Geologic Resource Inventory Scoping Summary
Missouri National Recreational River, NE/SD

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The Geologic Resource Inventory (GRI) Program provides each of 270 identified natural area National Park System units with a geologic scoping meeting and summary (this document), a digital geologic map, and a geologic resources inventory report. The purpose of scoping is to identify geologic mapping coverage and needs, distinctive geologic processes and features, resource management issues, and monitoring and research needs. Geologic scoping meetings generate an evaluation of the adequacy of existing geologic maps for resource management, provide an opportunity to discuss park-specific geologic management issues, and if possible include a site visit with local experts.

The National Park Service held a GRI scoping meeting for Missouri National Recreational River (MNRR) and Niobrara National Scenic River (NIOB) on August 20, 2008 at the University of South Dakota, Vermillion, South Dakota. Lisa Norby (NPS GRD) facilitated the meeting and led the discussion regarding geologic processes and features at Niobrara National Scenic River. After Wayne Werkmeister (MNRR) presented an overview of some of the impacts of dams and stabilization projects to the river, Tim Connors (NPS GRD) led the discussion of map coverage. Scott Lundstrom (USGS) presented a geologic overview, and Matt Joeckel (NEGS) discussed mineral occurrences related to recent weathering in the Missouri and Niobrara valleys. Rob Jacobson (USGS) addressed the role of geology and hydrogeology with regards to managing threatened and endangered species in the park. On Thursday, August 21, Tim Cowman (SDGS), Scott Lundstrom (USGS), and Wayne Werkmeister (MNRR) led a field trip within the 59-mile District from Audubon Bend to Mulberry Bend in the morning, and in the afternoon, to an active quarry and to Ponca State Park. Participants at the meeting included NPS staff from the park and Geologic Resources Division (GRD) and cooperators from the South Dakota Geological Survey (SDGS), Nebraska Geological Survey (NEGS), USGS, and Colorado State University (CSU). This scoping summary highlights the GRI scoping meeting for Missouri National Recreational River including the geologic setting, the plan for providing a digital geologic map, geologic resource management issues, a description of significant geologic features and processes, mapping recommendations, and a record of meeting participants (table 1).

Park and Geologic Setting

One-sixth of the United States is drained by the Missouri River, which encompasses 1,371,017 sq km (529,350 sq mi) as it flows nearly 3,900 km (2,400 mi) from its headwaters in the Rocky Mountains to its confluence with the Mississippi River near St. Louis, Missouri. Missouri National Recreational River manages 160 linear km (98 linear mi) of the Missouri River along the South Dakota-Nebraska border, a segment of the Niobrara River, and a segment of Verdigre Creek. Lewis and Clark Reservoir separates the park into the 59-mile District, located downstream from the reservoir, and the 39-mile District, upstream from the reservoir. Prior to the construction of the Fort Randall, Gavins Point, and four other mainstem dams in the 1930s to 1950s, the Missouri River carried an average of roughly 140 million tons of sediment per year past Yankton. Following the dam construction, that amount fell to an average of approximately 4 million tons per year.

The 59-mile District contains a wide, meandering channel, shifting sandbars, secondary channels, and some of the last remaining forested floodplain and floodplain wetland habitats on the Missouri River. The topography ranges from a nearly level floodplain on the South Dakota side of the river to steep, tree-covered bluffs on the Nebraska side. Riverbanks vary from sandy flats of bars and islands to vertical cliffs 3-5 m (10-15 ft) high that are a result of post-dam river incision into floodplain sediments, to exposed Cretaceous bedrock intermingled with landslide terrain where the river impinges on uplands.

The 39-mile District is influenced by controlled releases from Fort Randall Dam for power generation known as “power peaking.” In this district, the Missouri River flows through a valley that varies in width from 1,500-2,700 m (5,000-9,000 ft). Forested chalkstone bluffs adjacent to gently rolling to flat agricultural bottomland mark the Nebraska shoreline while on the South Dakota side, the valley is up to 1.6 km (1 mi) wide and is bordered by chalkstone bluffs and rolling hills.

The high plains of South Dakota and Nebraska were covered by relatively shallow marine environments during the Cretaceous Period, approximately 65-85 million years ago (Ma). Cretaceous strata are the oldest rocks exposed in the park and include the flat-lying, chalky limestones of the Niobrara Formation that form the bluffs along the river and dark gray to black marine shales of the Carlile and Pierre Formations. After the sea receded, sandstones and siltstones were deposited in Tertiary Period floodplain environments. Continental glaciers advanced into the region as climate cooled during the Pleistocene Ice Age. When the glaciers melted, they left a landscape of gently rolling plains and hills composed of a complex mosaic of glacial till, gravel, sand, silt and clay.

