National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Saint Croix National Scenic Riverway

Geologic and Soil Resources Inventory Summary

Overlooking the St. Croix River from Eagle Bluff. Photo by Matthew Harrington (Colorado State University).

Saint Croix National Scenic Riverway

Geologic and Soil Resources Inventory Summary

Matthew Harrington

Colorado State University Associate
National Park Service Geologic Resources Division
Geologic and Soil Resources Inventory
PO Box 25287
Denver, Colorado 80225

Please cite this report as:

Harrington, M. 2026. Saint Croix National Scenic Riverway: Geologic and soil resources inventory summary. Unpublished report. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2318552.

Abstract

This document summarizes the status of National Park Service (NPS) Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) deliverables for Saint Croix National Scenic Riverway. It also provides information on current geology and soils resource 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).

GRI hosted a baseline scoping meeting for Saint Croix National Scenic Riverway in 2010. Baseline surficial geologic maps were delivered to the park in 2022 with updated surficial geologic maps delivered in 2026. SRI delivered a legacy soil database and map to the park in 2007.

Geologic heritage resources of particular interest include glacial features, Indigenous connections, the legacy of the fur trade, logging industry, and mining, paleontological resources, caves, and a rich recreational history. Inventory needs include updated bedrock mapping and monitoring at-risk paleontological sites.

Geohazards include erosion, mass wasting, flooding, radon, and abandoned mineral lands. Inventory needs include a comprehensive inventory of historic mining sites and monitoring known slumping/mass wasting sites.

Additional guidance for park staff regarding proposal processes and timeframes for the new Inventory and Assessment (I&A) Program is available on the GSRI and I&A SharePoint sites.

Contents

List of Figures

List of Tables

Background of the GSRI

The Geologic and Soil Resources Inventory (GSRI) aids in the collection of new data and 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. The GSRI also includes the legacy Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) programs.

In the late 1990s, the GRI and SRI programs were established as two of the 12 original 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 the more than 270 parks that are part of the I&M networks. For both GRI and SRI, the primary deliverable was a digital (GIS) map. Between the 1990s and early 2020s, in addition to a digital map, GRI scoping summaries, geologic map posters, and GRI reports were produced for most of the 270 parks. GRI and SRI baseline inventory products are available through the NPS Geodiversity Atlas and the NPS DataStore. These products are designed to enhance stewardship of park resources by providing valuable information about soils, geologic formations, hazards, and links between geology, history, and other natural resources.

The GRI and SRI are now unified as one inventory, the GSRI, under the Inventories & Assessment (I&A) Program. The I&A Program, and henceforth the GSRI, operates under a park-proposed inventory strategy in which parks submit natural resource inventory and assessment project proposals to the Project Management Information System (PMIS) during the Servicewide Comprehensive Call (SCC). Park staff should refer to the GSRI SharePoint and I&A Program SharePoint for instructions on how to submit a project proposal including basic eligibility requirements, evaluation criteria, and the approval and implementation process.

As of 2025, the GSRI is in the process of completing baseline inventories for I&M parks and transitioning to the I&A model of accepting park-proposed projects from all NPS units. During this transition period, 13 parks, including Saint Croix National Scenic Riverway, were identified as not having a baseline GRI report. This GSRI summary serves as a substitute for a baseline GRI report and is intended to support the park's participation in the I&A Program. As such, it summarizes the status of GRI and SRI deliverables for Saint Croix National Scenic Riverway and provides information on current geology and soils resource management concerns with a focus on identifying inventory needs. Information in this summary was compiled from existing reports, meetings with park staff, and the best professional judgment from GSRI and Washington Support Office (WASO) Geologic Resources Division (GRD) geoscientists.

Baseline GSRI Products

Geology

Geologic maps provide information on the distribution of bedrock, surficial units, and geologic structures such as faults and folds. These maps are invaluable for understanding potential hazards (e.g., landslides, earthquakes), guiding resource management, and evaluating the suitability of areas for infrastructure, trails, and visitor use. GRI provides digital geologic geographic information system (GIS) data and a physical geologic map layout of the park as deliverables. For Saint Croix National Scenic Riverway, three geologic map layouts were created to cover the extent of the park. The map layouts can be accessed through the Integrated Resource Management Applications (IRMA) portal:

The GRI GIS data for Saint Croix National Scenic Riverway (referred to as the "park" herein) was updated in 2026 (released alongside this summary). This update converted all existing data to modern GIS formats and added new content from the Washington County Atlas in Minnesota (Bauer et al. 2016). Geologic-GIS data are provided in the following formats:

- Esri file geodatabase format
- 2.2 KML/KMZ format for use with Google Earth software
- Open Geospatial Consortium (OGC) geopackage format for use in QGIS (or other OGC software).

The digital geologic data, supporting ancillary map information, GIS readme document, and FAQ metadata file are available on the NPS DataStore, accessed through the Integrated Resource Management Applications (IRMA) portal: https://irma.nps.gov/DataStore/Reference/Profile/2317382.

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 Web Soil Survey along with NPS-specific uses for the data.

The SRI delivered products to the park in 2007. The digital Soil Survey Geographic (SSURGO) data for Saint Croix National Scenic Riverway is available on the NPS DataStore, accessed through the Integrated Resource Management Applications (IRMA) portal: https://irma.nps.gov/DataStore/Reference/Profile/1048969.

The most up-to-date soils data is available via the Natural Resources Conservation Service (NRCS) Web Soil Survey website, and management-focused maps for potential project areas can be developed on-demand at that site. The Web Soil Survey homepage gives instructions for how to view and download soil data.

Web Soil Survey data is broken down into county-level soil survey areas. The park encompasses 10 soil survey areas. Each soil survey area is assigned a code and a name (Table 1). The NRCS plans to complete all soil survey areas in the US by 2026 (Thompson et al. 2020). Table 1 lists the soil survey areas in the park and their completion status. To view the soil data for Saint Croix National Scenic

Riverway on the Web Soil Survey website, use the navigation pane on the left side of the main webpage to select the soil survey area or the NPS unit and set it as the "area of interest" using the "AOI" icon along the top of the map. 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.

Table 1. List of soil survey areas in the park and their completion status.

Web Soil Survey Area Code	Web Soil Survey Area Name	Status
WI007	Bayfield County, Wisconsin	Complete
WI013	Burnett County, Wisconsin	Complete
WI031	Douglas County, Wisconsin	Complete
WI095	Polk County, Wisconsin	Complete
WI109	St. Croix County, Wisconsin	Complete
WI113	Sawyer County, Wisconsin	Complete
WI129	Washburn County, Wisconsin	Complete
MN025	Chisago County, Minnesota	Complete
MN115	Pine County, Minnesota	Incomplete
MN163	Washington County, Minnesota	Complete

Geologic Setting and History

Saint Croix National Scenic Riverway, consisting of two rivers, the St. Croix River and the Namekagon River, spans 230 miles (370 km) along some of the least developed country in the Upper Midwest (National Park Service 2017). The headwaters of the St. Croix River begin in Upper St. Croix Lake, 13 river miles (21 km) from the boundary of the park at Gordon Dam. From there, the river flows 155 miles (250 km) south before joining the Mississippi River near Prescott, Wisconsin. The headwaters of the Namekagon River are located at Namekagon Lake, situated near Cable, Wisconsin. The following three paragraphs summarize the general geologic setting of the park based upon work by Cahow (1985). For a more detailed and complete analysis of the park's geographic setting and geology, please see Cahow (1985).

The Upper St. Croix River, flowing from Upper St. Croix Lake to the hydroelectric dam at St. Croix Falls, is characterized by exceptionally wide valleys (up to three miles [5 km]) carved out by the glacial St. Croix River (see "Glacial History" section). The Upper St. Croix River channel width averages 200 feet (61 m) at its uppermost section, widens to 400–600 feet (122–183 m) in the middle section, and widens farther to 600–700 feet (183–213 m) between Highway 70 and St. Croix Falls. It has a steeper gradient than the Lower St. Croix River (2.3 feet per mile [0.4 m/km] compared to 0.3–0.5 feet per mile [0.06 m/km–0.09 m/km]), occasional rapids, a well-developed floodplain with natural levees and backswamps, and active geomorphic processes such as island formation and sediment deposition. This section of the river is an underfit stream—occupying a valley much larger than its current size—with bluffs composed of sandy glacial outwash, lake sediments, stony till, and bedrock (Figure 1).

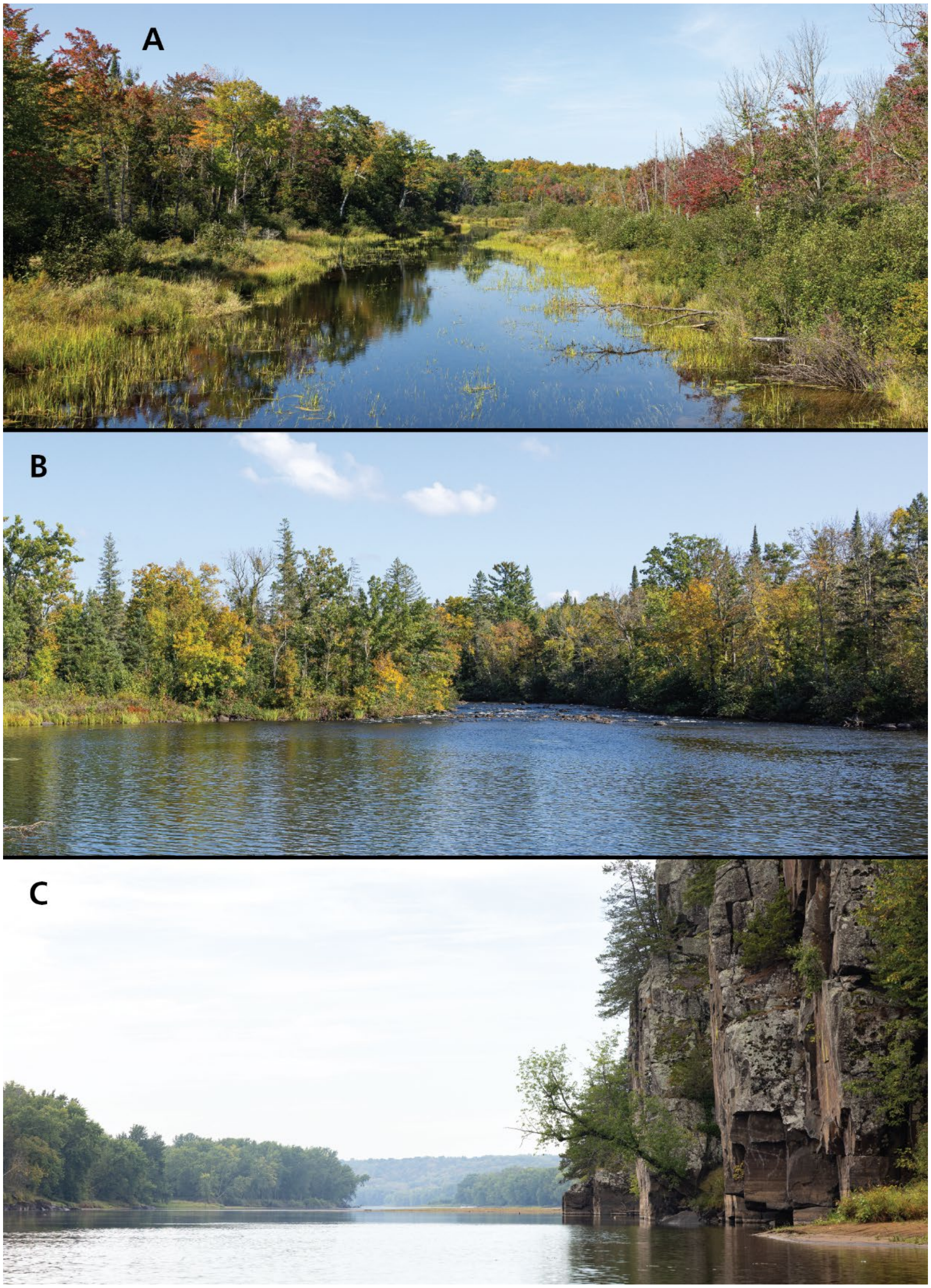


Figure 1. Photographs of the St. Croix and Namekagon Rivers. The park contains both the St. Croix and Namekagon rivers, with the St. Croix often separated into two subsections, the Upper and Lower St. Croix. A) Looking northwest down the Namekagon near the Namekagon Dam. Note the narrow river, bounded closely by trees on both banks. B) Taken from the North Country National Scenic Trail, this section of the Upper St. Croix showcases minor rapids. C) The Lower Dalles of the St. Croix tower over the Lower St. Croix, where the river is much calmer and wider than it is upstream. Photographs by Matthew Harrington (Colorado State University).

