



Stream Channel Monitoring for Wind Cave National Park

2021 Data Report

Natural Resource Data Series NPS/WICA/NRDS—2023/1386



**ON THIS PAGE**

Cross section of WICA SCM 001 at Wind Cave National Park, South Dakota, in September 2021.
Photograph courtesy of NGPN, National Park Service.

ON THE COVER

Photograph of Highland Creek at Wind Cave National Park, South Dakota, 2021
Photograph courtesy of Northern Great Plains Network, National Park Service.

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2021 Data Report

Natural Resource Data Series NPS/WICA/NRDS—2023/1386

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible and technically accurate.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of those protocols

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Executive Summary

The Northern Great Plains Inventory and Monitoring Network (NGPN) began stream channel monitoring in Highland Creek at Wind Cave National Park (WICA) in 2021. This data report summarizes the data collected during the 2021 season pertaining to watershed, reach, and physical habitat. After data are collected for at least four cycles, trends may be reported. This report covers three main areas: 1) Reporting on upland channel characteristics data that may affect habitat such as: land cover, drainage area, and total stream length; 2) Reporting of geomorphic dimensions such as: channel widths, bank angles, vegetative cover, reach slope, measures of bank stability; and 3) Determining physical habitat characteristics such as: size and distribution of bed sediment, large woody debris, and canopy cover.

Table ES-1 below shows the status of stream channel parameters for WICA for the collected data during 2021. Indices, benchmarks, and other studies are provided in the table for informational purposes to help put Highland Creek's measurements in context but should not be considered as a reference condition. Upland characteristics of the watershed indicate high natural land use cover (forest, grassland, and shrubland) with little development in the area. Reach characteristics include bank cover, heights, bank stability index, and vegetative cover. In addition to animal-induced erosion of the banks, bank sloughing and widening are occurring. Angles are steep, and there are some sandy banks that are unstable. When plots are revisited in three years, there will be greater understanding of the processes at play and the condition of the stream.

Physical characteristics include median particle size, percentage fine substrate, geomorphic units, and canopy cover. Gravel substrate still covers much of the stream; there are wide meanders in the stream bed; and a variety of geomorphic channel units (pool, riffle, run) occur in the creek all of which are indicators of healthy habitat. While there is an absence of large woody debris and canopy cover is low, many grassland streams in good condition can have similar characteristics. More data are needed to fully assess those components and determine a suitable reference condition that can be used to later assess the status and trends of Highland Creek. The reach data contained in this report are specific to a short 150-m segment of Highland Creek and cannot be extrapolated to conditions elsewhere in the creek or to the park in general. Bank erosion and bank instability were observed along the majority of transects at site WICA SCM 001.

Table ES-1. Summary table for stream channel data in Wind Cave NP. Current values are based on data from 2021 alone.

Indicator	Measure	Status	Indices, Benchmarks, other Studies
Upland Land Use	Upland Land Cover Change	2019 NLCD ¹ cover Grassland= 46%, Forest= 41.4%, Shrubland =10.5%	2001 NLCD land cover: Grassland= 49.5%, Forest= 43.1%, Shrubland=5.6%
	Land Development Change	2019 NLCD 0.2 % of watershed developed	2001 NLCD developed land cover: 0.2%
Reach Level	Mean Bank Angle	57.27° water to bank-full angle	Bank Stability Index (BSI): <=30° is good, <=60° is fair, >60° poor according to BSI
	Erosion	8 out of 11 transects show erosion in 2 m bank segments. Additional quantification of erosion showed 89% of bank eroded.	TBD
	Mean. Bank Heights	0.43m	BSI: <1 m bank is considered good
	Mean Bank-full width	3.61m	TBD
	Bank Vegetation Cover %	72.90%	BSI: Vegetative cover>80% is good, 50-80% fair, 20-49% poor, <20% very poor
	Bank Stability Index	10.8 on BSI index	<7 is considered stable, 7-10 at risk, 11-15 unstable, <15: very unstable
	Max Distance of Bank Migration	NA	TBD
	Cross-sectional Area	Mean bank-full area 0.87m ² ; mean channel full area 7.03m ²	TBD
Physical Habitat	Median Particle Size of Representative Riffle	32mm, very coarse gravel	TBD
	Percentage fine substrate	72%, dominant in 8 out of 11 transects. Expanded analysis concurred with 69-74% of reach covered in fine sediment.	Mean fine percentage was 10% in small NPS streams (Rust 2006).
	Geomorphic units	51.3% of reach is riffle, 42.8% run/glide, 5.9% pool	Reach has a good number and variety of habitats.
	Canopy cover	9% mean canopy cover	45% canopy cover was mean for small NPS streams (Rust 2006).

1 National Land Cover Dataset

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Abbreviations and Acronyms

>:	greater than
$\geq$:	greater than or equal to
<:	less than
$\leq$:	less than or equal to
#:	number
303(d) list:	List of Impaired Waters , under the CWA
cfs:	cubic feet per second
CSV:	comma-separated value
CWA:	Clean Water Act
°C:	degrees Celsius
DANR:	Department of Agriculture and Natural Resources
DENR:	Department of Environment and Natural Resources
DO:	dissolved oxygen
<i>E. coli</i> :	<i>Escherichia coli</i>
EMAP:	Environmental Monitoring and Assessment Program (USEPA)
EPA:	Environmental Protection Agency
EPT:	Ephemeroptera, Plecoptera, Tricoptera (pollution-sensitive insect orders)
ft ³ /s:	cubic feet per second
FY:	fiscal year
HBI:	Hilsenhoff Biotic Index
HR:	High Resolution
I&M:	Inventory & Monitoring
IRMA:	Integrated Resource Management Applications
km ² :	square kilometers

mi ² :	square miles
mg/L:	milligram per liter
mL:	milliliters
NARS:	National Aquatic Resource Survey (USEPA)
NAWQA:	National Water Quality Assessment (USGS)
ND:	North Dakota
NE:	Nebraska
NGPN:	Northern Great Plains Network
NHS:	National Historic Site
NM:	National Monument
NMEM	National Memorial
NP:	National Park
NPS:	National Park Service
NPSTORET:	National Park STORage and RETrieval
NRR:	National Recreational River
NSR:	National Scenic River
NWIS:	National Water Information System (U.S. Geological Survey)
SECN:	Southeast Coast Network
SD:	South Dakota
SOP:	standard operating procedure
TMDL:	total maximum daily load
USACE:	U.S. Army Corps of Engineers
USEPA:	U.S. Environmental Protection Agency
USGS :	U.S. Geological Survey
WRD :	Water Resources Division of NPS
WSC:	Water Science Center (U.S. Geological Survey)

WY: Wyoming

Park Four Letter Alpha Codes

AGFO: Agate Fossil Beds NM

BADL: Badlands NP

DETO: Devils Tower NM

FOLA: Fort Laramie NM

FOUS: Fort Union Trading Post NHS

JECA: Jewel Cave NM

KNRI: Knife River Indian Villages NHS

MNRR: Missouri NRR

MORU: Mount Rushmore NMEM

NIOB: Niobrara NSR

SCBL: Scotts Bluff NM

THRO: Theodore Roosevelt NP

WICA: Wind Cave NP

Introduction

Wind Cave National Park (WICA) was established in 1903 on the southern edge of the Black Hills of South Dakota approximately 45 miles south of Rapid City in Custer and Fall River counties. The park is bounded by Forest Service land to the west, Custer State Park to the north, and private land to the south and east (Ohms 2016). The 33,851 acres of WICA is a mosaic of ponderosa pine forest and mixed-grass prairie. Approximately 1/3 of the land area of Wind Cave is ponderosa pine forest, and the rest grassland or shrubland. Forests provide cover and shelter for wildlife while the grasslands provide abundant food. Forest cover in the Black Hills has increased since the late 1800s due to fire suppression techniques and invasion into grasslands (Komp 2011). Streams and riparian areas provide water and bring life to dry areas. Though wet areas make up less than 1% of the park, they provide vital habitats and water for wildlife (Burkhart 2013).

Wildlife such as prairie dogs, pronghorn antelope, bison, elk, porcupine, coyotes, white-tailed deer, and mule deer thrive at WICA. Endangered black-footed ferrets hunt among abundant prairie dog colonies. Grassland birds, hawks, and eagles populate the meadows. Underneath the rolling hills lies Wind Cave, one of the longest and oldest caves in the world. It is home to unique boxwork formations. In addition to the cave features, WICA is a place of spiritual significance, a home to many species of native wildlife, and a site of natural beauty and ecotone between the Black Hills, prairie, and riparian habitats. Native peoples have revered Wind Cave for thousands of years, and the park has a rich and varied cultural history. The park's relatively small size and wildlife populations necessitate active management of the park's ecosystems (NPS 2011). Prescribed burns, herbicide treatment of invasive plants, and active management of the park's elk and bison populations are some of the management tools used by the park. The park's purpose is to protect the unique Wind Cave resources and to preserve and enhance the mixed-grass prairie and native wildlife, while also providing for the enjoyment of the public (NPS 2011). The park's fundamental resources include cave and karst features, native wildlife, native vegetation (mixed grass prairie communities), water resources (including hydrology), and exploration and discovery of Wind Cave.

