



Big Hole National Battlefield

Geologic and Soil Resources Inventory Summary



On this page: The frame of a tipi sits at the site of the Nez Perce camp that was attacked by US soldiers on 9 August 1877. The camp was along the North Fork Big Hole River at the base of Battle Mountain. Photograph by T. L. Thornberry-Ehrlich taken in 2019.

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Abstract

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

GRI hosted a baseline scoping meeting for BIHO in 2004. A baseline bedrock geologic map was delivered to the park in 2009. SRI delivered a legacy soil database and map to the park in 2006 and delivered updated data and an “enhanced report” in 2013. Geologic and soil maps could be revised at a larger scale within BIHO boundaries for resource managers.

Geologic heritage resources of particular interest include Nez Perce history, the fateful battle, North Fork Big Hole River, geology and the Big Hole ecosystem, and stratotypes. Inventory needs include incorporating newer (2024) mapping from the Montana Bureau of Mines and Geology, investigating stratotype potential, updating interpretive materials, detailed surficial geologic mapping, and studying camas lily and Lemhi penstemon decline.

Resource management issues include fluvial issues, slope movements, seismicity, climate change impacts, and the legislatively required geologic inventories: caves and karst, geothermal features and springs, and paleontological resources inventory and protection.

Geohazards include riverine floods, climate change, drought, landslides, earthquakes, and burn probability. Inventory needs are climate change impact analyses, field-based paleontological surveys, and mineral resources inventories. Soil hazards in the park include shrink and swell layers (possibly derived from till or volcanic ash), as well as toxic soils containing radon, arsenic, cadmium, and lead. Inventory needs include detailed mapping of problematic soils.

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

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Background of the GSRI

The [Geologic and Soil Resources Inventory \(GSRI\)](#) is a new program encompassing the legacy Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) programs. To inform park management decisions and planning, 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.

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 more than 270 parks with significant natural resources, which served as a common starting point for natural resource stewardship. For both GRI and SRI, the primary deliverable was a digital (GIS) map.

Between the 1990s and early 2020s, GRI also produced scoping summaries, geologic map posters, and GRI reports for most of the 270 I&M parks. GRI and SRI baseline inventory products are available through the [NPS Geodiversity Atlas](#). 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. As of 2024, the I&M program is transitioning from a baseline inventory strategy to a park-proposed inventory strategy.

The GRI and SRI are now unified as one inventory program, GSRI, which is integrated into the new Inventories & Assessment (I&A) program. Through the new I&A program, parks will submit geology- and soil-related project requests in PMIS during the Servicewide Comprehensive Call (SCC). This transition will begin in FY25, with new guidance enacted for GSRI. See the [GSRI SharePoint site](#) for more information regarding this transition. During this transition period, 13 “priority” parks, including Big Hole National Battlefield (BIHO), were identified as missing a baseline GRI report. This GSRI summary serves as a substitute for a baseline GRI report and is intended to support BIHO’s participation in the new inventories program. As such, it summarizes the status of GRI and SRI deliverables for BIHO and provides information on current geology and soil resources management concerns with a focus on identified inventory needs. Information in this summary was compiled from existing reports, meetings with park staff, and the best professional judgment from GSRI and WASO Geologic Resources Division (GRD) geoscientists.

Baseline GSRI Products

Geology

The digital geologic map for BIHO is available on the NPS DataStore, accessed through the Integrated Resource Management Applications (IRMA) portal (see <https://irma.nps.gov/DataStore/Reference/Profile/1047475>), and was compiled and adapted from the following source geologic map in 2009:

- Ruppel, E. T., J. M. O'Neill, and D. A. Lopez. 1993. Geologic map of the Dillon 1 degree x 2 degrees quadrangle, Idaho and Montana (scale 1:250,000). Miscellaneous Investigations Series Map I-1803-H. US Geological Survey, Reston, Virginia.

However, the scale of this map (1:250,000) is not ideal for using the map data for resource management at BIHO. Recent, large-scale (1:24,000) data are available to be incorporated into the GRI GIS data for BIHO from the Montana Bureau of Mines and Geology:

- Elliott, C. G. 2024. Geologic map of the Big Hole Battlefield 7.5' quadrangle, southwestern Montana (scale 1:24,000). Geologic map 97. Montana Bureau of Mines and Geology, Butte, Montana.

Incorporating these data would be an ideal GSRI project in the new park-proposed inventory strategy. BIHO could submit a project request in PMIS during the SCC as part of the new I&A program. When accepted, the 2024 source data would be added to the GRI GIS data and made available on the NPS DataStore. A baseline GRI report could also be requested as part of the project proposal. A large format geologic map poster would also be produced for BIHO through this process.

Soils

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

SRI completed a soil map(s) for BIHO in 2006 and delivered updated data and an “enhanced report” in 2013. This is available on the NPS DataStore, accessed through IRMA (<https://irma.nps.gov/DataStore/Reference/Profile/1048822>). This map is a static dataset that will not be updated in the future as revisions or new data become available.

The most up-to-date soils data for BIHO is available via the Web Soil Survey, which is updated and maintained regularly. Management-focused maps for BIHO or potential project areas can be developed on demand on the website. The Web Soil Survey homepage gives instructions for how to view and download soil data.

The Web Soil Survey data are broken down into county-level soil survey areas. Each soil survey area is assigned a code and a name. BIHO includes one soil survey area (Table 1) that covers the entire park area. The soil survey status is complete for BIHO. To view the soil data for BIHO 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. Because BIHO only has one survey area, this can function as the AOI. 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. Web Soil Survey areas.

Web Soil Survey Area Code	Web Soil Survey Area Name	Status
MT610	Big Hole Area – Part of Beaverhead County, Montana	Complete

Future GSRI Products

As the GSRI becomes integrated into the I&A program, future GSRI products will be determined by the project proposals submitted by the parks. The GSRI will fund projects that

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

GSRI project examples:

- Features and processes eligible for funding through the GSRI program include cave/karst, geothermal, paleontological resources (fossils), landslides and rockfall, other geohazards (e.g., avalanche, permafrost, volcanoes, earthquakes, tsunamis, sinkholes), eolian, erosion, soil suitability and limitations for use, soil properties and qualities, ecological site descriptions, and other geologic or soil features or processes of management interest.
- Features and processes covered by other sources of funding and **not** eligible for GSRI funding are Abandoned Mineral Lands (AML), orphaned oil and gas wells, coastal processes, coastal storm response, sea level change projections or mitigation, coastal engineering structures, or shoreline sediment movement.
- The GSRI will also accept proposals for new baseline products, including a geologic (geologic or surficial) or soil map or report, especially for parks outside the original 270 I&M parks. Parks requesting these products will need to indicate a management need the baseline data will support.
- BIHO could request the compilation of the new, 1:24,000-scale geologic map data from the Montana Bureau of Mines and Geology into an NPS GIS, as well as a GRI baseline report and geologic map layout as a GSRI project in the new I&A program.

Geologic Setting and History

In the 1870s, the US government attempted to force the Nez Perce (nimí pu or Nee-Me-Poo) onto a smaller reservation surrounding Lapwai in Idaho, violating earlier treaties and prompting resistance from several bands who refused to give up their ancestral lands (Corrao and Erixson 2011; BIHO natural resource staff, written communication, June 2025). Tensions escalated into violence in June 1877, triggering a months-long military pursuit as the Nez Perce, led by Chief Joseph and others, attempted to flee to Canada to avoid further bloodshed. In August 1877, after engaging the US military in several conflicts in Idaho, a Nez Perce group of 800 individuals (including around 125–250 warriors) traveled to a well-known summer hunting, gathering, and camping area along the route between their homeland in central Idaho and their buffalo hunting grounds east of the Rocky Mountains (Catton and Hubber 1999; BIHO natural resource staff, written communication, June 2025). They made camp along the tranquil flow of the North Fork Big Hole River at the base of (now) Battle Mountain. Unfortunately, they were being pursued by US Army forces under the command of Colonel John Gibbon, as well as Montana citizen volunteers (Corrao and Erixson 2011; National Park Service 2013a, b). These forces staged a pre-dawn surprise attack on the Nez Perce camp on 9 August 1877, killing many men, women, and children before being forced into a retreat and siege position on a small point of timber near the center of the battlefield. The soldiers were surrounded and pinned down by Nez Perce warriors, who quickly regrouped and launched a fierce counterattack. The siege lasted through the day, with both sides suffering heavy casualties, until the Nez Perce chose to break off the engagement and continue their flight toward Canada, leaving the battlefield in control of the wounded and outnumbered US troops before reinforcements arrived (Corrao and Erixson 2011; National Park Service 2013a, b).

BIHO is named for the Big Hole Valley and is located along the eastern Bitterroot Range, 16 km (10 mi) west of Wisdom, Montana. The scenery and history at BIHO consistently attract about 50,000 recreational visitors per year to a remote part of Montana, according to NPS visitor-use statistics (<https://irma.nps.gov/Stats/>). BIHO is an administrative unit of the non-traditional, non-contiguous Nez Perce National Historical Park (NEPE)—a conglomerate of 38 units in the “Nez Perce Country” (National Park Service 2013a, b). As such, its purpose is to 1) facilitate protection and offer interpretation of Nez Perce sites that have exceptional value in commemorating the history of the United States; 2) preserve and protect tangible resources that document the history of the Nez Perce peoples and the significant role of the Nez Perce in North American history; and 3) interpret the culture and history of the Nez Perce peoples and promote documentation to enhance that interpretation (National Park Service 2017).

The current BIHO boundary encompasses about 409 ha (1,011 ac), including much of the conflict zone from 1877 (Corrao and Erixson 2011). NPS-owned lands at BIHO total 265 ha (655 ac; BIHO natural resource staff, written communication, June 2025). The elevation within BIHO is relatively high, ranging from about 1,860 m (6,100 ft) above sea level to over 2,160 m (7,100 ft) at the top of Battle Mountain. Big Hole Valley is the highest and broadest mountain valley in western Montana, separating the Pioneer Mountains to the east from the Bitterroot Mountains on the west (Corrao and

Erixson 2011; Henderson et al. 2022). Two self-guided trails lead to the location of the Nez Perce encampment and the siege area, where US soldiers were held at bay near the end of the fighting. A third trail, the Howitzer Trail, branches off as a spur from the main siege area and heads uphill on the slopes of Battle Mountain, where an army howitzer was captured by Nez Perce warriors (Corrao and Erixson 2011; BIHO natural resource staff, written communication, June 2025). The Nez Perce (Nee-Me-Poo) National Historic Trail runs through BIHO. Today, the landscape is peaceful; streams and rivers flow across a broad floodplain at the base of the mountain.