The Lower St. Croix River, stretching from the hydroelectric dam at St. Croix Falls to Stillwater, Minnesota, is characterized by narrower valleys, often with towering bluffs and steep cliffs that range from 125 feet (38 m) to over 250 feet (76 m) in height (Figure 1). The river channel width is more uniform on the Lower St. Croix River than the Upper St. Croix River, averaging 500 feet (152 m) in the unbraided sections. Width of the braided sections is highly variable, reaching up to 1 mile (1.6 km) in areas of numerous interconnected channels and islands. The Lower St. Croix River also has a slower flow than the upper due to its lower gradient (0.3–0.5 feet per mile [0.06 m/km–0.09 m/km]). It is, therefore, an aggrading stream (riverbed is rising due to sediment deposition), actively reshaping its course and creating new landforms such as islands, sandbars, and deltas. At Stillwater, the Lower St. Croix River flows into Lake St. Croix, a 25-mile-long ponded section of the river that formed as a result of delta-building at the St. Croix River's confluence with the Mississippi River.

The Namekagon River flows through a narrow valley, typically only slightly wider than the river itself, with a depth ranging from 5–20 feet (1.5–6 m) near the headwaters to about 80 feet (24 m) near its confluence with the St. Croix River. The valley alternates between narrow, stream-cut sections and wider, open sections formed by ice-block depressions that reflect its glacial history (Figure 1). The river width averages 200 feet (61 m), with periodic rapids in the narrow, stream-cut sections and sandy stream beds with giant sand ripples in the wider stretches of the valley. Unlike the St. Croix River, the Namekagon River is highly sinuous with winding, incised meanders. However, its meanders are largely restricted from migrating due to the staggered arrangement of ice-block depressions. The Namekagon River flows into the St. Croix River near Danbury, Wisconsin, north of Highway 77.

The park's present-day landscape reflects its geologic history. Buried Archean metamorphic rocks in the northeastern-most extremity of the park are the oldest rocks in the region. The most widespread ancient rocks in the park, however, are Mesoproterozoic volcanic rocks that belong to the Midcontinent Rift System (MCRS). A geologic time scale is provided in Table 2 as a helpful reference.

Table 2. Geologic time scale. The column "MYA" refers to "millions of years ago."

Eon	Era(s)	Period(s)	Epoch(s)	MYA
Phanerozoic	Cenozoic	Quaternary	Holocene	0.0117–today
Phanerozoic	Cenozoic	Quaternary	Pleistocene	2.6–0.0117
Phanerozoic	Cenozoic	Neogene	Pliocene	5.3–2.6
Phanerozoic	Cenozoic	Neogene	Miocene	23.0–5.3
Phanerozoic	Cenozoic	Paleogene	Oligocene	33.9–23.0
Phanerozoic	Cenozoic	Paleogene	Eocene	56.0–33.9
Phanerozoic	Cenozoic	Paleogene	Paleocene	66.0–56.0
Phanerozoic	Mesozoic	Cretaceous	Upper, Lower	145.0–66.0
Phanerozoic	Mesozoic	Jurassic	Upper, Middle, Lower	201.3–145.0

Eon	Era(s)	Period(s)	Epoch(s)	MYA
Phanerozoic	Mesozoic	Triassic	Upper, Middle, Lower	251.9–201.3
Phanerozoic	Paleozoic	Permian	Lopingian, Guadalupian, Cisuralian	298.9–251.9
Phanerozoic	Paleozoic	Pennsylvanian	Upper, Middle, Lower	323.2–298.9
Phanerozoic	Paleozoic	Mississippian	Upper, Middle, Lower	358.9–323.2
Phanerozoic	Paleozoic	Devonian	Upper, Middle, Lower	419.2–358.9
Phanerozoic	Paleozoic	Silurian	Pridoli, Ludlow, Wenlock, Llandovery	443.8–419.2
Phanerozoic	Paleozoic	Ordovician	Upper, Middle, Lower	485.4–443.8
Phanerozoic	Paleozoic	Cambrian	Furongian, Miaolingian, Series 2, Terreneuvian	538.8–485.4
Proterozoic	Neoproterozoic	Ediacaran, Cryogenian, Tonian	n/a	1,000–538.8
Proterozoic	Mesoproterozoic	Stenian, Ectasian, Calymmian	n/a	1,600–1,000
Proterozoic	Paleoproterozoic	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

Around 1.1 billion years ago, the North American continent began to rift apart, spewing out over 240,000 cubic miles (1 million cubic km) of volcanic rocks (Figure 2; Stein et al. 2015). Before the rift could fully split the continent apart, it failed, in part due to crustal compression from the Grenville Orogeny, a mountain building event to the east (Figure 3; Stein et al. 2016). Although buried throughout most of the park by Paleozoic bedrock and glacial sediments, Mesoproterozoic volcanic rocks crop out prominently at the upper and lower Dalles of the St. Croix (Figure 4). For more in-depth and interpretation-focused analysis of the MCRS, the park is directed to Stein et al. 2015.

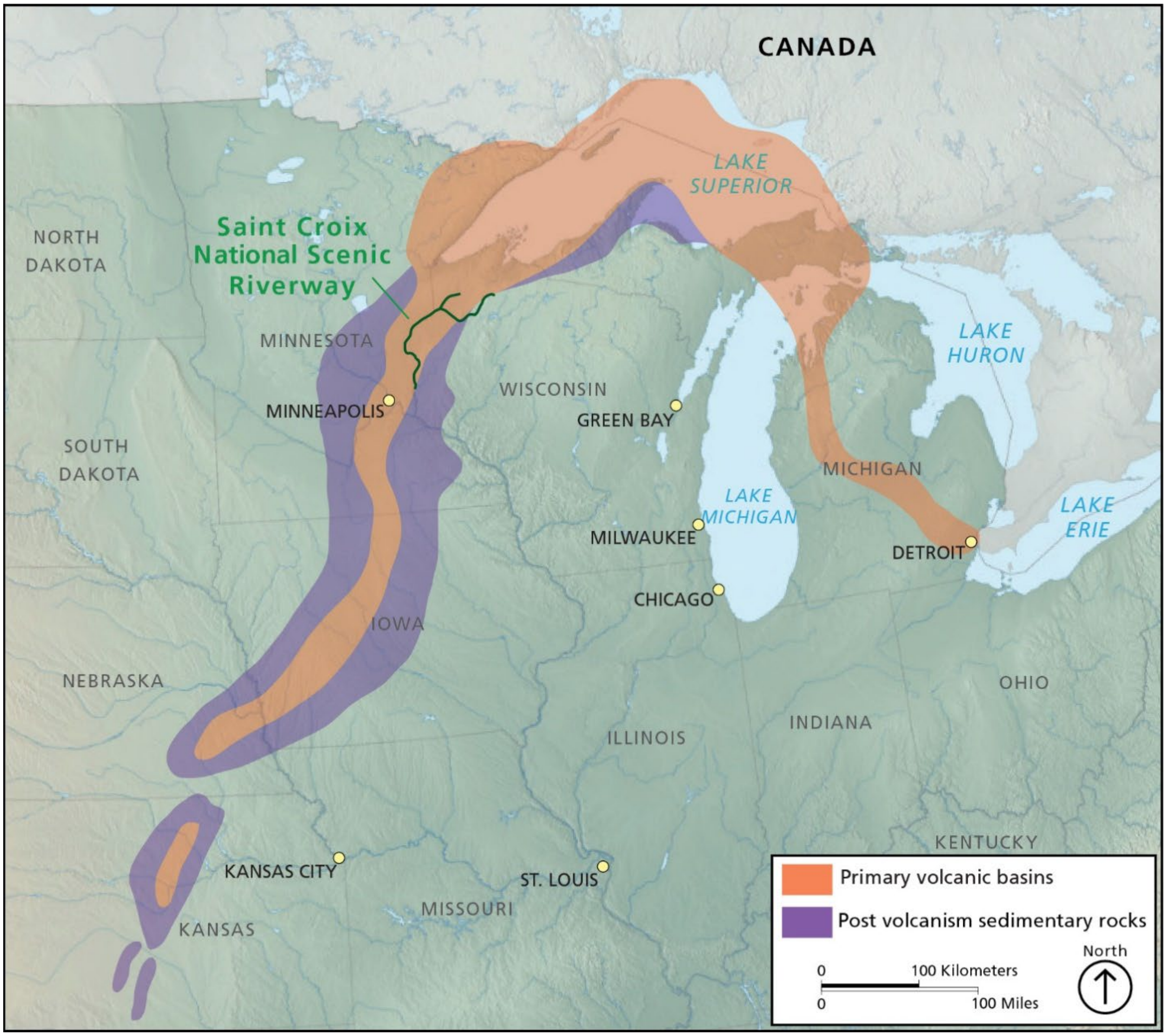
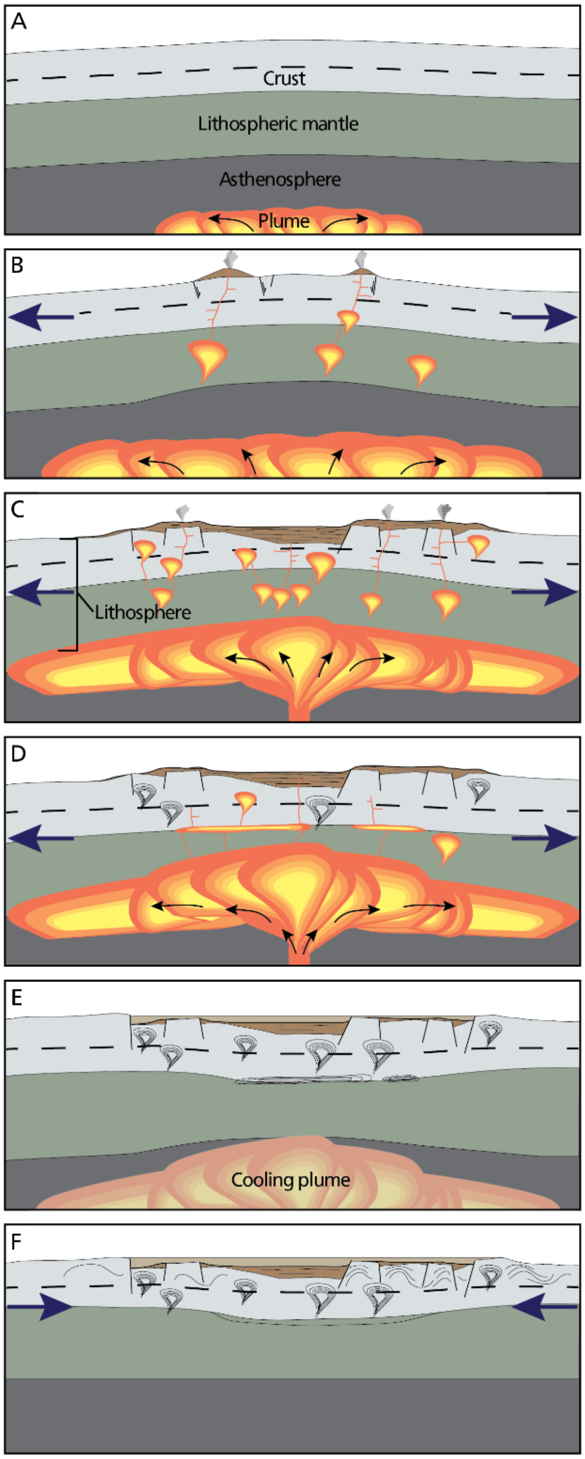


Figure 2. The Mesoproterozoic Midcontinent Rift. The failed rifting event began roughly 1.1 billion years ago and produced a wide variety of volcanic, intrusive, and sedimentary rocks distributed throughout the Great Lakes and the Great Plains. Graphic created by Trista L. Thornberry-Ehrlich (Colorado State University).



A. 1.110 billion years ago: Rifting initiated with a broad, domal uplift over a rising asthenospheric plume.

B. 1.108 billion years ago: Extension reached a point where thinning of the crust and upper mantle occurred. Mantle plumes began to rise and supplied lava to volcanoes on the surface.

C. 1.100 billion years ago: The top of the plume reached the base of the lithosphere and spread out laterally. Grabens developed in the rift axis. Massive volumes of lava extruded onto the surface.

D. 1.094 billion years ago: The plume continued to spread laterally and became the dominant source of lava for volcanic flows and igneous intrusions. Grabens continued to develop.

E. 1.080 billion years ago: The cooling plume dragged the attached lithosphere downward. The added weight of lavas and sediments contributed to sagging. The Jacobsville Sandstone and other sediments were deposited in the rift.

F. 1.060 billion years ago: After extension ceased, compression, possibly from the Grenville orogeny to the east, reactivated zones of weakness and caused regional folding.

Figure 3. Development of the Midcontinent Rift. The rift developed in a series of events: A–F. Large arrows indicate the tectonic stress direction (e.g., extension or compression). The lithosphere and asthenosphere refer to layers in Earth's crust, with the lithosphere being the solid outer crust and uppermost layer of the mantle. The asthenosphere lies beneath the lithosphere, and its material yields readily to persistent stresses in a "plastic" way. Schematic graphics are not to scale and represent a generalized cross section through the rift. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Hinze et al. (1997, figure 19).

Figure 4. The Dalles of the St. Croix, which also include the lesser known Lower Dalles, are exposed ancient volcanic rocks deposited while the Midcontinent Rift System was active roughly 1.1 billion years ago. A) The Dalles of the St. Croix, formed over an ancient fault line in the rock, create a nearly 90° angle in the St. Croix River. This photo was taken from the Minnesota side of Interstate State Park. B) The Lower Dalles, as seen here from the middle of the St. Croix River, consist of the same ancient Archean volcanic rocks of the Dalles of the St. Croix. Photographs by Matthew Harrington (Colorado State University).