Missouri National Recreational River rests between the glaciated and unglaciated portions of the Missouri Plateau in the Great Plains Province. The Missouri River approximates the southern extent of the last ice lobe that advanced into the area 12,000-14,000 years ago (Wisconsin glacial stage). Within the last 11,000 years, geologic processes in the park have been dominated primarily by fluvial (river) erosion and deposition and aeolian (wind) processes.

Impact of Dams and Stabilization Projects (Wayne Werkmeister)

Established in 1978 and 1991 under the Wild & Scenic Rivers Act (WSRA), the Missouri National Recreational River is a partnership-based park working with federal, state, county, and city agencies as well as commercial interests, private citizens and public interest groups. Missouri National Recreational River management often acts as a facilitator among these private and public stakeholders.

The Army Corps of Engineers and Bureau of Reclamation have each constructed six dams on the mainstem of the Missouri River. The Army Corps of Engineers’ dams make up the lowest six dams on the system and facilitate commercial navigation on the lowest 1,200 km (720 mi) of the Missouri River. Other primary project purposes, although not the only purposes, include flood control and hydropower generation. Within the 39-mile District and the 59-mile District, the Missouri River is a free-flowing system, as defined by the WSRA. However, river flow (e.g. the annual hydrograph) and sediment transport have been greatly affected by operation of the dams relative to pre-dam conditions.

Bank erosion has long been a management issue on the Missouri River. For example, farmers and riverbank owners would like the federal government to define and stabilize their land while resource managers see erosion as a natural process necessary for the health of a river environment. The 1978 legislation allowed for bank stabilization through a "demonstration" authority in 1974 WRDA, and the Army Corps of Engineers began using a variety of materials as riprap in 1978. Opposition to the Army Corps of Engineer's proposal to use riprap to stabilize 40 km (25 mi) of banklines in the 59-mile District led to the park's Wild and Scenic River designation. After 1978, the National Park Service signed a cooperative agreement with the Army Corps of Engineers, and together, they completed the most recent General Management Plan for the park.

More than 90% of the land along the river in both Missouri National Recreational River Districts is privately owned. Stabilization projects have impacted about 30% of the river's banks. Since the construction of the Fort Randall Dam and the Gavins Point Dam in the 1950s, and subsequent elimination of flood events, cabin development along the river has increased, adding pressure on park management to control bank erosion. The Army Corps of Engineers controls the dams and regulates flood frequency, but the dams have disrupted the ecology of the river system and made restoration of the natural system very difficult. Since construction of the dams, the "floodplain" downstream from the dams has been difficult to define. Disruption of the natural flow of the Missouri River has led to entrenched channels and problems with associated lowered water tables, as well.

Geologic Mapping for Missouri National Recreational River

During the scoping meeting, Tim Conners (NPS GRD) showed some of the main features of the GRI Program's digital geologic maps, which reproduce all aspects of paper maps, including notes, legend, and cross sections, with the added benefit of being GIS compatible. The NPS GRI Geology-GIS Geodatabase Data Model incorporates the standards of digital map creation for the GRI Program and allows for rigorous quality control. Staff members digitize maps or convert digital data to the GRI digital geologic map model using ESRI ArcGIS software. Final digital geologic map products include data in geodatabase and shapefile format, layer files complete with feature symbology, FGDC-compliant metadata, a Windows HelpFile that captures ancillary map data, and a map document that displays the map, and provides a tool to access the HelpFile directly from the map document. Final data products are posted at http://science.nature.nps.gov/nrdata/. The data model is available at http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm.

When possible, the GRI Program provides large scale (1:24,000) digital geologic map coverage for each park's area of interest, which is often composed of the 7.5-minute quadrangles that contain park lands (fig. 1). Maps of this scale (and larger) are useful to resource managers because they capture most geologic features of interest and are spatially accurate within 12 m (40 ft). The process of selecting maps for management begins with the identification of existing geologic maps and mapping needs in the vicinity of the park. Scoping session participants then select appropriate source maps for the digital geologic data or develop a plan to obtain new mapping, if necessary.