Geologic History

The Big Hole Valley is within the fold and thrust belt of the Northern Rocky Mountains physiographic province—a geographic region with distinct landforms, geology, and geologic history that differentiate it from surrounding areas. A fold and thrust belt is a zone of deformed rock layers that has been shortened and thickened by compression forces, resulting in a series of folds (bends in rock layers) and thrust faults (low-angle reverse faults where older rocks are pushed over younger ones). This province is characterized by numerous mountain ranges and intermontane valleys. The bedrock of mountainous portions is mostly Proterozoic (more than 538.8 million years ago) metamorphic (i.e., changed by heat and pressure) and Cretaceous (145 million to 66 million years ago) igneous (e.g., granite) rocks (Marvin 1997; International Commission on Stratigraphy 2024). The valleys are filled with Quaternary (2.58 million years ago to present) glacial deposits and alluvium (sediments carried and deposited by water) that overlie Tertiary (66.0 million to 2.58 million years ago) sedimentary layers; these form large groundwater aquifers (Marvin 1997; International Commission on Stratigraphy 2024).

Big Hole Valley is part of a deep (4,300 m [14,000 ft]), fault-bounded pull-apart basin (valley that forms when the Earth's crust stretches and breaks) in western Montana (National Park Service 2020). This basin or gap opened behind a big block of Earth's crust that detached from the top of the Idaho batholith (a large mass of granite that intruded an area greater than 100 km² [40 mi²] in northern Idaho and northwestern Montana). The block (composing the Pioneer Range along the eastern side of the Big Hole Valley) moved east, pushed by mountain-building forces, about 70 million years ago (National Park Service 2020). At the bottom of the pull-apart basin are volcanic rocks associated with extension (i.e., when the pull-apart basin opened and widened, volcanic material moved upward through the thinner crust). A thick pile of sediments (e.g., gravel, sand, clay, and mud) was then deposited atop the volcanic rocks.

BIHO's present-day landscape is a function of its geologic history. The following are notable geologic events that occurred at BIHO:

- The oldest rocks in BIHO are biotite-muscovite granites that are part of the Trail Creek pluton (a body of intrusive igneous rock that solidified from magma beneath the Earth's surface) of the Chief Joseph plutonic metamorphic complex. These rocks compose large portions of the mountains west of BIHO and likely formed (Figure 1A) in the Late Cretaceous (100.5 million–66.0 million years ago) to the Paleogene Period (66.0 million–23.03 million years ago). Dated samples of this granite are around 65 million–60 million

years old (Howlett et al. 2020; Elliott 2024). When these rocks break down, they contribute characteristic minerals to the eroded materials. The mica minerals (muscovite and biotite) in these rocks contribute to important marker layers in the Big Hole Valley sedimentary fill (Roe 2010).

- Faulting throughout the Cenozoic (66 million years to present) pulled apart Earth's crust, opening a gap that would accumulate both upwelling molten rock (magma) as volcanic rock layers and mixed sediments shed from adjacent uplands (Figure 1B; Ruppel 1991). Sedimentary layers mixed with volcanic rock in the early Eocene (around 56.0 million years ago). These rocks compose most of Battle Mountain and underlie the howitzer capture site (Elliott 2024). Other faulting episodes crushed the rocks in distinct zones along the base of the mountains in the BIHO area; these rocks are mapped as "fault zone rocks" (O'Neill 1982; Elliott 2024).
- Deposition of the Renova Formation (a mix of granitic and volcanic sandstone within a sequence of fine-grained fluvial and lacustrine [related to lakes] deposits), mapped along the southern edge of BIHO, and more regional faulting occurred during the Eocene to Oligocene (56.0 million–23.03 million years ago; Figure 1C; Elliott 2024). The source area for the rock that was eroded to form the clasts of the Renova Formation layers was likely to the west, draining away from the Idaho batholith (Thomas 1995).
- Ongoing weathering and erosion throughout the Cenozoic contributed gravel, sand, silt, and clay layers to cover the volcanic rocks, slowly filling the deep pull-apart basin (National Park Service 2020).
- In the Miocene (23.03 million–5.333 million years ago), crustal extension and uneven normal faulting occurred, likely associated with the initiation and movement of the Yellowstone hotspot, which caused Earth's crust to dome upward, with extensional normal faults and grabens (downropped block of a normal fault system) opening in radial patterns away from it (Sears et al. 2009). Coarse gravels were deposited at the flanks of upland areas (uplifted horsts adjacent to grabens) and into deep grabens (Figure 2A); these underlie the eastern portion of BIHO (Thomas 1995; Sears et al. 2009; Sears 2010; Elliott 2024). Intermittent lakes filled the Big Hole graben valley, collecting thick lacustrine and mixed deposits atop the Renova Formation and Eocene volcanic layers (Sears 2010). Collectively, this Sixmile Creek Formation (17 million to 4 million years ago) was deposited atop the Renova Formation after a period of nondeposition or erosion (an unconformity; Roe 2010). When lumped together, the Renova and Sixmile Creek Formations compose the Bozeman Group (Ruppel et al. 1993).
- From the Miocene to the Holocene (past 10,000 years), slope deposits, including alluvial fans, landslides, and debris flows, are part of a record of landscape change as weathering and erosion remove material from areas of higher elevation and deposit that material in the valleys and areas of lower elevation (Elliott 2024). BIHO's visitor center is located on debris flow deposits.

- During the Pleistocene (2.58 million to 10,000 years ago), alpine and continental glaciers sculpted and reshaped the landscape (Figure 2B). Glacial till was deposited by local glaciers (Elliott 2024). In some places, as the glaciers receded, ice dammed the outlets, leading to the formation of a glacial lake, which accumulated glaciolacustrine deposits. Glaciolacustrine refers to sediments or environments associated with lakes formed by glacial activity, typically consisting of fine-grained materials like clays and silts deposited in still water. Other lacustrine deposits near BIHO record lake or flooded basin conditions during the Pleistocene to Holocene (Elliott 2024).
- The current landscape is dynamic; Earth's surface processes continue to erode rock and move material from one place to another. The North Fork Big Hole River and its tributaries transport and deposit alluvium along their courses (Figure 2C and Figure 3; Elliott 2024). These youngest units underlie much of the battlefield, including the Nez Perce encampment. Combined with organic material, these unconsolidated materials form soil layers at BIHO.

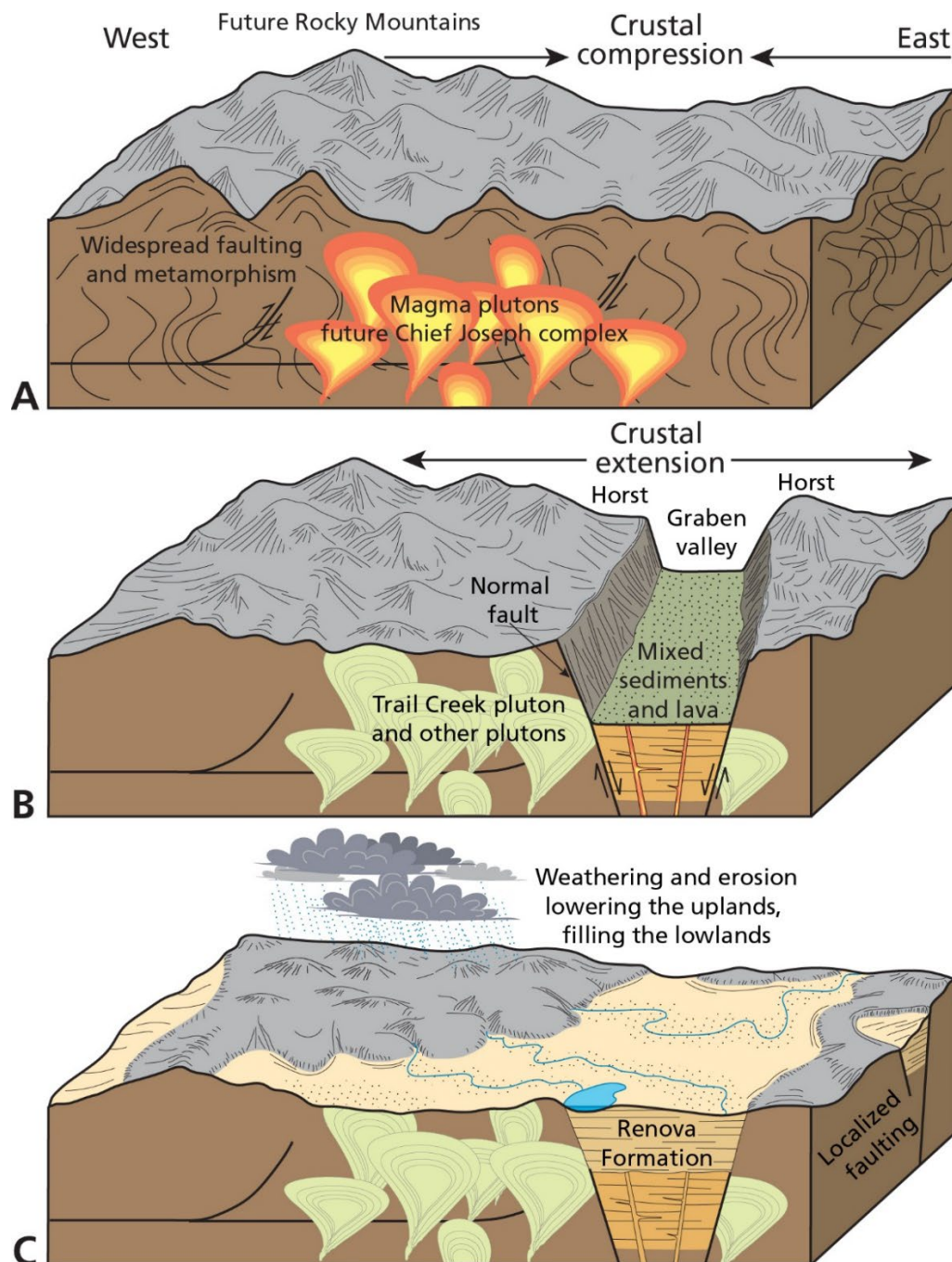


Figure 1. Geologic evolution of the BIHO landscape. A) During mountain building in the Late Cretaceous and early Tertiary, crustal compression squeezed and metamorphosed basement rocks. Igneous intrusions accompanied compression and eventually cooled into granitic plutons of the Chief Joseph complex. B) Portions of the complex broke off and were transported westward in the Eocene, opening gaps in Earth's crust that were quickly filled by mixed lava and sedimentary layers. C) The uplands were lowered by Earth surface processes of weathering and erosion, filling the normal-fault-bounded graben valleys. Graphics are generalized and not to scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Sears et al. (2009), Dudás et al. (2010), and Elliott (2024).