Approximately 1 billion years ago to 500 million years ago, any rocks or sediments that may have been deposited atop the MCRS eroded away, leaving a gap in the geologic record called an unconformity.

Approximately 500 million years ago, sea level rose, depositing thick marine sediments across the basin. The sandstones, shales, dolomites, and other sedimentary rocks that formed span the middle Cambrian to the Late Ordovician, with many of the units containing marine fossils. These sedimentary rocks are commonly seen along the river in the form of steep, vertical bluffs or cliffs (Figure 5). For a more in-depth analysis of the Paleozoic strata in the region, the park is directed to Tweet and Santucci (2018).

Figure 5. The St. Croix Boom Site is an excellent place to see the Mazomanie Formation, a fossiliferous sandstone formed in a near-shore marine environment during the late Cambrian. Photograph by Matthew Harrington (Colorado State University).

Following the end of the Ordovician (~450 million years ago), there is another gap in the geologic record where either no rocks were deposited or they were eroded away. This gap in the rock record extends until the glaciations of the Pleistocene.

Throughout the Pleistocene (2.58 million to 11,700 years ago), numerous glacial advances and retreats occurred, with each new glaciation scouring away the evidence of former. Vast quantities of glacial sediments, deposits, and landforms sit directly atop the Mesoproterozoic, Cambrian, and Ordovician rocks in the park.

The most recent, the Wisconsin Glaciation, advanced into the region ~35,000 years ago with the Superior Lobe, and then again ~14,000 years ago with the Des Moines Lobe (Lusardi 1994; Tweet and Santucci 2018). Each glaciation brought about large, glacial lakes fed by glacial meltwater. The Grantsburg Sublobe, part of the Des Moines Lobe, initially flowed over Taylors Falls, diverting the course of the St. Croix farther east than present, carving a river valley that can still be seen near Dresser, Wisconsin (Figure 6; Crawford 2009; Delikowski 2024). Glacial Lake Grantsburg, which formed around the Grantsburg Sublobe, only existed for roughly 100 years (Johnson and Hemstad 1998).

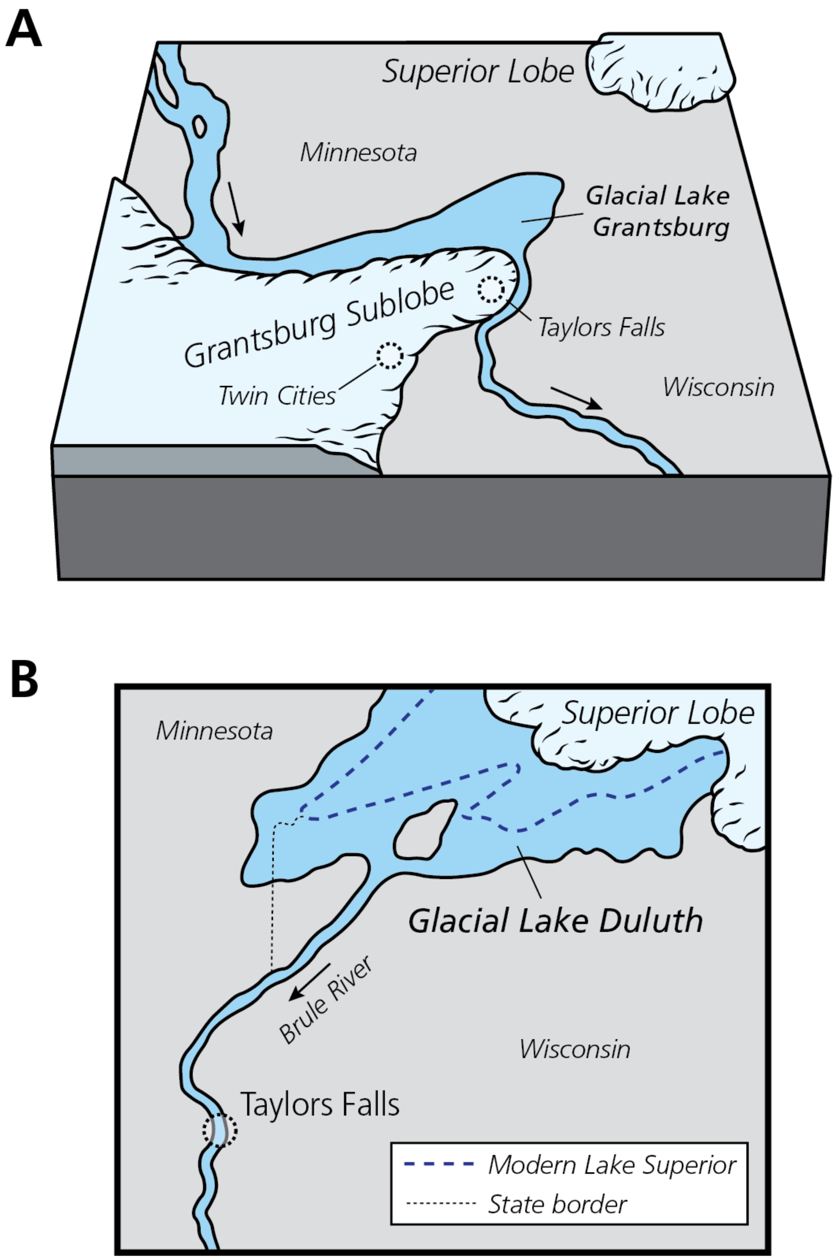


Figure 6. Glacial Lake Grantsburg and Glacial Lake Duluth. A) When the Grantsburg Sublobe advanced into the region roughly 16,000 years ago, it flowed over what are now the Twin Cities and Taylors Falls. Meltwater from the glacier formed Glacial Lake Grantsburg, which drained east of the present course of the St. Croix, as the present course was covered by ice. B) As the Superior Lobe began retreating for the last time across the Superior Basin and into Canada around 11,000 years ago, Glacial Lake Duluth formed at the western extent of the lobe. With water levels hundreds of feet higher than today, both steady drainage and catastrophic ice dam flooding from the lake emptied down the Kettle river valley and then the Brule River into the St. Croix, carving into the volcanic rock at Taylors Falls, creating the Dalles of the St. Croix. Graphics by Matthew Harrington (Colorado State University) adapted from Crawford (2009).

Following the retreat of the Grantsburg Sublobe, Glacial Lake Duluth formed along the southwest edge of the Superior Lobe, over what is now southwestern Lake Superior. Steady meltwater along with potentially catastrophic discharges (created when glacial ice dams break, discharging destructive floodwaters large and powerful enough to alter geomorphic features) from glacial Lake Duluth down the Kettle river valley and then the Brule river valley carved out the modern course of the St. Croix, incising the volcanic rock at Taylors Falls and creating the iconic glacial potholes found on both sides of Interstate State Park (Figure 7; Hudak et al. 2011). The final catastrophic discharge is believed to have occurred sometime between 11,300–11,690 years ago (Hudak et al. 2011).

Figure 7. Examples of filled glacial potholes on the Minnesota side of Interstate State Park. A) Either through natural or human removal, the side of this pothole has been removed, showing the depth of the feature. Water fills the base of the hole. B) This large pothole is filled with debris, masking the depth of the feature. C) This pothole exists between two taller outcrops of volcanic rock and is filled with algae-covered water. Photographs by Matthew Harrington (Colorado State University).

Geologic Heritage

Geologic heritage, or geoheritage, exists where geology overlaps with human experiences and values. It encompasses the significant geologic features, landforms, and landscapes characteristic of our nation, which are preserved for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, tourism, and other values. It is our history told through the lens of geology. This section highlights notable geoheritage at Saint Croix National Scenic Riverway.

Glacial History

The impact glaciers left upon the St. Croix river valley is hard to overstate. The modern channels of the St. Croix River and the Namekagon River, the topography of the region, the creation and location of lakes, and even the formation of the Dalles are all direct results of a complex glacial history in the region. For a comprehensive analysis of the glacial history of the region, including glacial retreats and advances, readers are directed to Cahow (1985), Mickelson et al. (2011), Attig and Mickelson (2017), Dalton et al. (2023), and Delikowski (2024).

- Cahow (1985) – A detailed and comprehensive geologic overview of the entire park.
- Mickelson et al. (2011) – A geologic field trip guide that leads hikers to glacial features in northwestern Wisconsin along the Ice Age National Scenic Trail and at Wisconsin Interstate State Park
- Attig and Mickelson (2017) – A chronology of the Laurentide Ice Sheet's retreats and advances in Wisconsin every 500 years from 31,500 years ago to 11,000 years ago.
- Dalton et al. (2023) – An updated sequence of the deglaciation of the Laurentide Ice Sheet and associated climatic events, sea level changes, and landscape features.
- Delikowski (2024) – An evaluation of the glacial history of the Lower St. Croix, focusing on Glacial Lake Grantsburg, the Osceola Bench, and the Dalles of the St. Croix.

When glacial Lake Duluth existed at the end of the Pleistocene, water in the Lake Superior basin was roughly 500 feet (150 m) higher than the present level (Mickelson et al. 2011). Initially, as ice blocked outlets to the east, water drained through the Moose Lake outlet, down the Kettle River channel, and into the St. Croix River. As the ice retreated, the lower-lying Brule outlet became the primary outlet, and the lake drained through the Bois-Brule River into the St. Croix River (Carney 1996). While researchers have debated if the steady, constant flow of glacial meltwater incised the Dalles, or if catastrophic glacial flood events also contributed (Clayton 1984; Carney 1996), it is understood that glacial outwash and meltwater created the modern drainage system of the St. Croix and Namekagon rivers. At its peak, the discharge of the glacial St. Croix River was almost 200 times that of the modern river; the average discharge of the glacial St. Croix River was about 140 times that of the modern river (Cahow 1985).

Glacial potholes can be found in many places around the world where large glaciers once existed but are commonly limited in quantity or size. With over 100 glacial potholes in the Dalles, some over 20 feet (6 m) wide and others over 50 feet (15 m) deep, no other locale in the world except Switzerland possesses a similar abundance and magnitude of potholes (St. Croix Scenic Byway n.d.). As torrents of water rushed down the glacial St. Croix River, rocks caught beneath eddies of spinning water drilled into the bedrock below, forming the cylindrical potholes that are seen today (Mickelson et al. 2011). The grinding rocks became smooth and spherical over time and occasionally remained within the pothole; two such stones can be seen at the Wisconsin Interstate State Park Interpretive Center.

The potholes around the Dalles vary drastically in size, with some of the smaller potholes measuring only a foot or two (0.3–0.6 m) in diameter, and the largest up to 20 feet (6 m) wide. Many of the larger potholes are filled in with plant debris, boulders, and/or water (Figure 7). One of the larger potholes has a trail leading into the bottom of it (accessible when not flooded), where hikers can stand in awe of the depth of the pothole and take photos looking up and out of the top of the pothole.

Potholes located well above the modern river level indicate that water levels in the St. Croix River during glacial episodes were considerably higher (Figure 8). Rocks on Eagle Peak, located 1 mile (1.6 km) southwest of the Dalles, showcase evidence of scouring by the ancient St. Croix River, indicating the river level at one point maintained an elevation of at least 900 feet (274 m; the modern river elevation is roughly 682 feet [208 m]), well over 200 feet (61 m) higher than the modern level (Mickelson et al. 2011). Another line of evidence for previous river levels is ancient river terraces. Located well above the modern river level, ancient terraces reflect the height of the glacial St. Croix River.

Figure 8. Many of the glacial potholes around the Dalles are well above the modern river, providing evidence that the river level was once considerably higher. This photo was taken on the Wisconsin side of Interstate State Park. Photograph by Matthew Harrington (Colorado State University).

In addition to the potholes, other glacial features exist throughout the park. Around the vicinity of the Dalles, glacial striations can be found atop exposed volcanic rock. Glacial striations are linear grooves or scratches etched into bedrock by rocks and sediments embedded in the base of moving glaciers. These marks indicate the direction of flow of the glacier, providing evidence for ice sheet movements.

Moraines, kames, eskers, and kettle lakes are all common glacial landforms found along the St. Croix and Namekagon river valleys (Figure 9). Moraines, the largest of these features, represent a build-up of rocks, soil, and debris left behind by a glacier as it advances and retreats. These mark the glaciers' edges, paths, or farthest extent. Kames, a mound/hill of sand and gravel formed when sediment is deposited in depressions on a glacier's surface and left behind when the glacier melts, are particularly common along the Namekagon River. Mt. Telemark, the tallest hill in the Namekagon Valley, located two miles (3.2 km) southeast of Cable, Wisconsin, is an example of a glacial kame (Cahow 1985).