WICA has water resources including three perennial streams (Highland Creek, Cold Spring Creek, and Beaver Creek), springs, wells, and underground water resources such as cave drips and cave lakes (Ohms 2016). Highland Creek (Figure 1) is spring-fed, and the creek originates less than ¼ mile from the WICA park boundary in nearby Custer State Park. The stream does drain the northwestern part of WICA and southwestern Custer State Park. Both Highland Creek and Cold Spring Creek watersheds are upstream of Beaver Creek watershed. Both Highland Creek and Beaver Creek have substantial loss of surface water to groundwater within limestone zones. The upper portion of Highland Creek generally has more water than the other two creeks (Heakin 2004). Highland Creek is ungaged, though Beaver Creek currently has a gage (see [BEAVER CREEK NEAR PRINGLE, SD - USGS Water Data for the Nation](#)). This USGS-managed gage is scheduled to go offline in 2022 unless more funding can be obtained. WICA is semi-arid with an average of 18.34 inches of precipitation per year since 1952 (Ohms 2016). The park's large wildlife population uses the streams as important water sources. Highland Creek is 303-d listed by the South Dakota DENR, Department of Environment and Natural Resources now DANR, Department of Agriculture

and Natural Resources for impairment of the stream's beneficial uses due to pH and temperature (SD DENR 2020) which violate the coldwater permanent fishery use.

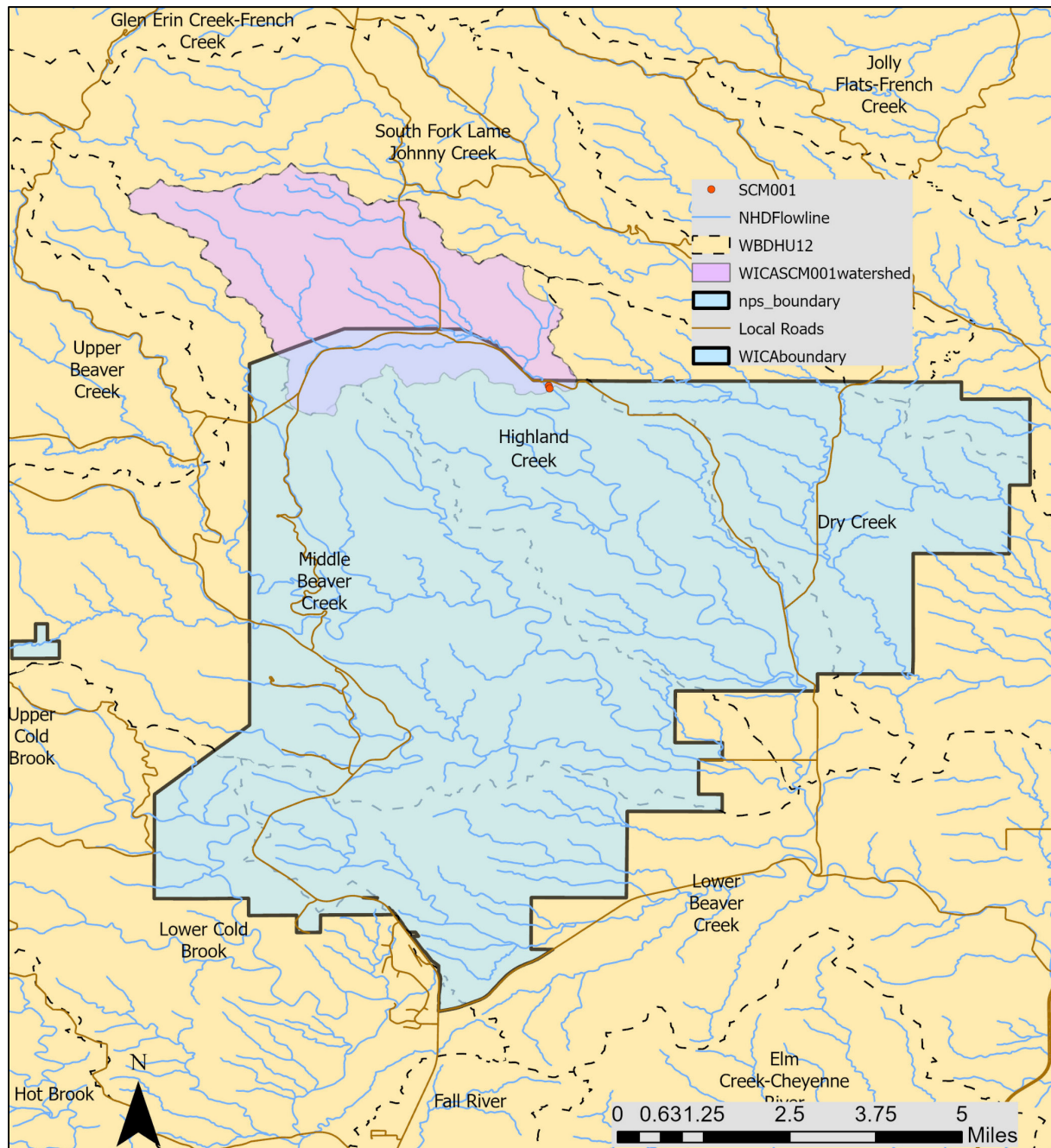


Figure 1. Map of Highland Creek in Wind Cave NP with stream channel monitoring site WICA SCM 001 and associated watershed.

The Northern Great Plains Inventory & Monitoring Program (NGPN) began monitoring stream channel characteristics in September 2021. The protocol is modeled after Southeast Coast Network's

(SECN) Wadeable Stream Habitat Condition Protocol (McDonald 2018). The protocol includes three different aspects of stream measurements:

- 1) Upstream **watershed characteristics** such as watershed area, catchment slope, and drainage density, as well as changes to land cover that may affect stream habitat.
- 2) **Geomorphic dimensions** (cross-sectional morphology) of selected wadeable stream reaches such as channel widths, bank characteristics (e.g., heights, angles, and vegetative cover), reach slope, and sinuosity.
- 3) **Physical** measures of benthic and riparian **habitat features** present in selected wadeable stream reaches such as the size, type, and distribution of bed sediment and large woody debris, the distribution of geomorphic channel units, canopy cover, and discharge.

Methods

The NGPN Stream Channel Monitoring Protocol (Thornburgh et al. 2019 [DataStore - Project - \(Code: 2259796\) \(nps.gov\)](#)) sets out the methods used for sampling stream channels. The protocol borrows heavily from the Southeast Coast Inventory and Monitoring Network [DataStore - Published Report - \(Code: 2254874\) \(nps.gov\)](#). Both protocols build on USGS's NAWQA survey (Fitzpatrick 1998) as the foundation. The spatial hierarchy of basin, reach and segment from the NAWQA survey is followed here as well as many of the channel, bank, and riparian characteristics. For full descriptions of protocols please reference the above links, the general approach is briefly described below.

Site Selection

Stream channel monitoring in NGPN parks is targeted to be co-located with the water quality monitoring (WQM) station when the WQM station is on the stream segment of interest. Bank inaccessibility on high cut banks which are sandy and unstable, avoidance of hard stabilization projects, and park property boundaries are all reasons to shift the reach to a more suitable location. Of the eight NGPN WQM sites [DataStore - Published Report - \(Code: 2216799\) \(nps.gov\)](#), one will not have stream channel measurements taken. The site at MNRR on the Niobrara River is not wadeable, so no stream channel measurements are performed there. Water quality monitoring and stream channel monitoring is done on a rotating basis at 9 parks. WICA, FOLA, and MNRR- Bow Creek are scheduled to be sampled together- starting in 2021 when only WICA was sampled. As this was the pilot for this protocol only one park was sampled in 2021. They will be sampled again together in 2024. There is no WQM site at WICA or MORU, so the stream channel sampling site must be selected with park staff. DETO, KNRI, and THRO will be sampled near their WQM gages in 2022. AGFO and NIOB will be sampled near their WQM stations in 2023 along with MORU.