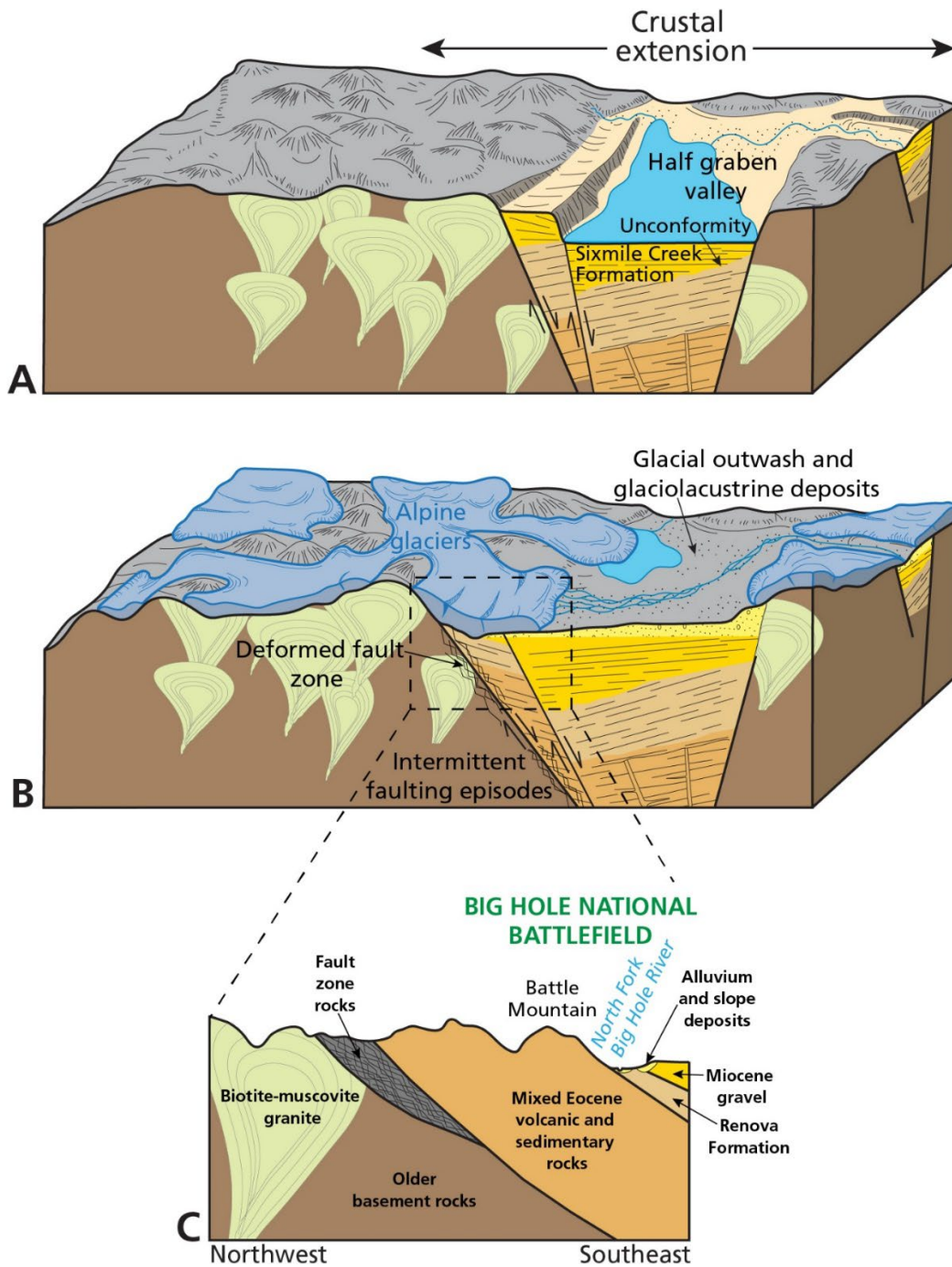


Figure 2. Geologic evolution of the BIHO landscape, continued. A) In the Miocene, crustal extension and uneven faulting occurred again intermittently, lowering one side of the Big Hole graben valley more than the other side. The Miocene sediments were unconformably deposited over the older sediments after a period of erosion and/or nondeposition. B) During the Pleistocene, colder periods supported the formation of alpine and continental glaciers. The glaciers scoured the landscape and left vast deposits in some areas. C) The modern BIHO landscape is a product of a long, diverse geologic history. The dashed box indicates the approximate relationship between blocks B and C. Graphics are generalized and not to scale. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) with information from Sears et al. (2009), Dudás et al. (2010), and Elliott (2024).

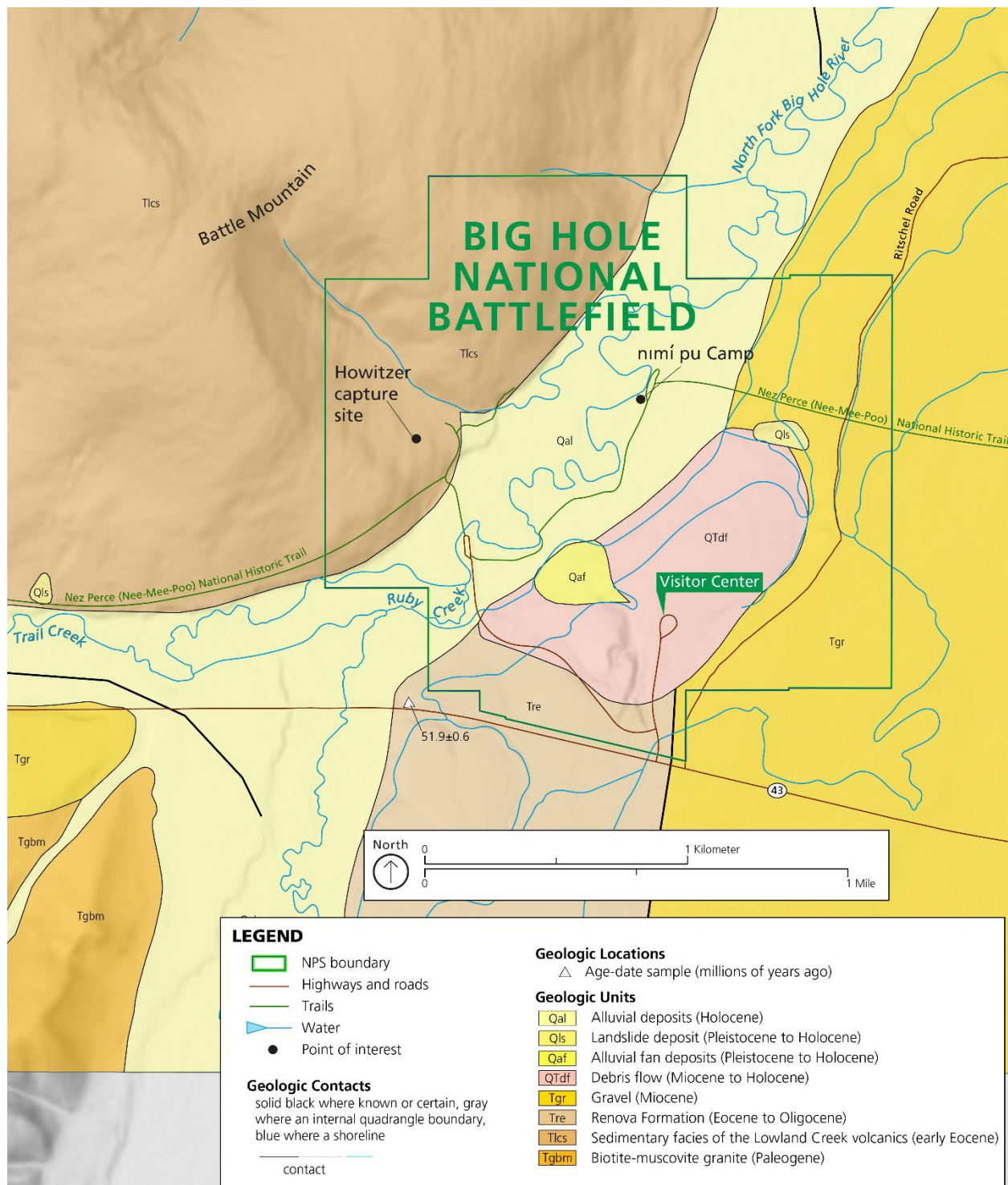


Figure 3. Geologic map of the BIHO landscape. Seven geologic units are mapped within BIHO boundaries. BIHO’s visitor center was built on debris flow deposits. The youngest map units are the alluvium along the local streams and the slope deposits at the base of slopes. Several normal faults cross the area. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University) after Elliott (2024).

Geologic Heritage

Geologic heritage, or geoheritage, exists where geology overlaps with human experiences and values. It is our history told through the lens of geology and encompasses the significant geologic features, landforms, and landscapes characteristic of our nation, which are preserved for the full range of scientific, aesthetic, cultural, ecosystem, educational, recreational, tourism, and other values that society places on them. The people and culture of BIHO are inextricably tied to the natural resources of the area (National Park Service 2013b). Cultural landscapes reveal the interrelationship between people, their natural environment, and their social ideals (Keremedjiev 2013). Geoheritage is part of BIHO's fundamental values. Wétas (the Land)—the geography and varied natural resources of the Nez Perce homeland have shaped and continue to shape Nez Perce culture. From rivers to riparian meadows, mountains, trails, and forests, BIHO protects diverse places that support traditional use and knowledge. The land itself, as well as the biological resources this land supports (e.g., fish, wildlife, and plants), continues to provide physical and cultural sustenance to the Nez Perce. Native plants, such as camas lilies, are a key resource and illustrate the resilient relationships between the people, the land (the soils and geology), and the resources (National Park Service 2017). This section highlights notable geoheritage at BIHO.