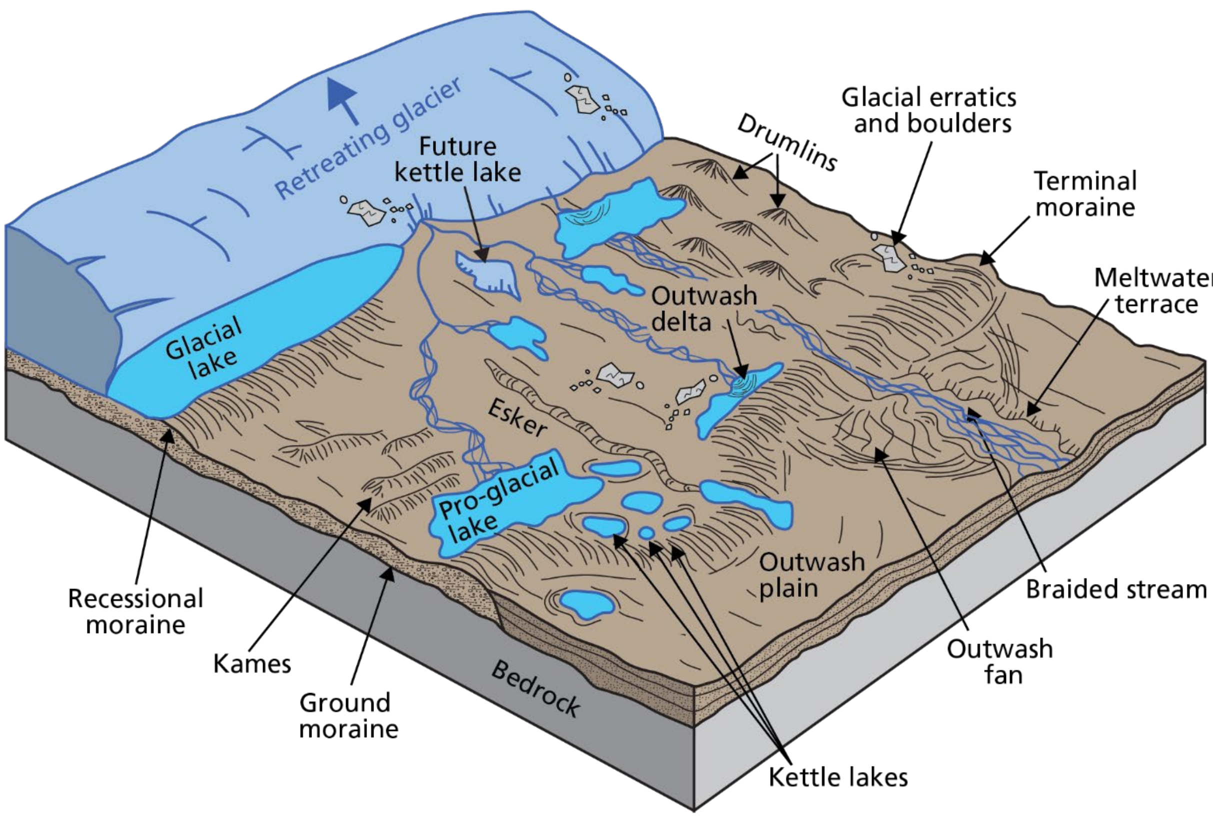


Figure 9. Physiographic features typically created by glacial ice sheets. Within Saint Croix National Scenic Riverway, moraines, kames, eskers, and kettle lakes are very common. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University).

Eskers, which typically are long, winding ridges of sand and gravel deposited by meltwater streams flowing beneath a glacier, are very common along both rivers. Figure 10 shows an example of a possible esker near Peaslee Island, Wisconsin. The narrow winding ridges of eskers can often be identified on topographic and LiDAR maps, where they often appear in groups. Kettle lakes, formed when a chunk of ice from a retreating glacier gets buried in sediments, melts, and leaves a depression that subsequently refills with water, are another prominent glacial feature across the park. These lakes are particularly common along the Namekagon River and Upper St. Croix River, where extensive glacial outwash plains from glacial ice sheets left behind thousands of ice-block depressions (Cahow 1985).

Figure 10. A possible esker located near Peaslee Island, along the St. Croix River. A park ranger can be seen in the center of the esker (circled) for scale. Photograph by Matthew Harrington (Colorado State University).

Drumlins exist in the region, although they are less commonly seen than moraines, kames, eskers, and kettle lakes. Drumlins are smooth, elongated hills made of glacial sediment formed by glacial movement. In the St. Croix river valley, the Superior Lobe stagnated before retreating for the final time, creating an environment better suited for the creation of kames, eskers, and kettle lakes than drumlins (Cahow 1985).

Much smaller in scale than glacial landforms, glacial erratics (large rocks or boulders transported and deposited by a glacier, often far from its original location) are also commonly found throughout the park. Glacial erratics can vary drastically in size from small, hand-held rocks to massive boulders over 40 feet (12 m) wide. Within the park, smaller, basketball-sized erratics are common, and can be easily seen along hiking trails such as those in the Arcola Bluffs Day Use Area and the North Country National Scenic Trail (Figure 11). One of the largest glacial erratics in the park can be seen near the Namekagon Dam, near the gravel parking area (Figure 11). The Superior Lobe carried this massive boulder to its current location during the last Ice Age; it was left behind when the ice sheets melted.

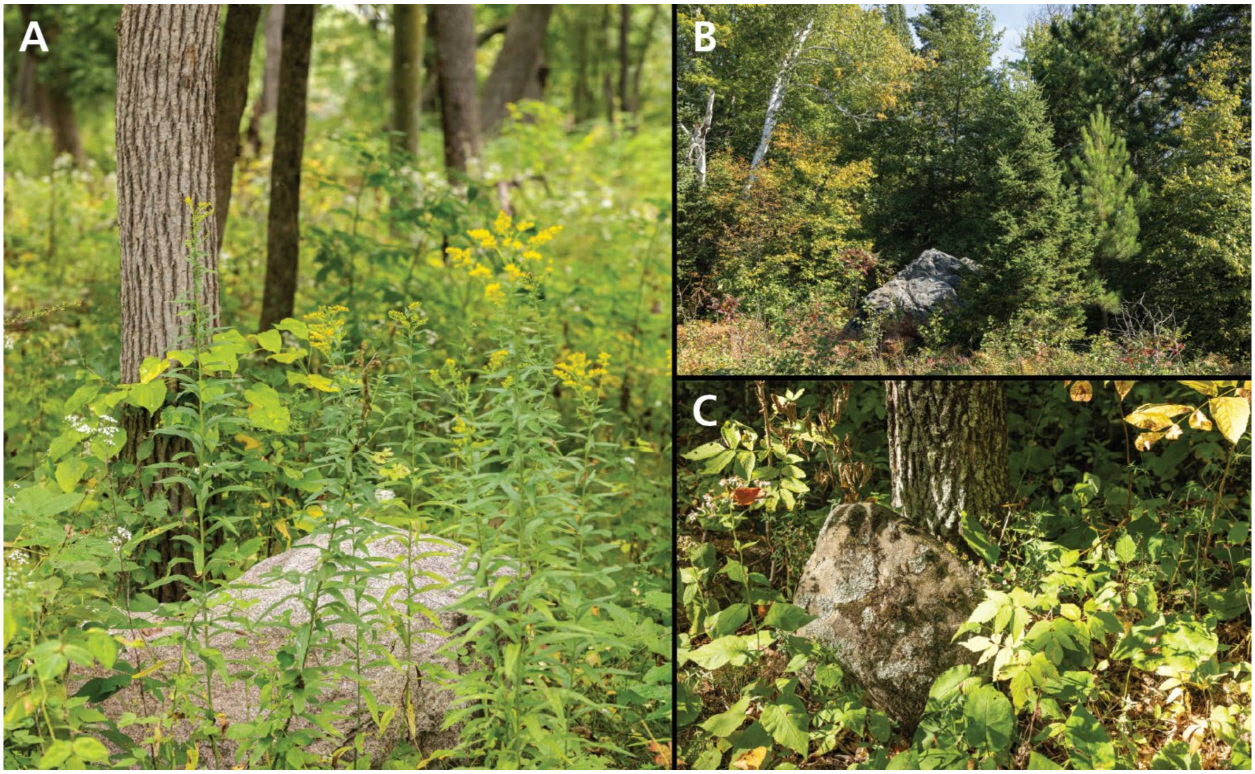


Figure 11. Glacial erratics are large rocks or boulders transported and deposited by a glacier, often far from its original location. These features can be found throughout the park, with a wide variability in size. A) A smaller glacial erratic lies at the base of a tree in the Arcola Day Use Area. B) A massive glacial erratic can be found near the parking area at the Namekagon Dam. Note the fully grown trees for scale. C) Small glacial erratics such as this one are common along the North Country National Scenic Trail in the park near the Upper St. Croix River. Photographs by Matthew Harrington (Colorado State University).

Indigenous Connections

Humans have occupied the St. Croix river valley for at least the past 11,500 years, entering the region following the retreat of glaciers at the close of the Pleistocene. Despite this, within park boundaries, the Paleo-Indian and Archaic eras (11,500–500 years BCE) are poorly represented, with few archeological remains (NPS 2019). Fluted points have been found north of the park and across the Great Lakes region, indicating that future finds could be possible. The Woodland stage (500 BCE to 1000 CE), however, is well-represented with a diversity of sites including rock art, former village sites, quarries, and burial mounds (NPS 2019; Figure 12).

Figure 12. An indigenous burial mound along the St. Croix River. Photograph by Matthew Harrington (Colorado State University).

In the period from 1000 CE to present, the Dakota, Ojibwe, and Fox lived in the region, and actively utilized the St. Croix and Namekagon river valleys for a wide array of resources. The rivers provided ample fishing, a mosaic of mature forest and prairie that sustained herds of elk and bison, and geological resources for tools, weapons, and cultural materials.

These nations were occasionally at conflict with each other, and one of the more notable battles occurred in 1770, at the Dalles of the St. Croix. The Dakota allied themselves with the Fox and engaged a large Ojibwe force at the Dalles. Confined by the narrow, rocky ravines of the ancient volcanic rocks, the fighting was intense and close-quartered. Many of the combatants were driven over the rocky cliffs into the cold, swirling waters of the St. Croix River below (McMahon and Karamanski 2002). A last-minute arrival by a war party of the Sandy Lake Ojibwe turned the tide of battle in favor of the Ojibwe, but the conflict took a heavy toll on all the nations, particularly the Fox (McMahon and Karamanski 2002).

Fur Trade, Logging, Dams, and Mining

Before the fur trade exploded on the St. Croix River and decimated the beaver population, their impact on the hydrology of the river system was notable. The abundance of dams, beaver ponds, and felled trees slowed the flow of tributary streams throughout the St. Croix river valley and trapped sediment flowing within the streams, filtering the water that entered the St. Croix River (Outwater 1996; McMahon and Karamanski 2002). As a result, the St. Croix River was clearer and less prone to flooding, the water table was higher, and springs were more abundant throughout the region (McMahon and Karamanski 2002). The loss of the beaver was the first of major alterations to come to the riverway.

Following the decline of the fur trade, logging became the primary industry along the St. Croix River. After felling trees all summer and autumn along the upper St. Croix River and its tributaries, logging companies needed to transport the logs downstream for processing. The construction of dams, built on smaller streams, tributary rivers like the Namekagon River, and the St. Croix River itself, were essential to create water levels high enough to float logs downstream (McMahon and Karamanski 2002). Meandering streams were straightened, boulders were removed, and entire forests were clear cut. The main channel of the St. Croix River went from eighty miles of transportable river to over one hundred miles between 1849 and 1869 (McMahon and Karamanski 2002).

Massive log drives were held every spring immediately following ice breakup, when natural water levels were at a high. But even with increased water levels from snow melt and damming, the St. Croix River possessed numerous rocky passages and choke points that were challenging for loggers. The most troublesome location along the St. Croix River, the Dalles, features a sharp, right-angle turn (Figure 4); a relic of ancient faulting in the Midcontinental Rift System. This stretch of river, already narrow and flanked by steep, vertical cliffs on both sides, created the perfect conditions for a massive bottleneck.

Some of the most intractable and spectacular log jams in logging history occurred at the Dalles, then known as Angle Rock (McMahon and Karamanski 2002). In 1865, a log jam at the Dalles extended 1.25 miles (2 km) upriver, attracting considerable attention from the local community. Excursion boats were chartered from Hudson, Wisconsin, Prescott, Wisconsin, and St. Paul, Minnesota to allow people to gape at the river of logs, frozen in place (McMahon and Karamanski 2002). Photographers and adventurous visitors even climbed out onto the log jam, taking photos of themselves standing amidst the piles of floating timber (McMahon and Karamanski 2002).

In 1886, despite over 50 years' worth of experience driving logs down the St. Croix River, an even larger log jam occurred, this time blocking over 150 million feet of pine (Figure 13; McMahon and Karamanski 2002). This jam stretched all the way to the falls and at least two miles beyond, catastrophically stopping any transport of timber. The front of the jam was repeatedly dynamited (to no success), steamboats attempted to attach to and drag the logs free, and overhead wires were installed to lift the logs up from the pile (McMahon and Karamanski 2002). In order to dissolve the jam as quickly as possible, large electric lights were installed atop the rocky cliffs, allowing workers to work 24 hours a day; interestingly, these lights were the first electric lights many people in the remote country of the St. Croix river valley had ever seen (McMahon and Karamanski 2002).

Figure 13. A photograph of the 1886 log jam along the St. Croix River. The log jam, created by the sharp bend in the river at the Dalles, stretched for miles upriver and took weeks to untangle. Photograph by unknown photographer available at https://commons.wikimedia.org/wiki/File:Log_jam_on_the_St._Croix_River_4343.jpg (accessed 19 May 2026) (Creative Commons Attribution 2.0 [CC by 2.0] Generic License).

