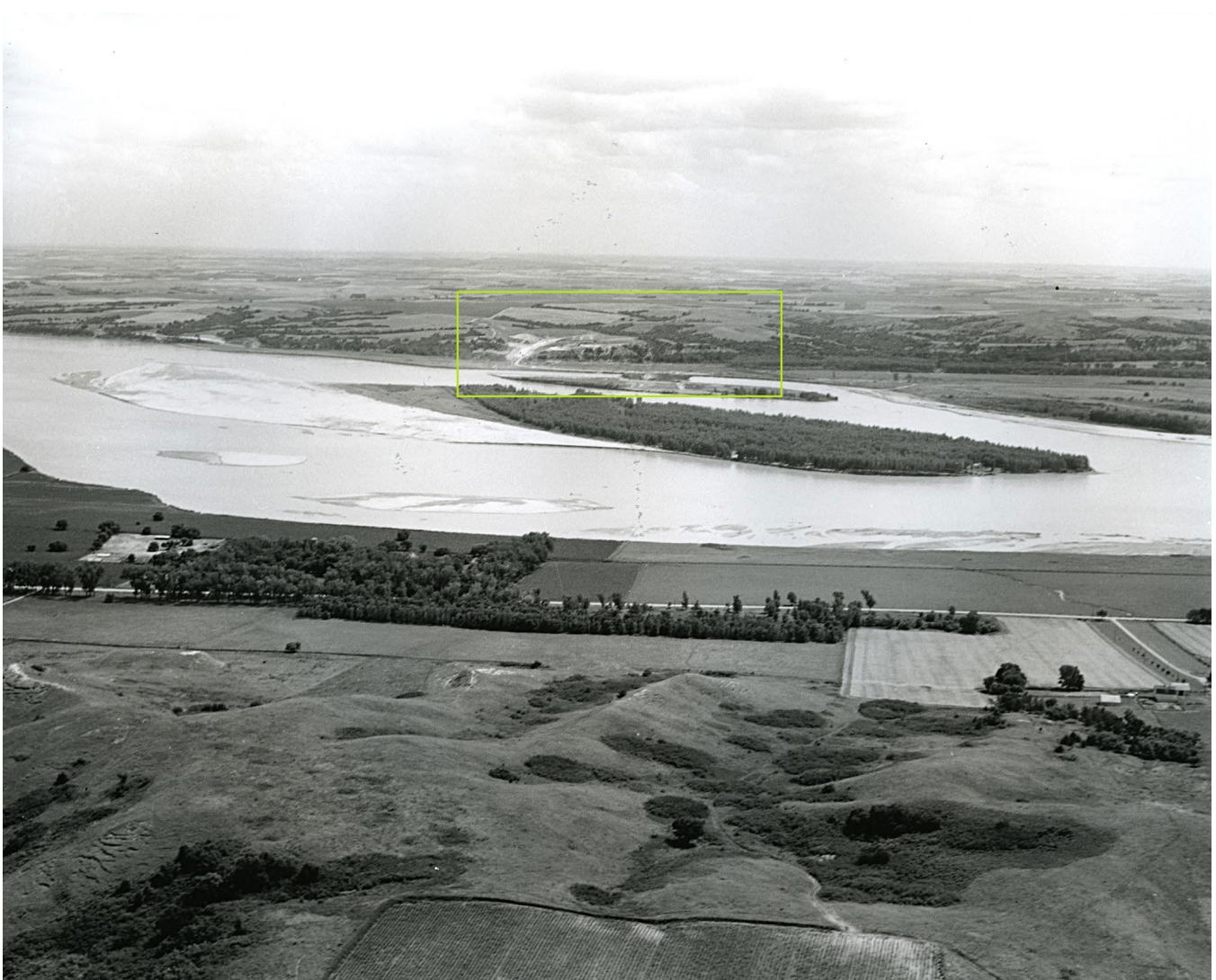


Figure 10. Calumet Bluff prior to the construction of the Gavins Point Dam. The historic photograph (1952) reveals a Missouri River that is very different from today. The green callout box indicates the presence of the bluff, which was a significant site of tribal negotiation associated with the Lewis & Clark Expedition. NPS photograph.

Old Baldy

On 7 September 1804, the Corps of Discovery hiked to the top of **Old Baldy** (also referred to as “The Tower”), an unvegetated, conical knob of the Cretaceous Pierre Shale (**Kp**) that rises nearly 21 m (70 ft) above the surrounding prairie in Boyd County, Nebraska (Figure 11; National Park Service n.d.-a; Joeckel et al. 2019). The knob was an important cultural feature noted by Lewis and Clark but is also where the expedition fulfilled part of its scientific mission by recording and capturing a “Petite Chien,” or prairie dog—the first the group had ever witnessed and the first to be scientifically documented (Franklin et al. 1994; Ambrose 1996; Graham 2008; National Park Service 2012). Due to its historic and scenic integrity, Old Baldy is one of four sites surrounding MNRR that are listed in the National Register of Historic Places (National Park Service 2017a).



Figure 11. Old Baldy. The Lewis & Clark Expedition explored the site in September 1804 and encountered a colony of prairie dogs—a species that had never been scientifically documented before. A prairie dog sculpture rests on top of the feature. Due to its scenic and historic integrity, the site is listed in the National Register of Historic Places. NPS photograph.

Steamboat History

Long before there were roads, railroads, or highways surrounding MNRR, the Missouri River was the main thoroughfare that had been utilized by Indigenous Peoples, fur traders, and early European Americans. In the beginning of the 19th century, shortly after the completion of the Lewis & Clark Expedition, American engineer and inventor Robert Fulton developed the first commercially successful steamboat in 1807. Steamboat technology revolutionized travel and commerce along the river, providing an easier means of transporting people and goods throughout the western frontier (see “[Steamboats on the Missouri](#)”; accessed June 2025). By 1831, the American Fur Company financed the first steamboat (the *Yellowstone*) journey north of Sioux City, Iowa (Franklin et al. 1994). Following the great Montana gold rush of 1863, steamboat traffic increased dramatically along the Missouri River (National Park Service n.d.-b, National Park Service and US Army Corps of Engineers 1999). However, the river had a volatile history and presented several navigational hazards, including floods, ice, shifting sandbars, currents, shallows, and snags (inundated obstacles such as dead trees). The erosive power of the river often filled the channel with deadly wooden debris, including downed trees that could rip open the hull of a boat (National Park Service n.d.-b). Some of the earliest modifications of the Missouri River were implemented by the federal government in the 1830s, as corporate interests successfully requested improvements to remove snags that were dangerous to steamboat businesses (Harvey and Harvey 2016). In addition to natural perils, steamboats were also susceptible to fire and boiler explosions that could occur with no warning (National Park Service n.d.-b; Franklin et al. 1994). By the beginning of the 20th century, at least 16 steamboats had wrecked or sunk between Sioux City and Fort Randall; many of these ship remains were never salvaged and lay buried below

the Missouri River (Chittenden 1897; National Park Service and US Army Corps of Engineers 1999; see figure 12 of Franklin et al. 1994). In the spring of 2004, the remains of the *North Alabama*—a steamboat that sank on 27 October 1870—reappeared during a period of low river levels near Bow River Bend (Figure 12; Franklin et al. 1994). Steamboat wreckage sites, such as that of the *North Alabama*, are a reminder of the dangerous perils that accompanied the early history of taming the formidable Missouri River. Although steamboats provided an early means of access to the continental interior, the industry could not compete with more efficient railroads and was obsolete by the late 19th century (Franklin et al. 1994; Harvey and Harvey 2016).