Nez Perce History

The Nez Perce traditional culture developed over more than 15,000 years of interaction with their environment (BIHO natural resource staff, written communication, June 2025). Nez Perce culture is closely tied to the natural world, and these relationships contribute to the overall understanding of Nez Perce subsistence, technology, medicine, spirituality, settlement patterns, travels, social organization, and relationships with other groups historically and today (National Park Service 2013b; National Park Service 2017; National Park Service 2020). Calling it “Izhkumizizlakipah” or “Iskumselalik Pah” (ickumcilé·likpe), meaning “Valley of the Buffalo Calf,” the Nez Perce regarded the Big Hole Valley as a middle ground between their homeland in the river valleys of Oregon and Idaho and the buffalo country east of the Rocky Mountains (Catton and Hubber 1999; Owens and Hammond 2008; BIHO natural resource staff, written communication, June 2025). BIHO is located where the mountains to the west (e.g., Battle Mountain) meet the floor of the Big Hole Valley. Here, thick valley-fill deposits and the North Fork Big Hole River system create habitat for the species of plants important to the Nez Perce culture in both material and spiritual dimensions (National Park Service 2020).

Crossing the mountains and valleys using traditional trails, the Nez Perce used the meadows of the Big Hole Valley as a harvesting area, which certainly influenced their decision to camp there in 1877 (Catton and Hubber 1999; Garrett et al. 2011; Stucki and Rodhouse 2017). Traditionally, plants provided over half of the dietary calories for the Nez Perce community, and winter survival depended largely on dried roots, especially cous (*Lomatium* spp.) and camas (*Camassia quamash*)—two species that thrive in the riparian/marshy conditions (water-saturated soils), high elevation, and relatively harsh climate at BIHO (Figure 4; Garrett et al. 2011; National Park Service 2020; BIHO natural resource staff, written communication, June 2025). The most important industrial woods were

red cedar, ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga menziesii*), willow (*Salix spp.*), and hardwoods. These species flourish in the riparian zones and along the floodplain of the North Fork Big Hole River (e.g., base of Battle Mountain; National Park Service 2020; BIHO natural resource staff, written communication, June 2025). Above the riparian zone, well-drained soils on the slope deposits and rock units of Battle Mountain supported dense lodgepole (*Pinus contorta*) pine-forested areas, as well as open grassy slopes where the Nez Perce grazed their horses (Guth and Scott 2020).



Figure 4. Photograph of blue camas lilies at BIHO. Camas blooms in June. The day before the battle, Nez Perce women gathered the camas bulbs to roast in pit ovens to prepare for long storage. Camas was a vital resource for the Nez Perce and of great cultural and traditional significance. The tipi frames seen in the background are a visual marker of the location of the Nez Perce camp and also a memorial to the Nez Perce who fought and died here. Some were buried in the camas roasting pit ovens. NPS photograph taken in 2016.

The day before the battle, Nez Perce women gathered lodgepole pines on the lower slopes of Battle Mountain, stripping them to dry so they could be used as lodge poles and travois. Camas root ovens were dug and used to roast the bulbs (Owens and Hammond 2008; BIHO natural resource staff, written communication, June 2025). Gathering and processing these roots was a necessity brought on

by the dire circumstances of the Nez Perce's flight. The fact that they collected and began to cook camas was evidence of their relative sense of security before the surprise attack. Some of the roasting pits were then hastily used as burial sites after the battle (Scott 1994; Owens and Hammond 2008).

The Fateful Battle

The location and condition of natural resources, including the meandering North Fork Big Hole River flanked by dense willow riparian vegetation, the floodplain meadow where the Nez Perce encampment was located, the open hillslopes overlooking the river to the west, and the Ruby Bench upland to the southeast, were fundamental to the way that the 1877 battle played out (Figure 5; Catton and Hubber 1999; National Park Service 2013b). Through their traditional use of natural resources, the familiarity that the Nez Perce had with the local terrain provided them with a strategic understanding of their environment, influencing both their movements and their interactions during the battle (National Park Service 2020). Patterns in the landscape that are essential to understanding the battle are evident at BIHO today, contributing strongly to the historical legibility of the site (National Park Service 2008). The underlying geology and soil influence 1) vegetation patterns such as the extent and character of the forest, the open horse pasture, the dense willow thickets, and the open meadows; the meandering river, with its associated bogs, sloughs, and ponds; 2) the topography of the mountain slope, low river bottom, the prairie bench, and the point of timber where the soldiers were besieged; and 3) the unobstructed views (Owens and Hammond 2008).



Figure 5. Photograph from the slopes of Battle Mountain showing the major natural features. These landforms factored heavily in the 1877 battle. The Nez Perce camp was on the camas meadow. The soldiers had to cross the marshy river floodplain and willow thickets to launch their surprise attack. After being rebuffed back to the siege area, the soldiers dug in to cut their losses. A handful of warriors kept them pinned in place while the majority of Nez Perce fled across the bench area southward toward Bannack Pass. The view is from the Howitzer capture site looking east. NPS photograph courtesy of the Pacific West Region office, taken in 2005.

During the surprise attack, in the hours before dawn, soldiers approached the Nez Perce camp from the west, following a trail on the west side of the river at the base of Battle Mountain (Guth and Scott 2020). They made their way across the marshy, meandering floodplain covered with riparian willows (Scott 1994; Guth and Scott 2020). The grade along the river is exceedingly low, dropping only about 5 m (15 ft) in the 1.6 km (1 mi) of river length that crosses the battlefield site. This creates the broad floodplain of marshy bogs, backwater sloughs, and disconnected oxbow ponds. Though somewhat disorganized from the marshy approach, soldiers overran the Nez Perce camp on the floodplain of the North Fork Big Hole River. The occupants fled to higher knolls and open prairie underlain by coarser-grained debris flow and gravel deposits where they were able to regroup. The soldiers then attempted to raze the camp, but the damp conditions made this futile because the vegetation was too wet to burn (Guth and Scott 2020).

Nez Perce warriors fought back, pushing the soldiers across the river toward the flanks of Battle Mountain. At a small, wooded point (“Point of Timber”) underlain by slope deposits atop

sedimentary layers of the Lowland Creek volcanics geologic unit, the Nez Perce warriors held the troops at siege for the rest of the day and night. During that time, the soldiers moved a 12-pounder mountain howitzer on the slope further west overlooking the valley and fired two rounds before the Nez Perce captured its position (Catton and Hubber 1999; Guth and Scott 2020). This small cannon had been held back to avoid its noise ruining the surprise attack; however, the howitzer was employed too far from the camp to be effective and was quickly overrun because the steep topography of Battle Mountain blocked the view of the Nez Perce approaches (Guth and Scott 2020). The soldiers were able to hastily dig snaking rifle pits in the siege area using trowel bayonets; these pits are still visible at BIHO today (Owens and Hammond 2008; Guth and Scott 2020). A Nez Perce sniper in the Twin Trees (two ponderosa pines that stood alone on the horse pasture slopes of Battle Mountain) harassed the soldiers during the siege (Guth and Scott 2020). Other Nez Perce used a small gully (called “Battle Gulch”) as cover to stealthily approach the siege location (Figure 6). A small group of warriors were able to keep the soldiers pinned down while the rest of the Nez Perce escaped (Catton and Hubber 1999; Owens and Hammond 2008). Reinforcement troops arrived the next day just as the remaining Nez Perce left to catch up with the retreat southward toward Bannack Pass (Owens and Hammond 2008).



Figure 6. Photograph of the gulch in the siege area. This topographic feature, called “Battle Gulch,” allowed Nez Perce warriors both lines of fire and a stealthy route of approach to the besieged soldiers. The view is from the siege area looking south. NPS photograph courtesy of the Pacific West Region office, taken in 2005.

In 1883, a six-ton granite “soldiers” monument was erected by the US government near the siege site to convey a nationalistic sentiment of honorable sacrifice; Nez Perce losses are not part of the monument (Figure 7 and Figure 8; Owens and Hammond 2008). The stout granite obelisk was cut in Concord, New Hampshire, shipped by railroad to Dillon, Montana, and hauled by ox teams to the battlefield (Catton and Hubber 1999). The dimensions and placement of the monument near the siege area were suggestive of a large, common gravestone. However, the monument made no specific reference to soldiers' graves (Owens and Hammond 2008).



Figure 7. Current photograph of the 1883 “soldiers” monument at Big Hole National Battlefield. The six-ton granite monument was placed in honor of the 7th Infantry and the Bitterroot civilian volunteers who fought and died at the battlefield on 9 and 10 August 1877. Note the thick brush and marshy conditions in the background that stifled the initial military approach and made their retreat difficult. NPS photograph taken in 2016.



Figure 8. 1951 photograph of the 1883 “soldiers” monument at Big Hole National Battlefield. The monument had a protective cage around it because visitors were chipping pieces of the granite to take away as souvenirs. The fencing was removed in 1967. From this view, the forested slopes of the Battle Gulch are behind the monument. NPS photograph.

BIHO today is surrounded by ranching operations and the Beaverhead National Forest but retains much of the character of the landscape as it was in 1877 (Owens and Hammond 2008; National Park Service 2013b). Agricultural use of the battlefield meadows has stopped, and the meadows with the meandering river have returned to a natural state. Trees and willows have been managed and/or removed to maintain the battle-era open spaces while still allowing natural surface processes to proceed and alter the landscape (Owens and Hammond 2008).

North Fork Big Hole River

The primary fluvial feature and natural resource within BIHO is the North Fork Big Hole River drainage (National Park Service 2013b). Its headwaters are at Skinner Lake in the Beaverhead National Forest; it forms inside BIHO at the confluence of Trail and Ruby Creeks (Erixson and Cogan 2012). The Big Hole River is a tributary of the Jefferson River, which in turn flows into the Missouri River. Snowmelt and rain from the surrounding mountains and hillsides coalesce into the flow of the Trail and Ruby Creeks. Beyond their confluence, the river flows 4 km (2 mi) in a

northeasterly flow through meadow bottomland characteristic of its floodplain (Corrao and Erixson 2011). The river channel meanders across its floodplain, eroding, transporting, and depositing its characteristic alluvial deposits along its course (Figure 9). As meanders become extreme, the flow will cut them off, establish a straighter course, and leave behind an oxbow lake or slough (Figure 10). The river is undammed and relatively free from historical impact from mining or industrial sources; farming, ranching, and recreation are the primary human interactions with the river system (Parker et al. 2005).