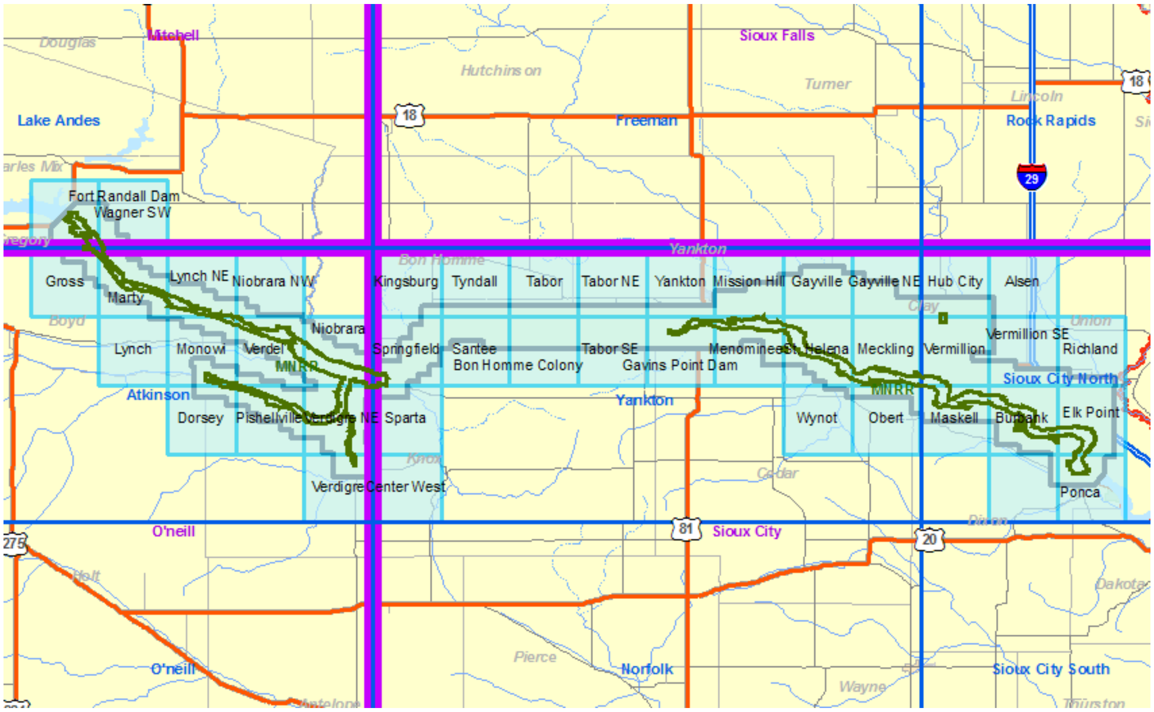

Figure 1. Area of interest for Missouri National Recreational River, Nebraska and South Dakota. The 7.5-minute quadrangles are labeled in black with light blue polygons infilled; names in blue indicate 30-minute by 60-minute quadrangles; names in purple indicate 1x2 quadrangles. Green outlines indicate monument boundaries and the gray line indicates the desired maximum extent of geologic mapping for MNRR. "39-mile" district is westernmost unit; "59-mile" district is easternmost unit.

After the scoping a group was convened to discuss desired mapping extent and arrived at the following consensus from comments from USGS, SDGS, and NPS staff: construct a geologic map with a minimum of one mile outside the park boundary, but in most areas the boundary is one mile beyond the valley wall. The boundaries are squared to the nearest section line.

Portions of the following 7.5' quadrangles involved are as follows: Wagner SW, Fort Randall Dam, Alsen, Hub City, Gayville NE, Gayville, Mission Hill, Yankton, Tabor NE, Tabor, Tyndall, Kingsburg, Niobrara NW, Lynch NE, Marty, Gross, Richland, Vermillion SE, Vermillion, Meckling, Saint Helena, Menominee, Gavins Point Dam, Tabor SE, Bon Homme Colony, Santee, Springfield, Niobrara, Verdel, Monowi, Lynch, Elk Point, Burbank, Maskell, Obert, Wynot, Sparta, Verdigre NE, Pishellville, Dorsey, and Verdigre Center West.

The 30x60 sheets this area covers are the Sioux City North, Yankton, and Atkinson.

The 1x2 sheets covered are the Sioux City and O'Neill.

Based upon this desired extent, NPS staff are now working with USGS Scott Lundstrom to find ways to incorporate his existing projects in the region to producing a dedicated MNRR digital geologic map. NPS-GRD staff (Bruce Heise and Tim Connors) will be in communications regarding this matter and will report back to the group. Scott estimates a minimum of two years to complete such a project. It is likely a formal scope of work will need to be developed for this project and will likely result in a USGS open-file publication.

From an abstract of GSA 2006 comes the following regarding this mapping project: "New Geologic Mapping along the Missouri National Recreational River" (http://gsa.confex.com/gsa/2006AM/finalprogram/abstract_111600.htm):

In cooperation with the National Park Service, South Dakota Geological Survey, Nebraska Conservation and Survey Division, and university partners, the U.S. Geological Survey began a geologic mapping project of the Missouri River corridor region along the Missouri National Recreational River (MNRR) of southeast South Dakota and northeast Nebraska. The geologic framework of the river corridor, especially the glacial and postglacial geology emphasized in our work, dominates the geomorphic and hydrogeologic bases of the physical habitat and ecology. The area of the corridor spanned by the MNRR includes several geologically significant terrains. The river valley, with a width of 3-6 km throughout most of the Dakotas and eastern Montana, expands markedly below Yankton, SD to a width of 10-16 km. The expanded reach coincides with the southernmost extent of the James River lobe of the late Wisconsinan Laurentide Ice sheet. In the uplands south of the river valley in eastern Nebraska, a much older and morphologically distinctive pre-Illinoian glacial terrain is partially mantled by loess. Both terrains include extensive glacial-buried-valley aquifers, which are contiguous with the alluvial-outwash aquifer that underlies the river and its valley.