At its peak output in 1890, the St. Croix river valley produced 450 million board feet, and the total production between 1840 and 1912, if loaded onto log railway cars, would have needed 2.2 million cars (McMahon and Karamanski 2002). The rapid, dramatic loss of the valley's old growth forest was the next major change to the region. Over 4,000 square miles (10,360 km^2) of old-growth white pine, with many trees over two to three hundred years old, were clear cut, creating an ecological shift not seen since the glaciers retreated.

The St. Croix River was permanently altered by the almost 75 years of intensive logging: what was a wild, free flowing river in 1837 (outside of a handful of Ojibwe fish weirs), had become one of the most manipulated and controlled rivers in the country (McMahon and Karamanski 2002). There were anywhere from 60 to 70 gated dams across the St. Croix watershed and an uncounted quantity of temporary (but ecologically damaging long-term) splash dams, created from brush, logs, and dirt (McMahon and Karamanski 2002). The hydrological impact was noticeable: the water no longer flowed as clear, and riverbanks were considerably more prone to erosion. In the far upper reaches of the St. Croix River, the dam constructed at Gordon created the St. Croix Flowage, flooding the marshy shores and destroying one of the most abundant wild rice habitats in the upper Midwest, what had once been a staple for the Dakota and Ojibwe people (McMahon and Karamanski 2002).

The history of mining in the St. Croix river valley was limited, primarily due to the scarcity of ore along the riverway. In the late 1760s, an English explorer named Jonathan Carver attempted to name the Namekagon the Coppermine Branch, having apparently discovered an abundance of copper along the banks of the river (McMahon and Karamanski 2002). It must not have amounted to much copper, as no copper mining operation occurred along the Upper St. Croix River until 1880, when two brothers from Taylors Falls began a copper mine on the Wisconsin side of the Dalles (McMahon and Karamanski 2002). Only small operations focused on copper mining occurred within the park; near the present site of the Coppermine Dam and near Interstate State Park in Wisconsin, near the ruins of the mansion. Both endeavors failed to produce profitable results. While copper-bearing rocks were common further north and east, particularly in the Keweenaw Peninsula, these deposits were buried under extensive glacial drift within the St. Croix river valley, creating a costly and difficult barrier.

Stratotypes

Stratotypes are important geologic reference exposures that help identify, define, and correlate geologic units from one location to another. When geologists propose or describe a new layer or body of rock, a stratotype is assigned to exposures containing all (or most) of the unique diagnostic criteria. Stratotypes have significant scientific value and are often easily accessible, world-class locations to study outcrops of rock. Akin to natural libraries of Earth history, stratotypes preserve meaningful clues to the past and serve as geologic classrooms. 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 (e.g., the Cretaceous Mesaverde Group named for Mesa Verde National Park, Colorado).

One stratotype has been formally identified as within or very close to the boundaries of Saint Croix National Scenic Riverway. The late Cambrian Franconia Formation, located near Franconia, Minnesota, primarily consists of thick-bedded, fine-grained white quartz sandstone with some seams of green shale (Henderson et al. 2021). However, the Franconia Formation has since been superseded by the Lone Rock Formation of the Tunnel City Group (Tweet and Santucci 2018).

Paleontological Resources

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. All fossils are nonrenewable resources.

The paleontological resources within the park primarily consist of late Cambrian and Ordovician (500–470 million years ago) marine invertebrates: brachiopods, trilobites, and trace fossils (Figure 14). To a lesser extent, fossils from the Late Pleistocene and early Holocene, including fossil spores, pollen, and vertebrates have been found within Lake St. Croix and Interstate State Park on the

Wisconsin side (Tweet and Santucci 2018). For a comprehensive analysis of the history of paleontological work in the region, the paleontological resources in and around the park, and the taxonomy of the fossils, readers are referred to the paleontological resources inventory by Tweet and Santucci (2018).

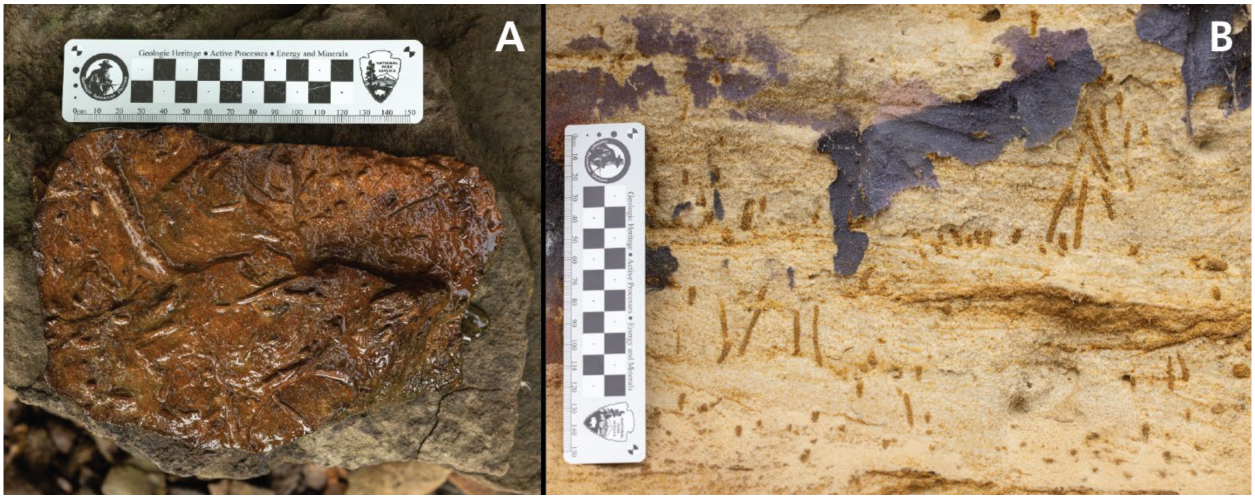


Figure 14. Examples of trace fossils found within the park. A) Fossilized burrows of an unknown ichnotaxon or ichnotaxa in the siltstone of the Tomah Member of the Lone Rock Formation near Marine Mill. B) Skolithos trace fossils (worm-like burrows) in the Mazomanie Formation near the St. Croix Boom Site. Photographs by Matthew Harrington (Colorado State University).

Recreation

Today, the park receives over 900,000 visitors annually, with recreationists enjoying paddling, boating, fishing, camping, and hiking along the riverway. The first documented tourist arrived via steamboat in 1823; an Italian named Giacomo Beltrami (McMahon and Karamanski 2002). He was awed by the towering bluffs along the river, comparing their scenery and beauty to the Rhine River in Europe (McMahon and Karamanski 2002).

In the late 1840s, the tourism industry to natural places was only in its infancy, but early attempts to draw tourists utilized artwork to promote the romantic and sublime destination that was the Dalles. One of the earliest paintings of the Dalles, “Gorge of the St. Croix,” painted by Henry Lewis in 1847, depicted a steamboat along the St. Croix River, surrounded by towering cliffs and large white pines (Figure 15). The shift in ideology from focusing primarily on resource extraction to valuing recreation, in part driven by the geologic wonders of the park, began the path towards future protection for the river.

Figure 15. “Gorge of the St. Croix” by Henry Lewis, 1847. A historic painting of the Dalles of the St. Croix, depicting a romanticized version of the landscape, featuring the towering rocky cliffs over the St. Croix River. Painting by Henry Lewis available at https://commons.wikimedia.org/wiki/File:Henry_Lewis_-_Gorge_of_the_St._Croix_-_47.5_-_Minneapolis_Institute_of_Arts.jpg (accessed 19 May 2026) (Creative Commons Attribution 2.0 [CC by 2.0] Generic License).

In the late 1860s, street builders from St. Paul, Minnesota, began experimenting with building roads with crushed rock sourced from the Dalles (McMahon and Karamanski 2002). To the young George Hazzard, who had first visited the St. Croix river valley in 1857 on a steamship and immediately fallen in love with the landscape, the notion was abhorrent (McMahon and Karamanski 2002). He worked diligently over the following decades with local business owners, landowners, and government officials to protect the Dalles, eventually leading to the official creation of Interstate State Park in 1899 (McMahon and Karamanski 2002). Although his work in protecting the region was invaluable for future recreationists, not all his aspirations came to fruition. In the early 1900s, Hazzard repeatedly pushed for the creation of a canal between the Bois Brule River and the Upper St. Croix River, creating a linkage between the Upper Mississippi River and Lake Superior (McMahon and Karamanski 2002). However, the Army Corps of Engineers, upon reviewing the plan, shut down the proposal.

Geologic formations around the Dalles were a strong draw to early tourists, featured on postcards and advertisements. They also doubled as easily identifiable navigational markers, providing boaters and paddlers easy landmarks to look out for. One such formation, known as the Devil’s Chair, towered over the river in a narrow spire, resembling a chair at the top (Figure 16). Composed of the same ancient volcanic rock that comprises the rest of the Dalles, the formation tragically toppled in 2005 (United Press International 2005). Initially assumed to be the work of vandals, it is probable that increased vehicle traffic and the ground tremors they cause led to the toppling of the precariously stacked rock. Another famous formation is the "Old Man of the Dalles." Located on the Wisconsin side of Interstate State Park, this formation faces out over the Dalles near the right-angle bend in the river (Figure 17). The Old Man of the Dalles has long been featured on postcards from the park and remains an iconic and recognizable feature of the St. Croix River.

Figure 16. A 1918 photograph of the Devil's Chair, a now-toppled formation on the Minnesota side of Interstate State Park. Public domain photo. National Park Service photo available at https://commons.wikimedia.org/wiki/File:Devils_Chair.jpg (accessed 19 May 2026) (Creative Commons Attribution 2.0 [CC by 2.0] Generic License).

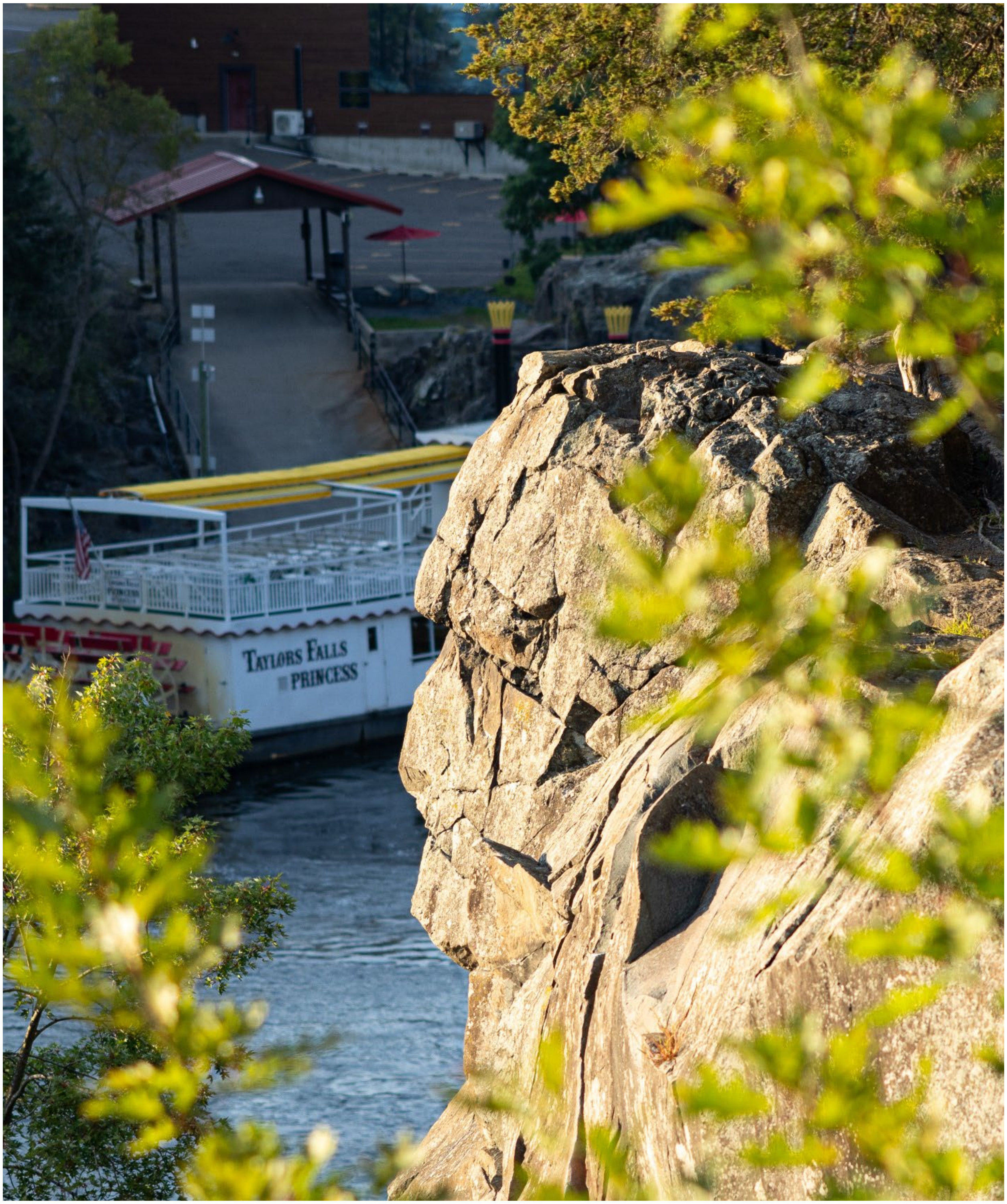


Figure 17. The Old Man of the Dalles. This rock formation that looks like the side profile of an old man has greeted visitors of the St. Croix for millennia. Photograph by Matthew Harrington (Colorado State University).