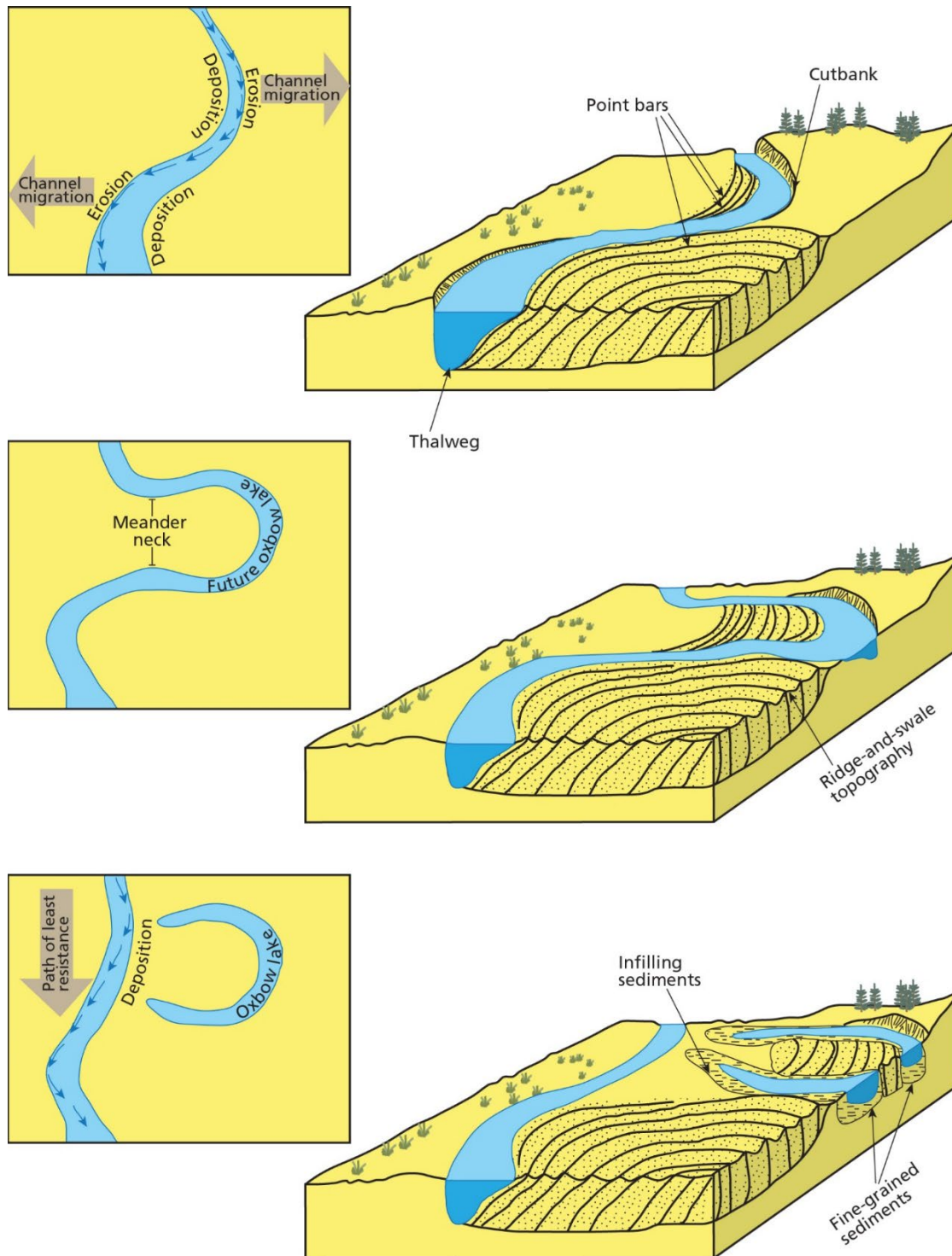


Figure 9. Illustration of fluvial processes of meandering. River meandering causes the formation of abandoned channels and oxbow lakes that infill with fine-grained sediments. Fluvial features at BIHO range from the broad, meandering North Fork Big Hole River to smaller streams like Ruby Creek and Trail Creek to numerous small, ephemeral streams and gullies. The marshy floodplains of the larger streams played a significant role in the 1877 battle—impeding troops and providing cover. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), with information from Allen (1964).

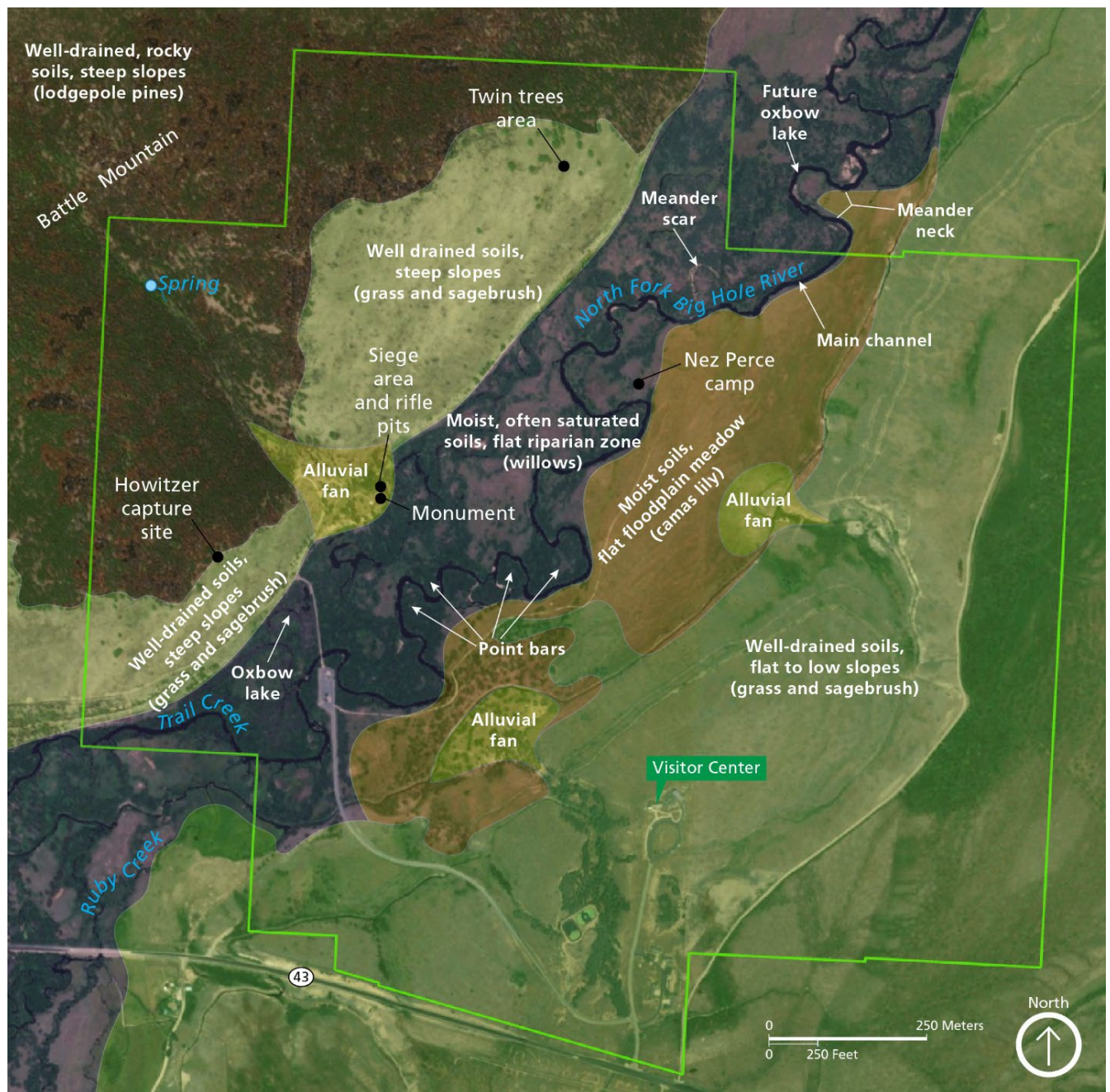


Figure 10. Aerial image with the fluvial system of the North Fork Big Hole River. The North Fork Big Hole River meanders across its floodplain with excellent examples of fluvial features such as meander necks, oxbow lakes, point bars, etc. The floodplain is characterized by moist, water-saturated soils, willow thickets, and floodplain meadows. To the east of the floodplain, well-drained areas compose the Ruby Bench. Small drainages all have alluvial fans that spread onto the main floodplain. To the west, the slopes of Battle Mountain rise sharply. The well-drained soils on these slopes support grasses and sagebrush, as well as lodgepole pine forests. Graphic by Trista L. Thornberry-Ehrlich (Colorado State University), using ESRI world imagery and information from Scott (1994) and National Park Service (2013b).

During the first two decades of the twentieth century, the homestead boom in Montana reached the Big Hole and other mountain valleys (Catton and Hubber 1999). Local homesteading families took advantage of the Desert Land Act of 1877, which authorized them to claim up to 260 ha (640 ac) at \$0.25 per acre provided the land was irrigated within three years. They raised cattle and hay. By 1915, the land along Ruby Creek, Trail Creek, and North Fork Big Hole River was riddled with ditches transmitting water away from the natural courses (Catton and Hubber 1999). The Ruby ditch is the most obvious scar within BIHO today. It was constructed to carry water to the benchlands above the valley, where the water was used in a hydraulic mining operation

Riparian zones flanking the waterways have seasonal wetlands. Corrao and Erixson (2011) assessed three ecological sites along the North Fork Big Hole River at BIHO. An ecological site is significant because it provides a scientifically defined unit of land that helps us understand how ecosystems function and respond to changes in climate, land use, and management. Each site is characterized by specific soils, climate, vegetation, and topography, and each is located along meanders of the river. The overall condition of all three was assessed as excellent. All three sites included riverine and palustrine (related to ponds) wetland systems. The streambanks at all three sites were considered stable. The presence of willow, sedge, and rush riparian zone vegetation contains deep binding root masses capable of protecting the stream banks from excessive erosion even during periods of high floodwater. In short stretches where the vegetation was only grass, observers noted the channel showed signs of widening and some lateral stream movement (Corrao and Erixson 2011).