Figure 12. Shipwreck remains of the 19th-century steamboat, North Alabama. The steamboat sank along the Missouri River on 27 October 1870 and reappeared in the spring of 2004 during a period of low river level. Multiple steamboat wrecks are scattered along MNRR and are a reminder of the dangerous perils that accompanied early navigation along the Missouri River prior to dam regulation. 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 outcroppings of rock. Akin to natural libraries of Earth history, stratotypes preserve meaningful clues to the past and serve as geologic classrooms. 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 (i.e., lithostratigraphic versus chronostratigraphic) 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).

The recreational river contains one stratotype that represents the Cretaceous Niobrara Formation (Henderson et al. 2022). The Niobrara Formation was originally referred to as the “Niobrara division” by Meek and Hayden (1861), who derived the name from the steep river bluffs along the mouth of the Niobrara River. Although Meek and Hayden (1861) never assigned a formal stratotype, the type area (a broad geographic zone where a geologic unit was first defined) of the formation has been described as the same exposures along the Missouri–Niobrara river confluence where the formation forms 27–30 m (90–100 ft) tall cliffs consisting of the Smoky Hill Chalk Member (Frerichs and Gaskill 1988 citing Meek and Hayden 1861).

Geology and Ecology

The geologic influence on MNRR’s landscape is undeniable, as the topography, slope stability, stream channels, channel features, soils, and biological communities are all influenced by the underlying rocks. The Missouri River system is an architect of change, rapidly manipulating and reworking its geologic foundation to form a plethora of unique habitats that serve as vital ecosystems (see “MNRR Geoheritage River Guide”). Steep, forested bluffs flanking MNRR help constrain the river from meandering and govern landform development while also providing a contiguous corridor for many wildlife species (National Park Service 2012). Major tributaries such as the Niobrara, James, and Vermillion rivers provide sediments, nutrients, flow, and turbidity considered necessary for aquatic and riparian communities. In areas where the floodplain is connected to the river and periodically inundated, the interactions of land, water, and biology support natural functions sustaining ecosystems and society (American Rivers 2016). Flooding provides an exchange of water, sediment, and organisms that nourish floodplains, making them some of the most biodiverse and productive lands on the planet (American Rivers 2016). Additionally, flooding helps transport massive amounts of silt, sand, and gravel that accumulate to form sandbars, deltas, and island complexes supporting forest regeneration—including mature cottonwood forests. Additionally, these channel features provide critical wintering, nesting, and migratory stopover habitat for bald eagles and a wide variety of migratory birds, including the federally threatened piping plover and state-listed endangered interior least tern (National Park Service 2012, 2017a; Elliot and Jacobson 2022). However, the alteration and modification of the Missouri River through dam construction has limited flooding, reduced sediment transport, impacted channel morphology, and disconnected portions of the river from its floodplain, resulting in a decrease in the river’s ecological integrity (see “Disturbed Lands”; National Park Service 2012; Elliot and Jacobson 2022).

MNRR Geoheritage River Guide

The establishment of MNRR was accomplished through amendments to the 1968 Wild and Scenic Rivers Act, which states that certain selected American rivers, especially those with outstanding geological, ecological, historical, cultural, recreational, and scenic values, shall be preserved for the benefit of present and future generations (National Park Service 2017a). When Congress designated the 59-Mile District in 1978 and the 39-Mile District in 1991, approximately 205 km (126 mi) of the Missouri River system (including the lower Niobrara River and Verdigre Creek) was inducted into the [National Wild and Scenic Rivers System](#)—the crown jewels of American rivers. The following table (Table 4) is adapted from National Park Service (2012) and provides a guide to the geological heritage values of MNRR broken down into eight distinct river segments. These segments are provided using river mileage (RM) measured upstream from the confluence with the Mississippi River.

Table 4. A river guide of MNRR divided into distinct river segments and geoheritage values.

River Segment	Description
Segment 1: Fort Randall Dam to Choteau Creek (RM 880–852)	SCIENTIFIC: Cretaceous bluffs occur along both sides of the Missouri River within the first 16 km (10 mi) of this segment and confine the river valley to a width of less than 1.6 km (1.0 mi). Rockfalls occur along many of these bluffs. Located a short distance west of the Missouri River is Old Baldy, an unvegetated, conical knob of the Cretaceous Pierre Shale (Kp) where the Lewis & Clark Expedition first encountered and captured a prairie dog. This stretch of the river contains Sanctuary Island, the largest island within the 39-Mile District. ECOLOGICAL: This reach of the Missouri River is largely undeveloped and wild. Extensive remnants of mature old-growth cottonwood forests (some over 100 years old) occur on the narrow floodplain and Sanctuary Island. The river corridor is surrounded by forested bluffs, which provide a contiguous corridor for many wildlife species. This segment also provides wintering, nesting, and migratory stopover habitat for bald eagles and a wide variety of migratory birds. CULTURAL: The area represents a significant cultural and historic trade route for Indigenous Peoples and European American explorers; there is great potential for undiscovered archeological sites. The Yankton Sioux Reservation is located along the north bank of the river and contains important cultural areas such as the 1858 Treaty Monument and Cemetery. SCENIC: Scenic vistas along this segment include views of Fort Randall and Old Baldy.
Segment 2: Choteau Creek to Running Water (RM 852–840)	SCIENTIFIC: Below Choteau Creek, the geology of MNRR transitions from the Pierre Shale (Kp) to stunning bluffs of the Smoky Hill Chalk Member of the Niobrara Formation (Knsh). The Missouri River contains numerous islands, sandbars, chutes, and backwaters. The Niobrara River confluence features a picturesque delta complex—the only large delta of MNRR—that provides critical habitats for birds, fish, and other wildlife. Large slumps also occur along the bluffs near the Niobrara confluence. ECOLOGICAL: The Missouri and Niobrara rivers work in tandem to provide woody debris and nutrients that are important for maintaining channel complexity and supporting diverse ecosystems. Old-growth cottonwood forests are more limited here than in segment 1; however, there is a greater degree of cottonwood regeneration, which provides habitats for songbirds. Extensive wetlands support waterfowl, river otters, whooping cranes, and other species. This reach is the only documented area within MNRR that supports naturally reproducing populations of paddlefish, which thrive due to warm, turbid water from the Niobrara River. CULTURAL: This stretch of the Missouri River includes the confluence of the Niobrara River, which created a natural crossroads for Indigenous Peoples, fur traders, explorers, settlers, and Mormons. The Poncas are long-time inhabitants of the confluence of the Niobrara and Missouri rivers, where they first met fur traders and later Lewis and Clark. Many archeological sites at Niobrara State Park and surrounding lands document the long-term human use of the area. SCENIC: Scenic vistas from Chief Standing Bear Bridge Overlook provide sweeping views of the Missouri and Niobrara River valleys.