At WICA, due to the loss zone (Ohms 2016) where most (or all) of the surface water returns underground, the sampling on Highland Creek was done as close as possible to the border with Custer State Park to ensure the most consistent water flow. The site was placed downstream of a concrete structure used for storing water for fire suppression and upstream of an exclosure fence. The mean wetted width was only 2.33 m. According to the original NGPN protocol, the reach should be 20 x the mean wetted width. No minimum reach length is specified in either the NGPN or the SECN protocol. If the protocol was followed, then the reach would have only been 46 meters in length, which would not have had the variety of habitat types needed to adequately assess a full range of meanders and habitats in the reach. Ideally, two meanders will contain a good portion of the pool, riffle, and run habitats. A 150-m minimum reach length is used in USEPA Environmental Monitoring and Assessment Program (EMAP), National Aquatic Resource Survey (NARS), and National Water Quality Assessment (NAWQA) protocols, and so was adopted here. Permanent benchmarks indicating the starting and ending points of the three detailed transects were marked with rebar and aluminum caps and located with a high accuracy GNSS receiver.

Data Collection

The Northern Great Plains Inventory and Monitoring Network (NGPN) began stream channel monitoring in Highland Creek at Wind Cave National Park (WICA) in 2021. Data collected during the 2021 season pertains to watershed, reach, and physical habitat. After data are collected for at least four cycles, trends may be reported. Data collection and reporting covers three main areas: 1) Status and trends of upland channel characteristics data that may affect habitat such as land cover, drainage area, and total stream length; 2) Status and trends of geomorphic dimensions such as channel widths, bank angles, vegetative cover, reach slope, measures of bank stability; and 3) Status and trends of physical habitat characteristics such as size and distribution of bed sediment, large woody debris, and canopy cover.

Following the protocol, which is available here: [DataStore - Published Report - \(Code: 2260277\) \(nps.gov\)](#), the NGPN crew established a plot at WICA SCM 001 in August 2021 with rebar marking the beginning and ends of the three detailed transects which are located along cross-sections of the stream. GNSS occupations with an Arrow Gold receiver were used to obtain high accuracy benchmarks. The T1 Left benchmark is located at 148505.651 Northing, 349532.488 Easting with an elevation of 1302.615 meters using the NAD83 (2011) datum and NAVD88 vertical datum. The T11 Left benchmark is located at 148596.055 Northing, 349470.432 Easting with an elevation of 1304.208 m in South Dakota S State Plane coordinate system (WKID= 6573). The detailed transects are the lines along which a total station is utilized to collect distance and elevation data along the transect line relative to the GPS benchmarks. A Trimble SX 10 unit was rented, personnel were trained, and data collected in early September 2021. A scan with a FARO laser scanner was taken as well.

The NGPN crew performed stream channel measurements in September 2021. Discharge, photos, geomorphic channel units (pool, riffle, run, etc), representative pebble count at the riffle between transect 7-8, canopy cover, large woody debris, bank and bed sediment, channel- and bank-full heights and angles were taken. Vegetative bank cover and other cover measurements were taken in a one-meter strip up to the channel-full height. Figure 2 shows the layout of the reach. The concrete structure (weir) just upstream of the reach was built in the 1960s and was used for pumping water from the stream for fires. The placement likely affects flow dynamics; the stream is much narrower below the structure as evident in Figure 2. The longer yellow lines at T1, T6, and T11 show the permanently marked detailed transects where the total station was used.



Figure 2. Layout of sampled reach of WICA stream channel monitoring site WICA SCM 001. Transects number 1-11 running from down to upstream. The dominant geomorphic channel unit is noted between each reach.

Due to a discrepancy between the protocol and the reporting sheets, several measurements were taken in March 2022 to replace the measurements previously taken after consulting with SECN. Bank angles were remeasured from the edge of water to bank-full since bank-full was present in

every transect, rather than to the channel-full top. Confusion stemmed from the term ‘top of bank’ which in the protocol can refer to either bank-full or channel-full positions. Vegetative cover and other bank cover measurements were re-taken in March 2022 in a 1-meter-wide strip from edge of water to bank-full rather than to channel-full as was done in fall 2021. Bank sediment was re-sampled with the bank sediment categories which includes a mix of particle sizes and the categories clay, silt, silt/clay, sandy silty clay, silty clayey sand, gravel/sand, boulder, and bedrock. Streambed classes are based on size alone and include the categories silt/clay, sand, gravel, cobble, boulder, and bedrock.

Watershed characteristics including total stream length, watershed size, and land use (among others) were calculated according to the Watershed and Segment Scale Assessment SOP [DataStore - Standard Operating Procedure - \(Code: 2259868\) \(nps.gov\)](#) by the NGPN Aquatic Ecologist during the fall and winter of 2021. The methods were followed as closely as possible, but some deviation was required. Further revisions are needed for this protocol as it is adapted from the Southeast Coast Network. Calculating perennial flow and stream order from the National Hydrography Dataset (NHD) in streams from the semi-arid and climatically variable areas such as those found in the Northern Great Plains Network (Fritz et al 2013, Hafen et al 2020) is more prone to error than in more climatically stable areas in the southeastern United States. In a study in Oregon, up to 50% of headwater reaches in field surveys did not match their NHD classification (2013). Seven of nine watersheds were predicted by NHD to have greater than 200% perennial stream length than as measured in field surveys (Fritz et al 2013).

Additionally, the protocol methods relying on the Watershed Characteristics Toolbox in ArcMap are outdated due to software changes and does not translate into ArcPro. The SOP will be updated to detail procedures to delineate the watershed. The basic workflow is described here: A 10-m digital elevation model (DEM) was downloaded and used to delineate the watershed. The DEM was projected into NAD 1983 (2011). Flow direction and flow accumulation rasters were derived from the elevation DEM using a 20-ha stream threshold as described in the SOP. SCM 001 is the downstream point on the reach used to delineate the watershed to that pourpoint.

Results

Basin Characteristics

The watershed was delineated, with methods according to the [DataStore - Standard Operating Procedure - \(Code: 2259868\) \(nps.gov\)](#) SOP using elevation data (Thornburgh 2019). However, Highland Creek is an intermittent stream and spring-fed. Elevation-derived models are extremely sensitive to spatial scale. The 20-ha scale as in the SOP creates too many stream segments which do not correspond to actual water on the landscape. A 20-ha stream scale results in Highland Creek described as a 4th order stream, with a total stream length of 35.41 km. A delineated watershed area using this scale is necessary to report the various metrics. However subsequent measurements such as drainage density, stream order, and bifurcation ratio were made using the NHD-Plus High resolution (HR) Flowline layer for stream which better describes water on the landscape.

Total stream length was based on NHD-Plus HR stream segment lengths (33.051 km) rather than the 20-ha derived stream network (35.41 km, see Table 1). Stream length includes ephemeral channels and draws that only collect waters during times of precipitation (NHD 2022). A medium resolution NHD stream network only contained 24.299 km of stream length within the watershed, however this dataset is not maintained and is considered legacy. Medium resolution NHD shows intermittent and ephemeral streams in the WICA SCM 001 watershed (Figure 3). The source of the headwaters is much higher in elevation due to the topography in the area, so slope and relief in Table 2 are extremely high numbers. Despite the high watershed slope, slopes in the immediate vicinity of the sampling site were less than 2%.

Table 1. Stream lengths and metrics of WICA SCM 001 watershed.

Data source	Total stream length (km)	Stream Order at SCM001	Bifurcation Ratio
NHD-Medium	24.299	2	1.50
NHD-Plus High	33.051	3	2.15
20-ha Derived Stream	35.518	4	2.47

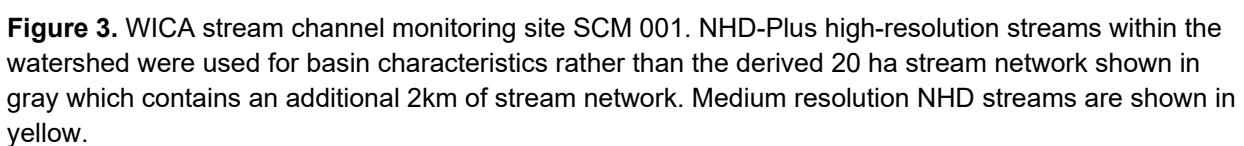


Table 2. Watershed Characteristics derived from elevation-derived delineated watershed using NHD-Plus stream length within derived watershed area.