Geology and the Big Hole Ecosystem

Weathering and erosion break down bedrock to create soil. In general, soils at BIHO are formed from a variety of parent materials, including igneous, sedimentary, and metamorphic rocks, loess (windblown silt), and volcanic ash. Major contributors to soil formation are unconsolidated surficial materials: alluvium and alluvial fan deposits, landslide deposits, or glacial till mixed with organic materials (National Park Service 2020).

In general, the climate at BIHO is rather harsh, with long, cold winters and short, dry summers. The climate is best described as a semi-arid continental climate with annual average precipitation of less than 30 cm (12 in) and annual temperature ranging from -17°C (1°F) to 26°C (79°F; Corrao and Erixson 2011). For such a small area, BIHO supports a high amount of biodiversity. About 40 threatened, endangered, sensitive, and species of special concern (mammals, birds, fish, amphibians, and plants) were identified as present or possibly present within BIHO, four of which are federally threatened, three are federally threatened and endangered candidates, and 20 are federally sensitive species (13 species had no federal designation). These species thrive in the range of habitats within BIHO (e.g., meadows, mixed shrublands, forest stands, sidehill parks, mainstem rivers, wetland, and floodplain habitats; see Figure 10; Corrao and Erixson 2011). A species of particular interest is the Lemhi penstemon (*Penstemon lemhiensis*)—a relatively short-lived perennial forb. This species thrives in two subpopulations within BIHO, clustered on steep, southeast-facing slopes (underlain by the sedimentary rocks of the Lowland Creek volcanics, as well as the biotite-muscovite granite [Howitzer Hill and Horse Pasture]) with high downslope soil movement (Elliott 2024). Populations of sensitive species are in decline in response to drought and fire suppression and are negatively

affected by invasive plant species, heavy livestock grazing, and road construction and maintenance (Montana Natural Heritage Program 2011; Corrao and Erixson 2011).

BIHO is located in the Montana valley and foothill prairies ecoregion, characterized by shortgrass prairie vegetation flanked by forested mountains (Taylor 2012). Ecosystems within BIHO vary based on their proximity to water and their slope. According to Corrao and Erixson (2011), seasonally saturated soils in riparian/wetland areas border the North Fork Big Hole River. Beyond the riparian zone are sagebrush steppe and grasslands. These meet the conifer forests upslope. BIHO contains the transition zones, or “ecotonal habitats,” where these ecosystems overlap. The lower slope of Battle Mountain (the “Horse Pasture”) is a treeless, grassy open area. To the west, there is an ephemeral draw known as Battle Gulch, below which the forest extends down to the valley floor over the low alluvial fan promontory of the siege area (Corrao and Erixson 2011; Erixson and Cogan 2012). These settings are typical of a fault-bounded valley wherein one side of the fault slides downward relative to the other side, creating a graben valley (Big Hole Valley) that fills with sediment. The streams flowing down from the upland areas carry sediment down their steep courses. These sediments are promptly deposited at the slope break and fan out in overlapping deposits across the valley floor (Erixson and Cogan 2012; Elliott 2024).

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). Geologic stratotypes are part of our national geoheritage and function as a cornerstone of the scientific value used to define the societal significance of geoheritage sites (Henderson et al. 2022).

There are no designated stratotypes identified within the boundaries of BIHO, and none identified within 48 km (30 mi) of BIHO boundaries (Henderson et al. 2022). However, new mapping by the Montana Bureau of Mines and Geology may support the presence of stratotypes. Similarly, Sears et al. (1989) proposed the name “Big Hole River gravel” for a distinctive layer of Tertiary-age, stream-washed gravel and associated debris flows that occurs across the area, though this layer was not officially named a stratotype.

Resource Management Issues and Inventory Needs

This section briefly summarizes the geologic resource management issues, inventory needs, and geologic hazards that have been identified through discussions with BIHO staff. Geologic issues refer to problems related to geologic resources. Inventory needs are highlighted to summarize what is currently known and what is needed to ensure best management practices at BIHO. 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. Please see the [GRD Energy and Minerals Branch SharePoint](#) and the [Guidance for Geologic Resource Management](#) for more information regarding the management of mining and minerals, AML, and oil and gas.

Fluvial Issues

Potential stressors to the fluvial system at BIHO include diversion or flow impairment, grazing, human recreation, nearby roads (stormwater runoff), and excessive irrigation reducing water supply (Corrao and Erixson 2011; National Park Service 2015a; Starkey 2016). These may be causing problems of siltation (accumulation of fine sediment in bodies of water), suspended solids, turbidity, bank erosion, and channel incision (Starkey 2016). Steps to reduce excess sedimentation include supporting or adding wood debris in channels to promote bed and bank stability and create step pools along steeper reaches, as well as maintaining densely vegetated riparian buffers to trap sediments prior to being washed into streams (Corrao and Erixson 2011). Irrigation facilities within the fluvial system are used by owners of private water rights (part of their deed); currently they use two irrigation ditches and have the right of access to maintain and repair them. One of these ditches is on the slope of Ruby Bench, the other is near the BIHO entrance. Both have service roads for access (National Park Service 1997; BIHO natural resource staff, written communication, June 2025).

Resource managers are concerned that the developments within the lower parking area of BIHO might have the potential to affect flooding patterns, sediment deposition, and stream channel characteristics, which, in turn affect other resources from riparian species to grayling spawning habitats (Corrao and Erixson 2011). The Upper Columbia Basin Network is currently monitoring stream channel characteristics and riparian zone conditions (Garrett et al. 2011; e.g., National Park Service 2013c, d; Starkey 2016). Among the parameters measured are bank angle, pool depth, channel substrate (alluvium; geologic map unit **Qal**), bankfull width-to-depth ratios, gradient %, and sinuosity (National Park Service 2013d). This will allow resource managers to identify changes in the fluvial system by comparing baseline data to future conditions over time. Monitoring erosion along the stream banks of the North Fork Big Hole River within BIHO is also important due to possible effects of disturbing cultural resources near the encampment area (Corrao and Erixson 2011). Recommended future research projects include water quality and quantity, monitoring and vegetation classification, and mapping within riparian zones.

A specific objective in BIHO's stream channel protocol is aimed at addressing riverbank erosion. Erosion along river channels is a natural process that occurs as rivers adjust to disturbance events and

to changes in water and sediment delivery over time (Field et al. 2025). The resulting migration (lateral movement) of river channels is fundamental to building complex, dynamic, and resilient landscapes and dependent habitats. Natural erosion is critical for sustaining healthy rivers and should be preserved whenever possible (Field et al. 2025). However, BIHO managers may deem protection from bank erosion necessary if bank retreat threatens infrastructure, developed land, or valuable natural and cultural resources (Field et al. 2025). Field et al. (2025) describe a variety of surface treatments and flow deflection treatments to protect designated riverbanks (Figure 11).

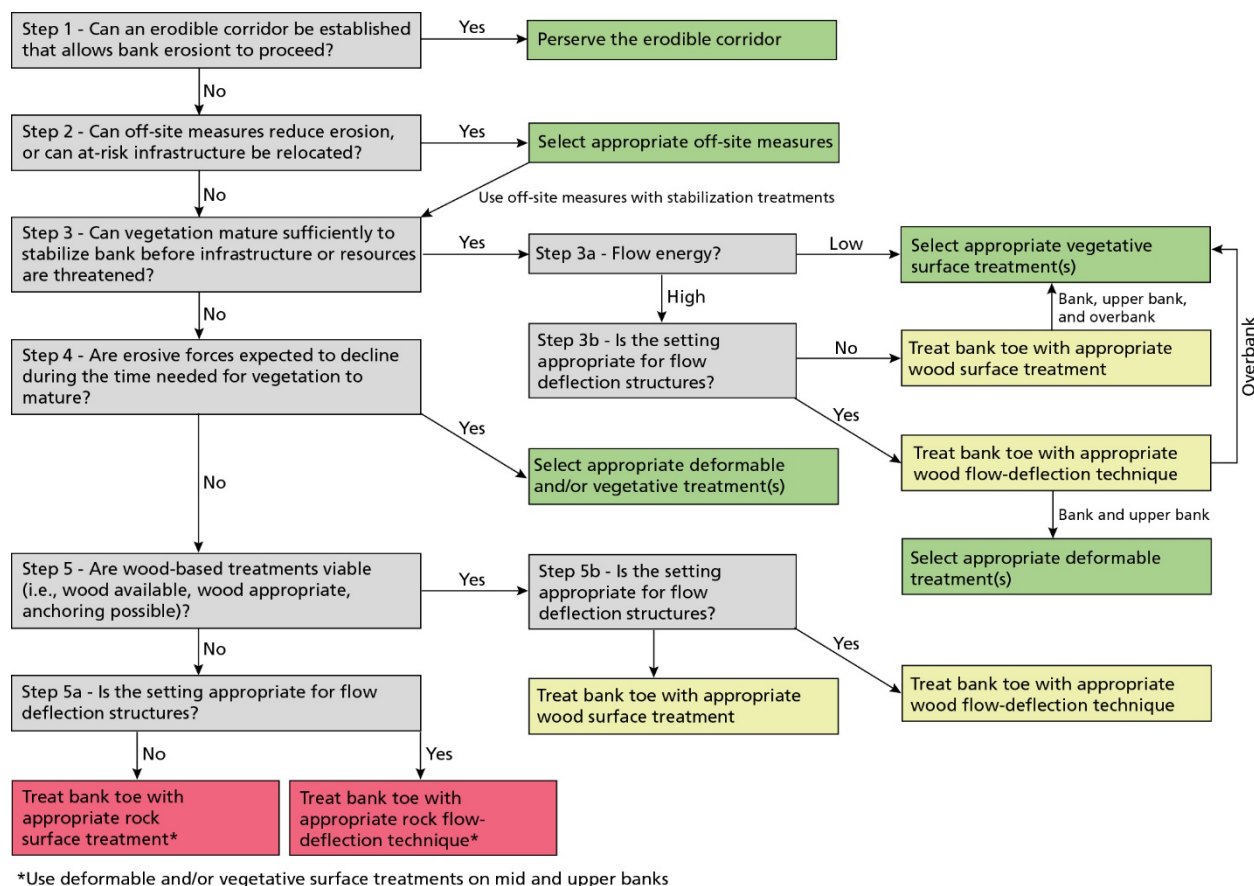


Figure 11. Decision tree to manage riverbank erosion. Step-by-step guidance to determine the best course of action is useful for BIHO managers assessing the feasibility of armoring or protecting a riverbank. The colored boxes represent a continuum of bank erosion management strategies going from more natural (green) to less natural (red) aligned with Wild and Scenic River (but also largely applicable to BIHO) values and NPS policies. Not included are processes regarding the decision to take management actions for riverbanks that may have significant cultural resources. Graphic is figure 10 in Field et al. (2025).