The geomorphology of the river valley is dominated by post-glacial Holocene deposits and by the presently active fluvial system. Before the dam system was built during the mid 1900s, the river episodically transported large but variable fluxes of sediment from the extensive drylands upstream of the study area. Particularly in the expanded part of the valley, numerous crosscutting packages of meander-scroll morphology provide a record of changing fluvial processes that reflect response of basin hydrology and sediment yield that we are testing with mapping and chronology studies . Exposures enhanced by incision of the sediment-poor post-dam river commonly show well-sorted sand of point bars and channels overlain by overbank sediments and well-bedded channel fills dominated by silt, clay, and mud. In contrast, sparse exposures of glacial outwash have much coarser gravel dominated by crystalline lithology. At riverbank exposures of outwash, we observed an unusual abundance of native mussels that suggest a potential control on local water chemistry and ecology by these gravels through enhanced groundwater flux to the river.

Additional items of interest related to MNRR area geologic mapping:

- The eastern half of the Yankton 30x60 quadrangle is planned as a preliminary open-file map
- South Dakota Geological Survey has 1:100,000 scale county-based surficial geology available

Geologic Overview (Scott Lundstrom)

Flowing through seven states, the Missouri River is the longest river in the United States. Geologic framework of the river valley and watershed provide major controls on erosion and sediment supply, the nature of the channel bed and floodplain, and groundwater and surface water interactions. Thus, geology is highly relevant to adaptive management. Mapping both the 59-mile District and 39-mile District should document the present river system and capture the changes in river morphology and meander belts.

Depositional environments of meandering river systems such as the Missouri River reflect various energy regimes and include point bars, cutbanks, oxbow lakes, crevasse channels and crevasse splays, sand flats, cross-channel bars, backwater marshes, chute channels, and overbank deposits. Sediments deposited in different energy regimes have distinctive grain size distributions. For example, overbank deposits are composed primarily of fine-grained sediments like silt and clay whereas well-sorted, coarse- to fine-grained sand is found on point bars.

Recent, ongoing draft mapping shows meander belts (both current and paleo-channels), upland geology, and glacial units, which contrast greatly in age and morphology north and south of the river. The use of riprap for bank stabilization, however, has partially covered bank exposures of fluvial deposits. Today, approximately 33% of the riverbank has undergone "bank stabilization". Some of the coarse-grained gravels found in the river system today are artificially derived from eroding bank stabilization projects and may be misinterpreted as gravels common to natural coarse-gained depositional environments. The park has blueprints of project locations and these should be located on the park's geologic map.

The ongoing USGS mapping includes essential collaboration with the geologic expertise of state agencies and universities. To address some of the needed geologic detail in the floodplain, Dr. John Holbrook and his students of the University of Texas are mapping and testing facies and the depositional record through hand auger studies. The South Dakota Geologic Survey has published geologic mapping at a variety of scales, including county geologic reports with maps, and borehole databases. The University of Nebraska – Lincoln, Conservation and Survey Division, has ongoing mapping of the Wynot 7.5' quadrangle, as well as a variety of published products relevant to the ongoing MNRR-oriented geologic mapping. USGS and SDGS have been included in a multiagency assessment of the history of is studying the river-banks at Goat Island, which lies within the 59-mile District.

The Missouri National Recreational River is located along a significant Quaternary geologic setting and boundary. To the north of the river, Wisconsin glacial deposits were deposited by the James Lobe of the Laurentide ice sheet (southwestern sector). Older pre-Illinoian glacial deposits are known to exist south of the river. These older glacial deposits are overlain by loess (wind-blown silt). In general, the late Wisconsin glacial deposits north of the river do not have a significant loess cover that is common south of the river.

In the 59-mile District, Quaternary loess on the south side of the river also covers older Mesozoic deposits. The bluffs at Bow Creek are composed of Cretaceous Carlile Shale overlain by Cretaceous Niobrara Formation, which is in contact with Quaternary loess. At Ponca State Park, Greenhorn

Limestone overlies the Graneros Shale and these Cretaceous units are overlain by loess. In the 39-mile District, the Niobrara forms chalk bluffs and weather to a distinctive orange color beneath Quaternary loess.