Caves 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 (Toomey 2009). Over time, dissolution can create open spaces or voids in the bedrock that develop into larger interconnected cavities or passages. In contrast, pseudokarst topography resembles true karst but is formed through non-dissolution mechanisms such as jointing (the development of cracks or fractures that lack displacement) and lava emplacement (lava tubes). Both karst and pseudokarst are considered valuable geologic resources within the NPS but present several hazards (e.g., surface collapse, ceiling collapse, rockfall), as the dissolution or fracturing of bedrock often weakens its structural integrity. Caves are naturally occurring underground voids such as solutional caves (commonly associated with karst), lava tubes (tunnel-like caves in a lava flow after lava has stopped flowing), sea caves (clefts or cavities in a sea cliff), talus caves (a void among collapsed boulders), regolith caves (formed by soil piping), and glacier caves (ice-walled caves) (Toomey 2009). Various inventory and monitoring methodologies for cave and karst landscapes are outlined in Toomey (2009).

Both natural and artificial caves exist along the riverway, almost exclusively between Osceola and the Arcola Day Use Area (Cahow 1985). With most of the bedrock along the riverway consisting of sandstone and shale, ideal conditions for cave-forming are not present. All the caves (regolith caves) along the riverway have formed by a process called piping. Water from natural springs seeps out at the contact between permeable sandstone underlain by impermeable shale. As the water percolates through the sand, it dissolves the natural cement holding together the sand grains, loosening the grains and eventually removing them via the water flow. Over time, the cave is enlarged as this process continues the cycle of dissolution and removal.

The largest cave along the riverway, Knapps Cave (Figure 18), is located on the Minnesota side of the St. Croix River within park boundaries, near the town of Scandia. The mouth of the cave is over 30 feet wide (9 m) and 14 feet tall (4 m), with a rich cultural history (Anderson 2024). Native American pottery tracing centuries of human presence has been recovered within the cave and in the 1850s, Swedish immigrants wintered in the cave to survive until they could build a permanent log cabin in the spring (Lauritsen 2024). Smaller caves can be found 1–2 miles (1.6–3.2 km) upriver along the Wisconsin-side bluffs but are difficult to access and often have standing water or active spring flow (Cahow 1985).

Figure 18. Knapps Cave is the largest cave along the St. Croix and has been utilized by people for centuries. The cave has seen usage by indigenous people, Swedish immigrants, and recreational hikers. Photograph by Matthew Harrington (Colorado State University).

Around the vicinity of Stillwater, Minnesota, artificial caves created during the lumbering era still exist along the riverway. These caves served as natural refrigerators for storing food and beer (Cahow 1985). Some of these caves were excavated over 100 feet deep, with multiple branching rooms (Cahow 1985). One of the best examples of the artificial caves can be found at the St. Croix Boom Site, located two miles (3.2 km) above Stillwater. This cave was carved directly into the Mazomanie sandstone right alongside the river (Figure 19). Although it has since been marked by graffiti (see "Theft of Geological or Cultural Resources and Graffiti" for more information), it remains an accessible example of an artificial cave, preserving a geoheritage connection between loggers and the ancient sandstone.

Figure 19. Artificial caves such as the one at the St. Croix Boom Site were excavated by loggers to create temperature-controlled storage for food and beer. NPS paleontologist Justin Tweet for scale. Photograph by Matthew Harrington (Colorado State University).

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 Saint Croix National Scenic Riverway staff. Geologic issues refer to problems related to geologic resources. Inventory needs are highlighted to summarize what is currently known and what information is needed for management of the Saint Croix National Scenic Riverway. 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.

Erosion, Mass Wasting, and Flooding

Riverbank erosion along the St. Croix and Namekagon rivers is a natural and frequent response to both short-term and long-term variations in streamflow and sediment input from the surrounding watershed. When rivers have the freedom and space to adjust to fluctuations in water and sediment input, they are remarkably resilient (Field et al. 2025).

One of the more common forms of riverbank erosion along the St. Croix River is the undercutting of banks by hydraulic action (the process of moving water eroding rock and sediments), followed by mass failure of the bank, and expansion of the channel (Figure 20). This process can be natural for riverbanks, but erosion can be triggered or exacerbated by human interference upstream. Stabilization efforts should only be considered when such erosion poses undesirable impacts to human uses of the river corridor, cultural resources, or park assets. For a comprehensive analysis of best practices for managing bank erosion within the NPS, readers are directed to Field et al. (2025).

Figure 20. Erosion along the St. Croix and Namekagon rivers often leads to bank undercutting and collapse. A) A tree tilts toward the Namekagon River due to its foundation having slumped into the water. B) Undercutting along a bank of the Namekagon River. The roots of the grasses and plants above will hold together the upper layer as the layer under it eventually collapses into the river. Backpack for scale. Photographs by Matthew Harrington (Colorado State University).

The areas most prone to river erosion that also possess the potential to negatively impact human use are located at landings along both rivers. While some landings (including those at Osceola and Interstate State Park) possess infrastructure for loading and unloading boats, many of the smaller, more remote landings utilize no infrastructure and are at risk of erosion. For example, at Phipps Landing, along the Namekagon, the access point to the river has eroded, creating a steeper, less accessible entry and exit point (Figure 21). Monitoring the landings throughout the park should be helpful in determining if active management will be required to stabilize access points.

Figure 21. Erosion along river landings has the potential to create challenges for boaters, floaters, and other recreational users. A) Phipps Landing along the Namekagon River has eroded along its access point. The access point is steep and could present issues to floaters attempting to leave the river. B) A close-up of the access point, where roots are holding together what hasn't been eroded away. Photographs by Matthew Harrington (Colorado State University).

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 (Wieczorek and Snyder 2009). Along the riverway, mass wasting events are generally influenced by erosional or freeze-thaw processes related to seasonal fluxes in temperature, rainwater, and snowmelt. However, several other factors, including geology (e.g., lithology, faults, folds, joints, swelling clays), slope angle, and aspect (slope direction), help control the development of landslides. These naturally occurring geologic disturbances not only reorganize the physical context and dynamics of the park but also pose a considerable hazard to visitors, park staff, infrastructure, ecosystems, and other natural resources. Mass wasting events can vary from minor inconvenience to life-threatening disaster and have the potential to destroy trails, damage buildings, disrupt utilities (e.g., electricity, water), and bury sensitive geologic features. Various inventory and monitoring methodologies regarding mass wasting are outlined in Wieczorek and Snyder (2009).

A map of landslide susceptibility for the park from the USGS Landslide Hazard Program shows the potential of landslides along the river corridor (Figure 22). While most of the park has low to no landslide potential, the Lower St. Croix bears moderate to high susceptibility areas due to the presence of towering geologic bluffs along the river. More information on landslides can be found on the program's website: https://www.usgs.gov/programs/landslide-hazards.

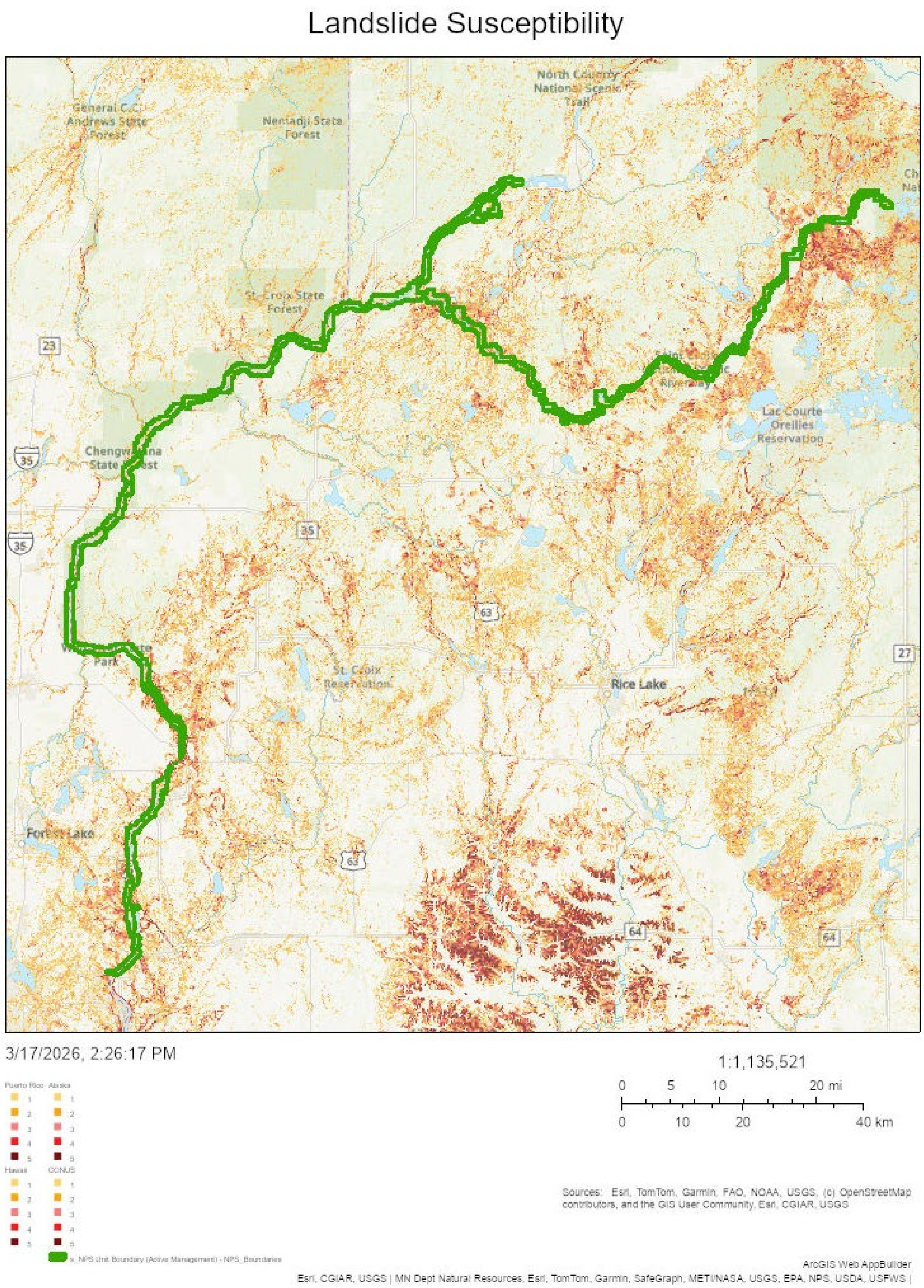


Figure 22. A map of landslide susceptibility for Saint Croix National Scenic Riverway and vicinity. These maps are useful for land-use planning and reducing risks. Landslide susceptibility is shown with colors ranging from yellow (lower) to red (higher), while areas with no color have negligible risk. Landslide susceptibility is highest along the Lower St. Croix River where river bluffs are prominent. Graphic created with the USGS Landslide Inventory Web Application (https://www.usgs.gov/tools/us-landslide-inventory-and-susceptibility-map) using data from Mirus et al. (2024) and Belair et al. (2024).

Flooding along the St. Croix and Namekagon rivers remains an annual hazard, with factors such as snowpack quantity, rate of snowpack melting, spring temperatures and spring precipitation determining the severity of floods. Large, catastrophic floods have occurred along the rivers, most recently along the St. Croix River in 1965 and 2001, where the river flowed up to 19 feet (5.8 m) above normal levels (Minnesota Department of Natural Resources 2019). For up-to-date flood hazard data, the park is directed to the FEMA National Flood Hazard Layer (https://www.fema.gov/flood-maps/national-flood-hazard-layer).

Theft of Geological or Cultural Resources and Graffiti

Vandalism of rock faces is a concern for the park. In various areas of the park, including the St. Croix Boom Site, Fairy Falls, and Sandrock Bluffs, graffiti and etchings are very common (Figure 23). Vandals have defaced entire boulders and rock exposures with graffiti in a short time and given the layout of the park's boundary (over 230 miles of riverway), monitoring or preventing these activities is very challenging. Graffiti on rock faces can be difficult and costly to remove and often is permanent. When sandstone bluffs are graffitied, any attempt to clean the surface would result in the removal or erosion of the sandstone itself. In the case of graffiti at the St. Croix Boom Site, that would entail the destruction of paleontological resources (Figure 23).

Figure 23. Graffiti on geological resources damages the resource, negatively impacts the viewscape, and is illegal. Photos of vandalized rocks at Fairy Falls (A) and the St. Croix Boom Site (B, C, & D). Photographs by Matthew Harrington (Colorado State University).