Watershed Characteristic	WICA SCM 001
Watershed Area (km ²)	22.53
Total Stream Length (km)	33.05
Drainage Density	1.47
Strahler Order	3
Bifurcation Ratio	2
Entire Stream Gradient	0.0308
Segment Gradient	0.0074
Slope - Average	12.53
Slope - Std. Dev.	8.82
Slope - CV	0.70
Watershed Length (km)	11.14
Watershed Shape	0.18
Watershed Relief (m)	431
Watershed Relief Ratio	0.039
Elevation - Std. Dev. (m)	74

Table 2 shows the basin characteristics from the WICA SCM 001 watershed. The watershed was derived using the 20-ha stream network according to the protocol. NHD-Plus High-definition streams were clipped to the watershed area, joined to the VAA tables (value-added network), and used for such metrics as total stream length, drainage density, Strahler order, and bifurcation ratio. To describe the variables in brief, watershed area is derived from a 20-ha stream network. Total stream length is the length of all NHD-Plus segments. Drainage density is the ratio of streams to drainage area. Strahler order is a stream order derived from the number of tributaries. NHD Plus does not include perennial, intermittent, and ephemeral stream classifications. NHD includes these classifications, but the results are inconsistent as shown in Appendix 1 where the only reach classified as ‘perennial’ is one of the headwater reaches. Fritz 2013 showed that significant deviation in semi-arid areas occurs in both the flow permanence classification (perennial, intermittent, and ephemeral classification) and the Strahler stream order calculated with NHD, especially in headwater streams. Indeed, in mesic areas, the NHD-generated stream order tended to underestimate stream lengths, but in arid or semi-arid areas, it overestimated stream lengths (Fritz 2013).

In addition to the confusion about stream length and stream order classification, most Black Hills streams lose a substantial portion of their flow when crossing the Madison and Minnelusa limestone (Carter 2002, Heakin 2004). These formations are downstream of WICA SCM 001 (Appendix C-1) though a limestone outcrop constrains the lowest transect. Also, large areas of alluvium, unconsolidated sediment, are present throughout the watershed. KellerLynn 2009 notes the ‘Qal’ alluvial layer on which our reach is located is not suited for development and that active gullying is evident in the Highland Creek drainage.

For consistencies' sake we will report the data in Table 2 as generated based on the SOP. The stream gradient is a measure of the difference in elevation at 85% and 10% of the mainstem stream length divided by the stream length between the points. Segment or stream gradient is a measure of the difference in elevation of that stream segment. Slope is based on the entire watershed area. Basin length is the length of the drainage divide. Watershed shape is the watershed area divided by the total stream length. For a complete definition of these terms, see the protocol and associated SOPs [DataStore - Published Report - \(Code: 2260277\) \(nps.gov\)](#).

The NLCD was downloaded and applied to the WICA SCM 001 watershed. Upland characteristics of the watershed indicate high natural land use cover (forest, grassland and shrubland) with little development in the area. Grassland cover in 2019 was 46%, forest cover was 41.4%, shrubland cover was 10.5%, and developed land cover was 0.2%. Grassland cover in 2001 was 49.5%, forest cover was 43.1%, shrubland cover was 5.6%, and developed land cover was 0.2% (Tables 3 and 4). Though development in the watershed is low, 9.94 km of roads run through the SCM 001 watershed (0.44km of road per km², SD DOT 2022). This is a higher road: land ratio than the 49.48 km of road in WICA in general, which is 137.296 km² in area, or 0.36 km road/km². Like many roads which follow the low areas in topography, NPS Park Road 5 crosses Highland Creek just upstream of SCM 001 and parallels the creek and tributaries for a substantial distance. Roads can be significant sources of sediment and disturbance to surface waters (Ramos-Scharron et al. 2007).

Table 3. National land cover dataset applied to elevation-derived delineated watershed.

NLCD Class	2001 Percent of Watershed	2006 Percent of Watershed	2011 Percent of Watershed	2016 Percent of Watershed	2019 Percent of Watershed
Open Water	0.0	0.0	0.0	0.0	0.0
Developed - Open ¹	1.4	1.4	1.4	1.4	1.4
Developed - Low ¹	0.2	0.2	0.2	0.2	0.2
Developed - Medium ¹	0.0	0.0	0.0	0.0	0.0
Developed - High ¹	0.0	0.0	0.0	0.0	0.0
Barren	0.0	0.0	0.0	0.0	0.0
Deciduous	0.0	0.0	0.0	0.0	0.0
Evergreen	43.1	42.6	42.1	42.3	41.4
Mixed Forest	0.0	0.0	0.0	0.0	0.0
Shrub	5.6	5.7	6.1	4.1	10.5
Grassland	49.5	50.1	50.1	51.9	46.4
Pasture	0.0	0.0	0.0	0.0	0.0
Cultivated	0.0	0.0	0.0	0.0	0.0
Woody Wetland	0.0	0.0	0.0	0.0	0.0
Herbaceous Wetland	0.2	0.0	0.0	0.1	0.1

¹ Developed subclasses: Open : <20% impervious surfaces; Low:20-49% impervious surfaces; Medium: 50-79% impervious surfaces, High: >80% impervious surfaces.

Table 4. 2019 National land cover dataset summarized categories applied to delineated Highland Creek watershed.

NLCD Class (2019)	WICA SCM 001
Developed Open & Low (%)	1.6
Developed Med. & High (%)	0.0
Forested (%)	41.4
Grassland (%)	46.4
Shrubland (%)	10.5
Wetland (%)	0.1

Reach Characteristics

Detailed Transects

Reach characteristics include measurements from the detailed (total station) transects on three permanently marked transects and reach-level measurements on all transects. Due to the small size of the stream, active erosion is occurring within a very small area between the water and bank-full; the angle is steep and difficult to capture with the total station. In the future, more total station measurements should be taken at the transition areas to better capture the changes in bank and slope and to obtain a more accurate area measurement.

Table 5 shows the cross-sectional area of each the three detailed transects with an average cross-sectional area calculated for the reach. The total station position and elevation measurements were used to calculate metrics such as area, perimeter, hydraulic radius (which is area divided by perimeter), width, depth, and width to depth ratio.

Transect 1 (T1) was the most difficult to access due to a limestone cliff up the right side (Figure 4) using the methods outlined in the SOP. It does appear the T6 bank-full area may have been overestimated, possibly due to the greater depth measured at bank-full which was taken at the T6 cross-section in a narrow portion of stream. The R code associated with SECN's 2.2.14 Wadeable Stream Processing and Analysis was updated slightly but in general, our analysis follows their SOP. From the detailed (SX-10 derived measurements) transects, mean bank-full area was 0.87 m² and mean channel-full area was 7.03 m² (Table 5).

The data were entered into R using SECN's R code with modifications. When plotting the transects on the same axis, the profiles were adjusted so left bank-full begins at the same position on the graph for all three transects. Figure 5 shows the cross sections below.

Additional measurements were taken with the total station at the water surface (ws) in the middle of each active channel area at the surface. Figure 6 shows the position of the ws at each transect and how the slope changes when moving downstream. Slope was -1.9% from the top to the bottom of the reach.



Figure 4. View of T1 from the flag at T2 showing steep limestone cliff impeding access of T1 transect and constraining the channel.

Table 5. Detailed transects derived from total station measurements.

Transect	Type	Area (m²)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/ Depth
T1	Bank-full	0.56	2.77	0.20	2.37	0.39	6.02
	Channel-full	6.02	13.09	0.46	12.43	1.04	11.94
	Ratio	10.70	4.73	2.26	5.24	2.64	1.98
T6	Bank-full	1.31	3.52	0.37	3.15	0.53	5.94
	Channel-full	11.47	14.43	0.79	13.66	1.86	7.36
	Ratio	8.76	4.10	2.14	4.34	3.50	1.24
T11	Bank-full	0.73	2.92	0.25	2.58	0.36	7.14
	Channel-full	3.61	8.45	0.43	7.95	0.93	8.52
	Ratio	4.92	2.89	1.70	3.08	2.58	1.19
Average	Bank-full	0.87	3.07	0.28	2.70	0.43	6.37
	Channel-full	7.03	11.99	0.56	11.35	1.28	9.27
	Ratio	8.13	3.91	2.03	4.22	2.91	1.47