River Segment	Description
Segment 3: The lower Niobrara River	SCIENTIFIC: Upstream of MNRR, the Niobrara River is primarily sustained by groundwater draining from the Nebraska Sandhills. The Niobrara River features a highly dynamic, braided channel that contains sandbars, islands, and chutes. Interesting outcrops of the Pierre Shale (Kp) are visible in this reach of the 39-Mile District. The mouth of the Niobrara River is the type area of the Cretaceous Niobrara Formation, named after the steep bluffs consisting of the Smoky Hill Chalk Member (Knsh). ECOLOGICAL: Geomorphological features of this segment support multiple special status species, including the state-listed endangered interior least tern, the federally listed endangered pallid sturgeon, and the federally threatened piping plover. This river segment contains some mature cottonwood forests and sandbars that provide potential habitat for cottonwood regeneration. CULTURAL: The Niobrara River and Verdigre Creek segments attracted significant Indigenous and early European American use. The rivers sustain a diverse and abundant source of vegetation and animal resources today, as they did in the past. Wild food gathering, hunting, trapping, and fishing remain important activities. These resources made it an attractive homeland for Ponca farmers and subsequent homesteaders. The historic 1881 flood forced the relocation of the city of Niobrara, which was originally located southeast of the Niobrara River mouth. SCENIC: Scenic vistas from Niobrara State Park provide sweeping views of the Missouri and Niobrara River valleys.
Segment 4: The lower part of Verdigre Creek	CULTURAL: The Niobrara River and Verdigre Creek segments attracted significant Indigenous and early European American use. The rivers sustain a diverse and abundant source of vegetation and animal resources today as they did in the past. Wild food gathering, hunting, trapping, and fishing remain important activities. These resources made it an attractive homeland for Ponca farmers and subsequent homesteaders. SCENIC: Lower Verdigre Creek features an undeveloped rural landscape that allows for dark night skies and provides excellent opportunities for stargazing. The undulating hills and vast open grasslands along this small meandering stream are evocative of simpler times and the original western landscape.
Segment 5: Gavins Point Dam to Rush Island (RM 811–804)	SCIENTIFIC: This segment of the Missouri River is highly stabilized, developed, and lacks channel complexity due to controlled reservoir releases from the Gavins Point Dam. Calumet Bluff is located along the southern riverbank near the dam and consists of the Cretaceous Niobrara Formation (Kn). Downstream of the dam, the river contains unique gravel beds. CULTURAL: The historic council between the Yankton Sioux and the Lewis & Clark Expedition took place below Calumet Bluff, along the southern banks of this river segment adjacent to Gavins Point Dam. This section of the Missouri River was impacted by the historic flood of 1881, which destroyed many steamboats and the town of Green Island. Remnants of early riverbank stabilization efforts dating back to World War II can still be seen in this segment.
Segment 6: Rush Island to Myron Grove (RM 804–787)	SCIENTIFIC: The geology of this segment is characterized by dramatic and exemplary outcrops of Cretaceous bluffs and alluvial floodplains. This stretch of the Missouri River features two major tributaries, the James River and Bow Creek, as well as sandbars, chutes, and James River Island—one of two major islands in the 59-Mile District populated with mature cottonwood forests. ECOLOGICAL: The Missouri River begins to widen in this segment and features a dynamically active channel, which creates a complex of geomorphological features (e.g., sandbars, chutes, tributaries, islands) supporting a wide variety of flora and fauna. Extensive and mature forests, including cottonwood, ash, and elm trees, are abundant along this reach, particularly on James Island. The James River and Bow Creek contribute large amounts of sediment and nutrients that are valuable to aquatic ecosystems. CULTURAL: The Missouri River corridor between Rush Island and Myron Grove holds evidence of the homeland of the Omahas through known archeological sites. This stretch of the Missouri River is known to contain historic steamboat wrecks. SCENIC: Scenic views of prairies, hills, and chalkstone bluffs are visible at the Bow Creek confluence. Hills and bluffs surrounding Bow Creek provide a dramatic viewpoint to appreciate the grandeur of the “Mighty Missouri.”

River Segment	Description
Segment 7: Myron Grove to Kate Sweeny Bend (RM 787– 767)	SCIENTIFIC: The geology of this segment is characterized by dramatic and exemplary outcrops of Cretaceous bluffs, loess deposits, and alluvial floodplains. This stretch of the Missouri River features sandbars, chutes, and Goat Island—one of two major islands in the 59-Mile District populated with mature cottonwood forests. Additionally, this segment contains several smaller forested islands (e.g., Gunderson Island and Ryan’s Island) and the confluence with the Vermillion River. Several unique geologic sites found within or near this segment include Spirit Mound, Gunderson backwater, and Burbank Lake. Spirit Mound is a bedrock-cored drumlin consisting of the Cretaceous Niobrara Formation (Kn) covered by glacial till. Burbank Lake is an oxbow lake, a U-shaped lake formed by an abandoned meander of the Missouri River. ECOLOGICAL: The wide and dynamic Missouri River provides a diverse array of habitats supporting burr oak savanna and extensive, mature forests (e.g., cottonwood, ash, and elm)—especially at Goat Island. The Vermillion River contributes valuable flows, sediments, and nutrients that support aquatic ecosystems. CULTURAL: This river segment contains Indigenous sites, including several village remains near Mulberry Bend. Located a short distance north of the Missouri River is Spirit Mound, a significant cultural site and location explored by the Lewis & Clark Expedition. Several historic steamboat wrecks occurred in this stretch of the Missouri River, including the North Alabama and Kate Sweeny. The original town of Vermillion was destroyed along this segment during the historic flood of 1881. SCENIC: Mulberry Bend Overlook provides a sweeping view of the Missouri River from North Alabama Bend to Mulberry Bend. Scenic bluffs and wooded hills are visible along the southern shore of the river. Spirit Mound is a large and visually inspiring geological feature of cultural and historical significance located a short distance north of MNRR.
Segment 8: Kate Sweeny Bend to Ponca State Park (RM 767– 752)	SCIENTIFIC: The geology of this segment is characterized by dramatic and exemplary outcrops of Cretaceous bluffs, loess deposits, and alluvial floodplains. Numerous landslide scars are visible along the bluffs. Cretaceous outcrops along this stretch of the Missouri River include some of the oldest rocks in MNRR, including the Dakota Formation (Kd, Kgd), Graneros Shale (Kgd, Kgg), Greenhorn Limestone (Kgd, Kgg), and Carlile Shale (Kc). These ancient strata are known to contain numerous fossils, including marine reptiles such as the “Ponca Monster” that was discovered near Ponca State Park in 1873. A unique geologic site found along this segment is Ionia Volcano, a misinterpreted “volcano” visited by the Lewis & Clark Expedition; the site consists of the Cretaceous Carlile Shale (Kc) that historically weathered to produce steam and heat. This stretch of river also features dynamic sandbars, islands, chutes, and the Ponca backwaters—the largest backwater complex in MNRR. ECOLOGICAL: The wide and dynamic Missouri River provides a diverse array of biologically rich habitats such as backwaters, cottonwood forests, Elk Point Bend Prairie, and extensive upland woodlands. CULTURAL: The Lewis & Clark Expedition encountered and named the Ionia Volcano along the southern bluffs of this river segment. The Kate Sweeny Bend is named after the historic steamboat wreck located further upstream. SCENIC: The scenic vistas at Ponca State Park are a popular attraction and provide sweeping views of the open floodplain and the last dramatic bend in the Missouri River before the beginning of the channelized section downstream.

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 MNRR 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 MNRR. 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.

The NPS GRD has developed an article series (<https://www.nps.gov/articles/series.htm?id=FA0A8F89-CD67-1CCE-5A6608B444E8A7C0>; accessed June 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 anthropogenic activity.

Summary of Geologic and Soil Hazards

Park resources are not only visitor attractions but may also be potentially hazardous. The landscape presents various geologic hazards, or “geohazards”—naturally occurring, dynamic geologic processes that have the potential to cause damage, loss of property, injury, or loss of life. The Addressing Climate Change and Natural Hazards Handbook (National Park Service 2015, 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. This table includes selected geologic and soil hazards listed in Part 1 of National Park Service (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 National Environmental Policy Act (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 and Jarvis 2015). It is meant to provide general information to identify the full range of natural hazard-based risks for the recreational river.