Mineral Occurrences Related to Recent Weathering, Missouri and Niobrara Valleys, Nebraska (Matt Joeckel)

Studies of recent mineral weathering address acid-rock weathering, phosphate mineral genesis and occurrence, and the association of hydrous iron oxide with weathering. Mineral occurrences associated with weathering are important for the following reasons:

- Segregation and liberation of ions
- Changing pH of solutions
- Formation, transformation, and destruction of minerals
- Biochemical processes

Acid-rock weathering sites in the Cretaceous of Nebraska are found in the Dakota Sandstone, Granerous Shale, Carlile Shale, and Pierre Shale. Hydration of sulfates has produced minerals such as alunogen, copiapite, epsimite, gypsum, and the rare mineral, slavikite. Oxidation of pyrite in the Pierre Shale has formed gerisite, gypsum, jarosite, aluminum sulfates, and other minerals. In Dixon County, approximately 20-30% of the Carlile Shale outcrop at Volcano Hill is composed of the yellow jarosite with a pH of 2.5. Weathering of pyrite in the Carlile has also produced halotrichite and melantrichite, hydrated sulfates which break down to sulfuric acid. A previously unreported locus of new mineral formation has been found at the contact of the Carlile Formation with the Niobrara Formation where aluminum-sulfate minerals such as aluminite, with a pH of 4-5, are forming. In the Pierre Shale, the aluminum-phosphate-hydroxite mineral, vashegyite, may be forming. Vashegyite is known only from about 15-20 sites around the world. Phosphate nodules such as fluorapatide (calcium halophosphate) and brushite (calcium phosphate, aka kidney stones) have also been discovered in the Pierre Shale.

Acid-rock weathering affects the vegetation and microbial habitat and may influence the geochemistry of groundwater. One measurement of surface water associated with acid-rock weathering recorded a pH of 1.82. In addition, many of these acid-rock weathering minerals are rare, and potential exists for developing and interpreting the unique mineralogy sites.

Geology and Management Resources of Parks (Rob Jacobsen)

Threatened and endangered species, such as the Pallid sturgeon, Interior least tern, and Piping plover, drive policy and management objectives in the USGS Columbia Environmental Research Center. Located in the Missouri River basin, Missouri National Recreational River is subject to decisions that are made by multiple stakeholders, not just NPS staff. The basin has many uses, includes six Army Corps of Engineer operated reservoirs, 91 cubic kilometers of water storage, 10 billion kilowatts of hydroelectric power generated each year, and an economic benefit exceeding $1.7 billion per year.

Since the Missouri River dams have been constructed, the river's hydrograph (a graph showing rate of flow) has been unnaturally altered above Sioux City. In order to manage the river's ecosystem, its natural hydrograph must be restored, but restoring a flow regime is extremely difficult to accomplish. The USGS Columbia Environmental Research Center is addressing questions involving the quantity of water needed in the river to not only sustain threatened and endangered species but also to establish functional habitats in the riparian ecosystem. Sediment fluxes have changed dramatically since flow has been regulated and sediment began being trapped behind dams. Historically, the Missouri River is a high sediment river. At Yankton, today's river contains only 0.2% of its historical suspended sediment load. With decreased sediment, the river has incised its channel. With channel incision, the river rarely overflows its banks to deposit nutrients and recharge groundwater in the floodplain. The water table lowers and this affects cottonwood regeneration and other riparian vegetation.

Surficial geologic mapping is needed to better understand flood frequency and water retention in the floodplain. Substrate reconnaissance mapping near Yankton will help answer questions about the construction and destruction of sand bars, an important habitat for some species. Geological information is needed to help answer questions related to the Missouri River's historical dynamics, historical flood events, channel migration, groundwater and surface water interactions, and erosion potential of the substrate. Knowing the configuration of the historical river channel may aid in defining the management area of influence. Information concerning the USGS Columbia Environmental Research Center programs may be accessed at http://www.cerc.usgs.gov.

Geologic Resource Management Issues

Participants at the scoping session for Missouri National Recreational River summarized the geologic issues that affect the park and the park's management. Primary issues involved the geomorphology of the river, such as bank stabilization, sediment flux, and slumps. The following issues will be addressed in greater detail in the GRI report.

Fluvial Issues

Primary geologic issues at Missouri National Recreational River involve river processes and the dams that impact these dynamic processes. In addition to inundating valuable agricultural land, the dams cut off sediment supply to the park and accelerate channel incision. At a rate of 3 m (10 ft) every 50 years, channel incision drives such factors as bank steepening, bank erosion, floodplain abandonment, channel armoring, disruption in Yankton water supply, and channel downcutting that exposes structures such as the steel plating on the bridge at Yankton that was designed to deflect debris in the river. Incision has also decreased channel sinuosity. Prior to construction of the Fort Peck Dam, the Missouri River was a braided stream, but the river now flows in one incised channel.