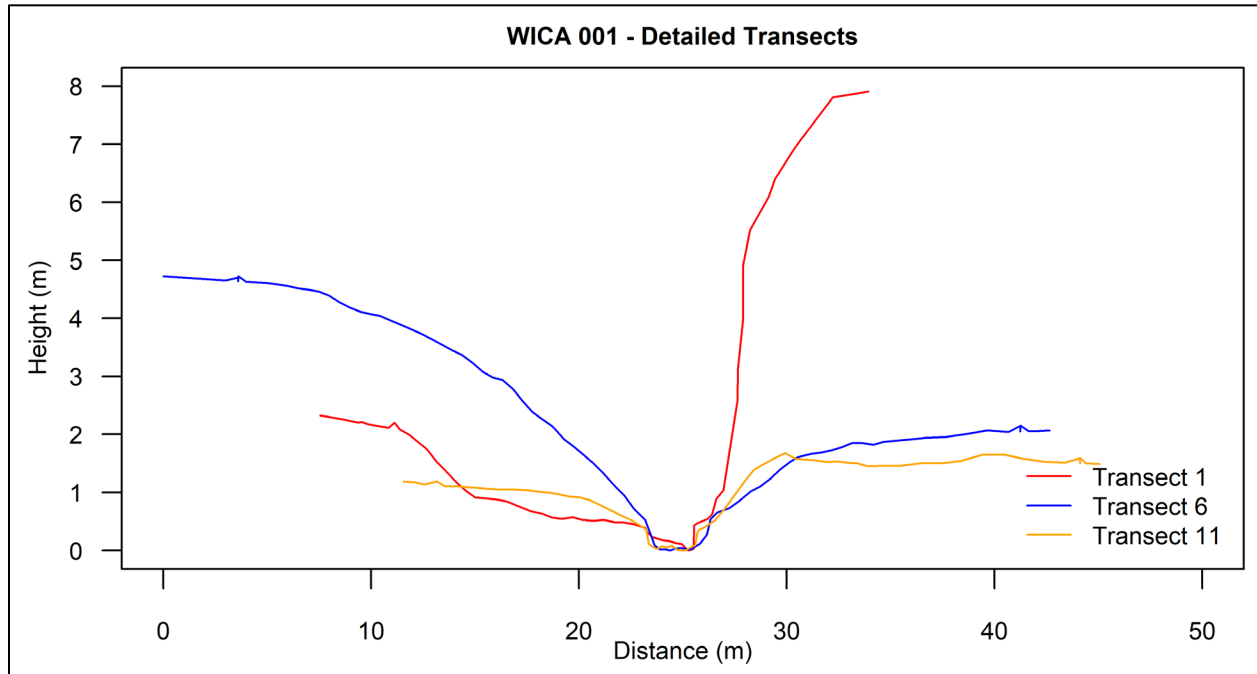


Figure 5. Detailed transects cross sections, plotting height above thalweg vs distance from the left benchmark (LBM). Axes were adjusted so that left bank-full begins at the same relative position for all three transects.

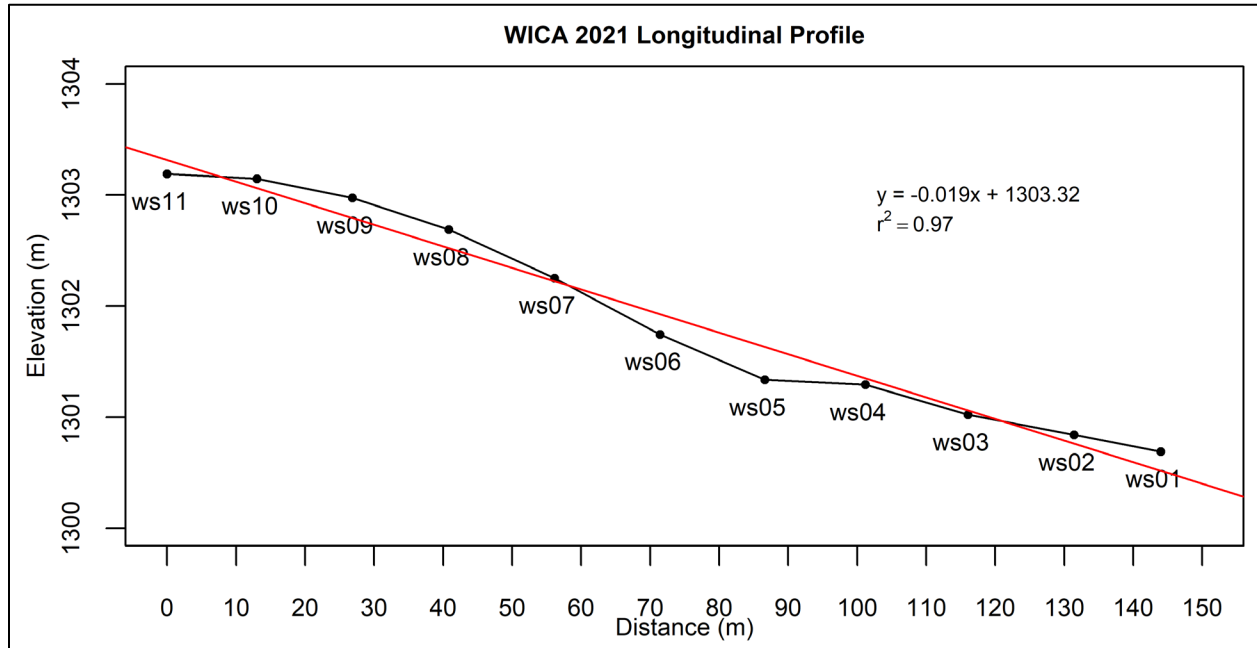


Figure 6. Elevational profile of WICA SCM 001. Slope is -1.9%.

Reach-level Transects

Water depths remained low throughout the reach with a mean thalweg (deepest spot of a stream along its cross-section) of 0.17m. Table 6 shows the thalwegs or maximum water depth at each transect. Mean thalweg depth is 0.17m.

Table 6. Thalwegs at 11 transects at site WICA SCM 001 in September 2021.

Thalweg	n	Min	Max	Mean	Median	SD	CV
Depth (m)	11	0.11	0.24	0.17	0.16	0.05	0.30
Position ¹ (%)	11	15.00	95.00	55.00	65.00	27.00	0.49

¹ position is percent distance from left bank

Channel widths also remained low throughout the plot as shown in Table 7. In all transects, wetted width was equal to active channel width. Active channel refers to the unvegetated portion of the channel. Wetted width refers to the portion of the channel that was wet at the time of sampling. The terms ‘top of bank’ and bank-full and channel-full caused confusion in the protocol. In all cases at Highland Creek ‘top of bank’ was synonymous with bank-full. The SECN protocol defines top of bank as the first flat spot as one moved upward and outward from the stream. It should correspond to either bank-full or channel-full position.

Table 7. Widths at transects at site WICA SCM 001 in September 2021.

Widths	n	Min (m)	Max (m)	Mean (m)	Median (m)	SD (m)	CV
Wetted	11	1.15	3.52	2.33	2.26	0.76	0.33
Active Channel	11	1.15	3.52	2.33	2.26	0.76	0.33
Bank-full	11	1.95	4.93	3.61	3.20	0.93	0.26
Channel-full	11	7.47	21.30	14.32	14.63	4.08	0.29
Floodplain	11	0.04	6.20	1.90	1.11	1.75	0.92

Figure 7 shows crew taking bank-full measurements at Transect 7.

Bank stability index (BSI) is an important measure of the banks that incorporates bank angle, vegetative cover, bank height, and bank sediment. Tables 8a and 8b displays the bank stability scoring and components. The left bank stability index was 10.36, right bank 11.27 for an average of 10.81 (Tables 8a and 8b). A BSI score of 8-11 is in the “at-risk” category (Table 7). These scores are based on national metrics (Fitzpatrick 1998) and what is appropriate for small Northern Great Plains stream with sandy substrate remains to be seen. The bank stability index is used in SECN’s protocol [DataStore - Published Report - \(Code: 2254874\) \(nps.gov\)](#) but is ultimately derived from Fitzpatrick’s 1998 National Water Quality Assessment (NAWQA) protocol which is meant to be used nationwide, modified from Simon and Hupp 1992. Sandy banks or banks with sand and gravel are predisposed to instability. Large amounts of alluvium are present in the watershed and gullying has been noted in the area (KellerLynn 2009).



Figure 7. NGPN crew takes bank-full measurements at Transect 7.

As more parks are visited and more years of data are collected, what is appropriate for Highland Creek will emerge. Erosion and continued bank sloughing is likely to continue. The banks contain a significant proportion of sand with gravel at many transects with a steep bank angle. Erosion is evident on every transect. Rust 2006 likewise found large areas of erosion on Highland Creek due to bison utilization. Constant trampling of the banks is likely to result in a widening of the stream. The steep bank angles indicate incision, instability, and widening. The sand and gravel substrate is a product of the area's geology and is more prone to erosion.

As seen in Figure 8, not only is animal trampling ubiquitous along the banks, but macrophyte and periphyton growth was quite heavy on much of the stream.



Figure 8. Animal trampling along bank with macrophyte growth evident in the stream.

Table 8a. Score range by bank stability Index scoring categories.

Category	Score Range
Stable	4 to 7.99
At-risk	8 to 10.99
Unstable	11 to 15.99
Very Unstable	16 to 22

Table 8b. Bank stability index scores by components range and type.

Component	Range or Type	Score
Angle (deg)	0-30	1
	31-60	2
	> 60	3
Vegetative Cover (%)	> 80	1
	50-80	2
	20-49	3
	<20	4
Height (m)	0-1	1
	1.1-2	2
	2.1-3	3
	3.1-4	4
	>4	5
Bank Sediment (type)	Bedrock, artificial	1
	Boulder, cobble	3
	Clay	4
	Silty clay	4.5
	Silt	5
	Sandy Silty Clay	5.5
	Silty Clay Sand	6.5
	Sand	8
	Gravel/sand	10

Tables 9 and 10 shows the reach-level bank stability index values.