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	Known hazard (low; DOI SHIRA)	Filina et al. (2018) Joeckel et al. (2017) Reagor et al. (1981a, b) Nebraska Seismicity - USGS South Dakota Seismicity - USGS US Department of Interior (DOI) Strategic Hazard Identification and Risk Assessment (SHIRA) Risk Mapper Report United States Geological Survey (USGS) Earthquake Hazard Probability Map (Petersen et al. 2023)
Slope movements (also called “mass wasting”)	Landslides (e.g., rockfalls, rockslides, slumping, or creep) Landslides could mobilize large amounts of woody debris Damage or destruction of park infrastructure (e.g., roads, buildings, boat landings) Damage to or loss of natural or cultural resource sites or features Human injury or casualty	Known hazard (very high; DOI SHIRA)	DOI SHIRA Risk Mapper Report Graham (2008) Joeckel et al. (2019) Lundstrom et al. (2022) National Park Service (2012, 2017a) USGS Landslide Inventory and Susceptibility
Permafrost	Not applicable	Not applicable	Not applicable
Cave/karst	Sinkhole development or collapse Enhanced erosion or mass wasting susceptibility Human injury or casualty	Potential hazard (moderate; DOI SHIRA)	DOI SHIRA Risk Mapper Report
Shrink/swell soils	Damage to infrastructure “Heaving” of ground beneath roads, trails, or structures Increased susceptibility to slope movements	Potential hazard (very high to low; Web Soil Survey). The 39-Mile District contains a higher degree of swelling clay susceptibility)	Graham (2008) USDA Web Soil Survey

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Coastal storm surge/sea or lake level change/shoreline erosion	Not applicable	Not applicable	Not applicable
Tsunami	Not applicable	Not applicable	Not applicable
Riverine Flood	Flooding (driven by storms, prolonged rainfall or snowmelt, and ice jams) that may last up to several months Inundation of entire cities Enhanced mass wasting susceptibility Enhanced flow regimes capable of carrying large amounts of unconsolidated rock, soil, and woody debris Destruction of infrastructure (e.g., roads, trails, boat landings, buildings, utilities, dams, or bridge structures) Stream bank erosion or channel incision Stream channel migration Damage or destruction of potential cultural and paleontological sites Damage or destruction of sensitive ecological habitats Human injury or casualty	Known hazard (extreme; DOI SHIRA)	American Rivers (2012, 2020, 2021) DOI SHIRA Risk Mapper Report Elliott and Jacobson (2006, 2022) Federal Emergency Management Agency (FEMA) Map Service Center Franklin et al. (1996) Graham (2008) Harvey and Harvey (2016) National Park Service (1999, 2012) Schenk et al. (2014) Stark et al. (2011)
Flash Flood	Sudden rising water levels along smaller tributaries (e.g., Bow Creek) Enhanced mass wasting susceptibility Enhanced flow regimes capable of carrying large amounts of unconsolidated rock, soil, or woody debris Destruction of infrastructure (e.g., roads, trails, boat landings, buildings, utilities, dams, or bridge structures) Stream bank erosion or channel incision Stream channel migration Damage or destruction of potential cultural and paleontological sites Damage or destruction of sensitive ecological habitats Human injury or casualty	Known hazard	Elliott and Jacobson (2006, 2022) Graham (2008) Schenk et al. (2014)

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Volcanic eruption	Not applicable	Not applicable	Not applicable
Hydrothermal activity	Not applicable	Not applicable	Not applicable
Radon	Health hazard	Potential hazard (high – Zone 1; exception for Gregory County, South Dakota [moderate – Zone 2])	Otton (1992) US Environmental Protection Agency (EPA) Map of Radon Zones by State
Toxicological soil (arsenic ¹ , cadmium ² , lead ¹ , selenium ² , and <i>Bacillus anthracis</i> [causes anthrax] ³)	Health hazard	¹ Potential hazard (very high) ² Potential hazard (high) ³ Potential hazard (known)	DOI SHIRA Risk Mapper Report Graham (2008)

Cave and Karst

Karst topography develops in limestone, dolostone, gypsum, and other similar geologic units by dissolution, as the rock is chemically and physically eroded by rainwater containing dissolved carbonic acid. Over time, dissolution can create open spaces or voids in the bedrock that develop into larger interconnected cavities or passages. Karst topography presents several hazards (e.g., surface collapse, ceiling collapse, rockfall), as the dissolution of bedrock often weakens its structural integrity. According to the DOI SHIRA Risk Mapper report, MNRR is rated as “moderate” for current and future karst-related sinkhole susceptibility. The Cretaceous strata that underlie the recreational river contain an abundant amount of carbonate rock that increases the susceptibility to cave and karst development.

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 recreational river’s resources, including geologic resources. The climate at MNRR 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 (National Park Service 2017a; Climate Change Response Program 2024). Forecasted climate scenarios for MNRR include exacerbated extreme weather events, including periods of heightened drought as well as more frequent or intense storms and enhanced flooding. Projected increases in several variables (e.g., air temperatures, evaporation rates, drought, precipitation) may negatively affect wildfire occurrence and aquifer recharge, as well as watershed quality and flow. These modifications to water availability are likely to impact additional geologic processes (e.g., landslides, erosion), in addition to ecological processes (e.g., invasive species, phenology), visitation, and park management procedures (Climate Change Response Program 2024). Invasive species of ecological concern for MNRR include purple loosestrife (*Lythrum salicaria*), salt cedar (*Tamarix spp.*), Russian olive (*Elaeagnus angustifolia*), Canada thistle (*Cirsium arvense*), spiny plumeless thistle (*Carduus acanthoides*), bull thistle (*Cirsium vulgare*), musk thistle (*Carduus nutans*), leafy spurge (*Euphorbia esula*), common reed (*Phragmites australis* subsp. *australis*), and spotted knapweed (*Centaurea maculosa*; Stark et al. 2011). These exotic species often outcompete and displace native plants, altering community structure and subsequently affecting the amount and quality of available habitat. In addition to invasive species, climate change may accelerate the replacement of mature cottonwood forests with red cedar (*Juniperus virginiana*), a native species that has exhibited aggressive spread into prairies, savannahs, and riparian forests (Stark et al. 2011; Elliot and Jacobson 2022). The loss of stabilizing vegetation, such as cottonwood forests, could significantly enhance erosion and reduce habitat availability along the Missouri River.

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

- Increased average temperatures
- Increased frequency and intensity of storms
- Increased frequency and magnitude of fires
- Increased susceptibility to mass wasting events
- Increased extreme weather scenarios, including drought and flooding
- Loss of stabilizing vegetation, leading to enhanced erosion and reduced habitat availability

Disturbed Lands

Disturbed lands occur 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. The “recreational river” designation of MNRR alludes to the amount of development along the banks of the Missouri River. Under the Wild and Scenic Rivers Act, a virtually untouched river is designated “wild,” a river with some development is designated “scenic,” and a river with significant development along its banks is designated “recreational.” Due to agricultural, residential, recreational, and tribal activities along the river, MNRR is designated a recreational river (National Park Service 2011). Lands disturbed by human activity often cause long-lasting problems that affect other resources. Many of these disturbances obliterate soil profiles, exacerbate the invasion of exotic plants, result in contamination of water and soil, or cause erosion and sedimentation. These damages, in turn, frequently impair the quality of habitats, disrupt ecosystem functions, and cause problems for parks managing areas as wildlands. Restoration involves returning a site, watershed, or landscape to a previous condition, which is often a desirable historic baseline. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities.