A lack of sediment in the river system impacts sand bar formation. Existing sand bars are now being maintained by the Army Corps of Engineers. Of the river's approximate 3,900 km (2,400 mi), one-third (1,200 km; 750 mi) has been channelized, another third is under water in reservoirs, and another third contains riverine habitat. No sand bars exist where the river has been channelized, but vegetation is growing on sand bars that have formed naturally in Missouri National Recreational River. Engineered sand bars disappear if not constantly maintained.

Channel incision has contributed to both lowering the water table and reducing seasonal flooding. A lowered water table decreases groundwater availability for tree roots, impacting cottonwood regeneration and other riparian vegetation. Lowered water tables may also impact water supply wells. With reduced flood frequency, fewer nutrients are spread across the floodplain. The only nutrients entering the system are those that come through the dams.

Approximately 33% of the river bank has been artificially stabilized by riprap. Riprap inhibits the river's lateral migration and discourages the formation of riparian habitat. Both the dams and placement of riprap disrupt habitat and impact the ability to sustain a habitat's natural function.

Changes in the river's morphology have affected land use and cultural patterns. Shifts in meanders have moved the river away from some cities. The confluence of the James River and Missouri River, for example, has changed by miles at least three times in the last one hundred years. The confluence of the Vermillion River and Missouri River has changed so that the Vermillion River now flows in a channel that was originally carved by the Missouri River. In the 19^{th} century, flooding caused the town of Niobrara to relocate to the top of the hill overlooking the river which is currently several miles from the town.

Pipelines, bridge construction, and bridge replacement have always been issues for Missouri National Recreational River management. Currently, four bridges cross the Missouri National Recreational River. The TransCanada Keystone pipeline is an oil pipeline that was directionally drilled 18 m (60 ft) below the river bed near Yankton. NuStar Energy has removed one overhead pipeline and has two underground pipelines beneath the Missouri National Recreational River. Hyperian Resources Inc. is considering building an $8 billion oil refinery to refine crude oil from Canadian oil sands in Alberta approximately 3 km (2 mi) northwest of Elk Point, near Ponca State Park and within the viewshed of the Missouri National Recreational River. If this site is selected, the company may wish to install new pipelines and drill water wells, which may impact the Missouri River.

Hillslope Processes
In the 39-mile District, the Pierre Shale is unstable and prone to landslides. The Carlile and Greenhorn Formations compose unstable slopes in the 59-mile District. Slumps and slides are common along the river's cliffs, and a slide in 2005 covered the boat ramp in Ponca State Park. These formations are also adjacent to the Lewis and Clark Reservoir where the slopes continue to erode. Calumet Bluff, west of Gavins Point Dam, is unstable. Hillslope failure may potentially impact the campground on the south side of Lewis and Clark Reservoir.

Mineral Extraction
Pleistocene sand and gravel is mined for aggregate from open pits in the area, but no other mining is being conducted in the park.

External Issues
Lewis and Clark Reservoir: The reservoir contributes to downstream resource impacts in the Missouri National Recreational River. The reservoir has become shallower due to slumping along the shorelines of the reservoir and impoundment of sediment behind the Gavins Point Dam. Only about 19 km (12 mi) of open water remains in the reservoir. The National Academy of Science has

contracted to study the sediment issue on the Missouri River and the Army Corps of Engineers is preparing a feasibility study for sediment bypass at Gavins Point Dam. If the sediment bypass plan is implemented, the sediment loads in the river would increase by 4.7 million tons (3.5%) above Yankton.

The Pierre Shale contains abundant selenium and arsenic, and the Sharon Springs Member of the Pierre Shale has a high uranium content. Continued slumping may cause leaching of these elements into the reservoir, potentially changing surface water geochemistry, impacting water quality, and changing arsenic levels in groundwater. These potential impacts have yet to be studied.

Grazing, Logging, and Agriculture: Livestock grazing and logging impact the riparian corridor. Cottonwood forests are still harvested, but the mills are gone. Agriculture presents a potential impact on Missouri National Recreation River with chemicals such as fertilizers being leached into the porous sandy substrate and river system, and the removal of natural vegetation adjacent to the river.

Private Bank Stabilization Projects: Private land owners attempt to stabilize the river bank through a variety of means, including dumping concrete and construction debris along the riverbank. Housing developments, such as Dakota Dunes, are examples of future developments that may encroach on the park boundaries.