Table 11 shows the transect-level bank stability index with Transect 1 being the most stable and Transect 8 the least stable. Bank sediment—especially those containing sand and gravel primarily and lack of bank vegetation secondarily—contributed to the transects with higher bank instability.

Table 9. Reach-level bank characteristics for WICA SCM 001, Highland Creek.

Bank Characteristics	n (L)	n (R)	Min (L)	Min (R)	Max (L)	Max (R)	Mean (L)	Mean (R)	Median (L)	Median (R)
Bank Height (m) ^{1,2}	11	11	0.29	0.24	0.54	0.58	0.44	0.41	0.45	0.40
Bank-full Height (m) ^{2,3}	11	11	0.29	0.24	0.54	0.58	0.44	0.41	0.45	0.40
Channel-full Height (m) ^{2,3}	11	11	0.76	1.07	5.33	6.54	2.91	2.45	2.44	1.52
Water Depth at Base (m) ⁴	11	11	0.00	0.00	0.10	0.16	0.03	0.03	0.00	0.00
Bank Undercut (m)	11	11	0.00	0.00	0.03	0.02	0.00	0.00	0.00	0.00
Bank Angle (°)	11	11	10	20	90	80	59	56	60	50
Vegetation Cover (%)	11	11	40	50	100	95	76	70	80	70
Bank Stability ⁵	11	11	At-Risk	Stable	Unstable	Unstable	Unstable	Unstable	Unstable	Unstable

¹ Bank height is at bank-full throughout the WICA SCM 001 site.

² above thalweg

³ statistics are based on the transects where feature is present (# in parentheses)

⁴ a negative number indicates base of bank is above the water surface

⁵ See Table 8 for explanation of scores

Table 10. Reach-scale bank characteristics.

Reach-Scale	n	Min	Max	Mean	Median	SD	CV
Bank Height (m) ^{1,2}	22	0.24	0.58	0.43	0.43	0.08	0.20
Bank-full Height (m) ^{2,3}	22	0.24	0.58	0.43	0.43	0.08	0.20
Channel-full Height (m) ^{2,3}	22	0.76	6.54	2.68	2.00	1.75	0.65
Water Depth at Base (m) ⁴	22	0.00	0.16	0.03	0.00	0.05	1.48
Bank Undercut (m)	22	0.00	0.03	0.00	0.00	0.01	3.31
Bank Angle (°)	22	10.00	90.00	57.27	60.00	24.96	0.44

¹ Bank height is at bank-full throughout the WICA SCM 001 site.

² above thalweg

³ statistics are based on the transects where feature is present (# in parentheses)

⁴ a negative number indicates base of bank is above the water surface

⁵ See Table 8 for explanation of scores

Table 10 (continued). Reach-scale bank characteristics.

Reach-Scale	n	Min	Max	Mean	Median	SD	CV
Vegetation Cover (%)	22	40.00	100.00	72.95	77.50	17.30	0.24
Bank Stability ⁵	22	7.00	15.00	10.82	10.50	2.31	0.21

¹ Bank height is at bank-full throughout the WICA SCM 001 site.

² above thalweg

³ statistics are based on the transects where feature is present (# in parentheses)

⁴ a negative number indicates base of bank is above the water surface

⁵ See Table 8 for explanation of scores

Table 11. Transect-scale bank characteristics.

Transect-Scale	Bank-full Height (m) ^{1,2}	Channel-full Height (m) ^{1,2}	Water Depth at Base (m) ³	Bank Undercut (m)	Bank Angle (°)	Vegetation Cover (%)	Left Bank Stability ⁴	Right Bank Stability ⁴
1	0.41	4.27	0.00	0.00	37.50	95.00	8.50	7.00
2	0.30	4.20	0.03	0.00	70.00	77.50	11.50	10.50
3	0.41	2.25	0.09	0.00	85.00	70.00	10.50	10.50
4	0.30	3.66	0.00	0.00	45.00	92.50	7.50	10.50
5	0.47	3.05	0.04	0.01	55.00	80.00	8.50	14.00
6	0.44	3.05	0.00	0.00	62.50	67.50	8.00	11.50
7	0.56	2.82	0.11	0.02	57.50	70.00	10.50	8.00
8	0.52	2.29	0.00	0.00	55.00	45.00	13.50	15.00
9	0.45	1.76	0.00	0.00	32.50	52.50	10.50	15.00
10	0.42	0.92	0.05	0.00	55.00	72.50	12.50	10.50
11	0.46	1.22	0.04	0.00	75.00	80.00	12.50	11.50

¹ above thalweg

² statistics are based on the transects where feature is present (# in parentheses)

³ a negative number indicates base of bank is above the water surface

⁴ See Table 8 for explanation of scores

Transect 8 was the worst scoring transect overall for stability, while Transect 1 was the best. Pictures comparing the two transects' banks are below (Figure 9). Transect 8 occurs in a narrow, straight stretch of channel while Transect 1 is located on a bend.



Figure 9. Transect 1 shows little erosion and has bank stability of score of 8.5 on the left bank (a) and 7.5 on the right bank (b). Transect 8 shows high areas of erosion and has bank stability of score of 13.5 on the left bank (c) and 15 on the right bank (d).

Bank erosion is not directly incorporated into the bank stability index which includes bank height, water depth at base, undercuts, bank angles, vegetative cover, and substrate. Bank erosion is measured in the protocol in a qualitative manner by recording erosion and type (none, slump, or lateral) within a meter up and downstream of each transect. 77% of bank measurements according to this method showed erosion. To compare to Rust 2006, additional measurements were taken by measuring the length of streambank eroded at each transect. A 10-m section was measured on each bank at each transect. 178.42 m out of 220 m were recorded as eroded, representing 81.1 % of the streambank.

Physical Characteristics

Physical characteristics include geomorphic units (Table 12a and 12b), median particle size in a representative riffle (measurements taken between transect 7-8, $d_{50}=32$ mm, Table 13), particle size and embeddedness (Table 14), percentage fine substrate (sand or silt/clay which was dominant in 8 out of 11 transects as well as percent of sediment particles sampled which were coded as “fines”, Table 15), and canopy cover (Table 16).

Table 12a. Transect-scale geomorphic channel units.

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1 - 2	55	40	0	5	0
2 - 3	35	65	0	0	0
3 - 4	85	10	0	5	0
4 - 5	5	0	70	25	0
5 - 6	30	15	20	15	0
6 - 7	90	5	0	2	3
7 - 8	100	0	0	0	0
8 - 9	100	0	0	0	0
9 - 10	10	70	20	0	0
10 - 11	0	93	0	7	0

Table 12b. Calculated geomorphic channel metrics for all transects.

Metric	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
Frequency	9	7	3	6	1
Max (%)	100	93	70	25	3
Mean (%)	51	30	11	6	0
Median (%)	45	13	0	4	0
SD (%)	40	35	22	8	1

Table 13. Sediment diameters from a representative riffle- transect 7-8.

Statistic (n = 100)	Diameter (mm)
Min	0.062
D ₅	0.06
D ₁₆	0.06
D ₅₀ (Median)	32.00
D ₈₄	128.00
D ₉₅	200.00
Max	512

Table 14. Particle size class and percent embeddedness at 5 points along each transect.

Transect	Left		Left-Center		Center		Right Center		Right	
	size	% em ¹	size	% em	size	% em	size	% em	size	% em
1	SiC ²	100	SiC	100	S ³	100	SiC	100	SiC	100
2	SiC	100	5.6	25	SiC	100	SiC	100	5.6	100
3	SiC	100	SiC	100	4	25	S	100	SiC	100
4	SiC	100	S	100	8	10	S	100	SiC	100
5	SiC	100	S	100	SiC	100	SiC	100	SiC	100
6	SiC	100	S	100	S	100	2.8	10	SiC	100
7	SiC	100	S	100	S	100	128	40	6.4	100
8	22.6	100	2	50	S	100	45	90	5.6	100
9	S	100	SiC	100	2.8	80	5.6	80	SiC	100
10	S	100	32	70	SiC	100	SiC	100	SiC	100
11	SiC	100	SiC	100	BR ⁴	80	S	100	SiC	100

¹ em= embedded

² SiC (silt/clay)= .062 mm

³ S (sand)= 2 mm

⁴ BR(bedrock)>512mm

Table 15. Dominant particle size class and percent fines in reach.

Transect	Dominant Particle Class	Left ¹	Left Center	Center	Center Right	Right	Percent Fines
1	Sand	SiC	SiC	S	SiC	SiC	100
2	Silt/Clay	SiC	5.6	SiC	SiC	5.6	60
3	Silt/Clay	SiC	SiC	4	S	SiC	80
4	Sand	SiC	S	8	S	SiC	80
5	Silt/Clay	SiC	S	SiC	SiC	SiC	100
6	Sand	SiC	S	S	2.8	SiC	80
7	Cobble	SiC	S	S	128.0	6.4	60
8	Cobble	22.6	2	S	45.0	5.6	20
9	Cobble	S	SiC	2.8	5.6	SiC	60
10	Sand	S	32	SiC	SiC	SiC	80
11	Sand	SiC	SiC	BR	S	SiC	80
Percent Fines for All Transects	72.73	–	–	–	–	–	72.73

¹ Particle size, Fines include sand (S), and silt clay (SiC), otherwise size is in mm.