Dams

During the 20th century, reservoir construction and channelization projects significantly altered the main stem of the Missouri River and affected nearly every natural component of MNRR (Stark et al. 2011). However, many of the unencumbered stretches of MNRR allow for substantial channel complexity (e.g., multiple channels, sandbars, island complexes) that support the scenic, recreational, ecological, geological, and cultural values of the river (National Park Service 2017a). Regulation of the river began in 1938 with the construction of Fort Peck Dam in Montana and has expanded to include a system of five additional dams under the 1944 Flood Control Act (Pick-Sloan Plan). The last dam was completed in 1963 (Spegel 2009; Stark et al. 2011; National Park Service 2017a; Elliot and Jacobson 2022). The construction of Fort Randall Dam was completed in 1954 and formed Lake Francis Case upstream of the 39-Mile District; the Gavins Point Dam was completed in 1957 and created Lewis and Clark Lake upstream of the 59-Mile District (Stark et al. 2011). Although the completion of these dams created one of the largest reservoir systems in North America and resulted in several societal benefits (e.g., hydroelectricity production, flood control, navigation, recreational use, irrigation), these projects have also altered the natural, free-flowing condition of the river (Rowe et al. 2013; Harvey and Harvey 2016; National Park Service 2017a). One of the principal issues that led to the designation of MNRR was the desire to protect the river corridor following intensified erosion spurred by dam construction (Harvey and Harvey 2016).

Within MNRR, the Fort Randall and Gavins Point dams have reduced the intensity and frequency of floods, diminished sediment transport dynamics, modified channel morphology, and altered the river’s temperature, water quality, and ecological integrity (National Park Service 2017a; Elliot and Jacobson 2022). Flow regulation of the Missouri River has reduced flood pulses responsible for floodplain rejuvenation, scouring, meandering, sedimentation, and the formation of channel features such as sandbars and islands (Stark et al. 2011). Many of these changes have direct and indirect effects on riparian vegetation (including cottonwood forest regeneration) as well as critical nesting habitats for threatened or endangered species. Additionally, the physical impediment of the Gavins Point Dam has promoted delta formation along the mouth of the Niobrara River, which has significantly increased the level of the Missouri River and decreased the storage capacity of

Lewis and Clark Lake (National Park Service 2017a; Elliot and Jacobson 2022). The immense amount of silt and debris that gave the Missouri River the nickname “Big Muddy” now largely settles out behind the dams; these changes in sediment load have subsequently altered the downstream expression of the river (American Rivers 2012; Schenk et al. 2014). Adjustments of sediment supply caused by the dams have resulted in rapid incision rates (approximately 3 m [10 ft] every 50 years) that promote riverbank erosion, bank steepening, floodplain abandonment, channel armoring (gravel-covered stream beds), water supply disruptions, and channel downcutting (Lundstrom et al. 2006; Graham 2008; Stark et al. 2011). Immediately downstream of the Fort Randall Dam, the river has incised downward, and bank erosion rates have slowed, resulting in a decrease in channel migration rates and an abandonment or disconnection of the river from its floodplain (National Park Service 2012; Elliot and Jacobson 2022). Abandoned floodplains often result in single-channel morphologies that lack inundation, channel complexity, and ecological diversity (National Park Service 2012).

Bank Stabilization

Bank stabilization is the process of installing resistant materials on streambanks to prevent channel bank erosion and migration (Figure 13). These stabilization projects have long been considered a concern in MNRR, especially along the 59-Mile District (Stark et al. 2011; Elliott and Jacobson 2022). Approximately 14% of the 39-Mile District and 33% of the 59-Mile District have riverbanks stabilized by rock revetment (protective, erosion- or impact-resistant structures) to prevent or limit bank erosion (Elliott and Jacobson 2006, 2022). Additionally, about 49% of the 39-Mile District and 5% of the 59-Mile District are adjacent to bedrock bluffs that naturally stabilize the Missouri River and prevent riverbank erosion and migration (Elliott and Jacobson 2022). While bank stabilization measures prevent undesired erosion that may undercut riverbanks and damage infrastructure (e.g., roads, bridges, buildings), these human interventions prevent the river from creating or maintaining channel features, which results in a loss of habitat such as wetlands, sandbars, side channels, and backwaters (Stark et al. 2011; National Park Service 2017a). Combined with dam construction, these bank stabilization projects have significantly altered the natural flow of the Missouri River system.

In 2017, the NPS published a pre-NEPA report (National Park Service 2017b) that addresses bank stabilization issues, needs, maintenance, methods, and coordination as it relates to MNRR. Several stabilization techniques mentioned in the report include (1) bioengineering, using plants or native, biodegradable materials; (2) riprap revetment, using fieldstone emplacement and hillslope modification; (3) buried revetment, in which a trench is dug along the riverbank and infilled with material; and (4) hard points, using resistant, deflective structures (e.g., rock vanes, wing deflectors) to redirect or control river current (National Park Service 2017b). Additionally, since large areas of the riverbank in MNRR are privately owned, the report recommends creating an outreach program to help educate the public and its partners about the stabilization process and how it is intimately connected to the recreational river’s mission to preserve the outstandingly remarkable values of the Missouri River.



Figure 13. Remnant bank stabilization structures along the recreational river. Located near Brooky Bottom in the 59-Mile District, these early stabilization structures demonstrate the erosive power of the Missouri River. Although bank stabilization is meant to prevent erosion and channel migration, these projects have significantly altered the natural flow regime of the river and inhibited its ability to construct or maintain vital habitats. NPS photograph.

Land Use and Development

As a river park, one of the main management goals of the recreational river is to preserve the free-flowing nature of the Missouri River. However, the long, linear nature of MNRR makes it susceptible to land use changes adjacent to or upstream from its administrative boundary. The recreational river protects a small component of the larger Missouri River watershed and is susceptible to upstream impoundments and water diversions that limit the flow of the river and its tributaries. Following the creation of the Fort Randall and Gavins Point dams in the 1950s, flood control regulation of the Missouri River opened new possibilities for human development (e.g., agricultural, urban, industrial) that have encroached upon the floodplain and stressed the region's surface water and groundwater resources. Agricultural and residential development pose a considerable impact on MNRR and have dramatically changed the historic land cover, encouraged bank stabilization efforts, and introduced fertilizers and other chemicals into the Missouri River (Graham 2008; Stark et al. 2011). From 1892 to 2006, large amounts of forest and grassland surrounding the recreational river were converted to agriculture, which demanded more water usage and stressed the water budget of the Missouri River system (Stark et al. 2011; National Park Service 2017a). Agricultural chemicals can

potentially enter the river via runoff from surrounding fields and farms or by leaching through the permeable sandy substrate (Graham 2008; Stark et al. 2011). Additionally, sewage treatment plants surrounding the recreational river have been compromised by flooding, which has introduced raw sewage into the tributaries feeding the Missouri River (Carolyn Campbell, NPS MNRR, personal communication July 2025). Continued pressures or stressors will likely exacerbate issues related to water availability or quality and may threaten the ecological, recreational, and scenic integrity of MNRR.

Energy Infrastructure

The recreational river occupies an area of the central United States that serves as a conduit for oil projects such as the Keystone Pipeline, a large pipeline system connecting hydrocarbon-rich oil sands in Alberta, Canada, to oil refineries in Illinois and Texas. According to Graham (2008), part of the Keystone Pipeline was directionally drilled about 18 m (60 ft) below the Missouri River near Yankton, South Dakota. Additionally, NuStar Energy has two underground pipelines beneath MNRR (Graham 2008). Potential spills of oil or other hazardous substances may reach MNRR from storm drains, highways, railways, pipelines, facilities, and aboveground storage tanks. Spills may enter MNRR directly (e.g., oil pipelines that cross under the Missouri River) or indirectly through tributaries (see [A Missouri River Spill Response Partnership](#); accessed June 2025). Any potential spill may significantly degrade the water quality and ecological integrity of the Missouri River system, resulting in species and habitat loss, costly cleanups, and remediation efforts. The US EPA provides guidance about oil spill prevention, control, and response planning (see [Oil Spill Prevention and Preparedness - US EPA](#); accessed June 2025).