Features and Processes

The scoping session for Missouri National Recreational River provided the opportunity to develop a list of geologic features and processes, which will be further explained in the final GRI report. The features and processes at Missouri National Recreational River include:

- *Aeolian*: Pleistocene glacial loess deposits are found on the south side of the river and local, Holocene sand dunes are building on the floodplain. Pahas, elongated glacial ridges or hills, on uplands may be streamlined by wind, and the vertical growth of islands, such as Goat Island, may result from vertical accretion of aeolian sand.
- *Fluvial*: Incised channels, sand bars, bank stabilization features (riprap), meander bends, cutbanks, oxbow lakes, crevasse channels and crevasse splays, sand flats, cross-channel bars, backwater marshes, chute channels, and overbank deposits.
- *Hillslope processes*: Cliffs with exposed Cretaceous strata; bentonite beds (altered volcanic ash) may contribute to instability of the hillslopes.
- *Lacustrine*: Lewis and Clark Reservoir and the Niobrara delta that is forming at the confluence of the Niobrara River and Missouri River, upstream from the reservoir; unstable slopes associated with the reservoir.
- *Marine*: Cretaceous bedrock stratigraphy is composed of lithified marine sediments.
- *Seismic*: Area considered low potential for earthquakes. The Spencer fault may affect the dam, but there is no historical evidence to this effect.
- *Glacial/periglacial*: The Missouri River's position marks the boundary between Late Wisconsin glaciations and older, pre-Illinoian glacial deposits that are exposed south of the river; Spirit Mound is a glacial erosional remnant; outwash and/or subglacial deposits are exposed near Yankton; clasts in glacial till originated in Canada; cobbles transported into the area by glaciers are weathering out of the banks of the Lewis and Clark Reservoir; peri-

glacial deposits are present to the northeast and ice-wedge deposits have been identified near Hartington, NE, southeast of the park.

- *Fossils*: A Plesiosaur was discovered at Ponca State Park, approximately 30 m (100 ft) downstream from the boat ramp; many bison bones have been discovered; marine invertebrate fossils are found in hundreds of Cretaceous sites throughout the area. Inoceramus clam shells and an occasional ammonoid can be found in the Greenhorn Limestone, mostly on private land, and invertebrate fossils are found in the Carlile and Niobrara Formations.
- *Cultural features*: Spirit Mound is a creation site for the Pawnee and the Yankton and Mandan Sioux; the Missouri River was a primary pathway for Native American tribes, fur traders, Lewis and Clark, and other pioneers; hundreds of steamship wrecks still exist in the park; largely buried by river sediment, the Ionia Volcano, named by Lewis and Clark who saw smoke emerging from the bluff, lies outside the park boundary and contains lignite, marcasite, and iron sulfate that may have generated smoke at the time; a cemetery at St. Helena is an archeological site; and Old Baldy is a knob of Niobrara Formation, also outside the park boundary, where Lewis and Clark saw their first prairie dog.
- *Geochemistry*: Acid-rock weathering has produced regionally noteworthy minerals that are rare and that may impact the environment.
- *Type Sections*: No type sections exist in the park but the Miocene Fort Randall Formation's type section is south of Bijou Hills in the northwest corner of Charles Mix County, southeast South Dakota and upstream from the 39-mile District. The formation was named for old Fort Randall and Fort Randall Reservoir. The Niobrara Formation does not have a designated type section, but it is named from the cliffs along the Niobrara River at its confluence with the Missouri River, Knox County, NE.

Field Trip

The field trip on Thursday, August 21, 2008 visited the following locations:

1. *Upstream from Myron Grove launch site, north side of river, near the location of historical confluence of James River with Missouri River*: Active slumping; river undercutting trees and bank collapse; fallen trees provide habitat for fish and invertebrates and are more stable than sand bars; buried soil or fluvial overbank deposits in dark horizon; river has moved approximately 1.6 km (1 mi); lots of feedlots on Bow Creek affect river's nutrient levels.
2. *Audubon Bend*: bluff on south side of river where Quaternary loess caps a cliff of Niobrara Chalk overlying Carlile Shale, a gypsum rich black shale; yellow jarosite exposed on the surface of Carlile Shale; slump blocks of chalk, eroded shale, and undercut loess.
3. *North Alabama steamboat*: Bank riprap along both sides of river as part of the Army Corps of Engineers' Project 32; North Alabama steamboat wrecked in 1870 and is still a snag in the river.
4. *Goat Island*: ownership of Goat Island still in limbo – both South Dakota and Bureau of Land Management (BLM) claim the island; if island existed before statehood, BLM owns the land and will turn it over to NPS.
5. *Natural ESH sandbar*: Natural sandbar built by high flow; sand moves up onto sandbar in high flow but is also transported downstream; sand is not being replenished since dams were built; sand eroded from sand bars is now filling holes eroded in the channel; and filling

holes; Army Corps of Engineers is building approximately 100 acres of habitat/year with $10 million/year.