Table 16. Canopy cover in reach.

Transect	Canopy Cover (%)
1	29
2	7
3	3
4	21
5	40
6	1
7	0
8	0
9	0
10	0
11	0
Min (%)	0
Max (%)	40
Mean (%)	9
Median (%)	1
SD (%)	14
CV	1.53

Gravel substrate still covers a good portion of the stream and a variety of geomorphic channel units (pool- 6%, riffle-51%, run-41%) are present in the creek (Table 12). While there is an absence of large woody debris (0%) and canopy cover is low (mean canopy cover was 9%; Table 16), many grassland streams in good condition can have similar characteristics.

Sediment particles were measured following the protocol and using a gravelometer to record the size of the hole the particle can pass through. The segment between transect 7 and 8 was selected as the representative riffle. Diameters are summarized in Table 13, with the median particle size (D_{50}) corresponding to 32mm, classified as very coarse gravel. Particle size decline over time can be evidence of siltation and increased embeddedness. Particles less than 2 mm were recorded as silt clay and assigned a .062 mm value. Particles greater than 512 mm were recorded as bedrock and assigned a diameter of 512 mm. The pebble count is taken solely from the riffle and does not account for changes in depositional areas which may accumulate high sediment.

Stream substrate is an important habitat feature. Dominant substrate can be difficult to determine visually when there is a mix of particle sizes. Additions were made to the SOP to better quantify the substrate with methods other than those in the protocol. Implementing the protocol depends on accurately identifying the dominant habitat type. Since the habitat is not uniform across the transect, additional measurements were taken to support the dominant habitat data. Five sediment particles were selected at regularly spaced intervals across the wetted width of each transect and measured

with a gravelometer (Table 14). Those points were recorded. These additional survey points produced the same percentage of fine substrate as when estimating the dominant particle class as according to the protocol. The SOP will be updated to continue to measure five sediment particles across the transect in order to more accurately determine the percentage of fine sediment. Percent embeddedness was also recorded since sediment deposition is of interest in Highland Creek. Rust 2006 found percent embeddedness was higher in areas of higher bison utilization and negatively correlated with some invertebrate measures of stream integrity such as HBI (Hilsenhoff Biotic Index) and number of EPT (Ephemeroptera, Plecoptera and Tricoptera) taxa. Rust did not recommend Highland Creek as a reference site due to organic enrichment, habitat degradation, and altered invertebrate assemblages.

Canopy cover was low across the reach (Table 16). Unsurprisingly, Rust found that in the NGPN, canopy cover was lower at grassland sites as compared to forested sites though her measurements on Highland Creek in 2006 were 17% canopy cover at Highland Creek with 45% mean canopy cover overall for small to medium sized NGPN streams. This is another case again where the protocol adopted differs from Rust 2006. In addition to canopy at the center of the reach, she measured canopy cover at the banks. In the future we will include a bank canopy measurement on each bank in addition to the 4 center measurements and have incorporated this update into our new SOP and datasheet ([DataStore - Project - \(Code: 2259796\) \(nps.gov\)](#)).

The last component of physical characteristics was the discharge which was measured 15m upstream of the site at the weir. Measured discharge was measured with a Marsh-McBirney flow meter and was 1.06 cfs using the velocity area method (Figure 10). Cross section mean stream velocity at WICA SCM 001 was 0.51 ft/s. In the future, taking velocity measurements at the detailed transects would be useful to better understand how stream velocity changes throughout the reach. Where the stream is narrow and straight, we would expect stream velocity to be great. Indeed, the transects with the worst bank stability scores were on straight sections of stream.



Figure 10. Discharge was measured just upstream of the site at the weir.

Further Analysis

This Data Report is intended to provide a basic review of the data collected during the 2021 stream channel monitoring at Wind Cave National Park. All data included in this report are available upon request from the Northern Great Plains Inventory and Monitoring Network. Data are also archived locally on the NGPN Server and will be re-named following Network standards. NGPN will store data on the NGPN Server in an NGPN Geodatabase. Certified data will also be uploaded to the Data Store annually, and to NPS Environmental Quality Information Systems (EQuIS) database when available. Reporting will consist of brief Natural Resource Data Series reports every year that the park is sampled which will summarize watershed characteristics, reach level geomorphic dimensions, and habitat features for selected wadeable stream reaches. After four sampling cycles (or twelve years), and every three sampling cycles thereafter, NGPN will publish trend reports for each park unit sampled.

Further investigation into the causes and solutions to bank erosion at WICA SCM 001 and implications for park management is warranted. WICA SCM 001 is one site within the park. If ample resources could be allocated to increase sampling effort at WICA, then these processes could be better quantified at a park level and the mechanisms of erosion could be better understood.

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Appendix A

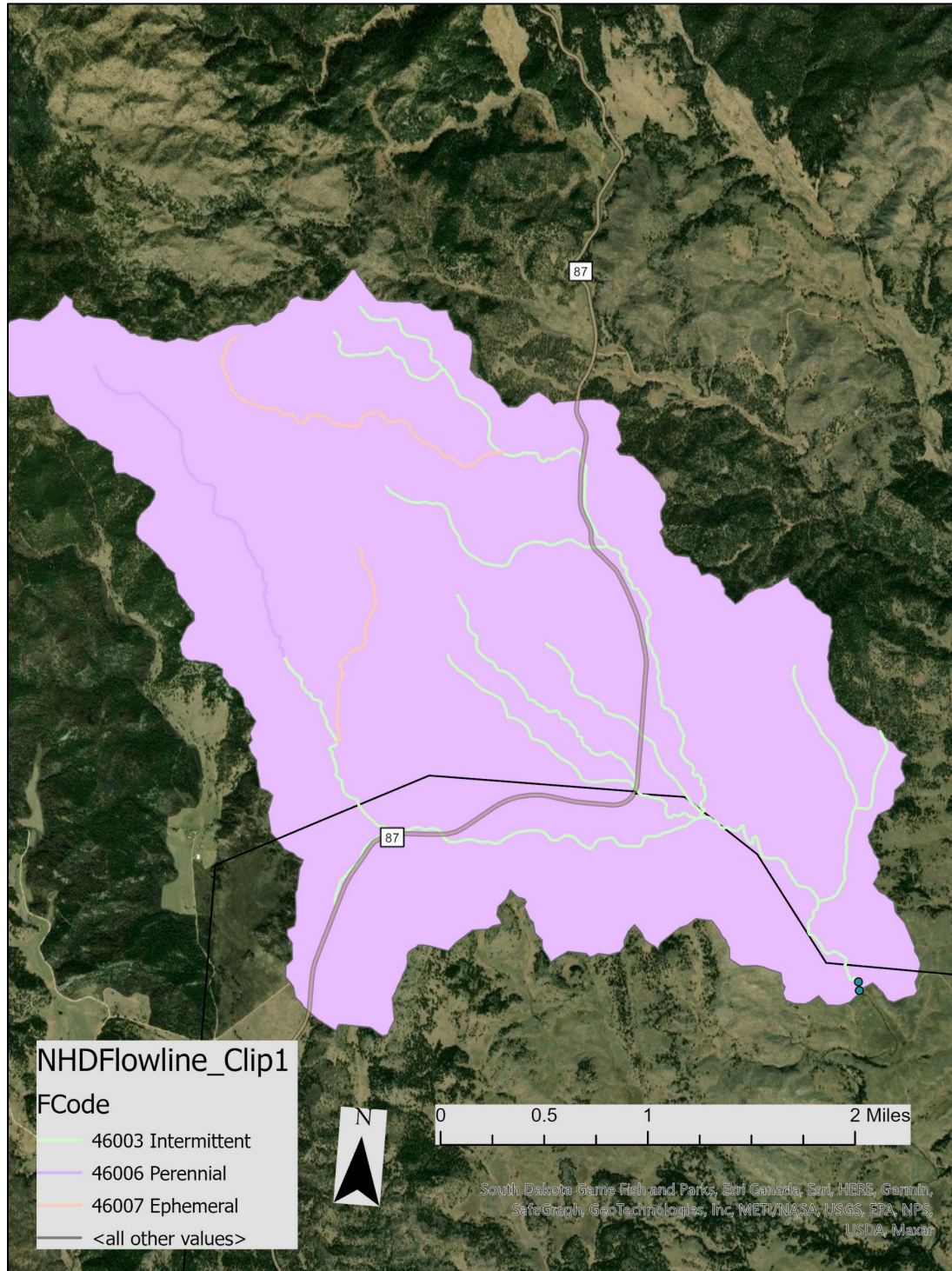


Figure A-1. NHD stream segments in WICA SCM 001 watershed, shown by FCODE which classifies streams as perennial, intermittent, or ephemeral. In this system, the elevation-derived FCODEs do not accurately reflect flow in the stream. A perennial reach is located above the site, which is on a reach classified as “intermittent”.