Theft of cultural and paleontological resources is an active concern. Eroding fossils, particularly fossil brachiopods and trilobites, are potentially at risk of collection by uninformed visitors who aren't aware that fossil collection is illegal on park lands. However, most of the commonly visited sites in the park are not at major risk of paleontological theft, as the primary fossils at these sites are trace fossils without a physical form (e.g. *Skolithos* [Figure 14] vs a fossilized shell of a brachiopod) to steal. There are no known major hot spots of illegal fossil collection along popular trails or landings. Cultural resources, including indigenous and historic materials and artifacts, are always at risk of theft. Protecting the locations of known sites can help to limit theft and disturbance.

Disturbed Lands

Disturbed lands occur where natural conditions and processes have been directly impacted by development, including facilities, mining, roads, dams, campgrounds, and trails; agricultural activities such as farming, grazing, timber harvest, and irrigation ditches; and overuse or inappropriate use. 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.

Active Mining and Abandoned Mineral Lands

Although mining was not as prominent along the St. Croix river valley as it was on the Keweenaw Peninsula, minor operations did occur along the river. The NPS Geologic Resources Division (GRD) maintains an Abandoned Mineral Lands (AML) database (https://irma.nps.gov/AML/, accessible on NPS computers only). According to the database (accessed 28 January 2026), the park currently has 20 AML features at 4 unique locations. However, only three of the features (all being surface mines) lie within park boundaries: near the St. Croix Boom site, just above the state zone of the park on the Minnesota side of the river (in Washington County, Minnesota), north of Osceola (in Chisago County, Minnesota), and near the CCC Bridge Landing on the Upper St. Croix (in Burnett County, Wisconsin). The sites near Osceola and the CCC Bridge Landing currently require no action. The site near the St. Croix Boom Site is awaiting an assessment.

Active mines and AMLs present numerous hazards that pose significant risk to public safety, as well as natural and cultural resource integrity. The large-scale excavation of mineral resources alters natural drainage patterns and produces large tailings or waste rock piles that can lead to destabilization, erosion, and degradation of the local viewshed (Burghardt et al. 2014). Additionally, these sites can contain contaminants that may be released into the surrounding soil, water, or air. The principal cause of death attributed to AMLs is drowning in quarries or pits that may be deceptively deep, dangerously cold, and contain old machinery or other hazards hidden beneath the water's surface (AML Dangers | Bureau of Land Management). Additional causes of death or injury related to AML sites are attributed to (1) falls in vertical shafts or open stopes at abandoned mines; (2)

deadly gases and radioactive air trapped in confined spaces; (3) unstable structures prone to collapse; (4) steep and unstable pit highwalls; (5) sharp, wooden infrastructure or rusty machinery; (6) unexploded ordnance; and (7) other hazardous chemicals discarded during mining operations (Burghardt et al. 2014).

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, two counties around the park are identified as zones of highest potential (zone 1) for elevated indoor radon levels greater than 4 pCi/L: Washington County, Minnesota and St. Croix County, Wisconsin (see https://www.epa.gov/radon/epa-maps-radon-zones-and-supporting-documents-state; accessed January 2026). Although radon is of relatively little concern for outdoor hikers, these ratings apply to AML sites or infrastructure (e.g., visitor centers, maintenance buildings) along the riverway. Refer to the EPA for guidance for radon mitigation.

Inventory Needs

The following table (Table 3) presents several geologic and soil resources inventory needs that were identified during the 2024 follow-up meeting, in NPS planning documents, or through literature review.

Table 3. List of identified geologic and soil resource inventory needs for the national park.

Subject	Inventory Need(s)
Abandoned mineral lands	Comprehensive inventory of historic mining sites across the park
Geohazards	Inventory of known slumping/mass wasting sites
Geoheritage	Comprehensive guide/inventory of all glacial activity in the St. Croix valley (also benefits the interpretation of the last Ice Age in the park)
Geoscience Research	Comprehensive inventory of glacial features in and around the park
Mapping	Bedrock geologic map, particularly for sites of high ecological value
Paleontology	Inventory of sites that present opportunities for theft or damage

Legislatively Required Geologic Inventories

Certain laws, regulations, and policies apply specifically to geologic and soil resources or processes. The NPS GRD has developed an article series (Geology & Minerals—Resource Laws, Regulations, and Policies; accessed January 2026) 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: Geoheritage Framework (accessed January 2026).

Caves and Karst

All cave features are nonrenewable resources. The Federal Cave Resources Protection Act of 1988 stipulates that all "significant caves" in NPS areas will be identified, regulation or restriction of use will be employed as needed to protect cave resources, and significant caves will be included in land management planning. The act also imposes penalties for causing harm to a cave or cave resources and exempts park staff from releasing specific location information for significant caves in response to a Freedom of Information Act request. For more on caves and karst, see "Caves and Karst" in the "Geologic Heritage" section.

Geothermal Features and Springs

Geothermal refers to heat or energy produced in Earth's interior. Geothermal features may include geysers, fumaroles, hot springs, and bubbling mud pits. The Geothermal Steam Act of 1970, amended in 1988, prohibits geothermal leasing in parks, and authorizes the Secretary of the Interior to mitigate or not issue geothermal leases outside parks that would have a significant adverse impact on significant thermal features in the 16 park units listed in the act.

Although the park does not possess any geothermal features, natural springs are abundant along the St. Croix and Namekagon rivers (see the Minnesota Spring Inventory for spring location information and additional physical, chemical, and historical data for spring sites, where available. https://www.dnr.state.mn.us/waters/groundwater_section/mapping/springs-msi.html). Along the Lower St. Croix, springs commonly seep out between rock units, typically where a permeable sandstone overlies an impermeable shale (Figure 24).

Figure 24. A spring seeping water beneath the Mazomanie Formation, approximately at the contact with the underlying Lone Rock Formation. Photograph by Matthew Harrington (Colorado State University).

Paleontological Resources Inventory and Protection

All paleontological resources are nonrenewable and subject to science-informed inventory, monitoring, protection, and interpretation as outlined by the 2009 Paleontological Resources Preservation Act (PRPA). Fossils in NPS areas occur in rocks or unconsolidated deposits, museum collections, and cultural contexts such as building stones or archeological resources. For more information on the paleontological resources of the park, see “Paleontological Resources” in the “Geologic Heritage” section.

Summary of Geologic and Soil Hazards

The natural resources that attract visitors to a park (e.g., waterfalls, steep terrain, and caves) may also be hazardous. Geologic hazards, or "geohazards," are naturally occurring, dynamic geologic processes that have the potential to cause damage, loss of property, injury, or loss of life. The Natural Hazards Handbook (NPS 2025) provides a process and information to help teams and decision-makers identify, avoid, and mitigate risks associated with natural hazards and their effects on planned and proposed facility investments. The handbook supports reviews made during the regional or bureau investment review board (BIRB) process. Managers should apply the guidance in the handbook to identify options to manage natural hazard risks throughout all levels of facility planning and design. The handbook is maintained and updated by the Associate Director for Park Planning, Facilities, and Lands (PPFL).

Table 4 includes selected geologic and soil hazards listed in Part 1 of National Park Service (2025). The GSRI team has added additional hazards where appropriate for the park. Part 2 outlines the process to follow and decisions to be made throughout the project, if a potential hazard is identified in Part 1. Contact the NPS GRD with any questions.

Table 4. Geologic and soil hazards checklist. This checklist includes selected hazards listed in Part 1 of NPS (2025).

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgement	Source(s) of Information About Natural Hazards and Used for Best Professional Judgement
Sea Level Change	Inundation. Shoreline erosion. Destruction of infrastructure, e.g., through saturation. Water quality effects. Water supply diminished.	Not applicable	NPS Coastal and Ocean Advisory & Support Team (COAST): COAST: Coastal and Ocean Advisory & Support Team NOAA Sea Level Rise Viewer https://coast.noaa.gov/slr/ NASA Interagency Sea Level Rise Scenario Tool https://sealevel.nasa.gov/task-force-scenario-tool DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com).
Coastal Storm Surge	Wind driven rising water, e.g., hurricane, nor'easter.	Not applicable	NPS: Sea level rise and storm surge projection (Caffrey et al. 2018) NOAA SLOSH https://vlab.noaa.gov/web/mdl/slosh FEMA: National Flood Hazard Layer (NFHL) https://www.fema.gov/flood-maps/national-flood-hazard-layer DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Flash Flood	Sudden rising water, e.g., in a dry wash or canyon. Loss of life due to unexpected flooding. Destruction of infrastructure, e.g., through impact or saturation. Reduced or precluded visitation. Power failure due to areawide power outages.	Known hazard	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) Climate Toolbox: Climate Mapper (for Western US) https://climatetoolbox.org/tool/Climate-Mapper FEMA: NFHL https://www.fema.gov/flood-maps/national-flood-hazard-layer
Riverine Flood	Inundation. Destruction of infrastructure, e.g., through impact or saturation. Stream channel migration and streambank erosion. Water quality effects. Water supply diminished. Reduced or precluded visitation.	Known hazard (extreme; SHIRA)	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) FEMA: NFHL https://www.fema.gov/flood-maps/national-flood-hazard-layer

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgement	Source(s) of Information About Natural Hazards and Used for Best Professional Judgement
Lake and Reservoir Level Change	Water supply diminished. Flooding and erosion impacts to infrastructure. Diminished or lost recreational opportunities.	Not applicable	University of Michigan: Great Lakes Integrated Science and Assessments (for Great Lakes only) https://glisa.umich.edu/ NOAA: Lake Level Viewer (for Great Lakes only) https://coast.noaa.gov/llv/ USGS: Lakes and reservoirs dataset https://waterdata.usgs.gov/nwis/current/?type=lake&group_key=state_cd US Bureau of Reclamation Water Operations https://www.usbr.gov/main/water/#GP
Precipitation: Increased Extreme Events	Surface erosion. Floods. Water damage to structures from driven rain. Unstable saturated soils. Reduced or precluded visitation. Power failure due to areawide power outages.	Potential hazard	NPS: National Park historical and projected climate change trends https://irma.nps.gov/DataStore/Reference/Profile/2266988 Climate Toolbox: Climate Mapper (for Western US) https://climatetoolbox.org/tool/Climate-Mapper NASA: DAYMet gridded climate data https://daymet.ornl.gov/ DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Precipitation: Altered Patterns and Changing Humidity	Local flooding. Mold growth. Wood decay. Drought. Fire. Water supply change.	Potential hazard	NPS: National Park historical and projected climate change trends https://irma.nps.gov/DataStore/Reference/Profile/2266988 Climate Toolbox: Climate Mapper (for Western US) https://climatetoolbox.org/tool/Climate-Mapper NASA: DAYMet gridded climate data https://daymet.ornl.gov/
Drought: Increased Frequency, Intensity, Magnitude, and Duration	Limited water supply for visitor, staff, and operational needs (e.g., potable and fire suppression water). Increased competition for available water and water supply impacts (e.g., water supply curtailment by state agencies). Crack/heave damage in drier soils. Increased vulnerability to wildfire.	Potential hazard (low; SHIRA)	Climate Toolbox: Climate Mapper (for Western US) https://climatetoolbox.org/tool/Climate-Mapper FEMA: Drought risk https://hazards.fema.gov/nri/drought University of Nebraska-Lincoln: Drought Monitor https://droughtmonitor.unl.edu/ DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Permafrost Dynamics	Thawing. Surface collapse. Increased landslide susceptibility. Road/service disruption. Frost heave.	Not applicable	NASA: Permafrost dataset https://neo.gsfc.nasa.gov/view.php?datasetId=PermafrostNSIDC NPS: Central Alaskan Network Permafrost Protocol Dataset https://irma.nps.gov/DataStore/Reference/Profile/2288714 DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgement	Source(s) of Information About Natural Hazards and Used for Best Professional Judgement
Landslide	Rockfall. Mud or debris slides or flows onto or from under structures. Reduced or precluded visitation. Avalanche	Known hazard (very high; SHIRA)	State geological surveys FHWA Unstable Slope Management Program (USMP): Geologic and Geotechnical Services | FHWA (dot.gov). FEMA: Landslide risk https://hazards.fema.gov/nri/landslide USGS: Emergency Assessment of Post-Fire Debris-Flow Hazards https://landslides.usgs.gov/hazards/postfire_debrisflow/ DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Earthquake	Falling objects. Collapsing structures. Inoperability of major building systems, e.g., power, sewer, water. Liquefaction - loss of strength to foundations, silt deposition, standing water. Trigger to other hazards, e.g., landslides, debris flows.	Potential hazard (very low; SHIRA)	State geological surveys USGS: Earthquake Probability Mapping https://www.usgs.gov/natural-hazards/earthquake-hazards/hazards FEMA: Earthquake risk https://hazards.fema.gov/nri/earthquake DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Tsunami	Coastal area inundation.	Not applicable	State Tsunami Inundation Mapping FEMA: Tsunami risk https://hazards.fema.gov/nri/tsunami DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Shrink/Swell Soils	Damage to structure. “Heaving” of ground beneath structure. Increased landslide susceptibility.	Potential hazard (low; NRCS)	State geological survey site-specific information NPS: Soil Resources Inventory USDA: Soils Survey https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/ (look for “linear extensibility” interpretation. DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Volcanic Eruption	Lava flows. Fire. Seismicity. Tsunamis. Toxic gas releases. Ash and air quality degradation. Reduced or precluded visitation.	Not applicable	USGS: Volcano Hazards Program https://www.usgs.gov/volcano FEMA: Volcanic activity risk https://hazards.fema.gov/nri/volcanic-activity Red Cross: Map of Volcano Risk Areas https://maps.redcross.org/website/maps/arc_map_links.html DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgement	Source(s) of Information About Natural Hazards and Used for Best Professional Judgement
Hydrothermal Activity (e.g., geysers)	Toxic gas release. Explosion. Boiling water. Steam. Surface collapse into void.	Not applicable	NREL: Geothermal resource data, tools, and maps https://www.nrel.gov/gis/geothermal.html USGS: Geothermal resources https://www.usgs.gov/programs/energy-resources-program/science/science-topics/geothermal DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Subsurface Hazards: Abandoned Mineral Lands Cave/Karst (sinkholes)	Surface collapse. Contamination.	Potential hazard (very low; SHIRA)	State geological hazards maps USGS: Karst in the United States: A Digital Map Compilation and Database (Weary and Doctor 2014) Evaluation of cave and karst programs and issues at US national parks (Land et al. 2013) DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)

Acknowledgments

The GSRI team thanks the participants of the 2010 scoping meeting and 2025 follow-up call meeting for their assistance in this inventory. The lists of participants reflect the names and affiliations of these participants at the time of the meeting and call.