Flooding

The modern Missouri River is not the same river encountered by the Lewis & Clark Expedition at the dawn of the 19th century. Once a wide, meandering, dynamic river spread out over its ecologically rich floodplain, the river has been constricted and regulated to meet conflicting water resource demands, including flood control, navigation, irrigation, hydroelectric power generation, water supply, recreation, and wildlife habitat (American Rivers 1998, 2020, 2021). Today, the river needs more room to safely accommodate flood waters, especially as climate change poses a considerable threat due to enhanced extreme weather activity (see “Climate Change”; American Rivers 2012, 2020, 2021). Flood management along the Missouri River could benefit by the implementation of a more natural, adaptive approach that reduces risk while safeguarding wildlife habitat (see “Hydrological Resources”; American Rivers 2012; Elliott and Jacobson 2022).

Historic Flooding (Pre-dam era)

Among its many nicknames, the Missouri River has been referred to as “Old Misery” due to its volatile behavior and history of destructive floods (Franklin et al. 1994; Harvey and Harvey 2016). Although flooding introduces several geohazards that can threaten or endanger lives (and entire cities), it is a natural phenomenon responsible for sculpting the landscape and sustaining biologically rich ecosystems. Several major historic floods have been documented along the river that ultimately led to the 1944 Flood Control Act and the construction of several dams, including the Fort Randall Dam in 1954 and the Gavins Point Dam in 1957 (Stark et al. 2011). Prior to the completion of the dams, flooding along the Missouri River was a frequent occurrence, driven primarily by seasonal rainfalls, melting snowpacks, large storms, and ice jams; many of these mechanisms still cause flooding today but to a significantly lesser degree (Figure 14; Table 6). Flood pulses carrying turbid, sediment-laden water routinely rejuvenated floodplains and constructed or reworked channel features such as sandbars and island complexes (Elliott and Jacobson 2022).



Figure 14. An ice jam along MNRR in January 2015. The ice jam formed between Clay County Park near Vermillion, South Dakota, and the Bow Creek Recreation Area. Ice jams such as these were serious navigational concerns during the early pioneering days of the Missouri River and contributed to flooding along the river corridor. NPS photograph.

Table 6. List of major historic and modern flood events along the recreational river. Information in the table was sourced from National Park Service (1999, 2012), Graham (2008), Stark et al. (2011), Schenk et al. (2014), Harvey and Harvey (2016), and Elliott and Jacobson (2022).

Year	Description
1844	A major flood that damaged homes, farmlands, and population centers.
1881	A destructive ice jam flood that damaged homes and farmlands and decimated the town of Green Island. The flood destroyed much of the Yankton riverfront and smashed steamboats tied up for the winter. The flood demolished the <i>Western</i> and battered the <i>Butte</i>, the <i>Helena (II)</i>, and the <i>Black Hills</i>. The icy waters lifted the <i>Peninah (No.2)</i>, the <i>Nellie Peck</i>, and the ferryboat <i>Livingston</i> out of the riverbed and dumped them on shore, with the <i>Nellie Peck</i> coming to rest on the railroad tracks. The Yankton steamboat industry never recovered from the 1881 flood. The 1881 flood restructured portions of the Missouri River system, creating a meander cutoff that allowed the Vermillion River to flow into the old Missouri River channel; this prompted the relocation of the city of Vermillion (formerly located at present-day Cotton Park, South Dakota). Additionally, the flood caused the citizens of Niobrara, Nebraska, to relocate the city approximately 2.4 km (1.5 mi) uphill from its original location southeast of the Niobrara River confluence. Damages related to the flood persuaded Congress to commit federal money to channelize the Missouri River for barge navigation.

Year	Description
1903	A major flood that damaged homes, farmlands, and population centers.
1904	A major flood that damaged homes, farmlands, and population centers.
1905	A major flood that damaged homes, farmlands, and population centers.
1908	A major flood that damaged homes, farmlands, and population centers.
1915	A major flood that damaged homes, farmlands, and population centers.
1927	A major flood that damaged homes, farmlands, and population centers.
1937	A major flood that damaged homes, farmlands, and population centers.
1943	A major flood that damaged homes, farmlands, and population centers.
1947	A major flood that damaged homes, farmlands, and population centers.
1952	A major flood that damaged homes, farmlands, and population centers. The flood resulted in considerable sediment transport and sandbar formation just prior to dam closure in MNRR.
1984	The second largest flood along MNRR prior to the 2011 record flood. Peak discharge during the 1984 flood reached approximately 104,000 ft ³ /sec.
June–September 1993	The Great Midwest Flood of 1993. Major flooding occurred across North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, and Illinois, resulting in over 50 deaths and billions of dollars in damages.
1997	The 1997 flood was generated by record snowmelt and near-record seasonal rainfall in the Upper Missouri River. The flood sustained 251 days of discharge exceeding 60,000 ft ³ /sec. In the 59-Mile District, the flood redistributed sediment and created sandbars, contributing to land cover changes along the river corridor.
Spring and summer 2011	The largest post-dam era flood on record. The 2011 flood was caused by large amounts of snowmelt and near-record seasonal rainfall in the Upper Missouri River watershed. The maximum discharge recorded at the Gavins Point Dam was about 192,000 ft ³ /sec. The flood sustained discharge rates exceeding 100,000 ft ³ /sec for 94 days, with an additional 180 days of discharge greater than 60,000 ft ³ /sec. Entire communities, particularly along the middle and lower Missouri River, were entirely submerged, and the Nebraska side of the Chief Standing Bear Memorial Bridge across the 39-Mile District was inundated for months. The devastating nature of the 2011 flood led to destroyed communities, mass evacuations, environmental catastrophes, infrastructure damage, and the closure of MNRR to the public throughout the summer of 2011. The flood eroded riverbanks, added sand to sandbars (especially in the 59-Mile District), and moved the thalweg of the river channel in many places.
March 2019	High-intensity, short-duration flood driven by a wet spring and rain-on-snow event. The flood generated a peak discharge of 154,000 ft ³ /sec and resulted in 38 days of discharge greater than 100,000 ft ³ /sec. The flood damaged more than 1,365 km (850 mi) of levees in downstream parts of Iowa, Kansas, Missouri, and Nebraska, with estimated repair costs exceeding \$2 billion.
June 2024	Flooding along the MNRR occurred south of the James and Vermillion rivers. Downstream of the recreational river, Sioux City was heavily impacted by the floods.

Modern Flooding (Post-dam era)

The completion of the Fort Randall and Gavins Point dams reduced the occurrence, intensity, and duration of floods, which have driven significant changes in sediment transport, erosion, channel morphology and complexity, and ecological diversity (National Park Service 2012). However, large flood events—such as those in 1997, 2011, and 2019—still occur sporadically and have serious ramifications regarding geohazards, public safety, park operations, natural resource protection, and the river’s geomorphology and ecology (Figure 15). The 1997 and 2011 floods were generated by record snowmelt and near-record seasonal rainfall in the Missouri River watershed, an extensive drainage basin of the northern Great Plains encompassing over 1,350,000 km² (525,000 mi²; US Bureau of Reclamation 2021). Both floods lasted several months, in part due to dam restrictions intended to limit downstream flood damages (Schenk et al. 2014; Harvey and Harvey 2016; Elliott and Jacobson 2022). The amount of precipitation generated during the flood stressed the dams along the main stem of the Missouri River and allowed water levels to dangerously rise. The 2011 flood represents the most powerful, longest-duration flood event in the post-dam era, with a record discharge of