Appendix B

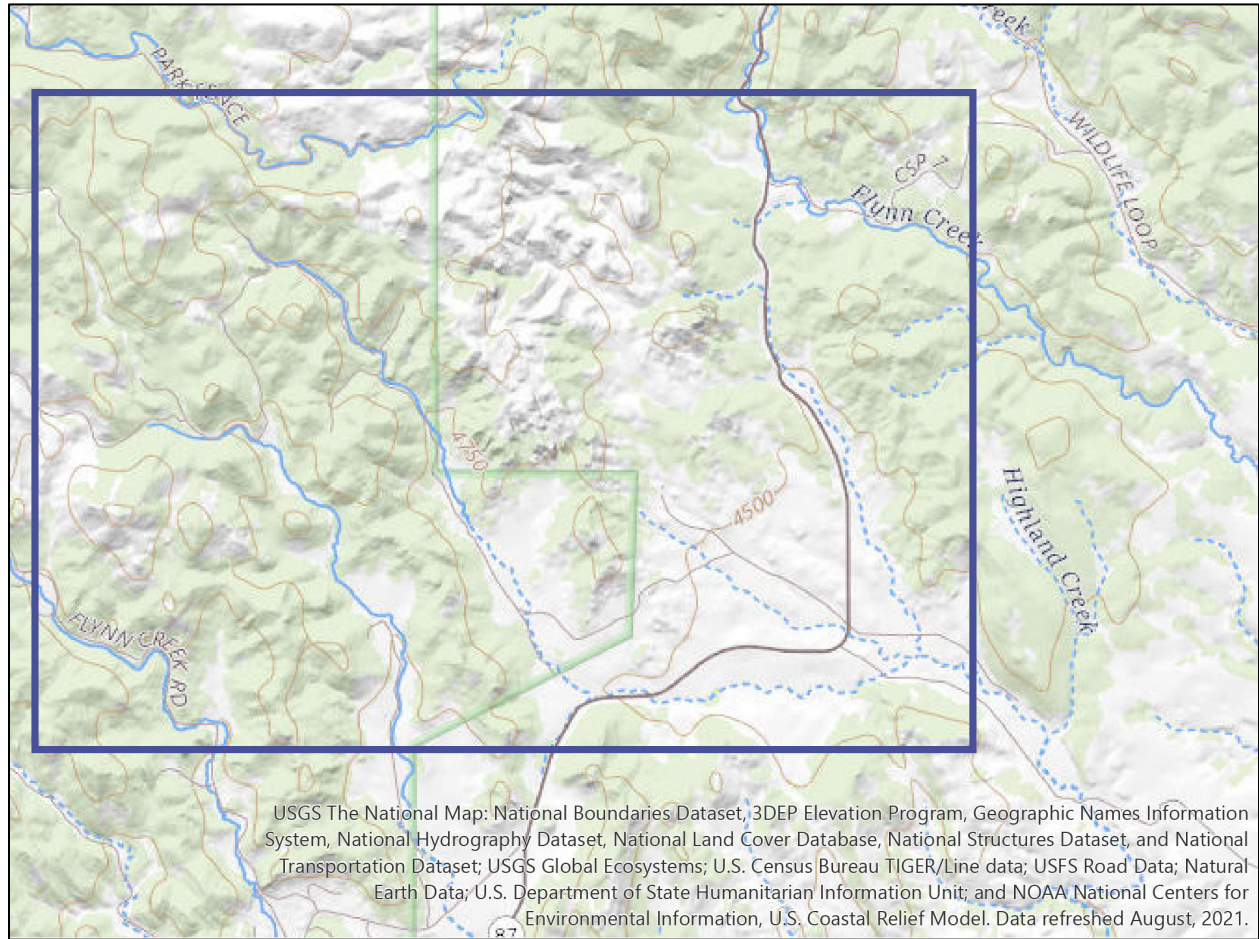


Figure B-1. USGS 7.5 minute topo showing the WICA SCM 001 streams. Solid blue lines are perennial and dashed blue are intermittent. Box shows approximate extent of WICA SCM 001 watershed.

Appendix C

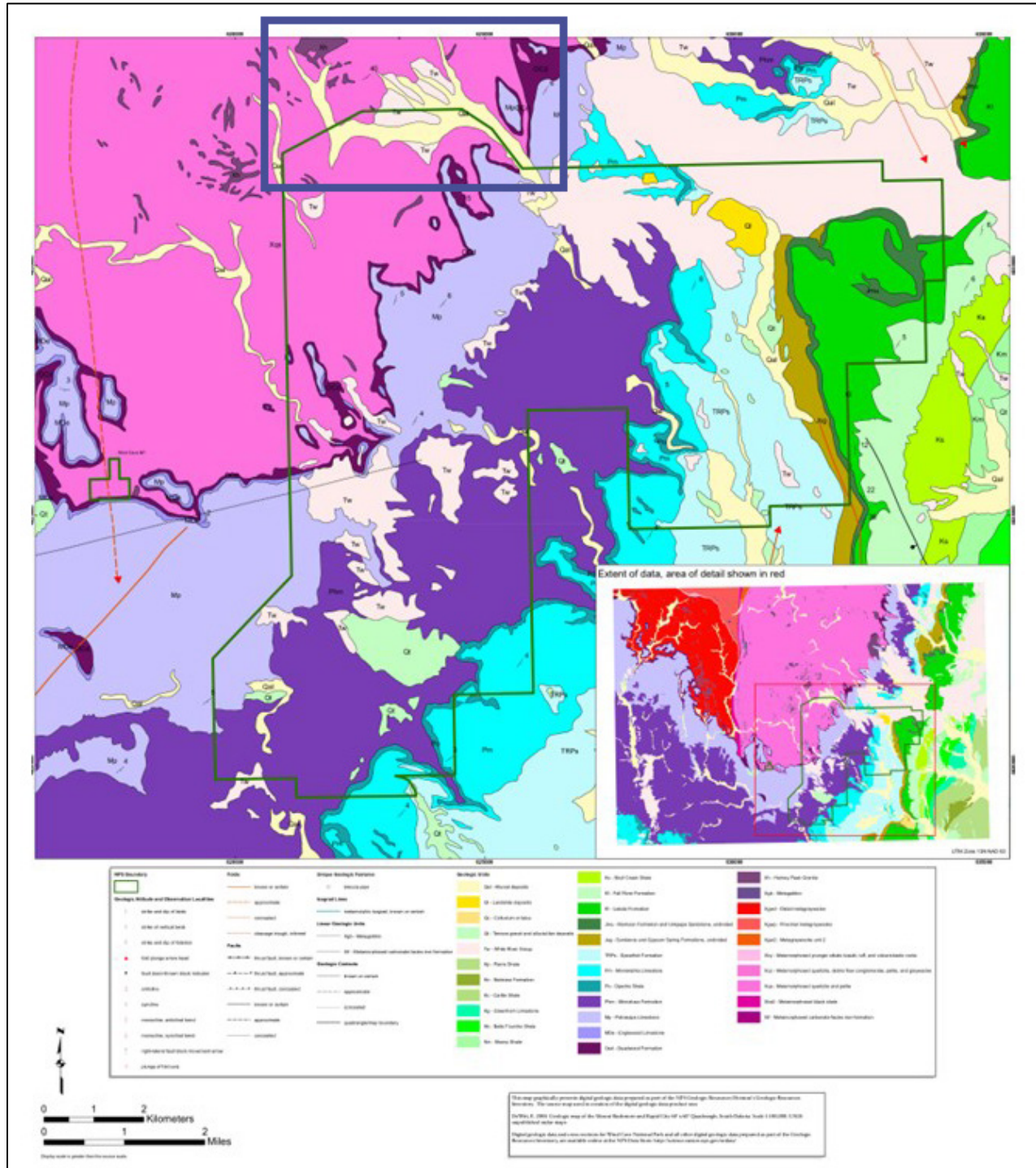


Figure C-1. Wind Cave geologic map (DeWitt 2004). The box shows metamorphic rocks in the upper reaches of the watershed (Xqs), sandy siltstone and alluvium layers in yellow (Qal- Alluvium deposits) and pale pink (Tw- White River group) along the stream. Limestone areas (Mp- Pahasapa Limestone in lavender and Phm – Minnelusa Limestone in dark purple) are downstream of WICA SCM 001.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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