Slope Movements

Potential for slope movement exists on all BIHO slopes, particularly where the streams cut into the toes (lowest part or base) of the slopes. Slope movements are the downslope transfer of material

(e.g., soil, regolith, and/or rock; Figure 12). Slope movements can occur rapidly (e.g., debris flows or rockfalls) or over long periods of time (e.g., slope creep). The magnitude of slope movements depends on the degree of slope, aspect, soil type, and geology. Frost and plant-root wedging, fluvial undercutting, and erosion are the primary causes of slope instability at BIHO.

Evidence of former slope movements is present at BIHO. Landslide deposits and alluvial fans, composed of loose and incoherent deposits transported by gravity, occur at the base of many slopes and are mapped within BIHO boundaries (Elliott 2024). Ancient rockfalls, slides, and debris flows left scars along the slopes of Battle Mountain and Ruby Bench (Elliott 2024).

Any steep slope at BIHO poses a landslide hazard, and rockfall is a threat along stretches of the trails. Most ancient slides are relatively stable. Anthropogenic changes to the hill slopes, such as road and trail construction, mining, undercutting, and deforestation, are the most common triggers of active sliding. Visitors need to be aware of rockfall potential and be warned about any active slide and rockfall areas. The Montana Bureau of Mines and Geology identifies, maps, and categorizes landslides across the state

(<https://www.mbmge.mtech.edu/MontanaGeology/geohazards/landslides/main.asp#gsc.tab=0>).

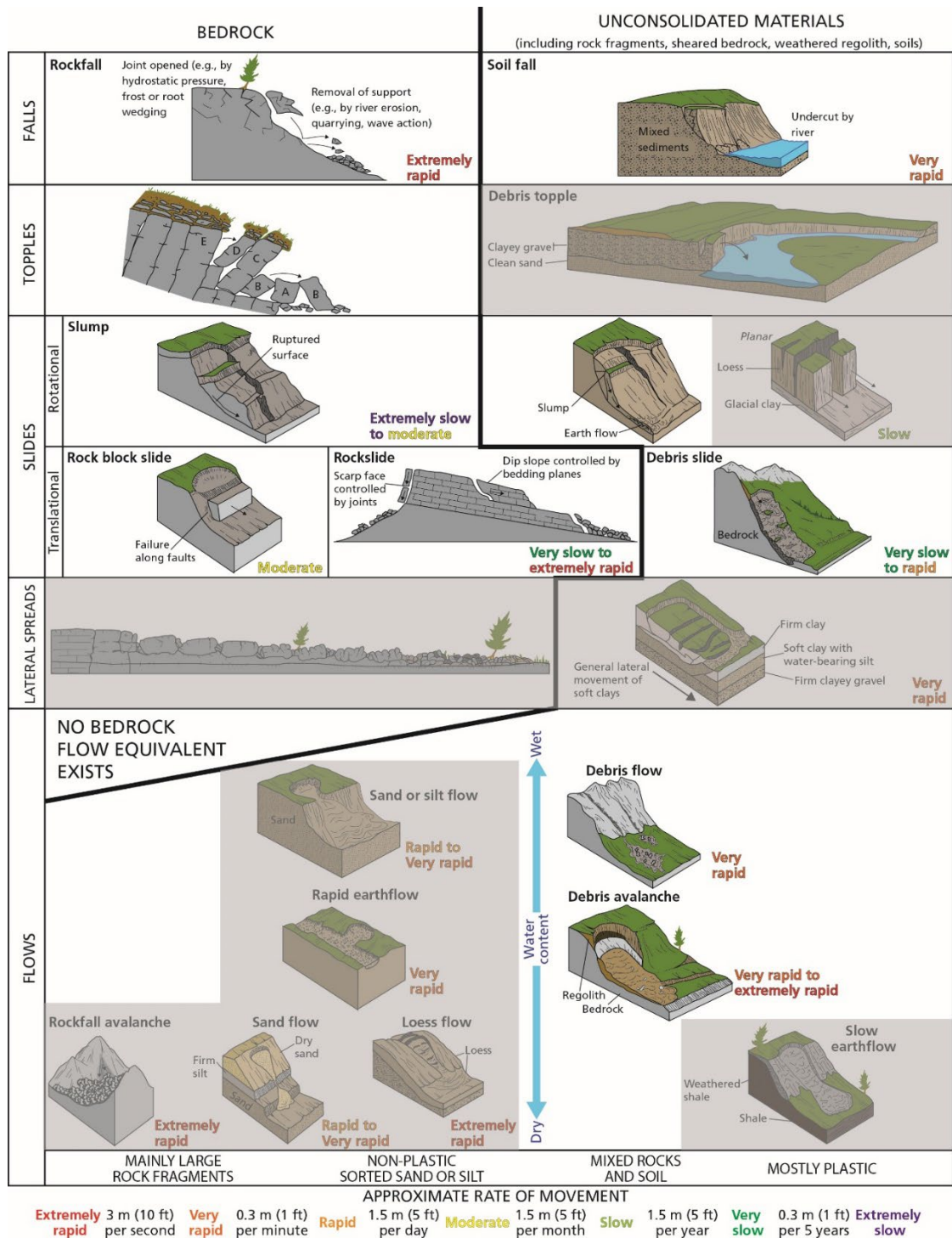


Figure 12. Illustrations of slope movements. Different categories of slope movement are defined by material type, nature of the movement, rate of movement, and moisture content. Grayed areas depict conditions unlikely to exist at BIHO. The abundant vegetation in the park stabilizes some slopes, but slope issues could be exacerbated by factors such as natural or anthropogenic removal of vegetation, upstream development, and climate change. Graphic by Trista Thornberry-Ehrlich (Colorado State University), redrafted after a graphic and information in Varnes (1978) and Cruden and Varnes (1996).

Seismicity

Seismicity refers to the ground shaking that occurs during earthquakes. Although BIHO is not traditionally considered a seismically active area, it is located near several seismically active regions in northwestern Montana that extend across Idaho and southern Montana along the Wyoming border (Figure 13). Since 1982, several ~4.0 magnitude earthquakes have been recorded in the BIHO area (Montana Bureau of Mines and Geology 2025). The potential for seismicity is present (moderate risk) at BIHO and may trigger landslides, cause liquefaction along the floodplain, unleash rockfall, and damage infrastructure. Liquefaction occurs during earthquakes when loosely packed, water-saturated soils and sediments lose their strength and behave like a fluid or liquid. Liquefied soils may cause buildings to shift, large ground areas to move laterally, and rigid surfaces like roads and bridges to crack. Liquefaction may contribute to ground subsidence, deformation, and/or cracks. Water and sand can erupt through the cracks, creating characteristic sand blows or cones. The Tertiary and Quaternary valley-fill sediments and shallow groundwater table at BIHO are conditions prone to liquefaction (Li et al. 2019). Whenever possible, construction on liquefiable ground surfaces should be avoided. Where construction on liquefiable soils is unavoidable or has already occurred (e.g., much of the infrastructure at BIHO), geotechnical methods are available to reduce the potential of liquefaction during earthquakes. These methods include compacting or draining the area prior to construction, installing gravel columns, driving metal or wooden poles into the ground, or injecting chemicals that will stabilize the soil. However, these methods are commonly expensive and not always effective. (Li et al. 2019).

The US Geological Survey and Montana Bureau of Mines and Geology (<https://www.mbmng.mtech.edu/MontanaGeology/geohazards/main.asp#gsc.tab=0>) inventory active faults and monitor seismic activity throughout the region. A seismic station is located about 10 km (6 mi) north of the BIHO boundary, maintained by the Montana Bureau of Mines and Geology.

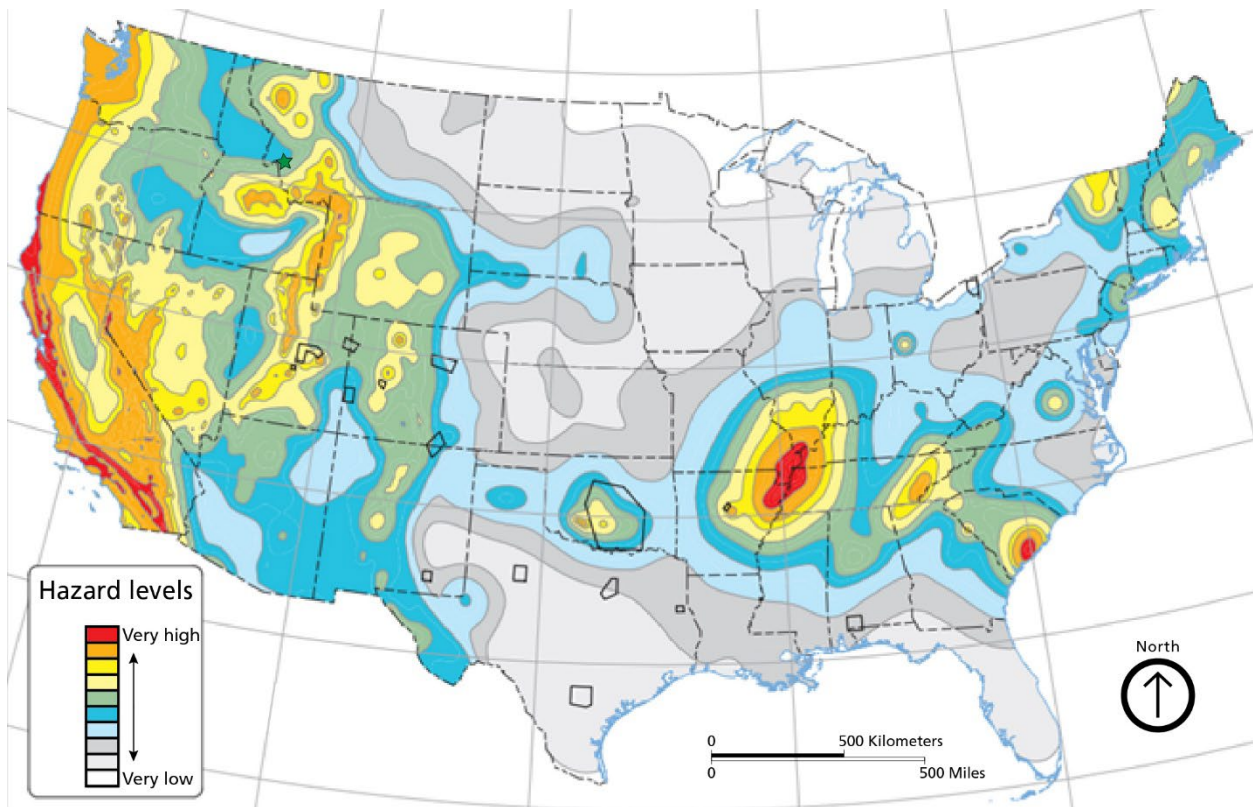


Figure 13. National seismic hazard map. The map shows the relative hazard associated with potential earthquakes in different areas. The map is based on USGS models that calculate the probability of an earthquake within 50 years for a firm rock site based on seismicity, fault-slip rates, and the frequency of earthquakes of various magnitudes. Locally, the hazard may be greater than shown because site geology may amplify ground motions. The BIHO location is at the green star within moderate hazard levels, near the border with Idaho and several areas of higher hazard levels. Public domain graphic courtesy of the US Geological Survey; available at <https://www.usgs.gov/media/images/2018-long-term-national-seismic-hazard-map>.