about 192,000 ft³/sec measured at the Gavins Point Dam (Schenk et al. 2014). The flood sustained discharge rates exceeding 100,000 ft³/sec for 94 days, with an additional 180 days of discharge greater than 60,000 ft³/sec (Elliott and Jacobson 2022). Entire communities, particularly along the middle and lower Missouri River, were entirely submerged, and the Nebraska side of the Chief Standing Bear Memorial Bridge across the 39-Mile District was inundated for months (Figures 16–17; Harvey and Harvey 2016). The devastating nature of the 2011 flood led to destroyed communities, mass evacuations, environmental catastrophes, infrastructure damages, and the closure of MNRR to the public throughout the summer of 2011 (Harvey and Harvey 2016; see [2011 Missouri River Flood](#); accessed June 2025). The 1997 flood was smaller in magnitude but similar in duration, with 251 days of discharge exceeding 60,000 ft³/sec (Elliott and Jacobson 2022). The March 2019 flood was driven by a wet spring and rain-on-snow event that generated a peak discharge of 154,000 ft³/sec and resulted in 38 days of discharge greater than 100,000 ft³/sec (Elliott and Jacobson 2022). The flood damaged more than 1,365 km (850 mi) of levees in downstream parts of Iowa, Kansas, Missouri, and Nebraska, with estimated repair costs exceeding \$2 billion (American Rivers 2020, 2021).

Although large floods are considered rare in the post-dam era, these events are considered a necessary element in sustaining MNRR's ecological diversity. For example, the 2011 flood scoured the riverbed and redistributed sediment and moisture throughout the Missouri River corridor that were vital to cottonwood regeneration and floodplain rejuvenation. Additionally, the flood built substantial sandbar habitats in MNRR, especially in the downstream 59-Mile District, providing critical wintering, migratory, and nesting grounds for threatened or endangered species like the piping plover and interior least tern (Figure 18; National Park Service 2012; Schenk et al. 2014; Elliott and Jacobson 2022).



Figure 15. Flood waters at the Running Water boat ramp in June 2011. The flood completely inundated the ramp and several vegetated sandbars in the distance. Rising water levels associated with flooding present a danger to park infrastructure, resources, habitats, and human lives. NPS photograph.



Figure 16. Aerial view of the 2011 flood looking downriver (east) on Nebraska Highway 12. Civil Air Patrol photograph.



Figure 17. Aerial view of the 2011 flood looking upriver (west) on Nebraska Highway 12 toward the town of Niobrara. Civil Air Patrol photograph.



Figure 18. A sandbar created during the 2011 flood in MNRR. The floods redistributed massive amounts of silt, sand, and gravel along the river corridor that constructed new channel features and habitats. Following the flood, these sandbars were slowly eroded away by wind and water. NPS photograph.

Mass Wasting

The term “mass wasting” is used to describe downhill movements of rock, soil, or ice and includes several types of landslide phenomena, including debris (or snow) avalanches, rockslides (mobile masses of coherent rock), debris flows (mobile masses of water-laden rock or soil), slumping or slope creep (downhill movement of soil), and rockfalls. Within MNRR, steep river bluffs are continuously eroding and susceptible to slumps, rockfalls, and rockslides (Figure 19; Graham 2008; National Park Service 2012, 2017a). In the 39-Mile District, the Cretaceous Pierre Shale (**κp**) is prone to landslides, which may be exacerbated by the presence of bentonite beds that are known to swell in the presence of water (Graham 2008). In the upstream segment near Fort Randall Dam, the Missouri River is flanked by bluffs of the Pierre Shale that are prone to numerous landslides and rockfalls in many areas (National Park Service 2012; Joeckel et al. 2019). Further downstream, there are large slumps along the bluffs near the mouth of the Niobrara River (Diffendal et al. 2008; National Park Service 2012; Joeckel et al. 2019). Additionally, smaller landslides are mapped along the Niobrara River and Verdigre Creek by Diffendal et al. (2008) and Joeckel et al. (2019).

In the 59-Mile District, landslides are commonly caused by the Cretaceous Carlile Shale (**κc**) and Greenhorn Limestone (**κgd**, **κgg**), the latter of which is known to contain bentonite layers that may add to slope instability issues similar to the Pierre Shale (Graham 2008). Near Lewis and Clark Lake, Cretaceous bedrock is responsible for unstable hillslopes that may potentially impact Calumet Bluff and the campground on the south side of the reservoir (Graham 2008). According to Graham (2008), active slumping and bank collapse driven by river undercutting are occurring upstream from the Myron Grove boat launch near the historic confluence of the James River. At Audubon Bend, bluffs along the southern side of the Missouri River feature slump blocks consisting of (in order from oldest to youngest) eroded Carlile Shale and chalk of the Niobrara Formation (**κnc**) overlain by an undercut sequence of Peoria Loess (**Qlu**; Graham 2008). Additional landslides are mapped along the bluffs surrounding Mulberry Bend (Lundstrom et al. 2022). In the downstream portion of the 59-Mile District, numerous landslide scars are visible along the Cretaceous bluffs near Ponca State Park, including both the North Unit and the visitor center (Graham 2008; National Park Service 2012; Lundstrom et al. 2022). A rockslide consisting of the Greenhorn Limestone covered the Ponca State Park boat ramp in 2005, while massive rockslides and slumps in 2006 or 2007 impacted roadways near the park’s visitor center (Graham 2008).



Figure 19. A large rockslide along the bluffs of MNRR. A collection of bedrock, soil, trees, and other vegetation has fallen downslope into the Missouri River. Fresh rockslides such as this one leave unvegetated scars along the river corridor. NPS photograph.

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 US Environmental Protection Agency (EPA) map of radon zones, Boyd, Cedar, Dixon, and Knox counties, Nebraska, as well as Bon Homme, Charles Mix, Clay, Union, and Yankton counties, South Dakota, are identified as zones of highest potential (zone 1) for elevated indoor radon levels greater than 4 pCi/L (see <https://www.epa.gov/radon/epa-maps-radon-zones-and-supporting-documents-state>; accessed June 2025). In the 39-Mile District, Gregory County, South Dakota, is identified as a zone of moderate potential (zone 2) for elevated indoor radon levels between 2 and 4 pCi/L. The EPA has guidance for radon mitigation.

Seismicity

Nebraska and South Dakota are traditionally considered aseismic regions, meaning they lack significant earthquake activity. The USGS utilizes historic seismicity data to prepare seismic hazard probability maps, the latest of which (Petersen et al. 2023) indicates the recreational river occupies an area of low hazard compared to the rest of the country. The closest seismic monitoring station to the recreational river is approximately 80 km (50 mi) southeast of Ponca State Park near Lyons, Nebraska; an additional station is located about 97 km (60 mi) southwest of the 39-Mile District in Bassett, Nebraska ([EarthScope Seismic Station Map](#)). Joeckel et al. (2017) note that, despite the presence of major geologic structures (e.g., basement faults) underlying the MNRR region, earthquakes have been rare and weak over more than 160

years of historical records. Although powerful, recurring seismicity is scarce, several low-magnitude (4.3 or less) earthquakes have still occurred throughout northeastern Nebraska and southeastern South Dakota in surrounding Boyd, Cedar, Dixon, and Knox counties, Nebraska, as well as Bon Homme, Clay, Gregory, and Yankton counties, South Dakota (Reagor et al. 1981a, b; Filina et al. 2018; see also [Nebraska Seismicity - USGS](#) and [South Dakota Seismicity - USGS](#); accessed June 2025). These events are likely to occur as deeply buried structures such as faults accommodate stress within the interior of the Earth's crust (see figure 1 of Filina et al. 2018).