6. *Gunderson Backwater*: Reconstructed backwater 2.1-2.4 m (7-8 ft) deep; backwater was an open channel that filled during the 1950s and 1960s; dredged and reopened in 2008 to create shallow water habitat; monitoring water quality, benthic zone, and sediment deposition; time lapse photography.
7. *Engineered ESH sandbar*: Engineered sandbar to provide habitat for birds.
8. *Mulberry Bend*: Channel geomorphology; old meander; 1881 ice gorge and flood completely changed channel morphology; example of dynamic morphology.
9. *Cotton Park, Vermillion*: Site of Vermillion prior to the 1881 flood.
10. *Historical confluence of Vermillion and Missouri Rivers*: Confluence has moved from where Lewis and Clark camped; Vermillion River was a series of tight, wall-to-wall meanders in a narrow valley until it flowed into the Missouri River meander; lowering of Missouri has caused subsequent incision of tributaries, which are now 1.2-1.5 m (4-5 ft) deep.
11. *Pleistocene gravel pit*: Pleistocene-age gravel in unconformable contact with overlying loess; cross-bedding could represent an old Missouri River terrace but probably is a glacial outwash deposit; the feldspar-rich gravel is compositionally much different than Holocene and modern Missouri River channel sand; glacial and subglacial material carried into the site by pre-Wisconsin glacier over 400,000 years ago (based on U-series date on calcite cement); 0.3-0.6 m (1-2 ft) diameter, well-indurated clay balls (some are diamictons, probable till); modern genetics of the Pallid Sturgeon is related to what happened in pre-Wisconsin time.
12. *Ponca State Park*: Park is inside MNRR boundaries; boat ramp and 2005 landslide blocks of Greenhorn Limestone below undercut loess deposits; campground next to a cutbank where the river makes a 90° turn and has eroded a 9 m (30 ft) hole; Dakota Formation is exposed at low water at the campground and strata dip southward within tilted slump block; riprap put in by the Army Corps of Engineers; overlook into Iowa, South Dakota, and Nebraska; Visitors Center and artificial lake where piping caused massive landslide/slump in 2006 or 2007 beneath road.


Geology Scoping Field Trip
Aug 21, 2008
1. Myron Grove launch site
2. Audubon Bend
3. North Alabama steamboat
4. Goat Island
5. Natural ESH sandbar
6. Gunderson Backwater
7. Constructed ESH sandbar
8. Mulberry Bend

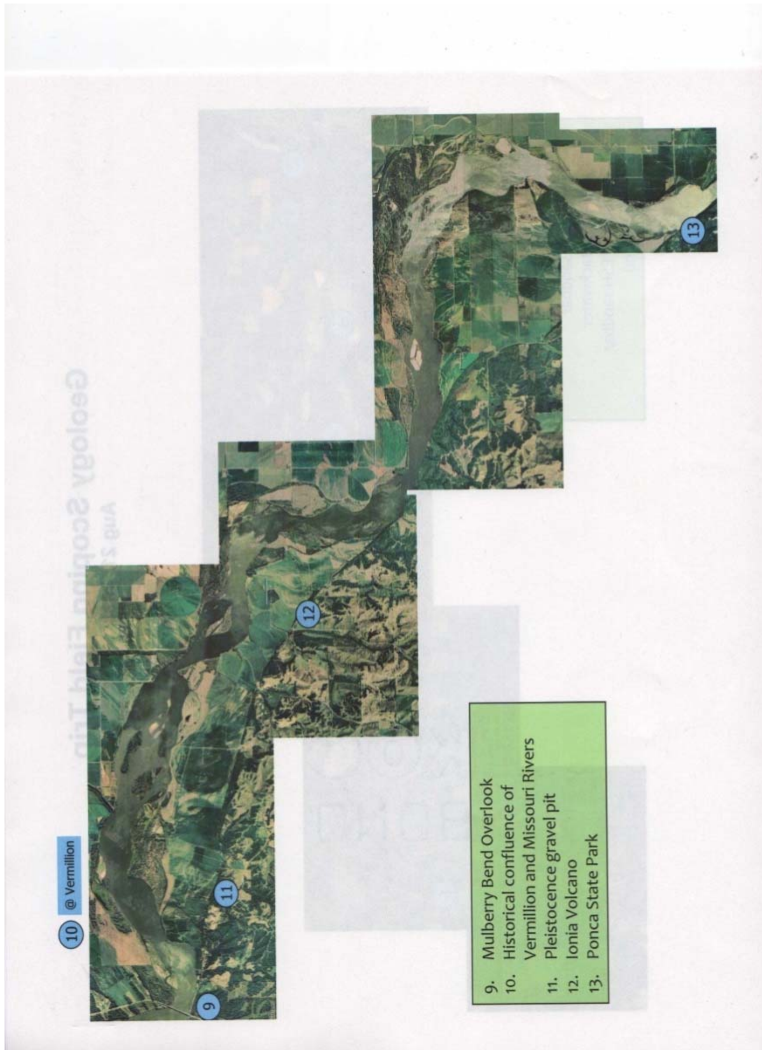

Figure 2. Field trip locations, Missouri National Recreational River.

Recommendations

- Meet with local experts to decide on an area to be mapped.

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