Climate Change Impacts on Geologic Resources

Accelerated global climate change may be the most far-reaching and consequential challenge facing any natural resource manager (Corrao and Erixson 2011). The Intergovernmental Panel on Climate Change (IPCC) has noted that climates in the BIHO region are becoming warmer and drier. Reported changes include variations in seasonal precipitation and temperature, timing of life-cycle events, plant growth or primary production, biogeographic distribution, and increased wildfires (Running 2006; Corrao and Erixson 2011). Drought within the Big Hole River drainage basin would negatively impact vegetation cover, accelerate water diversion to irrigate crops, and cause more rapid runoff. These events would negatively affect aquatic, riparian, and wetland habitats. Stressors would include changes in flow periodicity, reduced flows, decreased water quality, reduction of favorable habitat, and increased water temperatures (Corrao and Erixson 2011).

The threats to park resources from climate change include altered precipitation patterns, seasonal weather patterns, and temperature that could lead to altered stream flow regimes through changing

precipitation patterns; alteration could result in larger spring-season flows, increased flood stage, and hotter, drier summers. These climate change effects would pose a threat to the habitats and stream flows within BIHO (Corrao and Erixson 2011).

Visitor use also impacts the geologic resources of BIHO. For BIHO, a strong correlation between climate (temperature) and visitation exists. Climate models predict temperature increases between 1.3°C (2.3°F) and 3.7°C (6.7°F) by midcentury and correlate with a 14–48% increase in annual visitation and an 11–34% increase in peak season (summer) visitation (Fisichelli and Ziesler 2015). This increase in visitors will place increasing demands on water supply, trail integrity, and other park resources.

Inventory Needs

The following table (Table 2) presents several geologic and soil resources inventory needs that were identified during the scoping meeting, in NPS planning documents, or through literature review.

Table 2. List of identified geologic and soil resource inventory needs for BIHO.

Subject	Inventory and/or Planning Need(s)	Reference(s)
Abandoned mineral lands	Conduct mineral resources inventories.	Lipton et al. (1988)
Geohazards	Climate change impact analysis.	National Park Service (2017)
Geoheritage	Land use and zoning inventory. Cultural landscape treatment guidance. Resource stewardship strategy.	National Park Service (2017)
Geoscience Research	Determine any geology-related causes of camas lily decline.	Stucki and Rodhouse (2017)
Groundwater/hydrogeology	Conduct hydraulic conductivity and transmissivity tests to characterize the aquifer in the Big Hole Basin. Resolve existing non-NPS water rights.	Marvin (1997) National Park Service (1997)
Mapping	Detailed surficial geologic map. Land-use mapping. GIS data for archeological/cultural sites. Add new geologic mapping to GSRI data.	Erixson and Cogan (2012) Elliott (2024)
Interpretation	Update interpretive materials. Support accessible trail construction.	National Park Service (1997)
Paleontology	Conduct paleontological field survey.	Kenworthy et al. (2005)
Soils	Detailed mapping of problematic soils.	DOI Strategic Hazard Identification and Risk Assessment (SHIRA)
Stratotypes	Investigate stratotype potential for new mapping conducted by Montana Bureau of Mines and Geology. Investigate “Big Hole gravel” nomination.	Henderson et al. (2022) Elliott (2024) Sears et al. (1989)

Legislatively Required Geologic Inventories

Some laws, regulations, and policies specifically apply to geologic and soil resources or processes. These include legislatively required inventories. The NPS GRD has an article series

(<https://www.nps.gov/articles/series.htm?id=FA0A8F89-CD67-1CCE-5A6608B444E8A7C0>) that summarizes these laws, regulations, and policies. These protection measures were established to maintain the integrity of these resources or processes while minimizing the impacts of natural or anthropogenic activity.

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.

A field-based paleontological resource inventory remains a need at BIHO, but fossils are known from the same rock units beyond BIHO boundaries (Kenworthy et al. 2005). The layered sediments that fill the Big Hole Basin are known to contain trace fossils (e.g., burrows) and fossil invertebrates (e.g., gastropods [snails], ostracodes [small aquatic bivalved crustaceans], and pelecypods [clam-like bivalved mollusks]), vertebrates (e.g., turtles, rodents, rabbits, early horses, artiodactyls, rhinoceros, fish, and amphibians), and plants (e.g., fir, spruce, pine, dawn redwood, maple, birch, hackberry, beech, ash, Oregon grape, poplar, gooseberry, rose, elm, and keaki tree; Kuenzi and Fields 1971; Hanneman and Nichols 1981; Henrici 1994; Thomas 1995; Tidwell 1998; Kenworthy et al. 2005).

Summary of Geologic and Soil Hazards

The dynamic landscapes of many national park units present various natural hazards that threaten NPS facilities, staff, visitors, or resources. Many of these natural hazards are geologic (e.g., volcanoes, earthquakes, and landslides). The Addressing Climate Change and Natural Hazards Handbook (National Park Service 2015b, 2023), grounded in NPS Policy Memorandum 15-01 (Jarvis 2015), provides a process and information to help identify, avoid, and mitigate risks associated with changing environmental conditions, natural hazards, and effects on proposed and planned facility investments. The handbook supports NPS planning guidance, policy directives, and executive orders and does not supersede existing mandated compliance processes and policies. Additional guidance for facility management, such as [Climate-Smart Planning Principles](#) and [Recommended Practices](#), has been developed to support effective decision making.

According to PM 15-01, managers should apply the handbook guidance to identify options to manage natural hazard and climate change risks throughout all levels of facility planning and design. Project teams are required to submit the completed Natural Hazards Checklist (see Table 2) as part of Regional and Bureau Investment Review Board submissions. This information can also be used as part of the updated (2024) Automated Investment Review Board (AIRB) submittal process at the Investment Concept (IC) stage. Table 3 is a screening tool to be used at the IC stage to help teams determine potential climate change effects and natural hazards to a proposed facilities investment. It is appropriate for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or National Environmental Policy Act (NEPA) analysis. Ground-disturbing activities should neither be approved nor denied based upon the information here. Table 3 includes selected geologic and soil hazards listed in Part 1 of the handbook (National Park Service 2023). The GSRI

team has added additional hazards where appropriate for BIHO. If needed, Part 2 of the handbook could inform completion of the checklist, such as whether a hazard is applicable. Contact the NPS GRD with any questions.

Table 3. Geologic and soil hazards checklist. This checklist includes selected hazards listed in Part 1 of National Park Service (2023).

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment (SHIRA hazard level where known)	Source(s) of Information
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://sealevel.nasa.gov/task-force-scenario-tool 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.	Potential hazard	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) Climate Toolbox: Climate Mapper (for Western US) https://marine.usgs.gov/coastalchangehazardsportal/ 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)	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com) Climate Toolbox: Climate Mapper (for Western US) https://marine.usgs.gov/coastalchangehazardsportal/ FEMA: NFHL https://www.fema.gov/flood-maps/national-flood-hazard-layer

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment (SHIRA hazard level where known)	Source(s) of Information
Lake and Reservoir Level Change	Water supply diminished. Flooding and erosion impacts to infrastructure. Diminished or lost recreational opportunities.	Not applicable	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://marine.usgs.gov/coastalchangehazardsportal/ 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://marine.usgs.gov/coastalchangehazardsportal/ 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	Climate Toolbox: Climate Mapper (for Western US) https://marine.usgs.gov/coastalchangehazardsportal/ 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 DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment (SHIRA hazard level where known)	Source(s) of Information
Landslide	Rockfall. Mud or debris slides or flows onto or from under structures. Reduced or precluded visitation. Avalanche	Known hazard (very high)	Montana Bureau of Mines and Geology geohazards http://www.mbmgt.mtech.edu/MontanaGeology/geohazards 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.	Known hazard (low)	Montana Bureau of Mines and Geology geohazards http://www.mbmgt.mtech.edu/MontanaGeology/geohazards 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	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.	Known hazard	Montana Bureau of Mines and Geology geohazards http://www.mbmgt.mtech.edu/MontanaGeology/geohazards NPS: Soil Resources Inventory USDA: Soils Survey (a few areas with high rating) https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/ 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 Judgment (SHIRA hazard level where known)	Source(s) of Information
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)
Burn Probability (2053 model)	Removal of stabilizing vegetation leading to increases in erosion and slope instability.	Known hazard (high)	US Forest Service https://www.fs.usda.gov/managing-land/fire DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)
Subsurface Hazards: Abandoned Mineral Lands Cave/Karst (sinkholes)	Surface collapse. Contamination. Toxic mine drainage. Unsafe access or instable landforms.	Potential hazard	Montana Bureau of Mines and Geology geohazards http://www.mbmj.mtech.edu/MontanaGeology/geohazards 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)
Toxicological geology and/or soil	Asbestos or erionite content Radon Arsenic Bacillus anthracis Cadmium Lead Selenium Valley fever fungus	Potential hazard (high for radon and arsenic; low for bacillus anthracis and selenium; moderate for cadmium and lead)	DOI Strategic Hazard Identification and Risk Assessment (SHIRA) SHIRA - Home (sharepoint.com)

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