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, numerous soils mapped along the recreational river are rated “low” to “very high” 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 MNRR indicate that swelling clays can cause large volume changes capable of damaging buildings, roads, and other structures. The 39-Mile District contains and is surrounded by an extensive amount of soil rated high to very high in shrink-swell potential. In comparison, the downstream 59-Mile District is characterized by soils with low to medium shrink-swell potential with isolated occurrences of high to very high potential. The contrasting distribution among the two districts is likely influenced by the presence of bentonite layers contained within the Cretaceous Pierre Shale (Kp; Graham 2008).

Toxicological Soil

According to the DOI SHIRA Risk Mapper report, soils within the recreational river include potentially hazardous elemental abundances 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). The MNRR scoping summary report (Graham 2008) states that the Cretaceous Pierre Shale (Kp) and its associated Sharon Springs Member contain abundant levels of selenium, arsenic, and uranium. The Pierre Shale is susceptible to slope failure, which may leach these elements into the Missouri River and surrounding reservoirs, potentially changing the geochemistry and water quality of surface water and groundwater (Graham 2008). However, these potential impacts have yet to be studied (see “Inventory Needs”). 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 September 2024).

Anthrax is a rare, naturally occurring disease caused by the bacteria *Bacillus anthracis* that can cause severe illness in both people and livestock who are 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 September 2024).

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 June 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 26 June 2024).

Paleontological and Cultural Resources

The paleontological and cultural resources of MNRR are invaluable and provide a unique window into the geologic and historic past. Distributed along the Missouri River and its tributaries, these sensitive resources are susceptible to both natural and anthropogenic activities that can lead to their degradation or destruction. The recreational river protects approximately 203 km (126 mi) of waterway, making it difficult to monitor activities related to vandalism and resource damage everywhere. Surveillance is not always reliable, and the recreational river is currently developing a dedicated visitor and resource protection program that is still limited in coverage and staff (see “Inventory Needs”; National Park Service 2017a; Carolyn Campbell, NPS MNRR, personal communication July 2025). In the past, there have been cases of natural and cultural resource violations across both sides of the Missouri River (National Park Service 2017a). The dynamic river setting is constantly changing due to riverbank erosion, channel migration, mass wasting, and sedimentation that can either expose or bury sensitive resources. According to Elliott and Jacobson (2022), identifying the locations of substantial erosion and migration may provide useful insights related to risk assessments and the protection of paleontological and cultural resources preserved along the recreational river.

For additional information regarding paleontological resource laws, regulations, and policies, the NPS GRD developed the following summary article: <https://www.nps.gov/articles/paleontology-legal-instruments.htm> (accessed May 2025).

Hydrological Resources

The management of MNRR seeks to balance multiple landowner (e.g., private, tribal, federal, state) needs for bank stabilization and flood control with preservation of the ecological integrity of the Missouri River and its tributaries. NPS staff are faced with the challenging dilemma of protecting two distinct river segments with unique geological, geomorphological, and ecological settings that require different management approaches

(Elliott and Jacobson 2022). Dam construction and riverbank stabilization along the Missouri River have significantly altered its natural flow regime. Although large, devastating floods are now considered rare, these events are a natural phenomenon responsible for building and sustaining vital habitats that support threatened or endangered species (National Park Service 2012). The NPS may want to consult the US Army Corps of Engineers and other stakeholders regarding the management of controlled releases associated with dams along the main stem of the Missouri River. The timing of controlled releases could be adapted to support recreational needs, biological processes (e.g., phenology), and the needs of riverside communities (American Rivers 1998). Another management strategy the NPS may want to consider is the “room for the river” approach, an adaptive floodplain planning ideology that includes space along the river corridor for flooding and channel migration (Rijke et al. 2012; Biron et al. 2014; Elliott and Jacobson 2022). This approach acknowledges the benefits of erosion, channel migration, channel complexity, and flooding rather than fighting or confining the river’s natural tendency to meander and evolve. The benefits of the concept have already been documented along other US river systems and include decreased flood risk and increased ecological benefits (Rapp and Abe 2003; Piégay et al. 2005; Elliott and Jacobson 2022).

Inventory Needs

The following table (Table 7) presents several geologic and soil resources inventory needs that were identified in NPS planning documents or through literature review.

Table 7. List of identified geologic and soil resources inventory needs for the recreational river.

Subject	Inventory Need(s)	Reference(s)
Cultural resources	Develop detailed GIS imagery of all known steamboat wrecks and landings along MNRR. The Missouri River Institute has a project that started the process of gathering information on where some of the steamboat wrecks may be located; there are very few wrecks still on the river, and having this information would be helpful for interpretation.	National Park Service (2017a)
Cultural resources	Develop a comprehensive cultural resources management plan. This plan would provide specific guidance and set priorities for the long-term management of MNRR’s cultural resources and could involve intrapark cooperation with the Lewis and Clark National Historic Trail. Having this plan would help work with collaborators to outline roles and functions that would help build relationships with traditionally associated tribes and partners. This plan would be an extension of the currently funded traditional cultural properties inventory.	National Park Service (2017a)
Geohazards	Identify active slumping and erosion areas. Current bank stabilization monitoring provides this information about river dynamics and high-energy areas to prioritize for restoration or protection efforts.	National Park Service (2017a)

Subject	Inventory Need(s)	Reference(s)
Geomorphology	Develop a comprehensive bank stabilization baseline study and data monitoring plan. This plan would be completed in cooperation with partners (e.g., the US Army Corps of Engineers). There is continued interest in identifying riverbank stabilization methods that are acceptable, and it is one of the more important issues facing the recreational river. There is a need to identify areas that had bank stabilization prior to MNRR establishment and a regulatory process to go about doing stabilization. The plan would integrate climate change considerations. The recreational river received pre-NEPA funding in FY 2017 to further scope the merit of developing a comprehensive bank stabilization management plan. A pre-NEPA report was published in 2017 (National Park Service 2017) and provides excellent recommendations regarding riverbank stabilization but does not include a management plan.	National Park Service (2017a, b)
Geomorphology	Perform a sediment study of MNRR. This study would compile sediment data that relates to the recreational river and would investigate historical levels compared to current ones. Furthermore, the study would identify sediment deficiencies (i.e., what is needed to return to more historical levels).	National Park Service (2017a)
Geomorphology	Create a visual resource inventory of MNRR. This effort would include collecting information on what exists now and how it is changing over time. Having a baseline would assist in collaborating with park partners to determine future conditions. An inventory would identify observation points of significant viewsheds that could be used in discussion with partners and local groups to help prevent degradation.	National Park Service (2017a)
Hydrological resources	Develop a comprehensive river management and land protection plan. These plans would help substantiate MNRR's goals and form the basis for decision-making. A comprehensive river management plan is also mandated by the Wild and Scenic River Act. The plans would examine instream flows, water quality, specific goals, desired future conditions, land development, and the approach to collaboration. The plans would also address user capacity, including the amount and type of visitor and administrative use the river can sustain while protecting and enhancing its remarkable values, water quality, and free-flowing condition. The plans would integrate climate change considerations.	National Park Service (2017)
Hydrological resources	Long-term water quality monitoring. There are many partners working on this; the first step would be to synthesize and see if existing partner data and data sampling are adequate and sufficient.	National Park Service (2017a)
Natural resource management	Identify potential resources for geologic study of the entire MNRR.	National Park Service (2017a)
Natural resource management	Develop a natural resource stewardship strategy. This plan would provide comprehensive strategies designed to achieve and maintain the desired conditions of MNRR's natural and cultural resources.	National Park Service (2017a)
Paleontological resources	Perform a detailed paleontological resource assessment of MNRR. Systematic paleontological research has not been undertaken, and most recent discoveries have come from construction projects or roadcuts.	Tweet et al. (2011)

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