2010 Scoping Meeting Participants

Eric Carson (Wisconsin Geological Survey)

Jim Chappell (Colorado State University)

Nancy Duncan (NPS Mississippi National River and Recreation Area)

Bruce Heise (NPS Geologic Resources Division)

Howard Hobbs (Minnesota Geological Survey)

Steve Johnson (NPS Mississippi National River and Recreation Area)

Jason Kenworthy (NPS Geologic Resources Division)

Robin Maercklein (NPS Saint Croix National Scenic Riverway)

Richard Ojakangas (University of Minnesota [Duluth])

Jamie Robertson (Wisconsin Geological Survey)

Harvey Thorleifson (Wisconsin Geological Survey)

Trista Thornberry-Ehrlich (Colorado State University)

Laurel Woodruff (USGS)

Stan Zabel (NPS)

2025 Follow-up Call Participants

Jim Chappell (Colorado State University)

Matthew Harrington (Colorado State University)

Isaiah Messerly (NPS Saint Croix National Scenic Riverway)

Rebecca Port (NPS Geologic and Soil Resources Inventory)

Michael Rhoades (NPS Saint Croix National Scenic Riverway)

Cullen Scheland (NPS Geologic and Soil Resources Inventory)

Trista Thornberry-Ehrlich (Colorado State University)

Literature Cited

Anderson, M. 2024. Take a journey into the history of Knapp's Cave. Country Messenger. https://www.countrymessenger.com/news/take-a-journey-into-the-history-of-knapp-s-cave/article_b97460c6-2283-11ef-8709-5fe9dc130276.html

Attig, J.W., and D.M. Mickelson. 2017. Laurentide Ice Sheet: Ice-margin positions in Wisconsin. Report ES056. Wisconsin Geological and Natural History Survey, Madison, Wisconsin. https://wgnhs.wisc.edu/catalog/dataset/000939

Bauer, E.J., V.W. Chandler, J.R. Steenberg, A.J. Retzler, V.L. Stanley, G.N. Meyer, and R.S. Lively. 2016. Geologic Atlas of Washington County, Minnesota: Minnesota Geological Survey, County Atlas Series C-39 Part A (Plates 3, 4, 6), scale 1:100,000.

Belair, G.M., J.M. Jones, S.N. Martinez, B.B. Mirus, and N.J. Wood. 2024. Slope-Relief Threshold Landslide Susceptibility Models for the United States and Puerto Rico. US Geological Survey data release. https://doi.org/10.5066/P13KAGU3

Bureau of Land Management. n.d. AML Dangers. Online information. Bureau of Land Management. https://www.blm.gov/programs/aml-environmental-cleanup/aml/dangers

Burghardt, J.E., E.S. Norby, and H.S. Pranger, II. 2014. Abandoned mineral lands in the National Park System—comprehensive inventory and assessment. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2014/906. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2215804

Caffrey, M.A., R.L. Beavers, and C.H. Hoffman. 2018. Sea level rise and storm surge projections for the National Park Service. Natural Resource Report NPS/NRSS/NRR—2018/1648. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2253283

Cahow, A. 1985. Geology of the St. Croix National Scenic Riverway. National Park Service, Department of the Interior.

Carney, S.J. 1996. Paleohydrology of the western outlets of Glacial Lake Duluth. University Digital Conservancy, University of Minnesota. https://hdl.handle.net/11299/220217

Clayton, L. 1984. Surficial geology of Ashland, Bayfield, Burnett, Iron, Price, Sawyer, Washburn, and Douglas Counties, Wisconsin. Report IC46. Wisconsin Geological and Natural History Survey, Madison, Wisconsin. https://doi.org/10.54915/fdmm3282

Crawford, D. 2009. Geology of Interstate Park: The St. Croix Dalles – Home of the world's deepest potholes. Minnesota Department of Natural Resources. https://files.dnr.state.mn.us/destinations/state_parks/interstate/interstate_geology.pdf

Dalton, A.S., H.E. Dulfer, M. Margold, J. Heyman, J.J. Clague, D.G. Froese, M.S. Gauthier, A.L.C. Hughes, C.E. Jennings, S.L. Norris, and B.J. Stoker. 2023. Deglaciation of the North American ice sheet complex in calendar years based on a comprehensive database of chronological data: NADI-1. Quaternary Science Reviews 321: 108345. https://doi.org/10.1016/j.quascirev.2023.108345

Delikowski, H. 2024. Post-glacial landscape evolution of the lower St. Croix River Valley: The enigma of Glacial Lake Grantsburg, the Osceola Bench, and the St. Croix Dells. Master's thesis, Minnesota State University, Mankato. Cornerstone: A Collection of Scholarly and Creative Works for Minnesota State University, Mankato. https://cornerstone.lib.mnsu.edu/etds/1471/

Field, J.J., C.M. Leonard, D.M. Schook, J.M. MacCartney, and S.O. Erwin. 2025. Best practices for managing bank erosion within the National Park Service and National Wild and Scenic River System. Science Report NPS/SR—2025/234. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/2306106

Henderson, T.C., V.L. Santucci, T. Connors, and J. Tweet. 2021. National Park Service geologic type section inventory: Great Lakes Inventory & Monitoring Network. Natural Resource Report NPS/GLKN/NRR—2021/2327. National Park Service. Fort Collins, Colorado. https://doi.org/10.36967/nrr-2288210

Hinze, W.J., D.J. Allen, L.W. Braile, and J. Mariano. 1997. The Midcontinent Rift System: a major Proterozoic continental rift. Pages 7–35 *in* R. W. Ojakangas, A. B. Dickas, and J. C. Green, editors. Middle Proterozoic to Cambrian rifting, central North America. Special Paper 312. Geological Society of America, Boulder, Colorado.

Hudak, C.M., E.R. Hajic, and J.J. Walsh. 2011. Interpreting origins of landform sediment assemblages within the Upper Mississippi River valley and tributaries in the Twin Cities area of Minnesota. Pages 525–544 *in* J. D. Miller, G. J. Hudak, C. Wittkop, and P. I. McLauglin, editors. Field Guide 24. Archean to Anthropocene; field guides to the geology of the Mid-Continent of North America. Geological Society of America, Boulder, Colorado.

Johnson, M.D., and C. Hemstad. 1998. Glacial Lake Grantsburg: A short-lived lake recording the advance and retreat of the Grantsburg Sublobe. *In* Contributions to Quaternary Studies in Minnesota, edited by C.J. Patterson and H.E. Wright Jr., 49–60. Minnesota Geological Survey Report of Investigations 49. St. Paul, Minnesota.

Land, L., G. Veni, and D. Joop. 2013. Evaluation of cave and karst programs and issues at US national parks. Report of Investigations 4. National Cave and Karst Research Institute, Carlsbad, New Mexico. https://nckri.org/wp-content/uploads/2021/03/nckri-report-of-investigations-04.pdf

Lauritsen, J. 2024. Knapp's Cave in Scandia: A beautiful kayaking spot with rich history. CBS News Minnesota. https://www.cbsnews.com/minnesota/news/knapps-cave-scandia-beautiful-kayaking-spot-rich-history/

Lusardi, B.A. 1994. Revised May 2017 by E. L. Dengler. Minnesota at a glance quaternary glacial geology. Minnesota Geological Survey Miscellaneous Publications. Minnesota Geological Survey, University of Minnesota, St. Paul, Minnesota. https://hdl.handle.net/11299/59427

McMahon, E.M., and T.J. Karamanski. 2002. Time and the river: A history of the Saint Croix. A historic resource study of the Saint Croix National Scenic Riverway. National Park Service, Midwest Region, Omaha, Nebraska. https://npshistory.com/publications/sacn/hrs.pdf

Mickelson, D., M. Johnson, and K. Syverson. 2011. Geology of the Ice Age National Scenic Trail. The Geological Society of America. https://doi.org/10.1130/2011.0024(13)

Minnesota Department of Natural Resources. 2019. Remembering the 1965 floods. Minnesota Department of Natural Resources. https://www.dnr.state.mn.us/climate/journal/1965_floods.html

Mirus, B.B., G.M. Belair, N.J. Wood, J. Jones, and S.N. Martinez. 2024. Parsimonious high-resolution landslide susceptibility modeling at continental scales. AGU Advances, 5, e2024AV001214. https://doi.org/10.1029/2024AV001214

National Park Service. 2006. Management policies 2006. U.S. Department of the Interior, National Park Service, Washington, D.C. ISBN: 9780160768743. https://www.nps.gov/subjects/policy/management-policies.htm

National Park Service. 2017. Foundation document, St. Croix National Scenic Riverway, Minnesota and Wisconsin. NPS/SACN/630/140023. https://npshistory.com/publications/foundation-documents/sacn-fd-2017.pdf

National Park Service. 2019. Archeological Sites. Online information. National Park Service, Saint Croix National Scenic Riverway, Minnesota and Wisconsin. https://www.nps.gov/sacn/learn/historyculture/archeological-sites.htm

National Park Service. 2025. Natural Hazards Handbook: Assessing Natural Hazard Potential Effects and Resilience for National Park Service Built Asset Projects. Version 3. National Park Service Park Planning Facilities and Lands, Denver, Colorado.

Otton, J.K. 1992. The Geology of Radon. US Geological Survey Unnumbered Series, General Interest Publication. https://www.usgs.gov/publications/geology-radon

Outwater, A. 1996. Water: A natural history. Basic Books, New York, New York.

Perrone, S. 2023. Report: State of Soils Information at the National Park Service, WASO Level. National Park Service. https://irma.nps.gov/DataStore/Reference/Profile/2307328

Santucci, V.L., J.P. Kenworthy, and A.L. Mims. 2009. Monitoring in situ paleontological resources. Pages 189–204 *in* R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. http://go.nps.gov/geomonitoring

St. Croix Scenic Byway. n.d. 101: Geology and glacial history. St. Croix Scenic Byway, St. Croix, Wisconsin. https://stcroixscenicbyway.org/PDF/101%20Geology%20and%20Glacial%20History.pdf

Stein, S., C.A. Stein, E. Blavascunas, and J. Kley. 2015. Using Lake Superior parks to explain the Midcontinent Rift. Park Science 32(1):19–29. https://irma.nps.gov/DataStore/Reference/Profile/2225613

Stein, S., C. Stein, J. Kley, R. Keller, M. Merino, E. Wolin, D. Wiens, M.E. Wysession, G. Al-Equabi, W. Shen, A. Frederiksen, F. Darbyshire, D. Jurdy, G. Waite, W. Rose, E. Vye, T. Rooney, R. Moucha, and E. Brown. 2016. New insights into North America's Midcontinent Rift. Eos 97. https://doi.org/10.1029/2016EO056659

Thompson, J.A., S. Kienast-Brown, T. D'Avello, J. Philippe, and C. Brungard. 2020. Soils2026 and digital soil mapping – A foundation for the future of soils information in the United States. Geoderma Regional. 22. E00294. https://doi.org/10.1016/j.geodrs.2020.e00294

Tweet, J.S., and V.L. Santucci. 2018. Saint Croix National Scenic Riverway: Paleontological resources inventory. Natural Resource Report. NPS/SACN/NRR—2018/1585. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2250009

United Press International. 2005. Devil's Chair landmark toppled. United Press International. https://www.upi.com/Top_News/2005/04/12/Devils-Chair-landmark-toppled/59141113336925/

Weary, D.J. and D.H. Doctor. 2014. Karst in the United States: A digital map compilation and database. US Geological Survey Open-File Report 2014–1156. https://dx.doi.org/10.3133/ofr20141156

Wieczorek, G.F., and J.B. Snyder. 2009. Monitoring slope movements. Pages 245–271 in R. Young and L. Norby, editors. Geological monitoring. Geological Society of America, Boulder, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2203103

Young, R., and L. Norby, editors. 2009. Geological monitoring. Geological Society of America, Boulder, Colorado. http://go.nps.gov/geomonitoring